HYDROGEOLOGY, STRATIGRAPHY AND EVOLUTION OF THE PALAEO-LAGOON (KOLE LAND BASIN) IN THE CENTRAL KERALA COAST, INDIA

Thesis submitted to the

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

MARINE GEOLOGY

UNDER THE FACULTY OF MARINE SCIENCES

By

V. B. VINAYAN

DEPARTMENT OF MARINE GEOLOGY AND GEOPHYSICS

SCHOOL OF MARINE SCIENCES

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

COCHIN-682016

FEBRUARY 2009

Dedicated to my parents

DECLARATION

I **V. B. Vinayan**, do hereby declare that the thesis entitled **"HYDROGEOLOGY, STRATIGRAPHY AND EVOLUTION OF THE PALAEO-LAGOON (KOLE LAND BASIN) IN THE CENTRAL KERALA COAST, INDIA"** is an authentic record of research work carried out by me under the supervision and guidance of **Dr. P. Seralathan**, Professor, Department of Marine Geology and Geophysics, School of Marine Sciences, Cochin University of Science and Technology, in the partial fulfillment of the requirements for the Ph.D. Degree in the Faculty of Marine Sciences. This work has not been previously formed the basis for the award of any degree or diploma of this or any other University /Institute.

Cochin-16 **(V. B. Vinayan)**

05.02.2009

CERTIFICATE

This is to certify that the thesis entitled ***"HYDROGEOLOGY, STRATIGRAPHY AND EVOLUTION OF THE PALAEO-LAGOON (KOLE LAND BASIN) IN THE CENTRAL KERALA COAST, INDIA"*** *is an authentic record of research work carried out by* ***Mr. V. B. Vinayan*** *under my supervision and guidance in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Marine Geology and Geophysics, Cochin University of Science and Technology, under the Faculty of Marine Sciences and no part there of has been presented for the award of any degree or diploma in any other University/ Institute.*

Cochin-16

05.02.2009

P. Seralathan

Prof. P. Seralathan
(Research Supervisor)
Department of Marine Geology and Geophysics
Cochin University of Science and Technology
Cochin-682 016

ACKNOWLEDGEMENT

I wish to express my profound thanks and deepest sense of gratitude to Dr. P. Seralathan, Professor and former Head, Department of Marine Geology and Geophysics, Cochin University of Science and Technology, for suggestion of the research problem, and also for his unfailing guidance, constant encouragement, invaluable suggestions, moral support and critical comments through out the course of this investigation. He cultivated my curiosity, sharpened my thinking and inspired me to become a scientist. I am fortunate to having been associated with him here in the Cochin University of Science and Technology.

I express my gratitude to Sri. Abdul Majeed, former Director of the Kerala State Groundwater Department, Thiruvananthapuram for giving permission to do the research work. I place on record my sincere thanks to Sri. K. Pankajakshan Nair, Sri. J. P. Kukillaya and Sri. Johnson Anthraper, former Directors of Groundwater Department for giving permission to use the available facilities and data in the Department, valuable suggestions and encouragements, especially in the field of groundwater exploration, during this research work. I express my sincere thanks to Sri. R. Radhakrisnapillai, Director of the Groundwater Department, Thiruvananathapuram for making available the facilities in the department and for their constant encouragements.

My sincere thanks to Dr. C. G. Nambiar, Professor and Head, Department of Marine Geology and Geophysics, Cochin University of Science and Technology as well as to Prof. K. T. Damodaran (Retired) and Prof. K. Sajan, former Heads of the Department for making available the facilities of the Department and for their constant encouragements. I place on record my sincere thanks to Prof. A. C. Narayana (now in Central University, Hydrabad), Dr. S. Rajendran (Retired), Prof. A. D. Singh (now in Banaras Hindu University, Allahabad), Dr. M. Radhakrishna (now in IIT, Bombay) all former faculty members of the Department for the valuable suggestions and encouragements rendered by them. Dr.Ravisankar, Reader of the Department of Marine Geology and Geophysics is sincerely thanked for his valuable suggestions and encouragements. I express my thankfulness to Dr. K. R. Baiju, Lecturer, Department of Marine Geology and Geophysics for the help and encouragements. I express my sincere gratitude to Dr. N. R. Nisha, Dr. C. P. Priju and Dr. Reji Srinivas of the Department of Marine Geology and Geophysics, Cochin university of Science and Technology for their valuable suggestions and help for completing this research work.

I am indebted to Sri.Thomas Scaria, Hydrogeologist, Groundwater department, Thrissur and Sri. Subin K.Jose, Department of Environmental Studies, M.G.University, Kottayam for their valuable helps and encouragements in doing GIS works, other map preparation and secondary data collection. I express my sincere thanks to the Regional Director, CGWB and scientists; Mr. Vinayachandran and Dr. V. S. Joji for providing necessary help during this research work. I acknowledge Sri. C. T. Rajesh, District officer, Groundwater Department, Idukki, Sri. P. N. Ajithkumar, District officer Groundwater Department, Alappuzha, Sri. K. Krishanapanicker, District officer, Groundwater Department, Thiruvananthapuram, Sri. T. K. Subash, Electrical inspector, Electrical Inspector's Office, Moolamattom, Sri. P. Balakrishanan, Hydrogeologist, Groundwater Department, Ernakulam, Sri. B. Pradeep, Junior hydrogeologist Groundwater Department, Kollam, and Sri. K. Rajan, Junior hydrogeologist, Groundwater department Thiruvananathapuram for the timely help extended during this study.

I specially acknowledge Mr. Babu Nallusami, Senior Research Fellow, National Institute of Inter-disciplinary Sicence and Technology, Thiruvananthapuram, Smt. Priya, former Research Scholar of CUSAT, Ms. Sreekala, Junior chemist, Regional analytical lab, Groundwater Department, Ernakulum and Dr. Girish Gopinath, Scientist, Centre for Water Resources Development and Management, Kozhikode for their advice, personal help and valuable suggestions during every stage of this research work. I am also thankful to Dr. D. Padmalal and Dr. K. Maya, Scientists, Centre for Earth Science Studies, Thiruvananathapuram for their timely help. I express my thankfulness to Dr. R. V. Rajan and Dr. S. Sreekumar, Senior Lecturers, Department of Geology, Christ College, Irinjalakuda for their timely advice and help.

I thank Mr. V. Sunilkumar, Mr. K. R. Nithyan, Mr. Biju longinose, Mrs. Rekha and Mrs. Sreela in providing much of the impetus for various help during the course preparation of the thesis. I also recall the help rendered by the staff members of the Department of Marine Geology and Geophysics and staff members of Directors office and library of School of Marine Sciences, CUSAT. A number of individuals have helped me in various ways during the course of this work as it is impossible to mention all of them.

This work would not have been feasible but for the keen interest, love, affection, encouragement and support from my father, mother, wife Disha, children Anupama and Gayathri, brother, Dr.V.B.Ajidhan and other family members they stood behind me in the ups and downs and gave me immense inspiration and moral support for the successful completion of this task.

"The same regions do not remain always sea or always land, but all change their condition in the course of time".

Aristotle (384-322 B.C)

PREFACE

Water is the life blood of every living creature on the earth; hence it is precious and most commonly used resource of the world. Although about 72% of the earth's surface is covered with water, the fresh water including groundwater occupies a small portion of it. It is easy to understand the significance of water in our live however; it is difficult to understand the characteristics and movement of water with in the earth's surface. The surface water resources, being exploited time to time and again, may become short of supply or may not be easily available at site. There has been a marginal increase in groundwater development and utilization of the country for agriculture, industry and rural water supply schemes in last decade.

In India, more than 90% of rural and nearly 30% of urban population depends on groundwater for meeting their requirements. In addition, it accounts for nearly 60% of the irrigation potential created in the country. The spatio-temporal variation in rainfall and regional/local differences in geology and geomorphology has led to an uneven distribution of groundwater in different regions across the country.

The Palaeo-lagoon (Kole land basin) along the coast between Mathilakam and Chavakkad of Thrissur district (North latitude 10°17'29"and 10°43'43", East longitude 76°0'0" and 76°33'33") covers an area of 1690 km^2. The basin receives sediments from Karuvannur and Kecheri rivers. Within this basin an area of 300 km^2 lies below mean sea level from 0.5 to 1.50 m and gets water logged during monsoon season.

The Kole lands have some similarities with Polder areas of The Netherlands. The name "Kole land" is derived from the local word "Kole" means "Chance" due to unique method of paddy cultivation practiced in this low lying area. As the area is water logged during southwest monsoon season, cultivation is done at the end of north east monsoon season after dewatering the area. The basin is also famous for clay mining for manufacturing of tiles and bricks.

This basin experiences serious groundwater quality variations and water shortage during summer months. The groundwater availability and quality vary with land form, physiography, stratigraphy and hydrogeology. The present investigation deals with the hydrogeologic, stratigraphic characteristics, palaeo environment and evolutional history of the Palaeo-lagoon.

Major objectives of the present investigation are:

- To determine the groundwater potential, resource, aquifer parameters and groundwater quality of the basin.

- ❖ To evaluate the vulnerability of the aquifer to sea water intrusion in coastal area and groundwater vulnerability to pollution in the basin.
- ❖ To delineate the stratigraphic sequences of the area and evaluation of palaeo-environment of deposition.
- ❖ To study the evolutional history of the palaeo-lagoon

The thesis has been addressed in 8 Chapters.

Chapter 1 deals with general introduction. It also provides description about the study area, previous work, physiography, climate, drainage, geological setting, soil, landuse and finally the broad objectives.

The methodology adopted for the present work is given in Chapter 2. This includes field investigation, laboratory works and secondary data collection. The works such as ground water level collection from observation wells, sample collection from observation wells, core sample collection from different parts of the basin, geophysical investigations, aquifer tests, and level survey are included under field investigations. Under laboratory works chemical analysis of water samples, sieve analysis of the core samples, pipette analysis, ^{14}C dating etc. are included. Secondary data such as rainfall, climatic data, water level data of piezometers, river discharge and pumping test of bore wells were also collected.

Chapter 3 deals with hydrogeology, with regards to occurrence and movement of groundwater, water level fluctuations, evaluation of aquifer parameters and the ground water resource evaluation. Under water level fluctuation the phreatic aquifer fluctuation, semi confined deep aquifer, recharge and discharge areas, correlation of water level with rainfall, hydrograph analysis are discussed. Pumping tests methods such as Slug test (ST), Step-draw down test (SDT), Aquifer performance test (APT), Trasmissivity, Storage coefficient or Storativity, Yield, Specific capacity, drawdown and recovery analysis are included in this chapter.

Chapter 4 deals with the geophysical investigation. Resistivity of geological formations, interpretation of VES data, and delineation of ground water potential based on resistivity data analysis, determination of layer parameters and its corresponding thickness are provided in this chapter.

Hydrochemistry forms the basis of Chapter 5. Ground water contamination and sea water intrusion and its impact are discussed in this chapter. The different hydrochemical parameters studied are major anions and cations, pH, Electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), total iron, fluoride, bacteriological quality, quality criteria for various uses, evaluation of ground water for irrigation, Wilcox and USSL diagram, Evaluation of ground water for industrial purpose and corrosivity ratio. The groundwater types and hydro chemical fecies of the basin are analyzed using Hill-Piper diagram and facies diagrams. Study of ground water contamination and vulnerability to pollution by DRASTIC method and Saline intrusion and vulnerability of coastal aquifer to saline intrusion by GALDIT method are described in this chapter.

Chapter 6 is pertaining to stratigraphy, different formations within the palaeo-lagoon, sediment characteristics of Palaeo-lagoon, texture of the sediment and mineralogy are dealt in the chapter. Heavy and light minerals and clay mineralogy of the basin are also analyzed.

In Chapter 7 evolution of palaeo-lagoon, ^{14}C dating of core samples at various depth, mega and micro fossil assemblages in different stratigraphic sequences and the palaeo-environment of the basin are presented.

Summary of the work and major conclusions of the thesis are presented in Chapter 8.

V. B.Vinayan

Preface

CONTENTS

List of Figures
List of Tables
List of plates.

PAGE NO.

CHAPTER 1 GENERAL INTRODUCTION 1

1.1 Geologic records of Kerala 6
1.2 Structure and tectonics of Kerala basin 11
1.3 Evolution of Kerala coast 14
1.4 Study area 17
1.5 Previous works in Palaeo - lagoon (Kole land basin) 19
1.6 Physiography and slope 21
1.7 Climate 22
1.8 Drainage 23
1.9 Soils 24
1.10 Landuse 24
1.11 Geological setting of the study area 24
1.12 Objectives 25

CHAPTER 2 METHODOLOGY

2.1 Introduction 26
2.2 Field investigations 27
2.2.1 Groundwater level collection from observation wells 27
2.2.2 Sample collection 27
2.2.3 Geophysical investigations 28
2.2.4 Pumping test and evaluation of aquifer parameters 31
2.2.5 Groundwater resource evaluation 41
2.2.6 Level survey 43
2.3 Laboratory work 43
2.3.1 Chemical analysis 45
2.3.2. Groundwater contamination and vulnerability to pollution 47
2.3.3 Seawater intrusion and aquifer vulnerability to saline ingress 49
2.3.4 Sieve analysis 52
2.3.5 Pipette analysis 53
2.3.6 Heavyminerals 54
2.4. Secondary data collection 54
2.4.1 Rain fall and other climatic data 54
2.4.2 Water level data of piezometers 54
2.4.3 River gauge/river discharge data 55
2.4 4.Pumping test data of bore wells 55

CHAPTER 3 HYDROGEOLOGY

3.1 Introduction 56
3.2 Occurrence and movement of groundwater 58
3.2.1 Hydrological classification of geological formations 59
3.3 Pumping test and evaluation of aquifer parameters 62
3.3.1 Slug test 62
3.3.2 Well performance test (WPT) 62
3.4 Drawdown and recovery analysis 67
3.5 Water level fluctuations and their long term behaviour 69
3.6 Recharge - discharge areas and grid deviation map 72
3.7 Correlation of water level with rainfall 74
3.8 Hydrograph analysis 75
3.9 Groundwater resource evaluation 77

CHAPTER 4 GEOPHYSICAL PROSPECTING

4.1 Introduction 83
4.2 Resistivity of geological formations 84
4.3 Interpretation of VES data 84
4.4 Groundwater prospecting zone based resistivity analysis 87

CHAPTER 5 HYDROGEOCHEMISTRY

5.1 Introduction 88
5.2 Quality criteria for various uses 89
5.2.1 Hydrochemical characteristics of groundwater and evaluation for domestic use 89
5.2.2 Evaluation of ground water for irrigation 103
5.2.3 Evaluation of groundwater for industrial purpose 110
5.3 Chemical relationship of groundwater and hydrochemical facies 112
5.3.1 Hill-Piper trilinear diagram 113
5.3.2 Hydrochemical facies 114
5.4 Groundwater contamination and vulnerability to pollution 117
5.5 Seawater intrusion and aquifer vulnerability to saline ingress 117

CHAPTER 6 STRTIGRAPHY

6.1 Introduction 112
6.2 Stratigraphy of Palaeo-lagoon 123
6.3 Texture of sediment 128
6.4 Mineralogy 132
6.5 Heavy and light minerals 133
6.6 Clay mineralogy 141

CHAPTER 7 EVOLUTION OF PALAEO-LAGOON

7.1 Introduction 142
7.2 Radiocarbon (^{14}C) ages of Kerala coastal plain 142
7.3 Evolutionary history of palaeo-lagoon (Kole land basin) 143
7.4 Palaeoshorelines and rate sedimentation 147

CHAPTER 8 SUMMARY AND CONCLUSION 149

REFERENCES
APPENDIX

LIST OF TABLES

Chapter 1

1.1 Stage of groundwater development of Kerala state on 31st March 2004 in MCM.
1.2 Geological time scale and major geologic events in Kerala.
1.3 Stratigrahic sequences of Kerala (modified after Najeeb, 1999).
1.4 Important events in Indian startigraphy with an emphasize on Kerala from Lower Createaceous to Recent.
1.5 Stratigraphic succession and morphostratigraphic surfaces of Quaternary sediments of Kerala basin.
1.6 Physiographic units of Palaeo-lagoon (Kole land basin).
1.7 Landuse pattern of Palaeo-lagoon (Kole land basin).

Chapter 2

2.1 Location and details of observation wells in Palaeo-lagoon.
2.2 Location details of core and lithological samples collected from Palaeo-lagoon.
2.3 Porosity of aquifer materials (Manual of aquifer parameters, 1982 by CGWB).
2.4 Some typical values of hydraulic conductivity (after Morris and Johnson).
2.5 Standard solutions and indicators used for the analysis various parameters.
2.6 Various instruments working on different principles of energy.
2.7 Methods followed for the determination of various physical and chemical parameters of groundwater.
2.8 DRASTIC weightage for parameters.
2.9 Range and rating of parameters in DRASTIC method (Aller et al., 1985).
2.10 GALDIT weightage for parameters.
2.11 Rating and range parameters of GALDIT method (Chachadi and Lobo Ferreira, 1999).
2.12 Details of rain gauge station and rainfall in Palaeo-lagoon (Kole land basin).
2.13 Location and details of piezometers (bore wells) in Palaeo-lagoon (Kole land basin).

Chapter 3

3.1 Details of aquifer and well parameters derived by conducting SDT in Palaeo-lagoon area.
3.2 Details of aquifer and well parameters derived by conducting APT in phreatic aquifer of Palaeo-lagoon area.

3.3 Details of aquifer and well parameters derived by conducting APT in semi- confined aquifer of Palaeo-lagoon area.

3.4 Drawdown-recovery analysis of phreatic aquifer (Dug wells) in Palaeo-lagoon.

3.5 Drawdown-recovery analysis of semi-confined aquifer (Bore wells) in Palaeo-lagoon.

3.6 Long term trend of ground water level in dugwells of phreatic aquifer for the period from 01.01.1997 to

01.01.2007 in palaeo-lagoon.

3.7 Long term trend of ground water level in bore wells of semi-confined aquifer for the period from 01.01.1997

to 01.01.2007 in palaeo-lagoon.

3.8 Water level fluctuation and grid deviation computations of observation wells in Palaeo-lagoon area.

3.9 Specific yield values of the geological formations (Report of GEC-1997).

3.10 Rainfall infiltration factor (RIF) in different formations (Report of GEC-1997).

3.11 Recharge due to seepage from different type canals (Report of GEC-1997).

3.12 Recharge (as % of application) due to return flow from irrigation (Report of GEC-97).

3.13 General description of groundwater assessment units in Palaeo-lagoon (Kole land basin).

3.14 Groundwater resource potential in Palaeo-lagoon (Kole land basin) in MCM.

3.15 Stage of groundwater development in Palaeo-lagoon (Kole land basin) in MCM.

3.16 Criteria for categorization of assessment units (Report of GEC-97).

3.17 Categorization for groundwater development of the assessment units in Palaeo-lagoon (Kole land basin).

3.18 Additional potential recharge under specific conditions in Palaeo-lagoon (Kole land basin).

Chapter 4

4.1 Representative resistivity values for the earth materials (Mooney, 1980).

4.2 Range of resistivity values (ohm-m) of common rocks (Sighal and Gupta, 1999).

4.3 Analysed vertical electrical sounding (VES) data of the Palaeo-lagoon (Kole land basin).

Chapter 5

5.1 Average chemical composition (mg/l) of three major rock types and groundwater.

5.2 Various sources of ions in water (Hem, 1959)

5.3 Water quality standards for domestic use.

5.4 Water quality standards for irrigation.
5.5 Water quality standards for industrial use.
5.6 Chemical characteristics of groundwater in dug wells (phreatic shallow aquifer) of Palaeo-lagoon(Kole land basin) for the period 01.01.2000 to 31.12.2006 (mg/l) (attached with appendix).
5.7 Chemical characteristics of groundwater in bore wells (semi-confined deep aquifer) of Palaeo- lagoon(Kole land basin) for the period 01.01.2000 to 31.12.2006 (attached with appendix).
5.8 Trend of groundwater quality (PH) in phreatic and Semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon(Kole land basin).
5.9 The potability and classification of water in terms of Electrical conductivity (EC).
5.10 Trend of groundwatr quality (EC) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin).
5.11 The potability and classification of water in terms of TDS (mg/l) as per WHO (1984).
5.12 Trend of groundwatr quality (TDS) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin)
5.13 Classification of the degree of hardness in water (Sawyer and McCarty, 1967.
5.14 Trend of groundwater quality (Total Hardness)in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin).
5.15 Trend of groundwater quality (iron) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.
5.16 Trend of groundwater quality (fluoride) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.
5.17 Impact of fluoride in drinking water on health (Dissanayake, 1991).
5.18 Trend of groundwater quality (calcium) in phreatic and semi- confined aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon).
5.19 Trend of groundwater quality (magnesium) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.
5.20 Trend of groundwater quality (sodium) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.
5.21 Trend of groundwater quality (potassium) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.
5.22 Trend of groundwater quality (chloride) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.
5.23 Trend of groundwater quality (sulphate) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin).
5.24 Trend of groundwater quality (carbonate) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin).

5.25 Trend of groundwater quality (bicarbonate) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin).

5.26 Trend of groundwater quality (nitrate) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin).

5.27 Trend of groundwater quality (Alkalinity) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin).

5.28 Baceriological standard of water for various uses.

5.29 Details of bacteriological analysis water samples from observation wells in the Palaeo-lagoon.

5.30 Details of bacteriological analysis of water samples from piezometers (bore wells) of palaeo-lagoon.

5.31 Classification of groundwater quality for irrigation (after Wilcox, 1955).

5.32 Classification of water for irrigation based on U.S.S.L diagram (Wilcox, 1955).

5.33 Classification of groundwater based on SAR (Hermanbouwer, 1978).

5.34 Limits of residual sodium carbonate values in irrigation water (Lloyd and Heathcote, 1985).

5.35 Various ratios, percetages and indices derived from the chemical analysis date of water samples in phreatic aquifer (dug wells) of Palaeo-lagoon (Kole land basin) for the period 01.01.2001 to 31.12.2006 (attached with appendix).

5.36 Various ratios, percetages and indices derived from the chemical analysis data of water Samples in semi-confined aquifer (bore wells) of Palaeo-lagoon (Kole land basin) for the period 01.01.2000 to 31.12.2006 (attached with appendix).

5.37 The quality of groundwater based on Hill-Piper trilinear diagram.

5.38 Classification of hydrochemical facies (after Back, 1966).

5.39 Groundwater vulnerability assessment to pollution by DRASTIC method score computatin for palaeo-lagoon.

5.40 Chemical composition of average seawater (Goldberg, 1963).

5.41 Calculated ratios of major ions in phreatic and semi-confined aquifers of the Palaeo-lagoon (Kole land basin) for the period 01.01.1997 to 31.12.2006.

5.42 Aquifer vulnerability to sea water intrusion "GALDIT" method score computation for Palaeo-lagoon (Kole land basin).

Chapter 6

6.1 Details of litholog collected from various places of Palaeo-lagoon (attached as appendix).

6.2 Stratigraphic succession of Palaeo-lagoon (Kole land basin).

6.3 Grain size particulars of Vaikom formation (CGWB, 1984).

6.4 Statistical parameters of grain size in coastal plain sediment of Chavakkad area in Palaeo-lagoon.

6.5 Statistical parameters of the grain size in coastal plain sediment of Engadiyoor area in Palaeo-lagoon.

6.6 Statistical parameters of the grain size in coastal plain sediment of Vatanapilli area in Palaeo-lagoon.

6.7 Statistical parameters of grain size in coastal plain sediment of Nattika area in Palaeo-lagoon.

6.8 Statistical parameters of grain size in coastal plain sediment of Edamuttom area in Palaeo-lagoon.

6.9 Statistical parameters of grain size in coastal plain sediment of Mathilakam area in Palaeo-lagoon.

6.10 Gravel, sand, silt/mud and clay percentages of the coastal plain sediments in Palaeo-lagoon (Chavakkad and Engadiyoor).

6.11 Gravel, sand, silt/mud and clay percentages of the coastal plain sediments in Palaeo-lagoon (Vatanapilli and Nattika).

6.12 Gravel, sand, silt/mud, and clay percentages of the coastal plain sediments in Palaeo-lagoon (Edamuttom and Mathilakam).

6.13 Variation of heavy minerals at different depths (count %) in northern part of the coastal plain region (Engadiyoor in Kecheri basin) of Palaeo-lagoon.

6.14 Variation of heavy minerals at different depths (count %) in southern part of the coastal plain region (Edamuttom in Karuvannur basin) of Palaeo-lagoon.

Chapter 7

7.1 Radiocarbon dates of coastal sediments from the onland of Kerala-Konkan basin (KKB).

7.2 Radiocarbon dates of coastal sediments from Palaeo-lagoon (Kole land basin).

7.3 Rate of sedimentation in Palaeo-lagoon (Kole land basin).

LIST OF FIGURES

Chapter 1

1.1 Freshwater availability of the world.
1.2 Year wise water availability in India and future projection.
1.3 Irrigation source of India.
1.4 Country wise per capita storage of water.
1.5 Projected water demand in India.
1.6 Groundwater resource availability and utilization in India.
1.7 Location and extent of West coast offshore basins.
1.8 Geological map of Kerala (GSI 1973 & 1975).
1.9 Sub surface geological section along the coastal belt of Kerala based on borehole data.
1.10 Tectonic model for peninsular India.
1.11 Location map of the study area.
1.12 Map showing Physiographic divisions of the study area.
1.13 Map showing slope pattern of the study area.
1.14 Map showing geomorphic units of the study area.
1.15 Isohyetal map of the study area for the period from 1981 to 2007.
1.16 Map showing drainage of the study area.
1.17 Map showing soil drainage of the study area.
1.18 Map showing soil texture of the study area.
1.19 Map showing Soil depth of the study area.
1.20 Map showing landuse of the study area.
1.21 Map showing geology and major lineament of the study area.

Chapter 2

2.1 Location map of the study area showing locations of observation network (Bore wells and dug wells).
2.2 Electrical circuit for resistivity determination and electrical field for a homogenous substratum.
2.3 Common electrode arrangement of resistivity determination, Wenner and Schlumberger.
2.4 Schematic representation of groundwater flow during pumping of phreatic aquifer with fully penetrating
wells.

2.5 Schematic representation of groundwater flow during pumping of non leaky artesian aquifer with fully penetrating wells.
2.6 Schematic representation of groundwater flow during pumping of leaky semi-confined aquifer with fully penetrating wells.
3.1 Hydrogeological map of Palaeo-lagoon and adjoining areas.
3.2 Diagram showing classification of sub surface water.
3.3 Schematic cross section illustrating different types of aquifer.
3.4 Discharge Vs Specific capacity in semi-confined aquifer (in SDT).
3.5 Discharge Vs Well loss % in semi-confined aquifer (in SDT).
3.6 Discharge Vs Specific capacity in phreatic aquifer (APT).
3.7 Discharge Vs Transmissivity in phreatic aquifer (APT).
3.8 Discharge Vs Specific capacity in semi-confined aquifer (APT).
3.9 Discharge Vs Specific drawdown in semi-confined aquifer (APT).
3.10 Discharge Vs Transmissivity in semi-confined aquifer (APT).
3.11 Time - drawdown curves for different types of aquifers (CGWB, 1982).
3.12 Drawdown-recovery curves of phreatic aquifer (Dug wells) in Palaeo-lagoon.
3.13 Drawdown-recovery curves of semi-confined aquifer (Bore wells) in Palaeo-lagoon.
3.14 Drawdown curves of phreatic aquifers in log-log scale.
3.15 Drawdown recovery curves of semi confined aquifers in log-log scale.
3.16 Well frequency of different ranges of depth to water level in phreatic aquifer of Palaeo-lagoon.
3.17 Water table contour map of phreatic aquifer (dug wells) for the period from 1997-2007 in Palaeo-lagoon.
3.18 Long term trend of groundwater levels of phreatic aquifer in Palaeo-lagoon (Kole land basin).
3.19 Well frequency of different ranges of depth to water level (DTW) in semi-confined aquifer of Palaeo- lagoon.
3.20 Water table contour map of semi-confined aquifer (bore wells) for the period from 1997-2007 in Palaeo- lagoon.
3.21 Long term trend of groundwater levels of semi-confined aquifer in Palaeo-lagoon
3.22 Schematic representation of water levels in a recharge area.
3.23 Schematic representation of water levels in a discharge area.
3.24 Diagram showing recharge and discharge areas of the Palaeo-lagoon.
3.25 Groundwater flow pattern in phreatic and semi-confined aquifer of Palaeo-lagoon.
3.26 Monthly variations of rainfall and water level in phreatic aquifer of Palaeo-lagoon.
3.27 Daily variations of water level and rainfall in semi-confined aquifer of Palaeo-lagoon.
3.28 Monthly variations of rainfall and water level in semi-confined aquifer of Palaeo-lagoon.

3.29 Water level fluctuation in phreatic and semi-confined aquifers of recharge area in Palaeo-lagoon.

3.30 Water level fluctuation in phreatic and semi-confined aquifers of discharge area in Palaeo-lagoon.

3.31 Comparison of water level fluctuations in phreatic and semi-confined aquifers (multiple wells) of recharge and discharge areas in Palaeo-lagoon.

3.32 Map showing semi-critical areas of groundwater development in Palaeo-lagoon.

Chapter 4

4.1 Spatial distribution of resistivity in first layer of Palaeo-lagoon area.

4.2 Spatial distribution of resistivity in second layer of Palaeo-lagoon area.

4.3 Spatial distribution of resistivity in third layer of Palaeo-lagoon area.

4.4 Common type of sounding curves in three layered formation.

Chapter 5

5.1 Spatial distribution of pH in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.2 Spatial distribution of EC in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.3 Spatial distribution of TDS in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.4 Spatial distribution of TH (as $CaCO_3$) in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.5 Spatial distribution of Iron in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.6 Spatial distribution of Fluoride in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.7 Spatial distribution of calcium in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.8 Spatial distribution of magnesium in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.9 Spatial distribution of sodium in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.10 Spatial distribution of potassium in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.11 Spatial distribution of chloride in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.12 Spatial distribution of sulphate in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.13 Spatial distribution of carbonate in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.14 Spatial distribution of bicarbonate in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.15 Spatial distribution of nitrate in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.16 Spatial distribution of alkalinity in phreatic and semi-confined aquifers of the study area during pre and post monsoon period.

5.17 Spatial distribution of fecal coliforms (E.coli) in dug wells (phreatic aquifer) of the study area.

5.18 Spatial distribution of fecal coliforms (E.coli) in bore wells (semi-confined aquifer) of the study area.

5.19 Sodium percentage distribution in phreatic (dug wells) and semi-confined aquifer s of the study area.

5.20 SAR distribution in phreatic (dug wells) and semi-confined aquifers of the study area.

5.21 Groundwater classification of phreatic (dug wells) and semi-confined deep aquifer (bore wells) for irrigation based on U.S.S.L method in Palaeo-lagoon (Kole land basin).

5.22 Isocone map of residual sodium carbonate in phreatic (dug wells)and semi-confined deep aquifer (bore wells) of the Palaeo-lagoon.

5.23 Classification of irrigation water (Doneen, 1962) of phreatic (dug wells) and semi-confined deep aquifer (bore wells) based on permeability index in Palaeo-lagoon (Kole land basin).

5.24 Isocone map of magnesium ratio in phreatic (dug wells) and semi-confined deep aquifer (bore wells) of the Palaeo-lagoon (Kole land basin).

5.25 Isocone map of corosivity ratio in phreatic (dug wells) and semi-confined aquifer (bore wells) of the Palaeo-lagoon (Kole land basin).

5.26 Gibb's diagram illustrating the mechanism controlling the groundwater chemistry of phratic(dug wells) and semi-confined(bore wells) aquifers in the study area.

5.27 Hydrochemical facies classification of groundwater based of Hill-Piper trilinear diagram.

5.28 Hill-Piper trilinear diagram for phreatic (dug wells) and semi-confined deep aquifer (bore wells) in Palaeo-lagoon.

5.29 Hill-Piper trilinear diagram for phreatic aquifer (dug wells) for pre and postmonsoon in Palaeo-lagoon.

5.30 Hill-Piper trilinear diagram for semi-confined aquifer (bore wells) for pre and postmonsoon in Palaeo-lagoon.
5.31 Hydrochemical facies digrams of groundwater (Back, 1966 and Johnson, 1975).
5.32 Hydrochemical facies of phreatic and semi-confined aquifers of the study area.
5.33 Map indicating groundwater vulnerability to pollution of phreatic aquifer in Palaeo-lagoon (Koleland basin) by DRASTIC method.
5.34 Hydrochemical facies diagram for phreatic and semi-confined deep aquifers (1 to 10 km from shoreline) of palaeo-lagoon (Kole land basin).
5.35 Theoretical Cl Vs Na/Cl trends/postions in different type of water.
5.36 Bivariate plots for Cl Vs Na/Cl ratio in palaeo-lagoon (Kole land basin).
5.37 Bivariate plots for Na/Cl ratio Vs EC in palaeo-lagoon (Kole land basin).
5.38 Time series graph for major ions in phreatic and semi-confined aquifers of coastal plain and lowland region, Paleo-lagoon.
5.39 Bivariate plots for Cl Vs Na/Cl ratio in Palaeo-lagoon (Kole land basin).
5.40 Bivariate plots for Cl Vs HCO_3/Cl in Palaeo-lagoon (Kole land basin).
5.41 Bivariate plots for Cl Vs SO_4/Cl ratio in palaeo-lagoon (Kole land basin).
5.42 Bivariate plots for Ca Vs Mg/Ca ratio in Palaeo-lagoon (Kole land basin).
5.43 Bivariate plots for Na Vs Mg/Na ratio in Palaeo-lagoon (Kole land basin).
5.44 Bivariate plots for Na Vs Mg/Na ratio in Palaeo-lagoon (Kole land basin).
5.45 Map indicating aquifer vulnerability to sea water intrusion assessed in phreatic aquifer of Palaeo-lagoon (Kole land basin) by GALDIT method.

Chapter 6

6.1 Geomorphology of Palaeo-lagoon (Kole land basin).
6.2 Depth to bed rock of Palaeo-lagoon (Kole land basin)
6.3 Geology of palaeo-lagoon (Kole land basin).
6.4 Rose diagram for lineaments in Palaeo-lagoon (Kole land basin) (Kukillaya, 2007).
6.5 Stratigraphic cross section of Palaeo-lagoon and adjoining coastal plain.
6.6 Location of sediment samples collected for textural analysis from the study area.
6.7 Bivariate plot of depth Vs Phi Mean size in coastal plain region of Paleo-lagoon (Kole land basin).
6.8 Bivariate plot of Phi Mean size Vs Standard deviation in coastal plain region Palaeo lagoon.
6.9 Bivariate plot of phi Mean size Vs Skewness in coastal plain region of Palaeo-lagoon.
6.10 Bivariate plot of Phi Mean size Vs Kurtosis in coastal plain region of Palaeo-lagoon.

6.11 Bivariate plot of Standard deviation Vs Skewness in coastal plain region of Palaeo-lagoon.
6.12 Bivariate plot of Standard deviation Vs Kurtosis in coastal plain region of Palaeo-lagoon.
6.13 Bivariate plot of Skewness Vs Kurtosis in coastal plain region of Palaeo-lagoon.
6.14 Scatter diagram showing north-south variation of Mean size Vs Skewness in coastal plain between Mthilakam and Chavakkad of Palaeo-lagoon Kole land basin.
6.15 Scatter diagram showing east-west variation of Mean size Vs Skewness in coastal plain between Mathilakam and Chavakkad of Palaeo-lagoon Kole land basin.
6.16 Variation of gravel, sand and silt/mud percentages in sediments of the study area.
6.17 Distribution of heavy minerals in different depth zones and different size grades in northern part of the coastal plain region (Engadiyoor in Keecheri basin) of Palaeo-lagoon.
6.18 Distribution of heavy minerals in different depth zones and different size grades in southern part of the coastal plain region (Edamuttom in Karuvannur basin) of Palaeo-lagoon.

Chapter 7

7.1 Bivariate diagram of ^{14}C date Vs Depth of the samples in Quaternary sediments of Kerala Konkan Basin.
7.2 Bivariate diagram of ^{14}C date Vs Depth of the samples in Quaternary sediments of Palaeo-lagoon.
7.3 Cross-shore profile locations in coastal plain Palaeo-lagoon.
7.4 Profile variation across palaeo beach-ridges in the Palaeo-lagoon (Kole land basin).
7.5 Shoreline changes in Palaeo-lagoon area of Central Kerala.

LIST OF PLATES

Chapter 1

1.1 A view of Palaeo-lagoon during monsoon season.

1.2 A view of palaeo-lagoon during summer season.

1.3 A view of Palaeo-lagoon during initial phase of monsoon.

1.4 A view of Conoli canal and Chetwai estuary.

1.5 A view of the study area showing different landuse pattern.

Chapter 2

2.1 Photographs of core samples collected from the study area.

2.2 Team on level survey in coastal plain region of Engadiyoor area.

Chapter 3

3.1 Photograph of artesian well in the coastal plain region (Kaipamangalam) of the study area.

Chapter 5

5.1 A view of the seasonal flood in the study area.

5.2 Topgraphical view of the study area, which facilitates the groundwater to pollution.

5.3 A view of Enammavu and Illikkal regulators constructed across Chetwai and Karuvannur rivers to prevent seasonal saline water ingress.

Chapter 6

6.1 A section of palaeo-ridges in the coastal plain area showing different layers (Engadiyoor).

6.2 Laterite cappings in the eastern side of the Palaeo-lagoon (Vilangankunnu).

6.3 A view of residual laterite seen as isolated patches within in Palaeo-lagoon (coconut planted area, Alappad and Pullu).

6.4 A view of laterite uplands within Palaeo-lagoon (puzhakkal and Kanimangalam areas).

6.5 Development of spits across the mouth of Chetwai lagoon in the study area.

Chapter 7

7.1 Photgraphs of shells recovered from Palaeo-lagoon

7.2 A view of beach ridge plain in Kurikuzhi area of Plaeo-lagoon (Remanents of former seawall also seen).

7.3 A view of sand dunes in Chetwai and Moonnupeedika area of the Palaeo-lagoon.

CHAPTER 1

GENERAL INTRODUCTION

Water, the elixir of life, is a prime natural resource and basic human need. Of the total water on earth only 3% constitutes fresh water and the rest is saline water in the oceans. An area of 37.5 million cubic kilometer is occupied by fresh water and 1320 million cubic kilometer is occupied by saline water. The average annual rainfall of the country is 1170 mm. The maximum average rainfall is 11000 mm in Mawsynram (in Meghalaya) and minimum is 100 mm in western Rajasthan, India has got only 4.5% of World's water resources, though the country houses about 16 % of the global population. This indicates that the water sector of the Nation is under severe stress. The national figures indicate that the per capita availability of water is reduced to one third since independence. The national water demand is ever growing and is expected to be around 1447 BCM in 2050, which was about 600 BCM during the year 2000. Hence there is a need to conserve the soil profile, aquifers, ponds, lakes, reservoirs and rivers, for use during the dry periods. The situation of Kerala State is also not an exception. Water is consequently a scarce and precious national asset, which has to be planned, developed, conserved and managed in an integrated and eco-friendly manner, keeping in view of the socio economic dimension.

Growth process and the expansion of economic activities inevitably lead to increasing demand of water for diverse purposes; domestic, industrial, agricultural, hydro-power, thermal-power, navigation, recreation. etc. So far, the major consumptive use of water has been for irrigation. Agriculture is the greatest user of water, accounting about 80% of all consumption. But about 70% of irrigation water is wasted in run-off or inefficient irrigation systems (World Bank, 2003). Animal husbandry and fisheries also require abundant water. Water can as well create problems concerning human health, it being a carrier of vectors for diseases such as typhoid, cholera, diarrhoea, malaria, filariasis, etc., if it is mismanaged. In addition to this, availability of fresh water is too highly uneven in both space and time. Water has an economic value in all its competing uses and there has been growing demand that water should be recognised as an economic good. A major challenge today is to introduce economies in agricultural, municipal and industrial water use.

The country's population, which was over 1027 million in 2001 at present, is expected to reach 1390 million by 2025. Consequently, food grain production will have to be raised to around 350 million tons by 2025. This necessitates development of water resources by a substantial order, if the food and fibre needs of our growing population are to be met with. As per the published documents available, the ultimate irrigation potential of the country would be of the order of 139 million hectares. Some of the important statistics of water resources of the world and in India are given in Figs. 1.1 -1.6.

The State of Kerala constitutes a narrow strip of land on the southwestern Peninsular India, sandwiched between Western Ghats and Arabian sea. Its water regime is characterised by very high precipitation (over 3000 mm per annum) spread over relatively few (arguably shrinking) wet days, a long dry season (December to May) and a marked gradient from the Ghats to the sea rapidly re-conveying the rainfall back to the sea through several short, fast, west flowing rivers. The Kerala was considered to be very rich in groundwater resources with significant rainfall received over two monsoon seasons. Ironically, recent studies indicate that the water resource position of Kerala is not as rosy as it was in yester years. Due to the higher standard of living, the demands for water for all uses are also growing many folds during the last decades.

Man has been continuously developing groundwater, being easily accessible and wide spread, for various purposes right from the dawn of human civilization. Kerala has always been overly dependent on it, for over the centuries, human adaptation to the local water regime consisted of harvesting nature's bounty of abundant rainwater by excavating large number of open dug wells in homestead plots. It is estimated that the State presently has over 4 million such wells, roughly one well for every 8 to 10 persons.

The situation of Kerala is such that issues related with groundwater development are increasing day by day. It is noticed that there is a considerable imbalance in the availability of groundwater resources from place to place through out the State. Richly endowed with natural resources, human population in the state has stabilized at very dense levels following the demographic revolution. This has put

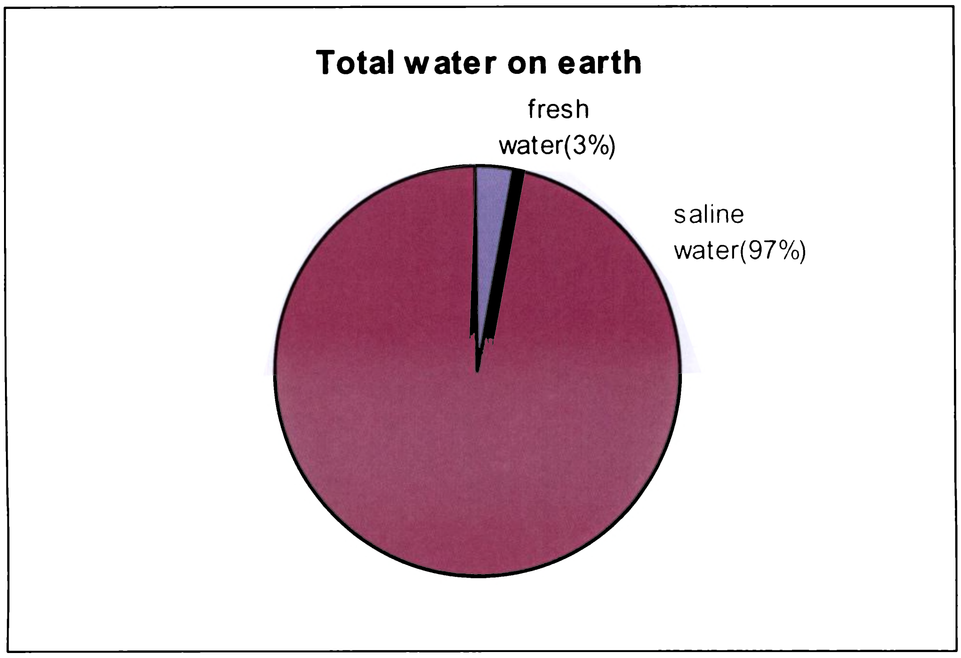


Fig. 1.1 Fresh water availability of the world

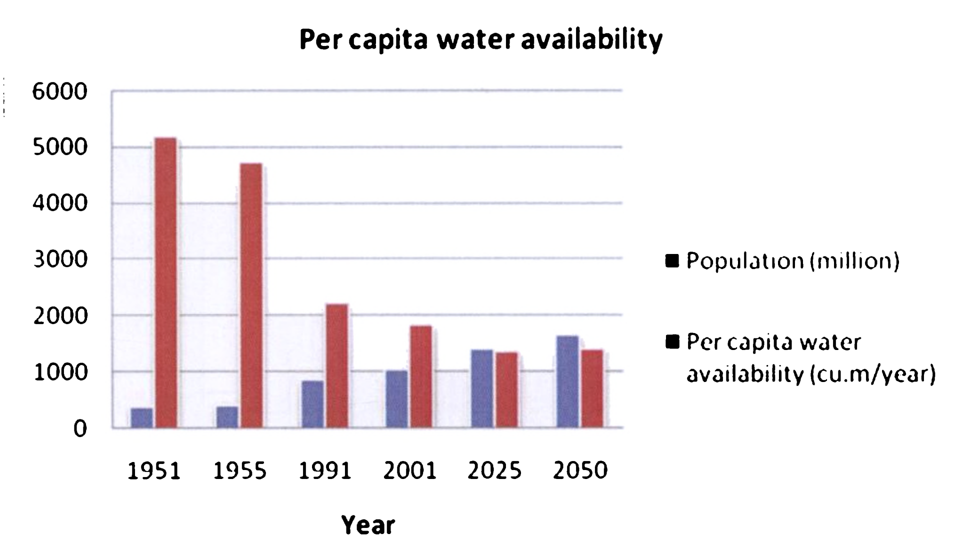


Fig. 1.2 Year wise water availability in India and future projection

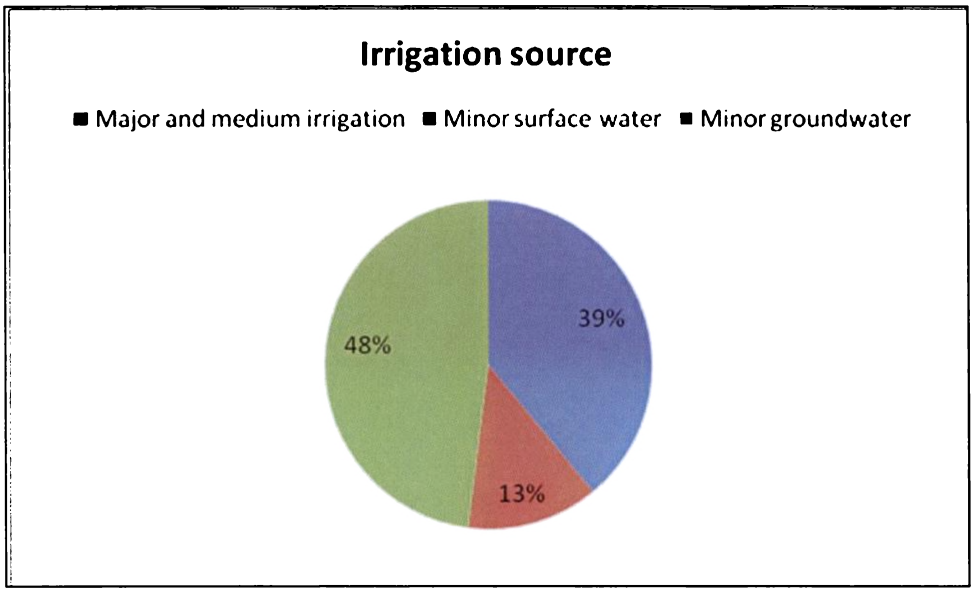


Fig. 1.3 Irrigation sources of India

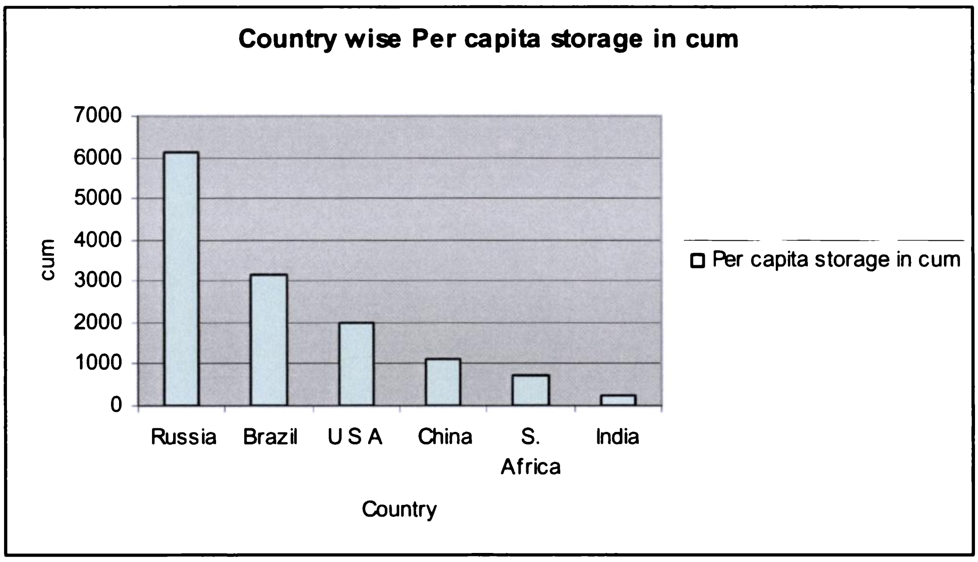


Fig. 1.4 Country wise per capita storage of water

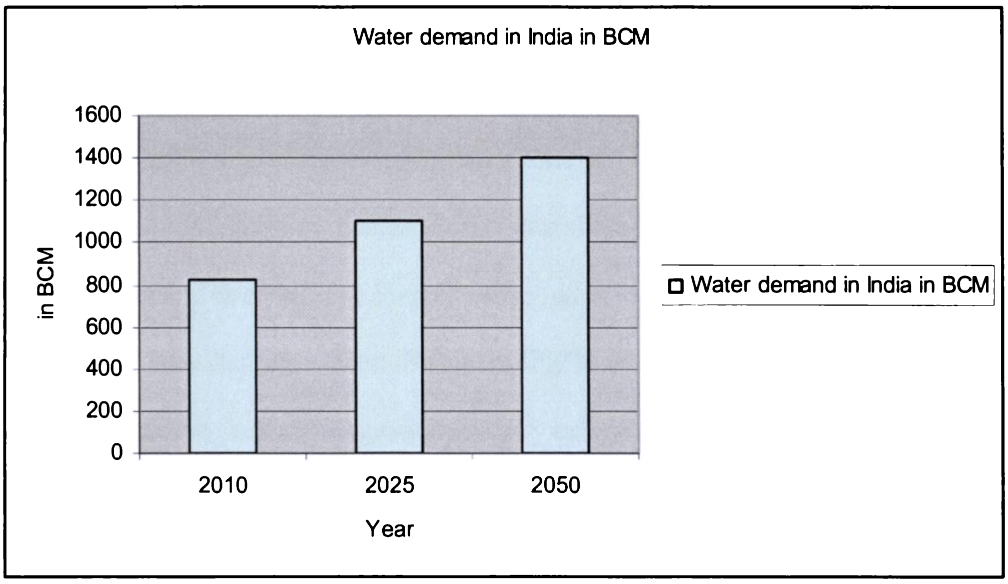


Fig. 1.5 Projected water demand in India

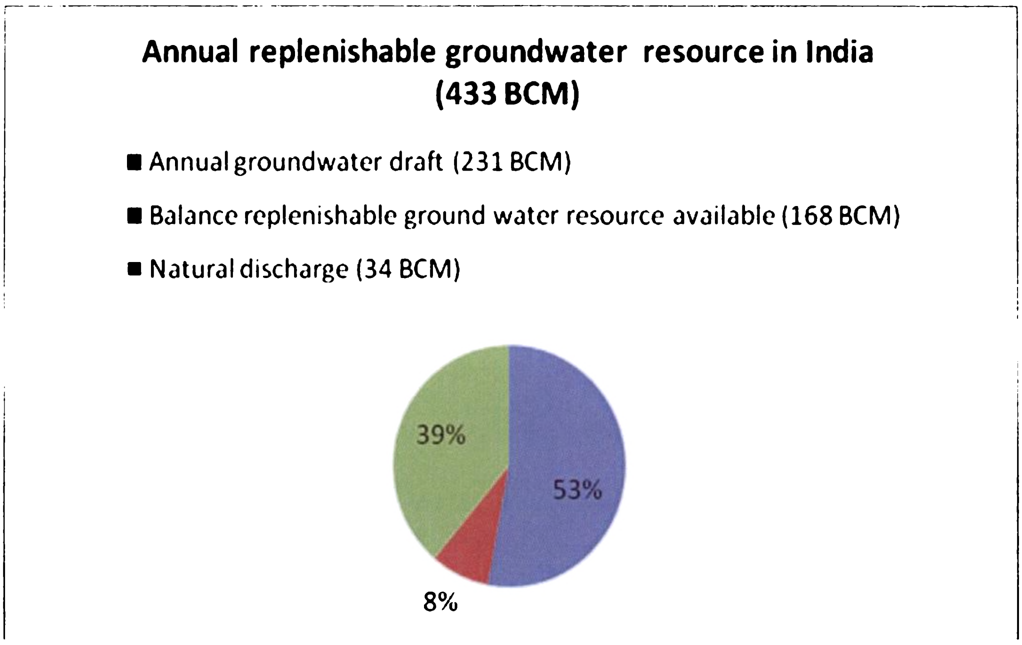


Fig. 1.6 Groundwater resource availability and utilization in India

tremendous strain on groundwater resources during the long dry season, especially in hilly and coastal areas, where saline intrusion is always been a problem. Since water rights in India is vested with property owners (unlike mineral rights that vested with the State); unregulated exploitation of groundwater through energised bore well is very common. The problem is compounded by large scale reclamation of paddy fields; natural fresh water sinks to cultivate more lucrative plantations like rubber, banana and coconut. The State has responded to these challenges putting in place both land use and groundwater legislation. Public policy in the water sector over the years has also endeavoured to ease the pressure on groundwater by extending treated piped water supply sourced in surface water bodies. The reliance on well water however continues, as piped water at the national benchmark of 40 litres per capita per day is available only about 25% of Grama panchayat wards. This dependence is recognised in the 'Swajaladhara' and ' Jalanidhi' initiatives, which seek to encourage community ownership and management of primarily well based water supply schemes.

According to National Water Policy "there should be a periodical reassessment of the groundwater potential on a scientific basis, taking into consideration the quality of the water available and economic viability of its extraction". Further, the exploitation of groundwater resource should be so regulated, so that it does not exceed the recharge possibilities. The over exploitation of groundwater has to be effectively prevented so as to avoid detrimental environmental consequences.

In view of the above, the Central Ground Water Board (CGWB), Ministry of Water Resources, Government of India and State Ground Water Department (SGWD), Government of Kerala have assessed the groundwater resources of the State block-wise as on 31st March 2004 (Table 1.1). The parameters used in the computations, as well as the vast amount of observation well data generated regularly by National Hydrology Project, so that the reassessment is done in a rigorous scientific manner, reflecting ground-level realities. The trends in groundwater level over the last decade were taken into consideration along with stage of groundwater development, before categorising the blocks. It is observed that there has been a spurt in the groundwater development during the last couple of decades. All the development blocks in the State were in safe category till 1992. The situation changed during the 1999 computations, where 3 blocks were categorized as over exploited, 6 critical while 6 others in semi-critical stage. A total 15 blocks moved out of the safe category between 1992 and 1998. However, in the year 2004, the number of such blocks has increased from 15 to 50, which is about one third of the total Block Panchayats in the State (5 over exploited, 15 critical and 30 semi-critical). Due to the ever increasing demand over this resource, about one third of blocks in the State are showing the higher stage of groundwater development. This indicates that the groundwater extraction in the State is showing an increasing trend. This situation warrants a systematic and planned response through more effective groundwater regulation and more intensive artificial recharge and conservation measures.

The Indian Peninsula has a remarkable southeastward slope, facilitating the major rivers to flow eastward. All the west flowing rivers originating in Western Ghats are small, but carry huge volume of water. The western continental margin of India can be classed as Atlantic type passive margin. It is featured by (i) a wide continental shelf extending in NW-SE direction, (ii) a remarkably straight shelf edge limited by 200 m isobaths, (iii) a narrow continental slope bounded by 200 m and 2000 m isobaths and (iv) the oceanic basin of the Arabian sea (Biswas, 1998). The continental shelf is 300 km wide in the Kutch-Saurashtra segment, but gradually narrows down southward to 50 km in the Kerala offshore. It again becomes wider (~150 km) off Kanyakuamari. A unique morphotectonic feature of the shelf is a shelf margin arch, and ridge that traverse the entire length of the shelf (Harbinson and Basinger, 1970). The continental shelf area of India is broadly divisible in to several sub-basins by traverse basement arches or fault bounded highs. These are the Kutch, Bombay offshore, Konkan - Kerala and deep sea basins (Fig. 1.7).

The Konkan - Kerala offshore basin extends from Vengurla Arch in the north to Kanyakumari in the south. The western boundary of the basin is defined by the Kori - Comorin Ridge and east by the Western Ghats, composed of Precambrian rocks, but devoid of Deccan traps (Rao and Talukdar,

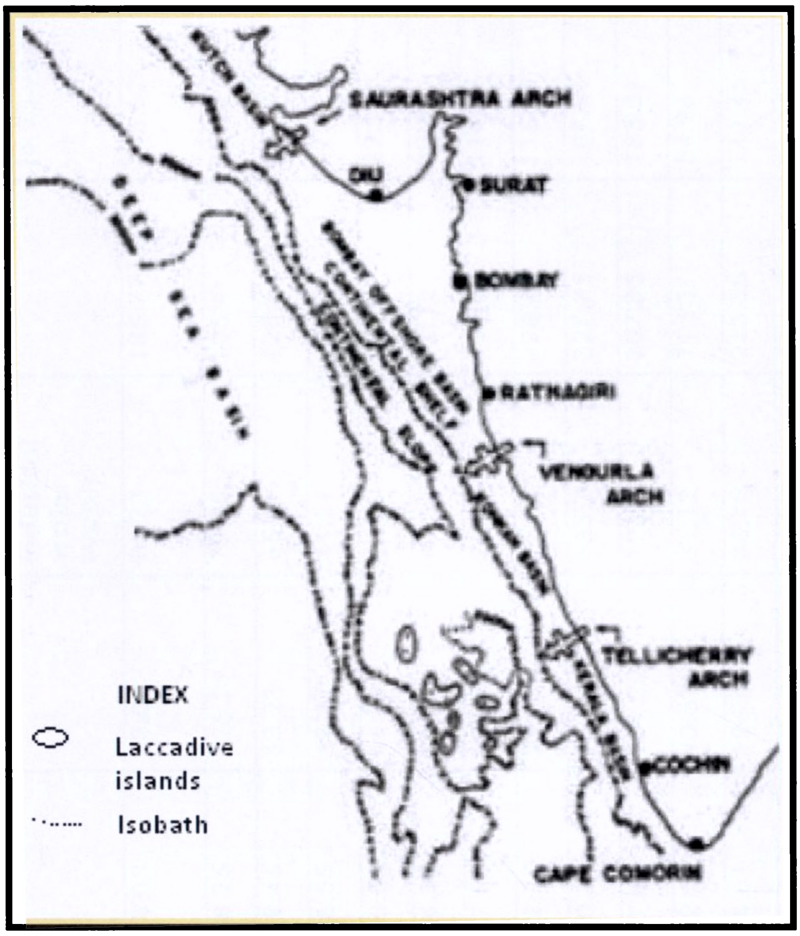


Fig. 1.7 Location and extent of west coast offshore basins (after Biswas, 1988)

Table 1.1 Stage of groundwater development of Kerala State on 31st March 2004 in MCM

Sl.No	District	Command or Non-command	Net annual groundwater availability	Existing gross groundwater draft for irrigation	Existing gross Groundwater draft for domestic and industrial water supply	Existing gross groundwater draft for all uses	Allocation for - domestic & industrial requirements supply up to 25 years	Stage of development in %
1	Thiruvananthapuram	N.C*	278.03	92.04	93.73	185.77	116.52	66.82
2	Kollam	N.C	448.25	125.29	79.75	205.4	98.52	45.82
3	Alappuzha	N.C	419.46	63.23	65.41	128.64	77.12	30.67
4	Pathanamthitta	N.C	316.55	59.37	41.14	100.50	47.49	31.75
5	Kottayam	N.C	470.83	66.30	67.30	133.6	82.17	28.37
6	Idukki	N.C	246.32	52.00	40.32	92.32	49.31	37.48
7	Ernakulam	N.C	567.83	201.84	91.96	293.8	114.65	51.74
8	Thrissur	N.C	702.75	234.38	91.74	326.44	116.92	46.45
9	Palakkad	N.C	750.33	164.01	163.74	327.75	189.51	43.67
10	Malappuram	N.C	507.64	181.22	126.62	307.85	183.31	60.65
11	Wayanad	N.C	292.59	40.81	31.12	71.93	54.96	24.58
12	Kozhikode	N.C	344.81	126.63	86.75	213.38	111.45	61.88
13	Kannur	N.C	540.62	184.59	76.59	261.18	95.58	48.31
14	Kasaragod	N.C	343.53	229.09	42.55	271.64	58.34	79.07

Data source: CGWB, Kerala region
NC*: Non command

1980). The basin covers an area 77,000 km^2 up to 200 m isobaths. The shelfal horst graben complex of Konkan - Kerala basin is differentiated into three major depressions namely, the Konkan depression, Cochin depression and Cape Comorin depression, traversed by basement arches. The Konkan basin is separated from Kerala basin by Tellicherry Arch basement high, both basins derive their sediments from the Western Ghats (Campanile et.al, 2008) and have a sedimentary record 80 to 90 Ma. BP (Fig. 1.7).

Sedimentation: The Konkan - Kerala Basin (KKB) can be divided in to five sub-sequences of post - rift sedimentation since the Late Cretaceous. The stratigraphic succession of Konkan - Kerala basin begins with the continental to bathyl coarse clastic sequence of Late Cretaceous age and continuous upward to Palaeocene. Eocene to Middle Miocene succession consists of limestone, shale and sandstone. The inner shelf has been a closed sediment sink for the erosional products of the Western Ghats and hence provides an excellent record of onshore denudation. The shelf sediments along the western margin of India are strongly compartmentalized and show marked affinities along the strike with their adjacent onshore areas. Thus, north of Goa, modern shelf sediments have a basaltic source, whereas south of Goa these sediments have gneissic source. The close relationship between onshore geology and offshore sediments reveals that there was little long shore transport of sediments in the Konkan and Kerala basins during the Cenozoic (Campanile et al., 2008).

The Upper Cretaceous early rift phase of sedimentation (ie. Campanian) in the Konkan - Kerala Basin (KKB) is localized in narrow grabens in the south west of Cochin. This sedimentation took place in a shallow continental setting (i.e. fan deltas, tidal flats, and carbonate platforms), suggesting that a major part of the stretched portion of the crust on which the basin developed had remained above sea level until at least pre - Santonian time. Upper cretaceous sediments in the deepest wells of Konkan - Kerala Basin overlie altered volcanic rocks. The basal volcanic rocks are undated, but outcrops of similar volcanic rocks near the coast (St.Mary's Island near Mangalore) have been dated as 85.6 Ma, and hence that are contemporaneous with Marion hot-spot magmatism (Joseph and Nambiar; 1996). Accordingly, basin initiation is likely to have occurred art 88 Ma, the time of India-Madgascar rifting and during the peak of Morion hot spot volcanism; nevertheless, the bulk of sediments in the Konkan-Kerala Basin appear to have been deposited during Cenozoic.

Occurrence of marine and non-marine rocks of Tertiary age in the on land part of Kerala sedimentary basin was reported by King (1882) and Foote (1883). Based on the distribution of sedimentary formations, Paulose and Narayanaswami (1968) recognised two major basins of deposition; (i) between Trivandrum and Ponnani in the South and Central Kerala with a maximum width of 16 km from Kollam to Kundara, and (ii) between Kannur and Kasaragod in north Kerala with a maximum width of 10 km at Cheruvattur. The basin from Thiruvanathapuran to Ponnani is called as the South Kerala sedimentary basin (SKSB) and the other between Kannur and Kasaragod as North Kerala sedimentary basin (NKSB) (Nair et al., 1980). The South Kerala Sedimentary Basin (SKSB) is the land ward extension of the offshore Kerala - Konkan Basin (KKB) (Nair et al., 1998).

1.1 Geologic records of Kerala

The Kerala region is an important segment of the South Indian Precambrian terrain, where major units of the Archaean continental crust, such as granulites, granites, gneisses and green stones are preserved. The southern part of the State, south of Achankovil shear zone, exposes an assemblage of migmatised meta- sedimentary and meta-igneous rocks (khondalite-chanockite assemblage). From north of Achankovil shear zone up to the southern flank of the Palghat Gap, the rocks are predominantly charnockites. Chanockite-gneiss and a variety of other gneisses with occasional assemblages of metasediments in Idukki-Munnar region representing the western continuation of the Madurai block in Tamil Nadu. Northern flank of the Gap consists of meta-sedimentary sequence of khondalites and calc-granulite with crystalline limestone bands. Granulites, schists and gneisses, intruded by acid and alkaline plutones, constitute the northern most part of the State.

The bulk of the rocks of Kerala, especially the granulites and associated gneisses belong to Precambrian. Sporadic Late Precambrian-Early Palaeozoic granites and associated pegmatites, and Meso-Cenozoic dykes intruded these ricks. The onland sedimentary formations are confined to Neogene period only. This indicates that the geologic column of the region is far from complete, with hardly any representation of rocks of the great periods belonging to Palaeozoic, Mesozoic and Early Cenozoic eras of the Geologic Time Scale.

A number of radiometric age determinations of rocks from the Kerala region have helped in classifying the rocks into broad age groups (Table 1.2). The geological map of Kerala region is given in Fig. 1.8. The oldest rock so far dated in Kerala, are the charnockites (massive), which yield U-Pb zircon age of 2930± 50 Ma. These also happen to be the most wide spread rock unit in the State. The largest patch of khondalite group of rocks is noticed south of Achankovil shear zone in south Kerala. These rock units occur as linear belt, wedged between chanockite massifs on both sides. They have recorded ages of ca 2100-2830 Ma, although there is whole rock model age 3070 Ma reported by Crawford (1969).

Ancient supracrustals: The oldest dated rocks in Kerala namely charnockites/charnockitic gneisses, contain several enclaves of schistose rocks. These occur as linear en-echelon bands and enclaves extending from Sultan's Battery, close to Karnataka border through Manathoddy in Wayanad plataue to Thaliparamba and Payyannur, and to the eastern parts of Kasargod district, being the southward extension of the schistose sequence in Karnataka. Lithology of the schistose rocks permits their identification with the Sargur complex of Karantaka, which are considered as the oldest rock assemblage there, consisting of group of sediments and associated intrusives.

Charnockite-Gneiss association: The most widespread rocks in Kerala are the charnockite and associated gneisses. These are pyroxene bearing granulites and gneisses and occupy a major part of the Western Ghats and the midland regions of the State, especially in central and north Kerala. Large bands of chanockites are also observed within the south Kerala khondalite belt. The available geochronologic data on a charnockite (massive) sample from Nedumannur in southeastern Kerala,

Table 1.2 Geological time scale and major geologic events in Kerala (Soman, 1997)

Age in M.Y	Era	Period		Geologic events
0	Phanerozoic		Intrussives	Laterites, Cenozoic sediments
				Dolerites (61-144 Ma)
				No record
				Pegmatites (460-680Ma) incipiant
570				Charnockite (540 Ma) acid & alkaline
	Proterozoic	PR3		No record
1000				
		PR2	Intrussives	Pegmatite (1420±20 Ma) Attappadi
				Migmatization in south Kerala 1550 Ma
				Dolerite dykes (1660 Ma) Attappadi
2000		PR1		No record
	Archaean	AR3		
3000				Khondalite, calc-granulite and gneisses
		AR2		Charnockite (massive) and chanockitic gneiss
				Sargur and associated schists
				Earliest basement
		AR1		No record of this age identification in Kerala region
4000				
	Hadean			Hadean (4500 - 4000 Ma) Origin of Earth
5000				Pre Hadean-Early cosmic evolution

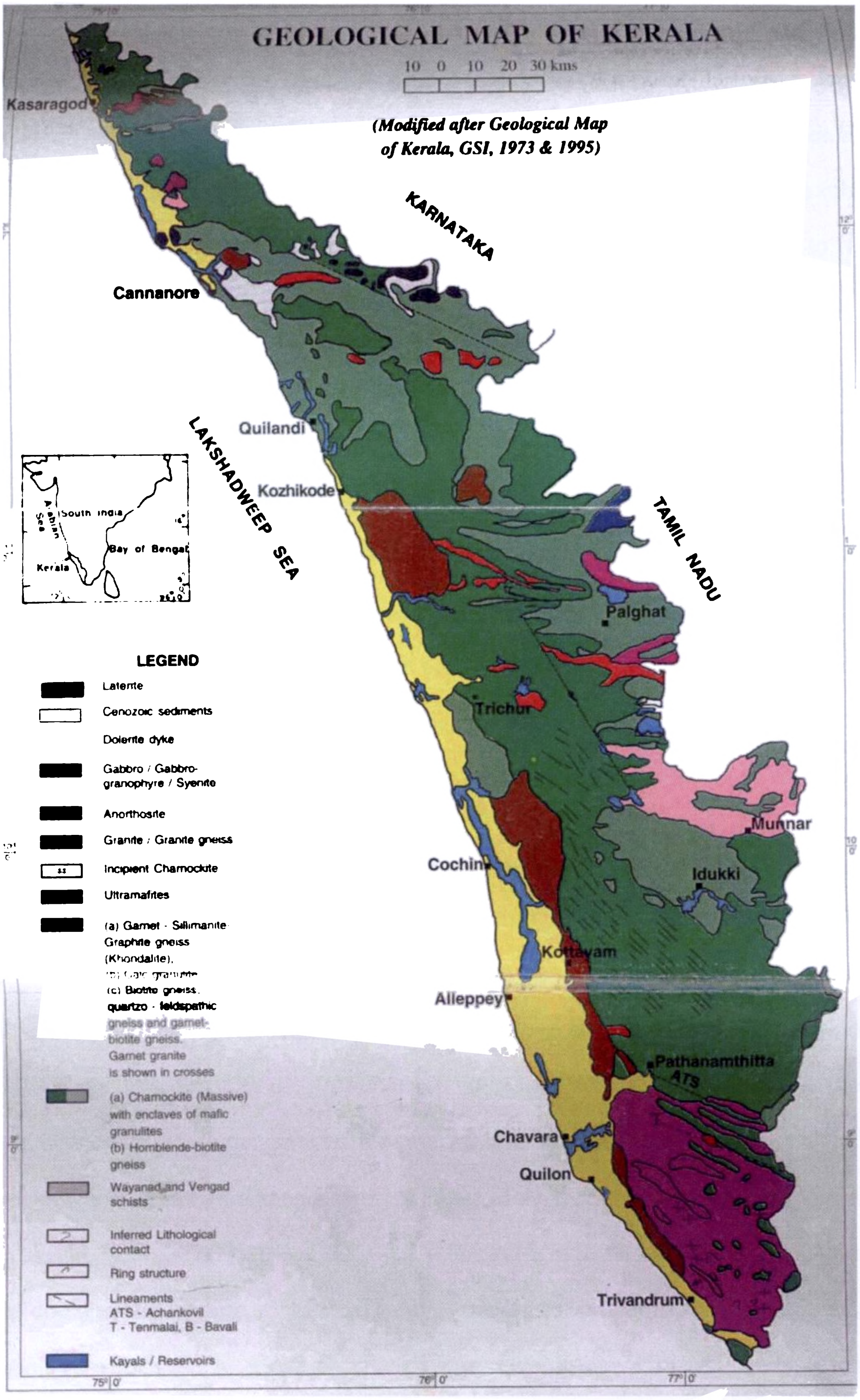


Fig. 1.8 Geological map of Kerala (GSI 1973 & 1975)

yielding U-Pb zircon age of 2930±50 Ma indicates that these are the oldest rocks dated so far in Kerala. In many localities enclaves of mafic granulites also occur within charnockites. Textural, mineralogical and geochemical variations are observed in chanockites from different localities. Field relations, including association with other metamorphic rocks, mineralogical and petrographical features are indicative of metamorphic origin of the rocks under high P-T conditions (8-to 10 kb pressure and around 800- 860°c) from a diverse source of precursors including igneous ones.

Khondalite: Garnet-sillimanite gneiss, containing varying amounts of graphite and some quartz and orthoclase is termed as khondalite. Its occurrences are seen in various parts of the State. The largest patch is noticed in south Kerala association with garnet-biotite gneiss and garnetifrous quartzo-feldspathic gneiss. This occurs as linear belt; wedged between chanockite massifs. Another linear belt is observed in northern flank of the Palghat Gap, where it is seen in association with cal-granulite and crystalline limestone. Minor occurrences have been reported from Idukki-Munnar region and from southeast of Kasargod. According to available data, rocks of this group range in age from 2830 to 2100 Ma, although there is an older whole rock Rb-Sr age of 3070 Ma reported by Crawford (1969).

Intrussive rocks: Intrusive phase within Kerala region includes sporadic occurrence of basic and ultrabasic bodies and dykes belonging to Lower-Middle Proterozoic age, pegmatites of Middle Proterozoic age, a host of younger granites (Late Precambrian-Early Palaeozoic age) with associated pegmatites, and later dolerite dykes, contemporaneous with Cretaceous-Palaeocene Deccan basalt magamtism. Of these, the younger granites and associated pegamatites constitute the bulk of the intrusive rocks, and are contemporaneous with the Pan-African tecto-magmatic event. Within the khondalite terrain, these are white coloured garnet granites (as in south Kerala), while within the charnockite domain; pink granite, syenite and gabbro-granophyre predominate. Pegmatite phase, closely associated with the younger granites phase, is more prominent within the khondalite terrain of south Kerala, where it contains gem-quality chrysoberyl mineralization. Pegmatites in north Kerala are relatively older and known for their muscovite mineralization.

Dolerite dykes, contemporaneous with the Deccan basalt magmatism are the dominant phase, and occur within both charnockites and gneisses with ages ranging from 141 to 61 Ma. The quartz veins, occurring in the Wayanad region is associated with syn or post pegmatite emplacement phase. In Nilambur valley, reef quartz is associated with gold mineralization.

Tertiary and Quaternary sediments: Onland sedimentary formations, belonging essentially to Neogene and Quaternary periods unconformably overlie Precambrian rocks. Both marine and non-marine rocks of the Neogene period fringe the coastal tract in two major basins of deposition; (i) between Thiruvanathapuram and Ponnani in the south and the central Kerala between Kollam and Kundara and (ii) between Kannur and Kasargod in the north at Cheruvathoor. These include rocks of the Vaikom formation, comprising gravel, coarse to very coarse sand with greyish clay and carbonaceous clay and seams of lignite; fossiliferous limestone, sands and clays of the Quilon formation and the overlying clays with lignite bed, sand, sandy clays and sandstone belonging to the Warkalli beds of the Late Moicene age. Sediments of Quaternary period, consisting of sands, lagoonal clays, shell deposits, teri sands etc. unconformably overlie the Neogene sediments. The total thickness of the sedimentary sequence exceeds 600m in the Ambalauzha-Alapuzha region (Fig. 1.9). The tentative stratigraphic succession of the Kerala basin is given in Table 1.3.

Table 1.3 Stratigraphic sequence of Kerala (modified after Najeeb, 1999)

Period	Formation	Lithology
Quaternary	Vembanad formation	Sands, clays, molluscan shell beds, riverine alluvium and flood plain deposits, laterite capping the crystallines and Tertiary sediments
Tertiary	Warkalli formation	Sandstone clay with lignite seams
	Quilon formation	Limestones, marls, clays/calareous clays with marine fossils
	Vaikom formation	Sandstones with pebbles and gravel beds, clays and lignite and carbonaceous clay
Mesozoic to Archaean	Intrussive	Veins of quartz, pegmatites, granites, granophyres, dolerite and gabbro.
	Crystallines	Garnet sillimanite gneiss, hornblende-biotite gneiss, garnet biotite gneiss, quartzo-feldspathic gneiss, charnockites, charnockite gneiss etc.

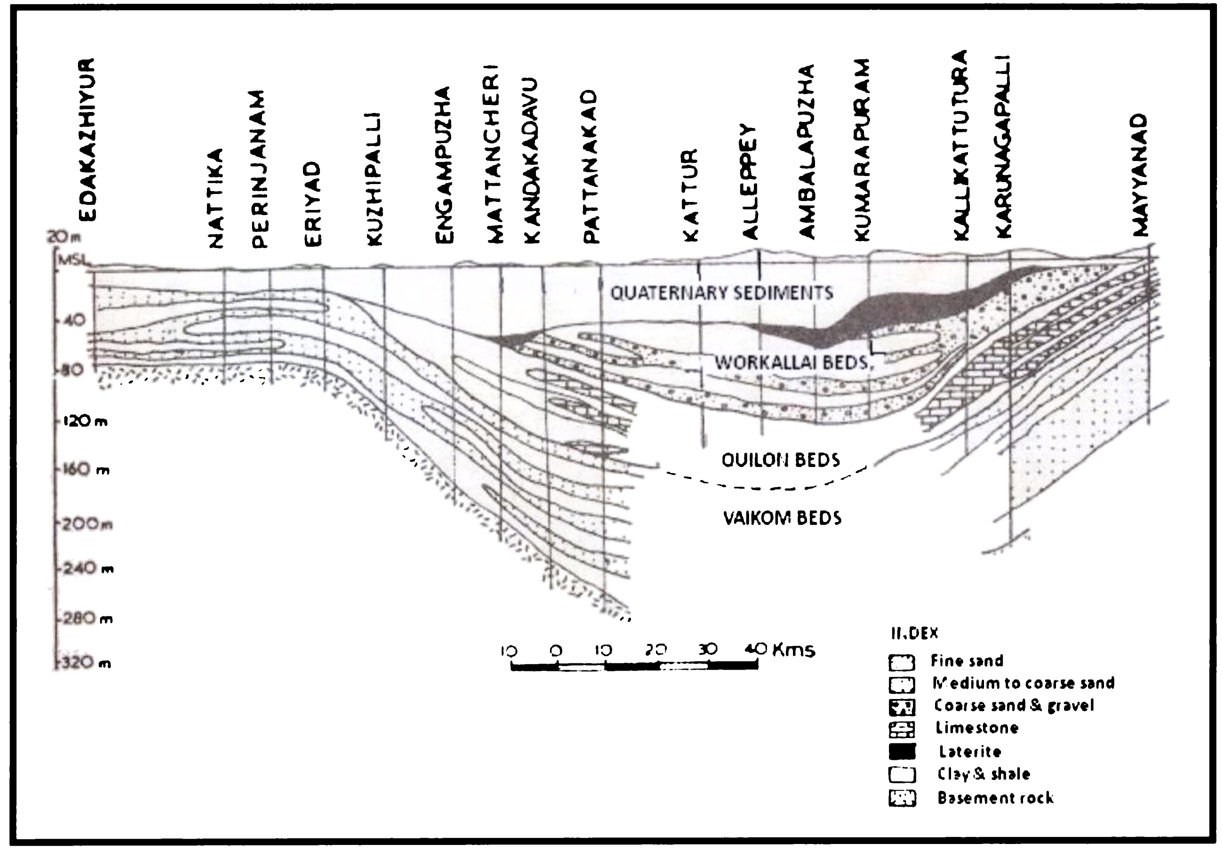


Fig. 1.9 Sub surface geological section along the coastal belt of Kerala based on borehole data

(after Raghava Rao, 1976)

Offshore sediments: The western continental margin of the Kerala coast has a 50 km wide continental shelf, hosting the Kerala-Konkan basin. The nearshore shelf part contains a clastic sequence of marine shale and sand with a very few limestone interbeds and Cretaceous-Palaeocene sediments. The offshore basin, with over 4000 m thick of Late Cretaceous to Quaternary sediments, consists of limestone, sandstone and a pile of volcanic. The sediments display two major unconformities during Palaeocene -Early Eocene and Middle Eocene- Early Oligocene periods.

Laterites: Buchanan first reported Laterite from Angadipuram during his traverse to Malabar. A weathering product of rocks, rich in secondary oxide of iron, aluminium or both, with or without quartz and clay. It serves as a building material, ore for aluminium/ nickel/manganese/iron etc. and is very good aquifer for groundwater. In Kerala, laterites of more than one generation are present, and are confined to elevations of 600 m and below, over Precambrian and Tertiary sediments. Interface of the coastal plain and lowlands is occupied by laterite. Vast dissected lateritic mesas are present in parts of Malappuram, Kannur and Kasagod districts. Two lateritization cycles are known to exist in Kerala; Pre-Warkalli and Post Warkalli cycles.

Soils: Ten broad groups of soils based on morphological features and physico-chemical properties have been identified in Kerala. Spatial distribution and physico-chemical properties of the soils are mostly consistent with the lithological diversities of the rocks, as well as physiographic and vegetational distributional patterns. The most predominant type, however, is the lateritic soil, reddish brown to yellowish red in colour, supporting a wide range of crops such as coconut, tapioca, rubber, arecanut, pepper, cashew etc. properties of the lateritic soil vary depending on the bedrock characteristics.

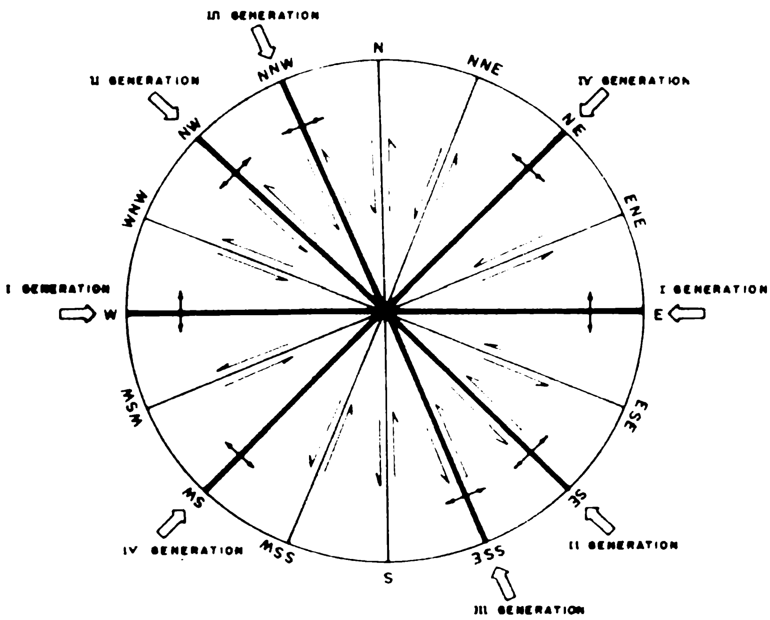
The available geological record of the State is suggestive of a protracted history for the region, spanning from Precambrian time onwards to the present. The onland record is, however, one of prolonged periods of erosion and non deposition. Offshore data indicate that the major geomorphic events took place during Tertiary-Quaternary times. Foundering of estuaries, and sequential uplift of the coast, it is presumed, must be quite recent events in the geologic history of the region. Continued geological and tectonic activity in the region is discernible from frequent tremors experienced in various parts of the State from historic records of river course changes. Much more detailed efforts are required to fully unravel the complex and protracted geological evolutional history of the state.

1.2 Structure and tectonics of Kerala basin

The Kerala region can be divided into two major tectonic provinces, namely, the Precambrian tectonic province and the Tertiary tectonic province. The higher ranges of the Western Ghats, the foot hills and parts of the midland constitute the Precambrian tectonic province area, which forms the western limb of NNW plunging synclinorium, the axis of which is traceable from Tuticorin in the south to Dharwar and Belgaum in the north (Rao, 1974). A narrow belt mostly between coastal and midland region extending from Thiruvananthapuram in the south to Kasargod in the north constitutes the Tertiary Tectonic province. The regional strike of the foliation of Precambrian rocks is NW-SE to WNW-ESE with a steep dip towards SW. The Tertiary rocks are almost horizontal to sub horizontal.

Structural trends: Rocks of the Precambrian tectonic province underwent many periods of tectogenesis as evidenced by the presence of fold pattern. The various rock types included under the Precambrian, except for the intrusive, dykes and pegmatites, have general foliation strike trending NW-SE in the southern part of the State, while in the northern part, it locally swings to NE-SW strike of Nilgiri range. In Wayanadu, to the west of Nigiris, NNW-SSE and N-S strikes of foliation are seen but some fedlspathic schists further west show an E-W strike of foliation. The E-W strikes possibly be westerly continuation of the strike of Nilgiris and may have a bearing on the presence of Palghat Gap (Krishnan, 1982). Within the Palghat Gap, the regional strike of foliation and banding are east - west with steep to moderate dips to the south. Local swings of strike direction from the NW-SE trend have also been observed in the shear zones, such as the Ariankavu, Gudallur and the Bodinayakkannur passes, as well as in the vicinity of granitic intrusions and domal structures in the

RUPTURAL DEFORMATION HISTORY



TECTONIC CYCLE	DIRECTION OF FRACTURE ZONE							
	WNW ESE	NW SE	NNW SSE	N - S	NNE SSW	NE SW	ENE WSW	E - W
I GENERATION	S	–	-	–	–	–	S	T
II GENERATION	S	T	S	–	–	–	–	–
III GENERATION	-	S	T	S	–	–	–	–
IV GENERATION	–	–	–	-	S	T	S	–

T – TENSILE FRACTURES S – SHEAR FRACTURES

Fig. 1.10 Tectonic model of Peninsular India (Najeeb, 1999)

Anaimalai and the Agasthyamalai hill ranges. In the Ariankavu pass region, local variations in foliation trend include NNE-SSE, E-W and ENE-WSW foliation tends are observed. Similar foliation trends are observed in Munnar also.

Naranaswami (1976) identified two major synclines: (i) in the Palghat Gap between the Nilgiris and Anaimalai-Palani ranges and (ii) in the Munar-Thodupuzha-Muvattupuzha region extending into the Kambam-Periakulam valley of Tamil Nadu between Palani and Varshanad hill ranges; and two major anticlines along the Kottayam-Pirmed-Kakkiar hill ranges. Another major antiform is discernable in the region between Kollam and Punalur, and extends for 25 to 30 km in NW-SE direction. Disrupted NW-SE trending antiformal structures separated by synforms are also seen in north of Chengannur. A major NW plunging antiform is discerned in the Ottappalm region (Nair and Nair, 1980), which has been refolded into open flexural folds.

Although the crystalline rocks of Kerala have undergone different episodes of superposed deformation, their nature, sequence and mutual relations attributable to different deformational events have not been adequately established for the entire terrain, mostly due to the paucity of exposures and rarity of marker horizons with exposure continuity. However, based on considerations of the geometry, orientation and superposition characteristics of folds, planar and linear structures of different generations have been identified in many regions of the State, as related to deformational episodes.

Tectonic history: On a cursory look at the toposheet or areal photographs we can see that most of the rivers in Kerala are aligned in a NW-SE direction, which is the predominant direction of fractures or lineament. But it may be strange to note that this is one of the least productive fracture directions as far as groundwater is concerned. Here comes the tectonic history of the area. The area has undergone four major episodes of tectonic deformation. In each of these tensile fractures are developed in the direction of force while shear fractures are developed on either side at about 25° to 30° angle to the direction of force (Fig. 1.10).

The major tectonic events of the area can be summarized as follows:

(i) The first generation happened to be the compression in EW direction resulting in tensile joints and shear fractures at 25 to 30° to it on either side.

(ii) The second generation involves compression in the NW-SE direction; incidentally it happens to be the direction emplacement of the innumerable dolerite dykes in the peninsular India.

(iii) The third generation was the one related to the west coast faulting, which was in NNW-SSE direction. The gabbro dyke emplacement is observed in this direction.

(iv) The fourth generation of tectonic activities resulted in the development of the NE-SW direction and is the latest episode.

From the above it can be seen that the NE-SW and E-W oriented lineaments are likely to be most potential for groundwater and they are tensile open joints which didn't have a history of shearing. The emplacements of dykes along these tensile joints are quite deep and open. Lineaments belonging to this category are seen in both within Western Ghats and in the coastal belt and are the youngest (Nair, 1990). In order to preference the NNW-SSE comes next as they are original shear zones opened by later tensile joints. These are a series of prominent, generally intermediate lineaments (around 50 km in length) seen in contact zone between the steeply rising Western Ghats and the step-like coastal terraces. They are more prominent in southern and northern extremity of Western Ghats. The leucogabbro dyke of this lineament from Kottayam area yields an emplacement age of 81±3 Ma and is correlated with the age of dyke from Idamalayar. The NW-SE direction happens to be the original tensile joints sheared in a later tectonic episode and would have become more tight and clayey. The NW-SE lineaments, often hosting dykes of dolerite/gabbroic composition have a definite signature in the geological setting of the region. The available age data on these dykes from south Kerala (61±9 Ma) suggests that they are coeval and genetically related to the Deccan trap volcanic activity (Radhakrishanan et al., 1990). The WNW-ESE, ENE-WSW, NNE-SSW and the N-S directions have only shear zones and they may be more clayey, tight and shallow fractures which may be good sites for dug wells.

1.3 Evolution of Kerala coast

The onland part of Kerala region, comprising highly metamorphosed Precambrian rocks as basement does not have the full geologic column. The Neogene formations are confined to the coastal belt of Kerala, having a maximum width of 16 km in Kollam district, and a maximum thickness of about 600 m in the Ambalapuzha region. Nearshore data from the west coast indicate that the thickness of the sedimentary formations increase towards the deeper part of the shelf.

The available sedimentation data indicate that the clastic-Deccan volcanic activity stage of the basin formation during Late Mesozoic was followed by a prolonged carbonate build up realm along the Kerala offshore during Eocene to Late Oligocene, and in some segments of the Kerala offshore till around Middle Miocene times (Ghosh and Zutshi, 1989). This corroborates the finding of McKenzie and Scalter (1971), who based on magnetic data identified two distinct phases of spreading in the region of Carlsberg ridge with a pause in spreading between 55 to 30 myrs.BP (i.e. between Eocene and Late Oligocene), and of Ewing and Ewing (1967) that this pause lasted until 10 myrs.BP (i.e. upto the end of Middle Miocene). The second phase of spreading after the pause, has been started to be slower than the first, with a change in direction of spreading, leading to the under thrusting of the Indian plate, that resulted in the strongest phase of the Himalayan orogeny (Gansser, 1964), the major west coast subsidence and the resultant uplift of the Western Ghats. The uplift of the provenance during Middle Miocene facilitated deposition of enormous amounts of clastics into the west coast basin, and hindered carbonate build up in most parts.

The absence of Pre-Miocene formations in most parts of the onland region suggests either a later submergence of the region or an uplift/regression and subsequent erosion prior to the Upper Miocene transgression. The reported erosion of Oligocene carbonates underlying the Miocene sediments in a well off Cochin suggests that an uplift affected present day offshore portions also. Since the well is located on the northwestern end of the Achankovil shear zone, it is suggested that upwarping along Achankovil shear, coinciding with the Ariankavu pass during that time has been responsible for the uplift. The Neogene sedimentary formation of the Kerala coast might have formed in shallow basins with well marked marine intercalations in the middle, as evidenced by the lithology.

The Quaternary formations unconformably overlie the Tertiaries. This indicates a break in sedimentation after the deposition of Warkallai (Mio-Pliocene) sediments. Towards the end of Pliocene, the basin might have been uplifted and subjected to erosion. Transgression towards the end of Pleistocene, coinciding with the third interglacial age, resulted in the formation of Quaternary sediments. In the Alleppey-Shertallai area, palaeo strandlines belonging to two generations have been observed. These may also have resulted from Late Pleistocene transgression.

In Kannur and Kozhikode districts, marine and esturine deposits have been located much above the sea level. The Geological Survey of India (1976) has indicated uplift in this area which is about 150 m. Radiocarbon dating of limeshell from Payyannur (onland) yielded ages of 4370 ± 100 and 4490 ± 90 yrs.BP. Peat from Thalasseri and Thanisseri gave ages of 7230 ± 120 and 6420 ± 120 yrs.BP, respectively. The analysis of the available ^{14}C dating from west coast falls in an age group between 5160 ± 130 to 8820 ± 120 yrs.BP. This indicates that the area in the west coast was uplifted to the present level from an estuarine environment quite recently, and naturally not earlier than about 4000 to 8000 yrs.BP. Such uplifted segments during around 4000 yrs.BP are seen near Rameswaram, Kanniyakumari etc. in the coastal tract of Southern India. This suggests that uplift 4000 yrs.BP was very prominent neotectonic /eustatic event in the Southern coastal stretches of Peninsular India. Root of a tree from a depth of 16.75 m from the Wellington Island, Cochin, gave an age of 8080 ± 120 yrs.BP. Limeshell from the bottom of Vembanad lake yielded ages of 3710 ± 90 and 3130 ± 120 yrs.BP, whereas limeshell from the Ashtamudi lagoon gave an age of 1330 ± 100 yrs.BP only. In the broadest possible terms, it can be interpreted that foundering of estuaries along the Kerala coast was sequential, with the northern estuaries being earlier than the southern ones. Offshore (off Varkala) molluscan shells yielding radiocarbon dates of 5470 ± 115 and 6120 ± 110 yrs.BP suggest that the configuration of the present day coast line of the South Kerala was attained not earlier than this period (Soman, 1997). Occurrence of uplifted segments of the coastline, as in Varkala, Kannur etc. suggests that various segments of the coastline underwent differential uplift and subsidence. The promontories seen along the coast are also associated with these movements. Escarpments seen along the fringes of the Ashtamudi, Vellayani and Sasthamkotta lagoons and Palaeo-lagoons of Thrissur indicate that these were formed due to down faulting (Soman, 1997). Occurrence of carbonaceous clay horizons with lateritic patches, 4.5 m above MSL near Thekkubhagam along the periphery of Ashtamudi lagoon indicates that the base of the lagoon was uplifted after foundering of the lagoon (Soman, 1997).

A high gradient of the rivers in the upper reaches, and their matured behaviour towards the coast is characteristic of most of the Kerala rivers. This is attributed to the uplift of the upper reaches, namely the high lands. The Chalakudi and Periyar rivers have gradients of 1/250 or more for three fourth of their courses. Such gradients are also observed in the upper reaches of the Karanmana and Vamanapuram rivers in Thiruvananthapuram district; and Pampa, Bharathapuzha, Chaliyar and Valapattanam rivers in Central and north Kerala. Behaviour of river courses in south Kerala (south of Achankovil shear zone) denotes an southerly veering of the river mouths, possibly due to a right-lateral strike -slip movement of the upper reaches along the faults that separates the midland and highlands with coupling movement along the coast line. North of Achankovil shear zone, and up to the Palghat Gap, the sense of movements appears to be left-lateral in the upper reaches along Idamalayar fault, resulting in the river courses close to their mouths turning northwest (Soman, 1997). Such a sequential contrast in river courses is discernible in the Mahe-Kannur stretch of the coast with southerly shift of the river mouths. This indicates that different segments of the Kerala region experienced non uniform tectonic history.

In the southern Kerala, the coastal tract of the debouching point of the Karamana river shows elevated topography compared to the northern stretch, with promontories at Kovalam and Vizhinjam having seaward extensions of charnockite/charnockite gneiss outcrops. Similarly, the coastal stretch north of the discharge Point of Vamanapuram River also shows elevated coastal stretch. The coastal tract between the two river courses is subdued with the exception of elevated hillocks near Veli. This suggests differential uplift of the coastal tracts along the major river courses, which generally follow fault/ lineament directions in Kerala (Soman, 1997). Although it is difficult to arrive at the chronology of these events based on the available data, it is presumed that the sub latitudinal uplift/subsidence along river courses including their upper reaches preceded the change in course brought about by strike slip movements. The network of promontories, seen mostly in the northern and southern segments might have originated due to sub-latitudinal uplift of the terrain along faults /lineaments, coinciding with river course.

Summery of the Stratigraphic and geomorphic evolution history of India with special emphasise on Kerala is given in Table 1.4.

1.4 Study area

The present study deals with the hydrogeology, stratigraphy and evolution of the palaeo-lagoon (Kole land basin) in the central Kerala coast, India. The palaeo-lagoon in the Central Kerala Coast is the northern most tip of the South Kerala Sedimentary Basin (SKSB), which roughly covers a geographic area between Ponnani and Munambam; the places in which Bharathapuzha and Periyar debouches to sea.

The Palaeo-lagoon (Kole land basin) along the coast of Mathilakam and Chavakkad covers an area of 1690 km^2 forming part of Thrissur, Thalapalli, Chavakkad, Kodungallur and Mukundapuram taluks of Thrissur district lies between North latitudes 10°17'29"and 10°43'43"and East longitudes 76°0'0" and 76°33'33" (Fig. 1.11). This basin covers the entire drainage area of the Karuvannur and Kecheri rivers. The Conoli canal connects these rivers and allows draining via Chetwai backwaters to Lakshadweep Sea. Within this basin, an area about 300 km^2 lies 0.5 to 1.50 m below mean sea level and is popularly known as 'Kole land'. This low lying tract; Palaeo-lagoon, which invariably gets water logged throughout the monsoon season (June to September) and separated from the sea by a sandy belt (Plates 1.1, 1.2 & 1.3). The study area bounded by Ponnani river basin in north and north east, Chalakudi river basin in south and south east and Lakshadweep sea in the west.

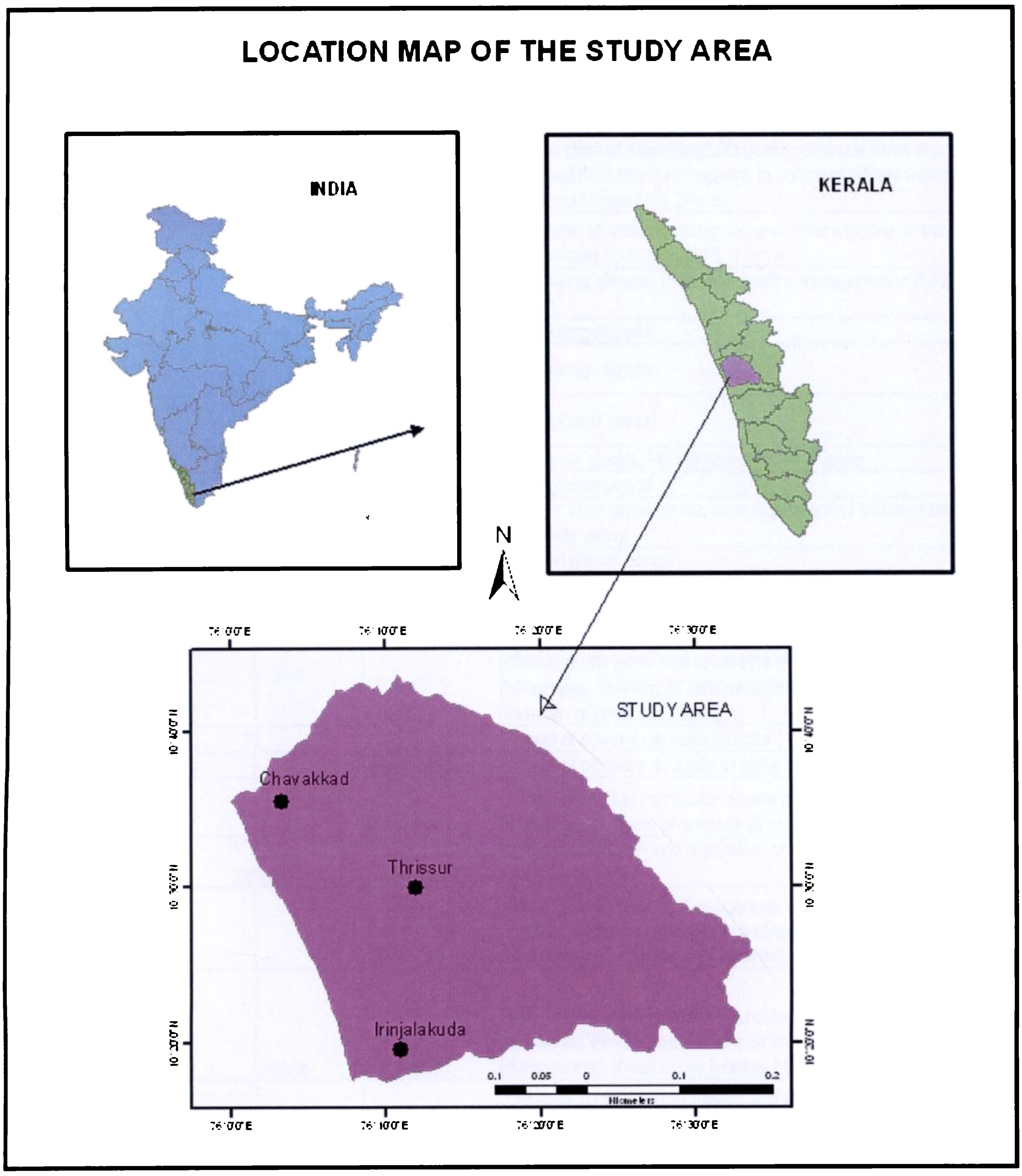


Fig. 1.11 Location map of the study area.

Table 1.4 Important events in Indian stratigraphy with special emphasize on Kerala from lower Cretaceous to Recent

Group	System	Age Myrs.BP.	Geological divisions	Stage	Impotant events in Indian stratigraphy & Kerala stratigraphy
Quaternary	Recent	0.01	Present	Present	Warming up climate. Beaches, alluvium, barrier flats and present topography
		0.2	Chalcolithic	Chalcolithic	Sucessive marine regression creates ridge runnel system in the coastal plain of west coast.Formation of crude form of present Kuttanad,Kole land and lagoons in southern Kerala including Ashtamudi kayal (~ 0.2 ky.BP)
		0.35	Bronze age		Formation of Vembanad lagoon and other lagoons in the northe kerala coast (~ 0.35 ky.BP)
	Holocene	0.8	Neolithic	Monasterian	Fluctuating climate, Holocene marine transgression in KKB (~7 ky.BP)
			Mesolithic		Fluctuating climate
	Base of Holocene	1			Fluctuating climate
	Top of Pleistocene	1.5	Upper	Wurm	Fouth glacial period
	Pleistocene			Tyrrhenian	Third inter glacial, Marine regression in Kerala.
			Middle	Riss	Third glacial period
				Milazzan	Second inter glacial priod, man appeared in Potwar plataue and Narmada valley
				Mindel	Second glacial period
		4.2		Sicilian	First inter glacial priod, marine deposits, Pleistoce marine transgression in KKB (> 42 ky BP)
			Lower	Gunz	Fisrt glacial period
				Calabrian	Marine fresh water and lacustrine deposits, final phase of rise of Himalayas, lowering of temperature in northern hemisphere and formatin of great ice sheets
Tertiary or Kainozoic	Pliocene	7		Astian	Period of coastal deposits in India
				Plaisancian	Period of offshore deposits in India
				Pontian	Period of marine regression marking the end of sedimentation, Lateritisation cycle of sediments in Kerala.
	Miocene	26	Upper	Sarmatian	Marine regression and deposition of Warkallai and Cuddalore beds in lagoons
				Tortonian	Warm humid climate, Ferrugenous sandstone and clay deposits. Uplift of sediemntary basin including its offshore parts, Plannar/erosion surface (Wayanadu plataue).
			Middle	Helvetian	The most violent episode mountain building (third Himalayan upheavel), Himalaya aquired their major features and Tethys disappeared. West coast faulting, Uplift of Wesern ghats
				Burdigalian	Deposition of Quilon formation and thick carbonate deposits in Kerala offshore
			Lower	Aquitanian	Marine transgression continue, Deposition of Vaikom beds
	Oligocene	38		Chattian	Period of marine transgression, deposits of open sea, shallow marine flysch facies, lacustrine and coastal facies.
				Rupelian (Stampian)	Deposition of clastics and carbonates in onshore and offshore basins of Kerala.
				Lattorfian (Sannoisian)	Planar/erosion surface (Nelliampathi and other plateaues)

	Eocene	54		Ludian	Second great Himalayan upheavel
Tertiary				Bartonian	Period of deep sea, coastal and fluvial Eocene deposits.
				Auversian	
				Lutetian	
				Cuisian	
				Ypreslan	Faulting of West coast and uplift of Western Ghats, dyke emplacement, clastic sedimentation in offshore basin of Kerala.
				Sparnacian	Deccan trap volcanism completed.
	Paleocene	65		Thanetian	Marine regression creates a stratigraphic gap with erosional unconformity.Planar/erosion surface over Western ghats(Munnar and Greater Periyar surfaces).Clastice sedimentation in offshore sedimentary basin of Kerala.
				Montian	Wide spread marine regression causes the destruction of Ammonites. Swift flowing short coastal rivers, intense phase of erosion and deposition of clastics in the offshore basin of Kerala.
Mesozoic	Cretaceous	140	Upper	Danian	Tension fractures developed in peninsular india and out pouring of Deccan traps;Offshore volcanism and emplacement of dyke awarms onland of Kerala.
				Maestrichtian	The great Mediterranean ocean and Tethys were shallowed as result tangential compression the Himalayan-Alpine mountain building movements began. Foundering of Kerala-Laccadive basin with attendant uplift of the Western Ghats.
				Campanian	Drifting of component parts of Godwanaland, India seperated from Madagasker.
				Santonian	
				Coniacian	
				Turonian	
				Cenomanian	Cenomanian transgression, deposition of Trichinoploy, Assam beds
			Lower	Albian	Universal Cenomanian marine transgression
				Aptian	
				Barremian	
				Hauterivian	
				Valanginian	

Plate.1.1 A view of Palaeo-lagoon during monsoon season

Plate.1.2 A view of Palaeo-lagoon during summer season

Plate 1.3 A view of palaeo-lagoon during initial phase of monsoon

These Kole lands have some similarities with Polder areas of The Netherlands. The name "Kole land" is derived from the local word "Kole" which means "Chance" due to unique method of paddy cultivation practiced in this low lying area. As the area is water logged during the monsoons, cultivation is done only after dewatering the area at the end of northeast monsoon season. One paddy crop is grown in the dewatered fields between December and April. The pumped out water is stored in open channels by constructing bunds. After transplantation of paddy, the water stored in the channel is let out to the field for irrigating the crop. As the water stored in the open channel gets depleted, water scarcity occurs in the later part of the crop period if the rainfall is also not adequate. If the summer rain is more than normal, there are chances for flooding in the crop area. Thus, the success of cultivation in this area is a gamble and left to chance or "Kole" and hence the name.

The Palaeo-lagoon is famousnot only for the cultivation of paddy but for clay mining. Being thickly populated, a substantial portion of the coastal and midland portion of the basin is utilized for residential purposes, and hence it experiences serious groundwater quality variations and water shortage during summer months. The groundwater availability and quality changes vary with landform, physiography, stratigraphy, hydrogeology etc of the area. The tile and brick industries of the Thrissur and adjoining areas have been using the clay deposits of this basin. The mining of sand deposits underneath the clay layer has been started in recent years on upper reaches of the palaeo-lagoon in Karuvannur river basin. These mining operations have created some hydrogeological and ecological imbalance in the area.

The study area covers almost 56% area of the Thrissur district. The basin is well connected with road and rail. The NH-17 is going through coastal plain region (western part) while NH-47 is connecting mid land and eastern part of the basin. The district and corporation head quarters are located in the central pat of the basin. Kunnamkulam, Chavakkad and Irinjalakuda are the municipalities and Guruvayoor is the only township with in the study area. Wadakkancherry, Vazhani, Peechi, Kodakara, Pudukkad, Mathilakam, Thriprayar and Chetwai are the other places of local importance. The places like Wadakkancherry, Thrissur, Guruvayoor and Irinjalakuda are connected by rail.

Peechi, Chimoni and Vazhani are the reservoirs in the basin providing irrigation facility to the crops. Apart from these, the right bank canal of the Chalakudi irrigation project is serving water in southeastern parts of the basin during summer months.

The important characteristic features of the Palaeo-lagoon (Kole land basin) are as follows.

Total catchment area of the basin: 1690 Km^2

Maximum altitude: 1116 m (Pundimudi and Karumalamudi in Palapalli reseved forest)

Minimum altitude: -1.49 m (Kole land near Enamavu)

Mean altitude: 557 m

Total length of the rivers: Karuvannur: 52 km, Kecheri: 49 km

Maximum length x breadth of the basin: 62 km x 49 km

Minimum length x breadth of the basin: 36 km x 18 km

Average length x breadth of the basin: 49 km x 33.50 km

Average rainfall: 2802 mm, Number of rainy days: 123.

A detailed hydrogeological, stratigraphical and structural investigation are necessary in the basin for its integrated planning, development, conservation and management of the natural resources in eco-friendly sustainable manner, keeping in view the socio economic-dimension. In that sense this study is expected to be useful to the people and Country.

1.5 Previous works in Palaeo - lagoon (Kole land basin)

The startigraphic aspects of the basin are broadly studied by Mahadevan (1964), Nair and Rao (1980), Krishnana Nair (1996), Kumaran et al., (2004) and Nair et al. (2006). Water resource of the area is first evaluated by Public works department, Government of Kerala (1974). Hydrogeologic aspect of the Palaeo-lagoon (Kole land basin) and adjoining area are studied by Menon (1988), CGWB (1992), Kukillaya et al. (2004) and Kukillaya (2007).

Mahadevam (1964) has carried out systematic mapping of Thrissur district and broadly delineated different geologic units. Subramaniam (1964) has conducted a study on the Tertiary sedimentaries of Kerala coast, which include the coastal plain region of the study area. Public works department, Government of Kerala (1974) has carried out an investigation about the water resource of this area in the published work "Water resources of Kerala". The recent advances in the exploration for groundwater in the coastal plains of Kerala has revealed that the best development of Cenozoic sediments is in a stretch between Kollam and Kodungallur, besides the Tertiary sedimentary rocks, there is a thick Quaternary sedimentary sequence deposited in a variety of marine, marginal marine and continental environments. Nair and Rao (1980) have studied the Quaternary sedimentation, sea level oscillations, palaeo- climate of Kerala basin in their work" Stratigraphic analysis of Kerala basin. The dynamic, narrow coastal plain of Kerala, unique for its diversified landforms developing as a result of depositional and denudational process has been studied in detail by Krishnana Nair (1996) in his publication "Geomorphology and evolution of coastal plain of Kerala". He classified Quaternary sediments into different morpho-stratigraphic units and chronological order of events leading to the development of present landscape. Six morpho stratigraphic units/surfaces namely, Kadappuram, Viyyam, Periyar, Ponnani, Guruvayur and Kunnamkulam are identified based on detailed mapping. Of these, first five are of depositional origin; while the sixth one is of erosional origin (Table 1.5). Evidences of both emergence and submergence are noticed along the coast and hence the Kerala coastline can be classified as a compound coastline. Nair et al. (2006) have worked out an out line of Quaternary geology of South Kerala sedimentary basin. The south Kerala sedimentary basin, extending along the coast of between Kollam and Kodungallur is the landward extension of the Konkan-Kerala basin. Based on sediment characteristics and tectonic setting, they divided the South Kerala Sedimentary basin into three separate blocks. (i) Southern block (uplifted during Pleistocene end), (ii) Central depression (undergoing subsidence from Early Miocene to present) and (iii) Northern block (uplifted during Pleistocene – Holocene transition but under going subsidence during Holocene).

Menon (1988) is the pioneer of the hydrogeological studies in the Kole land basin. The groundwater resource of the Kole land basin area has been evaluated by Central Groundwater Board in 1992 under SIDA assisted Coastal Kerala Groundwater project. Kukillaya et al. (2004) have studied the occurrence of brackish groundwater in fractured hard rock aquifers along a narrow N-S fracture zone in Puzhakkal –Avannur area, which is more than 17 km from sea. Relative proportion of

Table 1.5 Stratigraphic succession and morpho-stratigraphic surfaces of Quaternary sediments of Kerala basin (Krishanan Nair, 1996).

Time unit	Period	Environment	Morphostratigraphic unit	Landform	Lithostratigraphic unit	Lithology
		A. Depositional surface				
Quaternary	Holocene	Marine	Kadappuram surface	Beach, spit, barrier beach	Kadappuram formation	Coarse to fine grained sand
	Stratigraphic break					
	Middle to Late Holocene	Fluvio-marine	Viyyam surface	Tidal flat, mud flat, delta plain, inter-tidal ridges	Viyyam formation	Clay and mud(black in colour)
	Middle to Late Holocene	Fluvial	Periyar surface	Flood plan, channel bar, point bar, valley plain	Periyar formation	Sand, silt, clay admixture
	Stratigraphic break					
	Middle to Late Holocene	Fluvial	Ponnani surface	Terrace	Ponnani formation	Sand, silt, clay admixture
	Stratigraphic break					
	Early Holocene to Late Pleistocene	Marine	Guruvayur surface	Strandline, sandy flat, swale	Guruvayur formation	Coarse to fine sand (greyish white to light brown)
		B. Erosional surface			Stratigraphic break	
Tertiary	Pliocene	Erosional	Kunnamkulam surface	Upland	Kunnamkulam formation	Laterite

chloride and bicarbonate suggests intrusion of saline water into this fracture zone from low lying areas connected to saline back waters. Kukillaya (2007) studied the characteristic responses to pumping in hard rock fracture aquifers of Thrissur, Kerala and their hydrogeological significance. Pumping test data in the hard rock fracture aquifer of Thrissur district has revealed certain characteristic responses. Thirty two percent of pumping test data shows simultaneous recharge to the aquifer during pumping. Interconnections between phreatic and fracture aquifers and recharge from the phreatic zone to the fracture zone are indicated. Responses similar to double- porosity model are attributed to the probable large variations in fracture scales. Another characteristic response is that of continuous slope increase in semi-log plots of draw down indicating linear fracture zone with barrier boundaries on both sides. Geological features and good fracture connectivity support this inference. Similarity with the response of homogenous anisotropic aquifer is also seen when response over a large area considered. Large spatial variations in specific capacity indicate heterogeneity. Tests suggest that turbulent flow around pumped wells. The responses suggest that the fracture aquifers in the area have only limited potential.

1.6 Physiography and slope

Based on the physiographic and slope maps of Kerala the palaeo-lagoon (Kole land basin) can be classified into four physiographic zones: Elevation between 0-10 m- Coastal plains and lagoons; elevation between 10-300 m – Lowlands; elevation between 300-600 m - Midlands and the elevation between 600-1800 m - High lands (Fig. 1.12). The average altitude of the basin is 557 m above mean sea level. The highest point is Pundimudi (1116 m.amsl) in Palapalli reserved forest on the eastern part of the basin. Other important peaks are Karumalamudi (1115 m), Vellimudi (928 m), Manalkunnu (865 m) in the eastern part of Karuvannur river and Munippara (522 m), Vellani mala (575 m) in the north eastern part of Kecheri river basin. Velengankunnu near Puzhakkal (106 m) is an important physiographic feature (palaeo-topographic height) within palaeo-lagoon (Kole land). Areas of different landform unit are given as follows.

Fig. 1.13 describes the slope distribution of the study area. All the areas except southeastern and eastern part of the basin fall under very gentle to gentle category (slope $<10^{\circ}$).

Fig. 1.14 displays the different geomorphic units of the study area. The major geomorphic units are coastal plain, structural hill, denudational hill, pedeplain etc.

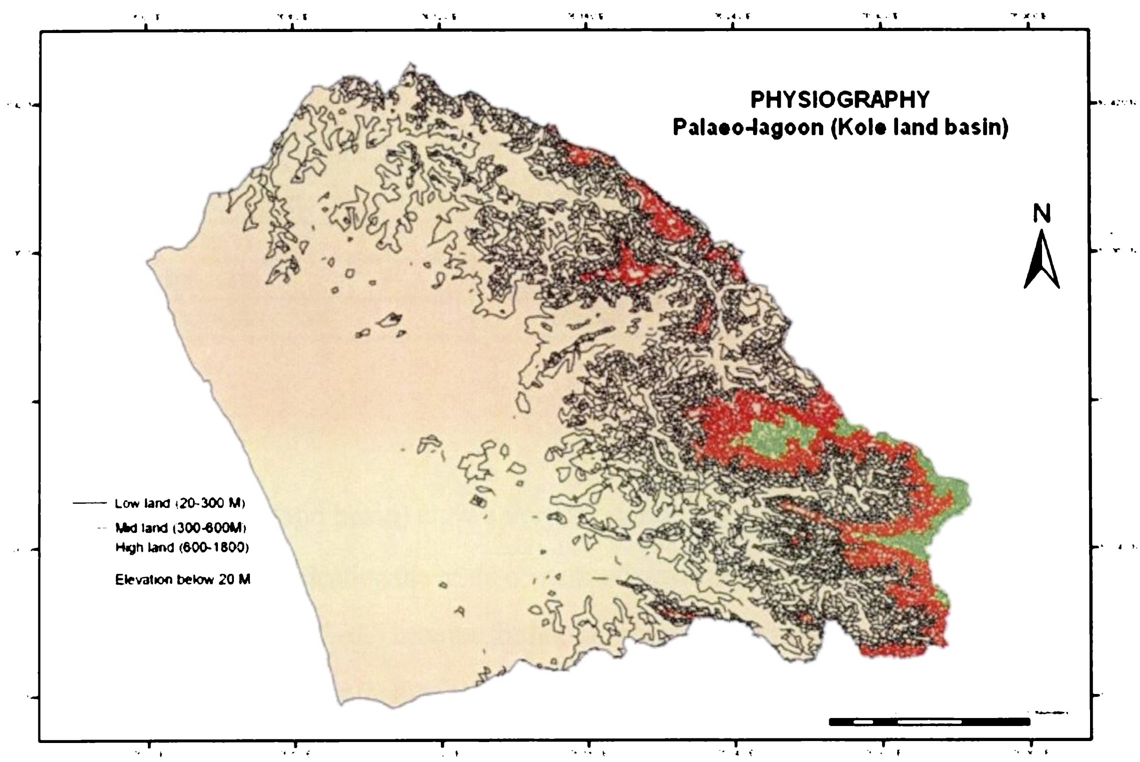


Fig. 1.12 Map showing physiographic divisions of the of the study area

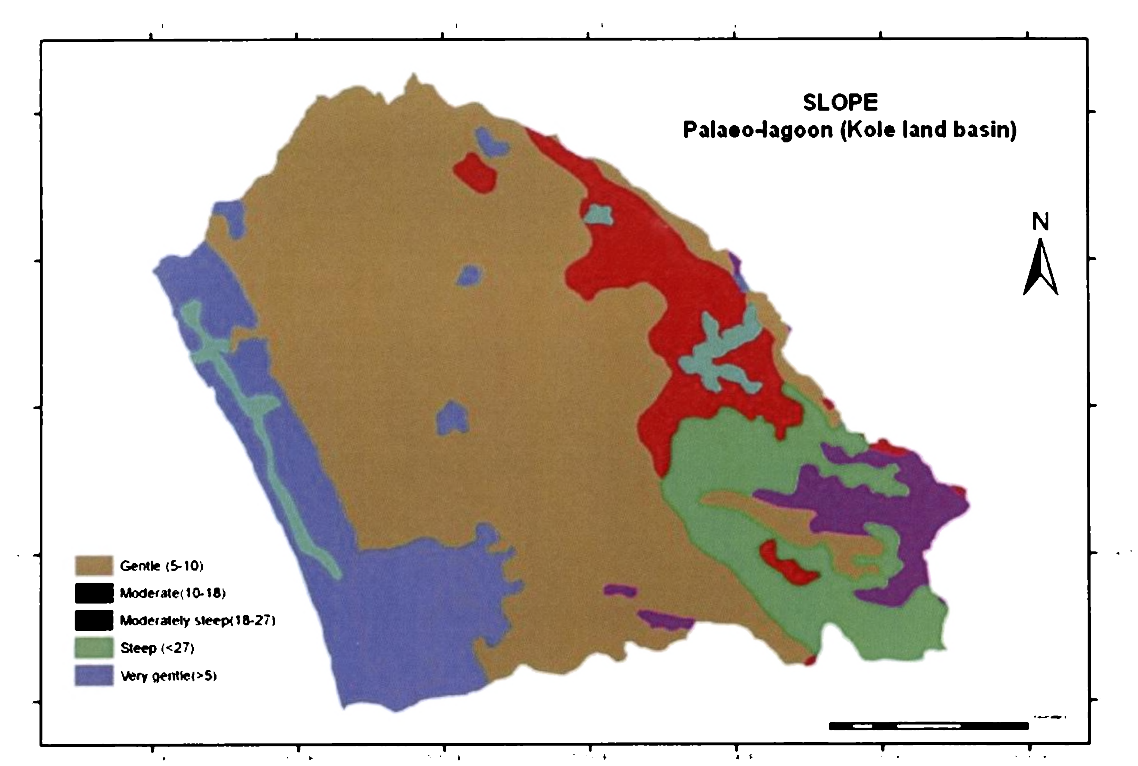


Fig. 1.13 Map showing slope pattern of the study area

Table 1.6 Physiographic units in the Palaeo-lagoon (Kole land basin)

S.No	Physiographic unit	Area km²	Percentage of the total area
1	Coastal plain and lagoon	216.00	12.78
2	Palaeo-lagoon (Kole land)	300.00	17.75
3	Mid land	682.00	40.35
4	High land	402.00	23.78
5	Mountain peak	90.00	5.33

1.7 Climate

The Palaeo-lagoon (Kole land basin) shows very moderate climatic variations. According to Thornthwaite's climatic classification the basin comes under wet rain forest type of tropical climate. In general four seasons are identified. These are the hot summer season from March to May, southwest monsoon season from June to September, the northeast monsoon season extending from October to December and cool post monsoon period during January and February.

On an average 2802 mm rainfall occurs annually in the basin. The maximum rainfall occurs during southwest monsoon season and nearly 72% of the total rainfall is received during this period. Out of total 123 rainy days in a year, 84 days are accounted during southwest monsoon period. The highest rainfall occurs in the northwestern part of the basin around Pazhanji and the lowest rainfall is recorded in the southwestern part of the basin around Irinjalakuda (Fig. 1.15).

Drought frequencies are worked out based on Agricultural definition of drought which takes into account the negative departure of rainfall from mean rainfall. During the period 1901 to 2005 the basin has not experienced any sever drought. However, it is observed that during the 105 year period 41 years have recorded below normal rainfall. Continuous occurrence of mild and normal drought is observed during the periods 1951 -54, 1972 -74 and 2000-03.

The December to January months registered high wind speed and it is less in July. The wind direction is predominantly from east and west during morning and evening hours respectively. The mean wind speed is 5.5km/hour. The mean monthly relative humidity varies from 76% to 93% during June to September. It is about 70% in January. The surface air temperature varies from 29°C to 36°C at the maximum and it ranges from 22°C to 25°C at the minimum. Evaporation is high during January to

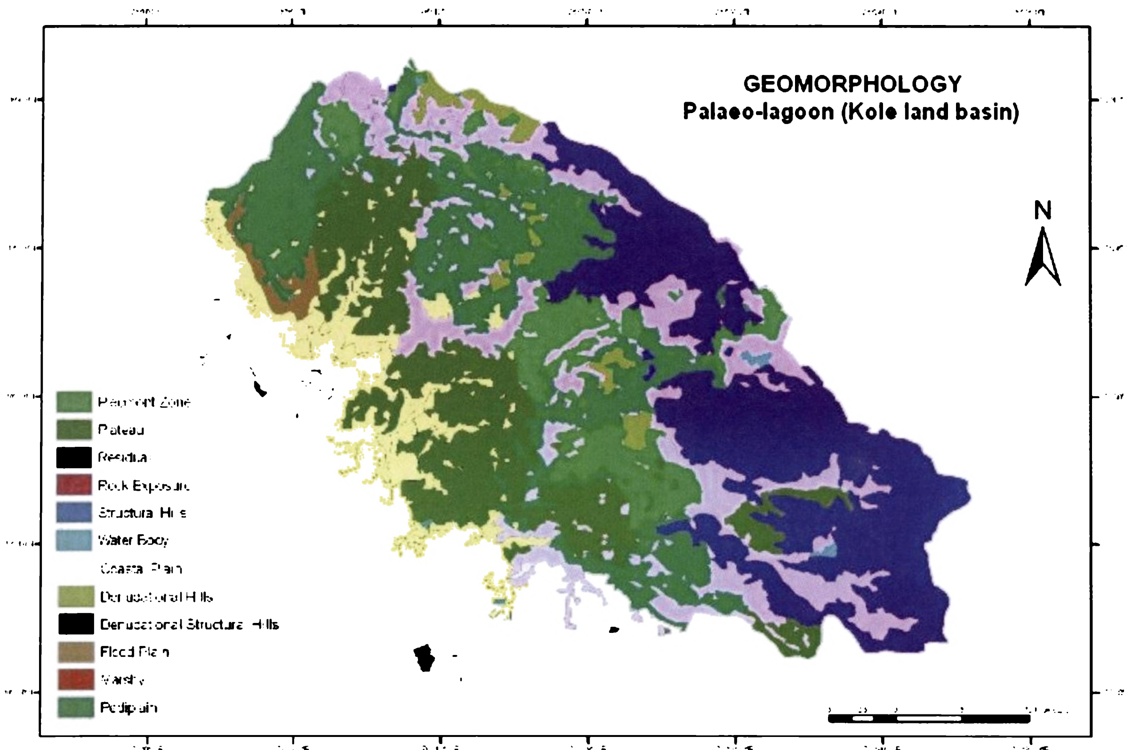


Fig. 1.14 Map showing geomorphic units of the study area

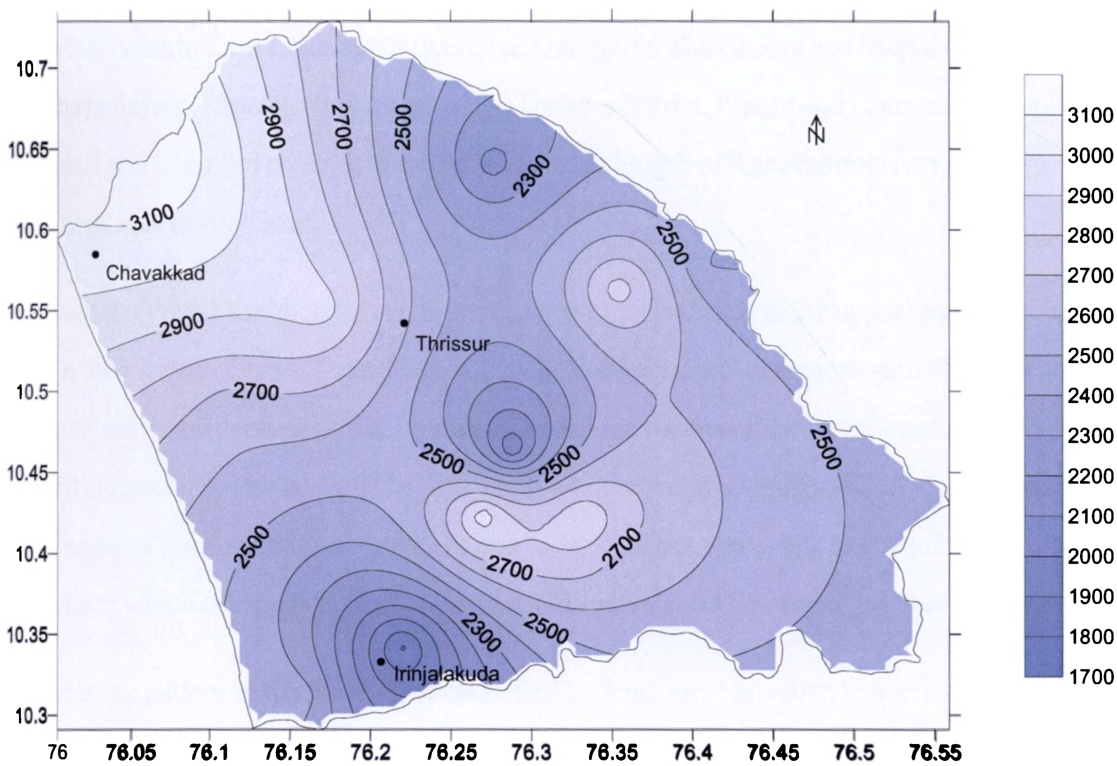


Fig. 1.15 Isohyetal map of the study area for the period from 1981 to 2007

April. The maximum is 6.7 mm /day and minimum is 1.8 mm/day is recorded during southwest monsoon period. The annual potential of evapo-transpiration is 1744.5 mm for the basin. Rainfall analysis data of the basin is given as follows.

Number of years of data analysed: 105

Mean annual rainfall: 2802 mm

Standard deviation: 670 mm

Highest rainfall: 4731 mm

Lowest rainfall: 1274 mm

1.8 Drainage

The Kole land basin is drained by two rivers namely the Karuvannur and Kecheri .The Karuvannur river originates from Palapilly reserved forest and flows towards south west up to Panakulam and then flows westward. The river bifurcates near Kuttamangalam; one of the branches flows southwards and joins the Lakshadweep sea near Kodungallur while the other branch flows northwards and joins the Lakshadweep Sea near Chettuvai. Manli and Kurmali are the main tributaries of Karuvannur river which joins to form Karuvannur river near Arattupuza. The Chonni and Mupili are the tributaries of Kurumali river. The major two dams of the Thrissur district, Peechi and Chimoni are constructed in Manali and Chimoni rivers respectively. The total length of Karuvannur river is 52 km and the catchment area is 1054 km^2.

The Kecheri (Wadakkanchery) river originates from Machadmala in the upper reaches of Thalaplli taluk in the Western Ghats. The river flows in the northwesterly direction up to Nelluvai and then takes a southwesterly course up to Choondal. There after, the river flows south wards up to Matukara where it empties into Palaeo-lagoon (Kole land) which are connected to back waters at Enamakkal. Total length of the Kecheri river is 49 km and the catchment area is 402 km^2. Puzhakkal is another minor river which empties into Palaeo-lagoon (Kole land) and has a catchment of 234 km^2.

The drainage pattern of the area can be classified as dendritic. However, some linear alignment of streams conforming to the structural features also observed at eastern and northeastern part of the basin. The rivers of the basin show meandering, braided pattern in palaeo-lagoon and coastal plain regions (Fig. 1.16).

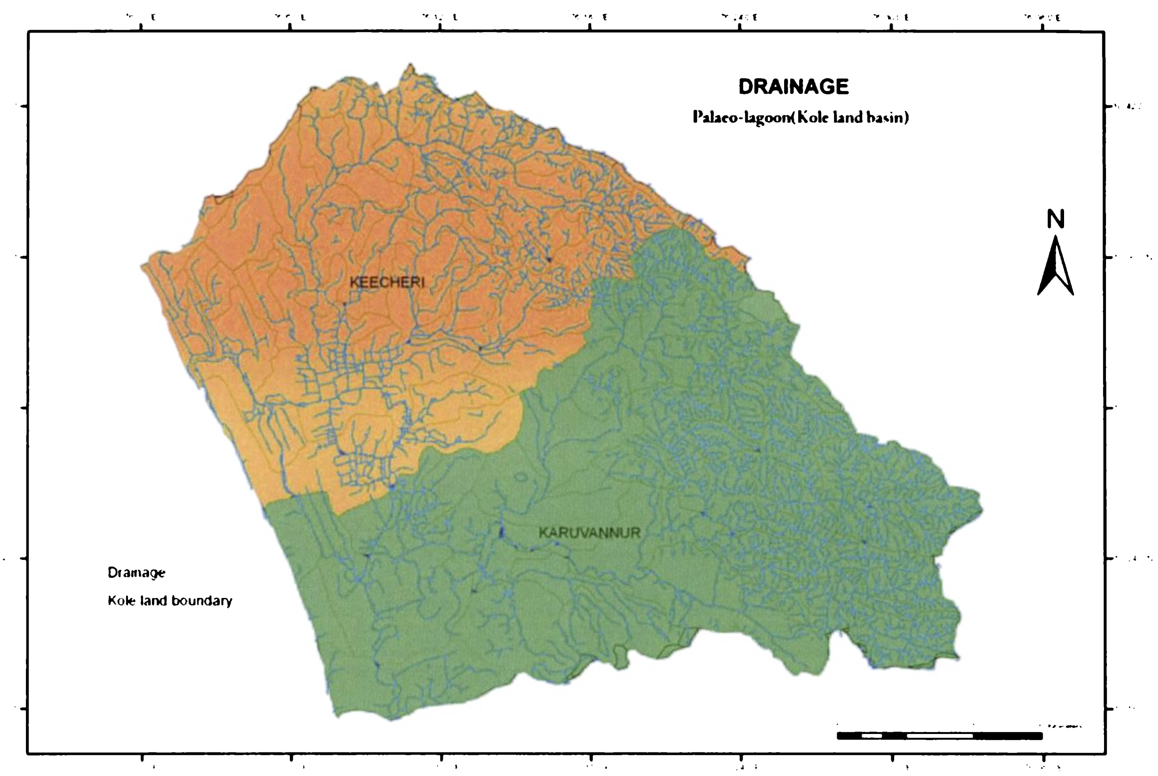


Fig. 1.16 Map showing drainage of the study area

Plate 1.4 A view of Conoli canal and Chetwai estuary

The mean annual flow of Karuvannur river at Karuvannur bridge is 1554 MCM (1975-2005) and that of Kecheri river at Pazhoor is 200 MCM. The drainage density and stream frequency of the Kole land basin has been worked out to be 0.24 km/km^2 and 0.06 stream/km^2 respectively. The run off coefficient varies from 0.34 for Kurumali sub-basin to 0.71 for Karuvannur and Kecheri basins. Since the runoff figures were not available due to the construction of check dams for irrigation during December and June, the annual rainfall could not be correlated with annual runoff.The Chetwai backwater and Muriyad lagoon are the other two water bodies in the basin. The Chetwai backwater has 4.08 km^2 water spread area and 12.24 MCM storage (Plate.1.4).

1.9 Soils

According to Soil survey department, Government of Kerala (1978), Thrissur district has basically 6 types of soils (i) brown hydromorphic, (ii) hydromorphic saline, (iii) laterites, (iv) riverine alluvim, (v) coastal alluvium and (vi) forest loam. Detailed soil map of the area showing different soil characteristics such as drainage, texture and depth have been prepared for reference (Figs. 1.17- 1.19).

1.10 Landuse

The landuse pattern of the basin is studied and mapped by Kerala State Land Use Board under Panchayat level resource mapping programme (2000). Details of landuse pattern in the palaeo-lagoon basin are given in Table 1.7. The mixed crop covers 30.18%, paddy field 20.14%, coconut 13.08%, forest 12.13% and rubber 7.10% area of the basin. Land use map of the basin area has been prepared for reference (Fig. 1.20 & Plate 1.5).

1.11 Geological setting of the study area

The coastal belt and mid land are primarily made up of sedimentary formations of age group varying from Recent to Sub Recent to Pleistocene. Whereas high land falls in the age of lower Precambrian to Archaean. The surface geological feature of the coastal belt consists of mainly sand, sandy clays, clays and laterites. The mid land and high land are characterised by laterites underlain by gneisses and primary charnockites.

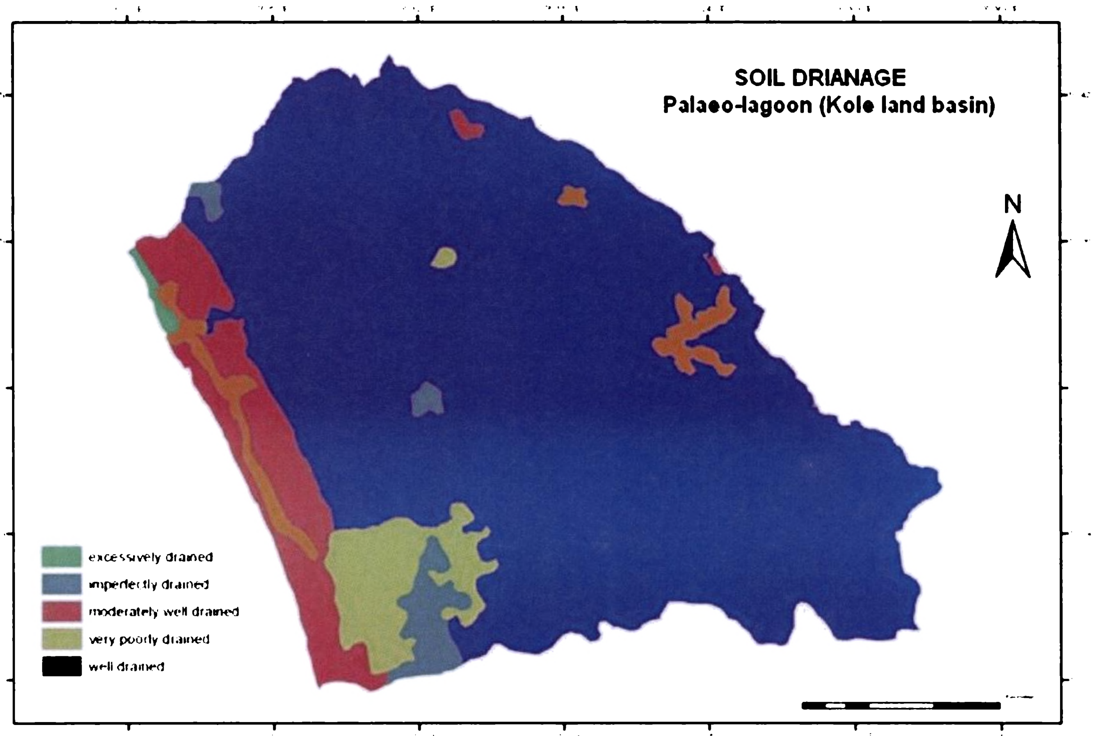


Fig. 1.17 Map showing soil drainage of the study area

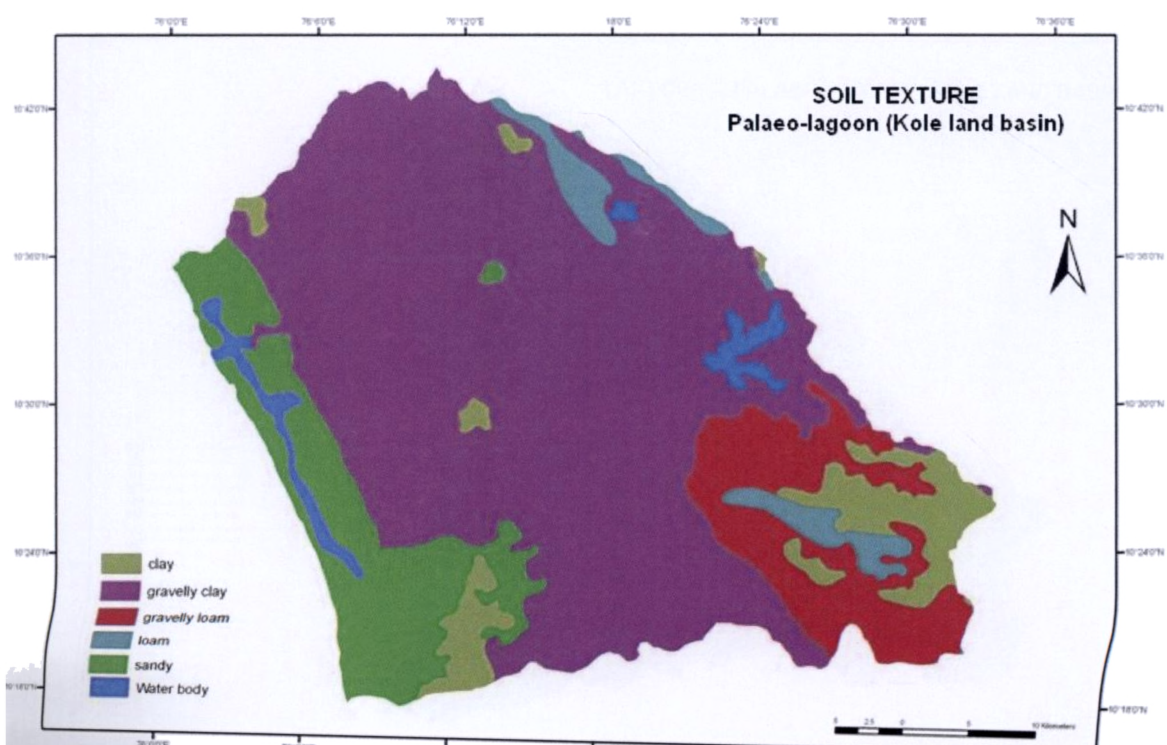


Fig. 1.18 Map showing soil texture of the study area

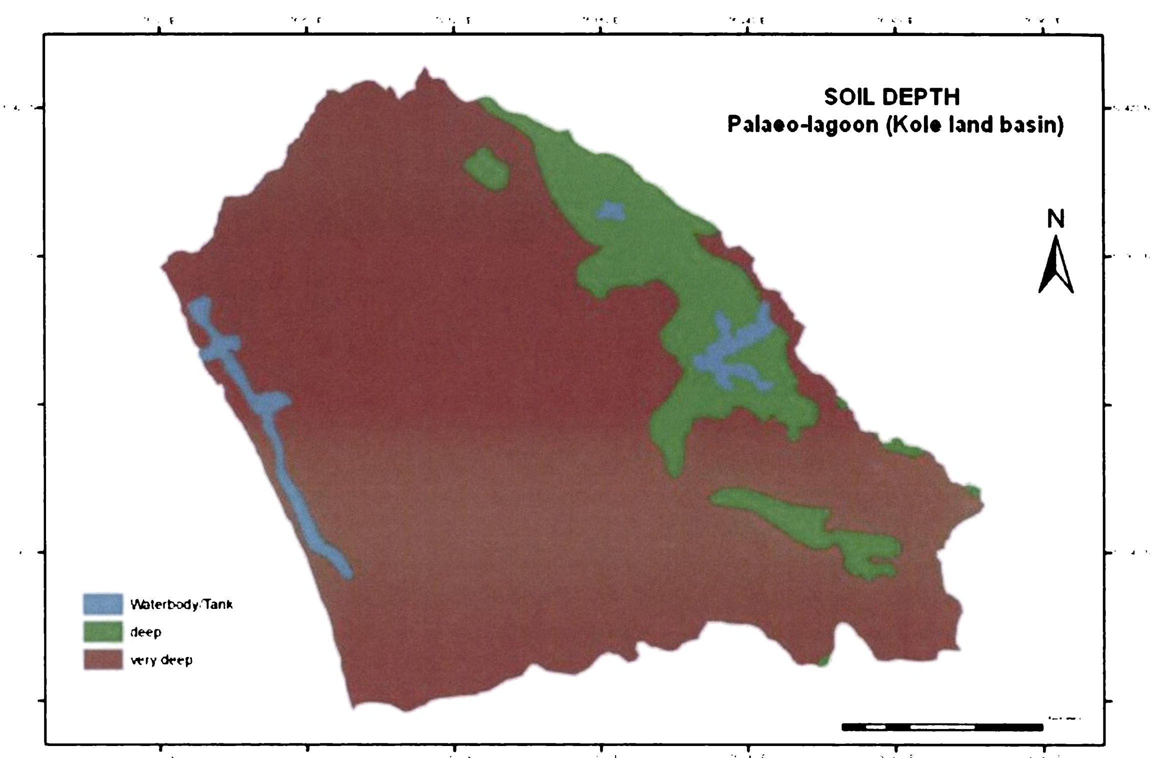


Fig. 1.19 Map showing soil depth of the study area

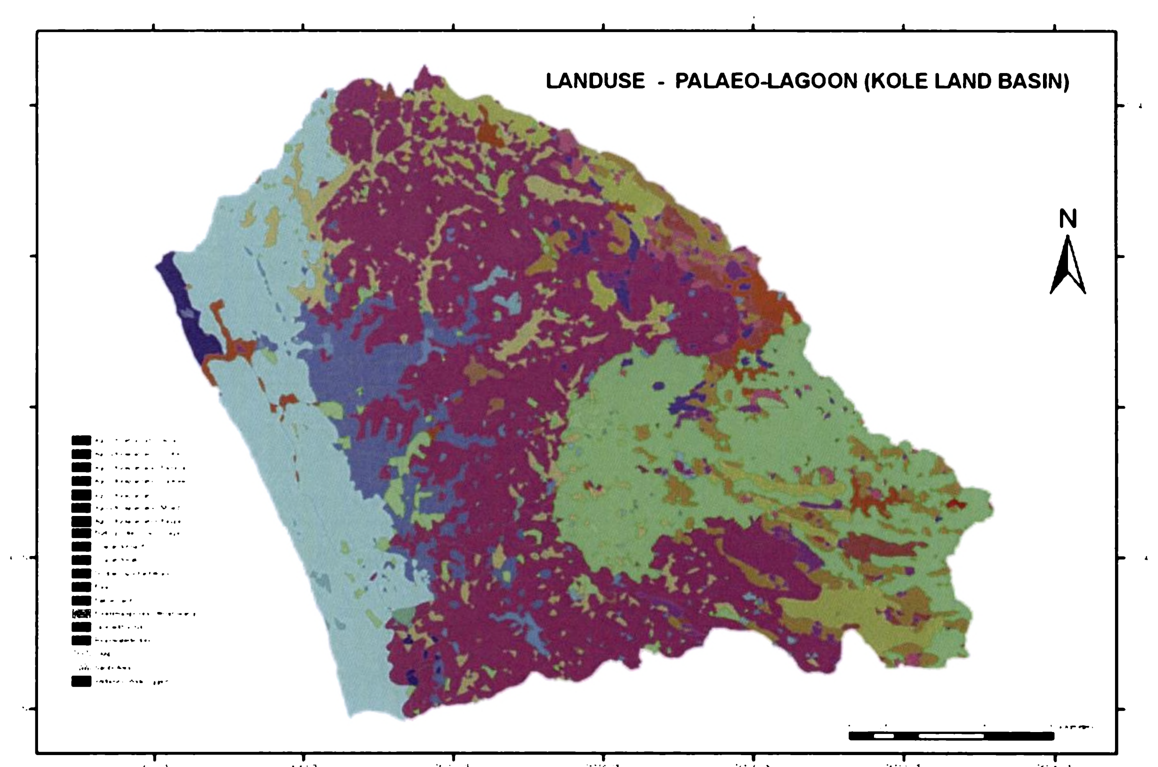


Fig. 1.20 Map showing landuse of the study area.

Table 1.7 Landuse pattern of Palaeo-lagoon (Kole land basin)

S.No	Land use	Area (km^2)	Percentage of the Total area
1	Mixed crop	510.00	30.18
2	Paddy field	345.00	20.41
3	Coconut	221.00	13.08
4	Forest	205.00	12.13
5	Rubber	120.00	7.10
6	Reclaimed paddy field	90.00	5.33
7	Water bodies	60.00	3.55
8	Other crops (Plantain, Vegetables, Pulses etc.)	50.00	2.96
9	Construction area	40.00	2.37
10	Cultivable waste land	15.00	0.89
11	Areca nut	12.00	0.71
12	Plantations (Teak, Eucalyptus etc)	10.00	0.59
13	Mines (Laterite, Rock quarry, Clay etc.)	5.21	0.31
14	Waste land	5.00	0.30
15	Beach	1.00	0.06
16	Marshy land	0.81	0.05

Data source: Kerala State Land Use Board

Plate 1.5 A view of the study area showing different landuse pattern

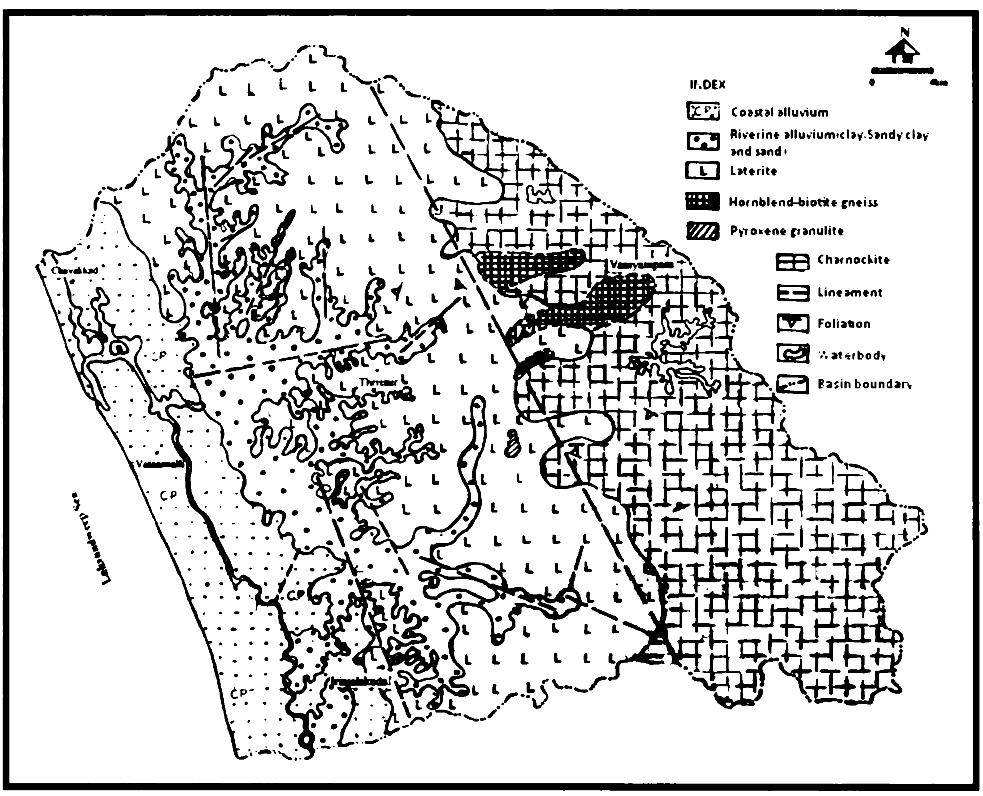


Fig. 1.21 Map showing geology and major lineaments of the study area

Precambrian and Tertiary tectonic activity was prevalent in Palaeo-lagoon (Kole land basin). As a result numerous major and minor lineaments have originated in the area. The lineaments trending NE-SW, NW-SE, NNW-SSE, E-W and N-S are present. Majority of lineaments fall in the NW-SE and NNW-SSE trending categories and are often hosting dykes of dolerite /gabbroic composition, having a definite signature in the geological setting of the region. These linear fracture zones form major aquifers in the northeastern part of the basin (Kukillaya et al., 1999, 2002). Next in importance are the WNW-ESE trending lineaments. In the groundwater point of view this fracture is also productive (Fig. 1.21).

1.12 Objectives

The Palaeo-lagoon (Kole land basin) of the Central Kerala coast received little attention on the hydrogeological and stratigraphical aspects. It is in this context the present work has been undertaken, Major objectives of the present investigation are:

- To determine the groundwater potential, resource, aquifer parameters and groundwater quality of the basin.
- To evaluate the vulnerability of the aquifer to seawater intrusion in coastal area and groundwater vulnerability to pollution in the basin.
- To delineate the stratigraphic sequences of the area and evaluation of palaeo-environment of deposition.
- To study the evolutional history of the palaeo-lagoon.

CHAPTER 2

METHODOLOGY

2.1 Introduction

Groundwater plays a key role in the maintenance of our country's environment and standard of living. It is a renewable natural resource, vitally important for man and nature, its relatively shallow circulation (tens to hundred meters) and it vulnerability due to geogenic and man made stress and ability to transport pollutants, groundwater has been recognized to be one of the most dangerous media, that degrade the quality of environment, with related to economic and social consequences. Perhaps most significant environmental problem in the 21^{st} century is the threat to public health with about 1.2 billion of global population with out adequate access to safe drinking water.

India has a very long coast line of about 7500 km, including Andaman and Nicobar islands and Lakshadweep islands. The east coast is about 2600 km long while that of the west coast is about 3400 km the rest being the coastal length of the two island groups. About 25% of the countries population is living along the coastal zone. Similarly urban centres are concentrated much more along the coast compared to inland area. Three out of the four Metros are falling along the coast. The coastal zone is the most industrialised area in the country. 14 major, 44 medium and 55 minor rivers or streams discharge in to the sea along the entire length of the coast.

Human civilization started evolving along the riverbanks and coastal areas due to easy availability of the water. Thus the hunt for groundwater also began along the alluvial tracts of rivers and coastal area. The semi consolidated and unconsolidated sediments along the coastline helped the man kind to go in for deeper groundwater exploration during the first half of the last century. As the exploration advanced towards deeper horizons, problems like salinity hazards, salt water intrusion etc. were faced which made the situation quite complex. One of the important features of the coastal deposits are the occurrence of groundwater in inter- bedded alluvial and marine sands, silts, clays and carbonate rocks deposited under beach, lagoon, estuarine and marine environments. Coarse sediments are found to occur along the coast where youthful river discharge. Generally due to the differential compaction and the nature of the bedrock topography, the coastal sediments attain a seaward dip. Porosity, permeability, grain size, lithification of the sediments, sedimentary structure and texture are the factors controlling the storage and movement of ground water in sedimentary areas. All these factors also have a control on the quality of the formation water.

In crystalline area fractures and discontinuities are the most important geological structures. Most rocks posses fractures and other discontinuities which facilitate storage and movement of fluids through them. Discontinuities like faults, dykes etc. act as barriers to groundwater flow. Main flow paths in fracture rocks are along joints, fractures, shear zones, fault and other discontinuities.

From the above mentioned facts it is clear that hydrogeology, stratigraphy and evolution are interrelated as far as an area is concerned; it is not treated as water tight compartments. Hence different scientific methodologies have to be adopted to study the hydrogeology, stratigraphy and evolution of the basin. This chapter deals with the various methodologies adopted to achieve the objectives of the research work in Palaeo-lagoon (Kole land basin).

2.2 Field investigations

The Palaeo-lagoon consists of two minor basins namely Kecheri in the north and Karuvannur in the south. The area includes various physiographic units such as coastal plains, palaeo-lagoon, mid land and high land. Scientific investigation methodologies and techniques suitable to each terrain has been adopted for water level collection, sample collection geophysical data collection, pumping tests and level survey in the basin area.

2.2.1 Groundwater level collection from observation wells

Twenty three observation wells were fixed in various parts of the basin for monitoring the ground water level of the phreatic aquifer. The details such as location name, latitude, longitude, total depth, diameter, height of parapet, formation type etc. of each observation well were recorded before starting the monitoring (Fig. 2.1 & Table 2.1). Out of 23 observation wells, 5 were in coastal alluvium while the remaining 18 were in lateritic formation of mid land and high land. Observation well density is 1 per 73 km^2. Water level data of the observation wells have been collected every month.

2.2.2a Ground water sample collection

Groundwater samples have been collected from 23 observation wells of the basin during the years from 2000 to 2006 covering pre-monsoon (April) and post monsoon (December). Groundwater

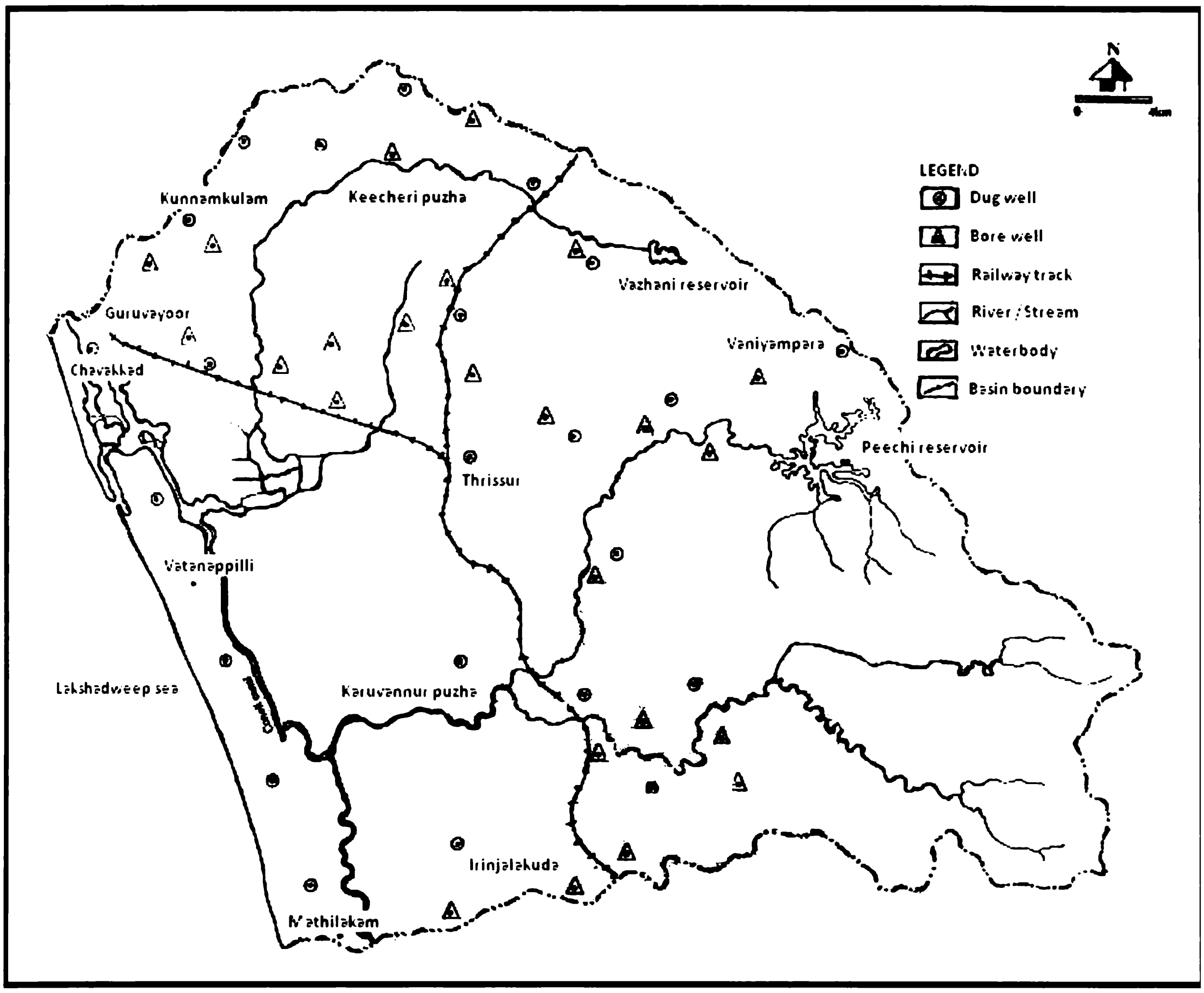


Fig. 2.1 Map of the study area showing locations of observation network (open wells and Bore wells)

Plate 2.1 Core samples collected from the study area

Table 2.1 Details of observation wells in the palaeo-lagoon (Kole land basin)

Well No	Location	Lattitude	Longitude	Toposheet No	Well type	Well dia. (m)	Total Depth (mbgl)	Mini. WL (mbgl) 1997-07	Max. WL (mbgl)	Avg. WL (mbgl) 1997-07	Formation	Basin
OW-1	Thrissur	10?31'13"	76°13'07"	58 B/2	Dug Well	1.67	9.45	2.63	7.98	6.24	Laterite	Kole land
OW-2	Mannuthi	10°31'53"	76°15'48"	58 B/6	Dug Well	2.50	7.78	1.67	4.93	2.73	Laterite	Kole land
OW-3	Pattikkad	10°33'23"	76°19'56"	58 B/6	Dug Well	2.20	8.00	3.55	9.75	7.91	Laterite	Kole land
OW-4	Pudukkad	10°25'07"	76°16'18"	58 B/7	Dug Well	2.50	10.20	3.34	7.58	5.41	Laterite	Kole land
OW-5	Kodakara	10°22'19"	76°18'19"	58 B/7	Dug Well	2.31	9.80	0.65	4.58	2.40	Laterite	Kole land
OW-6	Irinjalakudaa	10°20'32"	76°13'11"	58 B/3	Dug Well	3.80	12.42	3.35	9.00	7.60	Laterite	Kole land
OW-7	MG kavu	10°36'00"	76°12'41"	58 B/2	Dug Well	4.35	11.95	2.34	5.96	3.78	Laterite	Kole land
OW-8	Ottuppara	10°39'53"	76°15'24"	58 B/6	Dug Well	2.40	6.80	0.90	7.80	3.47	Laterite	Kole land
OW-9	Chelakkara	10°43'38"	76°11'12"	58 B/6	Dug Well	2.09	7.55	2.32	7.73	5.81	Laterite	Kole land
OW-10	Kunnamkulam	10°38'49"	76°04'11"	58 B/2	Dug Well	3.65	13.25	2.68	9.37	6.59	Laterite	Kole land
OW-11	Chavakkad	10°34'49"	76°01'29"	58 B/2	Dug Well	1.62	5.35	0.60	3.26	1.75	Alluvium	Kole land
OW-12	Pazhanji	10°41'20"	76°03'26"	58 B/2	Dug Well	3.80	9.60	0.01	3.60	1.48	Laterite	Kole land
OW-13	Nattika	10°25'11'	76°06'26"	58 B/3	Dug Well	1.65	4.30	0.00	2.30	0.79	Alluvium	Kole land
OW-14	Edamuttam	10°22'19"	76°07'34"	58 B/3	Dug Well	2.56	3.56	1.59	4.64	3.18	Alluvium	Kole land
OW-15	Mathilakam	10°17'30"	76°09'53"	58 B/3	Dug Well	2.00	4.80	1.07	4.12	2.46	Alluvium	Kole land
OW-16	Engadiyoor	10°29'39"	76°04'04"	58 B/2	Dug Well	1.85	5.15	0.12	5.00	2.00	Alluvium	Kole land
OW-17	Vaniyampara	10°34'38"	76°24'35"	58 B/7	Dug Well	2.50	5.23	0.29	7.74	3.34	Laterite	Kole land
OW-18	Varandarappilly	10°25'18"	76°19'54"	58 B/7	Dug Well	2.50	10.35	3.45	9.75	6.36	Laterite	Kole land
OW-19	Cherpu	10°12'53"	76°14'25"	58 B/8	Dug Well	3.10	15.25	5.07	14.45	10.83	Laterite	Kole land
OW-20	Puthur	10°26'25"	76°12'44"	58 B/3	Dug Well	3.25	13.15	4.76	12.34	9.22	Laterite	Kole land
OW-21	Elavally	10°28'57"	76°17'26"	58 B/7	Dug Well	2.60	6.90	1.55	6.82	3.61	Laterite	Kole land
OW-22	Kadangode	10°34'34"	76°05'14"	58 B/2	Dug Well	3.27	10.19	4.69	10.17	7.23	Laterite	Kole land
OW-23	Wdakkancherry	10°42'07"	76°08'27"	58 B/2	Dug Well	4.00	8.56	3.85	8.40	6.86	Laterite	Kole land

samples were collected in a pre cleaned poly ethylene bottles. Prior to sampling, the containers were rinsed two to three times with the respective groundwater under sampling. Many of the water quality parameters such as pH, Electrical conductivity (EC) and Total dissolved solids (TDS) were measured in the field itself. For analysing total iron, the samples were preserved in the field by adding concentrated HNO_3 (2ml/100ml) as preservative agent and transported to the laboratory following standard guide lines (APHA, 1985). For bacteriological analysis the samples were collected aseptically in sterilised bottles and transported to laboratory in icebox maintaining the temperature at 4°C. Test for total coli forms and faecal coli forms were done within 12 hours of sampling. Bacteriological analyses were done in the year 2006 covering pre and post-monsoon periods.

2.2.2b Collection of core and lithological samples

The collection of core sample is essential for scanning sub surface geology of an area. The stratigraphic sequences, mineralogy, grain characters, mega and micro fossil assemblages, microstructures and textures of the sediments etc. are determined using these samples.

Core and lithological samples from 57 places, with depth varying from 2 to 300 m were collected from various parts of the basin (Table 2.2). Out 57 samples 6 were continuous undisturbed samples collected up to a depth of 30 m bgl from palaeo-lagoon with the help of calyx drilling (Plate 2.1) while disturbed samples were collected from 14 places of the coastal plain area at 0.30 m interval using cable tool method. In the remaining 37 places, disturbed samples were collected at 1 m intervals during the drilling of bore well/tube well by Central Groundwater Board (CGWB) or State Ground Water Department (SGWD) or Private drilling agencies. Samples were collected and labelled at site for textural analysis of the sediments. Lithologs of each location have been prepared for reference.

2.2.3 Geophysical investigations

Geophysical exploration is the scientific measurement of physical properties of earth's crust for investigating mineral deposits, groundwater, petroleum, geologic structure etc. Geophysical techniques are generally sub divided into static and dynamic techniques. The static techniques measure the resident physical parameters of subsurface rocks. In dynamic technique rock parameters are measured as a response to energy fluxes injected into earth. The common static type geophysical techniques are magnetometric, gravimetric and telluric. The geo-electrical, electro-magnetic and seismic methods are the usual dynamic geophysical techniques used in the field.

Table 2.2 Location details of core and lithological samples collected from palaeo-lagoon (Kole land basin)

1	2	3	4	5	6	7
Sl.No	Location	Topo Sheet	Lattitude	Longitude	Total depth (m)	Remarks
1	Kaduppasserry	58 B/7	10°19'53"	76°15'26"	45	DTH lithdog
2	Matthathur	59 B/7	10°22'26"	76°22'24"	30	DTH lithdog
3	Nellayi	60 B/7	10°23'24"	76°17'03"	30	DTH lithdog
4	Tholur	58 B/2	10°34'00"	76°07'30"	45	DTH lithdog
5	Thrikkur	60 B/7	10°27'49"	76°17'17"	50	DTH lithdog
6	Choondal	58 B/2	10°37'30"	76°05'58"	30	DTH lithdog
7	Madakkathara	58 B/6	10°32'42"	76°17'25"	30	DTH lithdog
8	Panancherry	58 B/6	10°33'47"	76°21'15"	55	DTH lithdog
9	Kolazhi	58 B/2	10°35'03"	76°12'55"	30	DTH lithdog
10	Athani	58 B/2	10°36'53"	76°12'48"	30	DTH lithdog
11	Chengaloor	60 B/7	10°24'15"	76°18'01"	30	DTH lithdog
12	Mupliyam	60 B/7	10°24'02"	76°21'08"	34	DTH lithdog
13	Mudikode	58 B/6	10°32'56"	76°18'34"	30	DTH lithdog
14	Velapaya	58 B/2	10°36'08"	76°11'23"	45	DTH lithdog
15	Kaiparambu	58 B/2	10°36'31"	76°08'30"	40	DTH lithdog
16	Peechi	58 B/6	10°32'13"	76°20'11"	32	DTH lithdog
17	Chittilappilly	58 B/2	10°33'23"	76°09'23"	30	DTH lithdog
18	Nelluvayi	58 B/2	10°40'35"	76°10'06"	40	DTH lithdog
19	Kandanissery	58 B/2	10°35'53"	76°04'56"	45	DTH lithdog
20	Aloor	58 B/7	10°20'08"	76°04'26"	85	DTH lithdog
21	Vellangallur	58 B/3	10°16'53"	76°12'52"	75	DTH lithdog
22	Varavoor	58 B/2	10°42'52"	76°12'48"	70	DTH lithdog
23	Arthat	58 B/2	10°37'30"	76°03'05"	70	DTH lithdog
24	Wdakkancherry	58 B/6	10°38'24"	76°16'32"	70	DTH lithdog
25	Pudukad	58 B/7	10°25'25"	76°16'10"	200	DTH lithdog
26	Vellanikkara (KAU Veg.Garden)	58 B/6	10°32'30"	76°17'15"	125	CGWB data
27	Chiranellur	58 B/2	10°38'20"	76°07'15"	200	CGWB data
28	Alur	58 B/2	10°36'05"	76°06'55"	300	CGWB data
29	Vellanikkara (KAU Main gate)	58 B/6	10°32'30"	76°17'10"	300	CGWB data
30	Vellanikkara (KAU Pepper garden)	58 B/6	10°33'10"	76°17'00"	150	CGWB data
31	Nattika	58 B/3	10°24'30"	76°05'45"	77	CGWB data
32	Edakazhiyoor	58 B/2	10°36'00"	76°00'30"	75	CGWB data
33	Maruthiyoor	58 B/2	10°33'28"	76°03'00"	33	CGWB data
34	Vattekkad	58 B/2	10°32'17"	76°02'00"	41	CGWB data
35	Anjangadi-Kadappuram	58 B/2	10°32'16"	76°01'30"	83	CGWB data

1	2	3	4	5	6	7
38	Mathilakam (Emmad)	58 B/3	10°17'55"	76°08'15"	78.5	Calyx litholog
39	Vatanapplli east	58 B/3	10°28'05"	76°05'20"	18.5	Calyx litholog
40	Vatanapilli west	58 B/3	10°27'48"	76°04'22"	15.5	Calyx litholog
41	Kanjani	58 B/3	10°28'45"	76°07'00"	18.5	Calyx litholog
42	Vatanappilli	58 B/3	10°28'10"	76°05'00"	12	Cable tool litholog
43	Irimbranellur	58 B/2	10°00'30"	76°07'30"	3.5	Cable tool litholog
44	Venkitangu	58 B/3	10°01'00"	76°05'45"	18	Cable tool litholog
45	Kandasamkadavu	58 B/3	10°28'15"	76°05'45"	7.5	Cable tool litholog
46	Manaloor	58 B/3	10°29'30"	76°06'45"	11.5	Cable tool litholog
47	Pokulangara	58 B/2	10°00'23"	76°03'55"	8.5	Cable tool litholog
48	Engadiyoor	58 B/3	10°29'37"	76°03'25"	9	Cable tool litholog
49	Chavakkad (Mandekadavu)	58 B/2	10°34'30"	76°01'10"	9	Cable tool litholog
50	Pulavaya	58 B/2	10°34'37"	76°03'07"	6	Cable tool litholog
51	Edathuruthi	58 B/3	10°21'45"	76°08'30"	8	Cable tool litholog
52	Edamauttam (West)	58 B/3	10°22'08"	76°07'00"	7.5	Cable tool litholog
53	Kattoor	58 B/3	10°27'00"	76°12'00"	12.5	Cable tool litholog
54	Alappad	58 B/3	10°26'37"	76°09'45"	8	Cable tool litholog
55	Eravu	58 B/3	10°28'45"	76°07'53"	2	Cable tool litholog
56	Cheloor	58 B/3	10°14'30"	76°12'00"	13	Well section
57	Thottippal	58 B/3	10°23'45"	76°14'08"	8	Well section

Geophysical techniques are the most helpful in areas where the geology is not too complex and a large contrast between the physical parameters of various rock formations exists. Geophysical field techniques are engaged to determine physical parameters of core, mantle and crust of the earth. The physical parameters of the subsurface rocks such as shock wave velocities, resistivity, magnetic susceptibilities etc. can be determined using geophysical equipments. The geophysical techniques are most important tool in the search of natural resources including potential oil field, mineral resources occurrences. For oil and mineral exploration the first few thousand meters of the crust may be considered. Groundwater investigations usually do not exceed below 500m depths.

Electrical resistivity method is one of the most widely used geophysical investigation technique, which gives good indication of the occurrence of fractured zone as well as the quantity and quality of groundwater. If a material of resistance R has cross sectional area A and a length L, then its resistivity can be expressed as $\mu = RA/L$. Units of resistivity are ohm-m^2/m or simply ohm-m. The resistivities of rock formations vary over a wide range, depending on the material, density, porosity, pore size and shape, water content and quality, and temperature. There are no fixed limits of resistivities of various rocks; igneous and metamorphic rocks yield values in the range of 10^2 to 10^8 ohm-m; sedimentary and unconsolidated rocks from 10^0 to 10^4 ohm-m. In porous formations the resistivity is controlled more by water content and quality within the formation than by the rock resistivity. For aquifers composed of unconsolidated materials, the resistivity decreases with degree of saturation and salinity of groundwater. Clay minerals conduct electric current through their matrix; there for, clay formations tend to display lower resistivity than do permeable alluvial aquifer. Actual resistivities are determined from apparent resistivities, which are computed from measurements of current and potential differences between pairs of electrodes placed in the ground surface. The procedure involves measuring potential difference between two electrodes (P in Fig. 2.2) resulting from an applied current through two other electrodes (C in Fig. 2.2) out side but in the line with the potential electrodes. If the resistivity is every where uniform in the subsurface zone beneath the electrodes, an orthogonal network of circular arcs will be formed by the current and equipotential lines, as shown in the Fig. 2.2. The measured potential difference is a weighted value over a subsurface region controlled by the shape of the net work. Thus, the measured current and potential differences yield an apparent

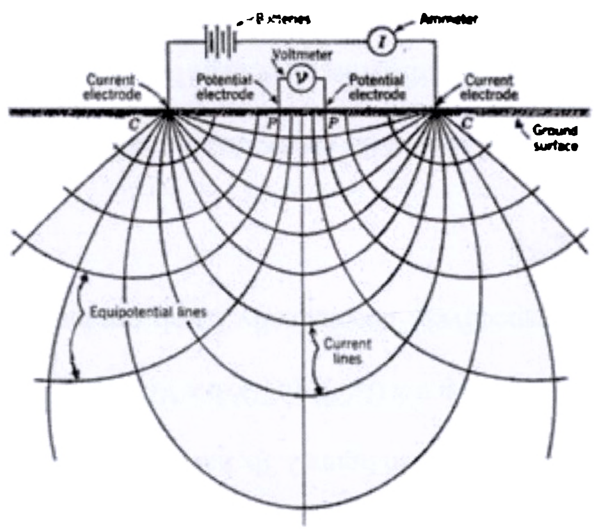


Fig. 2.2 Electrical circuit for resistivity determination and electrical field for a homogenous subsurface stratum

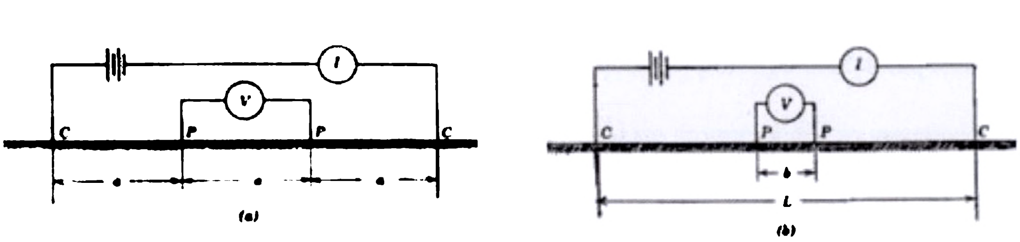


Fig. 2.3 Common electrode arrangements for resistivity determination. (a) Wenner. (b) Schlumberger.

resistivity over an unspecified depth. If the spacing between electrodes is increased, a deeper penetration of the electric field occurs and different apparent resistivity is obtained. In general, actual subsurface resistivities vary with depth; therefore, apparent resistivities will change as electrode spacing are increased, but not in a like manner. Because changes of resistivity at great depths have only a slight effect on the apparent resistivity compared to those at shallow depths, the method is seldom effective for determining actual resistivities below a few hundred meters.

Electrode consists of metal stakes driven into the ground. Various standard electrode spacing arrangements have been adopted in electrical resistivity method; most common are Wenner and Schlumberger arrangements.

The Wenner arrangement shown in the Fig. 2.3a has potential electrodes located at third points between current electrodes. The apparent resistivity is given by the ratio of voltage to current times a spacing factor. For Wenner arrangement, the apparent resistivity $\mu = 2\pi a V/I$, where" a" is the distance between adjacent electrodes, V is the potential difference between adjacent electrodes, and I is the applied current.

The Schlumberger arrangement, shown in figure 2.3b, has the potential electrodes close together. The apparent resistivity is given by $\mu = \pi (L/2)^2 - (b/2)^2/b \times V/I$ where L and b are the current and potential electrode spacing respectively. Theoretically, L >>b, but for practical applications good results can be obtained if $L \geq 5b$.

The apparent resistivity is plotted against the electrode separation. This resistivity curve is then interpreted in terms of horizontally stratified materials, there by obtaining the number of layers, their respective thickness and resistivity, with the help of standard curves prepared by Oreelana and Mooney (1966) for Schlumberger arrays. Standard computer programme is also available for this purpose.

As the part of research work, there are 57 VES surveys conducted in various parts of the basin during the years 2003 to 2006. Aquameter (CRM-20) and Schlumberger configuration were used in the field for geophysical data collection. Geophysical investigation has been carried out in 45 places of the Palaeo-lagoon (Kole land basin) up to a depth of 150 m below ground level to understand the subsurface geology, fracture pattern and groundwater quality of the basin and analysed VES data.

2.2. 4 Pumping test and evaluation of aquifer parameters

Pumping tests are the methods used for the determination of aquifer parameters such as hydraulic conductivity (K), coefficient of transmissibility or transmissivity (T), coefficient of storage or storativity (S) and drainage factor (B). In addition to these, the important hydraulic characters of confining layer are hydraulic resistance (c) and leakage factor (L). This is one of the most useful means in not only for determining the aquifer hydraulic properties of aquifer and confining beds, but also the determination of yield, drawdown, specific capacity and designing of the well. However, various formulae, which are used for the analysis of pumping test data, are based on certain assumptions and therefore while analysing the test data it is essential to have a clear understanding of the application of a particular method to the prevailing field conditions.

A German scientist Adolph Theim published the first formula based on the work of Darcy and Dupuit, for determining aquifer characteristics from pumping tests. Since then, various workers for determining aquifer properties under different geo hydrological condition have suggested many formulae. Excellent accounts of these methods are given by Walton (1962, 1970), Hantush (1964), Kruseman and De Ridder (1970). Aquifer parameter could be evaluated using classical and digital methods. Many of the available classical pumping test analyses are mostly graphical (Cooper and Jacob, 1946; Papadopulos and Cooper, 1967; Romani, 1987; Boultan and Stretsova, 1974; Mishra and Chachadi, 1985; Singh and Gupta, 1999) which require data plotting and individual judgment during the curve fitting procedures.

Porosity (θ): It is an important hydrological characteristic of a formation. Porosity is measure of the interstices present in a formation. It is defined as the ratio of the volume of voids to its total volume and can be expressed either in percentage or in decimal fraction.

$\theta = V_p / V_b$; where, θ= porosity, v_p= volume of pore space and V_b= bulk volume

Porosity is usually of two types; primary porosity and secondary porosity. Primary porosity is the inherent character of a rock, which is developed during the formation of the rock. In sedimentary rocks and unconsolidated formations; the porosity is of primary nature due to intergranular spaces. Secondary porosity is developed due to subsequent process such as fracturing and jointing of igneous and metamorphic rocks and dissolution in carbonate rocks. The shape and arrangement of constituent grains, degree of sorting, cementation and compaction, fracturing and dissolution control the porosity of the rock. The porosity of aquifer materials is given in the Table 2.3.

The porosity of an aquifer is the sum of specific retention (Sr) and specific yield (Sy). The specific retention is a measure of the volume of water, which is retained by the aquifer material against gravity on account of cohesive and inter-granular forces. Specific yield is the water yielding capacity and is also termed as effective porosity. The specific yield is expressed quantitatively as the percentage of the total volume of rock occupied by the water, which can be drained out by gravity.

Specific yield increases with increase in grain size and sorting while specific retention increases with decrease in grain size and assortment.

Hydraulic conductivity (K): The hydraulic conductivity, also known as permeability, is a measure of the ease with which a fluid moves through a formation and is defined as the amount of flow per unit cross sectional area under the influence of a unit gradient. It has the dimension of velocity (LT^{-1}) and is usually expressed in m/day. The range of hydraulic conductivity values for various types of geological formations is given in Table. 2.4.

Transmissivity (T): Transmissivity or coefficient of transmissivity is a hydraulic characteristic of the aquifer, which was first introduced in groundwater literature by Theis (1935). It is defined as the rate of flow of water at the prevailing field temperature under a unit hydraulic gradient through a vertical strip of aquifer of unit width and extending through the entire saturated thickness of the aquifer. It is therefore, a product of the average permeability and saturated thickness of aquifer i.e. T= Kb where b is the thickness of aquifer. Transmissivity has the dimensions of L^2T^{-1} and is usually expressed in m^2/day.

Coefficient of storage or storativity (S): The storage coefficient of an aquifer is defined as the volume of water that vertical columns of aquifer of unit cross sectional area releases from storage as the average head within this column declines a unit distance. It is dimensionless. In confined aquifers where water released from or taken into storage is entirely due to compressibility of aquifer and of water, the storage coefficient (S) is given by S = (b x Ss) where b is the thickness of the aquifer and Ss is the specific storage with dimensions of L^{-1} and is defined as the volume of water which a unit volume of aquifer releases from storage because of expansion of water and compression of the aquifer under a unit decline in the average head within the unit volume of the aquifer (Hantush, 1964).The storage coefficient in confined aquifers has the order of magnitude of 10^{-3} to 10^{-5}. The storage coefficient for water table aquifer is given by Sw = Sy + bSs, where b is the height of watertable above the base of free aquifer, and Sy is the specific yield of the aquifer. Usually Sy >>> bSs. Thus Sw for all practical purposes can be regarded as the specific yield. The specific yield is defined as the ratio of the volume of water that a rock or soil will yield by gravity to its own volume. In other words, it represents very closely the effective porosity (Hantush). The storage coefficient in unconfined aquifers ranges from 0.05 to 0.30.

Hydraulic diffusivity (D): Hydraulic diffusivity is defined as the ratio of transmissivity and storativity and is given as D = T/S. Diffusivivty has the dimensions of L^2T^{-1} and is generally expressed in m^2/day.

Table 2.3 Porosity of aquifer materials (Manual of aquifer parameters, 1982 by CGWB)

S.No	Aquifer material	No.of anlaysis	Porosity range	Arithmatic mean
I	Igneous rocks			
1	Weathered granite	8	0.34 - 0.57	0.45
2	Weathered gabbro	4	0.42 - 0.45	0.43
3	Basalt	94	0.03 - 0.35	0.17
II	Sedimentary rocks			
1	Sandstone	65	0.14 - 0.49	0.34
2	Siltstone	7	0.21 - 0.41	0.35
3	Sand (fine)	243	0.35 - 0.53	0.43
4	Sand (coarse)	26	0.31 - 0.46	0.39
5	Gravel (fine)	38	0.25 - 0.38	0.34
6	Gravel (coarse)	15	0.24 - 0.36	0.28
7	Silt	281	0.34 - 0.61	0.46
8	Clay	74	0.34 - 0.57	0.42
9	Limestone	74	0.07 - 0.56	0.3
III	Metamorphic rocks			
1	Schist	18	0.04 - 0.49	0.38

Table 2.4 Some typical values of hydraulic conductivity (after Morris and Johnson, 1975)

S.No	Aquifer material	Hydraulic conductivity, m/day
1	Gravel (coarse)	150
2	Gravel (medium)	270
3	Gravel (fine)	450
4	Sand (coarse)	45
5	Sand (medium)	12
6	Sand (fine)	2.5
7	Silt	0.08
8	Clay	0.0002
9	Sansstone, fine grained	0.2
10	Sandstone, medium grained	3.1
11	Limestone	3.1
12	Dune sand	20
13	peat	507
14	Schist	0.2
15	Slate	0.00008
16	Basalt	0.01
17	Gabbro, weathered	0.2
18	Granite, weathered	1.4

Leakage coefficient or Leakance (1/c): It is the property of the semi-confining layer and is defined as the ratio of the vertical permeability of semi confining layer to its thickness, ie, K/b. It has the dimension of $time^{-1}$.

Hydraulic resistance (C): It is also called reciprocal of leakage coefficient or resistance against vertical flow and is a property of leaky aquifers. It is equal to b/K. It characterises the resistance the semi-pervious layer to upward or down ward leakage. It has the dimensions of time.

Leakage factor (L): The leakage factor determines the distribution of the lekage in to leaky (semi) confined aquifers. High value of leakage factor indicates a great resistance of the semi-pervious strata to flow. This factor is dimensions of length and is expressed in meters.

Drainage factor (B): The drainage factor is a property of unconfined aquifers. The drainage factor $B = \sqrt{(T/ Sy)}$. A large value of B indicates a fast drainage. The drainage factor has the dimensions of length and expressed in meters.

Specific capacity (c): The production capacity of a well is rated by its specific capacity, which is defined as the discharge for unit time for unit draw down. It is expressed by the relation $C = Q/s$, where C is the specific capacity, Q is the discharge and s is draw down in meters. The specific capacity of a well depends on several factors.

Optimum yield: Optimum yield is one of the important characteristics of the aquifer, which forms the basis for any type of planning and implementation. Optimum yield of a well is the volume of water per unit time discharge by pumping and it is measured commonly as a pumping rate in cubic meters per day (Karanth, 1987).

2.2.4a Groundwater movement

Groundwater in its natural state is invariably moving. This movement is governed by established hydraulic principles. A judicious exploration of groundwater resources is not possible without the basic knowledge of groundwater hydraulics. Therefore, a number of fundamental laws governing the flow of groundwater through permeable formations and practical formulae for flow through aquifer are discussed here.

Darcy's law: Darcy's law states that the filtration velocity of seeping fluid depends linearly on the loss of head over the given path and can be expressed by the following relation V= -Kdh/ds

where,

V= Filtration velocity or specific discharge, the discharge per unit cross sectional area of the soil through which the water is flowing.

K= Coefficient of permeability of soil, also termed the hydraulic conductivity or transmission constant.

h = Head of groundwater at the point in consideration, measured with respect to a given reference level.

Dh/ds = Hydraulic gradient at that point, i.e, the loss of head dh divided by the distance ds along the direction of flow.

The piezometric head of the groundwater or groundwater potential can be expressed as

$h = P/\rho g + Z + V^2/2g$ Where,

$P/\rho g$ = The pressure head of the groundwater at the point in consideration.

P = The pressure at that point.

ρ = The density of water.

g = The acceleration due to gravity.

Z = The elevation of the point with respect to the given reference level. It is also termed as the elevation head or geodetic head.

V = velocity of flow at the point under consideration

The piezometric head can be therefore defined as the sum of pressure head, elevation head and velocity head. In case of groundwater, velocity of flow is small and hence velocity head is comparatively much smaller than other heads and hence is neglected. To simplify mathematical treatment, aquifers will be assumed to be homogenous and isotropic.

The groundwater head h has the dimension of length, (L). The specific discharge (or the filtration velocity) V has the dimension of velocity, (L/T) and m/day be used as unit for K.

Darcy's law is valid for laminar flows. For Reynold's number (N_R) up to 1, the flow is fully laminar; the flow is fully turbulent at Reynolds number greater than 1000. For $1<N_R<1000$, the flow is in a transition zone. The Reynolds number N_R is defined as $N_R = Vd/u$, where V is the filtration velocity defined by Darcy's law, d is the characteristic grain diameter of the soil and u is the kinematic viscosity of water.

Steady state flow: A steady flow implies that no change occurs with time. Flow conditions are differing for confined and unconfined aquifers.

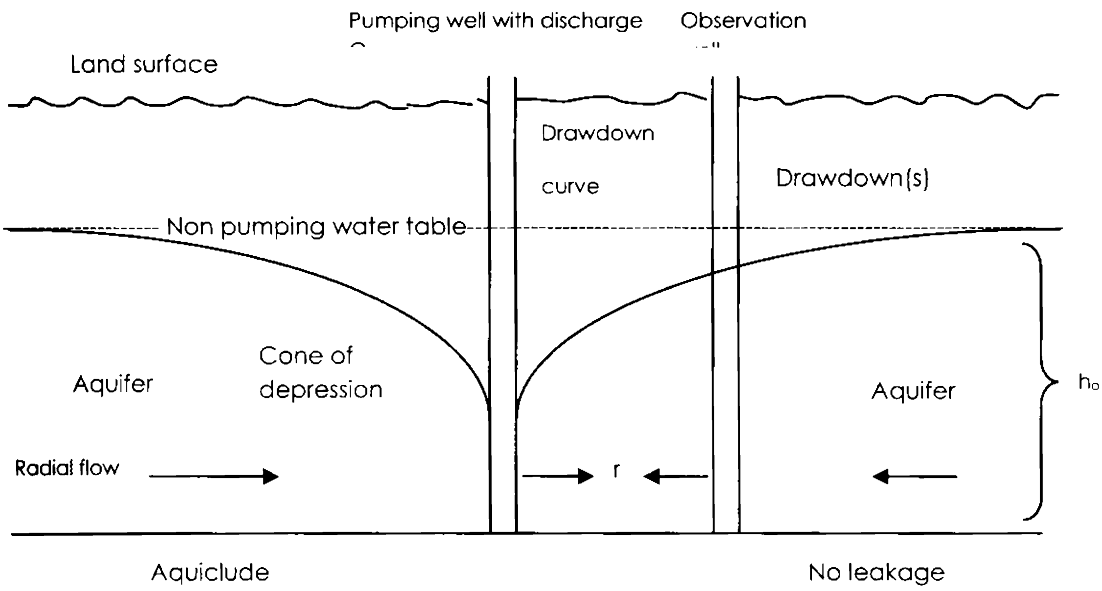
Confined aquifer: The steady radial flow to a well through the aquifer at a distance 'r ' from the central axis; follow Theim's (1906) equilibrium equation. The draw down 's ', at a radial distance 'r ' from the well is given as $s = h_o - h = Q/2\pi Kb \text{ in } r_o/r$.

Unconfined aquifer: Consider the case of pumped well located in an unconfined aquifer and discharging steady discharge Q. The flow at radial distance r from the well is given by the following equation under the simplifying assumptions made by Dupuit (1853). $Q = AV = 2\pi K\, h\, dh/dr$ where h denotes the height of water table above the lower impermeable boundary at any distance 'r' from the well (Fig. 2.4).

Unsteady state flow: Unsteady state flow implies the decline of head as long as the pumping continues due to the reduction of storage in the aquifer.

Confined aquifer: Consider a well fully penetrating an artesian aquifer overlain and underlain by aquiclude pumped at constant rate Q. The aquifer is assumed to be homogenous, isotropic, infinite in areal extend and is the same thickness through out. The flow is radial through out (Fig. 2.5). When production well in such an aquifer is pumped, water is continuously withdrawn from storage within the aquifer as the cone of depression progress radially further from the well. Because of the absence of source of recharge in the form of vertical leakage or a recharge boundary, there can be no stabilization of water levels and the head in the aquifer will continue to decline provided the aquifer is effectively infinite in areal extend.

The unsteady state: The equation for radial flow in son leaky artesian aquifer is applied by Theis (1936) and Jacob (1950).



ig. 2.4 Schematic representation of groundwater flow during pumping of phreatic aquifer with lly penetrating wells

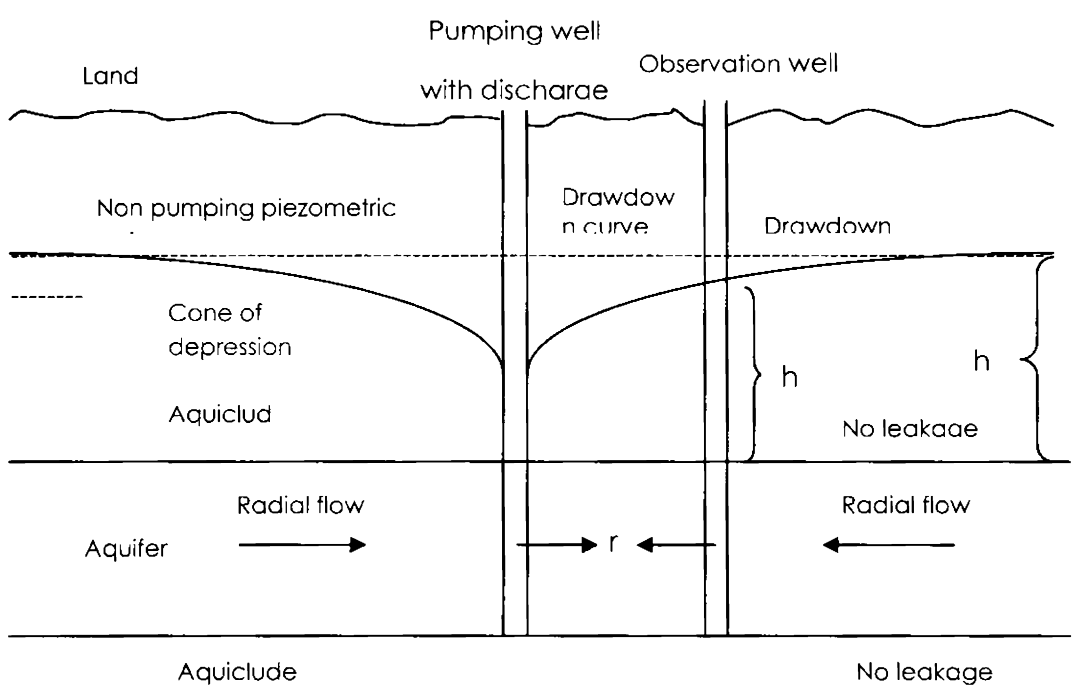


Fig. 2.5 Schematic representation of groundwater flow during pumping of non leaky artesian aquifer with fully penetrating wells.

The equation may be written as $s = Q/4\pi T\ W(u)$. Where, $u = r^2S/4Tt$, s = drawdown (L), r = distance from pumped well to observation well (L), Q = discharge (L^3/T), t = time after pumping started (T), T = coefficient of transmissibility (L^2/T), S = coefficient of storage and W(u) is the well function for non leaky artesian aquifers fully penetrated by wells and constant discharge conditions. Values of W(u) is obtained from the chart of Winzel (1942). When the pumping period is large or the distance r is small, values of u will be small. When u d" 0.01, then (Cooper and Jacob, 1946) the equation may be written as

$T = 2.30Q/4\pi\Delta s$, where Δs = drawdown difference per log cycle (L).

The straight line plot of distance -drawdown and time-drawdown may be extrapolated to their intersection with zero drawdown axis. At the zero drawdown intercepts, s = 0, then equation may be written as $S = 2.25Tt_0/r^2$ and $S = 2.25\ Tt/r_0^2$ where t_0 = intersection of time drawdown semi log straight line with zero drawdown axis (T), r_0 = intersection of distance drawdown semi log straight line with zero drawdown axis(L) and other terms are as defined earlier.

Unconfined aquifer: The non equilibrium equation assumes that water is released instantaneously from storage by lowering of head. In a confined aquifer this is essentially true because the water is released by expansion of the water and compression of the aquifer. As the water drains over a finite time, the storage coefficient during a pumping test varies with time. It increases at a diminishing rate with time and approaches the specific yield.

Because of this difference between confined and unconfined aquifers, the non equilibrium equation can be applied to unconfined aquifers, only if the following limitations are observed:

(i) Drawdown should be small in relation to the saturated aquifer thickness, and

(ii) A specified minimum pumping time should have elapsed so that the drainage effect is minimized. The minimum pumping time can be determined by the equation

$t\,min = 5.00syh_0/K$ where t min is the time after pumping began in days, Sy is the specific yield, h_0 is the saturated aquifer thickness in meters and K is the coefficient of permeability in meter per day (Fig. 2.4).

Leaky confined aquifer: Consider a well fully penetrating an artesian aquifer overlain by an aquitard and underlain by an aquiclude. The overlying aquitard are deposits in which there is water table. The aquifer is homogenous, isotropic, infinite in areal extent, and is of the same thickness through out. The flow in the aquifer is radial through out and is augmented by vertical leakage through the aquitard. The flow lines are assumed to be refracted at full right angles as they cross the aquitard aquifer interface. The aquitard is assumed to be more or less incompressible so that water release from storages is negligible. The water table is not influenced appreciably by pumping (Fig. 2.6). The discharge of water from a well in such an aquifer is supplied from storage with in the aquifer, as well as from leakage through the aquitard. Because of the presence of recharge in the form of leakage, water levels will stabilize when the entire discharge of the well is derived from leakage. The rate of vertical leakage is proportionate to the difference in head between the water table and the piezometric surface of the aquifer. If K' is the coefficient of permeability of the aquitard, b' is the thickness of the aquitard, then, L2 = (T/K'b') where L is termed as the leakage factor. The groundwater flow through the aquifer may be solved by the flow equations developed by Hantush-Jacob, Walton and De Gloes.

2.2.4b Methods of analysing pumping test data: In general, the pumping test data can be used either to determine the yield of the well, efficiency of the well and aquifer characteristics. In the former case, wells are pumped at variable discharges and corresponding drawdowns are noted. The data is analysed using various methods to determine the yield and efficiency of the well. The pumping test conducted for determining yield and efficiency of wells is known as Well test. Step draw down test (SDT) is an example for well test.

Pumping test is carried out to determine the aquifer characteristics which can be broadly divide into two, viz., drawdown method and recovery method. In drawdown method, the drawdown data since pumping started is collected while in recovery method the rate of recovery since pumping stopped is noted. The drawdown methods are further subdivided into two types-steady state (equilibrium) methods and the unsteady state (non equilibrium methods). All these methods are based on certain assumptions, some of which in many times do not hold well under natural conditions.

There are different methodologies adopted for conducting a pumping test. (i) Slug test (ST), (ii) Step-drawdown test (SDT), and (iii) Aquifer performance test (APT).

Slug test: In the instantaneous discharge test, a small quantity of water is suddenly removed from a well. The resulting rate of rise of water level in the well is then measured. Alternately, a small **slug** of water can be instantaneously introduced into the well and the rise and subsequent fall of water level can be measured. The initial head (Ho) and the head after adding slug to the well (H) is measured

with time (t) in seconds. Plotted the values of H/Ho against the corresponding time't' on semi log paper. Superimposed the plotted curve on standard type curves (Cooper et al., 1967) and identified match line for the values 't' at $Tt/r^2 = 1.0$. Computed the transmissivity (T) by the formula $T = 1.0\ r^2/t$ where r^2 is the square of radius of the bore well. A small volume of aquifer in the immediate vicinity of the well is sampled through these tests. These tests are generally conducted in wells of low yields. The results of these tests are only approximate estimates of aquifer parameters, when compared to the pumping test results.

Slug test was conducted in a low yielding bore well near Irinjalakuda in the study area.

Well performance test (WPT): When a well is pumped, there is lowering in its water level, which is termed as drawdown. This drawdown is primarily caused due to decrease in water level in the aquifer (aquifer loss). However, due to entrance resistance in the well, there is an additional drawdown within the well itself which is the well loss. Thus, total drawdown in the pumped well comprises of two components; the aquifer losses and well losses. Well performance tests are used to determine specific capacity and other well characteristics such as well loss aquifer loss etc. The classical tests conducted for determining the well losses are the step draw down tests.

Step drawdown tests (SDT): In the step drawdown test, the well is first pumped at a low constant discharge rate until the drawdown with in the well stabilises. The pumping rate is then increased to a higher constant discharge rate and the well is pumped until the drawdown stabilises again. This process is repeated for a number of steps. For analysing the step draw down test data, at least three steps and ideally five steps are required. Each step should be in of equal duration ranging from 30 minutes to 2 hours.

The step drawdown test was first performed by Jacob (1947), in order to understand the drawdown in the well at different discharge rates. He gave the following equations $sw = BQ+CQ^2$. where $B = B_1+B_2$ B_1 is the linear aquifer loss coefficient, B2 is the linear well loss coefficient and Q is the discharge.

Aquifer performance test (APT): In an aquifer performance test, the well is pumped at constant rate and the drawdown caused due to pumping is noted in pumping well and in one or more observation wells. The number of pumping tests to be performed, the site of these tests and general set up depend on the kind of problem to be solved, the amount of information, which is desired and of course upon funds available for programme. A prior knowledge of the geohydrological conditions is essential before the pumping and observation wells are installed and test is carried out. Knowledge of thickness and nature of the aquifer, boundary conditions and direction of ground water flow is essential.

The Jacob's straight line method (Cooper and Jacob, 1946) is based on Theis's equation. The plot of drawdown versus logarithm of time (t) or distance (r) from the pumped well describes a straight line.

The solved equation for this method is $T = 2.30\,Q/4\pi\Delta s$ and $S = 2.25\,T\,t_0/r^2$ where T = Transmissivity in m^2/day, S = storativivty, Q = well discharge in m^3/day, t_0 = the time intercept in days corresponding to interception of straight line with zero drawdown axis, r = the distance of observation well in meters and Δs = slope of the straight line in meters.

The Papadopulose- Cooper method (1967) is an extension of the non equilibrium formula developed by Theis (1935). The solved equation for this method is $sw = Q/4\pi T\,W(u)$ and $\theta = 4\,Tt/r^2S$ where sw = drawdown, Q = well discharge in m^3/day, T = transmissivity in m^2/day, S = storativity, t = time since pumping started, r = radius of the well, w (u) and θ are well functions where $u = 1/\theta$. For estimation of T and S, the field data of drawdown (sw) versus time (t) were plotted on a log-log paper of the same scale as that of type curves. The data curve obtained for a single test was matched with one of the type curves (Papadopulose - Cooper type curves) and a match point was selected. An arbitrary point was chosen, for which the values of well function such as θ, 1/u sw and t were obtained from the type curve plot and drawdown plot. The Q and r were known from field measurements. The T and S values were computed by substituting the values in the above equations.

Lay out of the test: The following basic factors are considered before taking up a pumping test.

- The test is carried out at a place, which is representative of the area for which aquifer characteristics are to be determined. Care has also to be taken that the pumped water does not return to the aquifer.

- The pumping well should have full penetrations that the screen extends down to the bottom of the aquifer.

- At least one observation well is essential to record the drawdown during pumping tests.
- The duration for which the test should be run depends up on the type of aquifer to be tested and the degree of accuracy desired in determining aquifer characteristics. The test may be carried out till equilibrium conditions have been reached. However, this may not be feasible in all cases especially in unconfined aquifers.

Measurements: The measurements to be taken during pumping test fall in to three groups (i) pre-pumping phase measurements such as height measuring point, well depth below measuring point, diameter, static water level below measuring point, distance of observation wells and its static water level etc. (ii) pumping phase measurements such as time, drawdown, discharge etc. and (iii) Recovery phase measurements such as recuperation level, time etc.

The water levels during a pumping test are measured by using automatic water level recorders.

The slug test was carried out in 1 place, Step drawdown test in 7 places and aquifer performance test in 7 places and yield test in 5 places of the basin. The pumping test data was analysed by using Papadopoulos-Cooper method (1967), Jacob's straight line method (1946) and Theis's recovery method to determine aquifer characteristics. Romani's method (1987) was used to determine the yield of the dug wells at various parts of the basin. The composite computer programme developed by UNESCO (1987) as well as graphic methods have been followed in the present study for analyzing the pumping tests and recovery data. The secondary data of pumping tests conducted by the Kerala Samoohya Jalasechana Samithi (KSJS) in various parts of the Thrissur district were also used for present study.

2.2.5 Groundwater resource evaluation

The "National water policy" adopted by the Government of India in 1987 regards water as one of the crucial elements in developmental planning. It emphasizes that the efforts to develop, conserve, utilize and manage this resource have to be guided by national perspective. Water is a scarce and precious national resource to be developed and conserved as such and on an integrated and environmentally sound basis.

The National water policy enunciates the following guidelines for groundwater

- There should be a periodic assessment on scientific basis of the groundwater potential, taking into consideration the equality of water available and economic viability
- Exploration of groundwater resource should be so regulated as not to exceed the recharge possibilities, as also to ensure social equity.
- Groundwater recharge projects should be developed and implemented for augmenting the available supplies.
- Integrated and coordinated development of surface water and groundwater and their conjunctive use should be envisaged right from the project planning stage and should form an essential part of the project.
- Over-exploitation of groundwater should be avoided near the coast to prevent ingress of seawater in to fresh water aquifers.

The Kerala state has varied hydrogeological characteristics and hence the groundwater potentials differ from place to place. Increasing urbanization and growing dependence on groundwater for irrigation and industry in the State have called for judicious and planned exploitation of the groundwater resources. For proper planning and management of groundwater development in a judicious and socio-economically equitable manner, quantification of groundwater resource is one of the most important prerequisites.

The present methodology used for groundwater resource assessment is based on the guidelines of Groundwater Resource Estimation Committee, 1997 (GEC'97). Two approaches were recommended in this methodology (i) water level fluctuation method and (ii) rainfall infiltration method. The water level fluctuation method is based on the concept of storage change due to difference in various input and output components. Input refers to recharge from rainfall and other sources and subsurface flow into the unit of assessment. Output refers to groundwater draft, evapotranspiration, base flow to stream and subsurface out flow from the unit. Since the data on subsurface inflow/ outflow are not readily available, it is advantageous to adopt the unit for groundwater assessment as basin/sub-basin/watershed, as the inflow/outflow across these boundaries may be taken as negligible.

Thus it is ideal to have the groundwater resource assessment unit as watershed particularly in hard rock areas. In the case of alluvial areas, where data on watershed wise is not available, administrative block can also be the assessment unit. In each assessment unit, hilly areas having slope more than

20% are deleted from the total recharge area to get the area suitable for recharge. Further, areas where the quality of groundwater is beyond the usable limits should be identified and handled separately. The remaining area after deleting the hilly area and separating the area with poor groundwater quality is to be delineated into command and non-command areas. Groundwater assessment in command and non-command areas is done separately for monsoon and non-monsoon seasons.

2.2.6 Level survey

Levelling may be defined as the art of determining the relative heights or elevations of points or objects on earth's surface. It deals with measurements in a vertical plain. The common technical terms used in level survey are level surface, horizontal plain, vertical plain, datum surface, bench mark, line of collimation, vertical axis, back sight, foresight, intermediate sight, height of the instrument etc.

Level survey has been carried out across coastal plain areas using Theodalite and box type 4-meter staff. Survey started from the benchmark (created by State groundwater department for their observation well in Engadiyoor) at Engadiyoor near Chetwai and recorded the station, back sight, intermediate sight, foresight readings, rise, fall or height of collimation reduced levels and remarks in field book (Plate 2.2). Arithmetic checking also made for the collected data. The east-west profiles (covering coastline and eastern boundary of the palaeo-lagoon) were prepared using the above data to know the elevation of various places in relation to mean sea level especially the palaeo-lagoon area. The profiles were prepared across the places (i) Chavakkad, (ii) Engadiyoor, (iii) Vatanapalli, (iv) Edamuttom and (v) Mathilakam and analysed the palaeo change in the coastal plain area.

2.3 Laboratory works

The main laboratory works conducted with this investigation are the chemical and bacteriological analysis of water samples, sieve and pipette analysis of the core samples.

2.3.1 Chemical analysis

The original quality of groundwater is parented by the quality of precipitation water, which is further modified by reaction with organic matter, soils and rocks over a period time. In general groundwater quality tends to be uniform within given aquifer system in respect of location and time. The constituents, which comprise the bulk of the chemical composition of groundwater, are calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride, sulphate and silica. The minor constituents in groundwater in general are iron, manganese, strontium, fluoride, nitrate etc. The constituents found to occur in traces are aluminium, arsenic, cadmium, cobalt, chromium, copper, lead, mercury, nickel, phosphate, selenium, silver, zinc etc.

The chemical characters of groundwater determine its usefulness for domestic, industry and agricultural purposes. It is also essential to ensure that various constituents are within prescribed limit in drinking water supplies to avoid adverse impact on human health. It is widely recognized that the man, life forms and the domestic animals are affected by alteration in water quality due to natural or anthropogenic reasons. Likewise, the quality of irrigation water for agricultural use should be such that it does not impart plant growth or adversely affect the productivity of the land. Now a days chemical data are used to study the hydro chemical environment and evolution of groundwater.

Methods of analysis: Many quantitative methods for chemical analysis of water samples are based on standard quantitative techniques, other methods of analysis include advanced instrumental methods. The procedures of these techniques have been standardised internationally while some other methods are under development and evaluation.

Elecrtometric method: Hydrogen ion activity (pH) is analysed by this method. When a glass membrane separates two solutions of different strength a potential is developed across the membrane proportional to the difference in concentration of ions. pH meters employing glass-indicating electrodes and saturated calomel reference electrodes are now commonly used for pH measurements. The electrodes, connected to pH meters are immersed in the sample and the meter measures the potential developed at the glass electrode due to hydrogen ion concentration in the sample and displays it directly in pH units.

Electrical conductivity (EC): EC of natural water is due to the presence of salts, which dissociate into cations and anions. It is the ability of a solution to conduct current. The units of EC are μmhos/cm or μS/cm and it is expressed at 25°C. The conductivity meter is used to measure EC, which consists of a conductivity cell and a meter with three known resistivity (P, Q and R) and an unknown resistivity (sample-S). The meter measures the resistivity of sample, which is reciprocal of conductivity $P/Q=R/S$.

Numeric method: Some of the parameters are analysed by the relationship existing between concentrations of some irons and certain factors.

Total dissolved solids (TDS): TDS mg/l = ((HCO_3 mg/l)/2.03) + all dissolved constituents in mg/l

Total hardness (TH): TH as $CaCO_3$ meq/l = 2.497(Ca mg/l) + 4.118 (Mg mg/l)

Titration method: This is a visual end point colour method. The standard solution is added from a graduated burette to the substance to be determined until the reaction is completed. An auxiliary reagent or indicator is also added to the substance. After the reaction between the substance and standard solution is practically completed, the indicator should give a clear visual change in the solution being titrated. The point at which this occurs is called the end point of titration. The concentration of the substance is calculated from the volume of the standard solution is used (Table 2.5).

Spectroscopic method: In this method; the instrument works based on the principle of absorption, emission and scattering of energy (Table 2.6).

Atomic absorption spectrometry: The parameters analysed in AAS are Cu, Zn, Fe, Mn, Cr, Co, Pb, Al, Ca, Mg, Ni and Sr.

UV-Spectrophotometry: This is the method used for the analysis of F, Fe, NO_3 and PO_4.

Flame photometry is used for the analysis of Na, K, Li and Sr.

Nephelometer is used for the analysis of turbidity and SO_4.

Seasonal concentration of various anions and cations of the groundwater were chemically analysed using standard procedures (APHA, 1985). Major focus was given to concentrations of ions such as Na^+, K^+, Ca^{++}, Mg^{++}, HCO_3^-, CO_3^-, SO_4^{--} and Cl^-. Sodium and potassium in groundwater samples were analysed using flame photometer (Systronics FPM digital model). Calcium, magnesium and total hardness were estimated EDTA (0.01M) titrimetric method, whereas chloride was determined by argentometric titration using standard silver nitrate as reagent. Carbonate and bicarbonate concentrations of groundwater were determined titrimetrically against standard hydrochloric acid (0.01N). Sulphate concentration was carried out following turbidity method using spectrophotometer. The total Iron and sulphate in samples were analysed through a double beam UV-Visible Spectrophotometer (Hitachi model 2000). The fluoride concentration was based on the colorimetric method using SPADNS reagent. TDS, EC and pH measurements were carried out in the field by TDS meter (CM-183), Conductivity meter (CM-183) and pH meter (pH scan 1) respectively. The value of TDS and EC were validated by the relationship TDS = 0.64*EC (Table 2.7).

Table 2.5 Standard solutions and indicators used for the analysis various parameters

Sl.No	Parameter	Standard solution	Indicator	Sample colour	End point colour
1	Total hardness (TH)	N/50 EDTA	EBT	Wine red	Bright
2	Ca	N/50 EDTA	Murexide	Pink	Purple -violet
3	Alkalinity	N/50 H_2SO_4	Phenolphthalein	Pink	Colourless
4	Cl	N/50 $AgNO_3$	Potassium chromate	Yellow	Red precipitate
5	Acidity	N/50 NAOH	Phenolphthalein	Colourless	pink

Table 2.6 Various instruments working on different principles

Sl.No	Absorption of energy	Emission of energy	Scattering of energy
1	Atomic absorption	ICP-row AES or OES	Turbidity
2	UV- Spectrophotometery	Flame photometry	Nephelometry

Table 2.7 Methods followed for the determination of various physical and chemical parameters of groundwater

Sl.No	Parameters	Methods
1	pH, TDS and Electrical conductivity (EC)	Electrolytic
2	Na^+ and K^+	Flame photometry
3	Ca^{++}, Mg^{++},HCO_3^-,CO_3^-, Cl^- and total hardness	Titrimetry
4	SO_4^{--}, total iron and fluoride	Spectrophotometry

Minor errors in the chemical analysis of groundwater may occur due to (i) the reagents employed, (ii) limitations of the methods or instruments used, (iii) presence of impurities including distilled water and (iv) the personal error of the analyst. To minimise these errors; the instruments were periodically calibrated and analytical grade reagents were used to assure the quality and accuracy of the generated data.

Cation - anion balance is especially important in the case of groundwater analysis. Cation-anion balance check is a convenient technique to assess the reliability of measurements and the accuracy of data. The accuracy in the chemical analysis of water samples can be checked by calculating the cation-anion balance, in that sum of major cations should be equal to the sum of major anions which is expressed in $meql^{-1}$. To account for source dependency an allowable error limit of 10% is acceptable. The percentage error is termed as" ion balance error" (e), can be determined following the equation given by Matthess (1982).

$e = \Sigma \gamma c - \Sigma \gamma a / \Sigma \gamma c + \Sigma \gamma a$ where $\Sigma \gamma c$ and $\Sigma \gamma a$ are the sum of cations and anions respectively in meq/l.

The ionic concentration of groundwater can be expressed in two different ways; (i) the ppm (parts per million and (ii) epm (equivalent per million). The later type data is used for preparing hydrochemical facies diagrams like Hill-Piper, Durov's diagram etc.

The evaluations of data were carried out using several standard techniques of groundwater hydrochemistry. These techniques include (i) graphical representation of data such as bar diagram, vector diagram, pattern diagram (Stiff diagram (1951) etc, (ii) hydrochemical isocone maps, (iii) geochemical diagram such as Hill-Piper diagram and (iv) hydrochemical facies diagram (Johnson's (1975). The suitability of groundwater for irrigation was determined by the U.S.S.L (1954) and Wilcox diagram. Gibbs's (1970) diagram was used to study the mechanism, which control groundwater chemistry.

Bacteriological analysis: Bacteriological analyses of water samples were carried out in two seasons and evaluated the presence of total coli forms and faecal coli forms in the samples. For detection of E.coli, the samples were streaked on mac conkey agar plates. The brick red bacterial colonies in the agar plates after incubation indicate the presence of E.coli. The number of E.colis in each sample was identified by MPN method.

2.3.2 Groundwater contamination and vulnerability to pollution: The demand for freshwater is increasing rapidly all over the world as a result of rapid population growth. Yet, the supply of fresh water is finite and threatened by pollution. Conservation, judicious management of supply and demand and prevention of pollution have become imperative to avoid a water crisis. Increasing demand for safe drinking water and requirements to maintain healthy ecosystem are leading policy makers all over the world to ask complex social and scientific questions about ways to asses and manage our precious water resources. Scientific assessment potential for groundwater resources to become contaminated from natural as well as anthropogenic sources of pollution, otherwise termed 'vulnerability of groundwater resources to contamination.

Groundwater pollution, by definition, is the phenomenon involving modification of physical, chemical and biological properties of groundwater, restricting and preventing its use for which it had previously suited. It is the result of interaction between the pollutants, available moistures, subsurface materials and groundwater flow system. The term pollution and contamination are some times interchangeable in environmental matters to describe the introduction of a substance at a concentration sufficient to be offensive or harmful to human, animal and plant life. The word pollution is strictly used to describe contamination caused or induced by human activities and typically measured by reference to predetermined permissible or recommended maximum limit.

Concept of groundwater vulnerability: Groundwater vulnerability is natural intrinsic property of the groundwater system and depends on the ability/inability of this system to cope with natural process and human impacts at the strategic level of groundwater protection, the vulnerability of aquifers to pollution depends up on the interaction of several site- specific factors. The characteristics and depth of soil and unsaturated strata that lie between the land surface and the water table are important together with the properties of the aquifer itself. The interaction of these factors determines the nature and velocity of the pathway that will route pollutants to the water table via the process of advection and dispersion. In addition they will control the degree of attenuation that might restrict the penetration of pollutants through the soil and unsaturated zone.

DRASTIC method (Aller et al., 1987)

This is the most widely used index method to study the groundwater contamination and its vulnerability to pollution. The DRASTIC method incorporate major hydrogeological factors that affects the potential for groundwater pollution, namely depth to water, net recharge, aquifer media, soil media, topography, impact vadose zone and the hydraulic conductivity of aquifer. In this method; assign numerical scores to various physical attributes and develop a range of vulnerability categories. The factors considered in the method are Depth to water level, Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and Conductivity (hydraulic) of the aquifer. The acronym "DRASTIC" is derived from the first letters of each parameter, which are highlighted and underlined above. The parameters are weighed and rated according to their relative importance as per the procedure of Aller and others (1987). The final DRASTIC score; pollution potential was computed using the equation given below.

Pollution potential = DrDw+RrRw+ArAw+SrSw+TrTw+IrIw+CrCw; where 'r' is the rating and 'w' is the weight of the parameter.

The parameters are weighed according to their relative importance as shown in Table 2.8 and the range and rating of each parameter are given in Table 2.9.

If the calculated DRASTIC score is less than 80, then the vulnerability to pollution is considered as low, from 80 to 100 is moderate and more than 100 as high.

Assumptions of DRASTIC: The assessment of groundwater vulnerability using DRASTIC is based on the following assumptions.

(i) The contaminant is introduced at the ground surface

(ii) The contaminant is flushed into the ground water by precipitation

(iii) The contaminant has the mobility of water

(iv) The area being evaluated is > 0.4 km^2

(v) All geohydrological parameters of the area are well understood.

Pollution potential for 102 locations of the basin was calculated as per norms of Aller et al., (1987). The contours map for pollution potential values along with x and y co-ordinates were prepared using in Surfer- 7 package and identified the different areas of the basin vulnerable to groundwater pollution as per DRASTIC method.

Table 2.8 DRASTIC weights for parameters

Sl.No	Parameter	Weight
1	Depth to water	5
2	Recharge	4
3	Aquifer media	3
4	Soil media	2
5	Topography	1
6	Impact of vadose zone	5
7	Conductivity (Hydraulic)	3

Table 2.9 Range and rating of parameters in DRASTIC method (Aller et al., 1987)

1. Depth to water		**2. Recharge**	
Range	Rating	Range	Rating
0 to 1.5	10	0 to 50	1
1.5 to 4.5	9	50 to 100	3
4.5 to 9	7	100 to 175	6
9 to 15	5	175 to 250	8
15 to 22.5	3	> 250	9
22.5 to 30	2		
> 30	1		

Table 2.9 (continued) Range and rating of parameters in DRASTIC method (Aller et al., 1987)

3. Aquifer media		
Range	Rating (range & typical)	
Massive shale	1 to 3	2
Metamphic/ igneous rocks	2 to 5	3
Weathered igneous /metamorphic	3 to 5	4
Glacial till	4 to 6	5
Bedded sandstone, limestone & shale sequence	5 to 9	6
Massive sandstone	4 to 9	6
Massive limestone	4 to 9	6
Sand & gravel	4 to 9	8
Basalt	2 to 10	9
Karst limestone	9 to 10	10

4. Soil media	
Range	Rating
Thin or absent	10
Gravel	10
sand	9
Peat	8
Shrinking aggregated clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Muck	2
Non shrinking or non aggregated clay	1

5. Topography (slope)	
Range	Rating
<2%	10
2 to 6%	9
6 to 12%	5
12 to 18%	3
>18 %	1

6. Impact of vadose zone		
Range	Rating (Range & typical)	
Confining layer	1	1
Silt / caly	2 to 6	3
Shale	2 to 5	3
Metamorphic / igneous rocks	2 to 8	4
Limestone	2 to 7	6
Sandstone	4 to 8	6
Bedded sandstone, limestone, shale	4 to 8	6
Sand, gravel with silt and clay	4 to 8	6
Sand and gravel	6 to 9	8
Basalt	2 to 10	9
Karst limestone	8 to 10	10

7. Hydraulic conductivity	
Range (m/ day)	Rating
<4	1
4 to 12	2
12 to 29	4
29 to 41	6
41 to 82	8

2.3.3 Seawater intrusion and aquifer vulnerability to saline ingress

Coastal area of the world is an environmentally sensitive terrain, where land and ocean meet, and the hydrogeologic regime oscillates from fluvial to marine. Groundwater is a vital component of the coastal zone resource, which provides sustainable source of freshwater. But the coastal aquifers, though prolific water yielders are often beset with salinity hazards due to seawater ingress in the geological past and recent times. Unplanned developmental activities have also taken in toll on the environment through unbridled interception of freshwater flow offsetting the natural saltwater-freshwater balance. The salinization of the aquifers causes much harm to the coastal environment and ecology. Thus, an in-depth understanding of hydrogeologic and hydrogeochmical aspects of the basin is necessary for the scientific management of the aquifers of Palaeo-lagoon (Kole land basin).

Basic concepts: When an aquifer is open to the sea, there is a direct contact between continental freshwater and marine saltwater. There are differences of viscosity and density between two fluids. Normally freshwater floats over saltwater and an interface exist, which slopes landward. The saltwater body forms a wedge resting on the aquifer floor. The interface is not generally sharp, but a transition of mixing, diffusion and hydrodynamic dispersion. The formation of interface depends on hydrodynamic condition of the aquifer, expressed in its simplest form by Ghyben-Herzberg principle based on hydrostatic approach as in case of U-tube equilibrium of two immiscible fluids. The pressure of each side of the tube must be equal; therefore

$\rho_s g h_s = \rho_f g (Z+h_f)$; Where ρ_s is the density of saline water, ρ_f is the density of the freshwater, g is the acceleration due to gravity, h_f is height of freshwater above msl and z is the depth of interface.

Solving for z yields $z = (\rho_f/\rho_s-\rho_f)\, h_f$ which is the Ghyben-Herzberg relation. For typical seawater conditions, let $\rho s = 1.025 g/cm^3$ and $\rho f = 1.00 g/cm^3$ so that $z = 40\, hf$. Thus the interface depth at any point is 40 times the freshwater head (or water table elevation) above mean sea level.

In thin low permeability phreatic coastal aquifers, when freshwater flow is high the saltwater wedge is vey short and the penetration is limited to the vicinity of the shoreline. In thick highly permeable water aquifers with small freshwater flow, the wedge penetration is deep. Thus the wedge penetration is variable according to different hydrogeological circumstances.

In multilayered coastal aquifer the freshwater - salt water relationship depends up on vertical distribution of permeability, recharge, thickness and permeability of individual layers, saltwater wedge penetration is variable.

Table 2.10 GALDIT weights for parameters

Sl.No	Parameter	Weight
1	Groundwater occurence (aquifer type)	1
2	Aquifer hydraulic conductivity	3
3	Depth to water level above sea	4
4	Distance from the shore	2
5	Impact of existing status of seawater intrusion	1
6	Thickness of aquifer being mapped	2

Seawater contains large amounts of dissolved salt such as chloride, bromide, sulphate, sodium and magnesium. The dissolved salts include large amounts of sodium chloride, and significant quantities of alkaline earths sulphates, transmitting high hardness. Mixing of freshwater and seawater occurs within a transition zone, which is characterised by chloride concentration from 1000 to 10000 mg/l. The front of the transition zone is characterised by ion exchange as discussed above. Behind the ion exchange front, simple dilution characterizes deviation of the brackish water from seawater composition.

The various chemical ratios and diagrams of groundwater samples were analysed to identify seawater intrusion into the basin. They are the concentration of various ions, hydrochemical facies diagrams, ratios of major cations and anions, time series graphs of major cations & anions and bivariate plots of major cations and anions.

GALDIT method

"GALDIT" is an index method of aquifer vulnerability mapping proposed by Chachadi and Lobo ferreira (2001) to map and identify potential area of seawater intrusion in coastal areas. This has been derived from based mainly on the intrinsic aquifer properties and hence the time independent measure of aquifer vulnerability of an area to seawater intrusion problems. The mapable factors that control sea water intrusion considered in this method are (i) Groundwater occurrence (aquifer type; unconfined, confined and leaky confined), (ii) Aquifer hydraulic conductivity, (iii) Depth to groundwater Level above sea, (iv) Distance from the shore (distance inland perpendicular from shore line, (v) Impact of existing status of sea water intrusion in the area and (vi) Thickness of aquifer which is being mapped. The acronym "GALDIT "is formed from the highlighted and underlined letters of the parameters given above for easy reference.

The GALDIT factors represent measurable parameters for which data are generally available from a variety of sources and necessary fieldwork. The parameters are weighed and rated according to their relative importance as per the procedure of Chachadi and Lobo Ferreira (2001). The weights of parameters according to their relative importance are given in Table 2.10 and the range and rating of each parameter are given in Table 2.11.

(i) Groundwater occurrence (aquifer type) (G): In nature groundwater generally occurs in the geological layers and these layers may be confined, unconfined or leaky confined (semi-confined) nature. This basic nature of groundwater ha an influence on the extent of sea water intrusion. The ratings for unconfined, confined and leaky confined aquifers are 9, 10 and 8 respectively.

(ii) Aquifer hydraulic conductivity (A): The aquifer hydraulic conductivity is used to measure the rate of flow of water in the aquifer. The rating and range of this parameter are given in Table 2.11.

(iii) Depth to groundwater level above sea (L): The level of groundwater with respect to mean sea level is an important factor in the evaluation of sea water intrusion in an area primarily because it determines the hydraulic pressure availability to push the sea water front back. The range and rating are given in Table 2.11.

(iv) Distance from the shore (D): The impact of seawater intrusion generally decreases as one move inland at right angles to the shore. The rating and range are given in the Table 2.11.

(v) Impact of existing status of seawater intrusion (I): The area under mapping invariably is under stress and this has already modified the natural hydraulic balance between seawater and freshwater. This fact should be considered while analysing aquifer vulnerability to seawater intrusion in an area. The rating and impact status are given in Table 2.11.

(vi) Thickness of aquifer being mapped (T): Aquifer thickness or saturated thickness of an unconfined aquifer plays an important role in determining the extent and magnitude of seawater intrusion in the coastal areas. It is well established that, larger the aquifer thickness smaller the extent of seawater intrusion and vice versa. The range and rating are given in the Table 2.11.

Table 2.11 Rating and range parameters of GALDIT method (Chachadi and Lobo Ferreira, 2001)

Parameter (A)			Parameter (L)		
Sl.No	Rating	Hydraulic conductivity range(m/day)	Sl.No	Rating	Groundwater level above sea (m)
1	1	0 to 4.1	1	10	< 1.5
2	2	4.1 to 12.2	2	9	1.5 to 4.6
3	4	12.2 to 28.5	3	7	4.6 to 9.1
4	6	28.5 to 40.7	4	5	9.1 to 15.2
5	8	40.7 to 81.5	5	3	15.2 to 22.9
6	10	> 81.5	6	2	22.9 to 30.5

Parameter (D)			Parameter (T)		
Sl.No	Rating	Distance from shore to inland (m)	Sl.No	Rating	Aquifer thickness(m)
1	10	< 100	1	10	< 1
2	9	101 to 200	2	9	1.1 to 2.0
3	8	201 to 300	3	8	2.1 to 3.0
4	7	301 to 400	4	7	3.1 to 4.0
5	6	401 to 500	5	6	4.1 to 5.0
6	5	501 to 600	6	5	5.1 to 6.0
7	4	601 to 700	7	4	6.1 to 7.0
8	3	701 to 800	8	3	7.1 to 8.0
9	2	801 to 1000	9	2	8.1 to 10
10	1	> 1001	10	1	> 10.0

Parameter (I)		
Sl.No	Rating	Existing impact status of seawater intrusion
1	10	Area already intruded by seawater in all seasons, where epm value of the ratio of Cl/(HCO3+CO3) is > 2
2	5	Area already intruded by seawater in all seasons, where epm value of the ratio of Cl/(HCO3+CO3) is 1.5 to 2
3	0	Area already intruded by seawater in all seasons, where epm value of the ratio of Cl/(HCO3+CO3) is < 1.5

Mapping of final GALDIT index: According to the GALDIT method, each of the parameters has a pre-determined fixed relative weight that reflects its relative importance to vulnerability. The final GALDIT score; aquifer vulnerability index to seawater intrusion was computed using the equation given below.

GALDIT index = 1x G + 3 x A + 4 x L + 2 x D + I x 1 + 2 x T where G, A, L, D, I and T are the parameters mentioned as above. Once GALDIT score has been computed, it is possible to identify areas that are more likely to be susceptible to seawater intrusion relative to one another. The seawater intrusion potential is increases with increasing index. GALDIT index provides only a relative tool and is not designed to provide absolute answers.

The GALDIT score for 95 locations with in the basin was calculated as per norms of Chachadi and Lobo Ferreira (2001) and presented as table. The contour map for aquifer vulnerability index values along with x and y co-ordinates were prepared using in Surfer.7 package and identified the aquifer vulnerable areas to seawater intrusion in the palaeo-lagoon.

2.3.4 Sieve analysis

The sedimentary or detrital materials are formed by weathering, transportation and deposition of the solid materials by the various agencies. The mineralogical, textural and structural characters of the sediments in an area reveal the climate of deposition, nature of transportation, provenance and other palaeo- geographical features of the period, which the rocks belong in that area. Hence, the study of mineralogical and textural characters of the sediments in palaeo-lagoon (Kole land basin) is essential to reveal the evolutional history of the basin.

The distribution of size of sedimentary particles with intermediate diameters in the range of 1/16 to 16 mm is most commonly determined by sieving. About 150 samples from various places at different depths are analyzed to know the texture and mineralogy of each stratigraphic unit and the sedimentological properties of the palaeo-lagoon (Kole land basin). The grain size study of the beach ridge sediments from different cores has been investigated at 30 cm to 1 m interval, which enable to understand the grain size variations with depth.

Sand samples were washed, dried in air and subjected to coning and quartering and a representative portion (about 150 gm) was subjected to dry sieving. Each sample was sieved for 15 minutes on a Ro-Tap mechanical sieve shaker using a standard set of ASTM Endecott sieves at half phi ($^1/_2\Phi$) interval. The fractions left over in each sieve were carefully transferred; weighed and cumulative weight percentages were calculated. The cumulative weight percentages of the above analyses were plotted against the respective grain sizes (in phi units) on a probability chart. From the cumulative frequency curve the values of 1, 5, 16, 25, 50, 75, 84 and 95 percentiles were recorded. For a few samples (with high percentage of clay), which do not attain higher percentiles, the conventional extrapolation method suggested by Folk and Ward (1957) was adopted. The grain size parameters such as mean size (Mz), median (Md), standard deviation ($\sigma 1$), skewness (Ski), kurtosis (kG) and first percentile (C) were calculated by graphic method following Folk and Ward (1957).

The interrelationships existing between these parameters have also been worked out to elucidate the hydrodynamic conditions of the depositional medium. In addition to this, the percentages of sand (2-0.063mm) mud (< 0.063 mm) for the swale, intertidal, mud flat, alluvial plain and mangrove sediments were also plotted on a triangular diagram of Folk et al. (1970) to determine the sediment types.

2.3.5 Pipette analysis

Samples, which contains significant amount of silt and clay particularly from alluvial plains, mangroves, intertidal flats and swales were subjected to combined sieving and pipette analyses as suggested by Lewis (1984). Known quantities of silt and clay rich sediments were dispersed overnight in 0.025N solution of sodium hexametaphosphate. Using a 230 (63 μm) mesh coarse fraction was separated from the dispersed sediments by wet sieving. The filtrate containing the silt and clay fractions were carefully transferred to a graduated 1 litre measuring jar and volume made up. The solution was then stirred thoroughly to obtain a homogenous suspension. A 20 ml of the filtrate was pipette out into previously weighed 50 ml beaker at fixed time intervals from depths as suggested by Lewis (1984). All the aliquots were oven dried to constant weight at 60 ± 3° C and weighed accurately after cooling at room temperature. Dry sieving was carried out on sand fraction to complete the analysis.

2.3.6 Heavy minerals: For heavy mineral separation, the already sieved samples for textural analysis were used. Before separation the respective sand fraction of each class namely medium sand (+45 and +60 mesh), fine sand (+80 and +120 mesh) and very fine sand (+170 and +230 mesh) were thoroughly mixed and coned and quartered. Heavy minerals were separated from the lighter ones in three sand fractions using tribromomethane {Bromoform ($CHBr_3$) specific gravity is 2.89 at 20°C changing 0.0023 at 4°C} and separating funnel. The minerals thus separated were washed with acetone, dried and weighed to find out the total heavy and light mineral contents. The heavy minerals were then boiled for a few minutes with dilute HCl and a tinge of stannous chloride crystals to remove Fe/Mn coating over the detrital heavy grains. A total of 300 to 400 grains from each heavy residue was mounted on glass slides using Canada balsam. The individual minerals in each slide were studied under a Leitz petrological microscope following standard methods.

2.4 Secondary data collection

The primary data collection is not an easy task in the case of rainfall data, river gauge data and pumping test data of deeper aquifers. These date collections are either restricted to some agencies or time and money consuming task. In those cases; secondary data collection is the only desirable way and are inevitable part of research work.

2.4.1 Rainfall and other climatic data

Rainfall (Table 2.12) and other climatic data such as temperature, humidity, evapotranspiration etc. for the period 1981 to 2005 were collected from Ground water department, district office, Thrissur and Kerala Agriculture University, Vellaniiakra, Thrissur.

2.4.2 Water level and chemical quality data of piezometers (bore wells)

The District office of the State groundwater department, Thrissur has been maintaining 24 peizometer net works in Palaeo-lagoon (Kole land basin) since 1997 (Table 2.13). Water level and chemical

Table 2.12 Details of rain-gauge stations and rainfall in Palaeo-lagoon (Kole land basin)

Location	Amalanagar	Cheerakuzhi	Enamakkal	Irinjalakuda	Kunnamkulam	Mannuthi	Mathilakam	Mupliyam	Ollukkara	Panacherry	Peechi	Pudukkad	Vaniyampara	Varandarapilli	Vazhani
Lattitude	10°33'07"	10°27'49"	10°29'30"	10°20'32"	10°38'49"	10°32'30"	10°18'45"	10°24'02"	10°32'56"	10°33'47"	10°32'13"	10°25'25"	10°34'38"	10°25'18"	10°38'15"
Longitude	76°10'20"	76°17'17"	76°06'45"	76°13'11"	76°04'11"	76°17'10"	76°09'37"	76°21'08"	76°18'34"	76°21'15"	76°20'11"	76°16'10"	76°24'35"	76°19'54"	76°18'00"
Year	**Rainfall in mm**														
1981	NA*	2691.90	3213.40	NA	3498.20	NA	NA	NA	3266.80	3104.10	2774.30	3706.37	2941.50	3669.30	2894.30
1982	NA	2489.20	2419.20	NA	2655.10	NA	NA	NA	2688.30	2490.48	2709.58	2465.85	2384.70	2635.50	2248.50
1983	NA	2109.20	2471.20	NA	3053.20	2488.90	NA	NA	3059.60	2643.90	2673.10	2600.96	2332.04	2907.10	2237.05
1984	NA	1937.40	2248.80	NA	3166.00	2544.70	NA	NA	2370.30	2295.60	2572.70	2673.79	2580.90	2847.10	2138.60
1985	NA	2016.40	2437.70	NA	2905.20	2700.00	NA	NA	2559.10	2262.20	2472.70	2855.50	2391.20	2883.50	2154.00
1986	NA	1888.80	2355.60	NA	3130.50	2466.00	NA	NA	2232.90	2347.10	2383.33	2812.20	2015.50	2672.80	1923.76
1987	NA	1371.60	2626.70	NA	2955.10	2414.30	NA	NA	2161.60	2203.30	2424.50	2668.10	2286.00	2301.60	1577.00
1988	NA	1281.00	2771.00	NA	3392.80	2961.10	NA	NA	2744.10	2713.20	2725.10	3083.10	2052.30	2889.80	1578.80
1989	NA	1569.00	2449.01	NA	3129.40	2405.70	NA	NA	2062.53	2359.50	2476.50	2902.52	2248.50	2809.63	2220.85
1990	NA	1943.50	2531.60	NA	3429.70	3085.60	NA	NA	2983.90	2557.00	2756.00	3212.80	2603.00	2700.20	2231.25
1991	NA	2415.30	2953.00	NA	3634.80	3182.30	NA	NA	3745.50	2996.00	2758.70	3292.90	3060.00	3148.40	2498.80
1992	NA	2740.10	2924.40	NA	4189.30	3624.70	NA	NA	3123.30	3609.00	3143.50	3759.90	1974.00	3686.05	2579.60
1993	2877.40	1918.60	2947.00	NA	3326.90	2505.30	NA	NA	3088.50	2831.90	2266.30	2987.90	2834.50	2593.40	2075.70
1994	3573.40	2957.20	3268.60	NA	4371.50	NA	NA	NA	2674.30	3886.00	3471.20	3782.10	2400.50	3707.00	2942.50
1995	3111.70	2411.70	2959.00	NA	3654.40	NA	NA	NA	1553.10	3018.00	2544.80	3183.40	2241.50	3241.80	2342.60
1996	2017.30	2943.10	2387.80	NA	2672.70	NA	NA	NA	2031.40	2614.00	2437.00	2840.40	2469.50	2638.00	2070.10
1997	3682.40	2016.40	3061.40	NA	3775.70	NA	NA	NA	2742.50	3804.00	2890.80	2710.40	2862.50	3051.60	2814.80
1998	3402.10	2094.40	3771.70	NA	3618.70	NA	NA	3676.30	1713.60	3779.00	3217.40	3631.00	2342.00	3897.30	2594.90
1999	2780.92	1603.68	2627.80	NA	3336.70	NA	NA	2786.30	2084.00	NA	3099.90	2947.20	2254.80	3066.00	2428.90
2000	2214.90	1506.00	2026.20	NA	2006.30	NA	2336.90	2217.28	2105.10	NA	1886.60	2506.00	2114.80	2252.51	1751.40
2001	2784.80	1768.00	2707.00	NA	2817.40	NA	2705.10	2611.59	1856.30	NA	2616.52	2844.10	1925.70	2890.40	2171.60
2002	2897.50	1526.74	2304.20	1886.00	2505.20	2341.01	2346.80	2176.93	2866.90	NA	2279.98	2557.80	2627.00	2555.70	1991.72
2003	2617.00	1498.40	1926.20	1665.00	2534.20	1892.50	2112.20	NA	2220.20	NA	2079.33	2359.20	2205.20	2386.00	1950.22
2004	3322.70	2235.20	2851.00	NA	2974.20	NA	2880.00	NA	NA	NA	2448.30	3279.16	NA	2965.00	2864.50
2005	2951.71	1371.00	1996.90	NA	NA	NA	2235.40	NA	NA	NA	2311.60	2540.00	NA	2452.80	2738.50
Average	**2941.06**	**2012.15**	**2649.46**	**1775.50**	**3197.22**	**2431.52**	**2436.07**	**2693.68**	**2518.86**	**2861.90**	**2616.79**	**2968.11**	**2397.72**	**2913.94**	**2280.80**

* Not available

Table 2.13 Details of bore wells (Piezometers) in palaeo-lagoon (Kole land basin)

Well No	Location	Lattitude	Longitude	Topo sheet No	Well type	Total depth (m)	Over burden (m)	Diameter(mm)	Min. WL (mbgl) (1997-07)	Max. WL (mbgl) (1997-07)	(mbgl) (1997-07)	Formation
BW-1	Kaduppassery	10°19'53"	76°15'26"	58B/7	Bore Well	50.00	11.50	110	4.73	27.93	6.89	Charnockite
BW-2	Mattathur	10°22'26"	76°22'24"	58B/7	Bore Well	30.00	12.00	110	3.93	8.82	7.50	Gneiss
BW-3	Nellai	10°23'24"	76°17'03"	58B/7	Bore Well	30.00	15.50	110	2.34	4.79	3.66	Charnockite
BW-4	Tholur	10°34'00"	76°07'30"	58B/2	Bore Well	40.00	21.00	110	10.62	18.00	14.45	Gneiss
BW-5	Trikkur	10°27'49"	76°17'17"	58B/7	Bore Well	50.00	12.00	110	1.58	11.18	6.52	Charnockite
BW-6	Choondel	10°37'30"	76°05'58"	58B/2	Bore Well	33.00	9.50	152	0.79	16.52	4.90	Charnockite
BW-7	Madakkathara	10°32'42"	76°17'25"	58B/6	Bore Well	30.00	6.60	110	0.19	5.34	2.22	Gneiss
BW-8	Pananchery	10°33'47"	76°21'15"	58B/6	Bore Well	50.00	11.50	110	2.10	6.00	3.81	Charnockite
BW-9	Kolazhy	10°35'03"	76°12'55"	58B/2	Bore Well	30.00	9.00	110	-0.60	8.06	2.33	Charnockite
BW-10	Athani	10°36'53"	76°12'48"	58B/2	Bore Well	30.00	8.00	110	3.02	19.33	9.45	Charnockite
BW-11	Chengalur	10°24'15"	76°18'01"	58B/7	Bore Well	30.00	8.00	110	0.46	4.38	2.28	Charnockite
BW-12	Muppliyam	10°24'02"	76°21'08"	58B/7	Bore Well	40.00	10.00	110	1.20	8.73	4.49	Charnockite
BW-13	Mudicode	10°32'56"	76°18'34"	58B/6	Bore Well	50.00	18.50	110	1.04	8.24	6.16	Charnockite
BW-14	Velapaya	10°36'08"	76°11'23"	58B/2	Bore Well	40.00	13.41	110	5.35	16.30	10.04	Gneiss
BW-15	Kaiparambu	10°36'31"	76°08'30"	58B/2	Bore Well	40.00	28.35	110	8.51	15.50	11.47	Charnockite
BW-16	Peechi	10°32'13"	76°20'11"	58B/6	Bore Well	30.00	8.55	110	2.32	7.39	5.54	Charnockite
BW-17	Chittilappilly	10°33'23"	76°09'23"	58B/2	Bore Well	30.00	9.50	152	2.15	9.74	5.79	Charnockite
BW-18	Nelluvayi	10°40'35"	76°10'06"	58B/2	Bore Well	40.00	7.45	152	0.03	7.07	3.36	Charnockite
BW-19	Kandanissery	10°35'53"	76°04'56"	58B/2	Bore Well	40.00	24.39	110	15.72	33.42	22.58	Gneiss
BW-20	Aloor	10°20'08"	76°17'44"	58B/7	Bore Well	85.50	11.00	110	5.20	10.95	7.51	Gneiss
BW-21	Vellangallur	10°16'53"	76°12'52"	58B/3	Bore Well	75.00	15.00	110	2.79	9.53	5.97	Gneiss
BW-22	Wadakkancherry	10°38'24"	76°16'32"	58B/6	Bore Well	60.70	14.20	115	1.50	4.43	2.56	Gneiss
BW-23	Varavur	10°42'52"	76°12'48"	58B/2	Bore Well	69.70	8.75	115	-0.44	7.09	2.77	Gneiss
BW-24	Arthat	10°37'30"	76°03'05"	58B/2	Bore Well	70.00	16.60	115	1.30	15.78	5.27	Gneiss

quality data of these bore wells for the period 1997-2007 were collected and analyzed to study the seasonal groundwater fluctuations and quality variations in semi-confined deep aquifers of the basin.

2.4.3 River gauge/River discharge data

River gauge/River discharge data of Karuvannur and Kecheri rivers for the period of 1995 to 2005 were collected from state irrigation department, Hydrology division, Thrissur.

2.4.4 Pumping test data of bore wells

Pumping test data of 15 bore wells in the Kole land basin were collected from Kerala Samoohya Jalasechana Samithi (KSJS) project, Thrissur and State ground water department, District office, Thrissur and analyzed the data for determining the aquifer parameters in the basin.

CHAPTER 3

HYDROGEOLOGY

3.1 Introduction

Hydrogeology deals with the study of occurrence, distribution, movement and interaction of water with various geological environments. To study the water bearing, yielding and transmissive properties of the rock, an understanding of the nature of geological formations is necessary.

In the coastal area of Kerala, groundwater occurs in inter bedded sands, silts, clays and carbonate rocks deposited under alluvial beach, lagoon, estuarine and marine environments. Porosity, permeability, grain size, lithification of the sediments, sedimentary structure and texture are the factors controlling the storage and movement of groundwater in sedimentary areas.

In the crystalline area fractures and discontinuities are the most important geological structures. Most rocks posses fractures and other discontinuities, which facilitate storage and movement of fluids through them. Discontinuities like fault, dykes etc. act as barriers to groundwater flow. Main flow paths in fractured rocks are along joints, fractures, shear zones, fault and other discontinuities.

There are about 42 lakhs open wells in Kerala, of which 30 lakhs are being used to draw drinking water. Since 1983 the Ground Water Department has drilled large number of bore wells in the State. During this period Kerala also witnessed large scale private development of bore wells in all the blocks and it is estimated that there are about 1.30 lakhs bore wells in the State. In addition to the above, there are 2.20 lakhs ponds and 1.65 lakhs filter point wells in the State. Two third of population of the State depends on these wells for drinking water and irrigation. These wells are facing several problems such as (i) lowering of ground water table

(ii) quality problem due to fluoride, iron, salinity etc. and (iii) pollution due to biological contamination. Over exploitation of ground water takes place in various places of the State due to heavy withdrawal from open and bore wells and hence more and more blocks of the State become increasingly over exploited, critical and in certain cases semi critical. Industries, mineral water units and multinational companies like Coca-Cola and Pepsi are indiscriminately drawing groundwater and these results in groundwater depletion which leads to massive public protest and it is a concern of government now. It is with this objective the State Government has enacted groundwater legislation and ground water hydrology project for monitoring of water levels is started in 1996.

In the present groundwater scenario of the State, hydrogeologic component is having utmost importance and it is the most important service to be rendered to the Government and public. The regular monitoring of ground water levels is having utmost importance and it is done through the water level data collection from observation wells established in various parts of the State. Ground water resource evaluation is done by the analysis of water levels data being collected from these observation wells. Annual ground water recharge, draft and stage of development in all the blocks in the State are estimated directly from these groundwater fluctuation studies. Blocks are categorized into over-exploited, critical, semi-critical and safe based on these studies. Detailed master plan for groundwater recharge and management is also to be implemented to overcome the future ground water crisis in areas such as over exploited, critical and semi-critical areas of the state. The palaeo-lagoon (Kole land basin) in the central Kerala coast is a typical cross section of above mentioned facts. The hydrogological character of the area has depicted in the Fig. 3.1.

This chapter deals with hydrogeology, with regards to occurrence and movement of groundwater, water level fluctuations, evaluation of aquifer parameters and the groundwater resource evaluation.

3.2 Occurrence and movement of groundwater

Water, which occurs below the ground surface, is called subsurface water or groundwater. A classification of subsurface water with respect to its depth of occurrence and extend to which it saturates the soil is given in the Fig. 3.2. Depending on the degree of saturation, two depth zones can be broadly identified, i.e. the zone of aeration (vadose zone) and zone of saturation (phreatic or groundwater zone). In the vadoze zone, the intergranular space is only partially filled with water and the remaining space is being occupied by air. The zone of saturation is fully occupied with water. In an unconfined aquifer, the water table represents the upper surface of zone of saturation. Being the main source of water supply, phreatic water is of major interest for hydrogeologists.

The zone of aeration and zone of saturation are separated by a water table or phreatic surface, which is under atmospheric pressure. The water table may be either very close to the ground surface in areas of intensive recharge or may be several hundred meters deep in arid regions. Fluctuations in the water table indicate changes in groundwater storage, either due to or natural reasons or by anthropological activity. Therefore, the monitoring of water table is of importance for the management of water resources.

Most of the water is of meteoric type as it is a result of atmospheric precipitation being a part of hydrologic cycle. It is the main source of water to wells and springs. The other types water, which is more of academic interest, are connate water, juvenile or magmatic water and metamorphic water.

Juvenile water is also known as new water, as it is introduced into the hydrosphere for first time. Magmatic water is mainly of juvenile origin derived from deep seated magma or may be of shallow volcanic origin.

Connate water is the remnant of ancient water retained in the aquifers and is not in hydraulic continuity with the present day hydrological cycle. It is therefore also known as fossil water, although this term for water is a misnomer. It may be either marine or fresh water origin.

Metamorphic water or rejuvenated water is the term used for water derived from hydrous minerals like clays, micas etc. due to the process of metamorphism. It is more of academic interest rather than a source of water supply. The various genetic types of water can be distinguished on the basis of hydrochemical and isotopic data (Matthes, 1982).

3.2.1 Hydrological classification of geological formations

The occurrence and movement of groundwater depend on the geohydrological characteristics of the subsurface formations. These natural formations vary greatly in their lithology, texture and structure, which influence their hydrological characteristics. The geological formations are accordingly classified into the following types depending on their relative permeabilities.

(i) Aquifer: Aquifer is a water bearing formation or a geological structure saturated with water, which has good hydraulic conductivity to supply a reasonable quantity of water to a well or spring. Unconsolidated sedimentary formations like gravel and sand, form excellent aquifers. Fractured igneous and metamorphic rocks and carbonate rocks with cavities also form good aquifers. Generally hydraulic conductivity of an aquifer should be more than 10^{-6} m/s.

(ii) Aquiclude: A formation, which has high porosity but very low permeability or impermeable like, unfractured crystalline rock, clays and shales.

(iii) Aquifuge: It is a formation, which is neither porous nor permeable. E.g. Massive igneous and metamorphic rocks.

(iv) Aquitard: It is a formation having insufficient permeability to make it a source of water supply but allows interchange of groundwater in between adjacent aquifers due to vertical leakage. Therefore, aquitards serve as semi confining layers. Examples are those of silt, shale and kankar.

3.2.2 Types of aquifers

The lateral continuity and vertical boundaries of aquifers are often not well defined; the aquifers may be localized occurrence or may be extending over distances of several hundred kilometers. Aquifers in the great Australian basin and in the Sahara desert (Nubian sandstones) have been traced over lateral distances of several hundred kilometers.

Based on the hydraulic characteristics of confining layers, aquifers can be classified into five types:

(i Confined aquifer: A confined aquifer is overlain and underlain by a confining layer (aquiclude or aquifuge). Water in confined aquifers occurs under pressure, which is more than the atmospheric pressure. The piezometric (Potentiometric) surface, which is an imaginary surface to which water will rise in wells tapping the confined aquifer, should be above the upper surface of the aquifer, i.e. above the base of overlying confining layer. Confined aquifers, with the potentiometric surface above the land surface, support flowing wells (Fig. 3.3 & Plate 3.1). Confined aquifers may be formed under the following three types of geological conditions:

(a) Stratiform multilayered formations: They occur either as gently dipping beds, monoclines or synclines. They usually form high pressure system, viz the Cuddalore sandstones in south India.

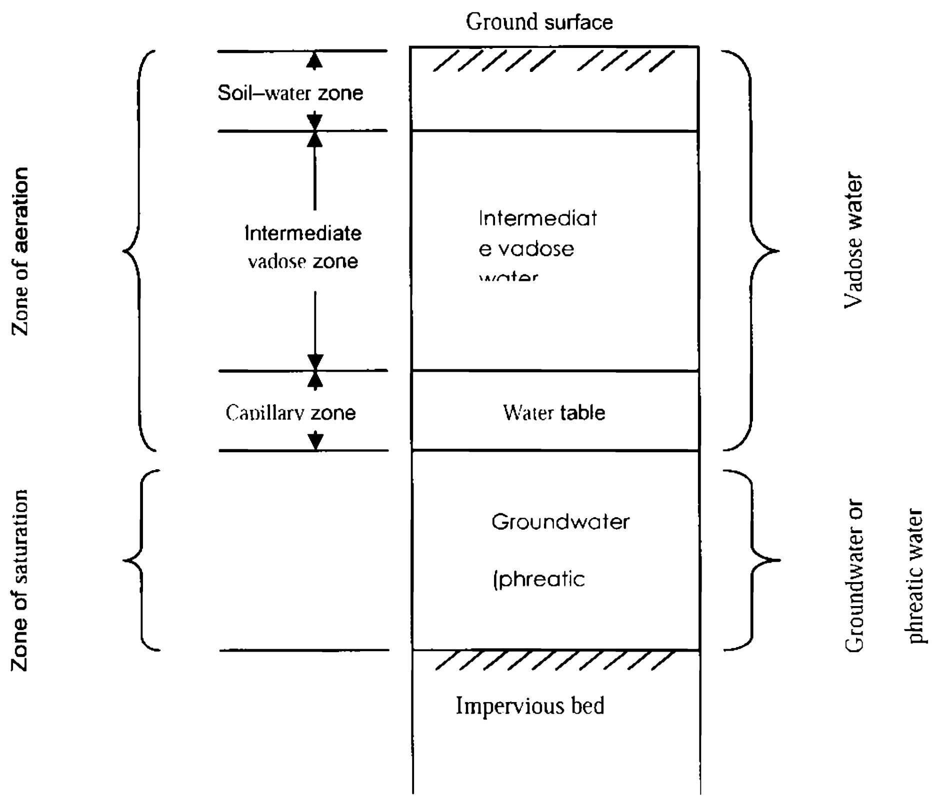


Fig. 3.2 Classification of sub surface water

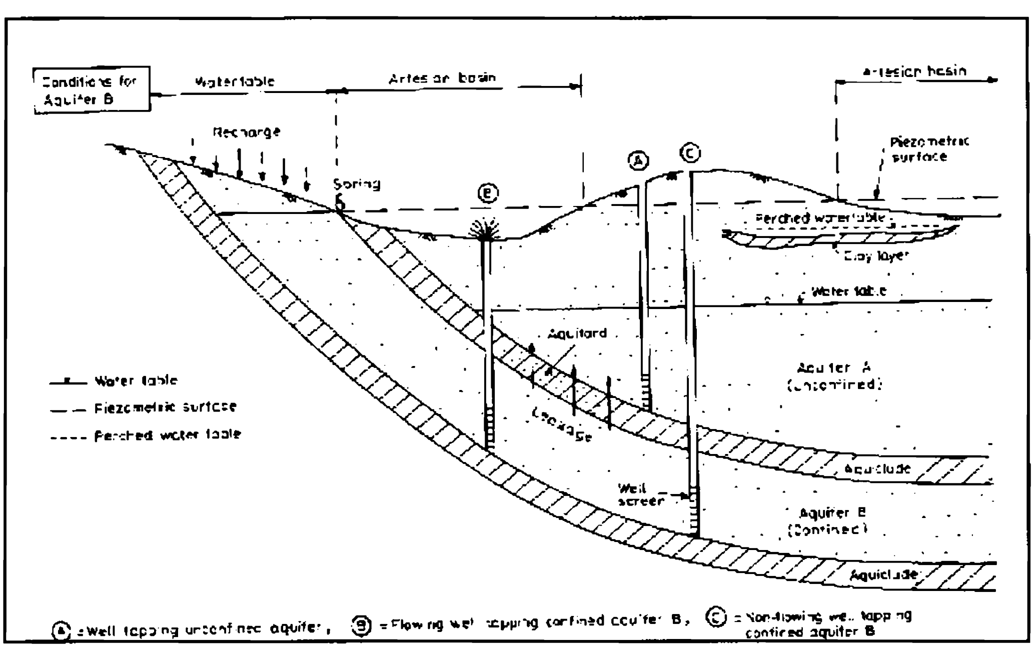


Fig. 3.3 Schematic cross section illustrating different types of aquifer

(b) Fractures and joints: In igneous and metamorphic rocks groundwater may occur under confined conditions in joints and fractures. In volcanic rocks, like the Deccan basalts of India, vesicular horizons and interflow spaces may form confined aquifers in some places.

(c) Solution cavities: Groundwater in soluble rocks, like limestone, may also occur under confined conditions.

(ii) Leaky or Semi-confined aquifer: In nature, truly confined aquifers are rare because the confining layers are not completely impervious. In semi-confined or leaky aquifers, aquitards form the semi-confining layers, through which vertical leakage takes place due to head differences across it. The aquifer is overlain by an aquitard or semi-pervious layer through which vertical leakage takes place due to head difference.

(iii) Unconfined aquifer: An unconfined or phreatic aquifer is exposed to the surface with out any intervening confining layer, but it is underlain by a confining layer saturated with water, the upper surface of saturation is termed as water table, which is under atmospheric pressure. It is recharged directly over the entire exposed surface the aquifer and gravity drainage due to pumping is not instantaneous; they show delayed drainage.

(iv) Perched aquifer: The perched aquifer is a type of unconfined aquifer separated from the main regional aquifer by localized clay lens or any impervious material in the zone of aeration (Fig.3.3). The thickness and lateral extend of the perched aquifer is controlled by the shape and size of the clay layer. A perched aquifer can be distinguished from the main unconfined aquifer, by a sudden fall of water level in the borehole during drilling, as it cuts across the underlying clay layer.

(v) Double porosity aquifer: A double or dual porosity aquifer, viz. fractured rock consists of two parts – the matrix blocks and the fractures. The blocks have low permeability but high storativity while fractures have high permeability but lower storativity.

The distinction between different types of aquifers is often difficult. It is necessary to have data about subsurface lithology, water level and hydraulic parameters of aquifer and confining layers to identify a particular type of aquifer.

3.3 Pumping test and evaluation of aquifer parameters

Pumping tests are commonly conducted for estimating hydraulic characteristics (aquifer parameters) such as transmissivity (T), coefficient of storage or storativity (S) and specific capacity (C) of the crystalline as well as sedimentary rocks of the basin. Methodologies have already explained in Chapter 2.

3.3.1 Slug test

Slug test was conducted in a low yielding bore well at Madathikkara near Irinjalakuda of Karuvannur basin. The estimated "T" value of the borewell in the area was 1.34 m^2/d.

3.3.2 Well performance test (WPT)

The step drawdown test (SDT) and aquifer performance test (APT) were used to analyse the performance of well as well as aquifer.

3.3.2a Step drawdown tests (SDT)

The data of step-drawdown test (SDT) from 18 locations (including 7 numbers conducted personally) of the basin collected from State groundwater department and KSJS were analysed. The aquifer and well parameters such as specific capacity, specific drawdown, formation loss coefficient, well loss coefficient, formation loss%, well loss% and total calculated drawdown were determined. The details of aquifer, well parameters derived by analysis of step drawdown test (SDT) of the various places of the basin are given in Table 3.1.

he specific capacity of the semi-confined aquifer of the basin varies from 3.22 lpm/m Koorkamattom-Kodassery G.P) to 208.90 lpm/m (Choolissery - Avannur G.P). The average pecific capacity of the area is 38.98 lpm/m, while the specific drawdown varies from 0.0047 m/lpm (Choolissery - Avannur G.P) to 0.4705 m/lpm (Melillam -Thekkumkara GP). The average specific drawdown of the basin is 0.072 m/lpm. The formation loss of the area varies from 0.57 m (Parappuram - Kaiparambu G.P) to 27.22 m (Kannara-Peechi), while the well loss shows a variation from 0.09 m (Kunnetheri - Erumapetti) to 23 m. (Kumaranellur-Mulloorkara G.P). The average formation loss and well percentage of the basin is 57.66 and 41.65 respectively. The formation loss of the basin varies from 18% (Gramela-Avannur) to 94% (Kannara-Peechi), while the well loss varies from 6% (Kunnetheri - Erumapetti) to 82% (Gramela-Avannur).

Fig. 3.4 shows the plot of discharge Vs specific capacity of 18 bore wells in which SDT conducted. There is an increase in specific capacity with increase in well yield. Large difference in specific capacity is noted in well located only a few hundred meters apart along the same lineament, indicating heterogeneous conditions. Higher specific capacity is due to presence of highly transmissive fracture around the well, which facilitates quick spreading of the area of influence with limited drawdown. A larger network of minor fractures in the surrounding area and the phreatic zone probably account for most of the groundwater storage. The high specific capacity may suggest an unrealistically high groundwater potential in the area (Kukillaya, 2007).

Percentage of well loss for different discharges, determined from step-drawdown tests, was plotted against the respective values of discharge (Fig. 3.9). Only those wells for which the specicfic drawdown plots formed nearly straight line were chosen. Well loss is noted to be high in majority of cases. It may be due to turbulant flow through open fractures around the well. Well with similar yield have different well losses, probably due to differnce in the scale of

fractures (Kukillaya, 2007). Turbulant flow is likely to be more around wells which encounter only a few major fractures than around wells tapping a large number of small scale fractures.

3.3.2b Aquifer performance test (APT)

Phreatic aquifer

The aquifer performance test (APT) was conducted in phreatic aquifer (dug wells) of 10 locations of the basin (including 3 numbers from KSJS and GWD) and the aquifer parameters such as specific capacity, specific drawdown, transmissivity, storativity, hydraulic diffusivity and drainage factor were determined. The details of aquifer parameters derived by analysing aquifer performance test data in various parts of the basin are given in Table 3.2.

The specific capacity of phreatic aquifer of the basin varies from 65.33 lpm/m (Adichira-Chelakkara) to 521.74 lpm/m (Paluvaya-Chavakkad). The average specific capacity of the phreatic aquifer of the basin is 247.82 lpm/m

Fig. 3.6 shows the plot of discharge Vs specific capacity of dug wells of the basin in which APT conducted. A major increase is seen in specific capacity with increase of well yield in phreatic aquifer of the basin.

The transmissivity (T) value of the phreatic aquifer of the basin varies from 20 m^2/day (Paruthipra-Mulloorkara) to 138 m^2/day (Irinjalakuda). The average transmissivity of the basin is 91.925 m^2/day. T value ranges from 20 m^2/day (Paruthipra) to 94 m^2/day (Prabhathnagar-Velur) in Jacob's -Theis's straight line method and 92 m^2/day (Prabhathnagar) to 138 m^2/day (Irinjalakuda) in Papadopulos-Cooper curve matching method. The average T value of the basin during Jacob's-Theis's and Papadioulos-Cooper are 48.85 m^2/day and 135 m^2/day respectively (Table 3.2).

Table 3.1 Details of aquifer and well parameters derived by analysing step drawdown test (SDT) data in Palaeo-lagoon (Kole land basin)

Sl.No	Location	Step	Discharge (lpm)	Drawdown (m)	Specific capacity (lpm/m)	Specific drawdown (m/lpm)	Formation loss coefficient	Well loss coefficient	Formation loss (m)	Well Loss (m)	Total calculated drawdown (m)	Formation loss (%)	Well loss (%)
1	2	3	Q	SW	Q/SW	SW/Q	B	C	BQ	CQ2	BQ+CQ2	BQ%	CQ%
1	Karoor-Alur GP	i	261.00	15.53	16.75	0.0596930	0.0423370	0.0000730	11.02	4.97	16.00	69.00	31.00
		ii	333.00	22.95	14.50	0.0689180	0.0422370	0.0000730	14.06	8.09	22.16	63.00	37.00
		iii	417.00	30.19	13.81	0.0723980	0.0422370	0.0000730	17.61	12.69	30.31	58.00	42.00
		iv	479.00	36.64	13.07	0.0764930	0.0422370	0.0000730	20.23	16.75	36.98	55.00	45.00
2	Prabhathnagar-Velur GP	i	162.00	3.66	44.26	0.0230000	0.0222000	0.0000196	3.60	0.52	4.11	87.50	12.50
		ii	257.00	6.86	37.46	0.0270000	0.0222000	0.0000196	5.71	1.30	7.00	81.50	18.50
		iii	347.50	10.03	34.65	0.0288000	0.0222000	0.0000196	7.71	2.37	10.08	76.50	23.50
		iv	451.00	15.32	29.44	0.0339000	0.0222000	0.0000196	10.01	3.99	14.00	71.50	28.50
3	Panthalloor-Pazhunnana-Chowannur GP	i	169.00	4.14	40.80	0.0240000	0.0207940	0.0000240	3.51	0.69	4.20	84.00	16.00
		ii	337.00	9.95	33.90	0.0295000	0.0207940	0.0000240	7.01	2.73	9.73	72.00	28.00
		iii	488.00	15.65	31.00	0.0321000	0.0207940	0.0000240	10.15	5.72	15.86	64.00	36.00
4	Vadakkumuri-Kadangode GP	i	181.00	4.19	43.19	0.0230000	0.0103910	0.0000650	1.88	2.16	4.04	47.00	53.00
		ii	334.00	10.31	32.39	0.0300000	0.0103910	0.0000650	3.47	7.36	10.83	32.00	68.00
		iii	491.00	20.81	23.59	0.0420000	0.0103910	0.0000650	5.10	15.91	21.01	24.00	76.00
		iv	556.00	26.48	21.00	0.0480000	0.0103910	0.0000650	5.78	20.40	26.18	22.00	78.00
5	Choolissery-Avannur GP	i	331.00	1.53	208.90	0.0047730	0.0234000	0.0000070	0.77	0.77	1.54	50.00	50.00
		ii	516.00	3.14	164.30	0.0060850	0.0234000	0.0000070	1.21	1.86	3.07	39.00	61.00
		iii	679.00	4.97	136.40	0.0073200	0.0234000	0.0000070	1.59	3.23	4.82	33.00	67.00
6	Kumaranellur-Mullorkara GP	i	63.00	7.13	8.20	0.1131750	0.0443300	0.0010500	2.79	4.17	6.96	40.00	60.00
		ii	114.00	17.98	6.09	0.1577190	0.0443300	0.0010500	5.05	13.65	18.70	27.00	73.00
		iii	148.00	30.17	4.88	0.2038510	0.0443300	0.0010500	6.56	23.00	29.56	22.00	78.00
7	Panthalloor-Chowannur GP	i	169.00	10.28	16.11	0.0608280	0.0453700	0.0000940	7.67	2.68	10.35	74.00	26.00
		ii	228.00	15.05	15.07	0.0660090	0.0453700	0.0000940	10.34	4.89	15.23	68.00	32.00
		iii	266.00	19.19	13.78	0.0721430	0.0453700	0.0000940	12.07	6.65	18.72	64.00	36.00
		iv	371.00	29.51	12.59	0.0795420	0.0453700	0.0000940	16.83	12.94	29.77	57.00	43.00

1	2	3	Q	SW	Q/SW	SW/Q	B	C	BQ	CQ2	BQ+CQ2	BQ%	CQ%
8	Kunnetheri-Erumapetti GP	i	324.00	1.57	206.57	0.0048460	0.0045220	0.0000009	1.47	0.09	157.00	94.00	6.00
		ii	483.00	2.41	200.57	0.0049900	0.0045220	0.0000009	2.20	0.21	2.41	91.00	9.00
9	Mundur-Kaiparambu GP	i	103.00	4.10	24.40	0.0398060	0.0218500	0.0001800	2.25	1.91	4.16	54.00	46.00
		ii	226.00	14.40	15.50	0.0637170	0.0218500	0.0001800	4.94	9.19	14.13	35.00	65.00
		iii	352.00	29.80	11.80	0.0846590	0.0218500	0.0001800	7.69	22.30	29.99	26.00	74.00
10	Parappuram-Kaiparambu GP	i	72.00	0.65	110.06	0.0090280	0.0079030	0.0000170	0.57	0.09	0.66	87.00	13.00
		ii	165.00	1.78	92.79	0.0107880	0.0079030	0.0000170	1.30	0.46	1.77	74.00	26.00
		iii	257.00	3.11	82.53	0.0121010	0.0079030	0.0000170	2.03	1.12	3.15	64.00	36.00
11	Choolissery west-Avannur GP	i	137.00	11.12	12.28	0.0811680	0.0351200	0.0003300	4.81	6.19	11.01	44.00	56.00
		ii	194.00	19.08	10.18	0.0983510	0.0351200	0.0003300	6.81	12.42	19.23	35.00	65.00
		iii	220.00	24.05	9.15	0.1093180	0.0351200	0.0003300	7.73	15.97	23.70	33.00	67.00
12	Gramala-Avannur GP	i	211.00	2.98	70.00	0.0141230	0.0043030	0.0000460	0.91	2.05	2.96	31.00	69.00
		ii	307.00	5.63	53.30	0.0183390	0.0043030	0.0000460	1.32	4.34	5.66	23.00	77.00
		iii	416.00	9.81	42.00	0.0235820	0.0043030	0.0000460	1.79	7.96	9.75	18.00	82.00
13	Snehapuram-Pudukkad GP	i	121.00	3.52	34.00	0.0290910	0.0211580	0.0000630	2.56	0.92	3.48	74.00	26.00
		ii	176.00	5.60	31.00	0.0318180	0.0211580	0.0000630	3.72	1.95	5.68	66.00	34.00
		iii	267.00	10.20	26.00	0.0382020	0.0211580	0.0000630	5.65	4.49	10.14	56.00	44.00
14	Palaparakunnu-Vellangallur GP	i	94.00	7.90	11.40	0.0840430	0.0696900	0.0001500	6.55	1.33	7.88	83.00	17.00
		ii	172.00	16.35	10.52	0.0950580	0.0696900	0.0001500	11.99	4.44	16.42	73.00	27.00
		iii	205.00	20.71	9.90	0.1010240	0.0696900	0.0001500	14.29	6.30	20.59	69.00	31.00
15	Koorkamattom-Kodassery GP	i	101.00	3.04	3.22	0.0300990	0.0267000	0.0000340	2.70	0.35	3.04	89.00	11.00
		ii	218.00	7.42	29.38	0.0340370	0.0267000	0.0000340	5.82	1.62	7.44	78.00	22.00
16	Melillam-Thekkumkara GP	i	16.60	4.82	4.82	0.2903610	0.1184000	0.0104000	1.97	2.87	4.83	41.00	59.00
		ii	34.00	16.00	16.74	0.4705880	0.1184000	0.0104000	4.03	12.02	16.05	25.00	75.00
17	Kannara - Panancherry GP	i	17.55	2.75	6.38	0.1566000	0.1660000	0.0006451	2.91	0.20	3.11	94.00	6.00
		ii	44.00	5.79	7.59	0.1316000	0.1660000	0.0006451	7.30	1.25	8.55	85.00	15.00
		iii	71.60	8.08	8.25	0.1212000	0.1660000	0.0006451	11.89	3.31	15.19	78.00	22.00
		iv	115.00	10.17	11.31	0.0884000	0.1660000	0.0006451	19.09	8.53	27.62	69.00	31.00
		v	164.00	41.96	3.91	0.2558000	0.1660000	0.0006451	27.22	17.35	44.57	61.00	39.00
18	Pazhoor village Rd- Velur GP	i	7.00	3.83	20.10	0.0497400	0.0387700	0.0001400	2.99	0.83	3.82	78.00	22.00
		ii	163.00	10.04	16.23	0.0615950	0.0387700	0.0001400	6.32	3.72	10.04	63.00	37.00
		iii	237.00	17.15	13.82	0.0723630	0.0387700	0.0001400	9.19	7.86	17.05	54.00	46.00

Fig. 3.7 shows the plot of discharge Vs transmissivity of dug wells in which APT conducted. A marginal increase is seen in transmissivity with increase in well yield.

The storativity (S) of phreatic aquifer of the basin was determined in Jacob's-Theis's striaght line method and Papadopulose - Cooper curve matching method. The storativity of the basin varies from 4.5 x 10^{-5} (Paruthipra-Mulloorkara) to 1.1 x 10^{-3} (Adichira-Chelakkara) in Jacob's-Theis's method and 3.4 x 10^{-5}(Padiyoor) to 5.9 x 10^{-3} (Choolissery) in Papadopulose-Cooper method respectively. The average storativity of phreatic aquifer of the basin is 1.08 x 10^{-3} (Table 3.2).

The hydraulic diffusivity of the phreatic aquifer of the basin varies from 3000 m^2/day (Adichira-Chelakkara) to 367647 m^2/day (Padiyoor). The average hydraulic diffusivity of the basin is 81491 m^2/day.

The drianage factor of the basin varies from 1.37 m (Adichira-Chelakkara) to 8.83m (Choolissery). The average drainage factor of the basin is 4.77 m. The high drianage factor shows fast drainage of the aquifer.

The optimum yield of the phreatic aquifer (dug wells) of the basin were analysed by Roamani's, (1946) method. The optimum yield values of the dug wells in the phreatic aquifer vary from 500 lph to 5000 lph in coastal plain region and in mid and high land region it varies dry to 25000 lph (Table 3.4).

Semi-confined aquifer

The aquifer performance test (APT) data of 28 locations (bore wells) of the basin (including 7 numbers conducted personally) were collected from State Groundwater Department, KSJS and CGWB were analysed. The aquifer parameters such as specific capacity, specific drawdown, transmissivity and storativity were determined. The details of aquifer parameters derived by analysing aquifer performance test data in various parts of the basin are given in the Table 3.3. The specific capacity of Semi-confined aquifer of the basin varies from 0.99 lpm/ (Padavaradu-Puthur) to 17.43 lpm/m (Thippallur-Erumapetti). The average specific capacity of the semi-confined aquifer of the basin is 34.26 lpm/m.

The Fig. 3.8 shows the plot of discharge V.s specific capacity of bore wells in which APT conducted. There is an increase in specific capacity with increase in well yield. Large differences in specific capacity are not observed like in SDT. Other characters of the aquifer are same as mentioned in SDT.

Fig. 3.9 shows the plot of discharge Vs specific drawdown of bore wells in which APT conducted. There is a decrease in specific drawdown with increase in well yield. Specific drawdown shows the inverse relation with specific capacity. The same pattern is seen in phreatic aquifer of the basin.

The trasmissivity (T) value of thesemi-confined aquifer of the basin vary from 0.38 m^2/day (Padavaradu) to 485.05 m^2/day (Choolissry). The average transmissivity of the basin is 61.05 m^2/day. T value ranges from 0.38m^2/day (Padavarau) to 485.05m^2/day (Choolissery) during pumping phase (Jacob's straight line method) and 2 m^2/day (Thuruthiparambu) to 369 m^2 /day (Choolissery) during recovery phase (Theis's recovery method). The average T value of the basin during pumping and recovery phase are 58.46 m^2/day and 63.64 m^2/day respectively (Table 3.3).

The transmissivity values of the semi-confined deep aquifer in the sedimentary area (Tube wells) vary from 22 m^2/day (West Mathilakam) to 104 m^2/day (Nattika) (Table 3.3).

Fig. 3.10 shows the plot of discharge Vs transmissivity of bore wells in which APT was conducted. There is an increase in transmissivity with increase in well yield. The high T value

Table 3.2 Details of aquifer parameters derived by analysing aquifer performance test (APT) data of phreatic aquifer (dug wells) in Palaeo-lagoon (Kole land basin)

Sl.No	Location	Discharge (m^3/d)	Distance of observation well from pumping well (m)	Maximum drawdown (m)	Jacob's-Theis's method			Papadopulose -Cooper method		Specific capacity (lpm/m)	Hydraulic diffusivity (m^2/d)	Drianage factor(m)
					Transmissivity during pumping phase (m^2/d)	Transmissivity during recovery phase (m^2/d)	Storativity	Transmissivity (m^2/d)	Storativity			
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	Prabhath nagar-Velur Gp	614.40	83.00	1.80	93.92	94.00	6.4 x 10-5	92.00	6.9x10-5	237.04	146875	6.06
2	Choolissery-Avanur GP	806.41	55.00	2.87	51.00			195.00	5.9 x 10-3	195.12		8.83
3	Madathikkara-Irinjalakuda MC	495.00		1.05				138.00	2.2 x 10-3	327.38	6273	7.43
4	Adichira-Chelakkara GP	117.60	80.00	1.25	33.00		1.1 x 10-3			65.33	3000	3.63
5	Adichira-Chelakkara	117.60	156.00	1.14	30.00		4.5 x 10-5			71.64	66667	1.37
6	Padiyoor-Padiyoor GP	1058.40		1.51				125.00	3.4 x 10-5	486.76	367647	7.07
7	Paruthipra-Mulloorkara GP	441.60	221.00	3.42		20.00	1.3 x 10-4			89.67	15385	2.83
8	Paruthipra-Mulloorkara GP	441.60	381.00	3.33		21.00	4.9 x 10-5			92.09	42857	2.90
9	Paluvaya-Chavakkad MC	345.60		0.46				125.00	3.88 x 10-4	521.74	3222	2.80
10	Edamottom-Valppad GP	345.60		0.80						300.00		

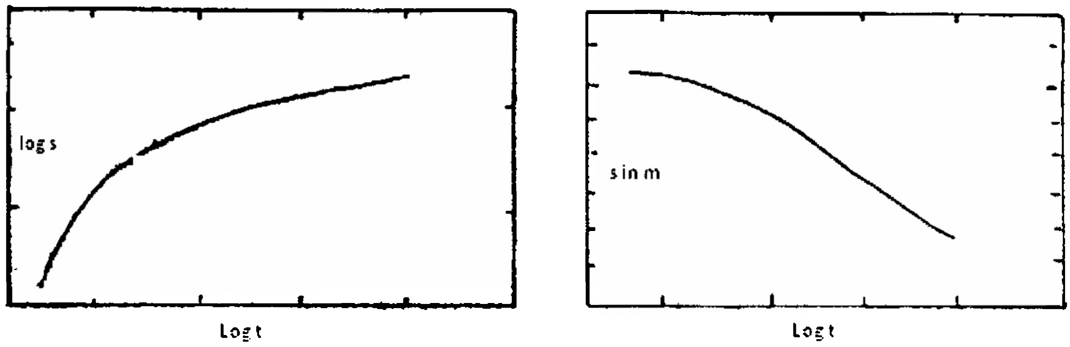
corresponding to initial flow is not only from bore well storage but also from the fractures. Heterogeneous fracture system with well connected fracture networks can behave in a manner similar to the ideal homogeneous aquifer; but this does not necessarily indicate the aquifer is an equivalent porous medium (Cohen, 1996)

The storativity (S) of semi-confined aquifer of the basin was able to determine only in two places, where the observation wells show drawdown while pumping. In other places the observation well did not show any drawdown. The storativity of semi-confined aquifers at Adichira-Chelakkara and Prabathnaga - Velur is 6.4×10^{-4} and 1.1×10^{-4} respectively. In sedimentary (tube wells) area it varies from 1.07×10^{-3} (Nattika) to 4.04×10^{-3} (Chavakkad) (Table 3.3).

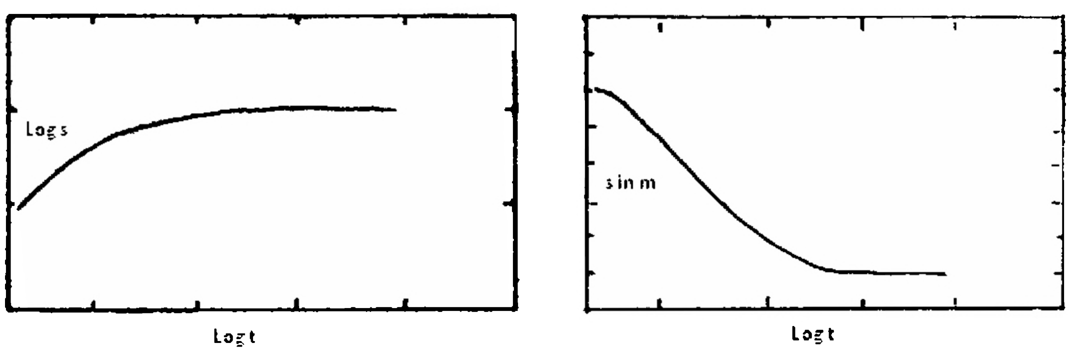
The optimum yield of the bore wells in the semi-confined aquifer varies from 1000 lph to 41700 lph. The yield of tube wells in the sedimentary area varies from 12000 lph to 115000 lph (Table 3.5 and Fig. 3.1)

3.4 Drawdown and recovery analysis

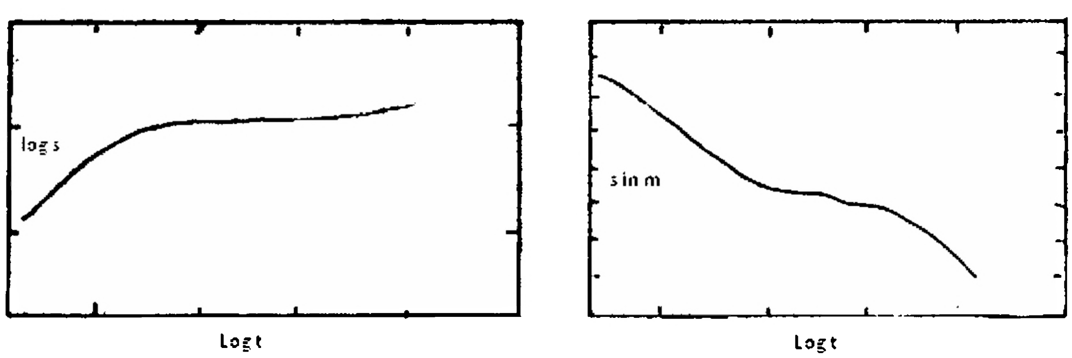
The drawdown -recovery analysis of the basin was done using the pumping test data of both phreatic (dug wells) and semi-confined deep aquifer (bore wells). Typical drawdown curves for phreatic and semi-confined aquifers under different scales are given in Fig. 3.11. Drawdown-recovery curves are prepared in normal, semi-log and log-log scale for each well and interpretations were done based on the pattern of the curve. Some of the examples are given in Fig. 3.12 (normal curve for phreatic aquifer), Fig. 3.13 (normal curve for semi-confined aquifer), Fig. 3.14 (log-log curves for phreatic aquifer), and Fig. 3.15 (log-log curves for semi-confined aquifer). The following interpretations are made for semi-confined and phreatic aquifers based on the responses evolved in the corresponding curve pattern.



(a) Time - drawdown curves for confined and unconfined aquifers



(b) Time - drawdown curves for semi-confined aquifer



(c) Time - drawdown curves for unconfined aquifer with delayed yield

Fig. 3.11a-c Time - drawdown curves for different types of aquifers (CGWB, 1982)

3.4.a Phreatic aquifer

The data of drawdown -recovery analysis of phreatic aquifer of the basin is given in Table 3.4. The maximum observed drawdown in phreatic aquifer varies from 0.46 m (Paluvaya-Chavakkad) to 3.42 m (Paruthipra-Mulloorkara). The average drawdown of the basin is 1.79 m.

The normal plot (Fig. 3.12) of drawdown-recovery data shows the percentage of drawdown in 1st minute since pumping stopped varies from 0.00 (Choolissery-Avanur) to 13 (Padiyoor). The average drawdown percentage of the basin in 1st minute since pumping started is 1.79.

The percentage of recovery in 1st minute since pumping stopped varies from 0.00 (Choolissry, Paluvaya) to 1 (Edamuttom, Padiyoor, Irinlalakuda and Prabhathnagar). The average percentage recovery of the basin in 1st minute since pumping stopped is 0.63.

3.4b Semi-confined aquifer

The data of drawdown -recovery analysis of semi-confined aquifer of the basin is given in Table 3.5. The maximum observed drawdown in semi-confined aquifer vary from 0.77 m (Thippallur-Erumapetti) to 43.05 m (Adichira-Chelakkara). The average drawdown of the basin is 16.70 m.

The normal plot (Fig. 3.13) of drawdown-recovery data shows the percentage of drawdown in 1st minute since pumping started varies from 7.2 (Padavaradu-Puthur) to 87 (Gramela-Avanur). The average drawdown percentage of the basin in 1st minute since pumping started is 38.60.

The percentage of recovery in 1st minute since pumping stopped varies from 5 (Padavaradu-Puthur) to 87 (Gramela-Avanur). The average percentage recovery of the basin in 1st minute since pumping stopped is 42.29.

The other main characters of the aquifer reflected in drawdown- recovery analysis are (i) responses similar to double porosity model, (ii) linear fracture zone with barrier (no-flow)

Table 3.3 Details of aquifer parameters derived by analysing aquifer performance test (APT) data of semi-confined aquifer (borewells) in Palaeo-lagoon (Kole land basin)

Sl.No	Location	Discharge (m^3/d)	Maximum drawdown (m)	Specific capacity(lpm/m)	Δs during pumping phase (m)	Transmissivity for pumping phase (m^2/d)	Δs during recovery phase (m)	Transmissivity for recovery phase (m^2/d)	Storativity	Drilling time yield (lph)	Remarks
A	**Crystalline terrain**					Jacob's method		Theis method		V-notch	
1	2	3	4	5	6	7	8	9	10	11	12
1	Karoor-Aloor GP	480.00	23.94	13.92	5.00	17.58	4.50	19.53		27000	
2	Thippallur-Erumapetti GP	190.08	0.77	171.43	0.50	63.87	0.23	155.27		27000	
3	Prabhathnagar-Velur GP	615.63	12.25	34.90			1.50	75.13	6.4 x 10-5	22000	No drawdown data
4	Panthalloor-pazhunnana-Chowannur GP	240.00	5.12	32.58	2.23	19.75	2.40	18.30		24750	
5	Vadakkumuri-Kadangode GP	554.00	18.42	20.89	2.60	39.00	2.85	52.00		25000	
6	Choolissery-Avanur GP	806.40	9.80	57.14	0.52	485.05	0.45	369.00		33000	
7	Kallettumkara-Aloor GP	941.76	7.90	82.78	2.83	80.66	1.69	209.00		20300	
8	Kandeswaram-Avanur GP	119.00	24.80	3.33	12.00	2.60	12.45	2.50		10000	
9	Attoor-Mulloorkara GP	171.41	24.54	4.85	4.75	6.61	12.45	2.50		7500	
10	Panthiloor-Avanur GP	389.00	20.20	13.37	5.50	12.95	7.85	9.00		12000	
11	Kunnetheri-Erumapetti GP	222.00	7.77	19.84			8.00	7.31		12000	Error in drawdown data
12	Mundur-Kaiparambu GP	310.00	23.72	13.07	5.79	14.00	5.23	15.60		15000	

1	2	3		5	6	7	8	9	10	11	12
13	Kurumal west-Velur GP	223.00	17.85	8.68	5.00	16.80	8.75	12.55		11000	
14	Parappuram-Kaiparambu GP	653.00	8.17	55.50	1.58	76.00				16000	No recovery data
15	Varadiyam-Avanur GP	226.54	3.63	43.40	2.23	105.50				41700	No recovery data
16	Choolissery west-Avanur GP	318.38	18.80	11.76	2.00	29.00	0.50	11.70		10400	
17	Gramala-Avanur GP	331.00	7.13	32.24	1.30	67.00				30000	No recovery data
18	Snehapuram-Pudukkad GP	292.90	7.65	26.59	1.00	53.64	1.65	33.00		10000	
19	Palaparakunnu-Vellangallur GP	243.29	16.84	10.03	4.54	9.81	3.80	11.70		9800	
20	Koorkamattom-Kodassery GP	511.00	23.11	15.36	7.00	13.37	4.25	22.00		14000	
21	Thuruthiparambu-Aloor GP	210.62	18.51	7.90	10.00	3.86	19.30	2.00		14100	
22	Padavaradu-Puthur GP	28.80	20.20	0.99	13.90	0.38				1000	No recovery data
23	Kannara-Panancherry GP	139.50	7.48	12.95						6000	
24	Adichira-Chelakkara GP	324.00	43.05	5.23		33.00			1.1×10^{-4}	14000	KSJS data
25	Paruthipra-Mulloorkara GP	504.00	35.76	9.79				47.00		21000	KSJS data
B	**Sedimentary terrain**										
26	Nattika-Nattika GP	2779.20	20.90	92.34		104.00			1.07×10^{-3}	115800	CGWB data
27	Chavakkad-Kadappuram GP	288.00	5.30	37.74		95.00			4.04×10^{-3}	12000	CGWB data
28	West Mathilakam-Mathilakam GP	567.36	23.50	16.77		22.00			3.19×10^{-3}	23640	CGWB data

Table 3.4 Drawdown-recovery analysis of phreatic aquifer (Dug wells) in Palaeo-lagoon (Kole land basin)

Sl.No	Location	Lattitude	Longitude	Discharge(m^3/d)	Pumping period in minutes	Drawdown (m)	Observed recovery period in minutes	% of drawdown in first 1 minute since pumping started	% of drawdown in first 1 minute since pumping stopped	Specific capacity (lpm/m)	Specific drawdown (m/lpm)
1	Prabathnagar-Velur GP	10°38'15"	76°10'30"	615.63*	2400*	1.79	720	3.00	1.00	238.84	0.004187
2	Choolissery-Avanur GP	10°34'45"	76°11'35"	806.41*	570*	2.87	137	0.00	0.00	195.12	0.005125
3	Madathikkara-Irinjalakuda Municipality	10°20'45"	76°13'30"	495	65	1.05	1440	10.00	1.00	327.38	0.003055
4	Adichira - Chelakkara GP	10°39'00"	76°18'15"	117.6		1.25				65.33	0.015307
5	Adichira - Chelakkara GP	10°38'30"	76°18'30"	117.6		1.14				71.64	0.013960
6	Padiyoor-padiyoor GP	10°19'15"	76°10'45"	1058.4	120	1.51	1440	13.00	1.00	486.75	0.002054
7	Paruthipra-Mulloorkara GP	10°41'00"	76°15'00"	221		3.42				44.87	0.022284
8	Paruthipra-Mulloorkara GP	10°40'45"	76°15'52"	381		3.33				79.45	0.012586
9	Paluvaya-Chavakkad Municipality	10°34'45"	76°31'30"	345.6	30	0.46	1440	10.00	0.00	521.74	0.001917
10	Edamuttom-Valappad GP	10°22'38"	76°07'20"	345.6	14	0.80	1440	10.00	1.00	300.00	0.003333

*Discharge of pumped well

Table 3.5 Drawdown-recovery analysis of semi-confined aquifer (Borewells) in Palaeo-lagoon (Kole land basin)

Sl.No	Location	Lattitude	Longitude	Discharge(m^3/d)	Pumping period in minutes	Drawdown (m)	Observed recovery period in minutes	% of drawdown in first 1 minute since pumping started	% of recovery in first 1 minute since pumping stopped	Specific capacity (lpm/m)	Specif drawdown (m/lpm)
1	2	3	4	5	6	7	8	9	10	11	12
1	Karoor-Aloor GP	10°20'15"	76°18'35"	480.00	1000	23.94	180	34.00	7.00	13.92	0.071820
2	Thippallur-Erumapetti GP	10°41'21"	75°10'10"	190.08	1000	0.77	180	13.00	11.00	171.43	0.005833
3	Prabathnagar-Velur GP	10°38'15"	76°10'30"	615.63	2400	12.25	720	63.00		34.90	0.028654
4	Panthalloor pazhunnana-Chowannur GP	10°39'15"	76°05'48"	240.00	1440	5.12	360	24.00	23.00	32.55	0.030720
5	Vadakkummuri-Kadangode GP	10°41'48"	76°08'15"	554.00	540	18.42	120	26.00	74.00	20.89	0.047879
6	Choolissery-Avanur GP	10°34'45"	76°11'35"	806.40	570	9.80	140	43.00	33.00	57.14	0.017500
7	Kallettumkara-Alur GP	10°20'10"	76°16'30"	941.76	1440	7.90	105	26.00	23.00	82.78	0.012080
8	Kandeswaram-Avanur	10°36'15"	76°10'30"	119.00	570	24.80	100	30.00	27.00	3.33	0.300101
9	Attoor-Mullorkara GP	10°40'15"	76°16'05"	171.41	1000	24.54	1200	29.00	40.00	4.85	0.206161
10	Panthalloor-Avanur GP	10° 40'30"	76°06'50"	389.00	1000	20.20	1200	38.00	42.00	13.37	0.074776
11	Kunnetheri-Erumapetti GP	10°41' 45"	76°10'30"	222.00	510	7.77	100	58.00	86.00	19.84	0.050400
12	Mundur -Kaiparambu GP	10°36' 00"	76°09'15"	310.00	960	23.72	1440			9.08	0.110183
13	Kurumal-Velur GP	10°37' 45"	76°09'15"	223.00	960	17.85	100	32.00	70.00	8.68	0.115265
14	Parappuram-Kaiparambu GP	10°36'30"	76°08'33"	653.00	480	8.17	454	50.00	51.00	55.50	0.018017
15	Varadium-Avanur GP	10°35'30"	76°10'30"	226.54	1320	3.63	1440	41.00	48.00	43.40	0.023042

1	2	3	4	5	6	7	8	9	10	11	12
16	Chodissery west-Avanur GP	10°35'30"	76°11'30"	318.38	300	18.80	60	42.00	55.00	11.76	0.085030
17	Gramala-Avanur GP	10°37'05"	76°11'20"	331.00	560	7.13	360	87.00	87.00	32.24	0.031019
18	Shehapuran-Pudukkad GP	10°25'15"	76°16'15"	292.90	1160	7.65	103	51.00	48.00	26.59	0.037610
19	Palaprakunnu-Vellangallur GP	10°18'40"	76°13'16"	243.29	600	16.84	180	58.00		10.03	0.099674
20	Kockamattom-Kodassery GP	10°21'15"	76°25'15"	511.00	600	23.11	160	34.00	40.00	15.36	0.065124
21	Thuruthiparambu-Aloor GP	10°20'30"	76°17'45"	210.62	480	18.51	600	22.00	26.00	7.90	0.126552
22	Padavaradu-Puthur GP	10°29'15"	76°16'45"	28.80	720	20.20	840	7.20	5.00	0.99	1.010000
23	Kannara-Pananachery GP	10°32'00"	76°20'17"	139.50	300	7.48		11.00		12.95	0.077213
24	Adchira-Chelakkara GP	10°39'00"	10°38'30"	324.00	1310	43.05	105			5.23	0.191333
25	Paruthipra-Mullookara GP	76°15'00"	10°41' 00"	504.00	1440	35.76	360			9.79	0.102171
26	Nattika-Nattika GP	10°24'45"	76°05'35"	2779.20		20.90				92.34	0.010829
27	Chavakkad-Kadappuram GP	10°35'30"	76°00'45"	288.00		5.30				37.74	0.026500
28	West Mathilakam-Mathilakam GP	10°19'15"	76°07'35"	567.36		23.50				16.77	0.059645

boundaries, (iii) connectivity of semi-confined fracture aquifer with phreatic aquifer, (iv) drawdown curve shows slope change due to heterogeneity of the aquifer (v) depth wise interconnection between fractures and (vi) apparently homogenous response during pumping (Kukillaya, 2007). More in-depth investigation and study about the mentioned responses are not done in this thesis.

3.5 Water level fluctuations and their long term behaviour

The water table of an area is mainly controlled by variations in groundwater recharge, discharge and rainfall (Todd, 1980). The configuration of water table depends upon topography, geology, climate, water yielding and water bearing rocks in the zone of aeration and saturation, which also control the groundwater recharge. The upper surface of zone of saturation is the water table. In case of wells penetrating confined aquifers, the water level represents the pressure head or piezometric level at that point. Groundwater level represents the storage position of the reservoir. The difference over a period of time in the input and output components of the storage equation is reflected as change in storage, which is expressed as:

Groundwater inflow – Groundwater out flow = Change in storage.

The groundwater inflow includes recharge from rainfall and surface water bodies, canal seepage, return flow of irrigation and subsurface inflow from adjacent areas. The groundwater outflow accounts for groundwater discharge to streams, evaporation loss from the capillary fringe, evapo-transpiration loss of groundwater from phreatophytic vegetation, extraction by pumping and flowing wells, as also subsurface out flow. Water levels reflect the cumulative effects of natural recharge - discharge conditions and withdrawal from pumpage. The principal factors controlling the water level fluctuations are recharge, groundwater withdrawal and specific yield of the aquifers.

A total of 47 network hydrograph stations are monitored in the palaeo-lagoon (Kole land basin). Out of these 23 are observation wells for monitoring phreatic or unconfined aquifers and 24 are piezometers (bore wells) for monitoring deep semi-confined aquifer of the basin (Fig. 2.1). The observation stations were monitored in every month and water level data collected. Historical data of water levels available in State Ground Water department was also collected and used for the analysis of long term groundwater level trend.

3.5a Phreatic or water table aquifer

The average water level in coastal plain region varies from 0.79 m bgl (Nattika) to 2.46 m bgl (Mathilakam). In midland and highland regions of the basin, the average water level varies from 2.73 m bgl (Mannuthi) to 10.83 m bgl (Cherpu). The minimum, maximum and average water levels of the various places of the basin for the period 1997 to 2007 are given in Table 2.1 and the well frequency for different ranges of depth to water level (m bgl) in pre and post monsoon seasons are given in Figs. 3.16a-f.

Water level contour map of the observation well stations for the pre monsoon period indicate that the average water level in the coastal area varies from 3 to 4 m bgl, whereas in the central part of the basin the water level varies from 8 to 10 m bgl. For the post monsoon period, the average water level in the coastal area varies 0.5 to 3m bgl, whereas in the central part of the basin the water level shows a variation 6 to 9 m bgl. The water table of phreatic aquifer for the period 1997 to 2007 were analysed and prepared the contour map (Fig. 3.17)

Long term behaviour of water levels: The water levels over a long term period, extending to several years, are analysed to study the long term behaviour of water table. A series of wet and dry years, in which the rainfall is above or below the normal value in an area, produce decreasing or increasing trend of water levels. Though the rainfall is not an accurate indicator for change in the groundwater levels, an approximate correlation can always be made between the trends of rainfall and water level. In over developed basins where groundwater draft exceeds recharge, a downward trend of groundwater levels may continue for many years. In areas

where groundwater recharge component exceeds the withdrawal, an upward trend of groundwater level will result.

Out of 23 observation wells monitored, all the dug wells except at Puthur (OW-20) show a rise in groundwater level (Table 3.6). The long term rise of groundwater level varies from 0.22 m/year (Chavakkad) to 0.532 m/year (Kunnamkulam (Fig. 3.18a). The long term fall of groundwater level in Puthur is 0.008 m /year (Fig. 3.18b). The long term trend of groundwater levels of dug wells in coastal plain and high land regions of the basin are shown in Figs. 3.18c-d.

3.5b Semi-confined aquifer

A total of 24 bore well (piezometer) network stations are monitored in the basin. The piezometric head is seen above ground level in Kaipamangalam beach, which is a flowing well (Plate 3.1). The average piezometric surface in other places of coastal plain region varies from 0.79 m bgl (Nattika) to 2.46 m bgl (Mathilakam). In midland and highland of the basin, the average piezometric surface varies from 2.22 m bgl (Madakathara) to 22.58 m bgl (Kandanissery). The minimum, maximum and average piezometric surface of the various places of the basin for the period from 1997 to 2007 are given in the Table 2.7 and the well frequency for different ranges of depth to water level (m bgl) in pre and post monsoon seasons are given in Figs. 3.19a - f.

Water level contour map of the bore well stations for the pre-monsoon period indicates that the average water level in the coastal area varies from 3 to 4 m bgl, whereas in the central part of the basin the water level varies from 8 to 10 m bgl. For the post monsoon period, the average water level in the coastal area varies 0.5 to 3m bgl, whereas in the central part of the basin the water level shows a variation 6 to 9 m bgl. The water table of semi-confined aquifer for the period from 1997 to 2007 were analysed and prepared the contour map (Fig. 3.25)

Long-term behaviour of water levels: Out of 24 piezometers monitored, 8 bore wells shows fall in long term groundwater level trend and remaining 16 bore wells show rise in long term groundwater level trend (Table 3.7). The long term rise of groundwater level varies from 0.016m/

year (Mattathes) to 0.352 m/year (Athani (Fig. 3.21a)). The long term fall of groundwater level varies from 0.017m/year (Tholur) to 0.173 m/year (Kandanissery (Fig. 3.21b).

The long term behaviour of water levels in the dug wells and bore wells of the basin are analysed. A falling trend in water levels during pre monsoon indicates that there is an increase in groundwater development in the area. As long as the same trend is not observed in the post monsoon water level, it is a positive indication for optimum development. A falling trend in the post monsoon indicates that the rainfall is not just insufficient to recharge the aquifer to the required level. It may be due to a falling trend of rainfall or an increase in groundwater draft or out flow. Studying both pre and post monsoon trends can identify the exact reason.

3.6 Recharge - discharge areas and grid deviation map

An area can be delineated into either recharge or discharge depending on whether water is added to or withdrawn from the zone of saturation. In the case of phreatic aquifer, the natural addition of water to the aquifer may be due to recharge from rainfall, streams, tanks, reservoirs and other surface water bodies. The natural withdrawal of water from the aquifer may be due to the vertically downward flow (leakage) to the deeper aquifers or lateral outflow or vertical upward flow to the ground surface as seepage. In the case of confined aquifers, the recharge is due to the lateral inflow from the intake area, where the aquifer is exposed, or due to the vertical leakage from the upper aquifers through the confining layers. The natural discharge, in case of confined aquifers, is the vertical flow to the upper aquifers through the confining layers due to the difference in potential head or lateral out flow down to hydraulic gradient.

Recharge area: It is interesting to note that water levels decrease with the depth of piezometer setting in recharge areas, whereas the observation well, open through out its length, shows the average fluid potential (Fig. 3.22). Water level in the tube installed in the phreatic aquifer, stands at a higher level than the piezometric level in the piezometer or bore well, installed in the deeper aquifer. Because of this difference in the fluid potentials, groundwater is directed towards bottom showing conditions of recharge from the shallow aquifer to the deeper aquifer. The water level in the recharge area are characterised by deep levels, higher fluctuation range, steep limbs in hydrograph, depth to water table increases with depth and phreatic level is higher than piezometric level.

Table 3.6 Long term trend of groundwater level in dugwells of phreatic aquifer for the period from 01.01.1997 to 01.01.2007 in palaeo-lagoon (Kole land basin)

Well	Location	Number	All data		Pre monsoon		Post monsoon	
			Water level rise (m/year)	Water level fall (m/year)	Water level rise (m/year)	Water level fall (m/year)	Water level rise (m/year)	Water level fall (m/year)
OW-1	Thrissur	75	0.088	-	0.040	-	0.01	-
OW-2	Mannuthi	80	0.111	-	0.122	-	-	0.01
OW-3	Pattikkad	82	0.050	-	-	0.007	-	0.00
OW-4	Pudukad	78	0.027	-	-	0.039	-	0.06
OW-5	Kodakara	77	0.103	-	0.041	-	0.04	-
OW-6	Irinjalakuda	76	0.145	-	0.038	-	0.05	-
OW-7	M.G.Kavu	79	0.135	-	0.085	-	0.08	-
OW-8	Ottupppara	79	0.017	-	0.013	-	0.04	-
OW-9	Chelakkara	81	0.197	-	0.141	-	0.06	-
OW-10	Kunnamkulam	81	0.532	-	0.171	-	0.37	-
OW-11	Chavakkad	77	0.022	-	0.027	-	0.01	-
OW-12	Pazhanji	79	0.151	-	0.108	-	-	0.01
OW-13	Nattika	77	0.094	-	0.048	-	0.01	-
OW-14	Edamuttom	76	0.055	-	0.028	-	0.01	-
OW-17	Mathilakam	77	0.068	-	0.003	-	0.03	-
OW-16	Engadiyur	77	0.017	-	-	0.005	0.00	-
OW-18	Vaniyampara	80	0.077	-	-	0.027	0.08	-
OW-19	Varandarappilly	77	0.128	-	0.151	-	0.14	-
OW-20	Cherpu	75	0.151	-	-	0.008	0.18	-
OW-21	Puthur	77	-	0.008	-	0.095	0.02	-
OW-22	Elavally	77	0.068	-	0.003	-	0.08	-
OW-23	Kadangode	79	0.027	-	0.008	-	-	0.08
OW-24	Wadakkancherry	76	0.119	-	0.122		0.06	

3.7 Correlation of water level with rainfall

The magnitude of the water level fluctuation depends mainly on rainfall, drainage, topography and geological conditions. Monitoring of groundwater level fluctuations and its correlation with rainfall is very important on many accounts like agricultural practices, aquifer recharge and to study droughts. Most of the groundwater assessment studies involve correlation of water table fluctuations in wells against rainfall, surface water body, construction of man made canals for irrigation purposes, artificial recharge and withdrawals from wells. According to Davis and De Weist (1960) water table fluctuations may be affected due to (i) change in groundwater storage (ii) variation in atmospheric pressure in contact with water surface in wells, (iii) deformation of aquifers and (iv) disturbance within the well, that is, minor fluctuations attributed to chemical or thermal changes in and near the well. It is a well known fact that the rainfall produces considerable effect on the water table, but an exact correlation posses problems because of (i) the rainfall, before reaching the groundwater system, is subjected to evaporation or is discharged as surface run-off or is stored in the zone of aeration (ii) contribution of recharge to the groundwater system, from rainfall, depends on the antecedent soil moisture condition, intensity of rainfall, slope of the ground surface etc. and (iii) wide variation in the effective porosity of the formation in which water table fluctuates.

The monthly average rainfalls of 16 station of the basin for the period 1981 to 2005 were analysed (Table 2.12). The relation between rainfall and water level fluctuations were analysed in both in phreatic and semi confined aquifers by preparing hydrographs for various monitoring stations of the basin (Figs. 3.26-3.28). In phreatic aquifer, monthly average rainfall and water level are used for preparing hydrographs (Figs. 3.26a - f), whereas in semi-confined aquifer, daily average rainfall and water levels are used for hydrographs (Figs. 3.27a - f). Hydrograph for monthly average rainfall and water level is also prepared to analyse the correlation of water level and rainfall in semi-confined aquifer (Figs. 3.28a - f). The best fit line for the hydrographs will bring out the secular trend of water table with time. The peaks represent the low groundwater storage whereas the valleys correspond to more groundwater storage. From the above mentioned figures it is clear that the rising water levels in both phreatic and semi-confined aquifers are closely related to increase in rainfall and vice-versa. By analysing these data, it is concluded that rainfall has a major control over the water level fluctuation in the basin.

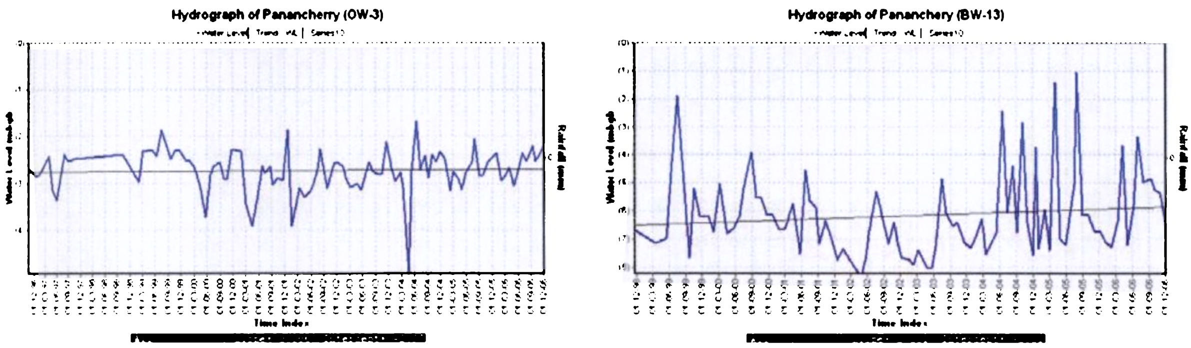
The behavior of water table with time, recharge and discharge area etc. are already explained in this chapter. The water level in recharge area is characterized by (i) deep levels, (ii) higher fluctuation range; (iii) steep limbs in hydrograph and (iv) phreatic level is higher than piezometric level.

The water level in discharge area is characterized by (i) shallow levels, (ii) low fluctuation range; (iii) gentle slope of the hydrograph and (iv) phreatic level is less than piezometric level.

The hydrographs of both phreatic and semi-confined aquifers of recharge and discharge area of the basin were analyzed and the above mentioned characteristics are proved. The water level of phreatic aquifer (dug well) of Panacherry area, a recharge area, is above the water level of semi-confined aquifer (bore well) in the same region (Figs. 3.29a &b). The water level of phreatic aquifer (dug well) of Kunnamkulam area, a discharge area, is below the water level of semi-confined aquifer (bore well) in the same region (Figs. 3.30a &b). The water level fluctuation of other areas of the basin such as Valappad, Wadakkancherry (phreatic aquifer), Nellai and Mattathur are given in the Figs. 3.31a & b.

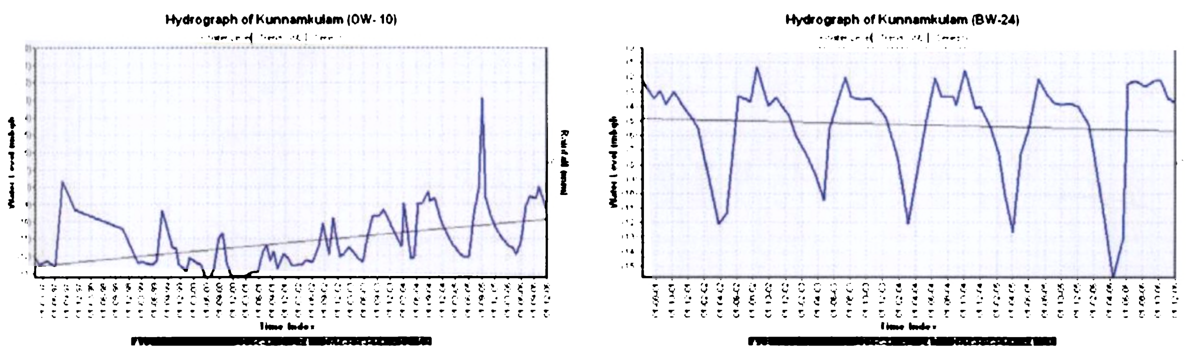
Comparison of hydrograph: A comparison of hydrograph; in an area, is useful to distinguish different groups of observation wells. A well belonging to one group shows a similar response to the recharge and discharge patterns of the area. Similar response means that the water levels in these wells start rising at the same time attains their maximum value at the same time and after recession starts, reaches its minimum value at the same time.

Estimation of groundwater recharge from well hydrograph: The annual groundwater recharge can be estimated approximately with the amount of rainfall received in an area. This method requires, however, several years of records on rainfall and water levels. An average relationship between the two factors can be established by plotting the annual rise in water level by annual rainfall. A straight line is fitted through the data points (Figs. 3.26 a & b). Once the relationship is established annual groundwater recharge can be estimated from the known annual rainfall data. Extending the straight line until it intersects the abscissa, gives the amount of rainfall below, that there is no recharge to the groundwater system.



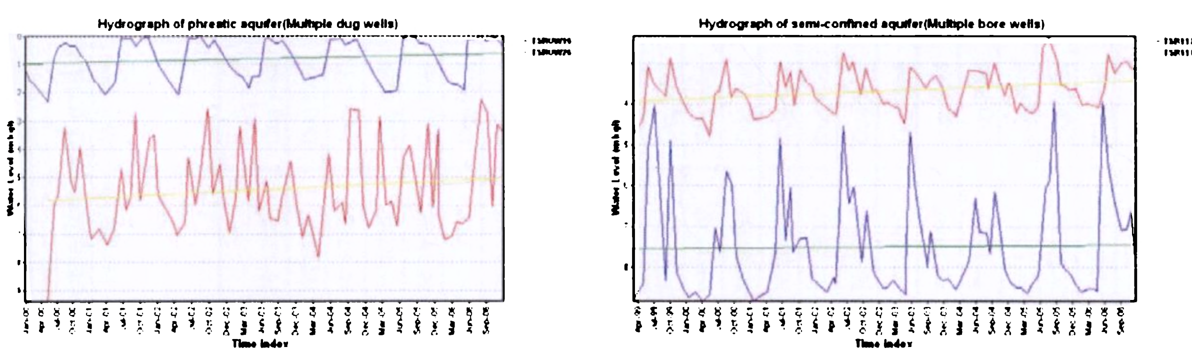
(a) Phreatic aquifer (Panancherry) (b) Semi-confined aquifer (Panancherry)

Fig. 3.29a & b Water level fluctuation in phreatic and semi-confined aquifers of recharge area in Palaeo-lagoon



(a) Phratic aquifer (Kunnamkulam) (b) Semi-confined aquifer (Kunnamkulam)

Fig. 3.30a & b Water level fluctuation in phreatic and semi-confined aquifers of discharge area in Palaeo-lagoon



----- Discharge area ----- Recharge area ----- Discharge area ----- Recharge area

(a) Phreatic aquifer (Valappad & Wadakkancherry) (b) Semi-confined aquifer (Nellai & Mattathur

Fig. 3.31a & b Comparison of water level fluctuations in phreatic and semi-confined aquifers (multiple wells) of recharge and discharge areas in Palaeo-lagoon

Table 3.8 Water level fluctuation and grid deviation computations of observation wells in the palaeo-lagoon (Kole land basin)

Well No	Location	Lattitude	Longitude	Well type	Well dia (m)	Total Depth in m(Bgl)	Mini WL in m(Bgl) 1997-07	Max WL in m(Bgl) 1997-07	Avg WL in m(Bgl) 1997-07	Fluctuation (m)	Altitude above msl(m)	Elevation of water table above	Grid deviation
OW-1	Thrissur	10°31'13"	76°13'07"	Dug Well	1.670	9.450	2.630	7.980	6.238	5.350	11.260	5.022	-11.835
OW-2	Mannuthi	10°31'53"	76°15'48"	Dug Well	2.500	7.780	1.670	4.930	2.729	3.260	16.454	13.725	-3.132
OW-3	Pattikkad	10°33'23"	76°19'56"	Dug Well	2.200	8.000	3.550	9.750	7.910	6.200	27.440	19.530	2.673
OW-4	Pudukkad	10°25'07"	76°16'18"	Dug Well	2.500	10.200	3.340	7.580	5.410	4.240	16.342	10.932	-5.925
OW-5	Kodakara	10°22'19"	76°18'19"	Dug Well	2.310	9.800	0.650	4.580	2.397	3.930	10.655	8.258	-8.599
OW-6	Irinjalakudaa	10°20'32"	76°13'11"	Dug Well	3.800	12.420	3.350	9.000	7.600	5.650	25.369	17.769	0.912
OW-7	MG kavu	10°36'00"	76°12'41"	Dug Well	4.350	11.950	2.340	5.960	3.775	3.620	31.867	28.092	11.235
OW-8	Ottuppara	10°39'53"	76°15'24"	Dug Well	2.400	6.800	0.900	7.800	3.471	6.900	30.174	26.703	9.846
OW-9	Chelakkara	10°43'38"	76°11'12"	Dug Well	2.090	7.550	2.320	7.730	5.812	5.410	33.740	27.928	11.071
OW-10	Kunnamkulam	10°38'49"	76°04'11"	Dug Well	3.650	13.250	2.680	9.370	6.591	6.690	28.474	21.883	5.026
OW-11	Chavakkad	10°34'49"	76°01'29"	Dug Well	1.620	5.350	0.600	3.260	1.750	2.660	2.606	0.856	-16.001
OW-12	Pazhanji	10°41'20"	76°03'26"	Dug Well	3.800	9.600	0.010	3.600	1.484	3.590	10.449	8.965	-7.892
OW-13	Nattika	10°25'11'	76°06'26"	Dug Well	1.650	4.300	0.000	2.300	0.794	2.300	3.525	2.731	-14.126
OW-14	Edamuttam	10°22'19"	76°07'34"	Dug Well	2.560	3.560	1.590	4.640	3.180	3.050	3.496	0.316	-16.541
OW-15	Mathilakam	10°17'30"	76°09'53"	Dug Well	2.000	4.800	1.072	4.120	2.464	3.048	4.896	2.432	-14.425
OW-16	Engadiyur	10°29'39"	76°04'04"	Dug Well	1.850	5.150	0.120	5.000	1.999	4.880	3.893	1.894	-14.963
OW-17	Vaniyampara	10°34'38"	76°24'35"	Dug Well	2.500	5.230	0.290	7.740	3.344	7.450	100.414	97.070	80.213
OW-18	Varandarappilly	10°25'18"	76°19'54"	Dug Well	2.500	10.350	3.450	9.750	6.361	6.300	20.774	14.413	-2.444
OW-19	Cherpu	10°12'53"	76°14'25"	Dug Well	3.100	15.250	5.070	14.450	10.825	9.380	16.910	6.085	-10.772
OW-20	Puthur	10°26'25"	76°12'44"	Dug Well	3.250	13.150	4.760	12.340	9.219	7.580	17.904	8.685	-8.172
OW-21	Elavally	10°28'57"	76°17'26"	Dug Well	2.600	6.900	1.550	6.820	3.606	5.270	11.267	7.661	-9.196
OW-22	Kadangode	10°34'34"	76°05'14"	Dug Well	3.270	10.190	4.690	10.170	7.234	5.480	32.980	25.746	8.889
OW-23	Wdakkancherry	10°42'07"	76°08'27"	Dug Well	4.000	8.560	3.850	8.400	6.856	4.550	37.869	31.013	14.156
										Grid or basin average		**16.857**	

The relationship between average rainfall and water level is established by analyzing hydrograph and rainfall in Karuvannur and Keecheri sub basins of the study area. The straight line equations for the data points in Karuvannur and Keecheri basins are R = 0.60P-21.8 and R = 0.81P-0.40 respectively, where R = average rise in water level and P = precipitation. Sufficient recharge of groundwater may not take place if the rainfall is below 40 mm in the basin.

3.9 Groundwater resource evaluation

Groundwater is an important resource for meeting the water requirements for irrigation, domestic and industrial uses. Groundwater is a replenishable resource but its availability is non-uniform in space and time. Hence, the sustainable development of groundwater resources warrants precise quantitative assessment based on reasonably valid scientific principles. National Water Policy, 2000 has also laid emphasis on periodic assessment of groundwater resources on scientific basis. The policy also reiterates that the exploitable quantity of groundwater should be limited to the amount, which is being recharged annually, more commonly known as dynamic groundwater resource. Technically, the dynamic groundwater refers to the quantity of groundwater available in the zone of water level fluctuation, which is active recharge zone and replenished annually. In addition to the dynamic groundwater resource, there exists a huge groundwater reservoir in the deeper zones below the active recharge zone and in the confined aquifers in areas covered by alluvial sediments of river basins, coastal and deltaic tracts constituting the unconsolidated formations. As 55% of water demand for agriculture and irrigation is met from groundwater, the development of shallow aquifers plays an important part for sustainability of tube wells. Thus, correct assessment of dynamic groundwater resource becomes significant for a planned agricultural growth.

The present work is an effort to bring the status of dynamic groundwater resource of the study area based on the methodology recommended by Groundwater Resource Estimation Committee, 1997 (GEC'97).

3.9.1 Groundwater recharge

Monsoon season: The resources assessment during monsoon season is estimated as the sum total of the change in storage and gross draft. The change in storage is computed by multiplying water level fluctuation between pre and post monsoon periods with the area of assessment and specific yield of the formation (Table 3.9). Monsoon recharge can be expressed as R = ˙h x Sy x A + D_G Where, h= rise in water level during monsoon season, A = area of computation of recharge, Sy = specific yield, D_G= gross groundwater draft during monsoon.

The monsoon groundwater recharge has two components - rainfall recharge and recharge from other sources. Mathematically it can be represented as

$$R\,(\text{Normal}) = R_m\,(\text{normal}) + R_c + R_{sw} + R_t + R_{gw} + R_{wc}$$

where, R_m is the normal monsoon rainfall recharge. The other source of groundwater recharge during monsoon season include R_c, R_{sw}, R_t, R_{gw}, R_{wc} which are recharge from seepage from canals, surface water irrigation, tank and ponds, groundwater irrigation and water conservation structures respectively.

The rainfall recharge during monsoon season computed by water level fluctuation (WLF) method is compared with recharge figures from rainfall infiltration factor (RIF) method (Table 3.10). In case the difference between the two sets of data are more than 20%, then RIF figure is considered, otherwise monsoon recharge from WLF is adopted. While adopting the rainfall recharge figures, weightage is to be given to WLF method over adhoc norms method of RIF. Hence, wherever the difference between RIF and WLF is more than 20%, data have to be scrutinized and corrected accordingly.

Non-monsoon season: During non-monsoon season, rainfall recharge is computed using rainfall infiltration factor. Recharge from other sources is then added to get total non-monsoon recharge.

Total annual groundwater recharge: The total annual groundwater recharge of the area is the sum of monsoon and non-monsoon recharge. An allowance is kept for natural discharge in the non-monsoon season by deducting 5% of total annual groundwater recharge, if WLF method is employed to compute rainfall recharge during monsoon season and 10% of the total annual groundwater recharge if RIF method is employed. Net groundwater availability = Annual groundwater recharge – Natural discharge during non-monsoon season.

Norms for estimation of recharge: GEC'97 methodology has recommended norms for various parameters being used in groundwater recharge estimation. These norms vary depending upon water bearing formations and agro-climatic conditions. The norms for specific yield and recharge from rainfall values, parameters like seepage from canals, return flow from irrigation, recharge from tanks and ponds, water conservation structures etc. are given below.

Recharge from storage tanks and ponds: 1.44mm/day for the period in which the tank has water, based on the average area of water spread. If the data on the average area of water spread is not available, 60% of the maximum water spread area may be used instead of average area of the water spread.

Recharge from percolation ponds: 50% of gross storage, considering the number of fillings, with half of this recharge occurring in the monsoon season and the balance in the non-monsoon season.

Recharge due to check dams and Nala bunds: 50% of the gross storage with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season. The norms for the estimation recharge due to seepage from different types of canals, return flow from irrigation etc. are given in Tables 3.11 and 3.12.

The groundwater recharge was computed separately for monsoon and non-monsoon season in the basin as given in methodology. The specific yield values and infiltration rates were taken as per recommended norms and wherever corrections needed were done considering field conditions and data availability. The area under command and non-command could not be separated mainly due to non availability of data. The total area of the assessment unit contains hilly areas, slopes more than 20% and areas with water bodies, which have been excluded for computing recharge (Table 3.13).

The total recharge of the basin by rainfall during monsoon and non-monsoon seasons is 305.88 MCM and 131.93 MCM respectively. Recharge from other sources such as canal, well and pond irrigation during non-monsoon season is estimated as 128.20 MCM. The total annual groundwater recharge of the basin is 566.01 MCM.

The net groundwater availability was calculated as per GEC'97 norms. From the assessment unit wise figures of recharge 10% was deducted as unaccounted losses and natural discharge if the recharge was computed based on rainfall infiltration method and 5% if the recharge was computed based on water level fluctuation method. The natural discharge such as base flow, evapotranspiration etc. of the basin during non-monsoon season is 52.99 MCM. Thus the net annual groundwater availability of the basin is 513.03 MCM. Details are given in Table 3.14.

3.9.2 Groundwater draft

The gross yearly groundwater draft is to be calculated for irrigation, domestic and industrial uses. The gross groundwater draft would include the groundwater extraction from all existing groundwater structures during monsoon as well as non-monsoon period. While the number of groundwater structures should preferably be based on latest well census, the average unit draft from dug well with pump set and bore well with pump set is 0.5 ham and 0.7 ham respectively in Kerala (Report of GEC-97).

The total draft of the basin is estimated based on census report (data on population), data of ground water abstraction structures obtained from the report of panchayat resource mapping, Thrissur district by Kerala State Land use board and the data of industries from Industries department.

The gross groundwater draft for all uses is computed as 222.09 MCM for the basin. The domestic and industrial drafts account for 28.82% of the total draft (64.01 MCM), the irrigation accounts for 71.18% of the total draft (158.08 MCM).

The net groundwater availability for future irrigation development was computed after deducting the gross draft for irrigation and allocation for domestic and industrial water supply for next 25 years from the net annual groundwater availability. A balance of 273.49 MCM is available in the basin for future irrigation development. The assessment unit wise figures are given in Table 3.15.

3.9.3 Stage of groundwater development and categorization of units

The stage of groundwater development is defined by

Stage of groundwater development (%) = (Existing groundwater draft for all uses/Net groundwater availability) x 100.

The units of assessment are categorised for groundwater development based on two criteria (i) stage of groundwater development and (ii) long term trend of pre and post monsoon water levels. Four categories identified (Table 3.16) based on the above norms (i) safe areas, (ii) semi-critical areas where cautious groundwater development is recommended, (iii) critical areas and (iv) over exploited areas where there should be intensive monitoring and evaluation and future groundwater development be linked with water conservation measures and micro level studies.

Table 3.9 Specific yield values of the geological formations (Report of GEC-1997)

SNo	Formation	Recommended value %	Minimum value %	Maximum value %
1	Sandy alluvium	16	12	20
2	Silty alluvium	10	8	12
3	Clayey alluvium	6	4	8
4	Weatherd granite, gneiss, schist with low clay content	3	2	4
5	Weatherd granite, gneiss, schist with significant clay content	1.5	1	2
6	Weathered or vescicula, jointed basalt	2	1	3
7	Laterite	2.5	2	3
8	Sandstone	3	1	5
9	Quartzite	1.5	1	2
10	Limestone	2	1	3
11	Karstified limestone	8	5	15
12	Phyllite, shales	1.5	1	2
13	Massive poorly fractured rock	0.3	0.2	0.5

Table 3.10 Rainfall infiltration factor (RIF) in different formations (Report of GEC-1997)

SNo	Formation	Recommended value %	Minimum value %	Maximumv alue %
1	Indo-Gangetic alluvium	22	20	25
2	East coast alluvium	16	14	18
3	West coast alluvium	10	8	12
4	Weathered granite, schist and gneiss with low clay content	11	10	12
5	Weathered granite, schist and gneiss with significant clay content	8	5	9
6	Granulites and Charnockite	5	4	6
7	Vescicular and jointed basalt	13	12	14
8	Weatherd basalt	7	6	8
9	Laterite	7	6	8
10	Semi-consolidated sandstone	12	10	14
11	Consolidated sandstone, quartzite and Lime stone	6	5	7
12	Phyllites, shales	4	3	5
13	Massive poorly fractured rock	1	1	3

The stage of groundwater development was computed separately for each assessment unit. Mala (91.11%), Thalikulam (83.76%), Mathilakam (77.58%) and Wadakkancherry (67.09%) are the assessment units showing maximum groundwater development in the basin. Places like Cherpu (23.83%), Kodakara (24.72%) and Puzhakkal (26.04%) show minimum groundwater development in the basin. The detailed data are given in Tables 3.15 and 3.17.

In the categorization of groundwater development, out of 14 assessment units of the basin (1690 km^2), 5 units are found to be semi-critical (712.20 km^2) and remaining 9 units are safe (977.80 km^2). The semi-critical units of the basin are Mala, Thalikulam, Mathilakam, Ollukkara and Wadakkancherry (Fig. 3.32). These units need immediate action plan for improving groundwater table and regulation of groundwater draft. The details of categorization are given in Table 3.18.

3.9.4 Allocation of groundwater resource for utilization

The net annual groundwater availability is to be apportioned between domestic, industrial and irrigation uses. Among these, as per the National water policy - 2002, the requirement for domestic water supply is to be accorded priority. The requirement for domestic and industrial water supply is to be kept based on the projected population growth of the year 2025. The water available for irrigation use is obtained by deducting the allocation for domestic and industrial uses, from the net annual groundwater availability.

The domestic and industrial needs for 2032 (25 years) were computed for each assessment unit of the basin. The total projected demand for domestic and industrial needs is worked out as 81.45 MCM. The assessment unit wise figures are given in the Table 3.15.

Poor quality of groundwater: Computation of groundwater recharge in poor quality water areas is to be done on the same line as described above. However, in saline areas, there may be practical difficulties due to non availability of data, as there will usually be no observation wells in those areas. Recharge assessment in such cases may be done based on rainfall infiltration factor method.

There is no mapable or large-scale poor groundwater quality area in the basin.

Table 3.11 Recharge due to seepage from different type canals (Report of GEC-1997)

S.No	Canal type	Recharge
1	Unlined canals in normal soils with some clay content along with sand	1.8 to 2.25 cumecs per million sq.km of wetted area or 15 to 20 ham/day/million sq.km of wetted area
2	Unlined canals in sandy soils with some silt content	3.0 to 3.50 cumecs per million sq.km of wetted area or 25 to 30 ham/day/million sq.km of wetted area
3	Lined canals and canals in hard rock areas	20% of above values for unlined canals

Note: The above values are valid if the water table is relatively deep. In shallow water table and water logged areas, the recharge from canal seepage may be suitably reduced.

Table 3.12 Recharge (as % of application) due to return flow from irrigation (Report of GEC-97)

Source of irrigation	Type of crop	Water table below ground level		
		< 10 m	10 - 25 m	> 25 m
Groundwater	Non-paddy	25	45	5
Surface water	Non-paddy	30	20	10
Groundwater	Paddy	45	35	20
Surface water	Paddy	50	40	25

Notes:

(i) For surface water, the recharge is to be estimated based on water released at the outlet. For groundwater, the recharge is to be estimated on gross draft.

(ii) Where continuous supply is used instead of rotational supply, an additional recharge of 5% of application may be used.

Table 3.13 General description of groundwater assessment units in Palaeo-lagoon (Kole land basin)

Sl.No	Name of the block	Formation type	Total area of the block (km²)	Command area (km²)	Non command area (km²)	Total area of assessment unit (km²)	Remarks
1	Chavakkad	Coastal alluvium and laterite	86.04	Nil	55.91	55.91	Assessment unit area including Guruvayoor township & Chavakkd Municipality
2	Chowannur	Laterite, coastal alluvium and crystalline rock	122.13	Nil	53.64	53.64	
3	Wadakkancherry	Laterite and crystalline rock	296.96	Nil	243.86	243.86	
4	Mullasseri	Laterite, coastal alluvium and crystalline rock	63.64	Nil	63.64	63.64	
5	Puzhakkal	Laterite, coastal alluvium and crystalline rock	145.96	Nil	158.61	158.61	Assessment unit area including Thrissur Corporation
6	Ollukkara	Laterite and crystalline rock	315.72	Nil	315.72	315.72	
7	Thalikulam	Coastal alluvium	65.68	Nil	65.68	65.68	
8	Anthikkad	Laterite, coastal alluvium and crystalline rock	72.48	Nil	72.48	72.48	
9	Cherpu	Laterite ,coastal alluvium and crystalline rock	87.11	Nil	87.11	87.11	
10	Kodakara	Laterite and crystalline rock	297.80	Nil	297.80	297.80	
11	Mathilakam	Coastal alluvium	71.81	Nil	52.55	52.55	
12	Irinjalakuda	Laterite, coastal alluvium and crystalline rock	95.49	Nil	106.73	106.73	Assessment unit area including Irinjalakuda Municipality
13	Vellangalloor	Laterite, coastal alluvium and crystalline rock	105.08	Nil	82.79	82.79	
14	Mala	Laterite and crystalline rock	126.71	Nil	34.39	34.39	
Total area of the blocks			**1952.61**				
Total area of the basin					**1690.91**	**1690.91**	

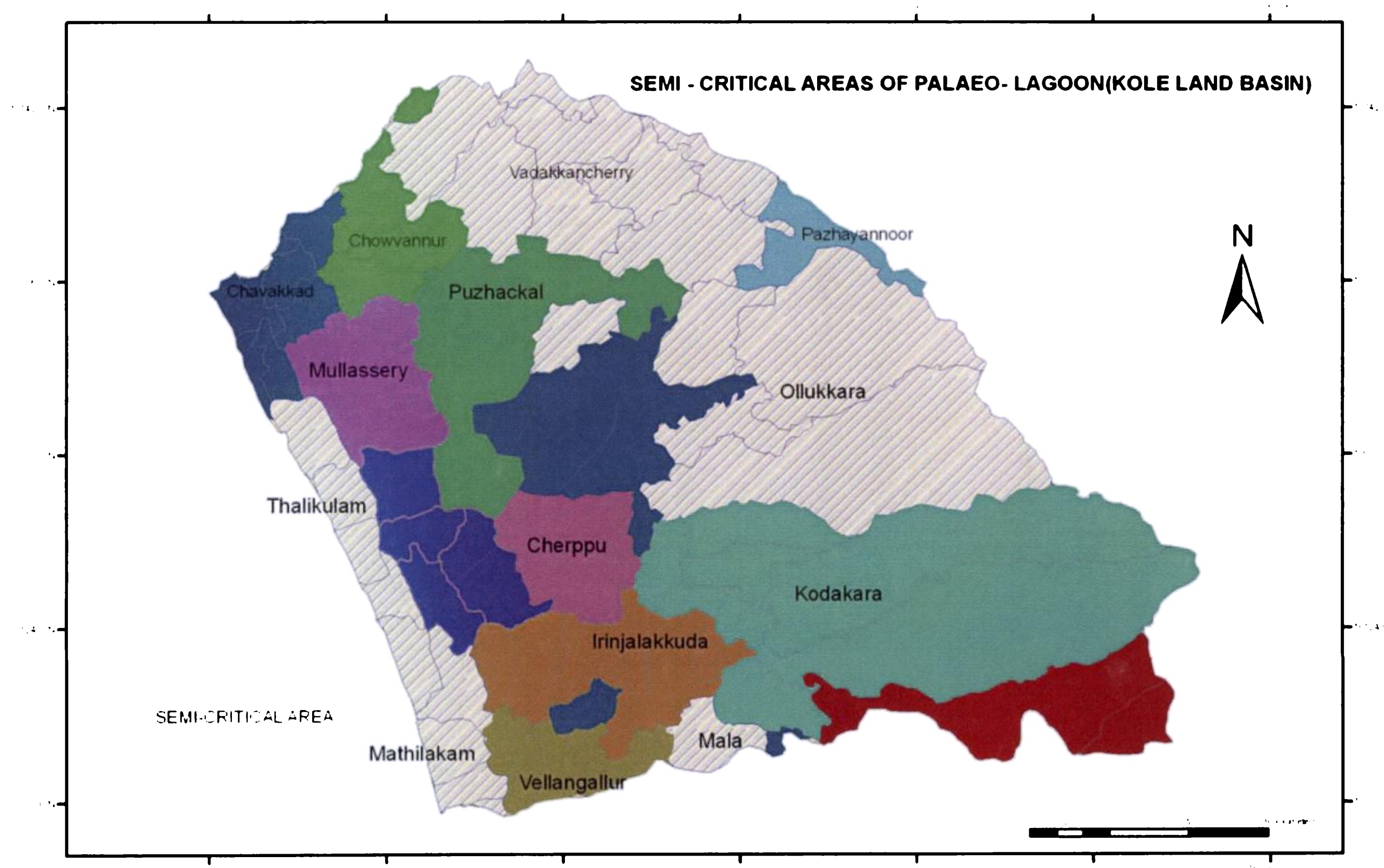


Fig. 3.32 Map showing semi-critical areas of groundwater development in Palaeo-lagoon (Kole land basin)

Apportioning of groundwater assessment from watershed to development unit: The basic unit of groundwater assessment is water shed. Later the groundwater assessment is converted in terms of administrative unit such as blocks and taluks. This is done by converting the volumetric resource into depth unit and then multiplying this depth with the corresponding areas of the block.

Additional potential recharge: In areas with shallow water table, particularly in discharge areas, rejected recharge would be considerable and water level fluctuation are subdued resulting in under estimation of recharge component. In areas where the groundwater level is less than 5 m bgl or water logged areas, groundwater resources have to be estimated up to 5 m bgl based on the equation.

Potential groundwater recharge = (5-D) x A x Sy where, D = depth to water table below ground surface in pre-monsoon season in shallow aquifer, A = area of shallow water table zone and Sy = specific yield.

The potential recharge was computed for all the assessment units underlain by coastal alluvium where the pre-monsoon water level is less than 5.0 mbgl. The potential recharge computed for the basin is 214.78 MCM (Table 3.18).

****

Table 3.14 Groundwater resource potential in Palaeo-lagoon (Kole land basin) in MCM

Sl.No	Name of the block	Command/Non command area total (km^2)	Total area of assessment unit (km^2)	Recharge from rainfall during monsoon season	Recharge from other sources during monsoon season	Recharge from rainfall during non monsoon season	Recharge from other sources during non monsoon season	Total annual groundwater recharge (5+6+7+8)	Natural discharege during non monsoon season	Net annual groundwater availability (9-10)
1	2	3	4	5	6	7	8	9	10	11
1	Chavakkad	Nil	55.91	15.22	Nil	4.86	2.79	22.87	2.29	20.59
2	Chowannur	Nil	53.64	6.57	Nil	3.04	3.86	13.47	0.67	12.80
3	Wadakkancherry	Nil	243.86	32.04	Nil	14.81	3.53	50.39	5.04	45.34
4	Mullasseri	Nil	63.64	16.74	Nil	6.21	9.60	32.55	3.25	29.30
5	Puzhakkal	Nil	158.61	36.72	Nil	11.74	32.60	81.06	8.11	72.95
6	Ollukkara	Nil	315.72	43.04	Nil	20.62	5.80	69.46	6.95	62.51
7	Thalikulam	Nil	65.68	17.21	Nil	6.40	0.00	23.61	2.36	21.25
8	Anthikkad	Nil	72.48	20.16	Nil	6.44	15.80	42.40	4.24	38.16
9	Cherpu	Nil	87.11	13.49	Nil	7.10	19.30	39.89	2.00	37.89
10	Kodakara	Nil	297.80	42.20	Nil	28.38	8.80	79.38	7.94	71.44
11	Mathilakam	Nil	52.55	14.35	Nil	4.58	0.00	18.93	0.94	17.99
12	Irinjalakuda	Nil	106.73	24.69	Nil	8.66	15.64	48.99	4.90	44.10
13	Vellangalloor	Nil	82.79	19.24	Nil	6.75	4.81	30.80	3.08	27.72
14	Mala	Nil	34.39	4.21	Nil	2.34	5.67	12.22	1.22	11.00
	Total	**Nil**	**1690.91**	**305.88**	**Nil**	**131.93**	**128.20**	**566.01**	**52.99**	**513.03**

Table 3.15 Stage of groundwater development in Palaeo-lagoon (Kole land basin) in MCM

Sl.No	Name of the block	Command area (km²)	Total area of assessment unit (km²)	Net annual groundwater availability (9-10)	Existing groundwater draft for irrigation	Existing gross groundwater draft for domestic and industrial water supply	Existing gross groundwater draft for all uses	Allocation for domestic and industrial requirement supply up to next 25 years	Net groundwater availability for future irrigation development (11-12-15)	Stage of groundwater development (14/11)*100 %
1	**2**	**3**	**4**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	Chavakkad	Nil	55.91	20.59	4.81	4.17	8.98	5.26	10.52	43.60
2	Chowannur	Nil	53.64	12.80	2.70	2.33	5.03	2.93	7.17	39.31
3	Wadakkancherry	Nil	243.86	45.34	23.44	6.98	30.42	8.97	12.94	67.09
4	Mullasseri	Nil	63.64	29.30	6.17	3.44	9.61	4.40	18.73	32.80
5	Puzhakkal	Nil	158.61	72.95	13.26	5.74	18.99	7.30	52.39	26.04
6	Ollukkara	Nil	315.72	62.51	18.61	6.34	24.95	8.31	35.59	39.91
7	Thalikulam	Nil	65.68	21.25	12.88	4.92	17.80	6.14	2.23	83.76
8	Anthikkad	Nil	72.48	38.16	10.84	4.09	14.93	5.23	22.09	39.12
9	Cherpu	Nil	87.11	37.89	5.43	3.60	9.03	4.59	27.87	23.83
10	Kodakara	Nil	297.80	71.44	9.32	8.34	17.66	10.63	51.49	24.72
11	Mathilakam	Nil	52.55	17.99	9.95	4.00	13.96	5.04	2.99	77.58
12	Irinjalakuda	Nil	106.73	44.10	20.73	5.22	25.95	6.57	16.79	58.85
13	Vellangalloor	Nil	82.79	27.72	11.39	3.37	14.76	4.24	12.09	53.27
14	Mala	Nil	34.39	11.00	8.55	1.47	10.02	1.85	0.60	91.11
	Total	**Nil**	**1690.91**	**513.03**	**158.08**	**64.01**	**222.09**	**81.45**	**273.49**	**50.07**

Table 3.16 Criteria for categorization of assessment units (Report of GEC-97)

S.NO	Stage of groundwater development	Significant long- term decline		Categorization
		Pre-monsoon	Post-monsoon	
1	<=70 %	No	No	Safe
		Yes/ No	No/ Yes	To be reassessed
		Yes	Yes	To be reassessed
2	>70 % and <=90 %	No	No	Safe
		Yes/ No	No/ Yes	Semi-critical
		Yes	Yes	To be reassessed
3	>90 % and <= 100 %	No	No	To be reassessed
		Yes/ No	No/ Yes	Semi-critical
		Yes	Yes	Critical
4	>100 %	No	No	To be reassessed
		Yes/ No	No/ Yes	Over exploited
		Yes	Yes	Over exploited

Note: "To be reassessed" means that data is to be checked and reviewed, if the groundwater resource assessment and the trend of long term water levels contradict each other. This anomalous situation requires a review of the groundwater resource computation, as well as reliability of water level data. The long term groundwater level data should preferably be for the period of 10 years.

Table 3.18 Additional potential recharge under specific conditions in Palaeo-lagoon (Kole land basin)

S.No	Assessment unit	Potential recharge in water logged and shallow water table area	Potential recharge in flood prone area	Total annual additional potential groundwater recharge
1	Chavakkad	33.98	Nil	33.98
2	Chowannur	Nil	Nil	0
3	Wadakkancherry	Nil	Nil	0
4	Mullassery	35.26	Nil	35.26
5	Puzhakkal	Nil	Nil	0
6	Ollukkara	Nil	Nil	0
7	Thalikulam	39.07	Nil	39.07
8	Anthikkad	31.74	Nil	31.74
9	Cherpu	11.78	Nil	11.78
10	Kodakara	Nil	Nil	0
11	Mathilakam	32.04	Nil	32.04
12	Irinjalakuda	6.43	Nil	6.43
13	Vellangalloor	24.48	Nil	24.48
14	Mala	Nil	Nil	0
	Total	**214.78**	**Nil**	**214.78**

Table 3.17 Categorization for groundwater development of the assessment units in Palaeo-lagoon (Kole land basin)

Sl.No	Name of the assessment unit (Blocks)	Stage of groundwater development in %	Is there a significant decline of pre-monsoon water table levels (Yes/No)	Is there a significant decline of post-monsoon water table levels (Yes/No)	Categorization for future groundwater development (Safe/Semi-critical/Critical/Over-exploited)	Remarks
1	Chavakkad	43.60	No	No	Safe	
2	Chowannur	39.31	No	No	Safe	
3	Wadakkancherry	67.09	yes	Yes	Semi-critical	
4	Mullasseri	32.80	No	No	Safe	
5	Puzhakkal	26.04	No	Yes	Safe	
6	Ollukkara	39.91	yes	yes	Semi-critical	Sharp decline in water level
7	Thalikulam	83.76	Yes	Yes	Semi-critical	
8	Anthikkad	39.12	No	No	Safe	
9	Cherpu	23.83	No	No	Safe	
10	Kodakara	24.72	No	No	Safe	
11	Mathilakam	77.58	No	Yes	Semi-critical	
12	Irinjalakuda	58.85	No	No	Safe	
13	Vellangalloor	53.27	No	No	Safe	
14	Mala	91.11	No	Yes	Semi-critical	
	Total	**50.07**				

CHAPTER 4

GEOPHYSICAL PROSPECTING

4.1 Introduction

Geophysics, as the name indicates, has to do with the physics of the earth and its surrounding atmosphere (Telford et al., 1990). Geophysics has been enjoying a long history of success in the groundwater exploration and delineation. It also addresses the solution of groundwater related problems goes by the names environmental, groundwater and near surface geophysics. The recent technological breakthrough, mainly in microprocessors and associated numerical modeling, has greatly boosted the potential of geophysical investigation (Johansen, 1975; Palacky, 1981).

Geophysical survey is necessary to ascertain the subsurface geological and hydrogeological conditions. Various physical properties employed in geophysical exploration include electrical conductivity, magnetic susceptibility, density, elasticity and radioactivity. Depending upon the scale of operations, geophysical surveys can help to delineate regional hydrogeological features and in pinpointing locations for drilling of bore wells. The proper use of geophysical techniques reduces the risk of drilling poor yield wells. It can also supplement the geological evaluation of proposed well locations. Often groundwater models are used to simulate subsurface flow for a more quantitative hydrogeological analysis of the effect of proposed water supply wells and for planning purposes in highly urbanized regions, which depend heavily on groundwater (Zohdy et al., 1974). In an area of saltwater intrusion, resulting from over pumping, geophysical techniques can provide additional data to improve the accuracy of groundwater models, which in turn can be used to determine the extent of the non-saline groundwater resource (Singh and Merh, 1982; Sathiyamoorthy and Banejee, 1985; Basak and Nazimuddin, 1987).

4.2 Resistivity of geological formations

The resistivity of geological formations varies very widely and it depends on (i) density, porosity, pore size and shape of the aquifer materials, (ii) quality of the water encountered in the aquifer, (iii) distribution of water in the rocks due to structural and textural characteristics and (iv) the temperature of the subsurface environment.

Gilkeson and Wright (1983) have found that the porous geological formations, saturated with groundwater of high ionic strength, are characterised by very low resistivity. However, low resstivity values need not always a water bearing zone. The horizontal discontinuities also show low resistivity values. It is possible that such anomaly/ discontinuity can be mistaken for water bearing zone at depth and in those cases it is necessary to carry out a detailed geophysical survey. A resistivity range from 10 to 46.8 ohm-m may be attributed to water bearing zone either a gravel or weathered/ fractured granite (Singhal and Gupta, 1999). Apparent resistivity maps and profiles are commonly used to delineate potential groundwater source (Zohdy et.al., 1974; Todd, 1980).

Bhimashankaram and Gour (1977), Patangay and Muali (1984) and Telford et al., (1990) have given comprehensive lists of resistivity values of various rock types, minerals and soils. Mooney (1980) has also given representative resistivity values for different kinds of earth materials (Table 4.1). Singhal and Gupta (1999) have given a range of resistivity values of common rocks/ materials under dry and saturated conditions (Table 4.2).

4.3 Interpretation of VES data

The resistivity distribution of 57 locations of the basin was used for the study and the results are presented in Table 4.3. The results are analyzed both qualitatively and quantitatively in the light of the available geological and hydrogeological information in order to locate groundwater potential zones.

Qualitative interpretation

The qualitative interpretation of VES is done by analyzing the apparent resistivity maps (Aravindan, 1999). This method helps in learning the general information about the geological structure and the changes in geoelectrical section of an area. Geophysical interpretation suggests a three layered sequence for the study area. The ρ_1 (resistivity of the first layer) of this basin ranges from 5 ohm-m (Vatanapilli) to as high as 3400 ohm-m (Peechi). Thickness of this layer varies from 5 to 50m. In majority of the stations, the top most layer is characterise by hard laterite capping (thickness 5 to 15 m); where the resistivity is more than 500 ohm-m of while in sedimentary area (western part) resistivity is below 500 ohm-m and the thickness varies from 5 to 50 m (Fig. 4.1). Eastern and southwestern part of the basin shows high resistivity values for the first layer. The average resistivity of this layer is 643 ohm-m.

The resistivity of the second layer (ρ_2) ranges from 25 (Pulavaya) to 1200 ohm-m (Alur) (Table 4.3; Fig. 4.2) and generally consists of weathered or fractured rocks and may or may not be saturated with water. From the iso-apparent resistivity map of the second layer, (Fig. 4.2) it is observed that a low resistivity zone is found (< 500 ohm-m) in almost all part of the basin except central and south westernern area. The thickness of this layer varies from 12 to 70 m and the average resistivity is 397 ohm -m. These areas can be correlated to a smaller extend with lineaments pattern, and to a greater extend with the optimum yield. Hence resistivity values below 500 ohm-m are considered here as potential aquifer zone for phreatic as well as semi-confined aquifers.

The very high resistivity values of the second layer (>1000 ohm-m) observed in certain areas of the basin may be due to the hard and massive nature of rock. As the basement rock of the study area is characterised by charnockites and Archean gneiss, so a resistivity limit of 200 ohm-m - 300 ohm-m is taken for groundwater development. Ramanujanachary and Balakrishna (1985) during resistivity survey in granitic terrains have stated that a resistivity range of 20-50 ohm-m relates to highly weathered layer, 50-120 ohm-m represents semi-weathered layer, 120-200 ohm-m for fractured granites and more than 200 ohm-m for jointed granite.

The resistivity of the third layer (ρ_3) ranges from 20 to 1600 ohm-m (Table 4.3: Fig. 4.3) and generally consists fractured rocks associated with major and minor lineaments and may or may not

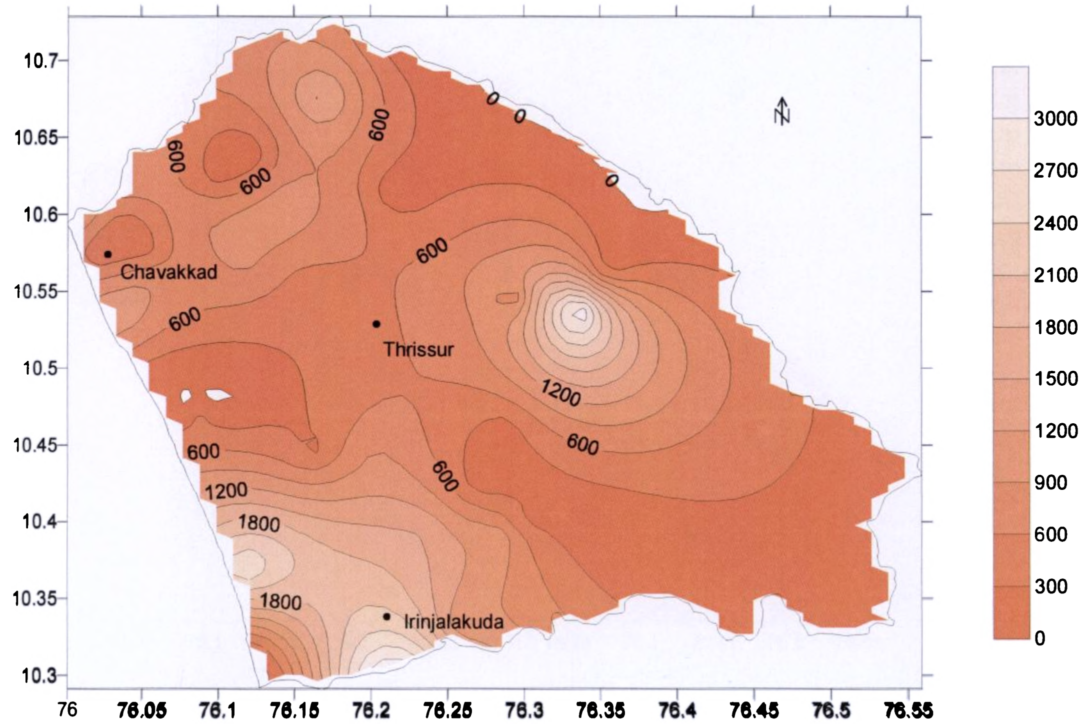


Fig. 4.1 Spatial distribution of resistivity in first layer of Palaeo-lagoon area.

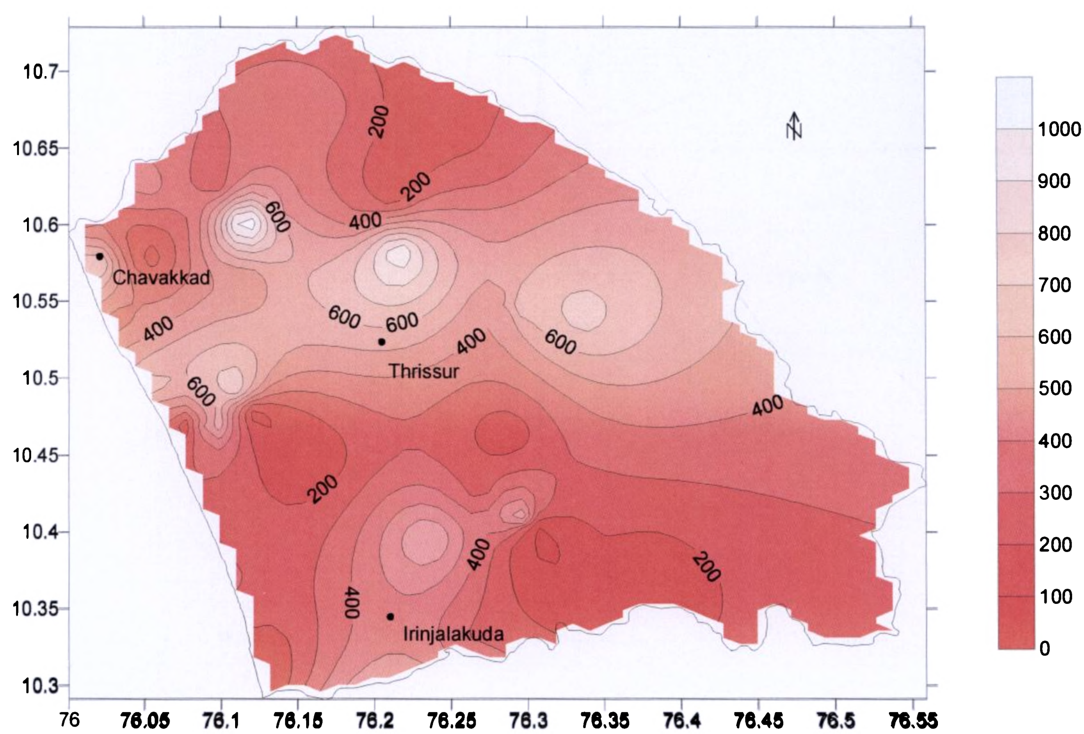


Fig. 4.2 Spatial distribution of resistivity in second layer of Palaeo-lagoon area.

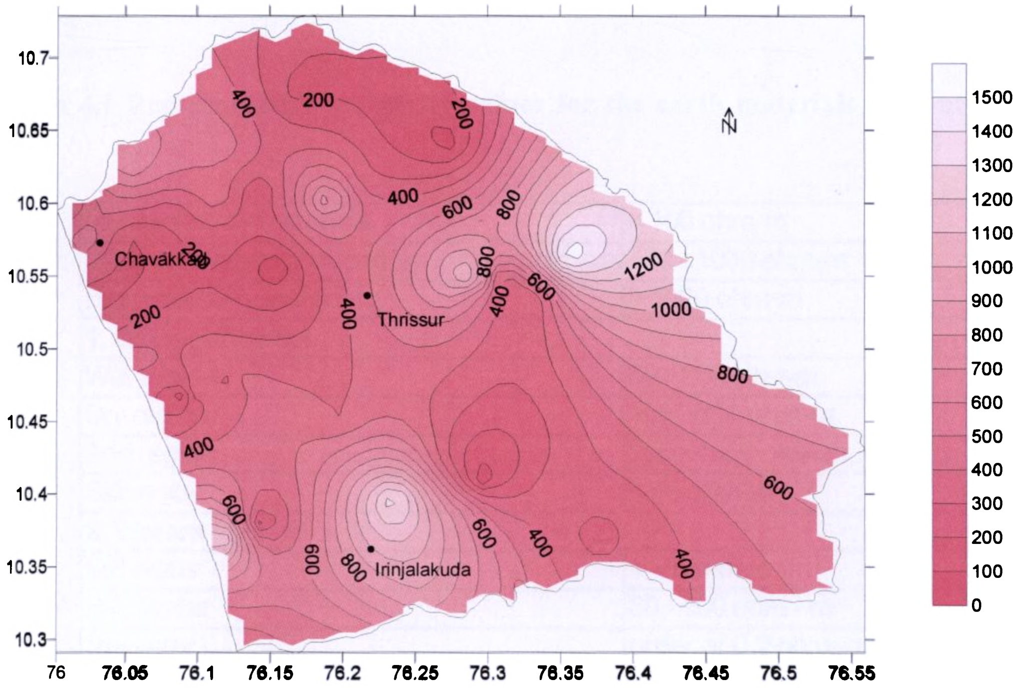


Fig. 4.3 Spatial distribution of resistivity in third layer of Palaeo-lagoon area.

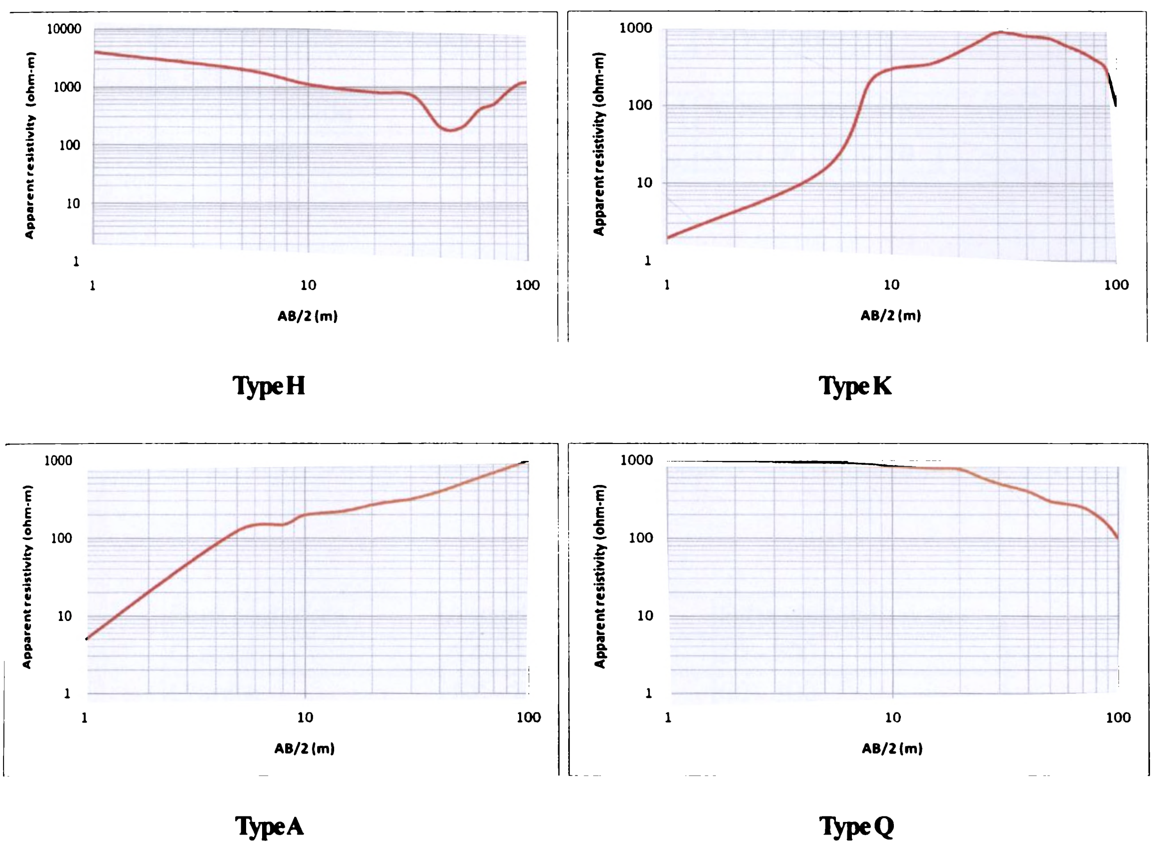


Fig. 4.4 Common type of sounding curves in three layered formation

Table 4.1 Representative resistivity values for the earth materials (Mooney, 1980)

Low resistivity materials	< 100 ohm-m
Medium resistivity matarials	100 - 1000 ohm-m
High resistivity materials	> 1000 ohm-m
1. Soil resistivitites	
Wet region	50 - 200 ohm-m
Dry region	100 - 500 ohm-m
Arid region	200 - 1000 ohm-m
Saline soil	< 50 ohm-m
2. Waters	
Soil water	1 - 100 ohm -m
Rain water	30 - 100 ohm - m
Seawater	order of 0.2 ohm - m
Ice	105- 108ohm - m
3. Rock types below water table	
Igneous and metamorphic	100 - 10000 ohm - m
Consolidated sediments	10 - 1000 ohm - m
Unconsolidated sediments	1 - 100 ohm - m
4. Ores	
Massive suphide	10?4to 1 ohm - m
Non metallic	order of 10^{10} ohm - m

Table 4.2 Range of resistivity values (ohm-m) of common rocks (Sighal and Gupta, 1999)

Rock materials	Almost dry	Saturated with water
Quartzite	4.4 x 10^3 - 2 x 108	50 - 500
Granite	10^3 - 108	50 - 300
Limestone	600 - 107	50 - 1000
Basalt	4 x 104- 1.3 x 108	10 - 50
Gneiss	6.8 x 104- 3 x 108	50 - 350
Sand	150 - 2 x 10^3	10 - 100

be saturated with water. The average resistivity of this layer is 414 ohm-m. This zone is confined to crystalline rocks. The low resistivity values, below 50 ohm-m, are seen in the western part in the places such as Chittilapilli, Venkidangu etc. and is due to the occurrence of brackish water in fractured hard rock aquifers of the area which is in contact with sea (Kukillaya et al., 2004).

Quatitative interpretation

The two geoelectrical parameters used in this computation are resistivity (ñ) and thickness (h) of layer. In the case of two layered ground surface, the simplest sounding curves are the ascending and descending types. An ascending type curves ($p_1 < p_2$) is characterised by either topsoil or weathered layer followed by hard compact basement and designated as resistive basement. In descending type curve ($p_1 < p_2$), a compact top layer is overlain by a thick layer of clay or saline water aquifer and is called conductive basement.

In three layered ground surface, four types of sounding curves are possible (Fig. 4.4). If ρ_1, ρ_2 and ρ_3 are resistivities of three successive layers from surface, the possible sounding curves are A type ($\rho_1 < \rho_2 < \rho_3$), Q type ($\rho_1 > \rho_2 > \rho_3$), H type ($\rho_1 > \rho_2 < \rho_3$) and K type ($\rho_1 < \rho_2 > \rho_3$). A type curve is obtained in typical hard rock terrain having a thin conductive top soil and there fore the resistivities of the layers continuously increase with depth. A sounding curve with continuously decreasing resistivity is called Q type and such curves usually obtained in coastal areas where saline water predominates. H type curves are obtained generally in hard rock terrains consisting of dry top soil (first layer) of high resistivity followed by either a water saturated or weathered layer of low resistivity and then a compact hard rock of very high resistivity at the bottom. Sounding curves of K type show a maximum peak flanked by a low resistivity values. Such curves are obtained in basaltic areas, where compact and massive traps exist between top soil and bottom vescicular basalt. In coastal areas also these types of curves will be encountered due to the fresh water aquifer occurring in between clayey layers at the top and saline zone in the bottom.

Table 4.3 Analysed vertical electrical sounding (VES) data of the Palaeo-lagoon (Kole land basin)

Sl.No	Location	Lattitude	Longitude	h_1* (m)	h_2 (m)	h_3 (m)	h_4 (m)	ρ_1* (ohm-m)	ρ_2 (ohm-m)	ρ_3 (ohm-m)	ρ_4 (ohm-m)	Curve type
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Kaduppasserry	10°19'53"	76°15'26"	3	30	21		970	300	890		H
2	Matthathur	10°22'26"	76°22'24"	9	31	20	65	85	105	250	550	A
3	Nellayi	10°23'24"	76°17'03"	4	26	70		1100	240	650		H
4	Tholur	10°34'00"	76°07'30"	15	25	60		950	400	230		Q
5	Thrikkur	10°27'49"	76°17'17"	6	14	30	60	200	110	310	750	H
6	Choondal	10°37'30"	76°05'58"	12	33	75		150	235	500		A
7	Madakkathara	10°32'42"	76°17'25"	15	35	50		350	700	1050		A
8	Panancherry	10°33'47"	76°21'15"	15	35	50		205	670	1600		A
9	Kolazhi	10°35'03"	76°12'55"	6	14	30	75	525	1025	450	1028	K
10	Athani	10°36'53"	76°12'48"	12	28	20	60	85	140	350	575	A
11	Chengaloor	10°24'15"	76°18'01"	20	30	70		165	80	200		H
12	Mupliyam	10°24'02"	76°21'08"	30	40	30		110	220	400		A
13	Mudikode	10°32'56"	76°18'34"	15	45	40		1800	670	325		H
14	Velapaya	10°36'08"	76°11'23"	25	25	50		720	350	900		Q
15	Kaiparambu	10°36'31"	76°08'30"	20	40	40		1100	475	190		Q
16	Peechi	10°32'13"	76°20'11"	15	15	40	30	3400	748	360	650	H
17	Chittilappilly	10°33'23"	76°09'23"	20	40	40		450	600	20		K
18	Nelluvayi	10°40'35"	76°10'06"	10	10	40	40	1600	375	160		Q
19	Kandanissery	10°35'53"	76°04'56"	20	60	40		900	320	260		Q
20	Aloor	10°20'08"	76°04'26"	10	30	60		1100	450	190		Q
21	Vellangallur	10°16'53"	76°12'52"	10	15	75		450	750	350		Q
22	Varavoor	10°42'52"	76°12'48"	8	17	25	50	80	151	230	550	A
23	Arthat	10°37'30"	76°03'05"	15	45	40	10	900	475	700	25	H
24	Wdakkancherry	10°38'24"	76°16'32"	30	20	20	30	130	225	60	350	K
25	Pudukad	10°25'25"	76°16'10"	25	45	30		140	250	350		A
26	Vellanikkara	10°32'30"	76°17'15"	10	40	80		975	430	650		H
27	Chiranellur	10°38'20"	76°07'15"	25	40	45		30	380	550		A

1	2	3	4	5	6	7	8	9	10	11	12	13
28	Alur	10°36'05"	76°06'55"	10	40	75	75	950	1200	450	1350	K
29	Vellanikkara	10°32'30"	76°17'10"	10	70	80		900	425	900		H
30	Vellanikkara	10°33'10"	76°17'00"	20	30	75	75	1200	450	1100	570	H
31	Nattika	10°24'30"	76°05'45"	20	40	40		375	750	20		K
32	Edakazhiyoor	10°36'00"	76°00'30"	8	12	30	70	950	260	60	450	Q
33	Maruthiyoor	10°33'28"	76°03'00"	8	14	45	75	900	265	75	500	Q
34	Vattekkad	10°32'17"	76°02'00"	8	12	30	70	1200	255	60	450	Q
35	Kadappuram	10°32'16"	76°01'30"	8	12	30	70	1100	275	60	450	Q
36	Kaipamangalam	10°19'00"	76°07'30"	30	50	50		16	90	450		A
37	Guruvayoor	10°35'30"	76°02'17"	50	50	30		27	160	300		A
38	Mathilakam	10°17'55"	76°08'15"	50	50	30		27	155	350		A
39	Chittilapilli	10°28'05"	76°05'20"	14	40	40		445	600	25		K
41	Kanjani	10°28'45"	76°07'00"	6	54	40		11	45	240		A
42	Vatanappilli	10°28'10"	76°05'00"	40	10	50		5	50	150		A
43	Irimbranellur	10°00'30"	76°07'30"	20	40	40		450	55	20		Q
44	Venkitangu	10°01'00"	76°05'45"	6	14	40	40	150	25	100	45	H
45	Kandasamkadavu	10°28'15"	76°05'45"	15	25	20	40	39	750	390	15	K
46	Manaloor	10°29'30"	76°06'45"	14	23	22	40	45	800	375	20	K
48	Engadiyoor	10°29'37"	76°03'25"	17	25	20	40	40	657	350	25	K
49	Chavakkad	10°34'30"	76°01'10"	15	25	20	40	43	775	400	15	K
50	Pulavaya	10°34'37"	76°03'07"	6	15	40	40	150	25	100	45	H
51	Edathuruthi	10°21'45"	76°08'30"	25	25	30	20	2200	250	170	800	Q
52	Edamauttam	10°22'08"	76°07'00"	40	10	20	30	2750	300	1300	450	H
53	Kattoor	10°27'00"	76°12'00"	15	45	55		900	260	400		H
54	Alappad	10°26'37"	76°09'45"	8	32	60		250	115	490		H
55	Eravu	10°28'45"	76°07'53"	8	35	60		250	130	420		H
56	Cheloor	10°14'30"	76°12'00"	5	15	70		550	1100	440		A
57	Thottippal	10°23'45"	76°14'08"	6	20	40	40	1450	750	1400	350	H

h*: thickness of layer

ρ*: resistivity

The different layer thickness and apparent resistivity values obtained from the 57 VES stations are given in Table 4.3 along with the curve types (Fig. 4.4). The percentage of curve types in the area are 35% (H type), 26% (A type), 21% (Q type) and 18% (K type) respectively. The common curve types in the coastal plain area are Q and A type while in mid and highlands is H and A type. Curve pattern of the coastal plain area shows the occurrence of fresh groundwater in between layers. This is agreeing with the finding of CGWB that the occurrence potable water is in Viakom formation of the coastal area.

4.4 Groundwater prospecting zone based on resistivity analysis.

The main groundwater prospecting zones of the study area are (i) sedimentaries in the west and (ii) laterites and crystalline rocks in the east of palaeo-lagoon. Coastal area of the basin is suitable for tube wells, filter point wells and shallow dug wells. Here ground water occurs in phreatic condition as well as semi- confined conditions. The low resistivity values of the first layer of the area indicates the occurrence of thick clay layer (20 to 30 m thickness) over saturated porous media which is underlain by crystalline basement. The midland region, being covered with laterites, is suitable for large diameter dug wells with moderate to high yield. Highlands are desirable for constructing low yielding dug wells. The north, northeast and southeast portion of the basin is very much suitable to moderate to high yielding bore wells. Here the groundwater occurs as three layered sequence (i) overburden portion (10 to 20 m thick) including clay and laterite above crystalline rock (first layaer), (ii) between 30 and 50 mbgl (fractured rock; second layer) and (iii) between 60 and 90 m bgl (third layer). Over abstraction of groundwater from borewells in places like Chitilapilli, Velapaya, Arthat , Puzhakkal, Penagam etc. may cause to saline water incursion through the fractures connected to brackish water.

CHAPTER 5

HYDROGEOCHEMISTRY

5.1 Introduction

The quality of groundwater has equal importance as the quantity and this has been recognised only a couple of decades ago. The characteristics of groundwater (hard or soft; mineralized or non mineralized) depend on the extent of reactions it made with the country rock (Edmunds, 1994). At this juncture it is important to know the mineral characteristics of the country rock, which will vary from place to place. Therefore, an understanding of the various geochemical processes, which control the groundwater quality, should form the starting point while conducting hydrogeological investigations and other applied studies. The natural chemistry of ground water can often has an important bearing on human health and on livestock. A detailed analysis of major, minor and trace constituents (including organic) of groundwater is a prerequisite while commissioning public water supply system. Various international bodies such as the World Health Organization (WHO), European Economic Community (EEC) and Bureau of Indian Standards (BIS) have given certain standards for drinking water. For hydrogeologist, an understanding of the geochemical characteristics of groundwater system is very important in determining the physical properties of flow system. Hydrochemical data can help to estimate such properties like the amount of recharge, the extent of mixing, the circulation path ways, maximum circulation depth, temperature at depth and residence time of groundwater (Edmunds, 1994).

The type and concentration of salts in groundwater depends on the geological environment and movement of groundwater (Raghunath, 1987). Generally, high concentration of dissolved constituents is found in groundwater than in surface water because of its greater exposure to soluble minerals of the geological formations (Todd, 1980). Bicarbonates, which are the primary anion in groundwater, are derived from carbon dioxide released by organic decomposition in soil (Langmur, 1997. Groundwater passing through igneous rocks dissolves only a very small quantity of mineral matter because of the relative insolubility of the rock composition (Todd, 1980). The average chemical composition of different rocks (igneous, sedimentary and carbonate rocks) and groundwater (Chebotarev, 1950; Hem, 1959) are given in Table 5.1 while the source of various ions in water (Hem, 1959) are given in Table 5.2.

Table 5.1 Average chemical composition (mg/l) of three major rock types and groundwater (after Chebotarev, 1950; Hem, 1959)

Constituents	Igneous rocks	Sandstone	Carbonates	Groundwater
SiO_2	285000	35900	34	1 to 30
Al	79500	32000	8970	1 to 2
Fe	42200	18600	8190	0 to 5
Ca	36200	22	272000	10 to 200
Mg	17600	400	45300	1 to 100
Na	28100	8100	393	1 to 300
K	25700	13200	2390	1 to 20
Sr	368	28	617	< 10
HCO_3	-	-	-	80 to 400
SO_4	-	-	-	10 to 100
Cl	200	150	-	1 to 150
Fe	715	220	112	0.1 to 2
Br	2.4	1	606	< 0.5
Br	7.5	90	16	< 2
TDS				100 to 1000

Table 5.2 Various sources of ions in water (Hem, 1959)

Major ions (> 1 mg/l)	Sources
Calcium Ca^{2+}	Carbonate, gypsum
Magnesium Mg^{2+}	Olivine, pyroxene, amphibole
Sodium Na^{+}	Clays, feldspars, evaporates, industrial waste
Pottassium K^{+}	Feldspar, fertilizers, K-evaporates
Bicarbonate HCO_3^-	Soil and atmospheric CO_2, carbonates
Chloride Cl^-	Windborne, rainwater, seawater and natural brines, evaporate deposits, pollution
Sulphate SO_4^{2-}	Gypsum and anhydrite, sea water, windborne, oxidation of pyrite
Nitrate NO_3^-	Windborne, oxidation of ammonia or organic nitrogen, contamination
Silica, SiO_2	Hydrolysis of silicates
Minor ions (1 to 0.1 mg/l)	
Iron Fe^{2+}	Oxides and sulphides (e.g. hematite and pyrite), corrosion of iron pipes
Manganese Mn^{2+}	Oxides and hydroxides
Boron B	Tourmaline, evaporates, sewage, seawater
Fluoride F^-	Flourine-bearing minerals (e.g. fluorite, apatite)
Trace elements (< 0.1 mg/l)	
As	Arsenic minerals (e.g. arsenopyrite, arsenic insectisides)
I	Marine vegetation,evaporates
Zn	Shalerite, industrial waste
Heavy metals (Hg, Pb, Cd, Cr)	Industrial waste and igneous rock weathering, under mild reducing conditions
Radioactive elements (U, Ra etc.)	Uraniferous minerals, nuclear tests and nuclear power plants

5.2 Quality criteria for various uses

The quality of water from different sources like rivers, streams, ponds, lakes, wells, etc. are assessed to ascertain its suitability for different uses. The major uses of water are for drinking and other domestic purposes, agricultural, recreational and industrial purposes. Water for drinking and other domestic purposes should be safe, palatable and aesthetically appealing. It should be free from pathogenic organisms, hazardous chemical and radioactive substances and objectionable colour, odour and taste. In order to understand the status and suitability of any water source, certain guidelines are proposed by competent authority as water quality standards. These standards vary according to different purpose of end use. The chemical constituents in groundwater determine its usefulness for domestic, industry and agricultural purposes. It is also essential to ensure that various constituents are within the prescribed limits in drinking water supplies to avoid adverse impact on human health. It is widely recognized that the man, life forms and the domestic animals are affected by alteration in water quality due to natural or anthropogenic reasons. Like wise, the quality of irrigation water for agricultural use should be such that it does not impair plant growth or adversely affect the productivity of the land. The water quality standards for some important uses such as domestic, irrigation, industry etc. and the likely adverse impacts are shown in Tables 5.3, 5.4 and 5.5 respectively.

The quality criteria depend on the use of water for a particular purpose and quality standards have to be maintained in water supply for different uses to avoid deleterious effects. Hence in this study an evaluation of groundwater of the basin for domestic, irrigational and industrial purposes is made. Groundwater samples collected from 23 dug wells (phreatic aquifer) and 24 bore wells (semi-confined deep aquifer) during pre and post - monsoon periods were analysed for physical parameters, major cations and anions, fluoride, total iron and total hardness (as CaCO3). The results are given as Tables 5.6 and 5.7 in appendix I.

5.2.1 Hydrochemical characteristics of groundwater and evaluation for domestic use

As groundwater is mainly used for drinking and other domestic purposes, a detailed chemical analysis is very much important, as although certain chemical constituents became toxic beyond particular

Table 5.3 Water quality standards for drinking purposes (BIS 10500)

S.No	Parameters	Prescribed limits IS 10500, 1999		Probable effects (if present in higher concentration)
		Desirable limit	Permissible limit	
1	Color (Hazen Unit)	5	25	Makes water aesthetically undesirable
2	Odour	Essentially free from objectionable odour		Makes water aesthetically undesirable
3	Taste	Agreeable		Makes water aesthetically undesirable
4	Turbidity (NTU)	5	10	High turbidity indicates contamination/ Pollution
5	pH	6.5	8.5	Indicative of acidic or alkaline waters, affects tase, corrosive and the harmful for water supply system
6	Hardness as $CaCO_3$ (mg/l)	300	600	Affects water supply system (scaling), excessive soap consumption, calcification of arteries. It may also cause urinary concretions, diseases of kidney or bladder and stomach disorder
7	Iron (Fe) (mg/l	0.30	1.00	Gives bitter, sweet & stringent taste, causes staining of laudry and porcelain. In traces it is essential for nutirition.
8	Chloride (Cl) (mg/l	250	1000	Harmful for people suffering from diseases of heart or kidneys. Taste, indigestion, palatability etc. are affected.
9	Total Dissolved Solids (TDS) (mg/l)	500	2000	Palatability decreases, may cause gastrointestinal irritation in human, laxative effect particularly upon transits and corrosion, may damage water system.
10	Calcium (Ca) (Mg/l)	75	200	Essential for nervous and muscular system, cardiac functions and in coagulation of blood. Causes encrustation in water supply system. While insufficiency causes severe type of Rickets, excess concentration causes concretions in the body organs like kidney or bladder stones and irritation in urinary passages.
11	Magnesium (Mg) (mg/l)	30	100	It is essential as an activator of many enzyme systems. High concentration however may have laxative effect particularly on new users. Magnesium deficiency is associated with structural and functional changes.
12	Copper (Cu) (mg/l)	0.05	1.50	Essential and beneficial element in human metabolism. Deficiency results in nutritional anemia in infants. Large amount may result in liver damage and affect central nervous system. In water supply it enhances corrosion of aluminium in particular.

13	Supphate (SO_4) (mg/l)	200	400	Causes gastro intestinal irritation. Along with Mg or Na can have a cathartc effect on users, concentration more than 750 mg/l may cause laxative effect along with magnesium.
14	Nitrate (NO_3) (mg/l)	45	100	cause infant methanoglobanaemia (blue baby syndrome), gastric cancer and affects adversely central nervous system and cardiovascular system.
15	Fluoride (F) (mg/l)	1.0	1.50	Prevent tooth decay in lower concentration, High concentration causes fluorosis.
16	Cadmium (Cd) (mg/l)	0.01	-	Acute toxicity may be associated with renal, arterial hypertension, itai-itai disease, (a bone disease). Cadmium salt causes cramps, nausea, vomiting and diarrhea.
17	Lead (Pb) (mg/l)	0.05	-	Toxic in both acute and chronic exposures, burning in the mouth, serve inflammation of the gastro intestinal tract with vomitting and diarrhea. Chronic toxicity produces anemia, severe abdominal pain, paralysis, mental disorder, visual disturbances, etc.
18	Zinc (Zn) (mg/l)	5	15	An essential element in human metabolism. Taste threshold for Zn occurs at about 5 mg/l, provides astringent taste to water.
19	Chromium (Cr+) (mg/l)	0.05	-	Hexavalant state of Chromium concentration is carcinogenic. Also causes nasal mucous membrane ulcers and dermatitis.
20	Boron (B) (mg/l)	1.00	5.00	Affects central nervous system. Its salt may cause nausea, cramps convulsions, coma etc.
21	Alkalinity ($CaCO_3$) (mg/l)	200	600	Impart distinctly unpleasant taste may be deleterious to human being in presence of high pH, hardness and total dissolved solids.
22	Pesticides (mg/l)	Absent	0.001	Impact toxicity and accumulate in different organs of human body affecting immune and nervous system, carcinogenic.
23	Phosphate (PO4) mg/l)	No guideline		High concentration may cause vomitting and diarrhea, stimulate secondary hyperthyroidism and bone loss.
24	Sodium (Na) (mg/l)	No guideline		Harmful to persons suffering from cardiac, renal and circulatory diseases.
25	Pottassium (K) (mg/l)	No guideline		An essential nutiritional element but its excessive concentration is cathartic.
26	Nickel (Ni) (mg/l)	No guideline		Non-toxic but may be carcinogenic in animals, may cause DNA damage in animals.
27	Pathogens (a) Total coliform (per 100ml) (b) Faecal coliform (per 100ml)	1	10	Cause water borne diseases like coliform Jaundice, typhoid, Cholera etc. May cause infections involving skin mucous membrance of eyes, ears and throat.

Table 5.4 Water quality standards for irrigation use.

Sl.No	Parameters	Prescribed limits IS:10500, 1991		Probable effects (if present in higher concentration)
		Desirable limit	Permissible limit	
1	Salinity (EC in µmhos/cm at 25° C)	Sensitive crops<1500; Semi tolerant 1500-3000; Tolerant crop > 3000		Plant growth is retarded with stunted fruits, leaves and stem.
2	Sodium Absorption Ratio(SAR)	SAR < 10 10-18 18-26 >26	Excellent Good Medium Bad	Causes deflocculating of soil. Restricting free movement of water.
3	Residual Sodium Concentration (RSC)(mg/l)	<1.25 1.25 - 2.5 >2.5	Excellent Good Bad	Result in increase of sodium causing adverse effect.
4	Sodium (Na) (%)	No guideline		Increase total salinity, has adverse effect on sodium sensitive species such as stone fruit trees and avocados. Effects soil structure & permeability.
5	Chloride (Cl) (mg/l)	No guideline		May have direct toxic effects along with sodium.
6	Nitrate (NO_3) (mg/l)	No guideline		An essential plant nutrient but its excess any delay maturity and seed growth in some plants
7	Boron (B) (mg/l)	Sensitive Crops <1.0; Semi tolerant crops 1.0 - 2;. Tolerant crops - 2.0 - 4.0; Unsatisfactory for most crops > 4.0		An essential plant nutrient at low concentration but high concentration are toxic to plant.
8	Copper (Cu) (mg/l)	0.20	5.00	Essential for plants as a micro nutrient. Deficiency may cause crop damages. Chlorosis also leading to dieback of plant.
9	Lead (Pb) (mg/l)	5.20	10.00	Some plants accumulate it, which may have harmful effects on human health. Very high concentration may reduce root growth.
10	Zinc (Zn) (mg/l)	2.00	10.00	An essential plant nutrient as activator of enzymes. Deficiency leads to several diseases such as by ionizing, rosette or little leaf. High concentration produces toxic effects.
11	Chromium (Cr) (mg/l)	0.10	1.00	Toxic to plants, very high concentration may reduce growth. Produce iron deficiency in plants and reduce the yields.
12	Cadmium (Cd) (mg/l)	0.01	0.5	Reduces plant growth, bio-accumulates in plants cause adverse effects (ilai-ilai) on human consumption, reduces yields.
13	Iron (Fe) (mg/l)	5.0	20.0	An important and essential element. Deficiecy caused by excess of lime in soils, results in chlorosis. Excess iron contributes to soil acidification.
14	Nickel (Ni) (mg/l)	0.20	2.0	Causes stunted growth of plant in the concentration 0.5 mg/l. Toxic to barley, beans, oats, when more than 2.0 mg/l

Table 5.5 Water quality standards for industrial use

S.No	Parameters	prescribed limits IS 10500, 1991		Probable effects (if present in higher concentration)
		Desirable limit	Permissible limit	
1	pH value	6.5	8.5	Low pH inceases corrosion of concrete, pH 7.0 is required for most industries. pH 2.7 - 7.2 advised for carbonated beverage industry.
2	Total dissolved solids (TDS) (mg/l)	50	3000	Causes foaming in boilers and solids interfere with clearness, color or taste of finished products. Low TDS values are required in most industries. High TDS leads to corrosion.
3	Iron (Fe) (mg/l)	0.1	2.0	Recommended values for food processing units is 0.2 for paper and photographic industry iron of 0.1 mg/l is recommended; iron less than 0.1 mg/l is recommended in cooling water.
4	Chloride (Cl) (mg/l)	25	200	Leads to corrosion of steel and aluminium.
5	Fluoride (F) (mg/l)	20	500	Harmful in industries involved in production of food beverages, pharmaceuticals and medical items.
6	Calcium (Ca) (mg/l)	20	500	High calcium leads to spots on films. Have undesirable effects like foaming scaling, precipitation in industries. It may interfere in formation of emulsions and processing of colloids upsetting the fermentation process and elecgtroplating rinsing operation.
7	Sulphate (SO_4) (mg/l)	25	250	Increase corrosiveness of water towards concrete, low sulphates (20 mg/l) is recommended for sugar industries,
8	Nitrate (NO_3) (mg/l)	15	30	Injurious to dyeing of wool and silk fabrics and harmful in fermentation pocess for brewing. Nitrate in some water protects metal in boilers from inter-crystalline cracking.
9	Copper (Cu) (mg/l)	0.01	0.05	Copper is undesirable in food industry as it has color reactions and imparts fishy taste to finished products. Affects smoothness and brghtness of metal deposits in metal plating-baths.
10	Chromium (Cr) (mg/l)	NA	NA	It is a corrosion inhibitor.
11	Zinc (Zn) (mg/l)	NA	NA	Zinc bearing water should not be used in acid drinks like lemonade.
12	Lead (Pb) (mg/l)	NA	NA	Traces of lead in metal plating baths affect smoothness and brightness of deposits.

concentrations, although they may be beneficial at lower amounts (Singhal and Gupta, 1999). The bacterial contamination should be minimised in groundwater for drinking and domestic uses. Prescribed standards for drinking water vary from country to country, depending up on the economic condition, climate, food habits and geographic locations. Drinking water standards as prescribed by Bureau of Indian Standards (1991) are given in Table 5.3.

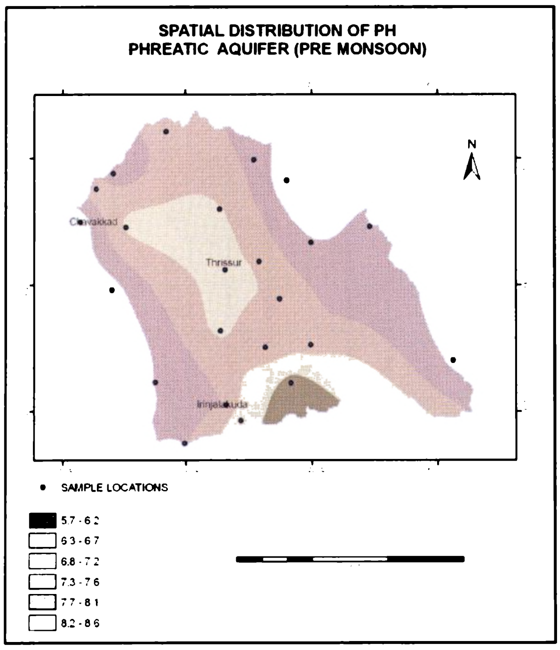
5.2.1a pH

The pH of the natural water is slightly acidic (5.0 – 7.5) and is caused by the dissolved carbon dioxide and organic acids (fluvic and humic acids), which are derived from the decay and subsequent leaching of plant materials (Langmuir, 1997). Waters of pH value above 10 are exceptional and may reflect contamination by strong base such as NaOH and $Ca(OH)_2$. The range of desirable limit of pH of water prescribed by BIS (1991) is 6.50 to 8.50.

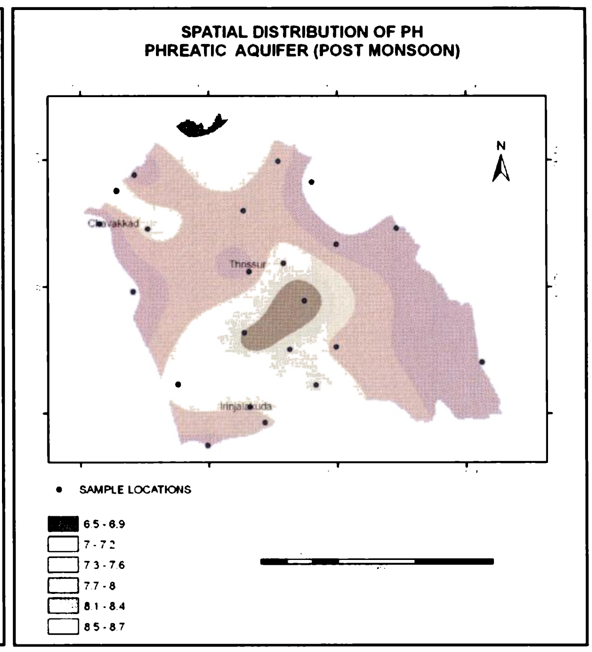
The spatial distribution of pH in the both phreatic as well as semi-confined deep aquifers of the basin is shown in the Figs. 5.1a-d. pH in the phreatic aquifer (dug wells) and semi -confined aquifer (bore wells) vary from 5 to 8.74 and 5.5 to 8.8 respectively. The long term trend of the pH in dug wells and bore wells of the basin is given in the Table 5.8.

The dug wells of the coastal plain areas, adjoining to the shore, show a decrease in pH below permissible limit during the pre monsoon period (Fig. 5.1a). Similar trend is also seen in some pockets of the eastern side of the basin. The extension of problematic area decreases after monsoon (Fig. 5.1b). Out of 23 observation wells monitored, 7 wells show a rising long term trend in pH while 16 wells show declining trend in pH (Table 5.8).

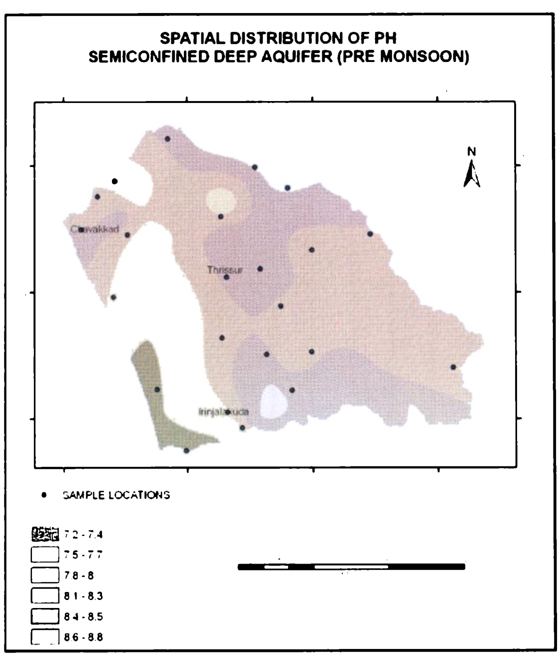
In the case of semi-confined deep aquifer, an increase in pH is seen in the Aloor and adjoining areas of the basin during pre monsoon. But the problematic area is extended to some more places after monsoon (Fig. 5.1d). Out of 24 bore wells monitored during the investigation, 13 numbers show a rising long trend in pH while 11 numbers shows declining trend (Table 5.8).



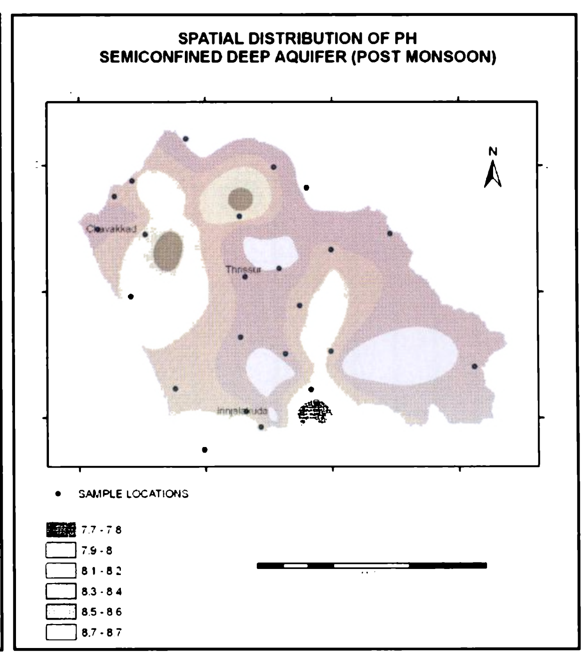
(a)



(b)



(c)



(d)

Figs. 5.1a-d Spatial distribution of pH in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.8 Trend of groundwater quality (pH) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon (Kole land basin)

Phreatic aquifer (dug well)					Semi-confined deep aquifer (bore well)				
Well No.	Location	No.of data analysed	Rise per year	Fall per year	Well No.	Location	No.of data analysed	Rise per year	Fall per year
OW-1	Thrissur	5	0.003	-	BW-1	Kaduppassery	13	-	0.07
OW-2	Mannuthi	12	-	0.074	BW-2	Mattathur	16	-	0.01
OW-3	Pattikkad	10	-	0.002	BW-3	Nellai	15	0.05	-
OW-4	Pudukkad	12	-	0.054	BW-4	Tholur	12	-	0.28
OW-5	Kodakara	5	-	0.530	BW-5	Trikkur	9	0.00	-
OW-6	Irinjalakuda	11	0.063	-	BW-6	Choondel	16	0.01	-
OW-7	M.G.Kavu	13	-	0.133	BW-7	Madakkathara	16	-	0.03
OW-8	Ottuppara	13	-	0.092	BW-8	Pananchery	8	-	0.12
OW-9	Chelakkara	15	-	0.008	BW-9	Kolazhy	13	0.01	-
OW-10	Kunnamkulam	15	-	0.048	BW-10	Athani	11	0.07	-
OW-11	Chavakkad	13	0.057	-	BW-11	Chengalur	12	-	0.08
OW-12	Pazhanji	6	0.063	-	BW-12	Muppliyam	12	-	0.08
OW-13	Nattika	14	0.012	-	BW-13	Mudicode	18	-	0.03
OW-14	Edamuttom	17	-	0.180	BW-14	Velapaya	11	0.00	-
OW-15	Mathilakam	14	0.040	-	BW-15	Kaiparambu	11	-	0.03
OW-16	Engadiyur	15	0.033	-	BW-16	Peechi	10	0.07	-
OW-17	Vaniyampara	14	-	0.038	BW-17	Chittilappilly	9	0.00	-
OW-18	Varandarappilly	15	-	0.010	BW-18	Nelluvayi	12	-	0.07
OW-19	Cherpu				BW-19	Kandanissery	13	0.02	-
OW-20	Puthur	12	-	0.000	BW-20	Aloor	10	0.12	-
OW-21	Elavally	12	-	0.152	BW-21	Vellangallur	10	0.01	-
OW-22	Kadangode	10	-	0.201	BW-22	Wadakkancherry	13	-	0.02
OW-23	Wadakkancharry	9	-	0.236	BW-23	Varavur	10	0.06	-
					BW-24	Arthat	12	0.04	-

In an unconfined aquifer system the pH will be often below 7 (Lanmuir, 1997). The acidic nature of the groundwater can be attributed to the dissolution of CO_2 that is being incorporated into the groundwater system by bacterial oxidation of organic substances (Matthess and Pekdger, 1981) and addition of CO_2 through rainwater. Moreover, the low pH of groundwater of the basin is related to the wide distribution of lateritic soil whose pH is always acidic (CESS, 1984). Further, the study area also encompasses extensive agricultural fields and therefore one of the main reasons for the observed low pH could be related to the use of acid producing fertilizers like ammonium sulphate and super phosphate of lime as manure for agriculture purpose (Rajesh et al., 2001).

A low pH below 6.5 can cause corrosion to water carrying metal pipes there by releasing toxic metals such as zinc, lead, cadmium, copper etc. (Davies, 1994) and bore well pipes. Further low pH value in groundwater can cause gastrointestinal disorders like hyper acidity, ulcers and stomach pain with burning sensation (Rajesh et al., 2001).

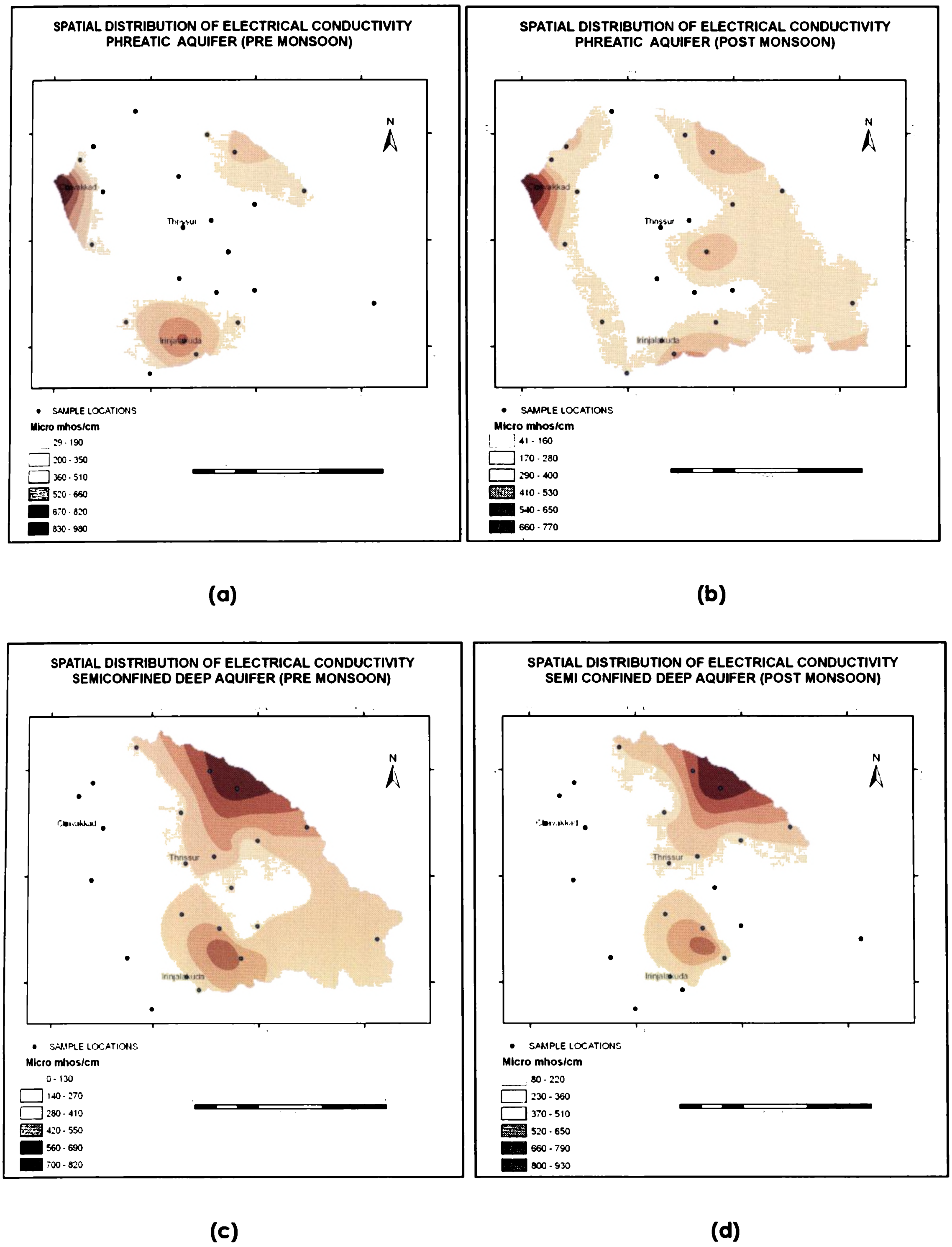
5.2.1b Electrical Conductivity (EC)

EC, measured in microseimens/centimetre (uS/cm) or micro mhos per centimetre (umhos/cm) is a measure of salt content of water in terms of ions (Karanth, 1987). The measurement of conductivity is potentially a very sensitive procedure for measuring ionic concentrations. The purity of distilled or de-ionised water is commonly checked by conductivity measurements. Conductivity monitoring of rivers, lakes and wells are used to determine salinity, pollution etc. The potability and classification of water in terms of conductivity is given in Table 5.9.

Table 5.9 Potability and classification of water in terms of Electrical conductivity (EC)

Sl.No	Rage of EC(μmhos/cm)	Quality
1	<333	Excellent
2	333 to 500	Good
3	500 to 1000	Permissible
4	1000 to 1500	Brackish
5	1500 to 10000	Saline

The spatial distribution EC in phreatic as well as semi-confined deep aquifers of the basin is shown in the Figs. 5.2a-d. EC in the phreatic aquifer (dug wells) and semi - confined aquifer (bore wells) varies from 29 to 980μmhos/cm (Chavakkad) and 10 to 930μmhos/cm respectively and is within permissible limit for domestic use. The long term trend of the EC in dug wells and bore wells of the basin is given in the Table 5.10.



Figs. 5.2a-d Spatial distribution of EC in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.10 Trend of Groundwatr quality (EC) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No. of data analysed	Rise per year (μmhos/cm)	Fall per year (μmhos/cm)	Well No	Location	No. of data analysed	Rise per year (μmhos/cm)	Fall per year (μmhos/cm)
OW-1	Thrissur	5	-	21.94	BW-1	Kaduppassery	13	-	28.87
OW-2	Mannuthi	12	-	12.55	BW-2	Mattathur	16	-	3.25
OW-3	Pattikkad	10	5.50	-	BW-3	Nellai	15	62.98	-
OW-4	Pudukkad	12	-	10.74	BW-4	Tholur	12	0.11	-
OW-5	Kodakara	5	12.27	-	BW-5	Trikkur	9	33.12	-
OW-6	irinjalakuda	11	-	84.10	BW-6	Choondel	16	-	17.07
OW-7	M.G.Kavu	13	-	8.00	BW-7	Madakkathara	16	14.22	-
OW-8	Ottuppara	13	-	5.48	BW-8	Pananchery	8	11.50	-
OW-9	Chelakkara	15	-	1.80	BW-9	Kolazhy	13	4.89	-
OW-10	Kunnamkulam	15	-	34.70	BW-10	Athani	11	32.74	-
OW-11	Chavakkad	13	30.32	-	BW-11	Chengalur	12	-	0.93
OW-12	Pazhanji	6	-	13.44	BW-12	Muppliyam	12	12.69	-
OW-13	Nattika	14	0.41	-	BW-13	Mudicode	18	9.40	-
OW-14	Edamuttom	17	-	11.65	BW-14	Velapaya	11	-	9.31
OW-15	Mathilakam	14	-	7.24	BW-15	Kaiparambu	11	2.32	-
OW-16	Engadiyur	15	-	2.14	BW-16	Peechi	10	21.19	-
OW-17	Vaniyampara	14	-	15.26	BW-17	Chittilappilly	9	2.32	-
OW-18	Varandarappilly	15	-	2.67	BW-18	Nelluvayi	12	2.58	-
OW-19	Cherpu				BW-19	Kandanissery	13	3.39	-
OW-20	Puthur	12	-	6.58	BW-20	Aloor	10	14.90	-
OW-21	Elavally	12	23.36	-	BW-21	Vellangallur	10	5.09	-
OW-22	Kadangode	10	21.74	-	BW-22	Wadakkancherry	13	-	3.79
OW-23	Wadakkancherry	9	13.42	-	BW-23	Varavur	10	-	1.01
					BW-24	Arthat	12	-	3.02

The spatial distribution of the EC in phreatic aquifer of the basin shows that, it gradually increases towards shoreline i.e. the western side of the basin. The maximum value of EC is reported from the samples of Chavakkad area (980 μmhos/cm). Comparatively a low EC is reported from the central and eastern part of the basin (Figs. 5.2a-b). Out of 23a observation wells monitored, 7 numbers show a rising long term trend in EC while 16 wells show declining trend (Table 5.10).

In the case of semi-confined deep aquifer, an increase in EC is seen in the northeastern (Wadakkancherry) and southcentral (Nellai) parts of the basin during pre monsoon. There is no much variation in the spatial distribution of EC after monsoon (Figs. 5.2c & d). This means that the EC of the groundwater in the semi-confined aquifer of the basin is mainly controlled by lineaments and rock type of that area. Out of 24 bore wells monitored during the investigation, 16 numbers show a rising long trend in EC while 8 numbers show declining trend (Table 5.10).

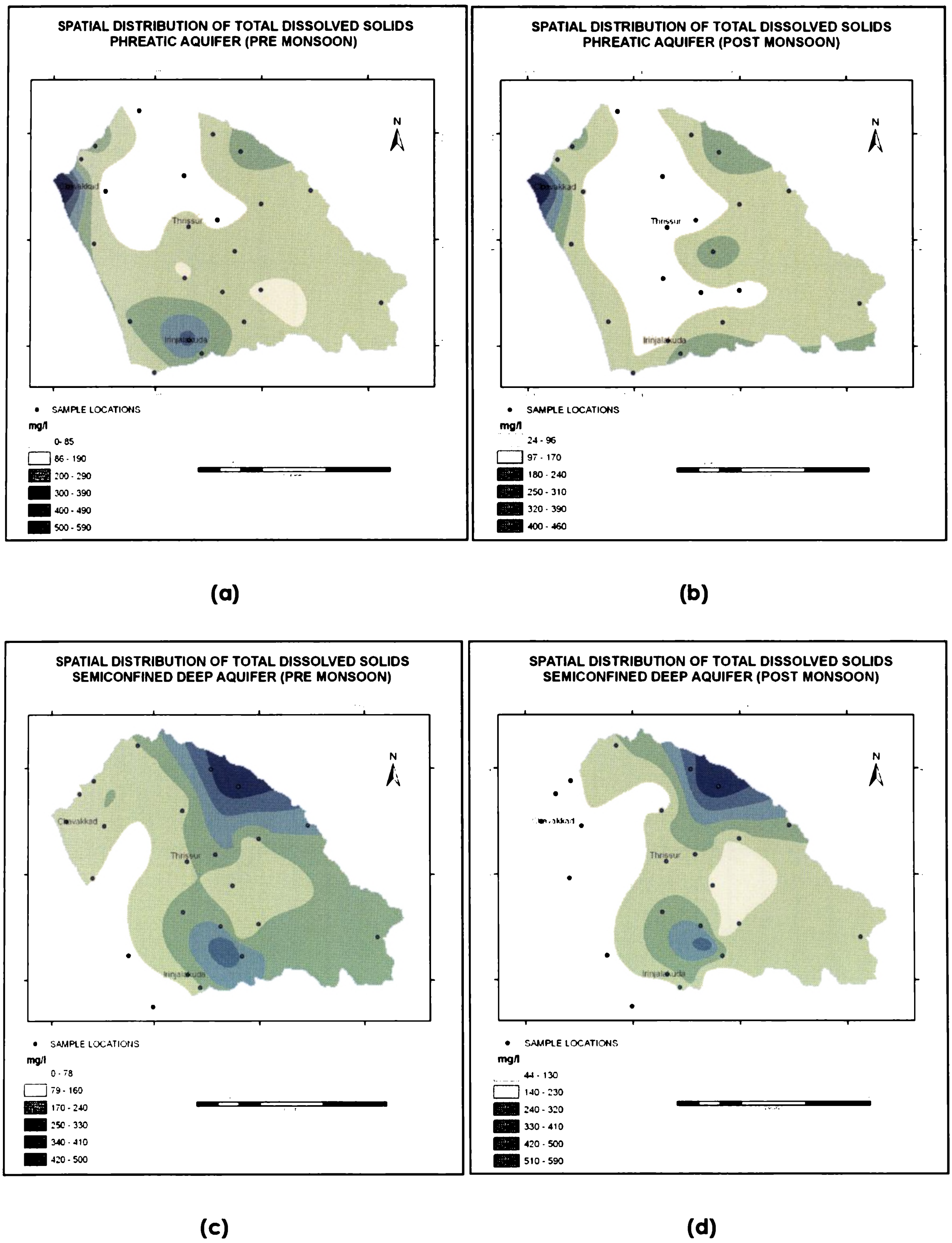
5.2.1c Total dissolved solids (TDS)

The quality of groundwater for drinking can be expressed in terms of total dissolved solids (TDS). Groundwater with a TDS value of less than 300 mg/l can be considered as excellent for drinking purpose (Table 5.11) according to WHO (1984). The TDS of the samples of both phreatic and semi- confined aquifers of the basin in all seasons fall below 600 mg/l and are belong to category 'good' as per norms of WHO (1984).

Table 5.11 The potability and classification of water in terms of TDS (mg/l) as per WHO (1984)

Sl.No	TDS(mg/l)	Water class
1	<300	Excellent
2	300 to 600	Good
3	600 to 900	Fair
4	900 to 1200	Poor
5	>1200	Unacceptable
6	1000 to 3000	Slightly saline
7	3000 to 10000	Moderately saline
8	3000 to 35000	Very saline
9	>35000	Brine

The spatial distribution of TDS in the study area shows a more or less same pattern that of the distribution of EC. It is gradually increasing towards the western side of the basin, nearshore. The maximum value of TDS is reported from the samples of Chavakkad area (590mg/l). Comparatively a low TDS is reported from the central and eastern part of the basin (Figs. 5.3a & b). Out of 23 observation wells monitored, 7 numbers show a rising long term trend in TDS while 16 wells show declining trend in TDS (Table 5.12).



Figs. 5.3a-d Spatial distribution of TDS in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.12 Trend of groundwatr quality (TDS) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5		14.11	BW-1	Kaduppassery	13	-	17.23
OW-2	Mannuthi	12		7.53	BW-2	Mattathur	16	-	2.58
OW-3	Pattikkad	10	3.32		BW-3	Nellai	15	42.23	-
OW-4	Pudukkad	12		6.43	BW-4	Tholur	12	-	0.46
OW-5	Kodakara	5	7.36		BW-5	Trikkur	9	16.59	-
OW-6	irinjalakuda	11		51.53	BW-6	Choondel	16	-	10.80
OW-7	M.G.Kavu	13		4.80	BW-7	Madakkathara	16	7.91	-
OW-8	Ottuppara	13		3.29	BW-8	Pananchery	8	6.90	-
OW-9	Chelakkara	15		1.08	BW-9	Kolazhy	13	2.93	-
OW-10	Kunnamkulam	15		20.82	BW-10	Athani	11	18.12	-
OW-11	Chavakkad	13	18.19		BW-11	Chengalur	12	-	1.41
OW-12	Pazhanji	6		8.07	BW-12	Muppliyam	12	7.61	-
OW-13	Nattika	14	0.24		BW-13	Mudicode	18	5.27	-
OW-14	Edamuttom	17		7.40	BW-14	Velapaya	11	-	5.58
OW-15	Mathilakam	14		4.44	BW-15	Kaiparambu	11	0.79	-
OW-16	Engadiyur	15		1.28	BW-16	Peechi	10	12.72	-
OW-17	Vaniyampara	14		9.15	BW-17	Chittilappilly	9	1.39	-
OW-18	Varandarappilly	15		1.60	BW-18	Nelluvayi	12	-	0.59
OW-19	Cherpu	12		20.17	BW-19	Kandanissery	13	1.42	-
OW-20	Puthur	12		4.15	BW-20	Aloor	10	8.22	-
OW-21	Eravally	12	12.69		BW-21	Vellangallur	10	2.14	-
OW-22	Kadangode	10	5.58		BW-22	Wadakkancherry	13	6.21	-
OW-23	Wadakkancherry	9	7.05		BW-23	Varavur	10	-	0.61
					BW-24	Arthat	12	-	1.79

In the case of semi-confined deep aquifer, an increase in EC is seen in the northeastern (Wadakkancherry), southcentral (Nellai) parts of the basin during pre monsoon. There is no much variation in the spatial distribution TDS after monsoon (Figs. 5.2c&d). This means that the TDS of the groundwater in the semi-confined aquifer of the basin is mainly controlled by lineaments and rock type of the area. Out of 24 bore wells monitored during the investigation, 15 numbers show a rising long trend in TDS while 9 numbers shows declining trend (Table 5.12).

5.2.1d Hardness as $CaCO_3$

The groundwater hardness is defined as the sum of divalent cations in solution but depends largely upon the concentrations of aqueous calcium and magnesium (Taylor and Howard, 1994). Hardness of water is grouped into two types, carbonate and non-carbonate type. Carbonate hardness includes that portion of the calcium and magnesium that combines with bicarbonate and the small amount of carbonate present. This is called as temporary hardness because it can be removed by boiling, which precipitates calcium and magnesium carbonates and sulphate minerals. Hardness is usually expressed in terms of calcium carbonate. The hard water is unsatisfactory for household cleaning purposes and hence, water - softening process are needed for the removal of hardness. The hardness of water has been classified as soft, moderately hard, hard and very hard (Table 5.13) by Sawyer and McCarty (1967).

Table 5.13 Classification of the degree of hardness in water (Sawyer and McCarty, 1967)

Sl.No	Water Class	Hardness (mg/l) as $CaCO_3$ l
1	Soft	0 to 75
2	Moderately hard	75 to 150
3	Hard	150 to 300
4	Very hard	>300

The spatial distribution of hardness in the basin clearly shows a seasonal variarions with monsoon. The water samples in the phreatic aquifer of Chavakkad and adjoining areas show hardness above 150 mg/l, the same situation persists after monsoon (Figs. 5.4a & b). Hence the ground water in the phreatic aquifer around Chavakkad area is identified as hard as per the classification given in Table 5.13. Out of 23 observation wells monitored, 9 numbers show a rising long term trend in TH while 14 wells show declining trend (Table 5.14).

Table 5.14 Trend of groundwater quality (Total Hardness)in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Loccation	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No. of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5		8.17	BW-1	Kaduppassery	13	-	10.29
OW-2	Mannuthi	12		3.03	BW-2	Mattathur	16	4.19	-
OW-3	Pattikkad	10	0.81		BW-3	Nellai	15	12.94	-
OW-4	Pudukkad	12	0.57		BW-4	Tholur	12	1.47	-
OW-5	Kodakara	5		6.64	BW-5	Trikkur	9	19.29	-
OW-6	Irinjalakuda	11		15.17	BW-6	Choondel	16	-	1.96
OW-7	M.G.Kavu	13	5.77		BW-7	Madakkathara	16	6.68	-
OW-8	Ottuppara	13		1.80	BW-8	Pananchery	8	14.10	-
OW-9	Chelakkara	15		5.24	BW-9	Kolazhy	13	-	2.25
OW-10	Kunnamkulam	15		8.54	BW-10	Athani	11	17.84	-
OW-11	Chavakkad	13	4.42		BW-11	Chengalur	12	2.37	-
OW-12	Pazhanji	6		3.93	BW-12	Muppliyam	12	0.39	-
OW-13	Nattika	14		1.84	BW-13	mudicode	18	4.50	-
OW-14	Edamuttom	17		8.85	BW-14	Velapaya	11	-	1.18
OW-15	Mathilakam	14		3.27	BW-15	Kaiparambu	10	3.30	-
OW-16	Engadiyur	15	1.96		BW-16	Peechi	10	9.67	-
OW-17	Vaniyampara	14		7.18	BW-17	Chittilappilly	9	1.63	-
OW-18	Varandarappilly	15		0.82	BW-18	Nelluvayi	12	0.65	-
OW-19	Cherpu			6.63	BW-19	Kandanissery	13	1.43	-
OW-20	Puthur	12	2.04		BW-20	Aloor	10	15.47	-
OW-21	Elavally	12	3.71		BW-21	Vellangallur	10	3.91	-
OW-22	Kadangode	10	4.69		BW-22	Wadakkancherry	13	-	18.25
OW-23	Wadakkancharry	9	3.09		BW-23	Varavur	10	-	0.20
					BW-24	Arthat	12	1.13	-

As far as the semi-confined deep aquifer of the basin is concerned, the hardness is seen only in the eastern part of the basin, around Wadakkancherry. This did not persist after monsoon. The groundwater in the semi-confined aquifer of the area becomes totally soft after the monsoon, may be due to dilution (Figs. 5.4c & d). Out of 24 bore wells monitored during the investigation, 18 numbers show a rising long trend in TH while 6 numbers shows declining trend (Table 5.14).

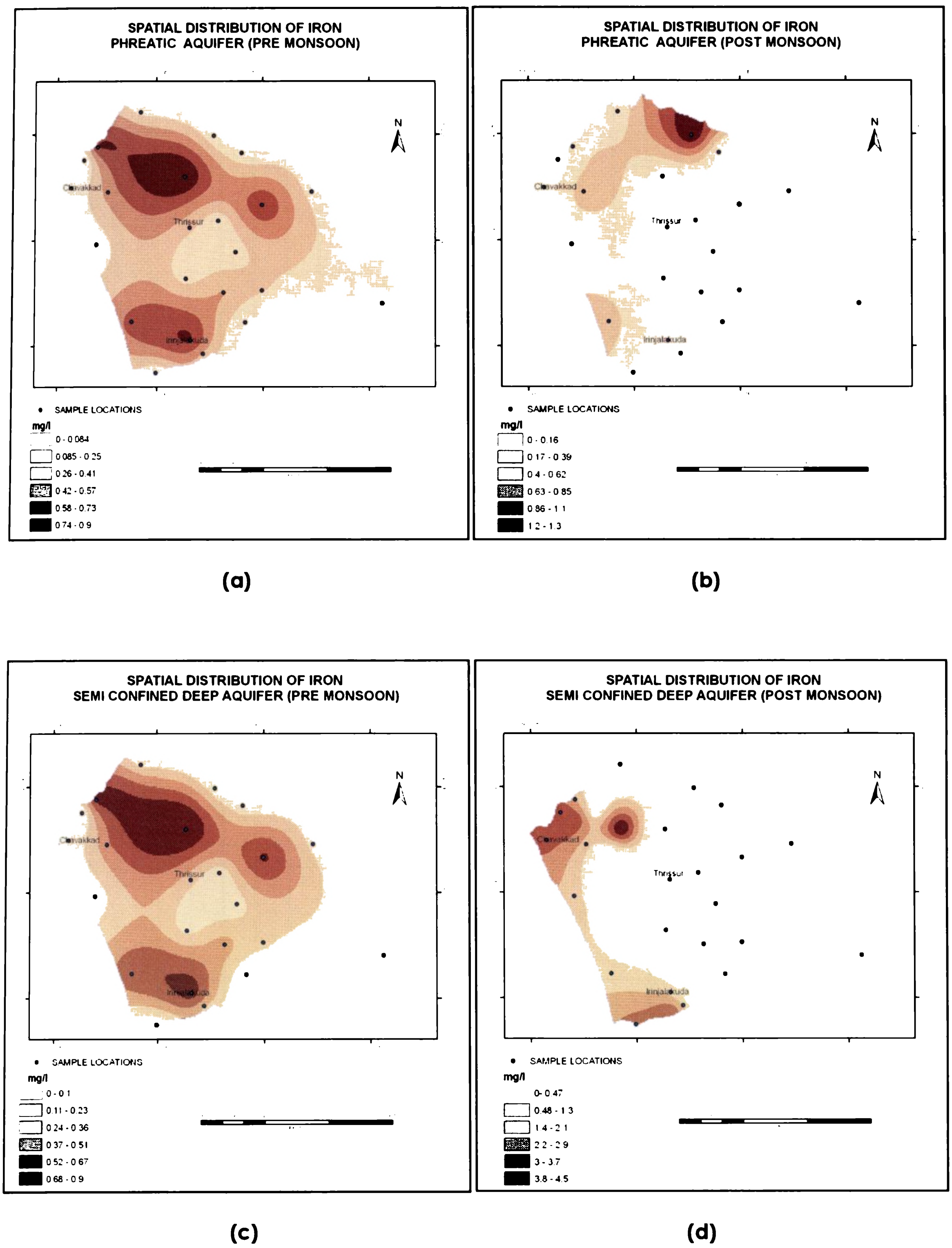
A low pH of groundwater favours the dissolution of carbonate mineral, which in turn enhances the hardness by dissolving carbonate minerals of the country rock (Todd, 1980). But such an equilibrium system is not prevailing in this basin in view of low hardness.

5.2.1e Total Iron

As per the norms of Indian Standard (IS 10500: 1991) the desirable and permissible limit of iron in drinking water are 0.3 and 1.0 mg/l respectively. The Figs. 5.5a-d shows the spatial distribution of Iron in both phreatic and semi-confined aquifers of the study area. In both seasons (in phreatic as well as semi-confined deep aquifers) the iron concentration is below permissible limit during pre monsoon and above permissible limit during post monsoon. The concentration of iron in groundwater of the phreatic aquifer (dug wells) varies from 0.084 to 1.3 mg/l and it is more than permissible during post monsoon period in areas such as Edamuttom, Kunnakulam, Kadangode and northeastern part of the basin (Figs. 5.5a & b). The long term trend of iron in the study area is given in Table 5.15. Out of 23 observation wells monitored, 6 numbers show a rising long term trend in Fe concentration and the remaining 17 shows a declining long term trend.

In the case of semi-confined deep aquifer, all the area except central part of the basin shows an iron concentration above permissible limit (1.0 mg/l) during post monsoon (Fig. 5.5c & d). Out of 24 bore wells monitored during the investigation, 15 wells show a rising long trend in Fe while 9 wells show declining trend (Table 5.15).

The reason for increase in the concentration of Fe in groundwater of the area during post monsoon period may be the dissolution of iron oxide from the laterite during monsoon (Singhal and Gupta, 1999). As the study area is primarily covered with laterites (70%), leaching of Fe will take place



Figs. 5.5a-d Spatial distribution of Iron in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.15 Trend of Groundwater quality (iron) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

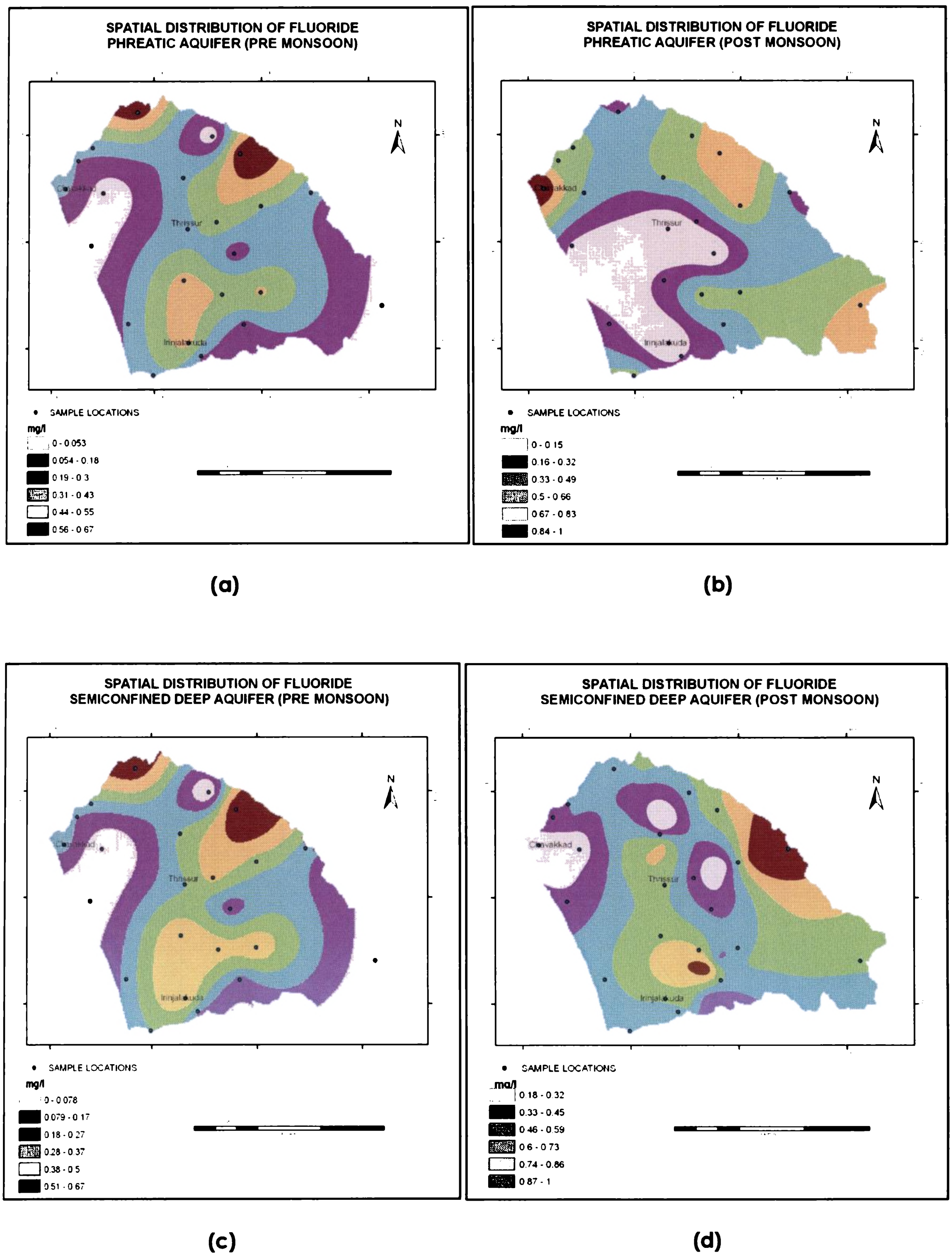
Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	0.01	-	BW-1	Kaduppassery	10	0.00	-
OW-2	Mannuthi	12	-	0.05	BW-2	Mattathur	13	0.05	-
OW-3	Pattikkad	9	-	0.06	BW-3	Nellai	14	-	0.07
OW-4	Pudukkad	11	-	0.01	BW-4	Tholur	11	0.08	-
OW-5	Kodakara	11	0.03	-	BW-5	Trikkur	9	0.09	-
OW-6	Irinjalakuda	11	-	0.11	BW-6	Choondel	15	0.09	-
OW-7	M.G.Kavu	11	-	0.44	BW-7	Madakkathara	13	-	0.06
OW-8	Ottuppara	12	-	0.13	BW-8	Pananchery	8	-	0.03
OW-9	Chelakkara	13	-	0.03	BW-9	Kolazhy	12	-	0.36
OW-10	Kunnamkulam	12	-	0.02	BW-10	Athani	9	0.04	-
OW-11	Chavakkad	13	-	0.03	BW-11	Chengalur	11	0.05	-
OW-12	Pazhanji	5	-	0.01	BW-12	Muppliyam	11	-	0.32
OW-13	Nattika	12	-	0.01	BW-13	Mudicode	15	0.02	-
OW-14	Edamuttom	15	-	0.10	BW-14	Velapaya	10	-	0.10
OW-15	Mathilakam	13	0.01	-	BW-15	Kaiparambu	9	1.08	-
OW-16	Engadiyur	14	0.03	-	BW-16	Peechi	9	-	0.33
OW-17	Vaniyampara	13	-	0.02	BW-17	Chittilappilly	8	-	0.02
OW-18	Varandarappilly	15	-	0.04	BW-18	Nelluvayi	12	1.21	-
OW-19	Cherpu				BW-19	Kandanissery	12	0.87	-
OW-20	Puthur	12	-	0.05	BW-20	Aloor	8	0.58	-
OW-21	Elavally	10	0.01	-	BW-21	Vellangallur	9	1.96	-
OW-22	Kadangode	9	0.08	-	BW-22	Wadakkancherry	13	0.32	-
OW-23	Wadakkancherry	9	-	0.01	BW-23	Varavur	10	-	0.16
					BW-24	Arthat	12	0.35	-

easily under the existing anoxic conditions and thus the concentration of total iron in groundwater of this basin is high above the permissible level. In the coastal plain region, the concentration of iron in groundwater will be higher under reducing condition due to bacteriological attack on organic matter which leads to the formation of various humic and fluvic compounds (Applin and Zhao, 1989; White et al., 1991). Under reducing condition (in bore wells and tube wells), the iron from biotite mica and laterites are leached into solution in ferrous state and added to groundwater. Because of the above reasons the concentration iron is generally seen above permissible limit in the tropical areas especially in areas with laterite capping. The rusting of galvenised iron pipes used, as casing pipe is also a reason for high iron content in bore wells and tube wells. In high rainfall areas like Assam, Orissa and Kerala the total iron content ranges from 6.83 to 55 mg/l (Singhal and Gupta, 1999). The common method of removal of iron from water is by aeration followed by sedimentation.

5.2.1f Fluoride

In groundwater, fluorine occurs mainly as simple fluoride ion. It is capable of forming complexes with silicon and aluminium, and is believed to exist at a $pH < 7$. According to Indian Standard (IS 10500: 1991) the desirable and permissible limit of fluoride in groundwater is 1.0 and 1.50 mg/l respectively. The spatial distribution of fluoride in phreatic and semi-confined aquifer during pre and post monsoon periods of the study area is given in Figs. 5.6a-d. In phreatic as well as semi - confined aquifers during both seasons the fluoride contents are within permissible limit. The samples from dug wells of the MG Kavu, Chavakkad, Pudukkad, Mathilkam and Varandarapilli have given a fluoride concentration around 1.0 mg/l in one or two pre monsoon times. Similarly the bore wells at Panancherry, Nelluvai and Arthat have given same fluoride concentration during pre monsoon period. The distribution of fluoride for both seasons shows more or less an identical pattern and most of the samples show a fluoride value as traces (Tables. 5.6 & 5.7).

The long term trends of the fluoride concentration in both types of aquifers are given in Table 5.16. Out of 23 observation wells monitored, 6 numbers show an increasing trend while remaining 17 numbers show a declining trend. Similarly, In the case of 24 bore wells observed, 5 numbers shows a positive long term trend whereas the remaining 19 numbers show declining long term trend.



Figs. 5.6a-d Spatial distribution of Fluoride in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.16 Trend of groundwater quality (fluoride) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	0.05	BW-1	Kaduppassery	10	-	0.06
OW-2	Mannuthi	12	-	0.01	BW-2	Mattathur	14	-	0.06
OW-3	Pattikkad	9	-	0.12	BW-3	Nellai	14	0.03	-
OW-4	Pudukkad	11	0.02	-	BW-4	Tholur	12	-	0.03
OW-5	Kodakara	11		0.12	BW-5	Trikkur	9	-	0.08
OW-6	Irinjalakuda	11	-	0.09	BW-6	Choondel	15	-	0.06
OW-7	M.G.Kavu	11	0.04	-	BW-7	Madakkathara	13	-	0.05
OW-8	Ottuppara	12	-	0.03	BW-8	Pananchery	8	-	0.06
OW-9	Chelakkara	13	0.00	-	BW-9	Kolazhy	12	-	0.01
OW-10	Kunnamkulam	12	-	0.11	BW-10	Athani	10	-	0.02
OW-11	Chavakkad	13	0.10	-	BW-11	Chengalur	11	0.04	-
OW-12	Pazhanji	5	-	0.13	BW-12	Muppliyam	10	-	0.03
OW-13	Nattika	12	0.04	-	BW-13	Mudicode	15	-	0.08
OW-14	Edamuttom	15	-	0.12	BW-14	Velapaya	10	0.00	-
OW-15	Mathilakam	13	-	0.03	BW-15	Kaiparambu	10	-	0.07
OW-16	Engadiyur	14	0.06	-	BW-16	Peechi	10	-	0.06
OW-17	Vaniyampara	13	-	0.05	BW-17	Chittilappilly	9	-	0.12
OW-18	Varandarappilly	15	-	0.02	BW-18	Nelluvayi	12	-	0.06
OW-19	Cherpu				BW-19	Kandanissery	13	-	0.09
OW-20	Puthur	12	-	0.02	BW-20	Aloor	9	-	0.08
OW-21	Elavally	10	-	0.06	BW-21	Vellangallur	9	0.02	-
OW-22	Kadangode	9	-	0.10	BW-22	Wadakkancherry	12	-	0.04
OW-23	Wadakkancherry	9	-	0.04	BW-23	Varavur	10	-	0.02
					BW-24	Arthat	10	0.00	-

Fluoride is beneficial if presents in small concentrations (0.8 to 1.0 mg/l) in drinking water for calcification of dental enamel but it causes dental and skeletal fluorosis if present in higher amount (Table 5.17). High concentration of fluoride in drinking water is also linked with cancer (Smedly, 1992). In Kerala, high concentration of fluoride is recorded in certain coastal plain areas of Alappuzha district and in eastern side of Palakkad district. The fluride of coastal plain region of Alappuzha is probably derived from sediments during freshening process of associated groundwater (CGWB, 2003) and in Palakkad it is derived from Kankar and associated crystalline rocks.

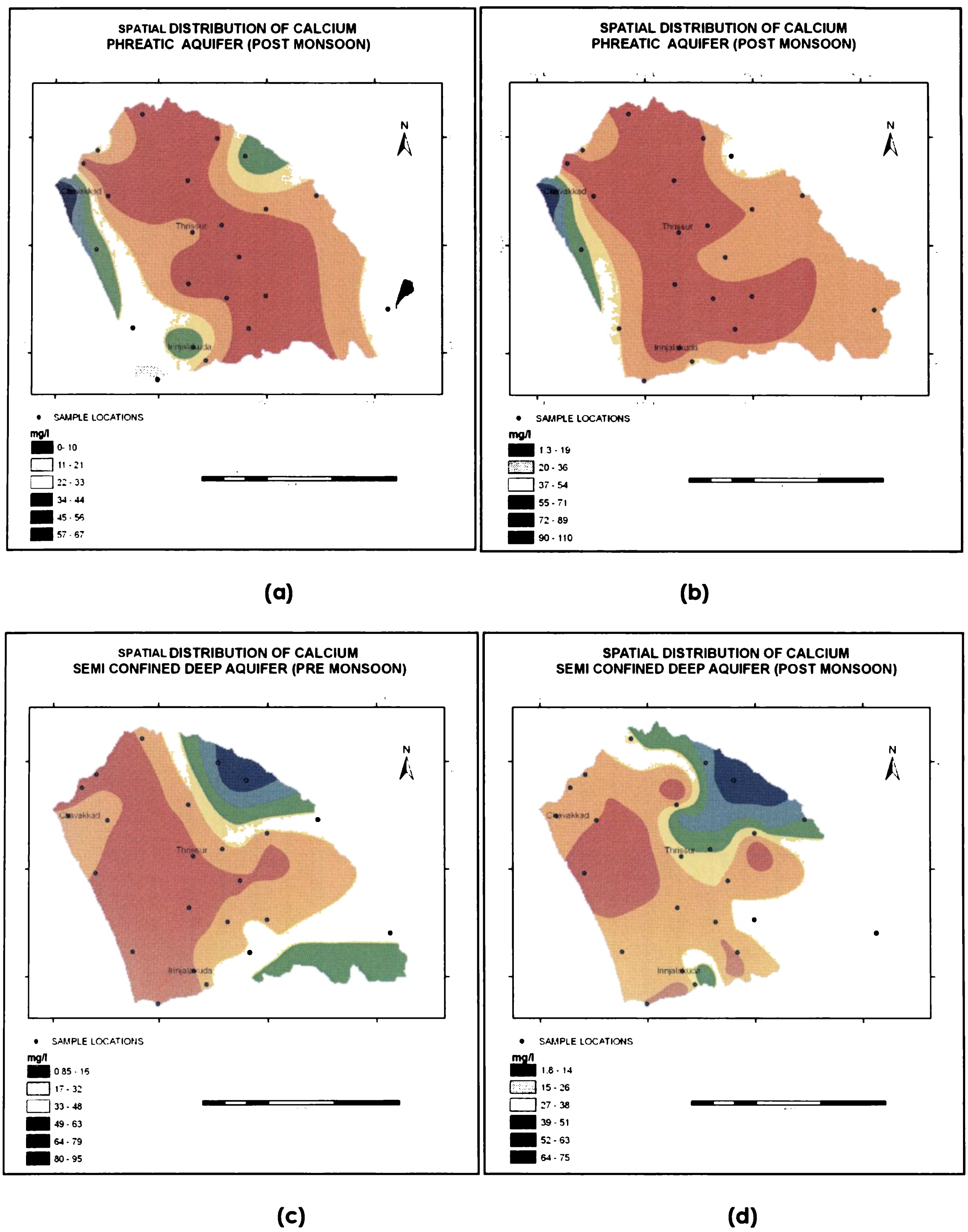
Table 5.17 Impact of fluoride in drinking water on health (Dissanayake, 1991)

Sl.No	Concentration of fluoride (mg/l)	Impact on health
1	Nil	Limited growth and fertility
2	0 to 0.50	Dental caries
3	0.5 to 1.50	Promotes dental health
4	1.5 to 4.0	Dental fluorosis (mottling of teeth)
5	4.0 to 10	Dental and skeletal flurosis
6	>10	Crippling flurosis

5.2.1g Major cations and anions

Major cations and anions such as Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, SO_4^{-}, CO_3^{-}, HCO_3^{-}, and NO_3^{-} (Tables 5.6 & 5.7) were plotted in hydrochemical pattern and facies diagrams (Part 5.3 of this Chapter). Here, the spatial distribution of the major cations and anions and their desirable and permissible limits for drinking purpose are discussed with supporting data and diagrams of the study area.

Calcium: Calcium is one of the freely dissolving ions from many rocks and soils. The principal sources of calcium in groundwater are some members of silicate mineral groups like plagioclase, pyroxene and amphibole among igneous and metamorphic rocks and limestone, dolomite and gypsum among sedimentary rocks. Calcium is present in water as Ca^{++}, which forms complex with some organic anions. The presence of K and Na also influences the solubility of calcium. Concentration of calcium in normal potable groundwater generally ranges between 10 and 100 mg/l. Calcium in this concentration has no effect on the health of humans. The desirable and permissible limits of calcium in drinking water are 75 and 200 mg/l respectively. Indeed, as much as 1000 mg/l of calcium may be harmless.



Figs. 5.7a-d Spatial distribution of Calcium in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

Table 5.18 Trend of groundwater quality (calcium) in phreatic and semi- confined aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	3.63	BW-1	Kaduppassery	13	8.03	-
OW-2	Mannuthi	12	-	1.51	BW-2	Mattathur	16	9.59	-
OW-3	Pattikkad	10	1.13	-	BW-3	Nellai	15	3.43	-
OW-4	Pudukkad	12	0.92	-	BW-4	Tholur	12	1.46	-
OW-5	Kodakara	5	-	2.62	BW-5	Trikkur	9	4.47	-
OW-6	Irinjalakuda	11	-	7.53	BW-6	Choondel	16	1.18	-
OW-7	M.G.Kavu	13	0.25	-	BW-7	Madakkathara	16	10.40	-
OW-8	Ottupara	13	0.47	-	BW-8	Pananchery	8	-	9.96
OW-9	Chelakkara	15	4.86	-	BW-9	Kolazhy	13	5.00	-
OW-10	Kunnamkulam	15	-	0.04	BW-10	Athani	11	13.08	-
OW-11	Chavakkad	13	11.15	-	BW-11	Chengalur	12	0.97	-
OW-12	Pazhanji	6	-	0.88	BW-12	Muppliyam	12	-	1.32
OW-13	Nattika	14	6.37	-	BW-13	Mudicode	18	5.72	-
OW-14	Edamuttom	17	1.80	-	BW-14	Velapaya	11	2.24	-
OW-15	Mathilakam	14	3.92	-	BW-15	Kaiparambu	11	2.79	-
OW-16	Engadiyur	15	6.95	-	BW-16	Peechi	10	6.38	-
OW-17	Vaniyampara	14	0.27	-	BW-17	Chittilappilly	9	2.03	-
OW-18	Varandarappilly	15	-	0.19	BW-18	Nelluvayi	12	2.16	-
OW-19	Cherpu				BW-19	Kandanissery	13	4.18	-
OW-20	Puthur	12	1.93	-	BW-20	Aloor	10	5.18	-
OW-21	Elavally	12	2.18	-	BW-21	Vellangallur	10	1.46	-
OW-22	Kadangode	10	1.97	-	BW-22	Wadakkancharry	13	-	7.19
OW-23	Wadakkancherry	9	1.15	-	BW-23	Varavur	10	1.57	-
					BW-24	Arthat	12	0.39	-

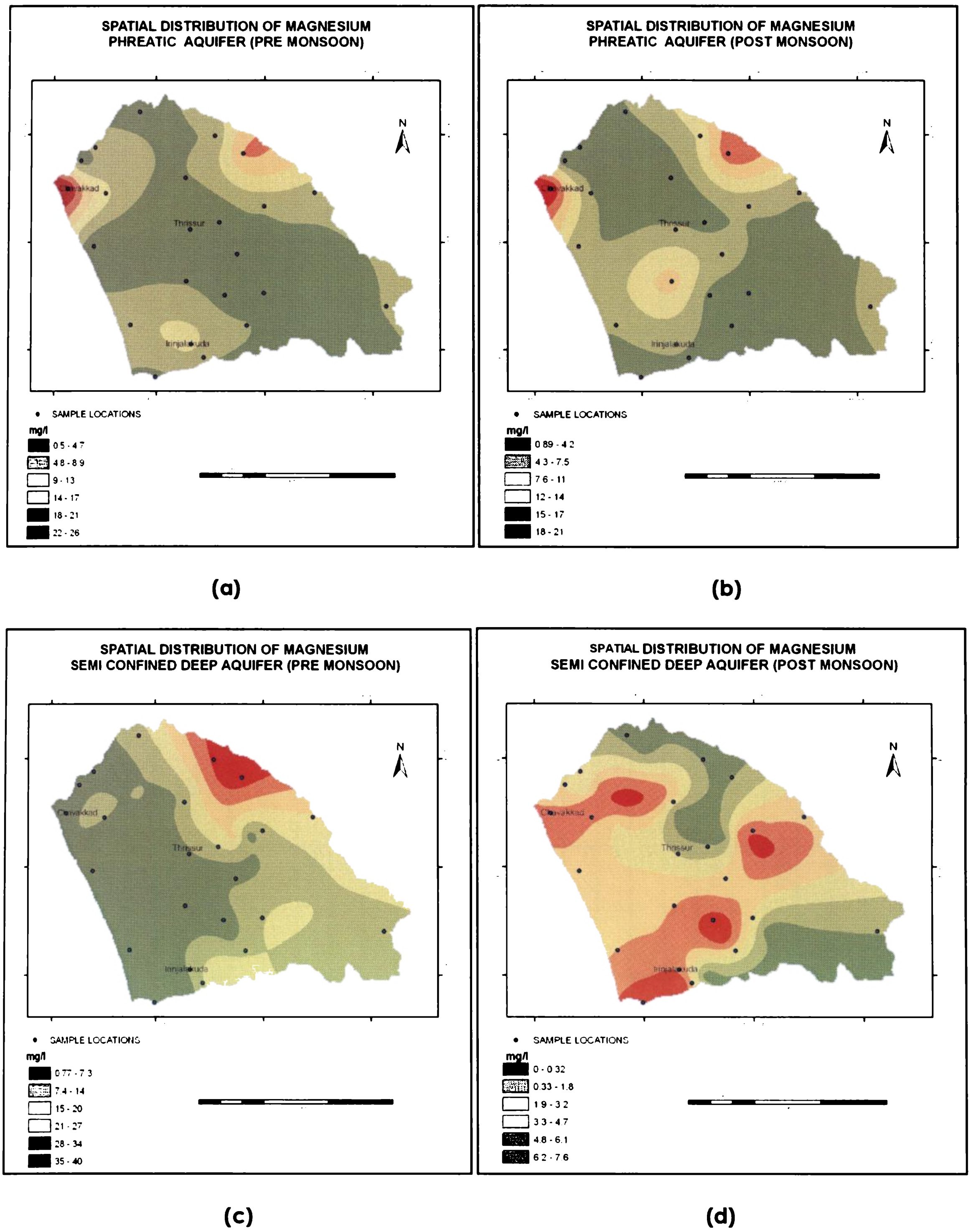
The spatial distribution of calcium of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.7a-d. The calcium concentration of the basin varies from 10 to 110 mg/l and it is within the permissible limit proposed by BIS for drinking. The long term trend of cacium in the phreatic as well as semi -confined aquifers of the study area is given in Table 5.18. Out of 23 observation wells monitored, 15 numbers show an increasing long term trend and the remaining 8 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 21 numbers show positive long term trend and the remaining 3 wells show declining trend.

Magnesium: Magnesium is commonly associated with calcium and causes hardness of water. The geochemical behavior of Mg^{++} is altogether different from that of Ca^{++}. In igneous and metamorphic rocks magnesium occurs in the form of insoluble silicates, weathering breaks them down into more soluble carbonates, clay minerals and silica. Concentration of magnesium in groundwater attains a rather wide range. The desirable and permissible limits of magnesium in drinking water are 30 and 100 mg/l respectively.

The concentration of magnesium both in phreatic and semi-confined aquifers in the study area is vary from 0.5 to 26 mg/l (Figs. 5.8a-d), which is below the desirable limit recommended by BIS.

The long term trend of calcium in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.19. Out of 23 observation wells monitored, 9 wells show an increasing long term trend and the remaining 14 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 12 wells show positive long term trend and the remaining 12 wells show declining trend.

Sodium: Sodium (unlike calcium, magnesium and silica) is not found as an essential constituent of many of the common rock forming minerals. The primary source of most sodium in natural water is from the release of soluble products during the weathering of plagioclase feldspars. The most important source of sodium in groundwater, with concentration of over 50 mg/l of sodium is the precipitation of sodium salts impregnating the soil in shallow water tracks, particularly in arid and semi-arid regions. Certain clay minerals and zeolites can increase the sodium content in groundwater by Base Exchange reactions.



Figs 5.8a-d Spatial distribution of Magnesium in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.19 Trend of groundwater quality (magnesium) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	0.05	-	BW-1	Kaduppassery	13	-	2.61
OW-2	Mannuthi	12	0.34	-	BW-2	Mattathur	16	-	0.17
OW-3	Pattikkad	10	-	0.74	BW-3	Nellai	15	0.91	-
OW-4	Pudukkad	12	0.19	-	BW-4	Tholur	12	-	0.01
OW-5	Kodakara	5	0.09	-	BW-5	Trikkur	9	1.55	-
OW-6	Irinjalakuda	11	-	0.82	BW-6	Choondel	16	-	0.28
OW-7	M.G.Kavu	13	-	0.33	BW-7	Madakkathara	16	-	0.36
OW-8	Ottupara	13	-	0.14	BW-8	Pananchery	8	0.57	-
OW-9	Chelakkara	15	-	0.51	BW-9	Kolazhy	13	-	0.67
OW-10	Kunnamkulam	15	-	0.52	BW-10	Athani	11	1.50	-
OW-11	Chavakkad	13	-	0.54	BW-11	Chengalur	12	0.21	-
OW-12	Pazhanji	6	-	0.41	BW-12	Muppliyam	12	-	1.74
OW-13	Nattika	14	-	0.56	BW-13	Mudicode	18	0.33	-
OW-14	Edamuttom	17	-	0.51	BW-14	Velapaya	11	0.19	-
OW-15	Mathilakam	14	0.10	-	BW-15	Kaiparambu	11	0.33	-
OW-16	Engadiyur	15	0.44	-	BW-16	Peechi	10	1.21	-
OW-17	Vaniyampara	14	-	0.25	BW-17	Chittilappilly	9	0.29	-
OW-18	Varandarappilly	15	0.31	-	BW-18	Nelluvayi	12	-	1.16
OW-19	Cherpu				BW-19	Kandanissery	13	-	0.13
OW-20	Puthur	12	1.08	-	BW-20	Aloor	10	1.81	-
OW-21	Eavally	12	-	0.42	BW-21	Vellangallur	10	0.51	-
OW-22	Kadangode	10	-	0.17	BW-22	Wadakkancharry	13	-	0.82
OW-23	Wadakkancherry	9	0.49	-	BW-23	Varavur	10	-	2.00
					BW-24	Arthat	12	-	0.31

The concentration of sodium in phreatic aquifer varies from 1.0 to 73 mg/l (Chavakkad). While in semi- confined deep aquifer it varies from 1 to 130mg/l. The maximum concentration in semi-confined aquifer is seen in the south central part of the basin around Irinjalakuda and Nellai (Figs. 5.9a to d). The long term trend of sodium in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.20. Out of 23 observation wells monitored, 13 wells show an increasing long term trend and the remaining 10 show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 18 wells show positive long term trend and the remaining 6 wells show declining trend.

Potassium: The sources of potassium are the products formed by the weathering of orthoclase, microcline, biotite, leucite, and nepheline in igneous and metamorphic rocks. The abundance of potassium in the earth's crust is about the same as sodium and potassium which is commonly less than one tenth of the concentration of sodium in natural water.

The spatial distribution of calcium of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.10a-d. The potassium concentration in the phreatic aquifer of the basin varies from 1 to 30 mg/l. While in semi-confined deep aquifer its concentration is below 10mg/l. The long term trend of potassium in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.21. Out of 23 observation wells monitored, 8 wells show an increasing long term trend and the remaining 15 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored, 10 wells show positive long term trend and the remaining 14 wells show declining trend.

Chloride: Chloride is a minor constituent in the earth's crust, but a major dissolved constituent of most natural water. Chloride bearing minerals such as sodalite and chlorapatite, which are very minor constituents of igneous and metamorphic rocks, and liquid inclusions, which comprise very significant fraction of rock volume, are minor source of chloride in groundwater. Most of the chloride in groundwater is present as sodium chloride but chloride concentration may exceed the sodium due

Table 5.20 Trend of groundwater quality (sodium) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	0.17	-	BW-1	Kaduppassery	12	2.80	-
OW-2	Mannuthi	12	-	0.21	BW-2	Mattathur	15	-	0.98
OW-3	Pattikkad	10	0.32	-	BW-3	Nellai	15	8.97	-
OW-4	Pudukkad	12	-	0.88	BW-4	Tholur	12	-	0.54
OW-5	Kodakara	5	4.13	-	BW-5	Trikkur	9	0.88	-
OW-6	Irinjalakuda	11	-	1.00	BW-6	Choondel	16	-	0.51
OW-7	M.G.Kavu	13	1.26	-	BW-7	Madakkathara	16	2.12	-
OW-8	Ottuppara	13	0.24	-	BW-8	Pananchery	8	4.99	-
OW-9	Chelakkara	15	0.68	-	BW-9	Kolazhy	13	1.99	-
OW-10	Kunnamkulam	15	-	3.67	BW-10	Peringandur	11	1.23	-
OW-11	Chavakkad	13	4.58	-	BW-11	Chengalur	11	1.50	-
OW-12	Pazhanji	6	1.30	-	BW-12	Muppliyam	12	1.31	-
OW-13	Nattika	14	0.46	-	BW-13	Mudicode	18	2.60	-
OW-14	Edamuttom	17	0.50	-	BW-14	Velapaya	10	-	1.13
OW-15	Mathilakam	14	-	0.42	BW-15	Kaiparambu	11	2.09	-
OW-16	Engadiyur	15	-	0.34	BW-16	Peechi	10	1.11	-
OW-17	Vaniyampara	14	-	1.05	BW-17	Chittilappilly	9	3.71	-
OW-18	Varandarappilly	15	-	0.52	BW-18	Nelluvayi	12	0.27	-
OW-19	Cherpu				BW-19	Kandanissery	13	-	0.24
OW-20	Puthur	12	-	0.29	Bw-20	Aloor	10	-	0.37
OW-21	Elavally	12	1.61	-	BW-21	Vellangallur	10	0.47	-
OW-22	Kadangode	10	1.51	-	BW-22	Wadakkancherry	13	1.93	-
OW-23	Wadakkancherry	9	0.54	-	BW-23	Varavur	10	2.11	-
					BW-24	Arthat	12	0.54	-

Table 5.15 Trend of Groundwater quality (iron) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	0.01	-	BW-1	Kaduppassery	10	0.00	-
OW-2	Mannuthi	12	-	0.05	BW-2	Mattathur	13	0.05	-
OW-3	Pattikkad	9	-	0.06	BW-3	Nellai	14	-	0.07
OW-4	Pudukkad	11	-	0.01	BW-4	Tholur	11	0.08	-
OW-5	Kodakara	11	0.03	-	BW-5	Trikkur	9	0.09	-
OW-6	Irinjalakuda	11	-	0.11	BW-6	Choondel	15	0.09	-
OW-7	M.G.Kavu	11	-	0.44	BW-7	Madakkathara	13	-	0.06
OW-8	Ottuppara	12	-	0.13	BW-8	Pananchery	8	-	0.03
OW-9	Chelakkara	13	-	0.03	BW-9	Kolazhy	12	-	0.36
OW-10	Kunnamkulam	12	-	0.02	BW-10	Athani	9	0.04	-
OW-11	Chavakkad	13	-	0.03	BW-11	Chengalur	11	0.05	-
OW-12	Pazhanji	5	-	0.01	BW-12	Muppliyam	11	-	0.32
OW-13	Nattika	12	-	0.01	BW-13	Mudicode	15	0.02	-
OW-14	Edamuttom	15	-	0.10	BW-14	Velapaya	10	-	0.10
OW-15	Mathilakam	13	0.01	-	BW-15	Kaiparambu	9	1.08	-
OW-16	Engadiyur	14	0.03	-	BW-16	Peechi	9	-	0.33
OW-17	Vaniyampara	13	-	0.02	BW-17	Chittilappilly	8	-	0.02
OW-18	Varandarappilly	15	-	0.04	BW-18	Nelluvayi	12	1.21	-
OW-19	Cherpu				BW-19	Kandanissery	12	0.87	-
OW-20	Puthur	12	-	0.05	BW-20	Aloor	8	0.58	-
OW-21	Elavally	10	0.01	-	BW-21	Vellangallur	9	1.96	-
OW-22	Kadangode	9	0.08	-	BW-22	Wadakkancherry	13	0.32	-
OW-23	Wadakkancherry	9	-	0.01	BW-23	Varavur	10	-	0.16
					BW-24	Arthat	12	0.35	-

easily under the existing anoxic conditions and thus the concentration of total iron in groundwater of this basin is high above the permissible level. In the coastal plain region, the concentration of iron in groundwater will be higher under reducing condition due to bacteriological attack on organic matter which leads to the formation of various humic and fluvic compounds (Applin and Zhao, 1989; White et al., 1991). Under reducing condition (in bore wells and tube wells), the iron from biotite mica and laterites are leached into solution in ferrous state and added to groundwater. Because of the above reasons the concentration iron is generally seen above permissible limit in the tropical areas especially in areas with laterite capping. The rusting of galvenised iron pipes used, as casing pipe is also a reason for high iron content in bore wells and tube wells. In high rainfall areas like Assam, Orissa and Kerala the total iron content ranges from 6.83 to 55 mg/l (Singhal and Gupta, 1999). The common method of removal of iron from water is by aeration followed by sedimentation.

5.2.1f Fluoride

In groundwater, fluorine occurs mainly as simple fluoride ion. It is capable of forming complexes with silicon and aluminium, and is believed to exist at a pH < 7. According to Indian Standard (IS 10500: 1991) the desirable and permissible limit of fluoride in groundwater is 1.0 and 1.50 mg/l respectively. The spatial distribution of fluoride in phreatic and semi-confined aquifer during pre and post monsoon periods of the study area is given in Figs. 5.6a-d. In phreatic as well as semi - confined aquifers during both seasons the fluoride contents are within permissible limit. The samples from dug wells of the MG Kavu, Chavakkad, Pudukkad, Mathilkam and Varandarapilli have given a fluoride concentration around 1.0 mg/l in one or two pre monsoon times. Similarly the bore wells at Panancherry, Nelluvai and Arthat have given same fluoride concentration during pre monsoon period. The distribution of fluoride for both seasons shows more or less an identical pattern and most of the samples show a fluoride value as traces (Tables. 5.6 & 5.7).

The long term trends of the fluoride concentration in both types of aquifers are given in Table 5.16. Out of 23 observation wells monitored, 6 numbers show an increasing trend while remaining 17 numbers show a declining trend. Similarly, In the case of 24 bore wells observed, 5 numbers shows a positive long term trend whereas the remaining 19 numbers show declining long term trend.

Table 5.16 Trend of groundwater quality (fluoride) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	0.05	BW-1	Kaduppassery	10	-	0.06
OW-2	Mannuthi	12	-	0.01	BW-2	Mattathur	14	-	0.06
OW-3	Pattikkad	9	-	0.12	BW-3	Nellai	14	0.03	-
OW-4	Pudukkad	11	0.02	-	BW-4	Tholur	12	-	0.03
OW-5	Kodakara	11		0.12	BW-5	Trikkur	9	-	0.08
OW-6	Irinjalakuda	11	-	0.09	BW-6	Choondel	15	-	0.06
OW-7	M.G.Kavu	11	0.04	-	BW-7	Madakkathara	13	-	0.05
OW-8	Ottuppara	12	-	0.03	BW-8	Pananchery	8	-	0.06
OW-9	Chelakkara	13	0.00	-	BW-9	Kolazhy	12	-	0.01
OW-10	Kunnamkulam	12	-	0.11	BW-10	Athani	10	-	0.02
OW-11	Chavakkad	13	0.10	-	BW-11	Chengalur	11	0.04	-
OW-12	Pazhanji	5	-	0.13	BW-12	Muppliyam	10	-	0.03
OW-13	Nattika	12	0.04	-	BW-13	Mudicode	15	-	0.08
OW-14	Edamuttom	15	-	0.12	BW-14	Velapaya	10	0.00	-
OW-15	Mathilakam	13	-	0.03	BW-15	Kaiparambu	10	-	0.07
OW-16	Engadiyur	14	0.06	-	BW-16	Peechi	10	-	0.06
OW-17	Vaniyampara	13	-	0.05	BW-17	Chittilappilly	9	-	0.12
OW-18	Varandarappilly	15	-	0.02	BW-18	Nelluvayi	12	-	0.06
OW-19	Cherpu				BW-19	Kandanissery	13	-	0.09
OW-20	Puthur	12	-	0.02	BW-20	Aloor	9	-	0.08
OW-21	Elavally	10	-	0.06	BW-21	Vellangallur	9	0.02	-
OW-22	Kadangode	9	-	0.10	BW-22	Wadakkancherry	12	-	0.04
OW-23	Wadakkancherry	9	-	0.04	BW-23	Varavur	10	-	0.02
					BW-24	Arthat	10	0.00	-

Fluoride is beneficial if presents in small concentrations (0.8 to 1.0 mg/l) in drinking water for calcification of dental enamel but it causes dental and skeletal fluorosis if present in higher amount (Table 5.17). High concentration of fluoride in drinking water is also linked with cancer (Smedly, 1992). In Kerala, high concentration of fluoride is recorded in certain coastal plain areas of Alappuzha district and in eastern side of Palakkad district. The fluride of coastal plain region of Alappuzha is probably derived from sediments during freshening process of associated groundwater (CGWB, 2003) and in Palakkad it is derived from Kankar and associated crystalline rocks.

Table 5.17 Impact of fluoride in drinking water on health (Dissanayake, 1991)

Sl.No	Concentration of fluoride (mg/l)	Impact on health
1	Nil	Limited growth and fertility
2	0 to 0.50	Dental caries
3	0.5 to 1.50	Promotes dental health
4	1.5 to 4.0	Dental fluorosis (mottling of teeth)
5	4.0 to 10	Dental and skeletal flurosis
6	>10	Crippling flurosis

5.2.1g Major cations and anions

Major cations and anions such as Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, SO_4^{-}, CO_3^{-}, HCO_3^{-}, and NO_3^{-} (Tables 5.6 & 5.7) were plotted in hydrochemical pattern and facies diagrams (Part 5.3 of this Chapter). Here, the spatial distribution of the major cations and anions and their desirable and permissible limits for drinking purpose are discussed with supporting data and diagrams of the study area.

Calcium: Calcium is one of the freely dissolving ions from many rocks and soils. The principal sources of calcium in groundwater are some members of silicate mineral groups like plagioclase, pyroxene and amphibole among igneous and metamorphic rocks and limestone, dolomite and gypsum among sedimentary rocks. Calcium is present in water as Ca^{++}, which forms complex with some organic anions. The presence of K and Na also influences the solubility of calcium. Concentration of calcium in normal potable groundwater generally ranges between 10 and 100 mg/l. Calcium in this concentration has no effect on the health of humans. The desirable and permissible limits of calcium in drinking water are 75 and 200 mg/l respectively. Indeed, as much as 1000 mg/l of calcium may be harmless.

Table 5.18 Trend of groundwater quality (calcium) in phreatic and semi- confined aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	3.63	BW-1	Kaduppassery	13	8.03	-
OW-2	Mannuthi	12	-	1.51	BW-2	Mattathur	16	9.59	-
OW-3	Pattikkad	10	1.13	-	BW-3	Nellai	15	3.43	-
OW-4	Pudukkad	12	0.92	-	BW-4	Tholur	12	1.46	-
OW-5	Kodakara	5	-	2.62	BW-5	Trikkur	9	4.47	-
OW-6	Irinjalakuda	11	-	7.53	BW-6	Choondel	16	1.18	-
OW-7	M.G.Kavu	13	0.25	-	BW-7	Madakkathara	16	10.40	-
OW-8	Ottupara	13	0.47	-	BW-8	Pananchery	8	-	9.96
OW-9	Chelakkara	15	4.86	-	BW-9	Kolazhy	13	5.00	-
OW-10	Kunnamkulam	15	-	0.04	BW-10	Athani	11	13.08	-
OW-11	Chavakkad	13	11.15	-	BW-11	Chengalur	12	0.97	-
OW-12	Pazhanji	6	-	0.88	BW-12	Muppliyam	12	-	1.32
OW-13	Nattika	14	6.37	-	BW-13	Mudicode	18	5.72	-
OW-14	Edamuttom	17	1.80	-	BW-14	Velapaya	11	2.24	-
OW-15	Mathilakam	14	3.92	-	BW-15	Kaiparambu	11	2.79	-
OW-16	Engadiyur	15	6.95	-	BW-16	Peechi	10	6.38	-
OW-17	Vaniyampara	14	0.27	-	BW-17	Chittilappilly	9	2.03	-
OW-18	Varandarappilly	15	-	0.19	BW-18	Nelluvayi	12	2.16	-
OW-19	Cherpu				BW-19	Kandanissery	13	4.18	-
OW-20	Puthur	12	1.93	-	BW-20	Aloor	10	5.18	-
OW-21	Elavally	12	2.18	-	BW-21	Vellangallur	10	1.46	-
OW-22	Kadangode	10	1.97	-	BW-22	Wadakkancharry	13	-	7.19
OW-23	Wadakkancherry	9	1.15	-	BW-23	Varavur	10	1.57	-
					BW-24	Arthat	12	0.39	-

The spatial distribution of calcium of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.7a-d. The calcium concentration of the basin varies from 10 to 110 mg/l and it is within the permissible limit proposed by BIS for drinking. The long term trend of cacium in the phreatic as well as semi -confined aquifers of the study area is given in Table 5.18. Out of 23 observation wells monitored, 15 numbers show an increasing long term trend and the remaining 8 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 21 numbers show positive long term trend and the remaining 3 wells show declining trend.

Magnesium: Magnesium is commonly associated with calcium and causes hardness of water. The geochemical behavior of Mg^{++} is altogether different from that of Ca^{++}. In igneous and metamorphic rocks magnesium occurs in the form of insoluble silicates, weathering breaks them down into more soluble carbonates, clay minerals and silica. Concentration of magnesium in groundwater attains a rather wide range. The desirable and permissible limits of magnesium in drinking water are 30 and 100 mg/l respectively.

The concentration of magnesium both in phreatic and semi-confined aquifers in the study area is vary from 0.5 to 26 mg/l (Figs. 5.8a-d), which is below the desirable limit recommended by BIS.

The long term trend of calcium in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.19. Out of 23 observation wells monitored, 9 wells show an increasing long term trend and the remaining 14 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 12 wells show positive long term trend and the remaining 12 wells show declining trend.

Sodium: Sodium (unlike calcium, magnesium and silica) is not found as an essential constituent of many of the common rock forming minerals. The primary source of most sodium in natural water is from the release of soluble products during the weathering of plagioclase feldspars. The most important source of sodium in groundwater, with concentration of over 50 mg/l of sodium is the precipitation of sodium salts impregnating the soil in shallow water tracks, particularly in arid and semi-arid regions. Certain clay minerals and zeolites can increase the sodium content in groundwater by Base Exchange reactions.

Table 5.19 Trend of groundwater quality (magnesium) in phreatic and semi- confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

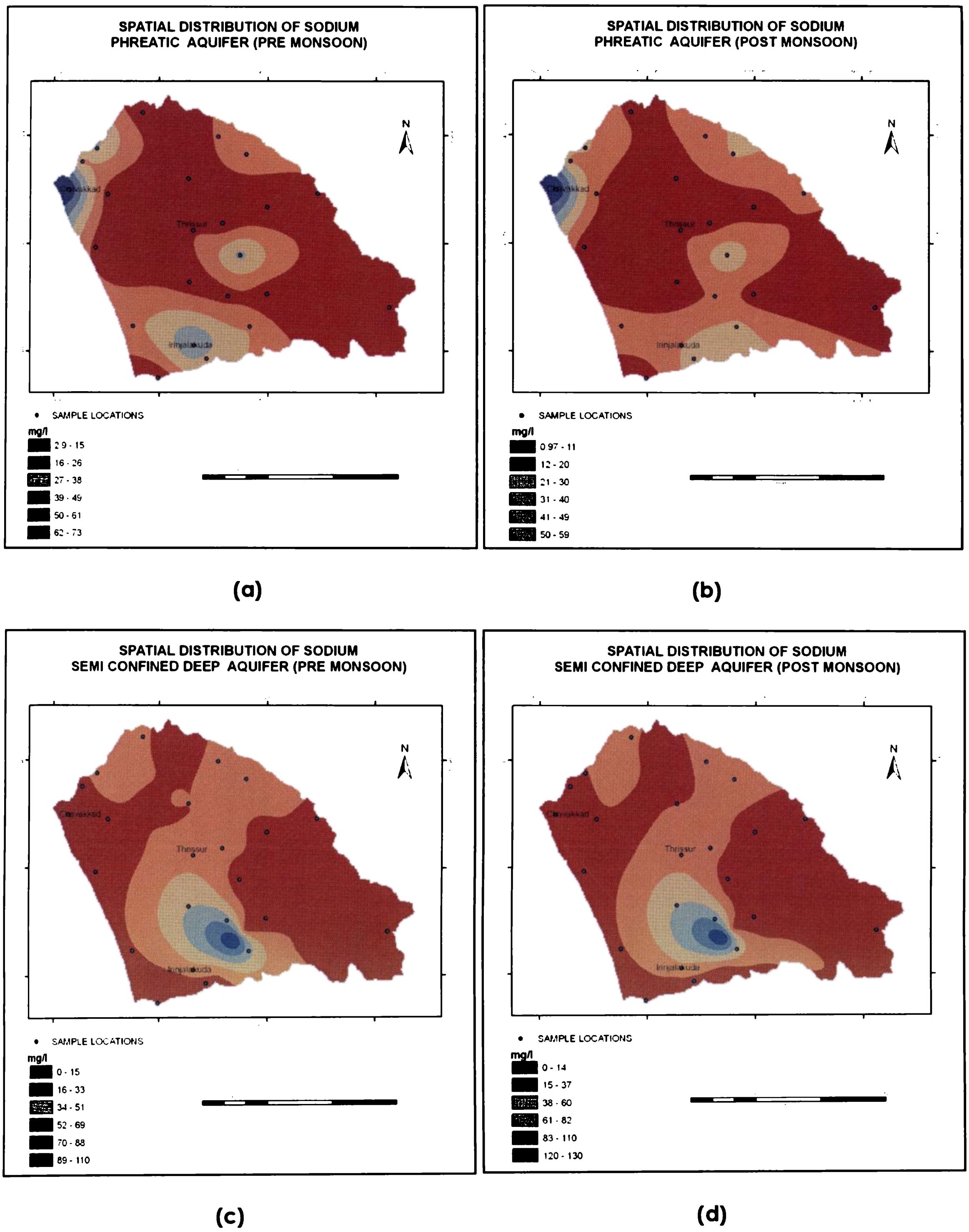
Phreatic aquifer (Dug well)					Semi confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	0.05	-	BW-1	Kaduppassery	13	-	2.61
OW-2	Mannuthi	12	0.34	-	BW-2	Mattathur	16	-	0.17
OW-3	Pattikkad	10	-	0.74	BW-3	Nellai	15	0.91	-
OW-4	Pudukkad	12	0.19	-	BW-4	Tholur	12	-	0.01
OW-5	Kodakara	5	0.09	-	BW-5	Trikkur	9	1.55	-
OW-6	Irinjalakuda	11	-	0.82	BW-6	Choondel	16	-	0.28
OW-7	M.G.Kavu	13	-	0.33	BW-7	Madakkathara	16	-	0.36
OW-8	Ottupara	13	-	0.14	BW-8	Pananchery	8	0.57	-
OW-9	Chelakkara	15	-	0.51	BW-9	Kolazhy	13	-	0.67
OW-10	Kunnamkulam	15	-	0.52	BW-10	Athani	11	1.50	-
OW-11	Chavakkad	13	-	0.54	BW-11	Chengalur	12	0.21	-
OW-12	Pazhanji	6	-	0.41	BW-12	Muppliyam	12	-	1.74
OW-13	Nattika	14	-	0.56	BW-13	Mudicode	18	0.33	-
OW-14	Edamuttom	17	-	0.51	BW-14	Velapaya	11	0.19	-
OW-15	Mathilakam	14	0.10	-	BW-15	Kaiparambu	11	0.33	-
OW-16	Engadiyur	15	0.44	-	BW-16	Peechi	10	1.21	-
OW-17	Vaniyampara	14	-	0.25	BW-17	Chittilappilly	9	0.29	-
OW-18	Varandarappilly	15	0.31	-	BW-18	Nelluvayi	12	-	1.16
OW-19	Cherpu				BW-19	Kandanissery	13	-	0.13
OW-20	Puthur	12	1.08	-	BW-20	Aloor	10	1.81	-
OW-21	Elavally	12	-	0.42	BW-21	Vellangallur	10	0.51	-
OW-22	Kadangode	10	-	0.17	BW-22	Wadakkancharry	13	-	0.82
OW-23	Wadakkancherry	9	0.49	-	BW-23	Varavur	10	-	2.00
					BW-24	Arthat	12	-	0.31

The concentration of sodium in phreatic aquifer varies from 1.0 to 73 mg/l (Chavakkad). While in semi- confined deep aquifer it varies from 1 to 130mg/l. The maximum concentration in semi-confined aquifer is seen in the south central part of the basin around Irinjalakuda and Nellai (Figs. 5.9a to d). The long term trend of sodium in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.20. Out of 23 observation wells monitored, 13 wells show an increasing long term trend and the remaining 10 show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 18 wells show positive long term trend and the remaining 6 wells show declining trend.

Potassium: The sources of potassium are the products formed by the weathering of orthoclase, microcline, biotite, leucite, and nepheline in igneous and metamorphic rocks. The abundance of potassium in the earth's crust is about the same as sodium and potassium which is commonly less than one tenth of the concentration of sodium in natural water.

The spatial distribution of calcium of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.10a-d. The potassium concentration in the phreatic aquifer of the basin varies from 1 to 30 mg/l. While in semi-confined deep aquifer its concentration is below 10mg/l. The long term trend of potassium in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.21. Out of 23 observation wells monitored, 8 wells show an increasing long term trend and the remaining 15 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored, 10 wells show positive long term trend and the remaining 14 wells show declining trend.

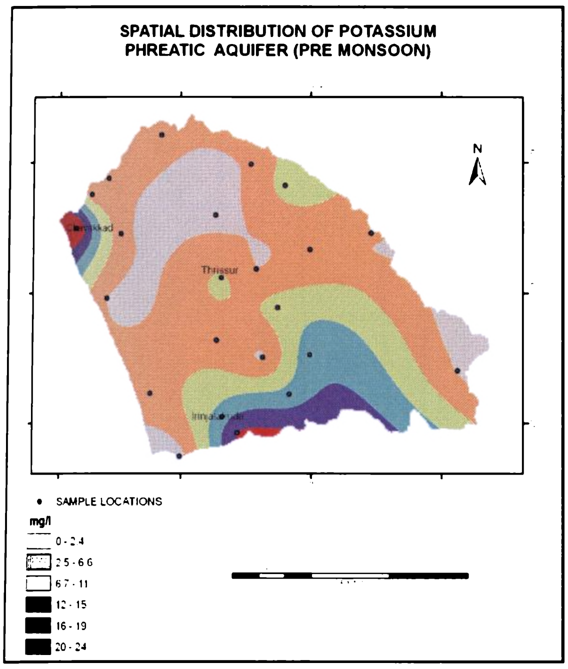
Chloride: Chloride is a minor constituent in the earth's crust, but a major dissolved constituent of most natural water. Chloride bearing minerals such as sodalite and chlorapatite, which are very minor constituents of igneous and metamorphic rocks, and liquid inclusions, which comprise very significant fraction of rock volume, are minor source of chloride in groundwater. Most of the chloride in groundwater is present as sodium chloride but chloride concentration may exceed the sodium due



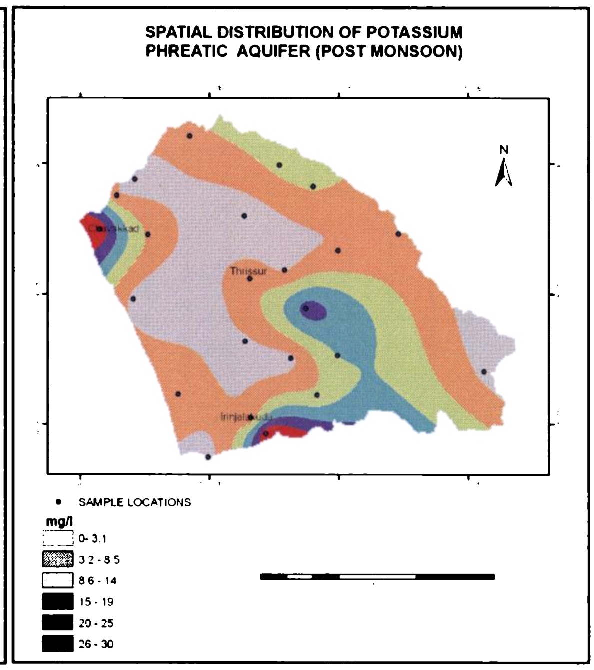
Figs. 5.9a-d Spatial distribution of Sodium in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.20 Trend of groundwater quality (sodium) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

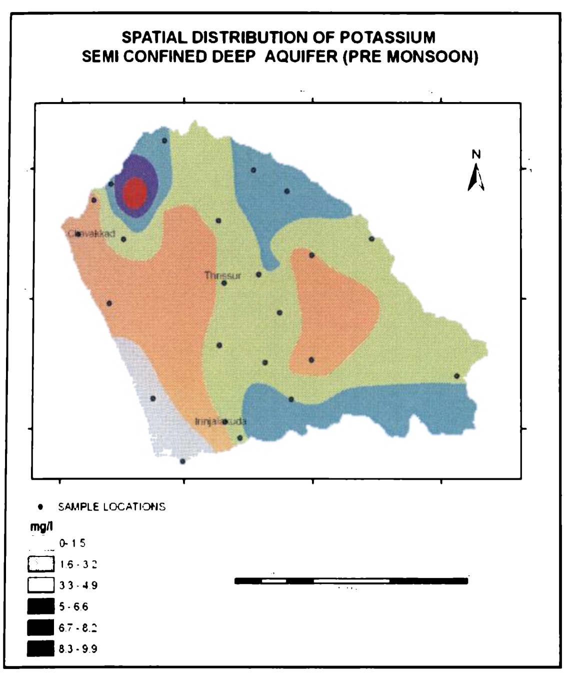
Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	0.17	-	BW-1	Kaduppassery	12	2.80	-
OW-2	Mannuthi	12	-	0.21	BW-2	Mattathur	15	-	0.98
OW-3	Pattikkad	10	0.32	-	BW-3	Nellai	15	8.97	-
OW-4	Pudukkad	12	-	0.88	BW-4	Tholur	12	-	0.54
OW-5	Kodakara	5	4.13	-	BW-5	Trikkur	9	0.88	-
OW-6	Irinjalakuda	11	-	1.00	BW-6	Choondel	16	-	0.51
OW-7	M.G.Kavu	13	1.26	-	BW-7	Madakkathara	16	2.12	-
OW-8	Ottuppara	13	0.24	-	BW-8	Pananchery	8	4.99	-
OW-9	Chelakkara	15	0.68	-	BW-9	Kolazhy	13	1.99	-
OW-10	Kunnamkulam	15	-	3.67	BW-10	Peringandur	11	1.23	-
OW-11	Chavakkad	13	4.58	-	BW-11	Chengalur	11	1.50	-
OW-12	Pazhanji	6	1.30	-	BW-12	Muppliyam	12	1.31	-
OW-13	Nattika	14	0.46	-	BW-13	Mudicode	18	2.60	-
OW-14	Edamuttom	17	0.50	-	BW-14	Velapaya	10	-	1.13
OW-15	Mathilakam	14	-	0.42	BW-15	Kaiparambu	11	2.09	-
OW-16	Engadiyur	15	-	0.34	BW-16	Peechi	10	1.11	-
OW-17	Vaniyampara	14	-	1.05	BW-17	Chittilappilly	9	3.71	-
OW-18	Varandarappilly	15	-	0.52	BW-18	Nelluvayi	12	0.27	-
OW-19	Cherpu				BW-19	Kandanissery	13	-	0.24
OW-20	Puthur	12	-	0.29	Bw-20	Aloor	10	-	0.37
OW-21	Elavally	12	1.61	-	BW-21	Vellangallur	10	0.47	-
OW-22	Kadangode	10	1.51	-	BW-22	Wadakkancherry	13	1.93	-
OW-23	Wadakkancherry	9	0.54	-	BW-23	Varavur	10	2.11	-
					BW-24	Arthat	12	0.54	-



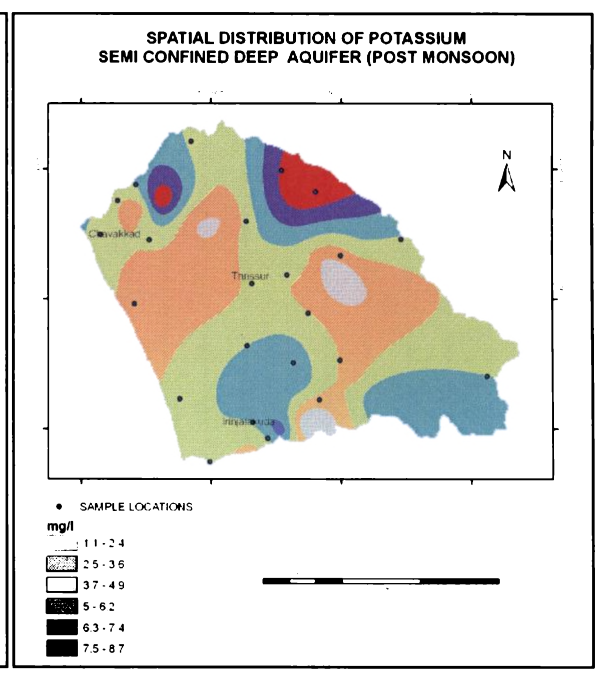
(a)



(b)



(c)



(d)

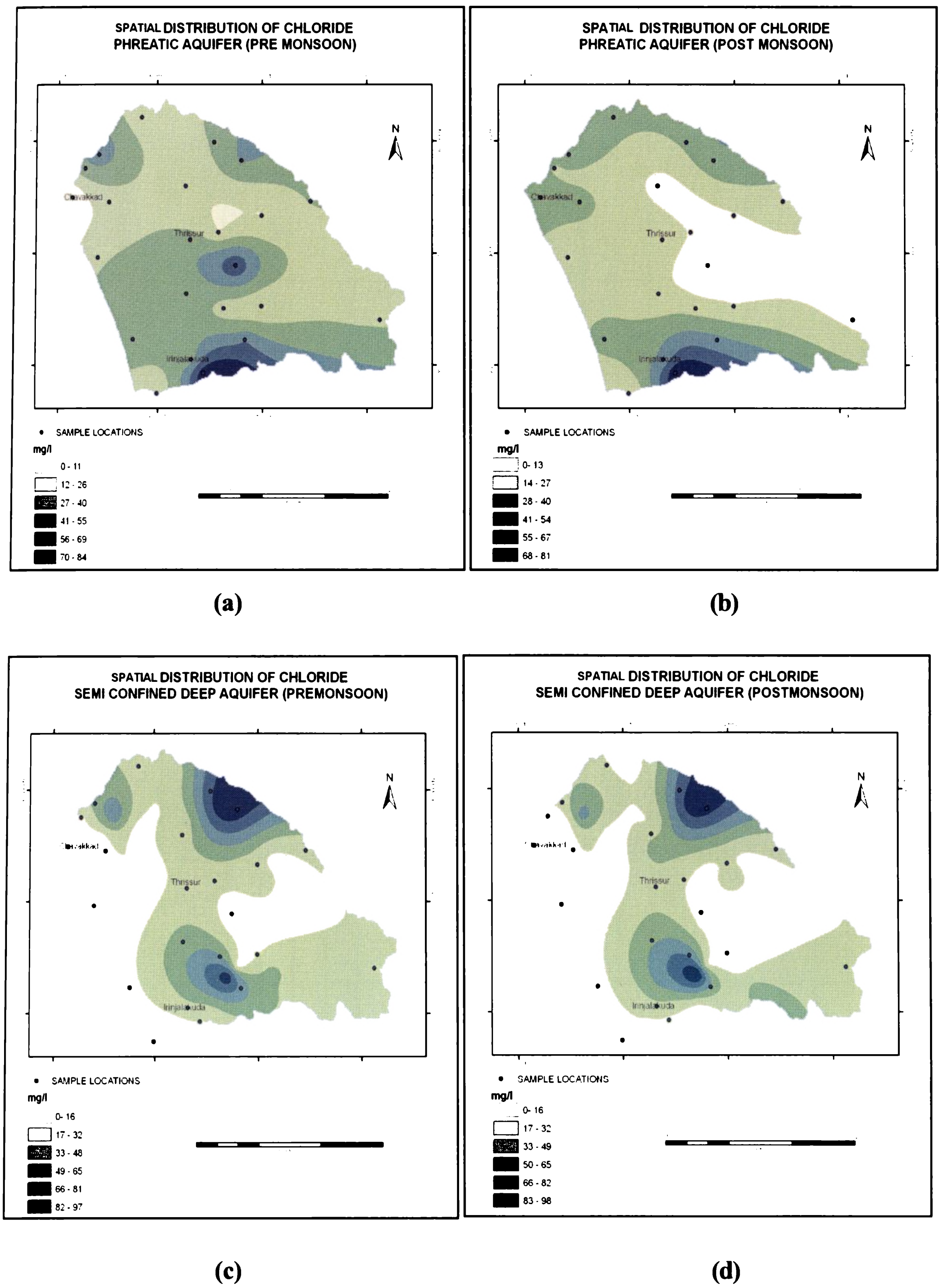
Figs. 5.10a-d Spatial distribution of Potassium in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

to Base Exchange phenomena. Chloride in water is a stronger oxidising agent than oxygen and chlorine with oxygen slowly decompose water. The permissible and desirable limit of chloride in water, proposed by Indian Standard (IS 10500: 1991) is 250 and 1000 mg/l respectively.

The spatial distribution of chloride of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.11a-d. The chloride concentration in the phreatic as well as semi-confined aquifer of the basin is varies from 1 to 95 mg/l, which is very below the permissible limit proposed by BIS. The long term trend of potassium in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.22. Out of 23 observation wells monitored, 15 wells show an increasing long term trend and the remaining 8 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored, 16 wells show positive long term trend and the remaining 8 wells show declining trend.

Sulphate: Usually in waters, sulphate is found in smaller concentrations than chloride. The sources of sulphate in water are sulphur minerals, sulphides of heavy metals, which are of common occurrence in the igneous and metamorphic rock, and gypsum and anhydrite found in some sedimentary rocks. The sulphate content of atmospheric precipitation is only about 2 mg/l but a wide range in sulphate content in groundwater is made possible through reduction, precipitation, solution and concentration as the water traverses through rocks. The permissible and desirable limit of sulphate in drinking water, proposed by Indian Standard (IS 10500: 1991) is 200 and 400 mg/l respectively.

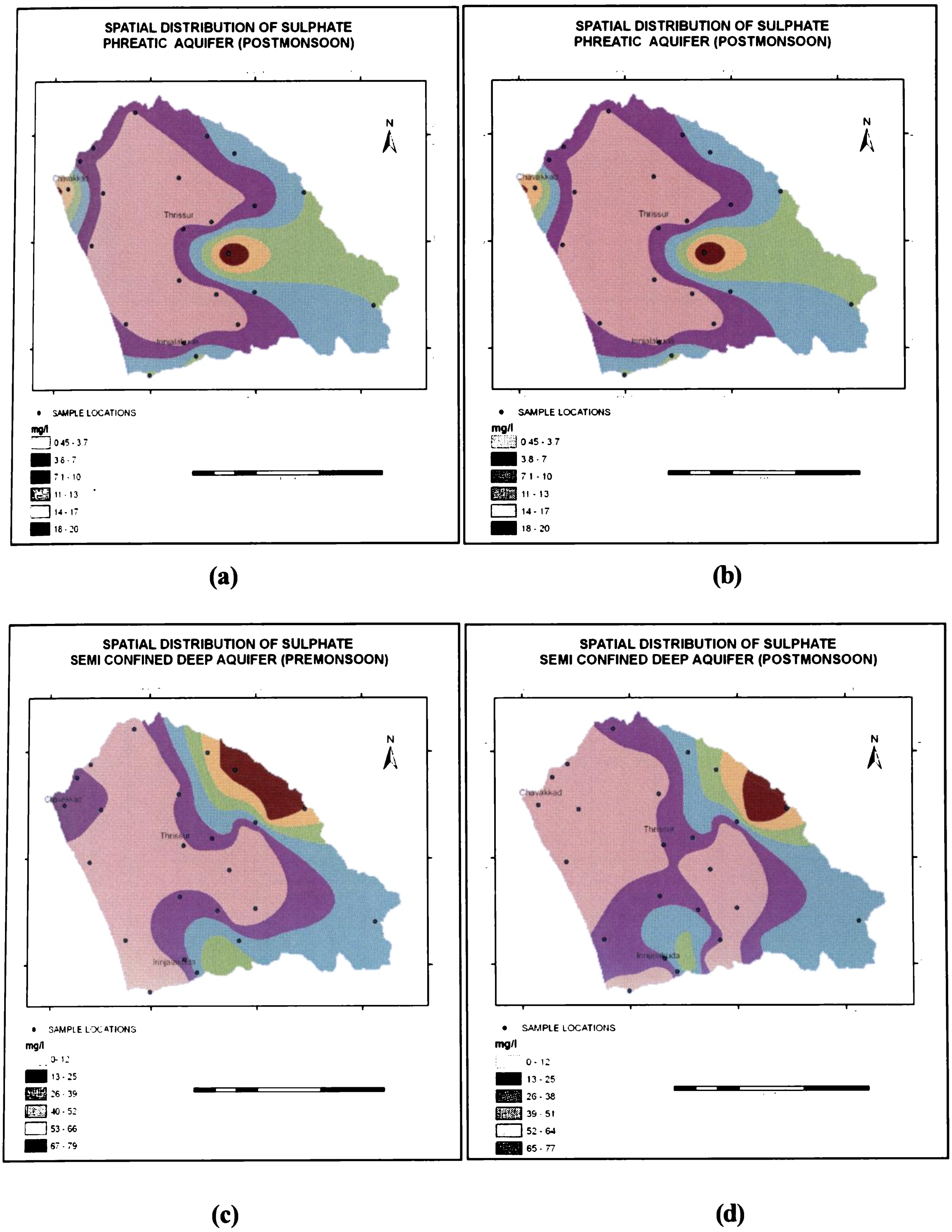
The spatial distribution of sulphate of both phreatic and semi -confined aquifers of the basin in pre and post monsoon periods are given in Figs. 5.12a-d. The sulphate concentration in the phreatic aquifer of the basin varies from 1 to 20 mg/l while in semi-confined aquifer from 1 to 80 mg/l, which are very below the permissible limit proposed by BIS. The long term trend of sulphate in the phreatic as well as semi -confined aquifers of the study area is given in Table 5.23. Out of 23 observation wells monitored, 14 wells show an increasing long term trend and the remaining 9 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 16, wells show positive long term trend and the remaining 8 wells show declining trend.



Figs. 5.11a-d Spatial distribution of Chloride in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

Table 5.22 Trend of groundwater quality (chloride) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phareatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analaysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Chembukavu	5	0.114	-	BW-1	Kaduppassery	12	1.302	-
OW-2	Mannuthi	12	0.021	-	BW-2	Mattathur	16	-	0.401
OW-3	Pattikkad	10	-	0.386	BW-3	Nellai	15	14.686	-
OW-4	Pudukkad	12	-	0.126	BW-4	Tholur	12	0.389	-
OW-5	Kodakara	5	6.659	-	BW-5	Trikkur	9	1.500	-
OW-6	Irinjalakuda	11	-	15.656	BW-6	Choondel	16	-	4.483
OW-7	M.G.Kavu	13	0.774	-	BW-7	Madakkathara	16	2.974	-
OW-8	Ottuppara	13	1.020	-	BW-8	Pananchery	8	-	3.138
OW-9	Chelakkara	15	-	1.264	BW-9	Kolazhy	13	0.607	-
OW-10	Kunnamkulam	15	-	7.855	BW-10	Athani	11	-	1.128
OW-11	Chavakkad	13	5.302	-	BW-11	Chengalur	12	1.959	-
OW-12	Pazhanji	6	0.242	-	BW-12	Muppliyam	12	7.046	-
OW-13	Nattika	14	0.028	-	BW-13	Mudicode	18	1.240	-
OW-14	Edamuttom	17	1.774	-	BW-14	Velapaya	11	-	2.363
OW-15	Mathilakam	14	-	0.365	BW-15	Kaiparambu	11	0.104	-
OW-16	Engadiyur	15	0.370	-	BW-16	Peechi	10	-	0.231
OW-17	Vaniyampara	14	-	0.630	BW-17	Chittilappilly	9	0.377	-
OW-18	Varandarappilly	15	0.482	-	BW-18	Nelluvayi	12	1.154	-
OW-19	Cherpu				BW-19	Kandanissery	13	0.432	-
OW-20	Puthur	12	-	0.904	BW-20	Aloor	10	-	0.392
OW-21	Elavally	12	8.439	-	BW-21	Vellangallur	10	0.019	-
OW-22	Kadangode	10	7.118	-	BW-22	Wadakkancherry	13	-	3.147
OW-23	Wadakkancherry	9	5.043	-	BW-23	Varavur	10	0.750	-
					BW-24	Arthat	12	1.185	-



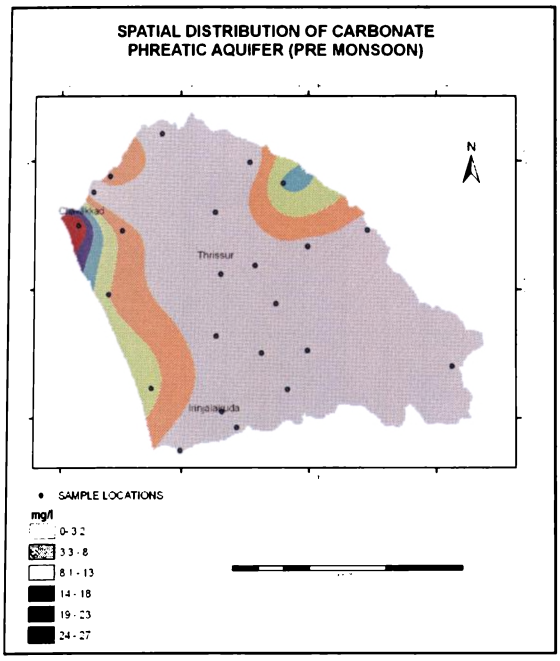
Figs. 5.12a-d Spatial distribution of Sulphate in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

Carbonates and bicarbonates: Most of the carbonates and bicarbonates ions in groundwater are derived from the carbon dioxide in the atmosphere, soil and dissolution of carbonate rocks. These two constituents along with hydroxides are responsible for the alkalinity of water. The relative amounts of these two anions depend on the pH of the water and other factors. Bicarbonates increase as pH decreases.

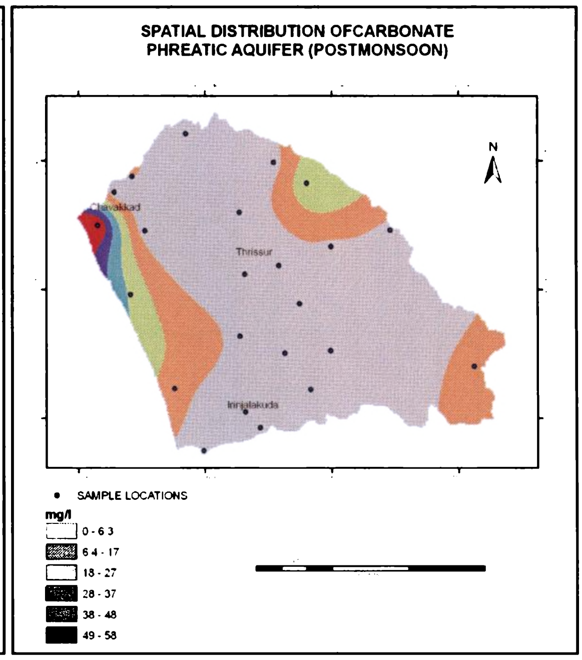
The spatial distribution of carbonate of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.13a-d. The carbonate concentration in the phreatic aquifer of the basin varies from 1 to 58 mg/l and of semi - confined aquifer from 1 to 32 mg/l. The long term trend of carbonate in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.24. Out of 23 observation wells monitored, 21 wells show an increasing long term trend and the remaining 2 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored, 20 wells show positive long term trend and the remaining 4 wells show declining trend.

The spatial distribution of bicarbonates of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.14a-d. The bicarbonate concentration in the phreatic aquifer of the basin varies from 1 to 290 mg/l and of semi-confined aquifer from 6 to 230 mg/l. The long term trend of bicarbonate in the phreatic as well as semi - confined aquifers of the study area is given in Table 5.25. Out of 23 observation wells monitored, 13 wells show an increasing long term trend and the remaining 10 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 18 wells show positive long term trend and the remaining 6 wells show declining trend.

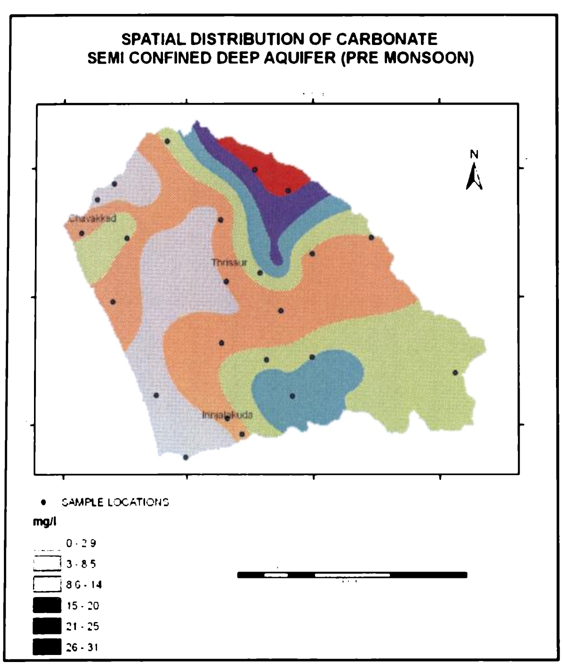
Nitrate: Nitrate in the groundwater is a measure of surface contamination and poor well hygiene. The desirable and permissible limits proposed by Indian Standard (IS 10500: 1991) are 45 and 100 mg/l respectively. The higher value of nitrate in groundwater is an indication of surface contamination.



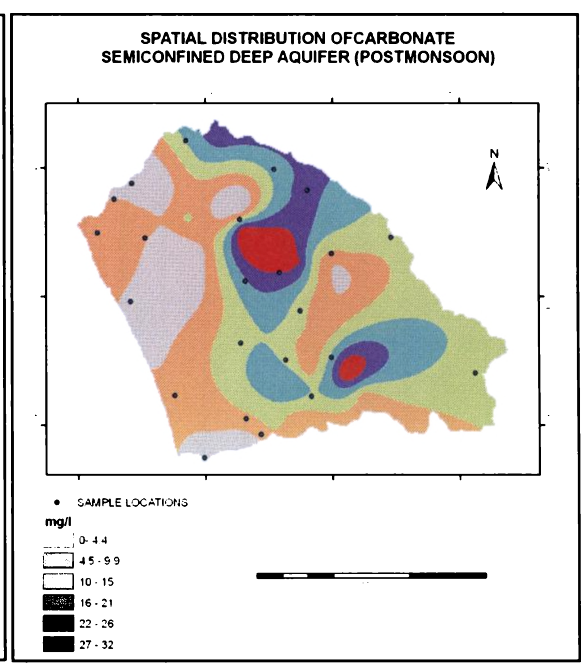
(a)



(b)



(c)

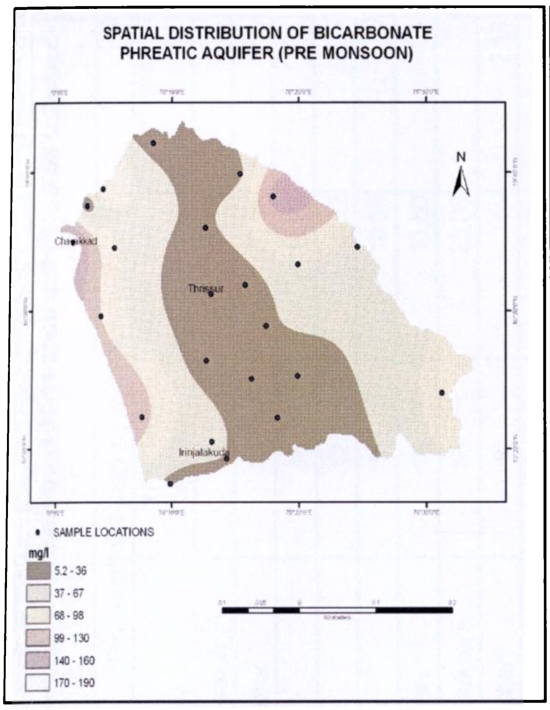


(d)

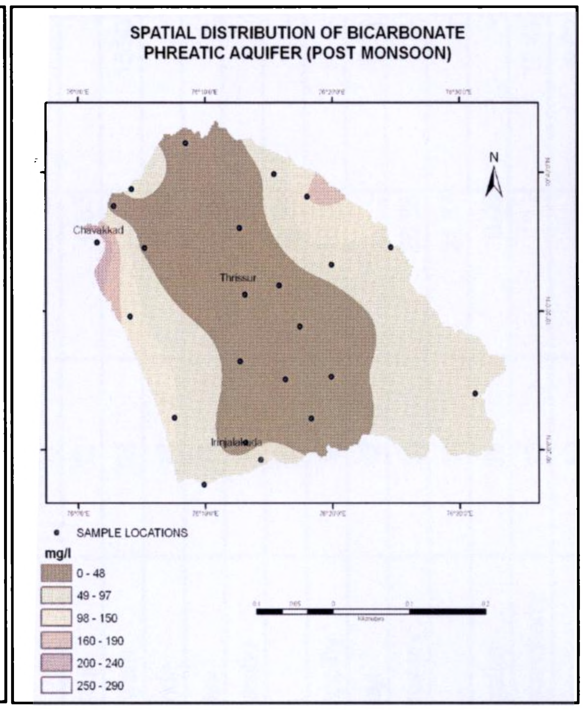
Figs. 5.13a-d Spatial distribution of Carbonate in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

Table 5.24 Trend of groundwater quality (carbonate) in phreatic aquifer and semi-confined aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

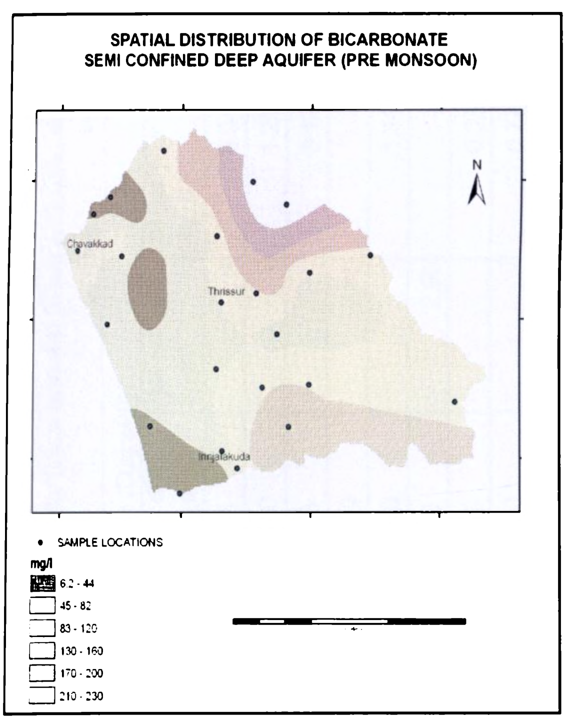
Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	0.403	BW-1	Kaduppassery	13	8.08	-
OW-2	Mannuthi	11	0		BW-2	Mattathur	16	3.86	-
OW-3	Pattikkad	9	0.08	-	BW-3	Nellai	15	4.84	-
OW-4	Pudukad	10	0.00		BW-4	Tholur		0.00	
OW-5	Kodakara	5	0.00		BW-5	Trikkur	9	4.95	-
OW-6	Irinjalakuda	11	0.00		BW-6	Choondel		0.00	
OW-7	M.G.Kavu	12	0.00		BW-7	Madakkathara	16	6.55	-
OW-8	Ottuppara	11	-	0.405	BW-8	Pananchery	8	-	4.75
OW-9	Chelakkara	12	4.44	-	BW-9	Kolazhy	13	5.97	-
OW-10	Kunnamkulam	13	1.20	-	BW-10	Athani	11	4.06	-
OW-11	Chavakkad	12	9.47	-	BW-11	Chengalur	12	0.68	-
OW-12	Pazhanji	5	0.00		BW-12	Muppliyam	12	-	2.37
OW-13	Nattika	12	3.18	-	BW-13	Mudicode	18	5.23	-
OW-14	Valappad	14	0.54	-	BW-14	Velapaya	11	1.85	-
OW-15	Edamuttom	11	0.22	-	BW-15	Kaiparambu	11	1.53	-
OW-16	Engadiyur	12	3.78	-	BW-16	Peechi	10	0.11	-
OW-17	Vaniyampara	11	0.82	-	BW-17	Chittilappilly	9	-	0.42
OW-18	Varandarappilly	13	0.00		BW-18	Nelluvayi	12	0.44	-
OW-19	Cherpu	11	0.00		BW-19	Kandanissery	13	-	0.73
OW-20	Puthur	11	0.67	-	BW-20	Aloor	10	2.13	-
OW-21	Elavally	11	0.00		BW-21	Vellangallur	10	0.88	-
OW-22	Kadangode	10	0.46	-	BW-22	Wadakkancherry	13	0.84	-
OW-23	Wadakkancherry	8	0.00		BW-23	Varavur	10	4.26	-
					BW-24	Arthat	12	0.92	-



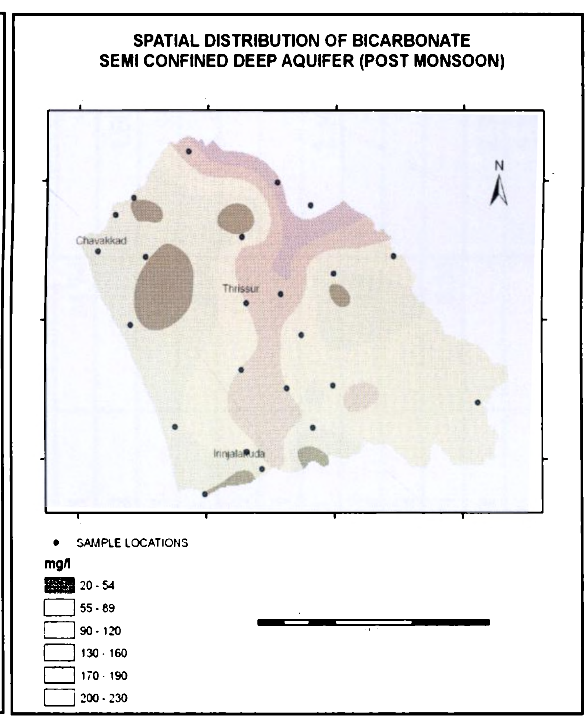
(a)



(b)



(c)



(d)

Fig.. 5.14a-d Special distribution of Bicarbonate in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

Table 5.25 Trend of groundwater quality (bicarbonate) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

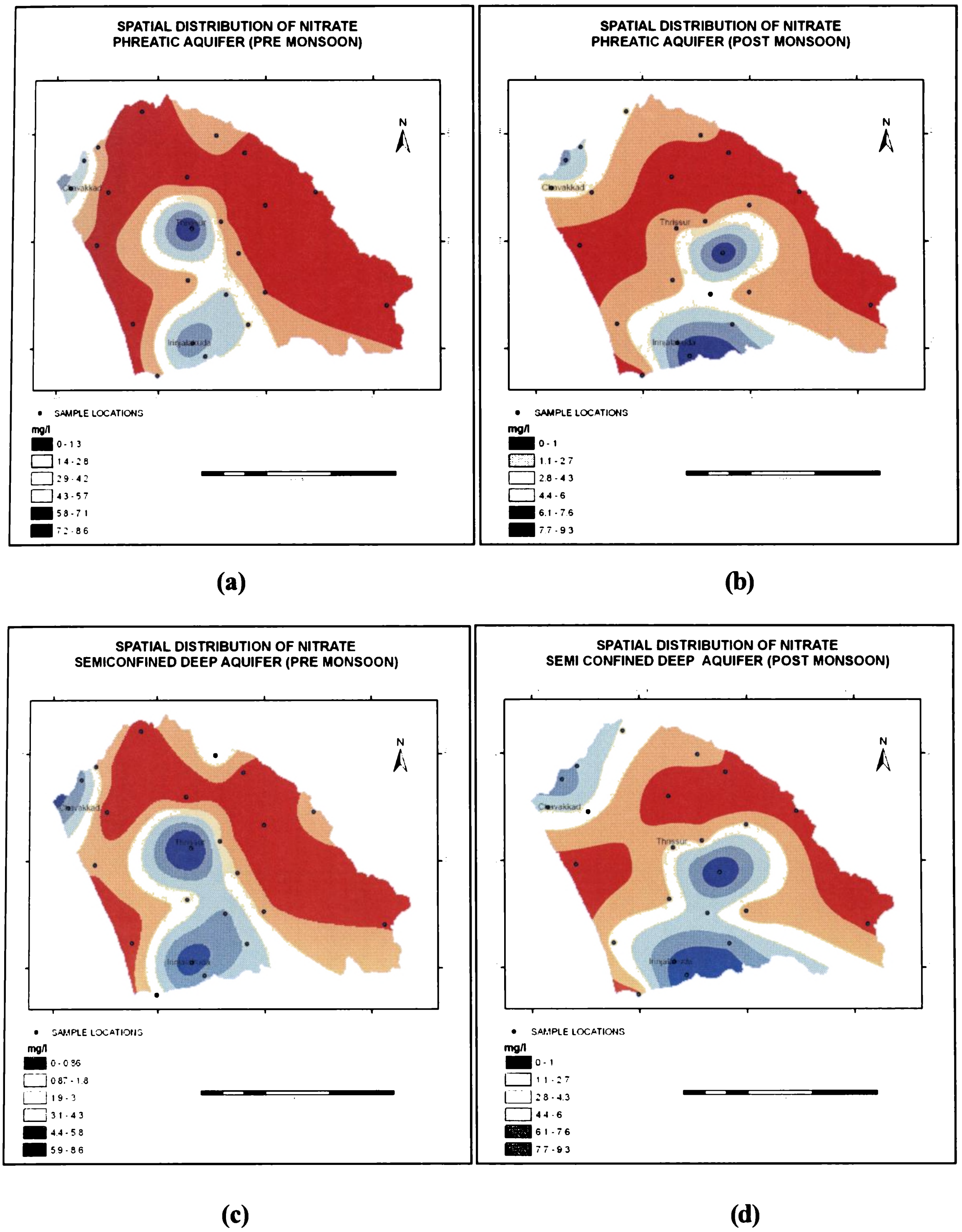
Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	6.94	BW-1	Kaduppassery	13	13.17	-
OW-2	Mannuthi	10	-	1.29	BW-2	Mattathur	16	20.57	-
OW-3	Pattikkad	8	-	0.19	BW-3	Nellai	15	18.66	-
OW-4	Pudukkad	10	2.40	-	BW-4	Tholur	12	3.92	-
OW-5	Kodakara	10	-	1.34	BW-5	Trikkur	9	10.39	-
OW-6	Irinjalakuda	9	2.90	-	BW-6	Choondel	16	13.60	-
OW-7	M.G.Kavu	7	-	0.33	BW-7	Madakkathara	16	25.36	-
OW-8	Ottupara	10	-	0.77	BW-8	Pananchery	8	-	2.18
OW-9	Chelakkara	11	16.87	-	BW-9	Kolazhy	13	6.98	-
OW-10	Kunnamkulam	12	2.58	-	BW-10	Athani	11	36.32	-
OW-11	Chavakkad	11	24.74	-	BW-11	Chengalur	12	0.63	-
OW-12	Pazhanji	12	-	1.69	BW-12	Muppliyam	12	-	15.90
OW-13	Nattika	11	13.52	-	BW-13	Mudicode	18	11.39	-
OW-14	Valappad	6	2.60	-	BW-14	Velapaya	11	8.58	-
OW-15	Mathilakam	11	11.29	-	BW-15	Kaiparambu	11	15.03	-
OW-16	Engadiyur	11	10.16	-	BW-16	Peechi	10	35.58	-
OW-17	Vaniyampara	6	-	2.40	BW-17	Chittilappilly	9	16.29	-
OW-18	Varandarappilly	13	1.87	-	BW-18	Nelluvayi	12	-	6.50
OW-19	Cherpu	12			BW-19	Kandanissery	13	20.55	-
OW-20	Puthur	11	5.34	-	BW-20	Aloor	10	21.67	-
OW-21	Elavally	9	-	2.36	BW-21	Vellangallur	10	9.46	-
OW-22	Kadangode	7	-	0.79	BW-22	Wadakkancherry	13	-	17.41
OW-23	Wadakkancherry	8	1.74	-	BW-23	Varavur	10	-	9.62
					BW-24	Arthat	12	-	3.74

The spatial distribution of nitrate of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.15a-d. The nitrate concentration in the phreatic aquifer of the basin varies from 1 to 10 mg/l and of semi - confined aquifer from 0.5 to 9.5 mg/l, which are very below the permissible limit proposed by BIS. The long term trend of nitrate in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.26. Out of 23 observation wells monitored, 18 wells show an increasing long term trend and the remaining 5 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored 12 wells show positive long term trend and the remaining 12 wells show declining trend.

5.2.1h Alkalinity

Alkalinity is defined as the capacity of water to accept H^+ ions (protons). Alkalinity is important in water treatment, and in the chemistry and biology of natural waters. Frequently, the alkalinity of water must be known to calculate the quantities of chemical to be added in treating the water. Generally the basic species responsible for alkalinity in water are bicarbonate, carbonate and hydroxyl ions. In groundwater samples it is considered as the total concentration of carbonates and bicarbonates. Alkalinity is a measure of buffering capacity of water. The alkalinity of groundwater increases when pH decreases. The desirable and permissible limits suggested by the Indian Standard (IS 10500: 1991) are 200 and 600 mg/l respectively.

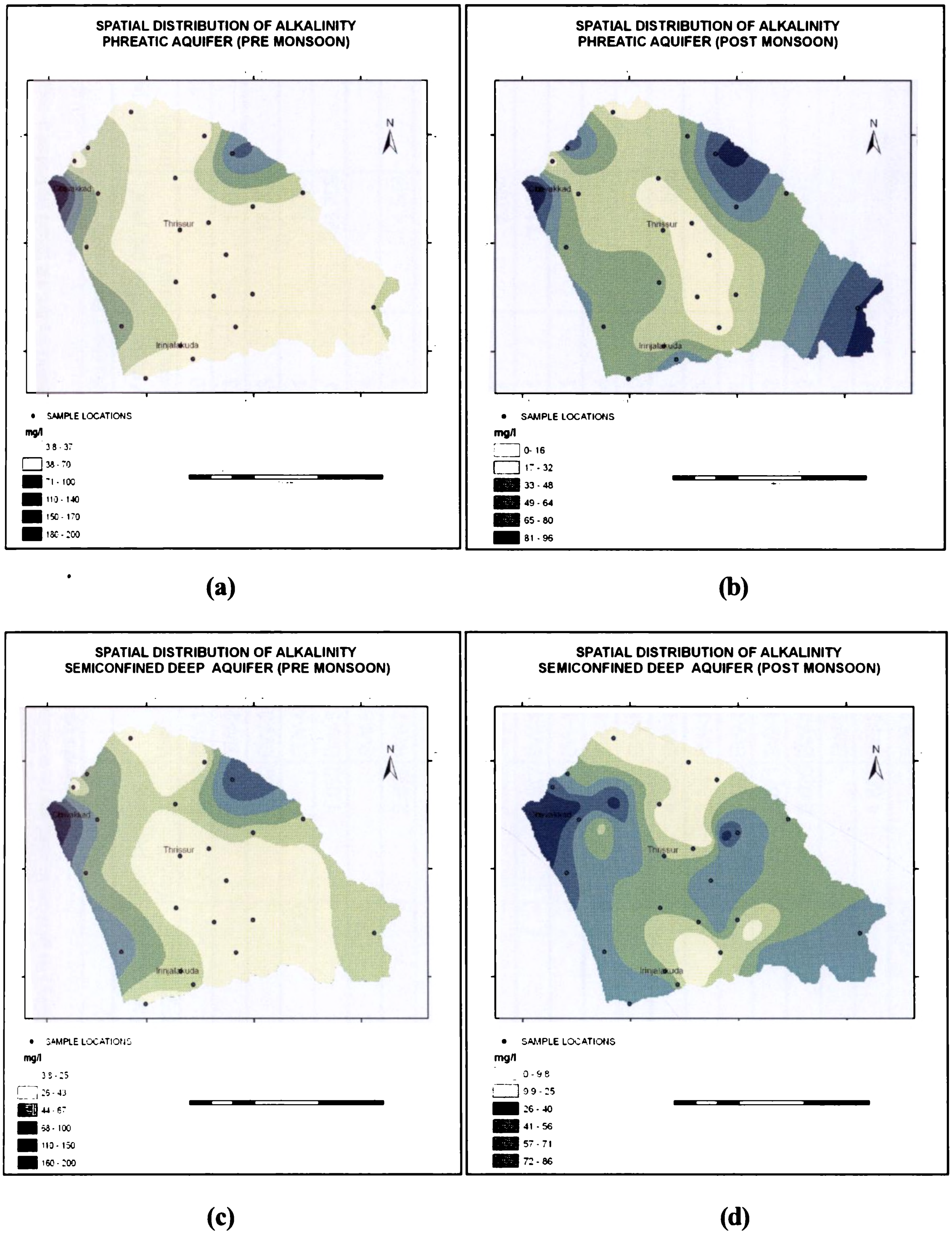
The spatial distribution of alkalinity of both phreatic and semi-confined aquifers of the basin in pre and post monsoon periods is given in Figs. 5.16a-d. The alkalinity concentration in the phreatic aquifer of the basin varies from 3 to 200 mg/l during pre monsoon and 1 to 100mg/l during post monsoon (Figs. 5.16a & b). The same pattern is repeated in the case of semi-confined aquifer of the basin. The alkalinity suddenly decreases after monsoon both in phreatic as well as semi - confined aquifers. The long term trend of nitrate in the phreatic as well as semi-confined aquifers of the study area is given in Table 5.27. Out of 23 observation wells monitored, 18 wells show an increasing long term trend and the remaining 5 wells show declining trend. In the case of semi-confined aquifer, out of 24 bore wells monitored, 12 wells show positive long term trend and the remaining 12 wells show declining trend.



Figs. 5.15a-d Spatial distribution of Nitrate in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

Table 5.26 Trend of groundwater quality (nitrate) in phreatic and semi-confined deep aquifers for the period 01.01.2000 to 31.12.2006 in Palaeo-lagoon.

Phreatic aquifer (Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No.of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No.of data anlysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	1.10	BW-1	Kaduppassery	7	0.19	-
OW-2	Mannuthi	10	-	0.11	BW-2	Mattathur	6	-	0.02
OW-3	Pattikkad	8	0.41	-	BW-3	Nellai	5	-	0.26
OW-4	Pudukkad	10	0.18	-	BW-4	Tholur	11		0.72
OW-5	Kodakara				BW-5	Trikkur	10	-	
OW-6	Irinjalakuda	9	0.10	' -	BW-6	Choondel	13	0.22	-
OW-7	M.G.Kavu	7	-	0.05	BW-7	Madakkathara	12	0.40	-
OW-8	Ottupara	10	0.59	-	BW-8	Pananchery	8	1.50	-
OW-9	Chelakkara	11	0.27	-	BW-9	Kolazhy	7	0.48	-
OW-10	Kunnamkulam	12	-	0.74	BW-10	Athani	7	-	0.26
OW-11	Chavakkad	11	-	0.10	BW-11	Chengalur	10	-	0.09
OW-12	Pazhanji				BW-12	Muppliyam	5	0.21	-
OW-13	Nattika	11	0.28	-	BW-13	Mudicode	5	0.47	-
OW-14	Valappad	6	2.02	-	BW-14	Velapaya	10		1.38
OW-15	Mathilakam	11	0.01	-	BW-15	Kaiparambu	6		0.11
OW-16	Engadiyur	11	0.07	-	BW-16	Peechi	7	-	0.22
OW-17	Vaniyampara	6	0.55	-	BW-17	Chittilappilly	8		
OW-18	Varandarappilly	13	0.15	-	BW-18	Nelluvayi	5	-	0.27
OW-19	Cherpu				BW-19	Kandanissery	6	-	0.12
OW-20	Puthur	11	0.21	-	BW-20	Aloor	7	-	0.38
OW-21	Elavally	9	0.75	-	BW-21	Vellangallur	6	-	0.33
OW-22	Kadangode	7	1.38	-	BW-22	Wadakkancherry	8	0.08	-
OW-23	Wadakkancherry	8	1.48	-	BW-23	Varavur	6	0.05	-
					BW-24	Arthat	5	0.31	-



Figs. 5.16a-d Spatial distribution of Alkalinity in phreatic (dug wells) and semi-confined deep aquifers (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006.

Table 5.27 Trend of groundwater quality (Alkalinity) in phreatic and semi-confined aquifers for the period 01.01.2000 to 31.12.2006 In Palaeo-lagoon (Kole lands basin)

Phreatic aquifer(Dug well)					Semi-confined deep aquifer (Bore well)				
Well No.	Location	No. of data analysed	Rise per year (mg/l)	Fall per year (mg/l)	Well No.	Location	No. of data analysed	Rise per year (mg/l)	Fall per year (mg/l)
OW-1	Thrissur	5	-	6.431	BW-1	Kaduppassery	10	-	12.982
OW-2	Mannuthi	11	-	6.416	BW-2	Mattathur	13	1.408	-
OW-3	Pattikkad	9	-	0.562	BW-3	Nellai	13	17.701	-
OW-4	Pudukad	10	1.300	-	BW-4	Tholur	11	1.056	-
OW-5	Kodakara	5	-	1.032	BW-5	Trikkur	9	16.759	-
OW-6	Irinjalakuda	11	1.739	-	BW-6	Choondel	14		2.299
OW-7	M.G.Kavu	12	-	2.597	BW-7	Madakkathara	13	4.544	-
OW-8	Ottuppara	11	-	7.085	BW-8	Pananchery	8		16.062
OW-9	Chelakkara	12	-	11.891	BW-9	Kolazhy	12	-	7.225
OW-10	Kunnamkulam	13	-	2.095	BW-10	Athani	9	8.024	-
OW-11	Chavakkad	12	-	5.517	BW-11	Chengalur	11	11.845	-
OW-12	Pazhanji	5	-	5.964	BW-12	Muppliyam	11	-	2.773
OW-13	Nattika	12	3.148	-	BW-13	mudicode	14	-	0.072
OW-14	Valappad	14	-	15.906	BW-14	Velapaya	10	-	4.092
OW-15	Edamuttom	11	-	4.430	BW-15	Kaiparambu	9	3.293	-
OW-16	Engadiyur	12	-	2.341	BW-16	Peechi	9	5.030	-
OW-17	Vaniyampara	11	-	15.903	BW-17	Chittilappilly	8		3.978
OW-18	Varandarappilly	13	-	3.671	BW-18	Nelluvayi	12	-	4.611
OW-19	Cherpu	11		2.025	BW-19	Kandanissery	12	1.101	-
OW-20	Puthur	11	5.479	-	BW-20	Aloor	8	18.107	-
OW-21	Elavally	11	-	1.685	BW-21	Vellangallur	9	12.659	-
OW-22	Kadangode	10	0.112	-	BW-22	Wadakkancherry	13		27.437
OW-23	Wadakkancherry	8	-	2.578	BW-23	Varavur	10	-	2.343
					BW-24	Arthat	12		2.093

5.2.1i Bacteriological quality

The bacteriological quality is one of the most important aspects in drinking water parameter and is the most common and wide spread health risk associated with drinking water is the bacteriological contamination causes either directly or indirectly by human or animal excreta. The bacteria most commonly used as indicators of sewage pollution are Bacillus coli, renamed in honour of Escheich as Escherichia coli and the coliform group as a whole. E. coli is selected as an indicator parameter of fecal contamination. Fecal contaminated water will lead to enteric diseases. The fecal contamination is mainly due to improper solid waste disposal from farmyard into the soak pits located very near drinking water wells, which is not having any protecting wall. According to Woods (1990) effluents from point sources such as septic tanks and general farmyard wastes are considered as the main sources of contamination of groundwater. The lack of protecting wall will lead to the entry of contaminated runoff water into the well from the upstream.

Bacteriological analysis assesses the quality of raw as well as treated water especially to detect fecal population. This enable to decide the adequacy of chlorination before finished water is supplied to the consumers. Baceriological analysis in potable water includes, estimation of (i) total bacteria count and (ii) coliform count (fecal coilforms and fecal streptococcus). MPN (Multiple tube dilution method) is the standard method for determining colifom quantification. The biological standard of water for various uses is given in the Table 5.28.

Table 5.28 Bacteriological standard of water for various uses

Sl.No	Parameter MPN index/ 100ml	Permisible level in drinking water 50/ 100ml	Permisible level in recreational water 500/ 100ml
1	Standard plate count (SPC)	Not more than 500 organism	No specific guidelines
2	Escherichia coli (Ecoli)	Should be absent	No specific guidelines

Bacteriological analyses of water samples were done in both phreatic (dug wells) and semi- confined aquifers (bore wells) of the study area. Details are given in Tables 5.29 and 5.30. It is found that almost all the dug wells in the study area are contaminated with coliforms and E.coli. While in bore

Table 5.29 Details of bacteriological analysis of water samples from phreatic aquifer of the Palaeo-lagoon (Kole land basin)

Well No	Location	Lattitude	Longitude	Toposheet No	Well type	Well dia (m)	Total Depth in m(Bgl)	Avg WL in m(Bgl) 1997-07	Formation	Sampling date	Total coliforms cnt/100ml	Fecal coliforms cnt/100ml	Basin
OW-1	Thrissur	10°31'13"	76°13'07"	58 B/2	Dug Well	1.67	9.45	6.24	Laterite	5/13/2006	274	20	Kole land
OW-2	Mannuthi	10°31'53"	76°15'48"	58 B/6	Dug Well	2.50	7.78	2.73	Laterite	5/13/2006	72	8	Kole land
OW-3	Pattikkad	10°33'23"	76°19'56"	58 B/6	Dug Well	2.20	8.00	7.91	Laterite	5/28/2006	104	4	Kole land
OW-4	Pudukkad	10°25'07"	76°16'18"	58 B/7	Dug Well	2.50	10.20	5.41	Laterite	5/28/2006	254	41	Kole land
OW-5	Kodakara	10°22'19"	76°18'19"	58 B/7	Dug Well	2.31	9.80	2.40	Laterite	5/14/2006	16	1	Kole land
OW-6	Irinjalakudaa	10°20'32"	76°13'11"	58 B/3	Dug Well	3.80	12.42	7.60	Laterite	5/14/2006	96	52	Kole land
OW-7	MG-Kavu	10°36'00"	76°12'41"	58 B/2	Dug Well	4.35	11.95	3.78	Laterite	5/14/2006	118	15	Kole land
OW-8	Ottuppara	10°39'53"	76°15'24"	58 B/6	Dug Well	2.40	6.80	3.47	Laterite	5/14/2006	183	48	Kole land
OW-9	Chelakkara	10°43'38"	76°11'12"	58 B/6	Dug Well	2.09	7.55	5.81	Laterite	5/28/2006	114	15	Kole land
OW-10	Kunnamkulam	10°38'49"	76°04'11"	58 B/2	Dug Well	3.65	13.25	1.75	Laterite	5/28/2006	300	19	Kole land
OW-11	Chavakkad	10°34'49"	76°01'29"	58 B/2	Dug Well	1.62	5.35	6.59	Alluvium	6/11/2006	230	19	Kole land
OW-12	Pazhanji	10°41'20"	76°03'26"	58 B/2	Dug Well	3.80	9.60	1.48	Laterite	5/20/2006	10	ND	Kole land
OW-13	Nattika	10°25'11'	76°06'26"	58 B/3	Dug Well	1.65	4.30	0.79	Alluvium	5/20/2006	26	15	Kole land
OW-14	Edamuttam	10°22'19"	76°07'34"	58 B/3	Dug Well	2.56	3.56	3.18	Alluvium	5/20/2006	14	9	Kole land
OW-15	Mathilakam	10°17'30"	76°09'53"	58 B/3	Dug Well	2.00	4.80	2.46	Alluvium	5/20/2006	24	5	Kole land
OW-16	Engadiyur	10°29'39"	76°04'04"	58 B/2	Dug Well	1.85	5.15	2.00	Alluvium	5/20/2006	108	21	Kole land
OW-17	Vaniyampara	10°34'38"	76°24'35"	58 B/7	Dug Well	2.50	5.23	3.34	Laterite	5/20/2006	74	19	Kole land
OW-18	Varandarappilly	10°25'18"	76°19'54"	58 B/7	Dug Well	2.50	10.35	6.36	Laterite	5/20/2006	4	18	Kole land
OW-19	Cherpu	10°12'53"	76°14'25"	58 B/8	Dug Well	3.10	15.25	10.83	Laterite	5/20/2006	98	84	Kole land
OW-20	Puthur	10°26'25"	76°12'44"	58 B/3	Dug Well	3.25	13.15	9.22	Laterite	5/20/2006	42	16	Kole land
OW-21	Bavally	10°28'57"	76°17'26"	58 B/7	Dug Well	2.60	6.90	3.61	Laterite	5/27/2006	66	30	Kole land
OW-22	Kadangode	10°34'34"	76°05'14"	58 B/2	Dug Well	3.27	10.19	7.23	Laterite	5/27/2006	116	51	Kole land
OW-23	Wdakkancherry	10°42'07"	76°08'27"	58 B/2	Dug Well	4.00	8.56	6.86	Laterite	5/27/2006	122	37	Kole land

Table 5.30 Details of bacteriological analysis of water samples from semi-confined aquifer of palaeo-lagoon (Kole land basin)

Well No.	Location	Lattitude	Longitude	Well type	Total depth (m)	Over burden (m)	Diameter (m)	Avg.WL (1997-06)	Date of Sampling	Total coliforms cnt/100 ml	Fecal coliforms cnt/100 ml	Formation
BW-1	Kaduppassery	10°19'53"	76°15'26"	Bore Well	50	11.5	110	6.89	2/20/2006	10	5	Charnockite
BW-2	Mattathur	10°22'26"	76°22'24"	Bore Well	30	12	110	7.50	2/20/2006	3	ND	Gneiss
BW-3	Nellai	10°23'24"	76°17'03"	Bore Well	30	15.5	110	3.66	2/20/2006	12	6	Charnockite
BW-4	Tholur	10°34'00"	76°07'30"	Bore Well	40	21	110	14.45	2/20/2006	12	ND	Gneiss
BW-5	Trikkur	10°27'49"	76°17'17"	Bore Well	50	12	110	6.52	2/22/2006	19	5	Charnockite
BW-6	Choondel	10°37'30"	76°05'58"	Bore Well	33	9.5	152	4.90	2/22/2006	25	10	Charnockite
BW-7	Madakkathara	10°32'42"	76°17'25"	Bore Well	30	6.6	110	2.22	2/22/2006	22	ND	Gneiss
BW-8	Pananchery	10°33'47"	76°21'15"	Bore Well	50	11.5	110	3.81	2/22/2006	18	ND	Charnockite
BW-9	Kolazhy	10°35'03"	76°12'55"	Bore Well	30	9	110	2.33	2/25/2006	9	5	Charnockite
BW-10	Athani	10°36'53"	76°12'48"	Bore Well	30	8	110	9.45	2/25/2006	33	22	Charnockite
BW-11	Chengalur	10°24'15"	76°18'01"	Bore Well	30	8	110	2.28	2/25/2006	32	13	Charnockite
BW-12	Muppliyam	10°24'02"	76°21'08"	Bore Well	40	10	110	4.49	2/27/2006	ND	ND	Charnockite
BW-13	Mudicode	10°32'56"	76°18'34"	Bore Well	50	18.5	110	6.16	1/7/2006	5	ND	Charnockite
BW-14	Velapaya	10°36'08"	76°11'23"	Bore Well	40	13.41	110	10.04	2/27/2006	6	ND	Gneiss
BW-15	Kaiparambu	10°36'31"	76°08'30"	Bore Well	40	28.35	110	11.47	2/27/2006	3	ND	Charnockite
BW-16	Peechi	10°32'13"	76°20'11"	Bore Well	30	8.55	110	5.54	2/27/2006	12	ND	Charnockite
BW-17	Chittilappilly	10°33'23"	76°09'23"	Bore Well	30	9.5	152	5.79	2/27/2006	15	ND	Charnockite
BW-18	Nelluvayi	10°40'35"	76°10'06"	Bore Well	40	7.45	152	3.36	2/27/2006	22	9	Charnockite
BW-19	Kandanissery	10°35'53"	76°04'56"	Bore Well	40	24.39	110	22.58	2/27/2006	ND	ND	Gneiss
BW-20	Aloor	10°20'08"	76°17'44"	Bore Well	86	11	110	7.51	2/27/2006	12	ND	Gneiss
BW-21	Vellangallur	10°16'53"	76°12'52"	Bore Well	75	15	110	5.97	2/27/2006	6	3	Gneiss
BW-22	Wadakkancherry	10°38'24"	76°16'32"	Bore Well	61	14.2	115	2.56	3/1/2006	16	ND	Gneiss
BW-23	Varavur	10°42'52"	76°12'48"	Bore Well	70	8.75	115	2.77	3/1/2006	12	6	Gneiss
BW-24	Arthat	10°37'30"	76°03'05"	Bore Well	70	16.6	115	5.27	3/1/2006	15	9	Gneiss

wells contamination percentage of E. coli is less than 50% when compared with dug wells. E. coli contamination is higher in urban areas such as Thrissur, Chavakkad, Irinjalakuda and Kunnamkulam than in the rural areas. The spatial distribution of total coliforms in and E.coli in dug wells and bore wells of the study area are given in the Figs. 5.17a-b and 5.18a-b.

5.2.2 Evaluation of groundwater for irrigation

The suitability of groundwater for irrigation depends on the chemical constituents of the water. A relatively high concentration of alkali and alkaline earths will affect directly the texture, structure, permeability and aeration of soils and indirectly plant growth (Lloyd and Heathcoat, 1985). So also high concentration of trace elements such as born, selenium, cadmium etc. is toxic to the growth of plants (Todd, 1980). The problem that results from using a poor quality water will vary both as to kind and degree, but most common one are (i) salinity (ii) permeability and (iii) toxicity.

A salinity problem related to water quality occurs if the total quantity of salts in the irrigation water is high enough that salts accumulated in the crop root zone to the extent that yields are affected. If excessive quantities of soluble salts accumulate in the root zone, the crop has extra difficulty in extracting enough water from the salty soil solution. This reduces the water uptake capacity of the plant, which results in slow or reduced growth and may also be shown by symptoms similar in appearance to those of drought such as early wilting.

Permeability problem related to water quality occurs when the rate of water infiltration into the soil is reduced by the effect of specific salt or lack of salts in the water to such an extent that crop is not adequately supplied with water and yield is reduced. Poor soil permeability greatly adds the cropping difficulties such as crusting of seed beds, water logging of surface soil etc.

A toxicity problem occurs when certain constituents in water are taken up by the crop and accumulate in the soils that result in a reduced yield and soil pollution. The water quality standards for irrigation use and the likely adverse impacts are shown in Table 5.4.

5.2.2a Evaluation based on percentage of sodium, EC and TDS

Wilcox (1955) has classified the waters for irrigation purposes, which is based on electrical conductivity (EC), TDS, sodium percentage and boron concentration (Table 5.31). Sodium concentration is very important in classifying the irrigation waters because sodium reacts with soil easily resulting in the reduction of permeability of soil (Houk, 1951). Sodium saturated soil will support a little or no

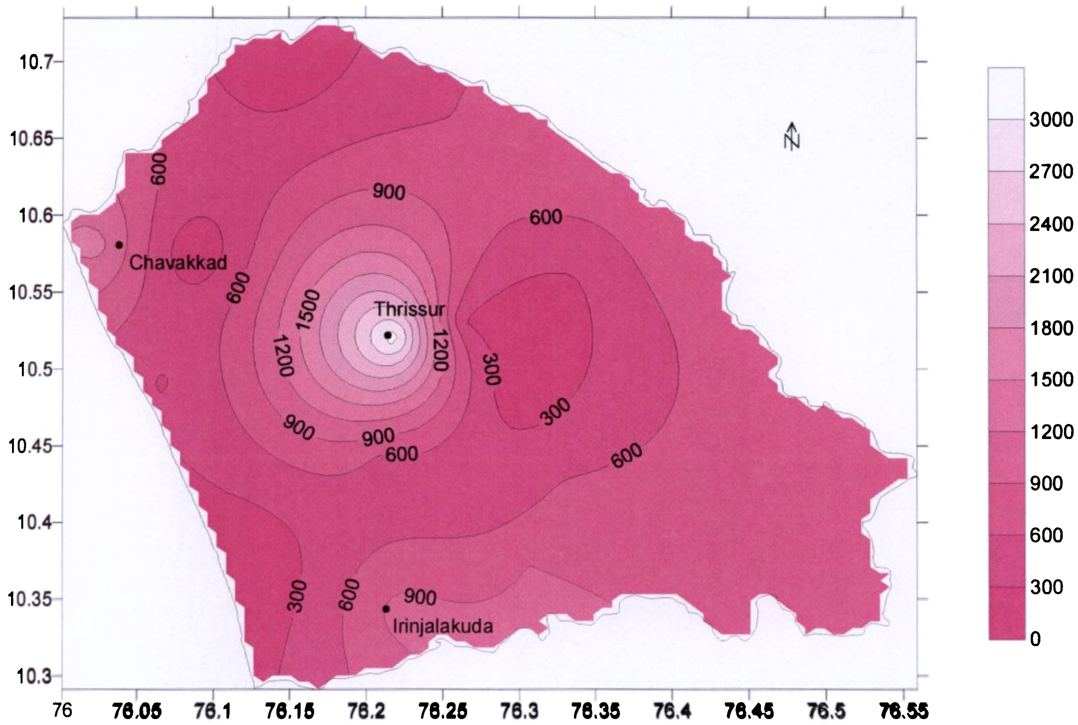


Fig. 5.17a. Spatial distribution of total coliforms in dug wells (phreatic aquifer) of the study area (Year - 2006)

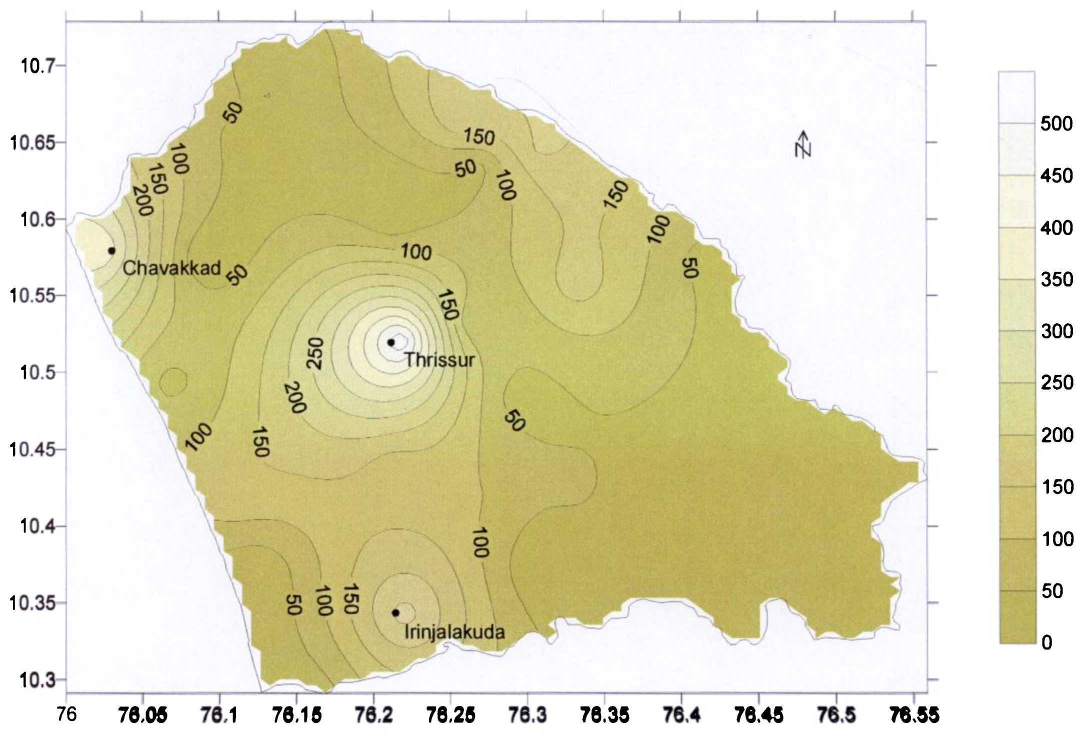


Fig. 5.17b. Spatial distribution of fecal coliforms (E.coli) in dug wells (phreatic aquifer) of the study area (Year - 2006)

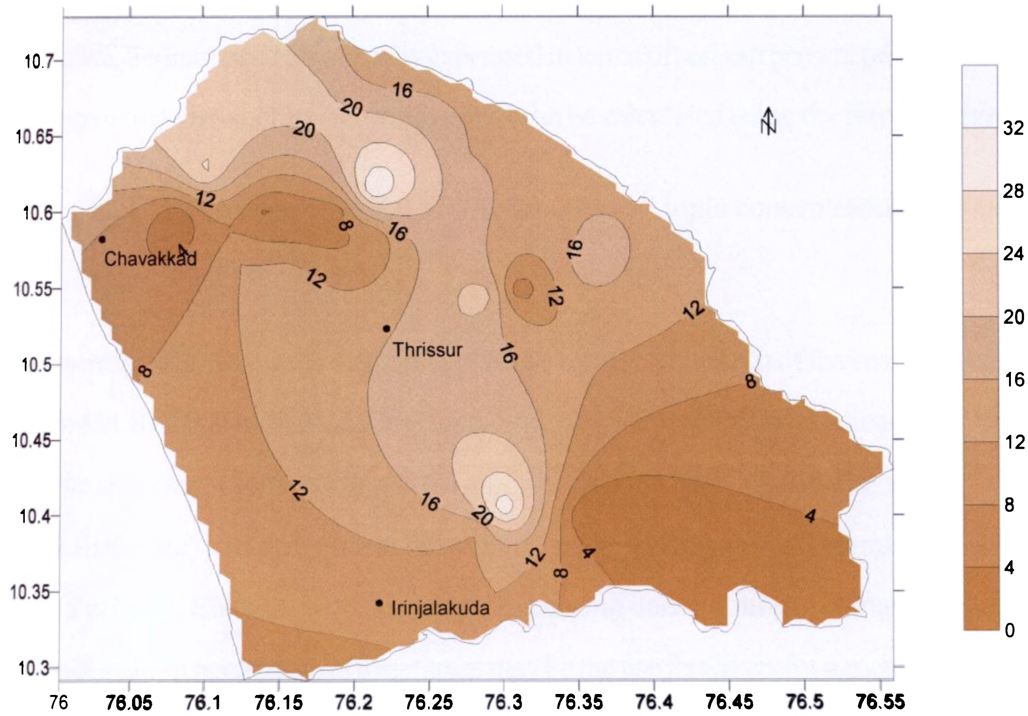


Fig. 5.18a. Spatial distribution of total coliforms in bore wells (semi - confined aquifer) of the study area (Year - 2006)

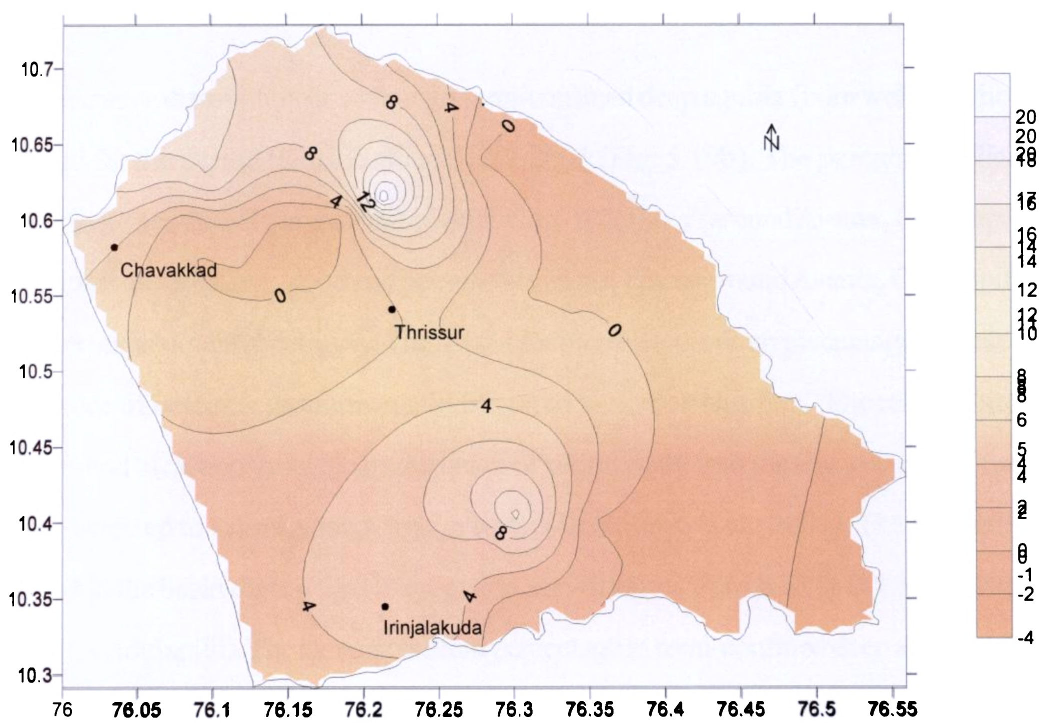


Fig. 5.18b. Spatial distribution of fecal coliforms (E.coli) in bore well (semi - confined aquifer) of the study area(Year - 2006)

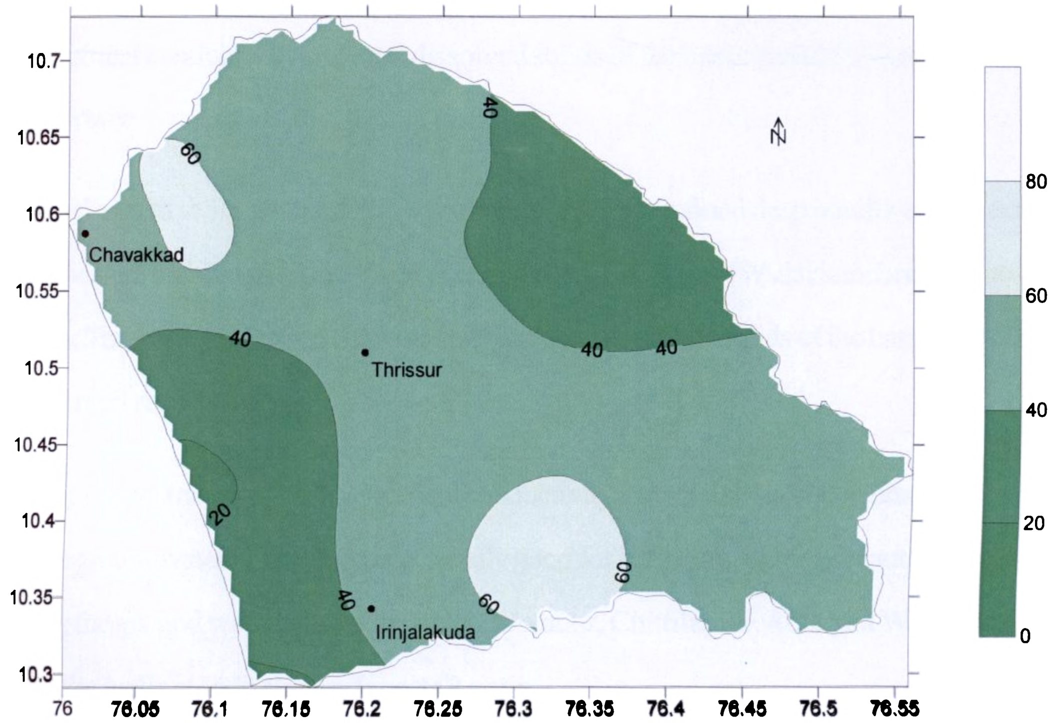


Fig. 5.19a. Sodium percentage distribution in phreatic aquifer (dug wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

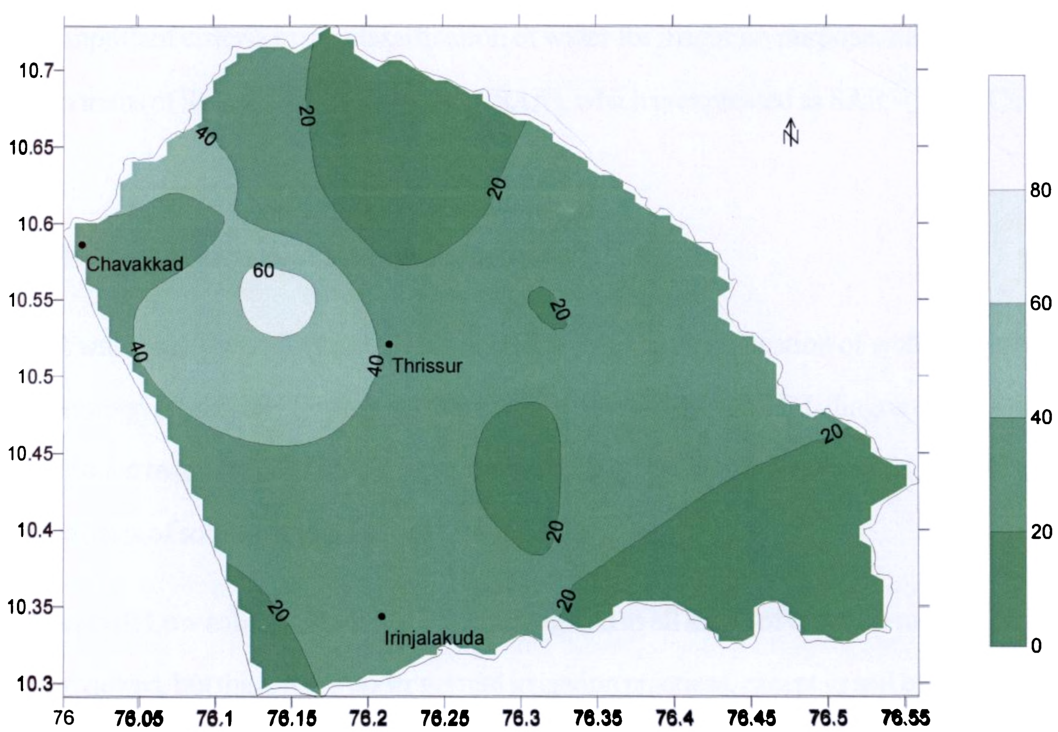


Fig. 5.19b. Sodium percentage distribution in semi-confined deep aquifer (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

plant growth. Sodium content is usually expressed in terms of sodium percent (also known as sodium percentage or soluble-sodium percentage) and can be calculated using the formula given below.

Na% = {(Na+K)/ (Ca+Mg+Na+K)} x 100; where in all ionic concentrations are expressed in meq/l.

The percentage distribution of sodium in phreatic aquifer (dug well) of the basin were analysed for the period 01.01.2000 to 31.12.2006 (Fig. 5.19a). The percentage distribution of sodium indicates that all the area except some portion in the northern (around Pazhanji and Elavalli) and the southern (around Kodakara) part of the basin fall within the excellent, good and permissible limits. Places such as Pazhanji, Elavalli, Kodakara etc. are coming under doubtful category. The reason for increase in sodium percentage in these areas may be the use fertilizers for agricultural purposes. The fertilizers used for agricultural purpose will enhance the percentage of sodium in groundwater especially in shallow aquifer (Paliwal and Yadav, 1976). The sodium percentages reported in the basin during the investigation period vary from 3.84% (Nattika) to 66.98% (Pazhanji). The average sodium percentage in phreatic aquifer of the basin is 41.29%.

The percentage distribution of sodium in semi-confined deep aquifer (bore wells) of the basin were analysed for the period 01.01.2000 to 31.12.2006 (Fig. 5.19b). The percentage distribution of sodium indicates that all the area except northwest of Thrissur (around Avanur, Chittilapilli and Adat) fall with in the excellent, good and permissible limits. Places around Avanur, Chittilapilli, Adat etc. are come under doubtful category. The reason for increasing sodium percentage in these areas is the occurrence of brackish groundwater in fractured hard rock aquifers. The relative proportion of chloride and bicarbonate suggests intrusion of saline water into the fracture zone from low lying areas connected to saline palaeo-lagoon waters (Kukillaya et al., 2004). The sodium percentage reported in the basin during the investigation period varies from 4.32 % (Chengaloor) to 86.26% (Avanur, Chittilapilli). The average sodium percentage in semi-confined deep aquifer of the basin is 31%.

The electrical conductivity and total dissolved solids of phreatic aquifer of the basin vary from 40 ìmhos/cm and 24 mg/l (M.Gkavu) to 1160 ìmohos/cm and 696 mg/l (Chavakkad) respectively. The average electrical conductivity and total dissolved solids of the basin are 266 imhos/cm and 159.3 mg/l respectively.

The electrical conductivity and total dissolved solids of semi-confined deep aquifer of the basin vary from 10μmhos/cm and 6 mg/l (Aloor) to 900μmhos/cm and 630mg/l (Wadakkancherry, Chittilapilli) respectively. The average electrical conductivity and total dissolved solids of the basin is 298 imhos/cm and 178 mg/l respectively.

Based on the concentration of Na%, electrical conductivity and total dissolved solids, it is concluded here that the groundwater of the basin is generally good for irrigation. Some precaution is necessary while using the ground water from bore wells at Avanur, Chittilapilli, Adat and Wadakkancherry areas and tube wells at sedimentary (coastal) areas.

5.2.2b Suitability of water through Wilcox-U.S.S.L diagram

The U.S salinity Laboratory (1954), Department of Agriculture, has used salinity and sodium hazards as the two important criteria in the classification of water for irrigation purpose. Salinity hazard is expressed in terms of Sodium Adsorption Ratio (SAR), which is expressed as $SAR = Na/\{(Ca+Mg)/2\}^{1/2}$

where in all ionic concentrations are expressed in meq/l.

When SAR and specific conductance of water are known, the classification of water for irrigation can be determined graphically by plotting these values on a Wilcox-U.S.S.L diagram. Waters of the basin are divided in to C1, C2, C3, C4 types on the basis of salinity hazard and S1, S2, S3 and S4 types on the basis of sodium alkali hazard (Table 5.32).

Salinity hazard: Low salinity water (C1) can be irrigated to all kinds of crops on most soils. Some leaching is required, but this occurs under normal irrigation practices, except in soil of extremely low permeability. Medium or moderate salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances with out special practices of salinity control. High salinity water (C3) is satisfactory for plants having moderate salt tolerance, on soils of moderate permeability with leaching. Very high salinity water (C4) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected. If the EC value is greater than 4000µmhos/cm (C5), that water is not suitable for irrigation under ordinary conditions, but may be used occasionally, under very special and unavoidable circumstances.

In this basin almost all samples of phreatic (dug wells) and semi-confined deep aquifer (bore wells) belong to C1 and C2 types. The water samples of phreatic aquifer at Chavakkad and Irinjalkuda shows an EC greater than 750µmhos/cm and hence these samples fall in C3 type. The water samples of semi-confined deep aquifer at Velapaya, Chittilapilli and Wadakkancherry shows an EC greater than 750 ìmhos/cm and hence these samples fall in C3 type.

Sodium Adsorption Ratio (SAR): The sodium concentration in groundwater is important since increase of sodium concentration in water effect deterioration of soil properties reducing permeability (Kelley, 1951 and Tijani, 1994. The process leading to the cation exchange reactions in soil may be studied from sodium absorption ratio (U.S Salinity Laboratory, 1954). Sodium absorbed on clay surface as substitute for calcium and magnesium may damage the soil structure making it compact and impervous.SAR is expressed as

$$SAR = Na/ \{(Ca^{2+} + Mg^{2+}/2)\}^{1/2}$$

where the concentrations are expressed in equivalent per million (epm).

The classification of water with reference to SAR by Hermanbouwer, (1978) is presented in Table 5.33.

The classification of irrigation water with respect to SAR (U.S. Salinity Laboratory, 1954) is based primarily on the capacity of exchangeable sodium with the soil. Sodium sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissue.

Low sodium water (S1) can be used for irrigation for almost all sorts of soils and plants with a little danger of the development of harmful level of exchangeable sodium. However, sodium sensitive

Table 5.31 Classification of groundwater quality for irrigation (after Wilcox, 1955)

Class of water	EC at 25°C in µmhos/cm	TDS (mg/l)	Sodium %	Boron (mg/l)
Excellent	< 250	< 175	< 20	< 1
Good	250 - 750	175 - 525	20 - 40	1 to 2
Permissible	750 - 2000	525 - 1400	40 - 60	2 to 3
Doubtful	2000 - 3000	1400 - 2100	60 - 80	3 to 3.75
Unusable	> 3000	> 2100	> 80	> 3.75

Table 5.32 Classification of water for irrigation based on U.S.S.L diagram (Wilcox, 1955)

Conductivity classes	Range EC at 25°C (µmhos/cm)	Salinity hazard	SAR classes	Range of values	Sodium alkali hazard
C1	<250	Low	S1	<10	Low
C2	250-750	Medium	S2	10 to 18	Medium
C3	750-2250	High	S3	18 to 26	High
C4	2250-4000	Very high	S4	>26	Very high

Table 5.33 Classification of groundwater based on SAR (Hermanbouwer, 1978)

Sl.No	SAR	Water quality
1	0 to 6	No problem
2	6 to 9	Increasing problem
3	> 9	Severe problem

crops, such as Stone-fruit trees and Avocados, may accumulate considerable concentration of sodium. Medium sodium water (S2) may cause an appreciable sodium hazard to fine textured soils, having high cation exchange capacity, especially under low leaching conditions, unless gypsum is present in the soil. This water may be used on coarse textured or organic soils, which have good permeability. High sodium water (S3) may produce harmful level of exchangeable sodium in most soils and will require special soil management like good drainage, high leaching and addition of organic matter. Gypsiferous soils may not develop harmful level of exchangeable sodium from such waters. Very high sodium water (S4) is generally unsatisfactory for irrigation purpose except at low and perhaps medium salinity. Application of gypsum or other amendments may make use of this water feasible. Gypsum application may also increases the crustal conductive properties of soils as elaborated by Goyal and Jain (1982).

Based on U.S.S.L diagram of irrigation, quality area can be divided into twenty water classes. Out of twenty water classes sixteen are shown the Figs. 5.21a & b.

In general, most of the SAR values of the study area are less than six for both phreatic as well as semi-confined deep aquifer (Figs. 5.20a & b). Further most of the water samples of the study area fall in C1 S1 and C2 S2 class of Wilcox (1955), indicating low to medium salinity-low sodium alkali hazard (Figs. 5.21a & b).

The SAR values of phreatic aquifer of the basin vary from 0.32 (Mathilakam) to 2.35 (Elavally). The average SAR of phreatic aquifer of the basin is 0.95.

The SAR values of semi-confined deep aquifer of the basin vary from 0.35 (Chengaloor) to 6.32 (Nellayi). The average SAR of semi-confined deep aquifer is 0.86. The water samples at Nellayi, Choondal and Arthat show an SAR greater than six during the period of investigation.

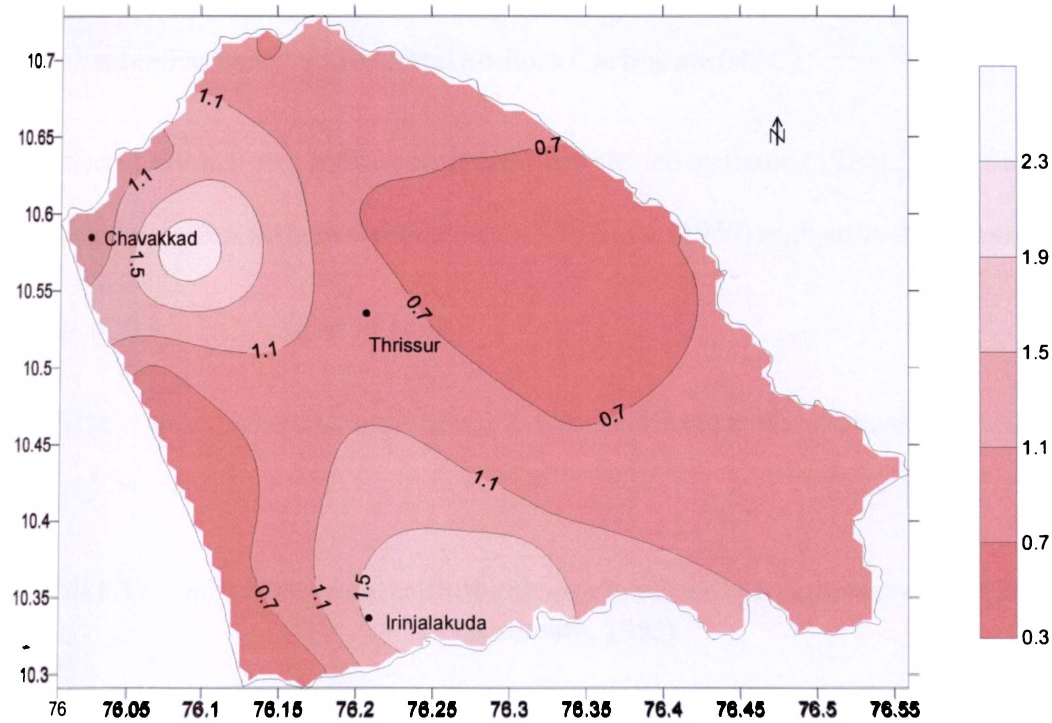


Fig. 5.20a. SAR distribution in phreatic aquifer (dug wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

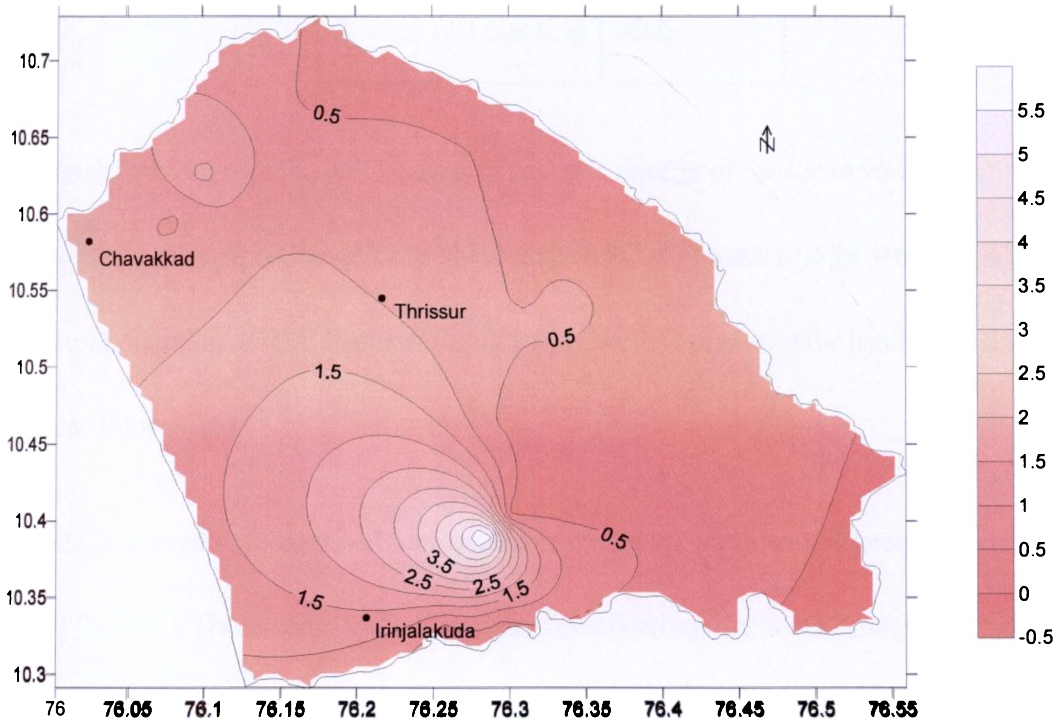


Fig. 5.20b. SAR distribution in Semi-confined deep aquifer (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

5.2.2c Evaluation based on Residual Sodium Carbonate (RSC)

The effect of residual sodium carbonate has been carried by Eaton (1950). The index, which is termed as the residual sodium carbonate (RSC) by Eaton (1950) is given by the equation

$$RSC = (CO_3^{2-} + HCO_3^-)\text{-}Ca^{2+} + Mg^{2+})$$

and the units are expressed in meq/l of water. The classification of water based on RSC is given in Table 5.34.

Table 5.34 Limits of residual sodium carbonate values in irrigation water (Lloyd and Heathcote, 1985)

Sl.No	Conditions	RSC(meq/l)
1	Suitable	<1.25
2	Marginal	1.5-2.5
3	Not suitable	>2.5

The spatial variation of the RSC values of phreatic aquifer of the basin varies from -3.14 meq/l (Thrissur) to 1.11 meq/l (Chavakkad). The average RSC of phreatic aquifer of the basin is -0.39meq/l. The concentration of RSC in phratic aquifer (dug wells) samples of the basin is <1.25 meq/l (Fig. 5.22a & Table 5.35).

The RSC values of semi-confined deep aquifer of the basin vary from -4.49meq/l (Wadakkancherry) to 2.93 (Nellayi). The average RSC of semi-confined deep aquifer is -0.32 meq/l. The water samples of bore wells at Nellayi shows an RSC >2.5 meq/l during the period of investigation (Fig. 5.22b & Table 5.36).

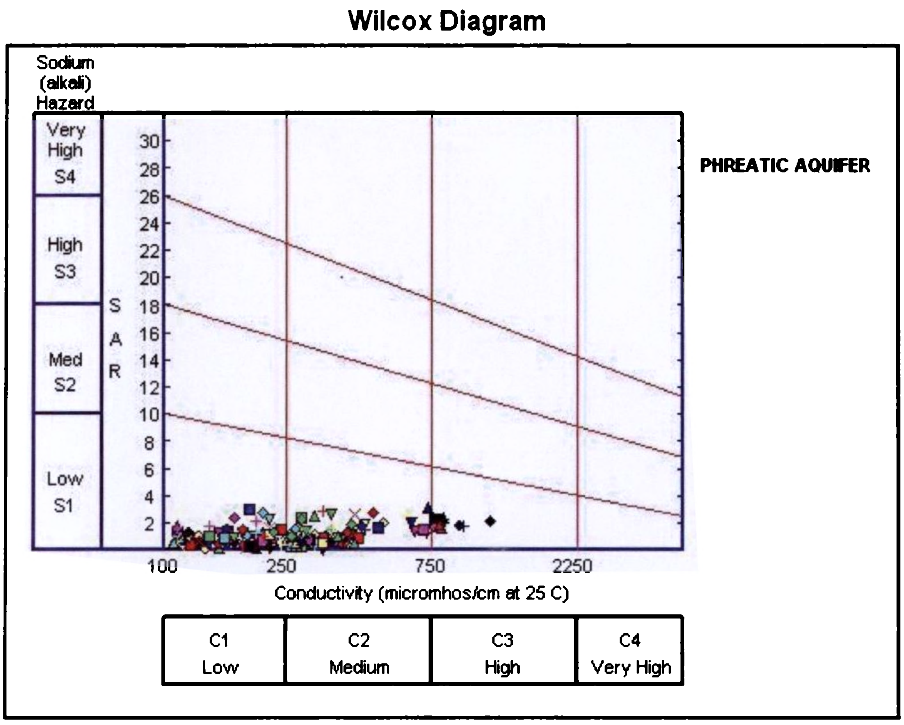


Fig.5.21a. Groundwater classification of phreatic aquifer (dug wells) for irrigation based on U.S.S.L. method in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

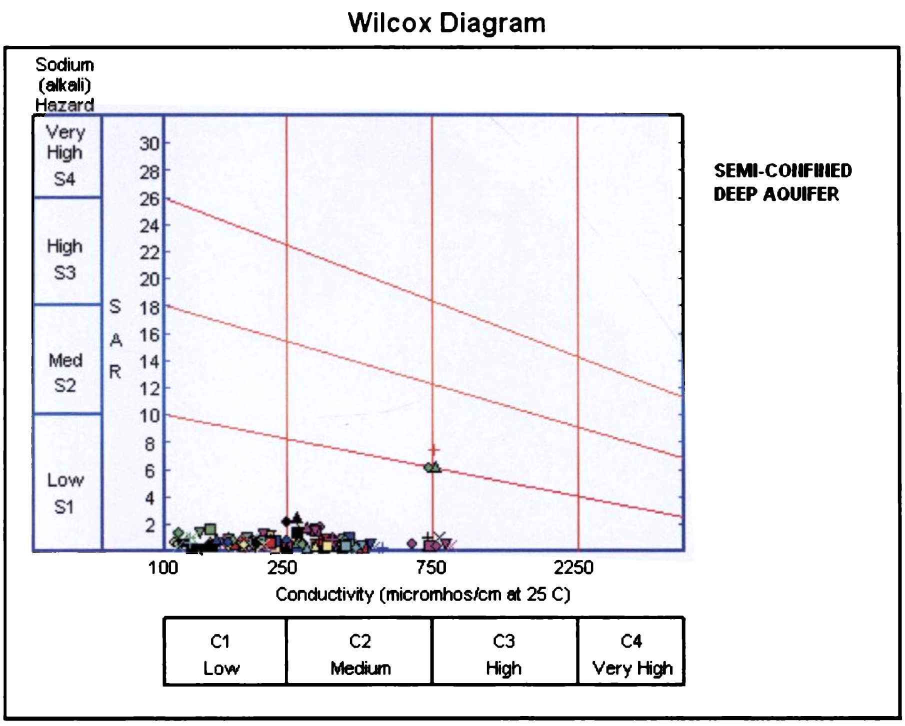


Fig.5.21b. Groundwater classification of semi-confined deep aquifer (bore wells) for irrigation based on U.S.S.L method in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

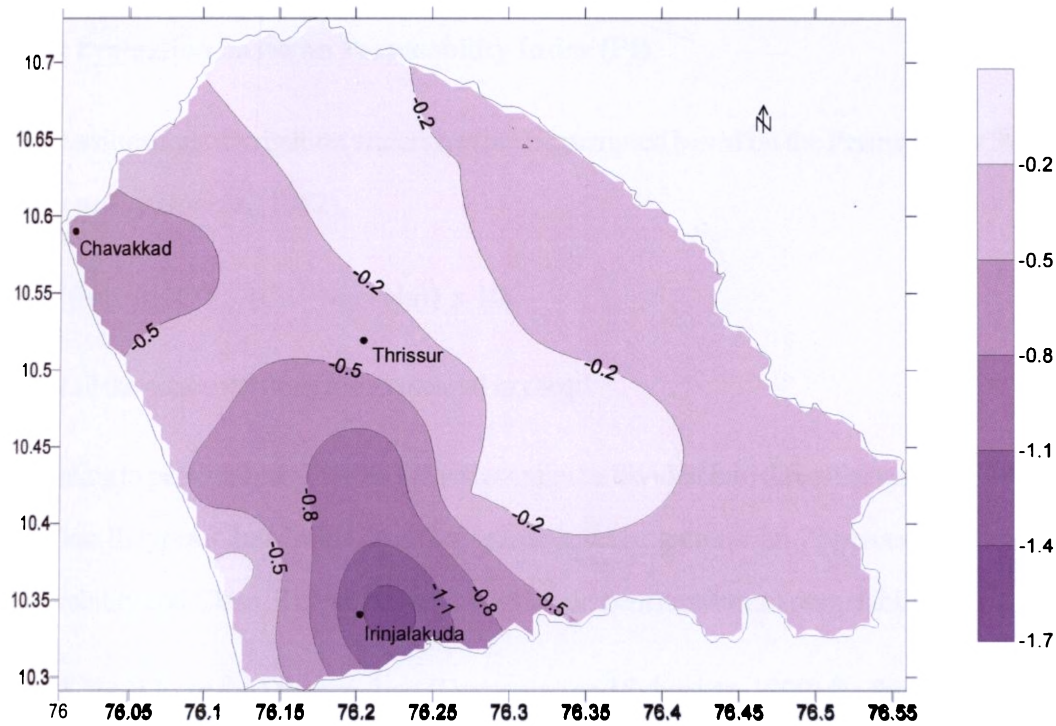


Fig. 5.22a. Isocone map of residual sodium carbonate in phreatic aquifer (dug wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

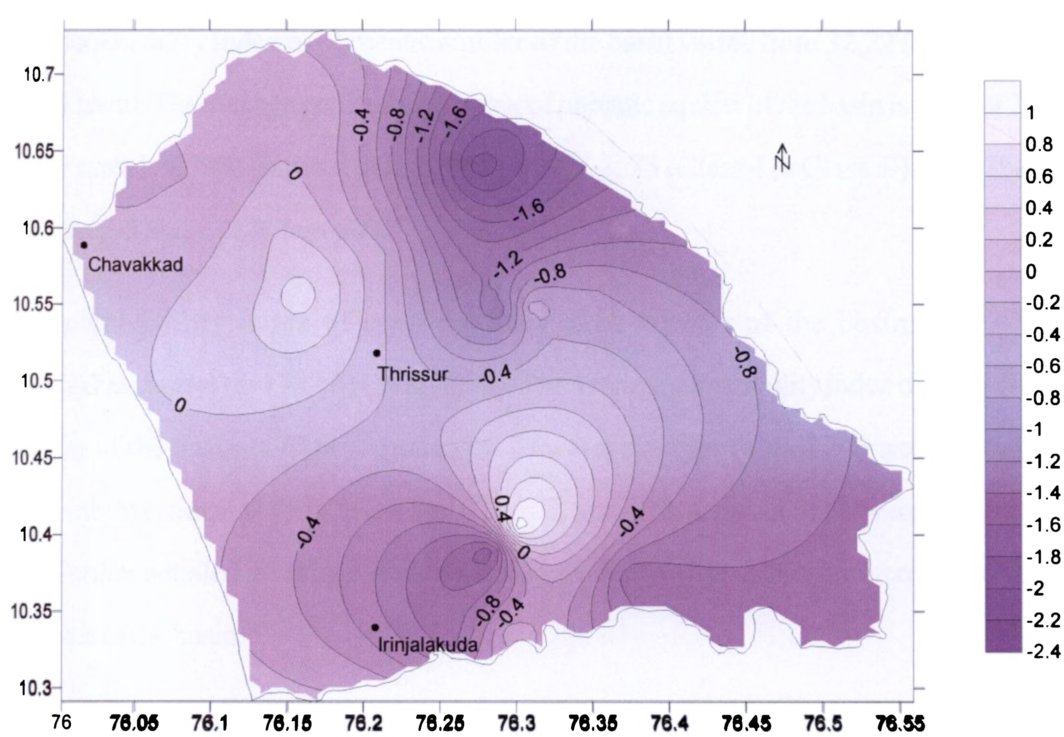


Fig. 5.22b. Isocone map of residual sodium carbonate in semi-confined deep aquifer (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

5.2.2c Evaluation based on Permeability Index (PI)

The classification of irrigation waters has been attempted based on the Permeability Index (PI), as developed by Doneen (1962).

$$PI = \{(Na + \sqrt{HCO_3})/(Ca + Mg + Na)\} \times 100$$

where all the concentrations are expressed in meq/l

According to permeability indices the waters may be divided into three classes viz. Class I, Class II and Class III types. Class I and Class II are suitable for irrigation with 75 percent or more maximum permeability and Class III types of water with 25 percent maximum permeability.

Figs. 5.23a & b are the Doneen chart (Domenico and Schwartz, 1990) for the water samples from phreatic (dug wells) as well as semi-confined deep aquifers (bore wells) of the basin. The groundwater samples in the study area fall in class 1, II and III.

The permeability index of phraeatic aquifer of the basin varies from 32.22 (Pattikkad) to 172.42 (M.G kavu). The average permeability index of phreatic aquifer of the basin is 89. Out 240 analysed water samples, 39% shows a permeability index $\leq$ 75 (Class-I & Class-II) and 62% shows a PI between 75 and 172 (Class-III).

The permeability index of semi-confined deep aquifer of the basin varies from 27.83 (Wadakkancherry)) to 172.18 (Chittilapilli). The average permeability index of semi-confined deep aquifer of the basin is 79.60. About 51% of water samples (out of 240 water samples) show a permeability index $\leq$ 75 (Class-I and Class-II) and 49% shows a PI between 75 and 172 (Class-III). Further detailed investigation is necessary to confirm the reason for increasing PI of the water samples of the basin.

5.2.2d Evaluation based on Magnesium Ratio (MR)

Presence of excess amount of magnesium over the combined value of calcium + magnesium in water samples is described as Magnesium Ratio (MR). It is expressed as

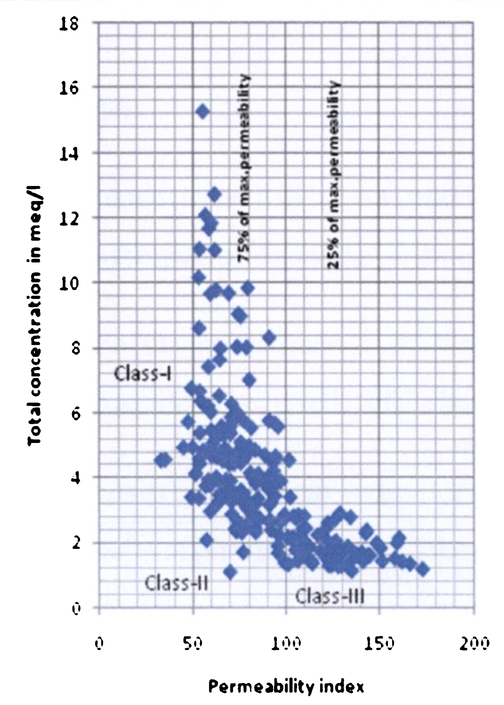


Fig.5.23a. Classification of irrigation water (Doneen, 1962) of phreatic aquifer (dug wells) based on permeability index in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

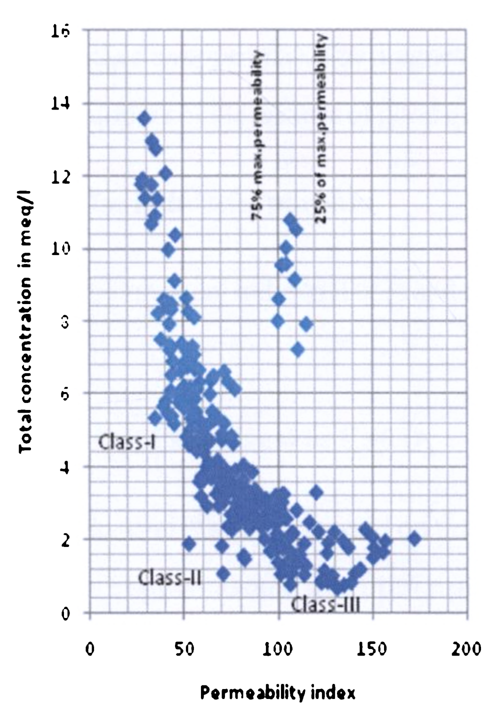


Fig.5.23b. Classification of irrigation water (Doneen, 1962) of semi-confined-deep aquifer (bore wells) based on permeability index in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

MR = Mg x 100/ (Ca+Mg)

where all the ions are expressed in epm.

Generally the calcium and magnesium in water will be in a condition of equilibrium (Das et al., 1988). Excess of magnesium affects the quality of soils that is the cause of poor yield of crops.

Figs. 5.24a & b are the isocone maps of magnesium ratio for the water samples from phreatic (dug wells) as well as semi-confined deep aquifers (bore wells) of the basin.

The magnesium ratio of phraeatic aquifer of the basin varies from 12.53 (Engadiyoor) to 59.07 (Puthur). The average magnesium ratio of phreatic aquifer of the basin is 36.74. About 92% of water samples (Out 240 analysed water samples) show a magnesium ratio $\leq$ 50 and 8% shows a MR between 50 and 59 (Table 5.35, attached as appendix).

The magnesium ratio of semi-confined deep aquifer of the basin varies from 23.24 (Mudicode) to 59.78 (Athani). The average magnesium ratio of semi-confined deep aquifer of the basin is 44.71.Out 260 analysed water samples, 87.5% shows a magnesium ratio $\leq$50 and 12.5% shows a MR between 50 and 59 (Table 5.36, attached as appendix). The magnesium ratio of the basin suggests that water of the shallow and deep aquifers of the basin is of good quality for irrigation.

5.2.3 Evaluation of groundwater for industrial purpose

The water quality standards for some important industrial uses and the likely adverse impacts are given in Table 5.5

5.2.3a Evaluation based on TDS and Hardness as $CaCO_3$

The quality criteria of water for industrial purposes depend on the type of industry, process and products. The water for high pressure boilers should free from suspended matter; have low TDS (<1 mg/l) and no acid reaction. On the other hand low pressure boilers can use water with TDS values up to 5000 m/l and CaCO3 hardness up to 80 mg/l (Singhal and Gupta, 1999).

In the study area the TDS in phreatic aquifer (dug wells) varies from 24 mg/l (M.G.Kavu) and 696 mg/l (Chavakkad) to 696 mg/l. The average TDS in the phreatic aquifer of the basin is 157.40 mg/l, while the

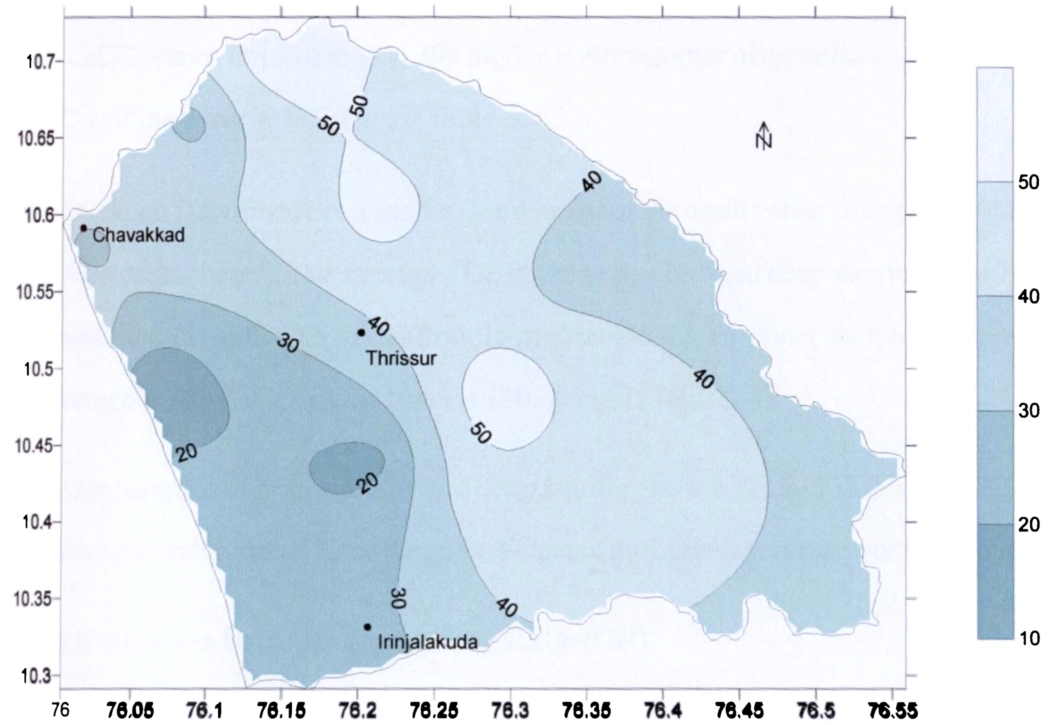


Fig. 5.24a. Isocone map of magnesium ratio in phreatic aquifer (dug wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

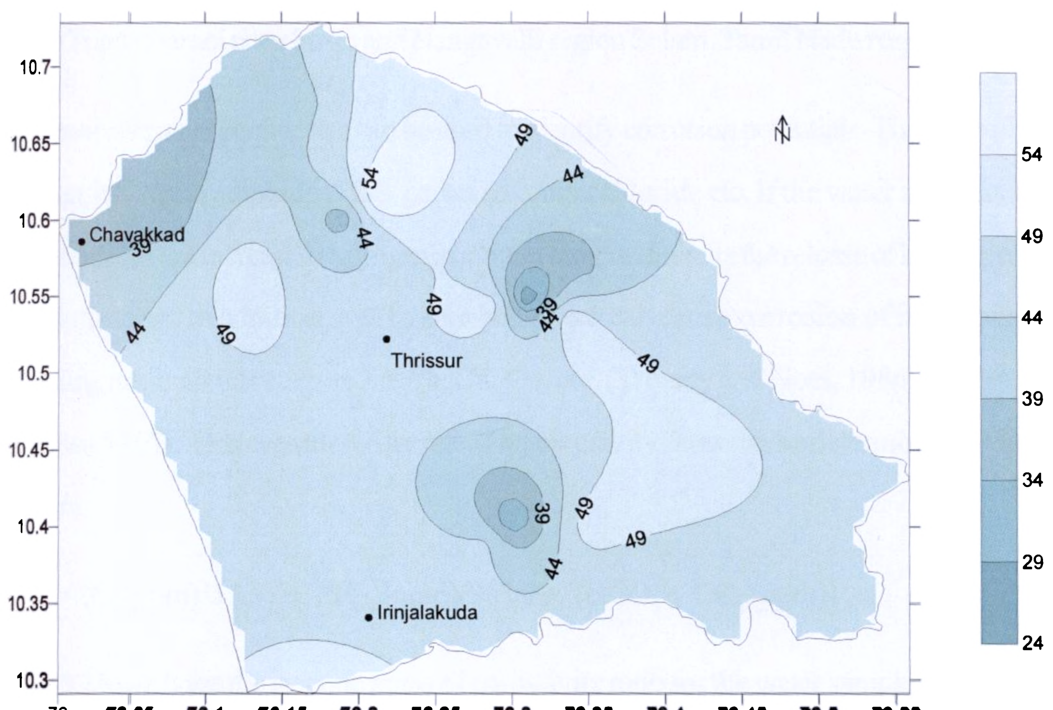


Fig. 5.24b. Isocone map of magnesium ratio in semi-confined deep aquifer (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

TH as $CaCO_3$ varies from 10 mg/l to 305 mg/l in water samples of same locations. The average TH as $CaCO_3$ of the basin is 76.70 mg/l (Table 5.3).

The TDS in semi-confined deep aquifer (bore wells) of the basin varies from 6mg/l (Aloor) to 630 mg/l (Wadakkancherry). The average TDS in the semi-confined deep aquifer of the basin is 177 mg/l, while the TH as $CaCO_3$ varies from 15 mg/l to 445 mg/l in water samples of same locations. The average TH as $CaCO_3$ of the basin is 110.63 mg/l (Table 5.4).

The water samples of both shallow and deep aquifer show a pH and TDS as $CaCO_3$ below the maximum allowable limit. Hence the groundwater of the basin is generally suitable for industries.

5.2.3b Evaluation based on Corrosivity Ratio (CR)

Corosivity ratio was initially proposed by Ryzner (1944), Badrinath et al., (1984) have used this index to evaluate the corrosive tendencies of Sabarmathi river, Gujarath. Similaly Balasubramanian (1986) and Rengarajan and Balasubramanian (1990) have studied corrosivity ratio of the groundwater of the Tamarabarani river basin and Nangavalli region Selam, Tamil Nadu respectively.

Different chemical parameters can be used to identify corrosion potentials. These are pH, dissolved oxygen, hydrogen sulphide, TDS, carbon dioxide, chloride etc. If the water is acidic, corrosion is accelerated as the increased hydrogen ion concentration favours the release of hydrogen and oxygen depolarization. In addition, a pH value below 6.5 can cause corrosion of metal pipes, there by releasing toxic metals such as Zn, Pb, Cd, Cu, etc. (Trivedy and Goel, 1986). A corossivity ratio less than 1 (CR. 1) is considered as safe. The corosivity ratio can be determined by the following formula.

$$CR = \{Cl(ppm)/35.5\} + \{SO_4\,(ppm)/96\}/2 \times \{HCO_3 + CO_3\,(ppm)\}.$$

Figs. 5.25 a & b are the isocone maps of corossivity ratio for the water samples from phreatic (dug wells) as well as semi-confined deep aquifers (bore wells) of the basin. The corosivity ratio of waters of both shallow and deep aquifers of the basin is <1 (CR, 1) and hence water of this basin is considered as under safe category (Tables 5.35 & 5.36, attached as appendix).

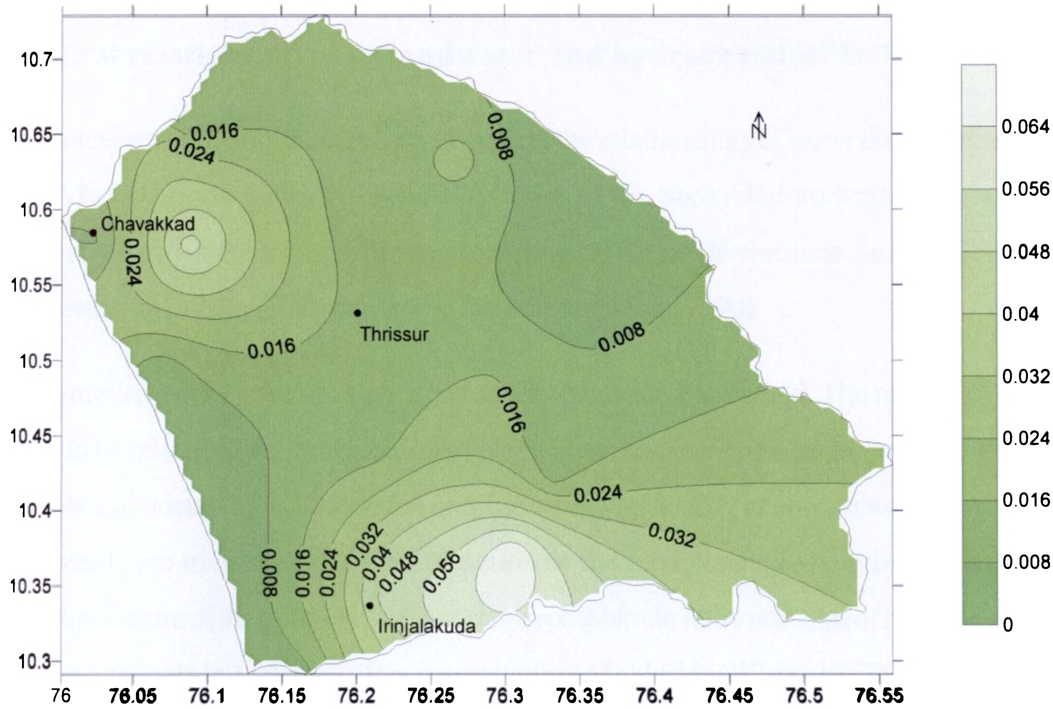


Fig. 5.25a. Isocone map of corosivity ratio in phreatic aquifer (dug wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

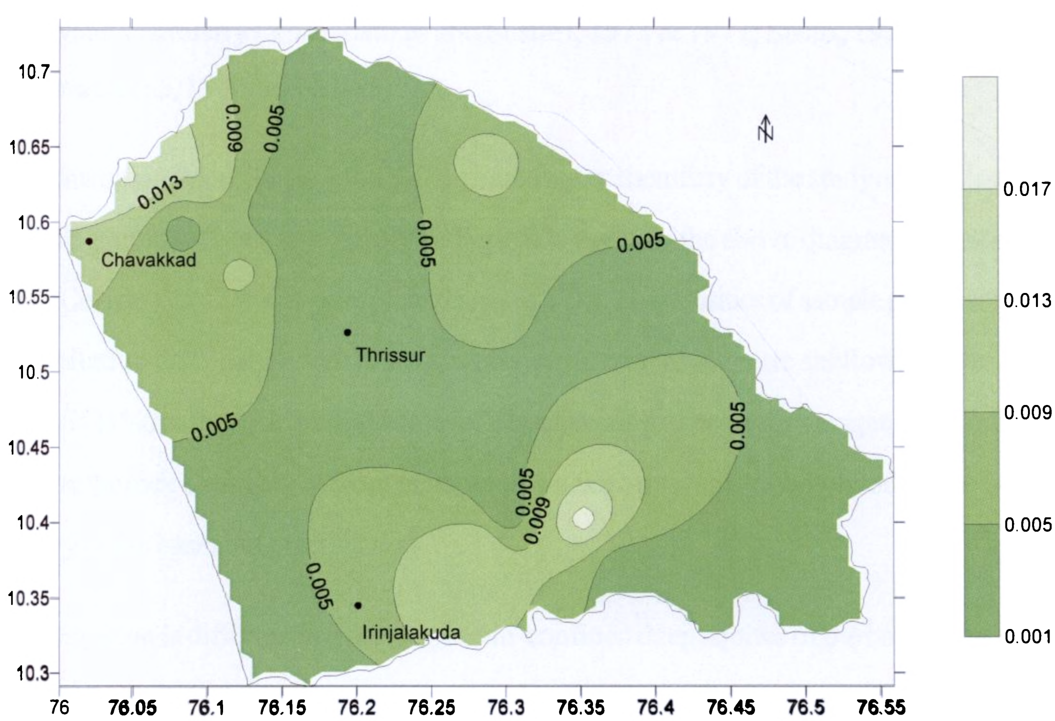


Fig. 5.25b. Isocone map of corosivity ratio in semi-confined aquifer (bore wells) of the Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

5.3 Chemical relationship of groundwater and hydrochemical facies

Hydrochemical water quality studies help to explain the relationships of water chemistry to aquifer lithology (Viwsanath and Sastri, 1973 & 1977; Sastri, 1976). Such relations would help not only to explain the origin and distribution of dissolved constituents but also to elucidate the factors controlling the groundwater chemistry (Rangarajan and Balasubramanian, 1990).

During the movement of groundwaters, ions and molecules are absorbed. The ratio of Ca to Na in water should be related to the composition of plagioclase feldspars present in the associated rocks (charnockite and gneisses). Likewise the proportion of Mg to other cations in water is an index of relative abundance of ferromagnesian minerals in the environment (Aravindan, 1990). The characteristics feature of the groundwater in metamorphic terrain is the presence of high concentration of sodium bicarbonate but relatively low concentration of chloride (White, 1957). Generally waters from metamorphic formations are likely to contain low dissolved solids thus resembling more closely with waters of igneous rocks. Gibbs (1970) proposed an elegant simple explanation for the general chemistry of streams and rivers. Later on so many workers have used Gibbs diagram to explain groundwater chemistry (Viswanathan and Sasthri, 1973 & 1977; Sastri, 1976; Rangarajan and Balasubramanian, 1990 and others).

The mechanism responsible to control the groundwater chemistry of the study area following Gibbs (1970) diagram have been represented in Figs. 5.26a & b. In the above diagrams ratios of (Na+K)/(Na+K+Ca) and Cl/(Cl+HCO_3) are plotted against TDS. The densities of sample points are maximum in precipitation dominance area (79%), while in the case of phreatic shallow aquifer only a few points fall (21%) in the rock dominance area. The clustering of points in precipitation domain clearly shows that the rock chemistry of the phreatic aquifer is not a major factor in controlling the groundwater chemistry of the basin but precipitation.

But the situation is different in the case of semi-confined deep aquifer of the basin. Out of 260 data points plotted, 77% data points fall in rock dominance area and only 23% data points fall in precipitation dominance are. The clustering of data points in rock domain clearly shows that rock chemistry of the semi-confined deep aquifers is a major factor in controlling the groundwater chemistry of the basin and not precipitation.

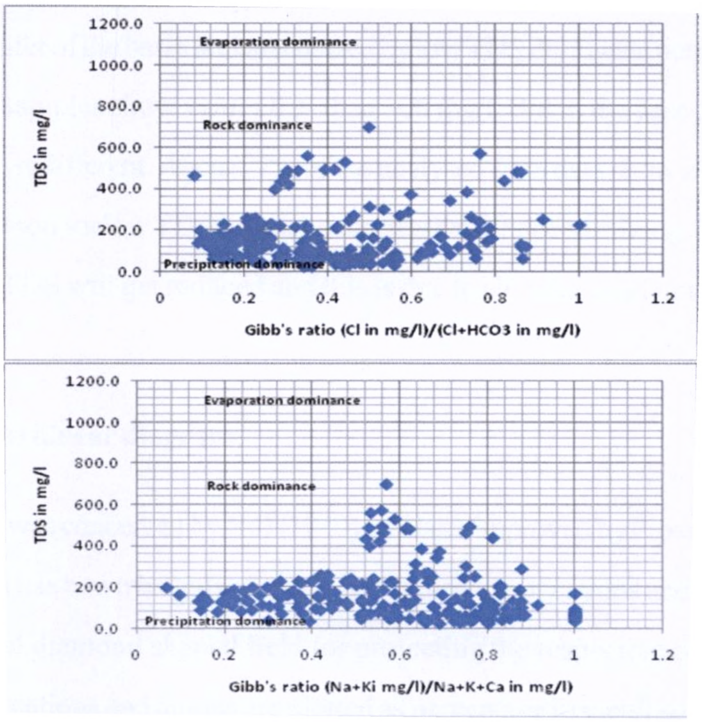


Fig. 5.26a. Gibb's diagram illustrating the mechanism controlling the groundwater chemistry of phreatic aquifer in the study area

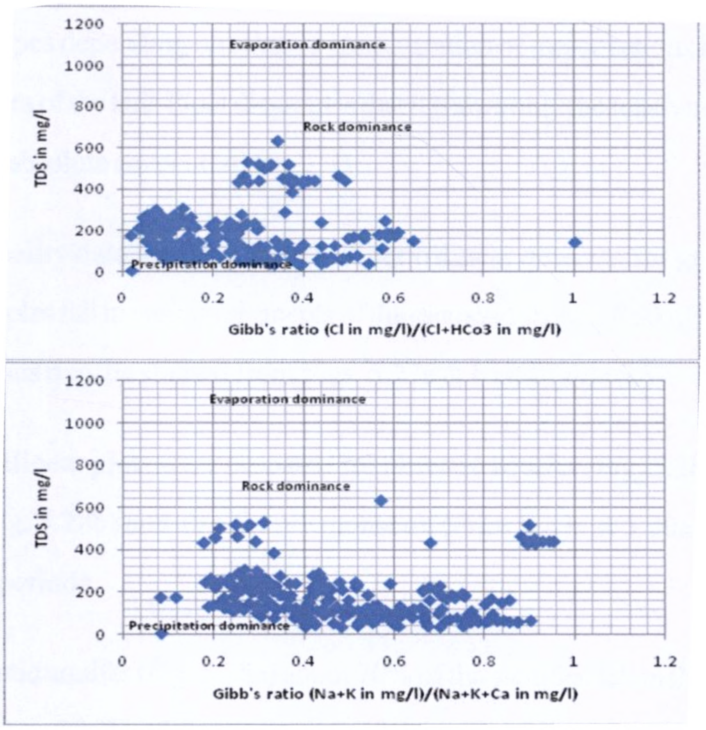


Fig. 5.26b. Gibb's diagram illustrating the mechanism controlling the groundwater chemistry of semi-confined aquifer in the study area

The phreatic aquifer of the basin is characterised by low TDS during the period of investigation and more than 79% samples show values less than 100 mg/l. But in the case of semi-confined deep aquifers the seen is different. About 77% of the analysed TDS data show a TDS values more than 100 mg/l. The reason for low TDS in preatic aquifer may be due to mixing. Once a mixing of water takes place, the TDS will get reduced and this is due to abundance of rainfall (Girish Gopinath, 2003).

5.3.1 Hill-Piper trilinear diagram

Pattern diagram was conceived by Hill (1940) and later improved by Piper (1944). The Hill-Piper trilinear diagram has two triangular fields, one for plotting of cations and other for anions and in between a central diamond shaped field for projecting the respective cations and anions. The concentration of cations and anions are plotted as percentage in meq/l so that the total of cations (Ca+Mg and Na+K) and anions (Cl, SO_4 and CO_3+HCO_3) are made to 100 percent. The Hill-Piper system has an advantage of plotting analytical data of a large number of samples into various hydrochemical types depending on relative concentration of major cations and anions. One of the main disadvantages of the Hill-Piper diagram is that it shows only the relative concentration of major ions but not their absolute concentrations.

The chemical quality data are used in Hill-Piper trilinear diagram for graphical analysis. The groundwater samples fall in various segments of the diamond shaped field of Hill-Piper diagram and their characteristics may be studied from Figs. 5.27a & b and Table 5.37.

The Hill-piper trilinear plots were prepared for phreatic aquifer (Fig. 5.28a) and semi-confined deep aquifers (Fig. 5.28b) and also for pre monsoon (Figs. 5.29a & 5.30a), post monsoon (Figs. 5.29b & 5.30b) periods.

In the plot of phratic aquifer (Fig. 5.28a) about 70% of the samples fall in the field 1 (alkaline earth exceeds alkalies) and 30% of the samples fall in the field 3 (weak acid exceeds strong acids). Similarly in the plot of semi-confined deep aquifer (Fig. 5. 28b) 90% of the samples fall in the field 1 and 10% of the samples fall in the field 3. The analysis of Hill-Piper trilinear diagram reveals that waters of both phreatic and semi-confined deep aquifer belong to Ca-Mg-HCO_3 facies and plot of

Piper Diagram

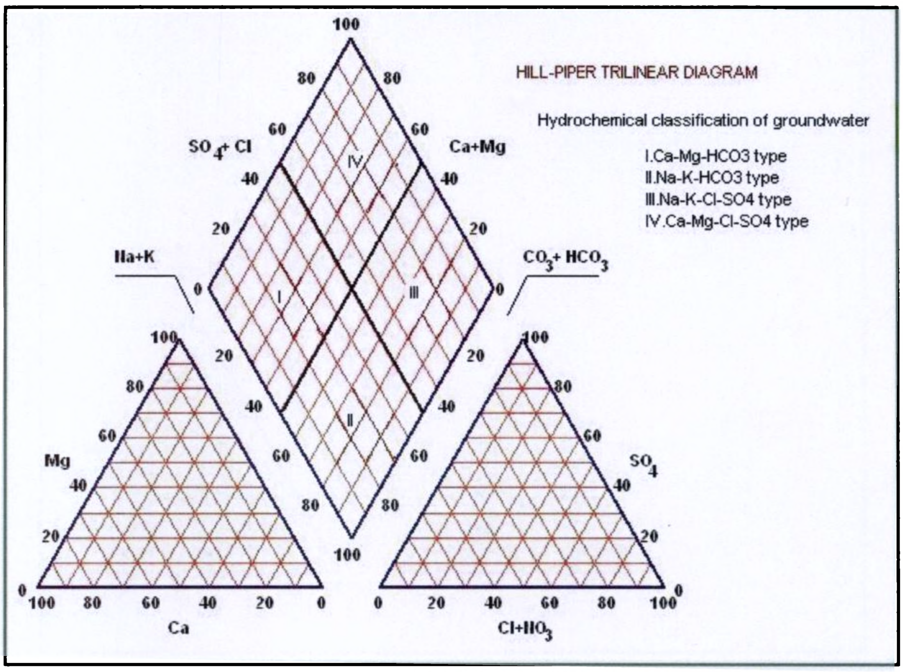


Fig. 5.27a. Hydrochemical facies classification of groundwater based on Hill-Piper trilinear diagram

Piper Diagram

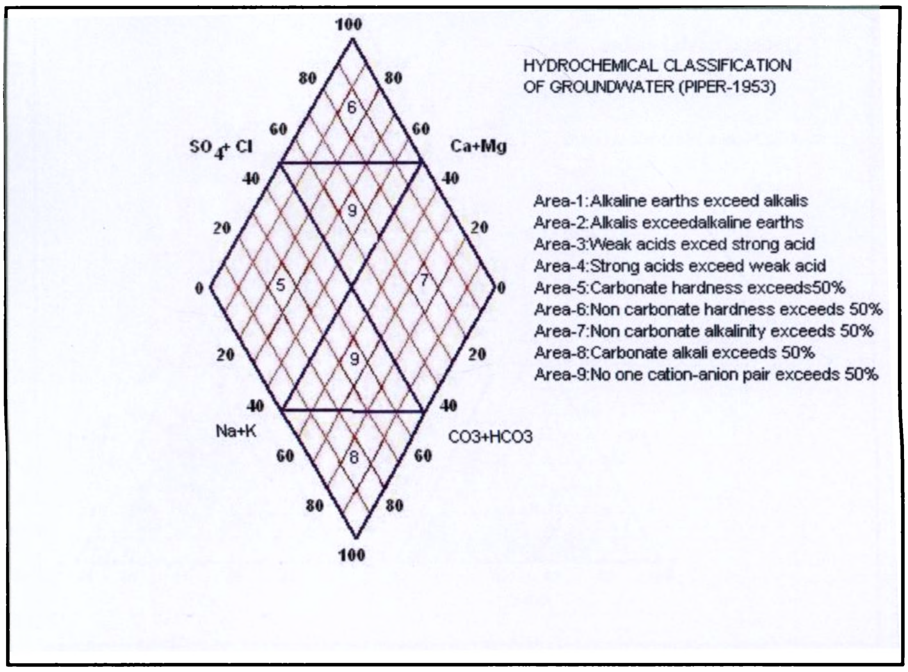


Fig. 5.27b. Hydrochemical facies classification of groundwater based on Hill-Piper trilinear diagram

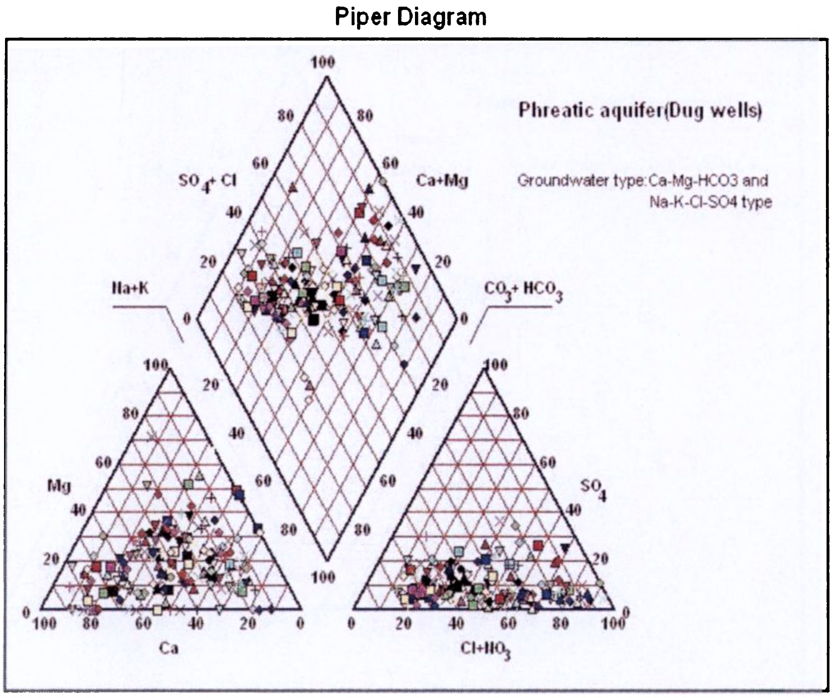


Fig. 5.28a. Hill-Piper trilinear diagram for phreatic aquifer (dug wells) in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

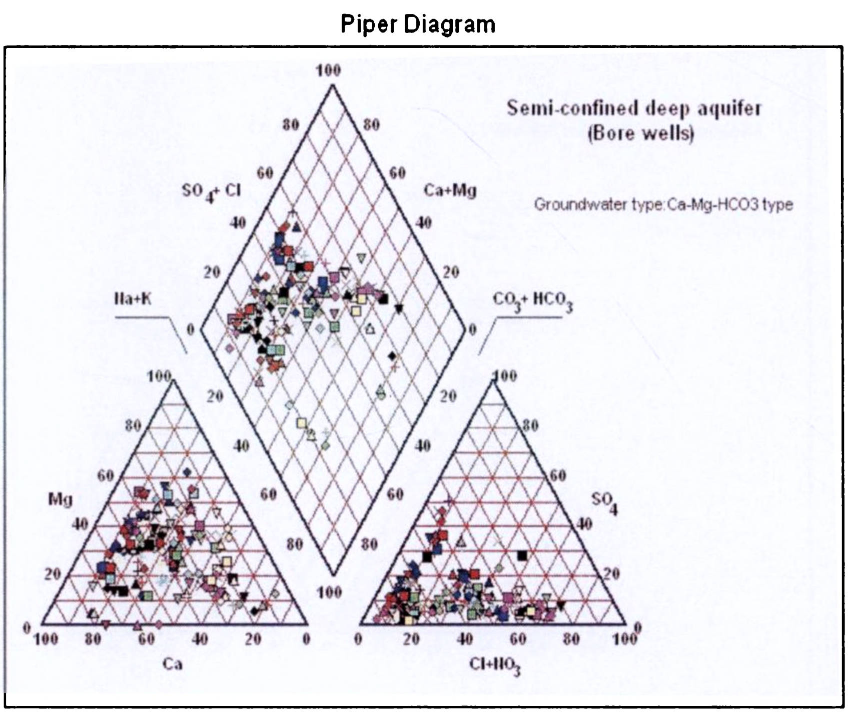


Fig. 5.28b. Hill-Piper trilinear diagram for semi-confined deep aquifer (bore wells) in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

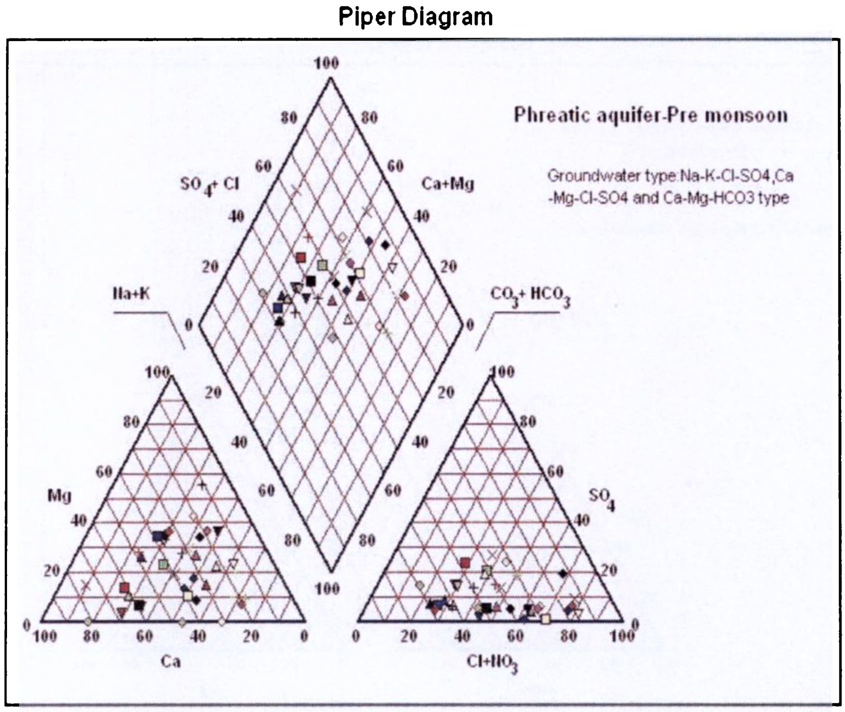


Fig. 5.29a. Hill-Piper trilinear diagram for phreatic aquifer (dug wells) in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006 (Pre monsoon)

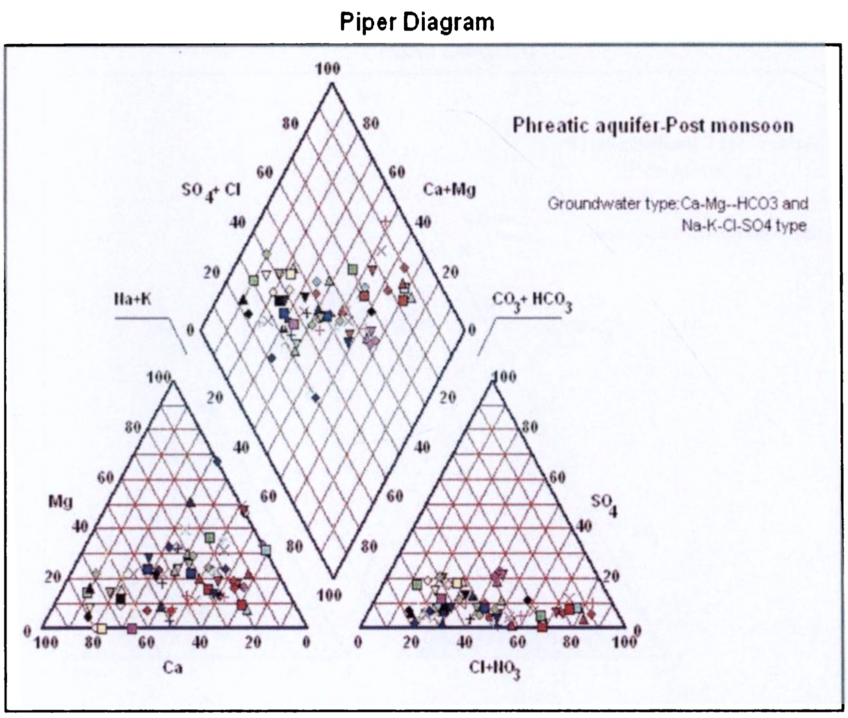


Fig. 5.29b. Hill-Piper trilinear diagram for phreatic aquifer (dug wells) in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006 (Post monsoon)

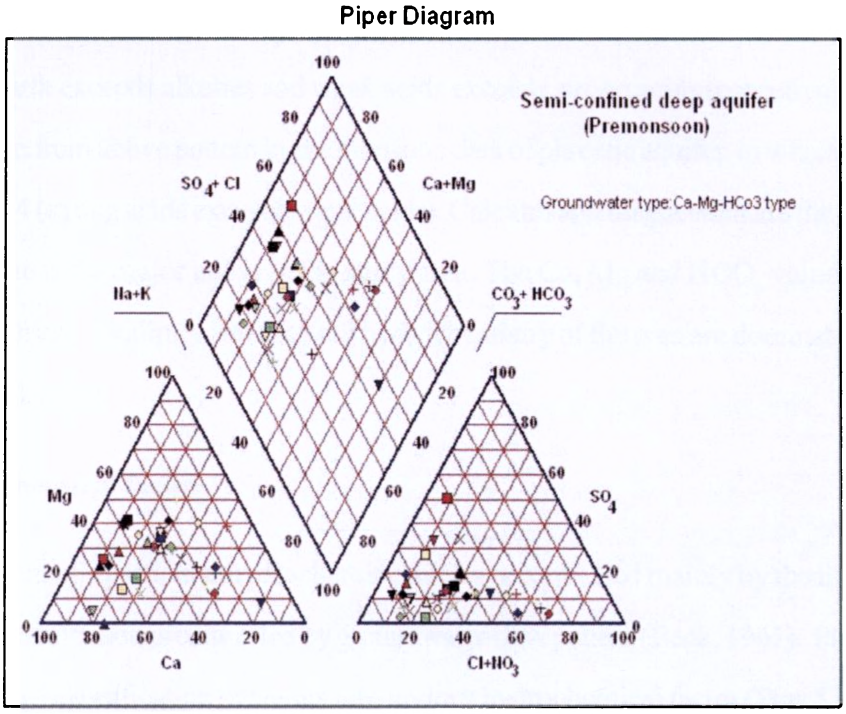


Fig. 5.30a Hill-Piper trilinear diagram for Semi-confined deep aquifer (bore wells) in Palaeo-lagoon for the period 01.01.2000 to 31.12.2006 (Pre monsoon)

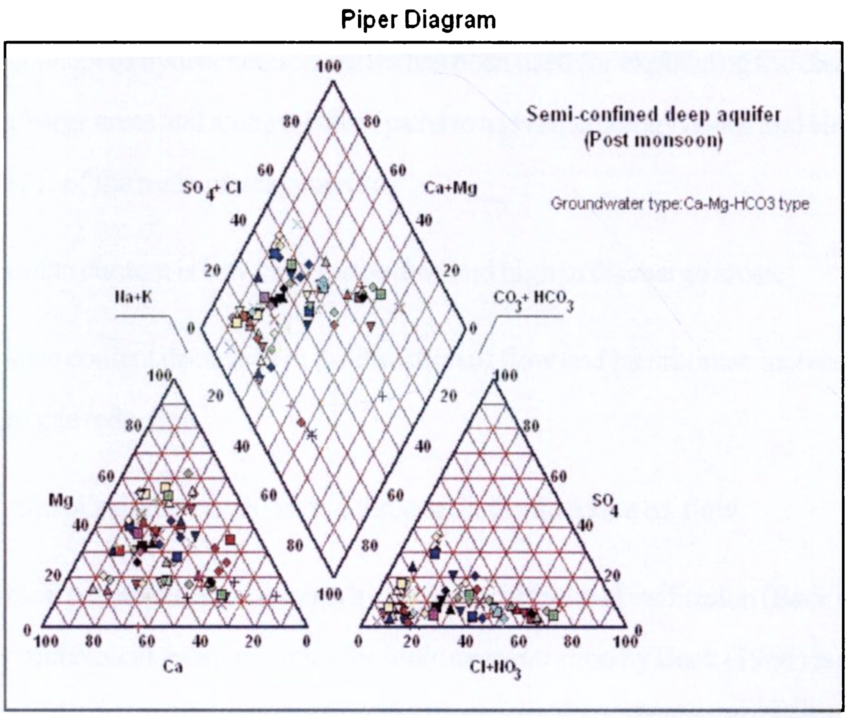


Fig. 5.30b. Hill-Piper trilinear diagram for Semi-confined deep aquifer (bore wells) in Palaeo-lagoon (Kole land basin) for the period 01.01.2000 to 31.12.2006 (Post monsoon)

the groundwater samples of pre and post monsoon data fall in the fields 1, 3 and 4 which suggest that alkaline earth exceeds alkalies and weak acids exceeds strong acids respectively. Very minor variation is seen from above pattern in pre monsoon data of phreatic aquifer, in which a few sample fall in the field 4 (strong acids exceeds weak acids). Calcium and magnesium are the major cations and bicarbonate is the major anion in the study area. The Ca, Mg and HCO_3 values indicate the temporary hardness, alkalinity and the total hydrochemistry of the area are dominated by alkaline earths and weak acids.

5.3.2 Hydrochemical facies

The development of a particular hydrochemical facies is controlled mainly by the lithology of the aquifer and its distribution is controlled by groundwater flow pattern (Back, 1961). Piper's diagram forms the basis of classification of waters into various hydrochemical facies (Figs 5.27a & b). The characteristics of various hydrochemical facies are given in Table 5.38. The difference between the Piper diagram and hydrochemical facies diagram is that instead of giving equal increments to various variables, the hydrochemical facies are distinguished into 0-10%, 10-50%, 50-90% and 90-100% domains. The concept of hydrochemical facies has been used for explaining the changes in water quality from recharge areas and along the flow paths in a given lithology (Back and Hanshaw, 1965; Back, 1966. Some of the main conclusions are

(i) Carbonate content is low in recharge area and high in discharge areas.

(ii) Sulphate content decreases in the direction of flow and bicarbonate increases, as a result of sulphate reduction.

(iii) The ratio of sulphate to chloride decreases in the direction of flow.

The hydrochemical pattern diagram helps in hydrochemical facies classification (Back and Hanshaw, 1965). The hydrochemical facies diagram for ionic concentration by Back (1966) is shown in Fig. 5.31a. The hydrochemical facies analysis of the basin was done for phreatic and semi-confined deep aquifers separately by superimposing the trilinear plots (Figs. 5.28a & b) over the hydrochemical facies diagram (5.31a).

Table 5.37 The quality of groundwater based on Hill-Piper trilinear diagram

Various segments of the diamond shaped field	Characteristics corresponding each small parts of diamond field
1	Alkaline earth (Ca+Mg) exceeds alkalies (Na+K)
2	Alkalies exceeds alkaline earths
3	Weak acid (CO3+HCO3) exceeds strong acids (SO4+Cl+F)
4	Strong acids exceeds weak acids
5	Carbonate hardness (secondary salinity) exceeds 50%
6	Non-carbonate hardness (secondary salinity) exceeds 50%
7	Non-carbonate alkali (primary salinity) exceeds 50%
8	Carbonate alkali(primary (alkalinity) exceeds 50%
9	None of the cation or anion pairs exceeds 50%

Table 5.38 Classification of hydrochemical facies (after Back, 1966)

(Percentage of constituents in meq/l)

Cation facies	Ca + Mg	Na + K	HCO3+ CO3	Cl + SO4
Calcium-magnesium	90 to 100	0 < 10		
Calcium-sodium	50 to 90	10 < 50		
Sodium-calcium	10 to 50	50 < 90		
Sodium potasium	0 to 10	90 to 100		
Anion facies				
Bicarbonate			90 to 100	0 < 10
Bicarbonate- chloride-sulphate			50 to 90	10 < 50
Chloride-sulphate-bicarbonate			10 to 50	50 < 90
Chloride-sulphate			0 to 10	90 to 100

Three hydrochemical facies are identified for the water samples of phreatic aquifer of the basin. They are (i) Ca^{2+}-Mg^{2+} - HCO_3^- facies (Field I), (ii) Na^+-K^+-Cl^- - SO4 facies (Field 3) and (iii) Ca^{2+}-Mg^{2+}-Cl^- -SO_4^{2-} facies (Field 4). The Ca^{2+}-Mg^{2+} - HCO_3^- facies (Field I) and Na^+-K^+-Cl^- -SO_4 facies (Field 3) are common to water samples of the basin for the entire period of investigation (Fig. 5.28a) and post monsoon time (Fig 5.29b). But slight shift is seen in the water sample of pre monsoon period towards the field 4 (Ca^{2+}-Mg^{2+}-Cl^- -SO_4^{2-} facies) and retain the previous pattern after monsoon. This indicates that the post monsoon samples are enriched with bicarbonate and sodium. From this it is evident that rainfall plays a major role in controlling the groundwater chemistry of phreatic aquifer of the basin rather than geology. The facies analysis of cations and anions shows that calcium and magnesium are the major cations (about 70 to 75%) and bicarbonate is the major anion (60 to 65%) of the basin. Sodium and potassium (25 to 30%) and chloride and sulphate (35 to 40%) are the minor cations and anions respectively.

Two hydrochemical facies are identified for the water samples of semi-confined deep aquifer of the basin. They are (i) Ca^{2+}-Mg^{2+}-HCO_3^- facies (Field I) and (ii) Na^+-K^+-Cl^- -SO_4 facies (Field 3). The Ca^{2+}-Mg^{2+}-HCO_3^- facies (Field I) and Na^+-K^+-Cl^- -SO_4 facies (Field 3) are common to water samples of the basin for the entire period of investigation (Fig. 5.28b), pre monsoon (Fig. 5.29a) and post monsoon times (Fig. 5.30b). There are not many variations of water samples observed in pre monsoon and post monsoon periods. From this it is evident that geology plays a major role in controlling the groundwater chemistry of semi-confined deep aquifer of the basin rather than rainfall. The facies analysis of cations and anions shows that calcium and magnesium are the major cations (about 60 to 65%) and bicarbonate is the major anion (70 to 75%) of the basin. Sodium and potassium (35 to 40%) and chloride and sulphate (25 to 30%) are the minor cations and anions respectively.

The changes in hydrogeochemical facies of the study area for the phreatic and semi-confined deep aquifer based on Johnson's (1975) modified diagram are shown in the Fig. 5.31b. The markings from the A to F in the diamond shaped field of the Hill-Piper diagram represent a specific class of water as given below.

HYDROCHEMICAL FACIES DIAGRAM

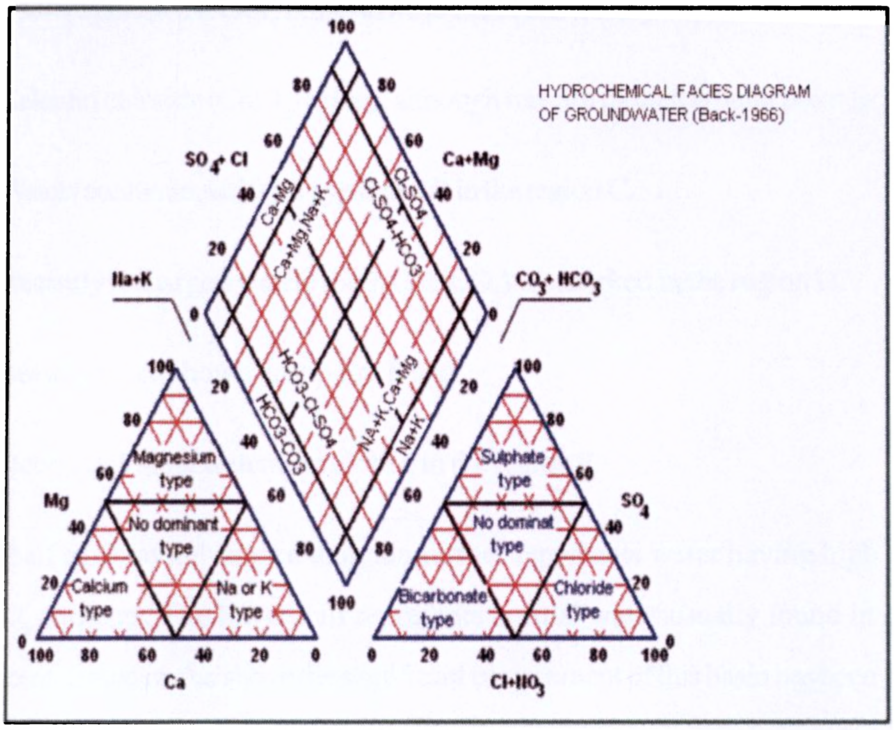


Fig. 5.31 a. Hydrochemical facies diagram of groundwater (Back, 1966)

HYDROCHEMICAL FACIES DIAGRAM

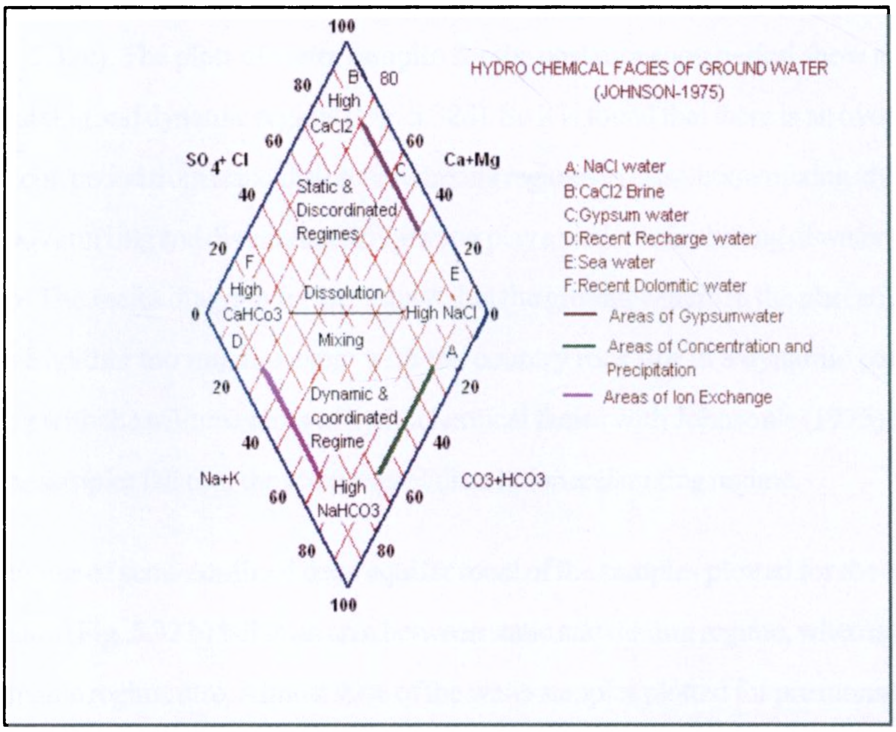


Fig. 5.31 b. Hydrochemical facies diagram of groundwater (Johnson, 1975)

(i) Sodium chloride (NaCl) brines always fall in the vicinity of point A.

(ii) Calcium chloride ($CaCl_2$) brines, although rare are plotted around point B.

(iii) Waters contaminated with gypsum fall in the region C.

(iv) Recently recharged waters (high $CaHCO_3$) are marked in the region D.

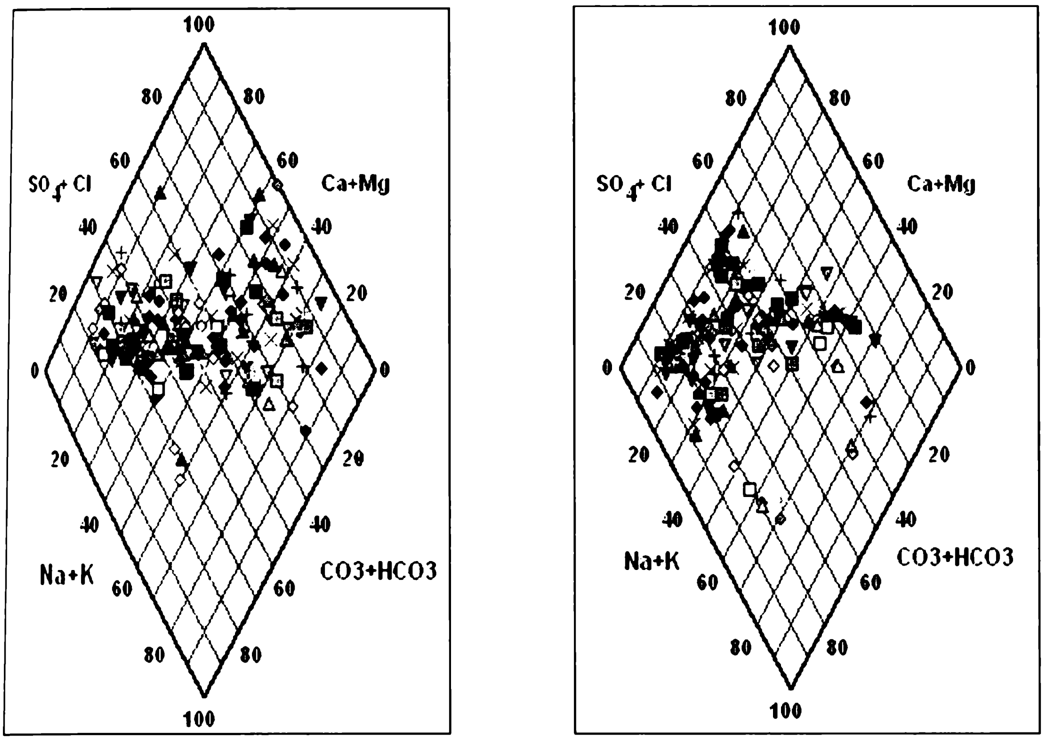
(v) Seawaters are shown near point E and

(vi) Recent dolomite waters are plotted in the region F.

The top half of diamond shaped diagram further represents water having high $Mg/CaCl_2$ and $CaMgSO_4$ contents. The lower half represents normal water usually found in dynamic basin environment. Based on the above the significant environment of this basin has been deduced below.

In the case of phreatic shallow aquifer most of the samples plotted for the entire period of investigation (Fig. 5.32a) fall in an area between static and mixing regime, whereas only a very few samples fall in dynamic regime. Almost 99% of the water samples plotted for pre monsoon period falls in the same field (Fig. 5.32c). The plots of water samples for the post monsoon period show a complete shift towards mixing and dynamic regime (Fig. 5.32d). So it is found that there is an overall shift during post monsoon period from static/dissolution/mixing regimes to dissolution/mixing /dynamic regimes. As said above mixing and dissolution of rainwater play a vital role in shifting of water from one facies to another. The facies diagram further attests that the ground waters in the phreatic aquifer of the basin have neither too much contact with the country rock nor in a dynamic condition. When comparing with the trilinear plots of hydrochemical facies with Johnson's (1975) diamond field, most of the samples fall near the proximity of dissolution and mixing regime.

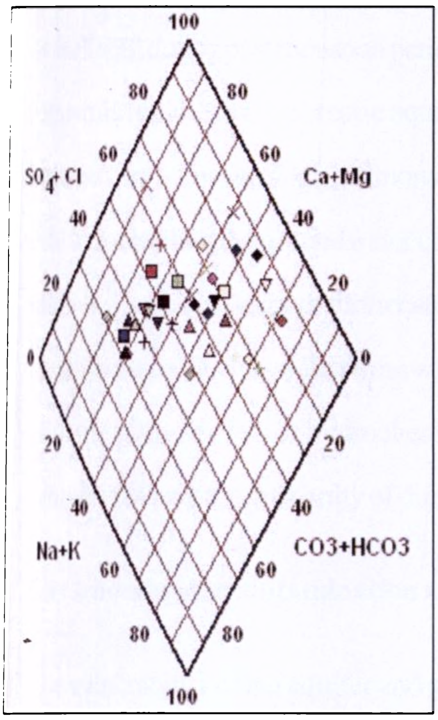
But in the case of semi-confined deep aquifer most of the samples plotted for the entire period of investigation (Fig. 5.32 b) fall in an area between static and mixing regime, whereas a few samples fall in dynamic regime also. Almost 90% of the water samples plotted for pre monsoon period falls in the same field (Fig 5.32e). The plots of water samples for the post monsoon period didn't show any marginal shift towards mixing and dynamic regime (Fig. 5.32f). So it is found that there is no



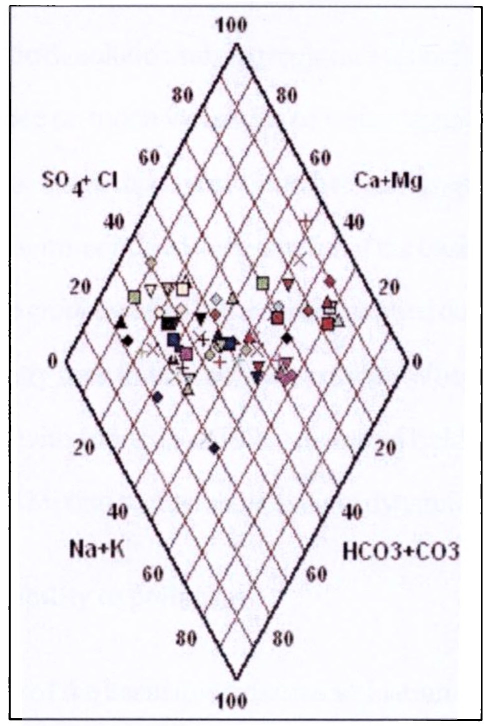
(a) Phreatic aquifer (dug well) (b) Semi-confined deep aquifer (bore well)

Figs. 5.32a&b Hydrochemical facies of phreatic and semi-confined deep aquifers of Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

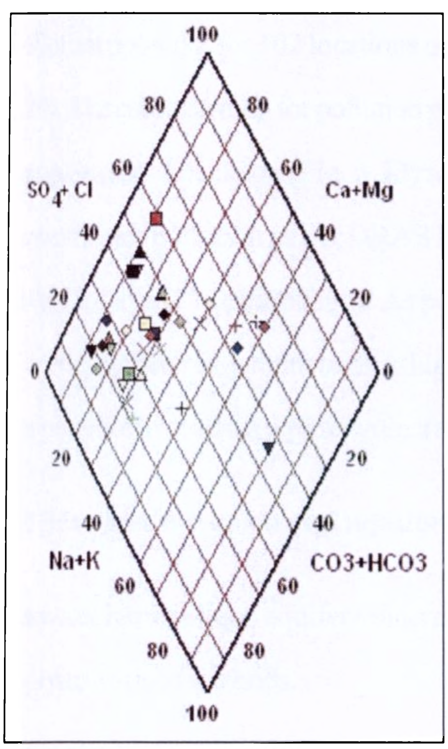
Plate 5.1 A view of the seasonal flood in the study area.

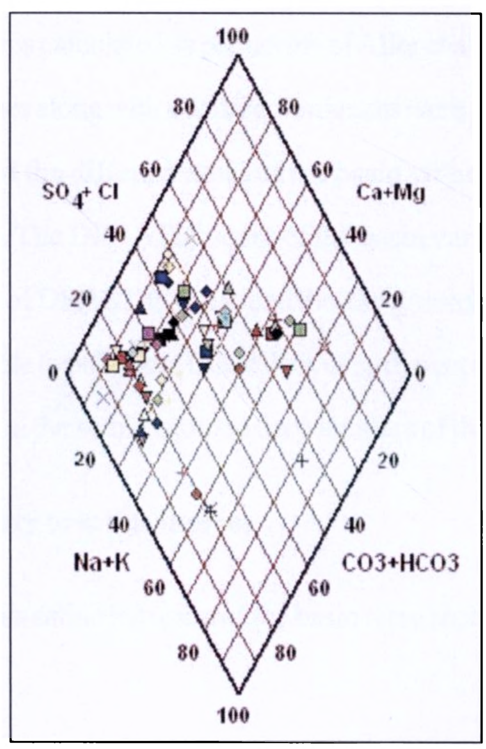


(c) Phreatic aquifer (pre monsoon)



(d) Phreatic aquifer (post monsoon)





(e) Semi-confined deep aquifer (pre monsoon) (f) Semi-confined deep aquifer (post monsoon)

Figs. 5.32c-f. Hydrochemical facies of phreatic and semi-confined deep aquifers (pre monsoon & post monsoon) of Palaeo-lagoon for the period 01.01.2000 to 31.12.2006

overall shift during post monsoon period from static/dissolution/mixing regimes to dissolution/mixing /dynamic regimes as in phreatic aquifer. There are no much variations of water samples observed between pre monsoon and post monsoon periods. From this it is evident that geology plays a major role in controlling the groundwater chemistry of semi-confined deep aquifer of the basin rather than rainfall. The facies diagram further attests that the groundwaters in the semi-confined deep aquifer of the basin have much resident time with the country rock than in phreatic aquifer. When comparing with the trilinear plots of hydrochemical facies with Johnson's (1975) diamond field, most of the samples fall near the proximity of dissolution and mixing regime show a slight dynamic nature.

5.4 Groundwater contamination and vulnerability to pollution

The vulnerability of the aquifer and groundwater of the basin towards contamination and pollution was analysed by DRASTIC method (Aller et al., 1987).

Pollution potential for 102 locations of the basin was calculated as per norms of Aller et al., (Table 5.39). The contours map for pollution potential values along with x and y co-ordinates were prepared using Surfer- 7 package (Fig. 5.33) and identified the different areas of the basin vulnerable to groundwater pollution as per DRASTIC method. The DRASTIC score of the basin varies from 110 (Tholur) to 176 (Kuttichira). As per the norms of DRASTIC it is found that the groundwater in phreatic aquifer of the entire basin is highly vulnerable to pollution. Due to lack of sufficient data, it is not possible to conduct aquifer vulnerability study in the semi-confined deep aquifers of the basin.

5.5 Seawater intrusion and aquifer vulnerability to saline ingress

Seawater intrusion and aquifer vulnerability towards saline intrusion of the basin were analysed by applying various methods.

Chemical parameters to identify seawater intrusion: Seawater contains large amounts of dissolved salt such as chloride, bromide, sulphate, sodium and magnesium. The dissolved salts include large amounts of sodium chloride, and significant quantities of alkaline earths and sulphates, transmitting high hardness. The average seawater composition is shown in the Table 5.40.

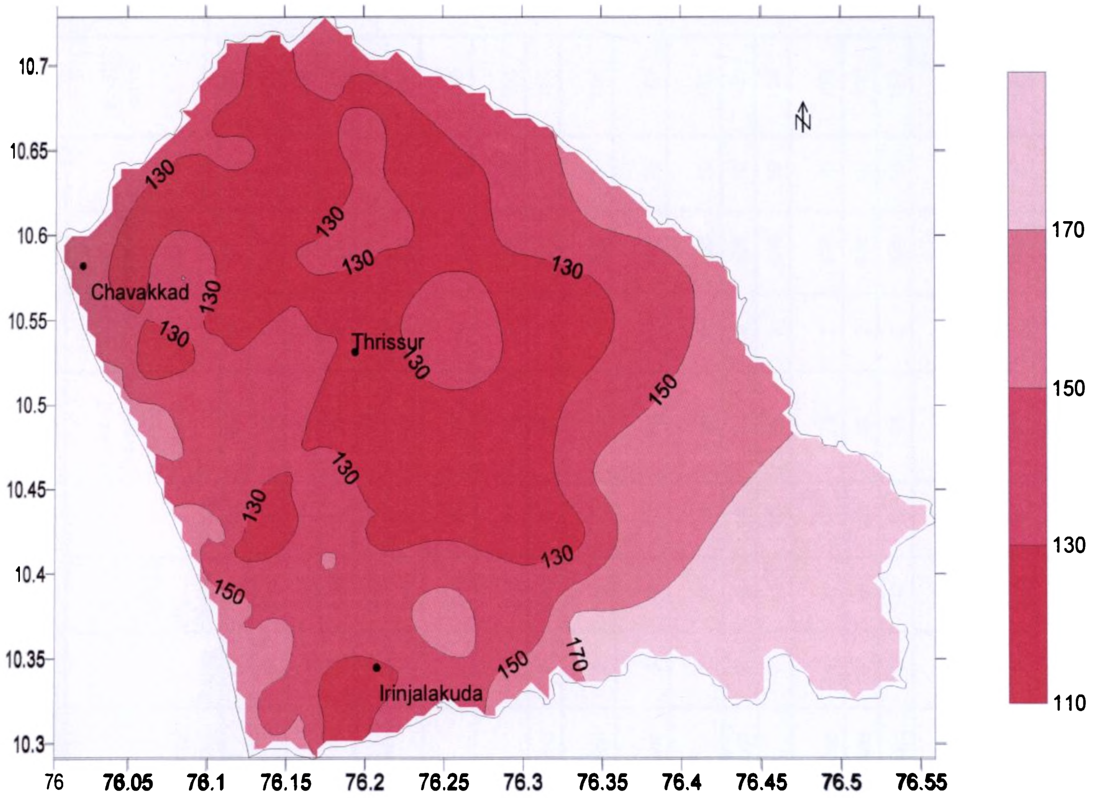


Fig. 5.33. Map indicating groundwater vulnerability to pollution of phreatic aquifer in Palaeo-lagoon (Kole land basin) by DRASTIC method.

Plate. 5.2. Topgraphical view of the study area, which facilitates the groundwater to pollution.

Table 5.39 Groundwater vulnerability assessment to pollution by DRASTIC method score computation for palaeo-lagoon (Kole land basin)

				Parameter D		Parameter R		Parameter A		Parameter S		Parameter T		Parameter I		Parameter C		
Sl.No	Location	Lattitude	Longitude	Depth to water table (BGLm)	Rating	Recharge (Water table fluctuation (m))	Rating	Aquifer media (Lithology)	Rating	Soil media (Soil type)	Rating	Topography (Slope)	Rating	Impact of Vadose zone (weatherd thickness (m))	Rating	Conductivity (Hydraulick:m/d)	Rating	DRASTIC score
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Chelur	10°20'30"	76°12'00"	3.2	9	4	6	Alluvium	7	Loam	7	2–5	6	20	2	6.5	2	126
2	Arippalam	10°18'08"	76°11'45"	4	9	3	6	Laterite	6	Loam	7	2--5	6	12	2	15	4	129
3	Edakulam	10°19'15"	76°12'02"	4	9	4	6	Laterite	6	Loam	7	2–5	6	15	2	15	4	129
4	Padiyoor	10°18'00"	76°10'45"	5.4	7	4	6	Alluvium	7	Loam	7	2--5	6	15	2	6.5	2	116
5	Edathirinji	10°19'17"	76°00'45"	5	7	4	6	Alluvium	7	Loam	7	2--5	6	14	2	6.5	2	116
6	Edathirinji Jn.	10°19'45"	76°10'35"	5	7	4	6	Alluvium	7	Loam	7	2–5	6	13	2	6.5	2	116
7	Edathirinji Jn.	10°19'45"	76°09'38"	2.2	9	4	6	Alluvium	7	Loam	7	2–5	6	13	2	436	10	150
8	Mathilakam	10°18'45"	76°09'37"	2	9	3	6	Alluvium	7	Clayi sand	9	2–5	6	35	2	436	10	154
9	Moonnupeedika	10°19'00"	76°08'32"	1.8	9	3	6	Alluvium	7	Clayi sand	9	<2	10	25	2	6.5	2	134
10	West Perinjanam	10°18'45"	76°07'30"	1.15	10	3	6	Alluvium	7	Clayi sand	9	<2	10	80	2	436	10	163
11	Chamakkala	10°21'08"	76°06'50"	1.1	10	3	6	Alluvium	7	Loam	7	<2	10	20	2	436	10	159
12	Edathiruthi	10°21'37"	76°08'28"	3.5	9	4	6	Alluvium	7	Clayi sand	9	<2	10	21	2	436	10	158
13	Kattoor	10°21'23"	76°07'38"	2.5	9	3	6	Alluvium	7	Loam	7	<2	10	15	2	436	10	154
14	Kazhimbram	10°22'28"	76°06'20"	2.2	9	2	6	Alluvium	7	Clayi sand	9	<2	10	75	2	436	10	158
15	Edamuttam	10°22'38"	76°07'20"	2.5	9	2	6	Alluvium	7	Clayi sand	9	<2	10	32	2	436	10	158
16	Nattika	10°24'57"	76°05'30"	2	9	4	6	Alluvium	7	Clayi sand	9	<2	10	32	2	436	10	158
17	Nattika beach	10°24'45"	76°05'15"	1.2	10	3	6	Alluvium	7	Clayi sand	9	<2	10	80	2	436	10	163
18	Nattika jn	10°25'00"	76°06'15"	2	9	4	6	Alluvium	7	Clayi sand	9	<2	10	28	2	6.5	2	134
19	Truprayar	10°2452"	76°07'08"	3.5	9	4	6	Alluvium	7	Loam	7	2–5	6	25	2	6.5	2	126
20	Chazhoor	10°26'00"	76°09'00"	7	7	6	7	Alluvium	7	Loam	7	2--5	6	15	2	6.5	2	120
21	Peringottukara	10°25'30"	76°08'05"	5.2	7	4	6	Alluvium	7	Clayi sand	9	2–5	6	20	2	6.5	2	120
22	Vatanapalli bea	10°27'30"	76°04'10"	0.9	10	3	6	Alluvium	7	Clayi sand	9	<2	10	80	2	6.5	2	139

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
23	Kanjani north	10°29'08"	76°06'40"	3	9	4	6	Alluvium	7	Clayi sand	9	2–5	6	26	2	6.5	2	130
24	Eravu	10°28'40"	76°08'22"	6.6	7	4	6	Weatherd rock	4	Gravelly loam	12	2--5	6	9	5	15	4	138
25	Vatanapalli jn	10°28'15"	76°04'45"	2.4	9	3	6	Alluvium	7	Clayi sand	9	2–5	6	29	2	436	10	154
26	Kundazhiyoor west	10°31'15"	76°02'50"	1.1	10	2	3	Alluvium	7	Clayi sand	9	<2	10	32	2	436	10	151
27	Kundazhiyoor east	10°31'20"	76°03'40"	3.3	9	2	3	Alluvium	7	Clayi sand	9	2--5	6	28	2	6.5	2	118
28	Kadappuram	10°31'30"	76°01'45"	1.4	10	2	3	Alluvium	7	Clayi sand	9	<2	10	81	2	436	10	151
29	Chavakkad west	10°34'35"	76°01'05"	3.9	9	2	3	Alluvium	7	Clayi sand	9	<2	10	80	2	436	10	146
30	Chavakkad east	10°34'35"	76°02'45"	4.1	9	2	3	Alluvium	7	Clayi sand	9	2–5	6	30	2	6.5	2	118
31	Tayakkad	10°35'45"	76°03'45"	3.4	9	3	6	Alluvium	7	Loam	7	2–5	6	20	2	6.5	2	126
32	Choondal	10°37'30"	76°05'30"	8.3	7	4	6	Alluvium	7	Loam	7	2–5	6	12	2	15	4	122
33	Ernellur	10°37'00"	76°07'48"	7	7	4	6	Alluvium	7	Loam	7	5--10	4	12	2	6.5	2	114
34	Kaiparamba	10°36'30"	76°08'30"	7	7	4	6	Alluvium	7	Loam	7	5--10	4	20	2	15	4	120
35	Tholur	10°34'08"	76°07'30"	14	5	4	6	Alluvium	7	Loam	7	5--10	4	18	2	15	4	110
36	Anakkara	10°32'30"	76°06'35"	1.2	10	3	6	Alluvium	7	Loam	7	2--5	6	20	2	6.5	2	131
37	Penagam	10°32'45"	76°06'45"	11.5	5	4	6	Laterite	6	Gravelly loam	12	2--5	6	19	2	15	4	119
38	Pavaratty	10°33'30"	76°04'00"	4.5	9	3	6	Alluvium	7	loam	7	2–5	6	12	2	15	4	132
39	Mullassery	10°31'38"	76°05'30"	3.8	9	3	6	Alluvium	7	Clayi sand	9	2–5	6	15	2	6.5	2	130
40	Irimbranellur	10°30'25"	76°06'08"	1.6	9	3	6	Alluvium	7	loam	7	<2	10	18	2	6.5	2	130
41	Ettumuna	10°24'43"	76°11'50"	1.2	10	3	6	Alluvium	7	Loam	7	2--5	10	19	2	6.5	2	135
42	Chirakkal	10°24'35"	76°10'40"	1.6	9	4	6	Alluvium	7	Loam	7	5--10	10	10	2	436	10	154
43	Cherpu	10°25'52"	76°12'30"	3.2	9	6	7	Alluvium	7	Loam	7	5--10	10	15	2	10	2	134
44	Palakkal	10°25'48"	76°12'30"	12	5	5	7	Laterite	6	Gravelly loam	12	5--10	4	18	2	15	4	121
45	Pallippuram	10°27'30"	76°11'15"	6.7	7	5	7	Laterite	6	Gravelly loam	12	5--10	4	13	2	15	4	131
46	Ammadam	10°27'16"	76°10'22"	3	9	5	7	Laterite	6	Gravelly loam	12	5--10	4	10	2	15	4	141
47	Alappad	10°26'37"	76°09'45"	2	9	4	6	Laterite	6	Gravelly loam	12	2--5	6	11	2	15	4	139

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
48	Pullu	10°27'23"	76°09'15"	4.6	7	4	6	Laterite	6	Gravelly loam	12	2--5	6	12	2	15	4	129
49	Manakkodi	10°28'30"	76°09'46"	5.6	7	4	6	Laterite	6	Gravelly loam	12	2--5	6	13	2	15	4	129
50	Kunnathangadi	10°29'45"	76°09'30"	8	7	6	7	Laterite	6	Gravelly loam	12	5--10	4	16	2	15	4	131
51	Ayyanthole	10°31'15"	76°11'23"	6.3	7	4	6	Laterite	6	Gravelly loam	12	5--10	4	15	2	15	4	127
52	Puzhakkal	10°32'15"	76°10'45"	0.8	10	3	6	Alluvium	7	Loam	7	2--5	6	15	2	6.5	2	131
53	Muthuvara	10°33'00"	76°10'20"	8.6	7	4	6	Laterite	6	Gravelly loam	12	5--10	4	15	2	15	4	127
54	Mundur	10°35'23"	76°09'30"	6.5	7	5	7	Laterite	6	Gravelly loam	12	5--10	4	15	2	15	4	131
55	Velur	10°38'15"	76°10'39"	8	7	5	7	Laterite	6	Gravelly loam	12	5--10	4	12	2	4.36	2	125
56	Karancheri	10°37'45"	76°13'31"	4.2	9	6	7	Alluvium	7	Loam	7	5--10	4	16	2	6.5	2	128
57	Thirur	10°35'15"	76°12'51"	5.8	7	4	6	Laterite	6	Gravelly loam	12	5--10	4	12	2	15	4	127
58	Patturackal	10°32'15"	76°13'00"	1.2	10	4	6	Alluvium	7	Loam	7	5--10	4	11	2	6.5	2	129
59	Adat	10°32'15"	76°08'37"	4	9	3	6	Laterite	6	Gravelly loam	12	2--5	6	10	2	15	4	139
60	Chittilapalli	10°33'43"	76°0857"	8.1	7	4	6	Laterite	6	Gravelly loam	12	2--5	6	16	2	15	4	129
61	Puthuruthi	10°39'30"	76°11'45"	3.5	9	4	6	Laterite	6	Gravelly loam	12	5--10	4	10	2	15	4	137
62	Mangadumkuzhi	10°41'21"	76°11'32"	6.8	7	4	6	Laterite	6	Gravelly loam	12	5--10	4	15	2	15	4	127
63	Mundathikode	10°41'38"	76°10'10"	6	7	5	7	Laterite	6	Gravelly loam	12	5--10	4	9	5	15	4	146
64	Kadangode	10°40'38"	76°09'38"	8.9	7	2	3	Laterite	6	Gravelly loam	12	5--10	4	16	2	15	4	115
65	Pannithadam	10°40'08"	76°06'50"	7.4	7	3	6	Weatherd rock	4	Gravelly loam	12	5--10	4	13	2	15	4	121
66	Kunnamkulam	10°38'22"	76°04'30"	4.2	9	6	7	Weatherd rock	4	Gravelly loam	12	5--10	4	13	2	6.5	2	129
67	Eyyal	10°39'00"	76°07'12"	2.7	9	3	6	Alluvium	7	Loam	7	5--10	4	9	5	6.5	2	139
68	Kundannur	10°40'37"	76°13'07"	3.4	9	5	7	Alluvium	7	Loam	7	5--10	4	12	2	6.5	2	128
69	Wadakkancherry	10°39'15"	76°14'45"	7.1	7	4	6	Laterite	6	Gravelly loam	12	10--18	3	13	2	4.36	2	120
70	Madayikonam	10°22'37"	76°14'45"	1.7	9	3	6	Alluvium	7	Loam	7	2--5	6	7	5	436	10	165
71	Thottippal	10°23'50"	76°14'07"	3	9	3	6	Alluvium	7	Loam	7	2--5	6	7	5	6.5	2	141

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
72	Parapookkara	10°24'08"	76°15'52"	3.2	9	3	6	Alluvium	7	Loam	7	2--5	6	7	5	6.5	2	141
73	Thrissur	10°31'13"	76°13'07"	6.24	7	4	6	Laterite	6	Gravelly loam	12	5--10	4	12	2	15	4	127
74	Mannuthi	10°31'53"	76°15'48"	2.73	9	5	7	Laterite	6	Gravelly loam	12	5--10	4	10	2	15	4	141
75	Pananchery	10°33'23"	76°19'56"	7.91	7	2	3	Laterite	6	Gravelly loam	12	10--18	3	12	2	15	4	114
76	Pudukkad	10°25'07"	76°16'18"	5.41	7	4	6	Laterite	6	Gravelly loam	12	5--10	4	· 15	2	15	4	127
77	Kodakara	10°22'19"	76°18'19"	2.4	9	3	6	Laterite	6	Gravelly loam	12	10--18	3	12	2	15	4	136
78	Irinjalakudaa	10°20'32"	76°13'11"	7.6	7	4	6	Laterite	6	Gravelly loam	12	2--5	6	14	2	15	4	129
79	MG kavu	10°36'00"	76°12'41"	3.78	9	3	6	Laterite	6	Gravelly loam	12	5--10	4	13	2	15	4	137
80	Ottuppara	10°39'53"	76°15'24"	3.47	9	2	3	Laterite	6	Gravelly loam	12	5--10	4	9	5	15	4	140
81	Chelakkara	10°38'15"	76°18'00"	5.81	7	4	6	Laterite	6	Gravelly loam	12	10--18	3	9	5	15	4	141
82	Kunnamkulam	10°38'49"	76°04'11"	6.59	7	6	7	Laterite	6	Gravelly loam	12	2--5	6	16	2	15	4	133
83	Chavakkad	10°34'49"	76°01'29"	1.75	9	2	3	Alluvium	7	Clayi sand	9	<2	10	32	2	436	10	146
84	Pazhanji	10°41'20"	76°06'26"	1.48	10	6	7	Laterite	6	Gravelly loam	12	2--5	6	12	2	15	4	148
85	Nattika	10°25'11'	76°06'26"	0.79	10	4	6	Alluvium	7	Clayi sand	9	<2	10	30	2	436	10	163
86	Edamuttam	10°22'19"	76°07'34"	3.18	9	2	3	Alluvium	7	Clayi sand	9	<2	10	29	2	436	10	146
87	Mathilakam	10°17'30"	76°09'53"	2.46	9	3	6	Alluvium	7	Clayi sand	9	<2	10	29	2	436	10	158
88	Engadiyur	10°29'39"	76°04'04"	2	9	3	6	Alluvium	7	Clayi sand	9	<2	10	31	2	436	10	158
89	Vaniyampara	10°34'38"	76°24'35"	3.34	9	4	6	Laterite	6	Gravelly loam	12	10--18	3	7	5	15	4	151
90	Varandarappilly	10°25'18"	76°19'54"	6.36	7	3	6	Laterite	6	Gravelly loam	12	10--18	3	9	2	4.36	2	120
91	Cherpu	10°26'25"	76°12'44"	10.83	5	6	7	Laterite	6	Gravelly loam	12	2--5	6	16	2	15	4	123
92	Puthur	10°28'57"	76°17'26"	9.22	5	4	6	Laterite	6	Gravelly loam	12	5--10	4	16	2	15	4	117
93	Elavally	10°34'34"	76°05'14"	3.61	9	3	6	Laterite	6	Gravelly loam	12	2--5	6	9	5	15	4	154
94	Kadangode	10°42'07"	76°08'27"	7.23	7	2	3	Laterite	6	Gravelly loam	12	2--5	6	16	2	15	4	117

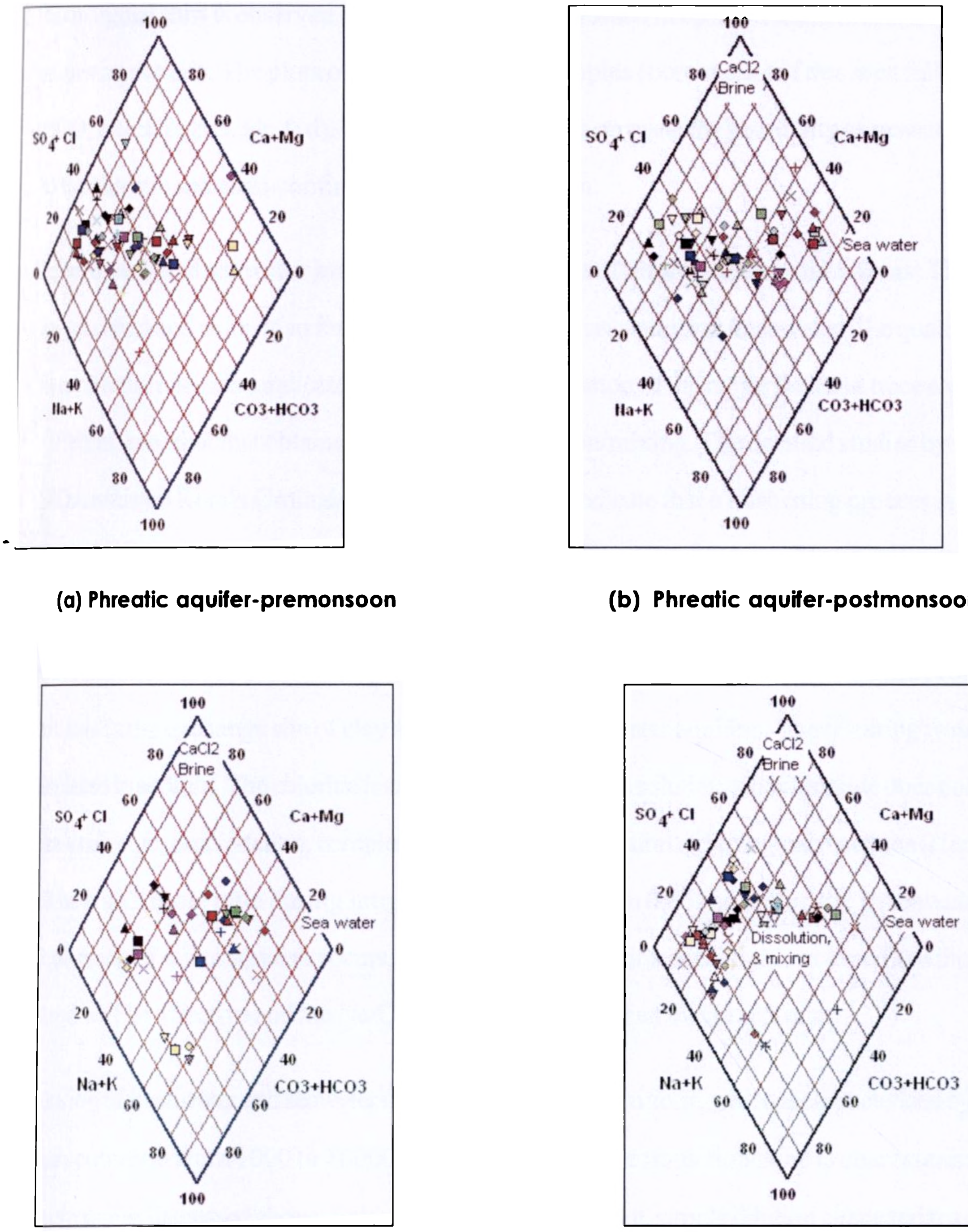
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
95	Punnamparambu	10°38'04"	76°16'11"	6.86	7	4	6	Laterite	6	Gravelly loam	12	10–18	3	11	2	15	4	126
96	Vazhani	10°38'15"	76°18'00"	6.2	7	3	6	Laterite	6	Gravelly loam	12	10–18	3	4	8	15	4	156
97	Monadi	10°21'30"	76°23'15"	5.2	9	2.5	6	Laterite	6	Gravelly loam	12	10–18	3	1	10	15	4	176
98	Matthathur	10°22'20"	76°20'00"	4.1	9	3	6	Laterite	6	Gravelly loam	12	10–18	3	1	10	15	4	176
99	Kuttichira	10°26'15"	76°28'15"	4.8	9	4	6	Laterite	6	Gravelly loam	12	10–18	3	1	10	15	4	176
100	Kallayi	10°27'30"	76°21'07"	5.1	9	3	6	Charnockite	10	Rock exposure	0	10–18	3	1	10	4.36	2	158
101	Munippara	10°37'00"	76°21'00"	4.8	9	3	6	Charnockite	10	Rock exposure	0	10–18	3	1	10	4.36	2	158

Continental freshwater is generally bicarbonate type, the alkaline earth to alkaline ion ratio being greater than seawater. Seawater is characterised by net predominance of chloride and sodium ions. Some of the chemical ratios like Mg/Ca and Cl/HCO_3 (in meq/l) are highly characteristic of seawater and helps to differentiate from continental water. When cationic ratios in water change, adsorbed cations on clay minerals are freed and replaced by new dominant ions. When marine water is changed for freshwater, the solid phase give up adsorbed calcium and part of magnesium, and replaces them by sodium. Thus marine water losses sodium and gain calcium and magnesium. Chloride ion remains unchanged. Thus in marine water Na/Cl ratio decreases and (Ca+Mg)/Cl ratio increases. When freshwater replaces marine water, marine water hardens. When fresh water is changed for marine water the reverse process takes. The alkaline to chloride ratio (Na+K)/Cl or Na/Cl give very useful indication of seawater intrusion.

In seawater sodium is the dominant cation and chloride is the dominant anion, whereas in most freshwaters calcium is the dominant cation and bicarbonate or sulphate is the dominant anions. Moreover the weight ratio of Ca/Mg in seawater is approximately 0.3. In contrast, in most of the freshwaters the Ca/Mg weight ratio is greater than 1.0.

In the study area, Ca and Mg are the prominent cations, HCO_3 is the prominent anion. Na/Cl ratio of both phreatic and semi-confined aquifers of the basin is greater than that of seawater and Ca/Mg ratio is >1. These evidences reject the possibility of seawater intrusion into aquifers the basin.

Identification of seawater intrusion through hydrochemical facies diagram: The Fig. 5.34 is the hydrochemical facies digram prepared for the phreatic (dug wells) and semi-confined (bore wells) aquifers of the basin within a limit of 10 km from the shoreline. The groundwater facies identified in phreatic aquifer of the basin are Ca-Mg-HCO_3 in pre monsoon and Ca-Mg-HCO_3, Na-K-Cl -SO_4 facies in post monsoon respectively. A slight shift is observed from the area of dissolution and mixing (bicarbonate facies) to the area of seawater (chloride- suphate facies) during post monsoon. This may not be due to saline intrusion to the phareatic aquifer but it is due to freshening of aquifer.



(a) Phreatic aquifer-premonsoon

(b) Phreatic aquifer-postmonsoon

(c) Semi-confiend deep aquifer- premonsoon

(d) Semi-confiend deep aquifer premonsoon

Figs. 5.34a-d Hydrochemical facies diagram for phreatic and semi-confined deep aquifers (1 to 10 km from shore line) of palaeo-lagoon (Kole land basin).

No marginal shift is observed in the plots of semi-confined deep aquifer in pre monsoon and post monsoon periods. The plots of the groundwater samples (bore wells) of this area fall in Ca-Mg-HCO_3 facies (Figs. 5.34c & d). The above mentioned facts reject the possibility of seawater intrusion to the phreatic and semi-confined aquifers of the basin.

Identification of seawater intrusion through ratios of major cations and anions: The ratios of major cation and anion is an important tool to identify seawater and freshwater. The quality of water in the Tertiary aquifers indicates the relative concentration of the major ions and trace elements are different from that that obtainable by seawater dilution/mixing. The detailed studies by CGWB in SIDA assisted Kerala Groundwater Project (1992), indicate that a freshening process is occurring in the aquifers. One of the parameter to indicate the long term process of freshening or sea water intrusion is the Na/Cl ratios (Mercade, 1985 and Jacks, 1987). In the course of seawater intrusion; part of the sodium ion is exchanged for calcium and magnesium ions, which are the predominant cations in the exchange site of clay minerals in the freshwater aquifers. The resulting water will be depleted in sodium. The chloride ions continue to remain in solution, since chloride does not undergo ion exchange, precipitation, complexing, oxidation, reduction or biological reactions (Hem, 1970). Thus Na/Cl mole ratio during intrusion shall be less than 0.85 the mole ratio in seawater. When freshening of saline aquifers occurs, the direction of the cation exchange is reversed and the opposite trend will be effective and the Na/Cl ratio will be higher than that in seawater.

Mixing of freshwater and seawater occurs within a transition zone, which is characterised by chloride concentration from 1000 to 10000 mg/l. The front of the transition zone is characterised by ion exchange as discussed above. Behind the ion exchange front, simple dilution characterizes deviation of the brackish water from seawater composition.

The Na/Cl ratios of the water samples from phreatic (shallow) and semi-confined (deep) aquifers of the basin were plotted against chloride content (Figs. 5.36a & b) and the theoretical trends for mixing, freshening and intrusion is shown in Fig. 5.35. It is seen that the Na/Cl ratio for most of the water samples is higher than that of seawater and seawater - freshwater mixing. Almost all samples ofboth phreatic and semi-confined aquifer of the basin fall in the field of rainwater (freshwater) and freshening. It also shows a trend of decreasing Na/Cl ratio with increasing Cl concentration (Figs. 5.36a & b). The above facts again confirm the freshening process of the aquifers.

The electrical conductivity (EC) value of the potable water is < 1000 ìmhos /cm (TDS ~ 600mg/l) and admixture of fresh and salt water ranges from 1500 to 20000 umhos/cm (TDS ~1000 to 12500 mg/l) (Rao, 1993). The EC values of the samples from phreatic (dug wells) as well as semi-confined deep aquifers of the basin were plotted as bivariate diagrams (Figs. 5.37a & b) and found that no sample fall above EC 1000 umhos/cm and Na/Cl ratio 0.85. The above mentioned facts again reiterate the non possibility of saline intrusion in the basin.

Identification of seawater intrusion through time series graphs of major cations and anions:

The time series graph shows the variation of concentrations of different ions in water samples with time. The desirable and permissible limits of major ions such as Cl, Ca, Mg and SO_4 and Na in drinking water are 75 and 200 mg/l, 30 and 100 mg/l, 200 and 400 mg/l and < 200 mg/l respectively (IS: 10500, 1991). There is no guideline for potassium.

Figs. 5.38a & b are time series graphs of major ions for water samples from phreatic and semi-confined deep aquifers of the basin. None of the samples show values above the permissible limit during the period of investigation. Cl and SO_4 ions in phreatic and semi-confined aquifers show an increasing trend may be due to freshening and sulphate reduction during subsurface flow through aquifer. This analysis also rejects the possibility of saline intrusion in the basin.

Identification of seawater intrusion through bivariate plots: Bivariate plot is an important tool for identifying saline intrusion. Figs. 5.39 to 5.44 show the bivariate plots of major cations and anions in pheatic and semi-confined aquifers of the basin. The calculated ratios by weight of major cations and anions in the phreatic and semi-confined aquifers of the basin are given in Table 5.41. The ionic ratios except Na/Cl, Mg/Ca and Mg/Na are very much close to fresh water or rainwater. But the ratios such as Na/Cl, Mg/Ca and Mg/Na in phreatic and semi-confined deep aquifers of the

Table 5.40 Chemical composition of average seawater (Goldberg, 1963)

Constituent	Concentration (mg/l)	Constituent	Concentration (mg/l)	Ionic ratio (by weight)	Value	Ionic ratio (by weight)	Value
Cl	19000	Na	10500	Cl/Na	1.81	Na/Cl	0.5526
SO_4	2700	Mg	1350	Ca/Mg	0.296	Mg/Ca	3.375
HCO_3	142	Ca	400	SO_4/Cl	0.142	Cl/SO_4	7.037
Br	65	K	380	HCO_3/Cl	0.0075	Cl/HCO_3	133.8
Br	4.6	Sr	8	Br/Cl	0.034	Cl/Br	292.3
F	1.3	SiO_4	6.14	B/Cl	0.034	Cl/Br	4138
N(total)	0.5	Li	0.17	HCO_3/SO_4	0.053	SO_4/HCO_3	19
P(total)	0.07	Rb	0.12	Sr/Ca	0.02	Ca/Sr	50
I	0.06	Ba	0.03	I/Br	0.0009	Br/I	1083
Fe	0.01	Al	0.01	Mg/Na	0.1286	Na/Mg	7.78

Table 5.41 Calculated ratios of major ions in phreatic and semi-confined aquifers of the Palaeo-lagoon (Kole land basin) for the period 01.01.1997 to 31.12.2006.

Sl.No	Ratios (by weight)	Sea water	Phreatic aquifer	Semi-confined aquifer	Sl.No	Ratios (by weight)	Sea water	Phreatic aquifer	Semi-confined aquifer
1	Na/Cl	0.5526	0.835	1.086	7	Cl/Na	1.81	1.1974	0.92
2	Mg/Ca	3.375	0.4174	0.8032	8	Ca/Mg	0.296	2.395	1.245
3	Cl/SO_4	7.037	3.956	1.917	9	SO_4/Cl	0.142	0.2527	0.521
4	Cl/HCO_3	133.8	0.948	0.442	10	HCO_3/Cl	0.0075	1.054	2.261
5	SO_4/HCO_3	19	0.2395	0.2307	11	HCO_3/SO_4	0.053	4.173	2.26
6	Na/Mg	7.78	1.7674	0.7653	12	Mg/Na	0.1286	0.5657	1.3

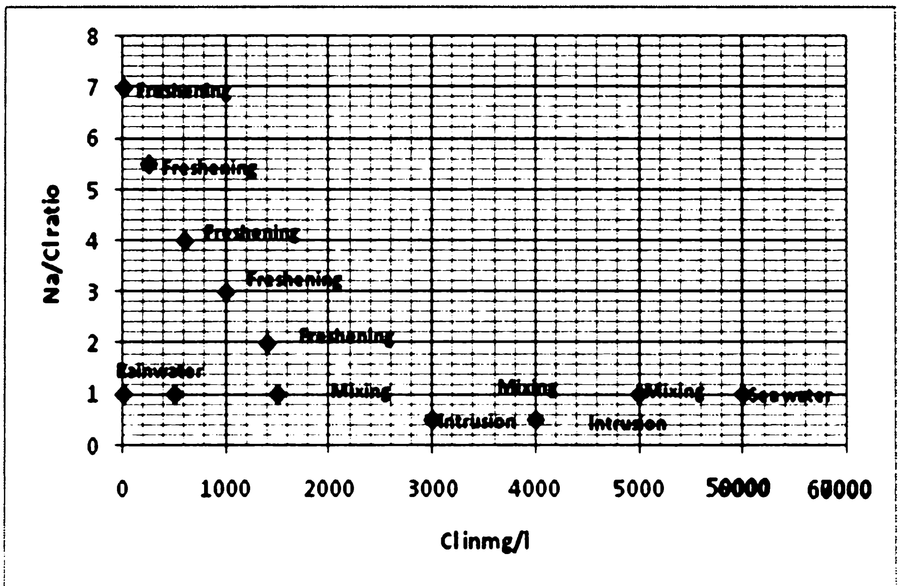
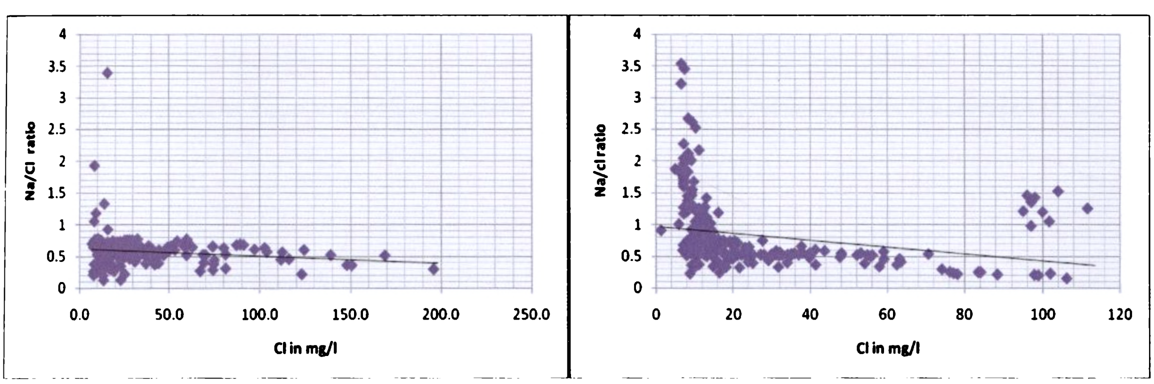
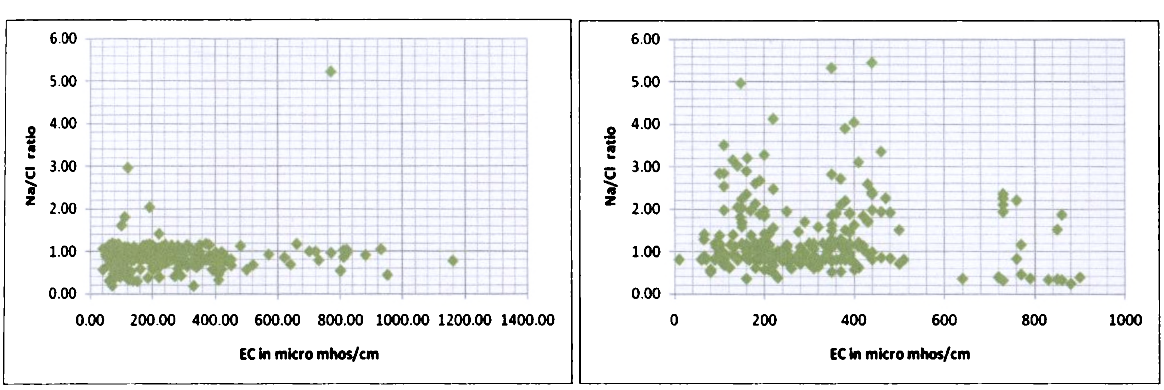


Fig. 5.35. Theoretical Cl Vs Na/Cl trends/postions in different type of water



(a) Phreatic aquifer **(b) Semi-confined aquifer**

Figs. 5.36a&b Bivariate plots for Cl Vs Na/Cl ratio in palaeo-lagoon (Kole land basin)



(a)Phreatic aquifer **(b) Semi-confined aquifer**

Fig. 5.37a&b. Bivariate plots for Na/Cl ratio Vs EC in palaeo-lagoon (Kole land basin)

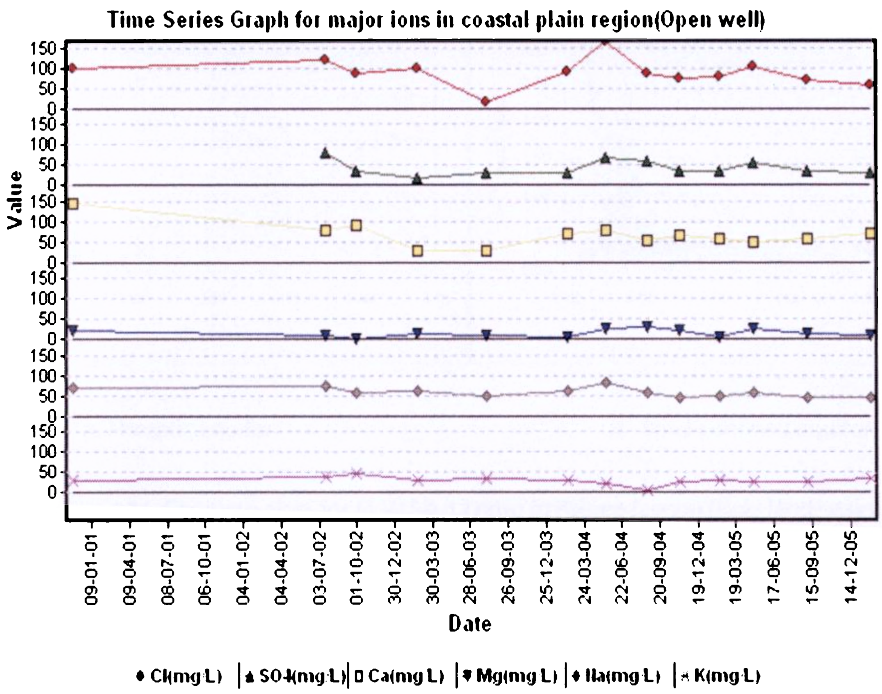


Fig. 5.38a. Time series graph for major ions in phreatic aquifer of coastal plain region, Paleo-lagoon for the period 01.01.2001 to 31.12.2006

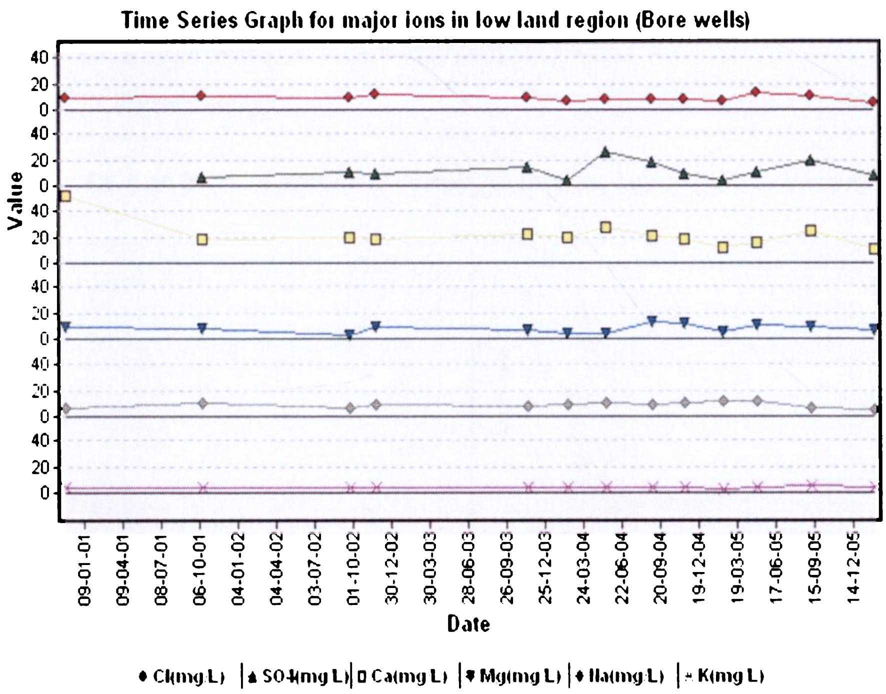
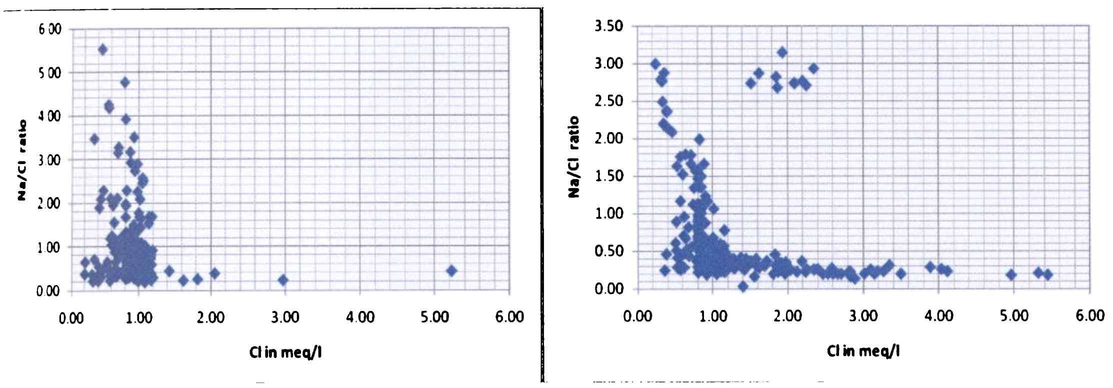
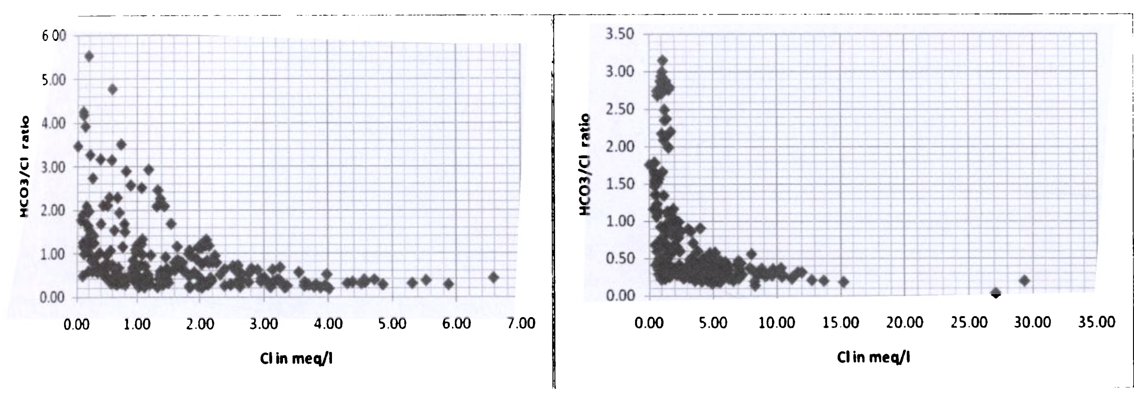


Fig. 5.38 b. Time series graph for major ions in semi-confined aquifer of low land region, Paleo-lagoon for the period 01.01.2001 to 31.12.2006



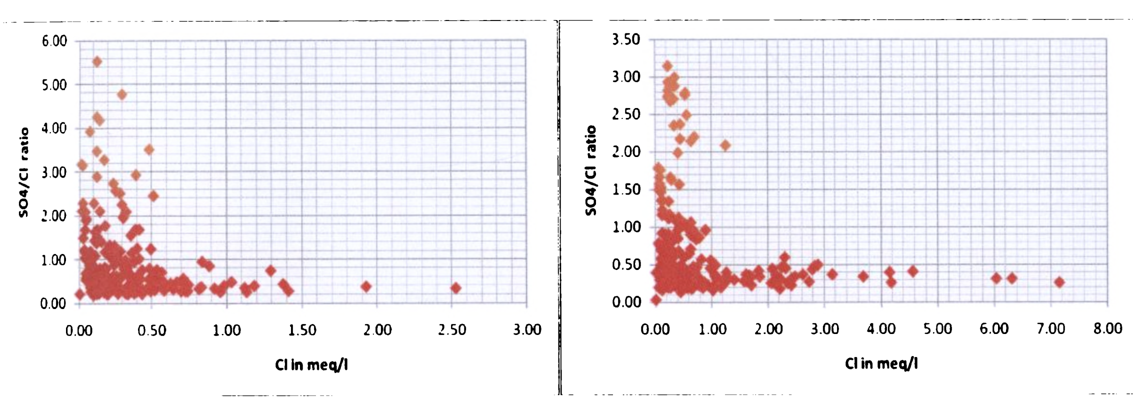
a. Phreatic aquifer **b. Semi-confined aquifer**

Fig. 5.39 Bivariate plots for Cl Vs Na/Cl ratio in Palaeo-lagoon (Kole land basin)



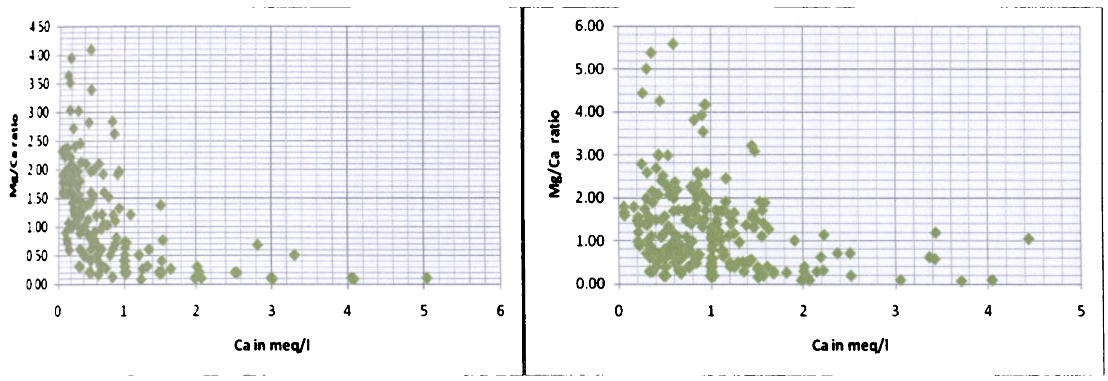
a. Phreatic aquifer **b. Semi-confined aquifer**

Fig. 5.40 Bivariate plots for Cl Vs HCO_3/Cl in Palaeo-lagoon (Kole land basin)



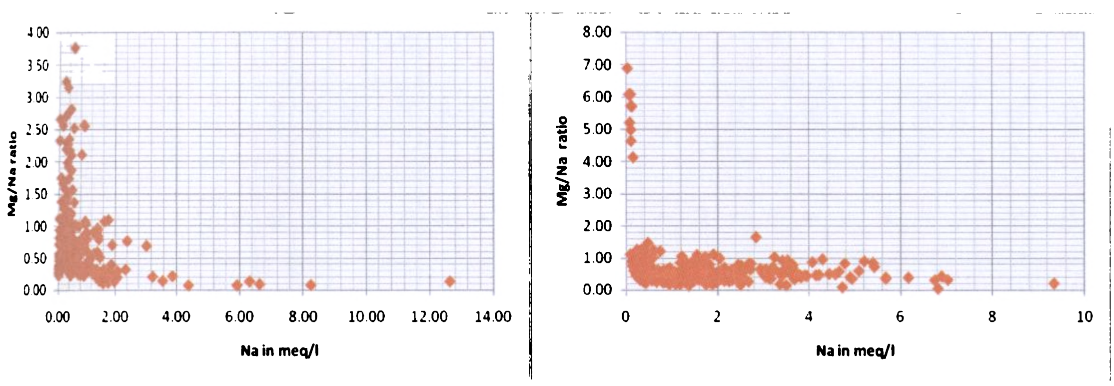
a. Phreatic aquifer **b. Semi-confined aquifer**

Fig. 5.41 Bivariate plots for Cl Vs SO_4/Cl ratio in palaeo-lagoon (Kole land basin)



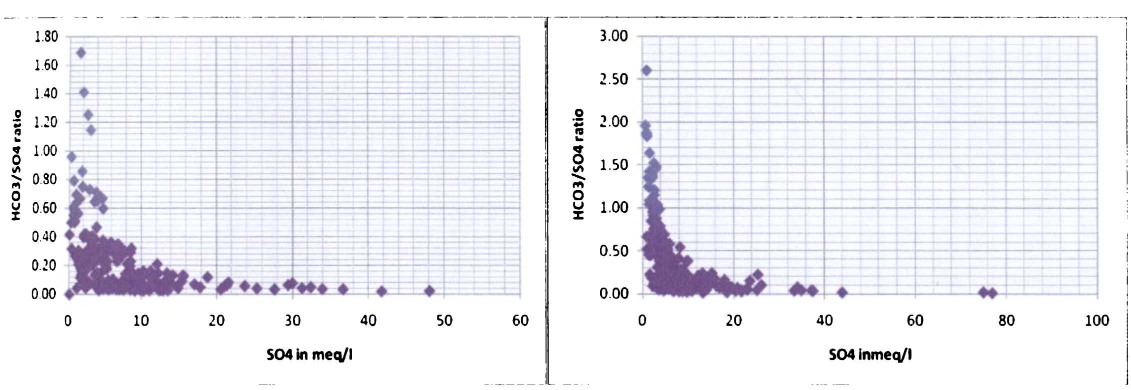
a. **Phreatic aquifer** **b. Semi-confined aquifer**

Fig. 5.42 Bivariate plots for Ca Vs Mg/Ca ratio in Palaeo-lagoon (Kole land basin)



a. **Phreatic aquifer** **b. Semi-confined aquifer**

Fig. 5.43 Bivariate plots for Na Vs Mg/Na ratio in Palaeo-lagoon (Kole land basin)



a. **Phreatic aquifer** **b. Semi-confined aquifer**

Fig. 5.44 Bivariate plots for SO_4 Vs HCO_3/SO_4 in Palaeo-lagoon (Kole land basin)

Table 5.42 Aquifer vulnerability to sea water intrusion "GALDIT" method score computation for Palaeo-lagoon (Kole land basin)

				Parameter G		Parameter A		Parameter L		Parameter D		Parameter I		Parameter T		Total
Well No	Location	Lattitude	Longitude	Aquifer type	Rating	K(m/d)	Rating	GWL (m)	Rating	Distance in (m)	Rating	Initial conditionCL/(CO_3+HCO$_3$) (epm)	Rating	Aquifer thickness (m)	Rating	GALDIT Score
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	Chelur	10°20'30"	76°12'00"	Phreatic	9	6.5	2	-0.39	10	>1000	1	1.5-2	5	12	1	64
2	Arippalam	10°18'08"	76°11'45"	Phreatic	9	15	4	-0.1	10	>1000	1	<1.5	0	8	3	69
3	Edakulam	10°19'15"	76°12'02"	Phreatic	9	15	4	-0.069	10	>1000	1	<1.5	0	12	1	65
4	Padiyoor	10°18'00"	76°10'45"	Semi-confined	8	6.5	2	0.891	10	>1000	1	<1.5	0	5	6	68
5	Edathirinji	10°19'17"	76°00'45"	Phreatic	9	6.5	2	-0.47	10	>1000	1	<1.5	0	7	4	65
6	Edathirinj Jn.	10°19'45"	76°10'35"	Phreatic	9	6.5	2	1.6	9	>1000	1	<1.5	0	7	4	61
7	Edathirinji Jn.	10°19'45"	76°09'38"	Phreatic	9	436	10	1.7	9	>1000	1	>2	10	4	7	101
8	Mathilakam	10°18'45"	76°09'37"	Phreatic	9	436	10	2.896	9	>1000	1	>2	10	3	8	103
9	Moonnupeedika	10°19'00"	76°08'32"	Phreatic	9	6.5	2	2.406	9	>1000	1	1.5-2	5	3	8	74
10	West Perinjanam	10°18'45"	76°07'30"	Phreatic	9	436	10	3.082	9	350	7	1.5-2	5	5	6	106
11	Chamakkala	10°21'08"	76°06'50"	Phreatic	9	436	10	1.28	9	450	6	>2	10	4	7	111
12	Edathiruthi	10°21'37"	76°08'28"	Phreatic	9	436	10	-1.05	10	>1000	1	<1.5	10	5	6	103
13	Kattoor	10°21'23"	76°07'38"	Phreatic	9	·436	10	2.75	9	>1000	1	<1.5	0	4	7	91
14	Kazhimbram	10°22'28"	76°06'20"	Phreatic	9	436	10	-0.064	10	450	6	<1.5	0	4	7	105
15	Edamuttam	10°22'38"	76°07'20"	Phreatic	9	436	10	3.71	9	>1000	1	<1.5	0	4	7	91
16	Nattika	10°24'57"	76°05'30"	Phreatic	9	436	10	1.525	9	750	3	<1.5	0	4	7	95
17	Nattika beach	10°24'45"	76°05'15"	Phreatic	9	436	10	0.6	10	250	8	1.5-2	5	4	7	114
18	Nattika Jn.	10°25'00"	76°06'15"	Phreatic	9	6.5	2	2.243	9	>1000	1	<1.5	0	4	7	67
19	Truprayar	10°2452"	76°07'08"	Phreatic	9	6.5	2	-0.004	10	>1000	1	>2	10	7	4	75
20	Chazhoor	10°26'00"	76°09'00"	Semi-confined	8	6.5	2	-0.261	10	>1000	1	<1.5	0	12	1	58
21	Peringottukara	10°25'30"	76°08'05"	Semi-confined	8	6.5	2	-0.01	10	>1000	1	>2	10	12	1	68
22	Vatanapalli beach	10°27'30"	76°04'10"	Phreatic	9	6.5	2	0.9	10	250	8	>2	10	3	8	97
23	Kanjani north	10°29'08"	76°06'40"	Phreatic	9	6.5	2	5.2	7	>1000	1	>2	10	6	5	65

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
24	Eravu	10°28'40"	76°08'22"	Phreatic	9	15	4	1.69	9	>1000	1	1.5-2	5	9	2	68
25	Vatanapalli jn	10°28'15"	76°04'45"	Phreatic	9	436	10	1.843	9	>1000	1	<1.5	0	5	6	89
26	Kundazhiyoor west	10°31'15"	76°02'50"	Phreatic	9	436	10	0.038	10	600	4	>2	10	3	8	113
27	Kundazhiyoor east	10°31'20"	76°03'40"	Phreatic	9	6.5	2	-1.18	10	>1000	1	>2	10	7	4	75
28	Kadapuuram	10°31'30"	76°01'45"	Phreatic	9	436	10	-0.216	10	250	8	>2	10	3	8	121
29	Chavakkad west	10°34'35"	76°01'05"	Phreatic	9	436	10	1.98	9	900	2	>2	10	6	5	99
30	Chavakkad east	10°34'35"	76°02'45"	Phreatic	9	6.5	2	-2	10	>1000	1	1.5-2	5	7	4	70
31	Tayakkad	10°35'45"	76°03'45"	Semi-confined	8	6.5	2	1.586	9	>1000	1	>2	10	6	5	72
32	Choondal	10°37'30"	76°05'30"	Phreatic	9	15	4	13.9	5	>1000	1	<1.5	0	10	2	47
33	Ernellur	10°37'00"	76°07'48"	Phreatic	9	6.5	2	-0.4	10	>1000	1	<1.5	0	8	3	63
34	Kaiparamba	10°36'30"	76°08'30"	Phreatic	9	15	4	13.1	5	>1000	1	<1.5	0	11	1	45
35	Tholur	10°34'08"	76°07'30"	Phreatic	9	15	4	4.93	7	>1000	1	<1.5	0	10	1	53
36	Anakkara	10°32'30"	76°06'35"	Semi-confined	8	6.5	2	7.735	7	>1000	1	<1.5	0	5	6	56
37	Penagam	10°32'45"	76°06'45"	Phreatic	9	15	4	3.8	9	>1000	1	<1.5	0	14	1	61
38	Pavaratty	10°33'30"	76°04'00"	Phreatic	9	15	4	3.395	9	>1000	1	>2	10	7	4	77
39	Mullassery	10°31'38"	76°05'30"	Phreatic	9	6.5	2	11.32	5	>1000	1	<1.5	0	8	3	43
40	Irimbranellur	10°30'25"	76°06'08"	Phreatic	9	6.5	2	6.295	7	>1000	1	>2	10	3	8	71
41	Ettumuna	10°24'43"	76°11'50"	Semi-confined	8	6.5	2	7.3	7	>1000	1	>2	10	6	5	64
42	Chirakkal	10°24'35"	76°10'40"	Phreatic	9	436	10	7.65	7	>1000	1	>2	10	5	6	91
43	Cherpu	10°25'52"	76°12'30"	Phreatic	9	10	2	0.55	10	>1000	1	1.5-2	5	9	2	66
44	Palakkal	10°25'48"	76°12'30"	Phreatic	9	15	4	-2.3	10	>1000	1	<1.5	0	15	1	65
45	Pallippuram	10°27'30"	76°11'15"	Phreatic	9	15	4	-2.95	10	>1000	1	<1.5	0	9	22	107
46	Ammadam	10°27'16"	76°10'22"	Semi-confined	8	15	4	9.25	5	>1000	1	<1.5	0	7	4	50
47	Alappad	10°26'37"	76°09'45"	Semi-confined	8	15	4	0.65	10	>1000	1	<1.5	0	6	5	72
48	Pullu	10°27'23"	76°09'15"	Phreatic	9	15	4	-0.35	10	>1000	1	1.5-2	5	8	3	74
49	Manakkodi	10°28'30"	76°09'46"	Phreatic	9	15	4	-0.76	10	>1000	1	>2	10	10	2	77
50	Kunnathangadi	10°29'45"	76°09'30"	Phreatic	9	15	4	7.25	7	>1000	1	<1.5	0	12	1	53
51	Ayyanthole	10°31'15"	76°11'23"	Phreatic	9	15	4	6.639	7	>1000	1	<1.5	0	12	1	53

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
52	Puzhakkal	10°32'15"	76°10'45"	Phreatic	9	6.5	2	2.7	9	>1000	1	>2	10	4	7	77
53	Muthuvara	10°33'00"	76°10'20"	Phreatic	9	15	4	4.1	9	>1000	1	<1.5	0	11	1	61
54	Mundur	10°35'23"	76°09'30"	Phreatic	9	15	4	13.22	5	>1000	1	<1.5	0	11	1	45
55	Velur	10°38'15"	76°10'39"	Phreatic	9	4.36	2	14.12	5	>1000	1	<1.5	0	11	1	39
56	Karancheri	10°37'45"	76°13'31"	Phreatic	9	6.5	2	25.92	2	>1000	1	<1.5	0	7	4	33
57	Thirur	10°35'15"	76°12'51"	Phreatic	9	15	4	2.49	9	>1000	1	<1.5	0	8	3	65
58	Patturackal	10°32'15"	76°13'00"	Phreatic	9	6.5	2	4.3	9	>1000	1	<1.5	0	5	6	65
59	Adat	10°32'15"	76°08'37"	Phreatic	9	15	4	3.2	9	>1000	1	>2	10	7	4	77
60	Chittilapalli	10°33'43"	76°0857"	Phreatic	9	15	4	2.02	9	>1000	1	<1.5	0	13	1	61
61	Puthuruthi	10°39'30"	76°11'45"	Phreatic	9	15	4	18.82	3	>1000	1	<1.5	0	7	4	43
62	Mangadumkuzhi	10°41'21"	76°11'32"	Phreatic	9	15	4	31.4	1	>1000	1	<1.5	0	12	1	29
63	Mundathikode	10°41'38"	76°10'10"	Phreatic	9	15	4	43.9	1	>1000	1	<1.5	0	7	4	35
64	Kadangode	10°40'38"	76°09'38"	Phreatic	9	15	4	16.4	3	>1000	1	<1.5	0	13	1	37
65	Pannithadam	10°40'08"	76°06'50"	Phreatic	9	15	4	8.06	7	>1000	1	<1.5	0	10	2	55
66	Kunnamkulam	10°38'22"	76°04'30"	Phreatic	9	6.5	2	24.274	2	>1000	1	1.5-2	5	10	2	34
67	Eyyal	10°39'00"	76°07'12"	Semi-confined	8	6.5	2	9.62	5	>1000	1	<1.5	0	6	5	46
68	Kundannur	10°40'37"	76°13'07"	Semi-confined	8	6.5	2	21.8	3	>1000	1	<1.5	0	9	2	32
69	Wadakkancherry	10°39'15"	76°14'45"	Phreatic	9	4.36	2	25	2	>1000	1	<1.5	0	10	4	33
70	Madayikonam	10°22'37"	76°14'45"	Semi-confined	8	436	2	6.55	7	>1000	1	<1.5	0	3	8	60
71	Thottippal	10°23'50"	76°14'07"	Semi-confined	8	6.5	2	5.75	7	>1000	1	<1.5	0	3	8	60
72	Parapookkara	10°24'08"	76°15'52"	Semi-confined	8	6.5	2	8.05	7	>1000	1	<1.5	0	3	8	60
73	Thrissur	10°31'13"	76°13'07"	Phreatic	9	15	4	4.246	9	>1000	1	>2	10	10	2	73
74	Mannuthi	10°31'53"	76°15'48"	Phreatic	9	15	4	10.484	5	>1000	1	1.5-2	5	8	3	54
75	Pananchery	10°33'23"	76°19'56"	Phreatic	9	15	4	25.019	2	>1000	1	<1.5	0	8	3	37
76	Pudukkad	10°25'07"	76°16'18"	Phreatic	9	15	4	7.302	7	>1000	1	1.5-2	5	10	2	60
77	Kodakara	10°22'19"	76°18'19"	Phreatic	9	15	4	3.965	9	>1000	1	<1.5	0	10	2	63
78	Irinjalakudaa	10°20'32"	76°13'11"	Phreatic	9	15	4	13.964	5	>1000	1	1.5-2	5	13	1	50
79	MGkavu	10°36'00"	76°12'41"	Phreatic	9	15	4	23.667	2	>1000	1	1.5-2	5	12	1	38

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
80	Ottuppara	10°39'53"	76°15'24"	Phreatic	9	15	4	24.754	2	>1000	1	<1.5	0	7	4	39
81	Vazhani	10°38'15"	76°18'00"	Phreatic	9	15	4	28.09	2	>1000	1	<1.5	0	8	3	37
82	Kunnamkulam	10°38'49"	76°04'11"	Phreatic	9	15	4	16.614	3	>1000	1	1.5-2	5	13	1	42
83	Chavakkad	10°34'49"	76°01'29"	Phreatic	9	436	10	-0.324	10	>1000	1	1.5-2	5	6	5	96
84	Pazhanji	10°41'20"	76°06'26"	Phreatic	9	15	4	1.859	9	>1000	1	>2	10	10	2	73
85	Nattika	10°25'11'	76°06'26"	Phreatic	9	436	10	0.775	10	>1000	1	<1.5	0	5	6	93
86	Edamuttam	10°22'19'	76°07'34"	Phreatic	9	436	10	1.516	9	>1000	1	<1.5	0	4	7	91
87	Mathilakam	10°17'30"	76°09'53"	Phreatic	9	436	10	0.636	10	>1000	1	<1.5	0	5	6	93
88	Engadiyur	10°29'39"	76°04'04"	Phreatic	9	436	10	0.173	10	>1000	1	<1.5	0	5	6	93
89	Vaniyampara	10°34'38"	76°24'35"	Phreatic	9	15	4	92.204	1	>1000	1	<1.5	0	6	5	37
90	Varandarappilly	10°25'18"	76°19'54"	Phreatic	9	4.36	2	13.634	5	>1000	1	<1.5	0	8	1	39
91	Cherpu	10°26'25"	76°12'44"	Phreatic	9	15	4	5.19	7	>1000	1	>2	10	13	1	63
92	Puthur	10°28'57"	76°17'26"	Phreatic	9	15	4	12.24	5	>1000	1	<1.5	0	7	4	51
93	Elavally	10°34'34"	76°05'14"	Phreatic	9	15	4	2.167	9	>1000	1	>2	10	10	2	73
94	Kadangode	10°42'07"	76°08'27"	Phreatic	9	15	4	24.86	2	>1000	1	<1.5	0	9	2	35
95	Punnamparambu	10°38'04"	76°16'11"	Phreatic	9	15	4	31.879	1	>1000	1	<1.5	0	10	2	31

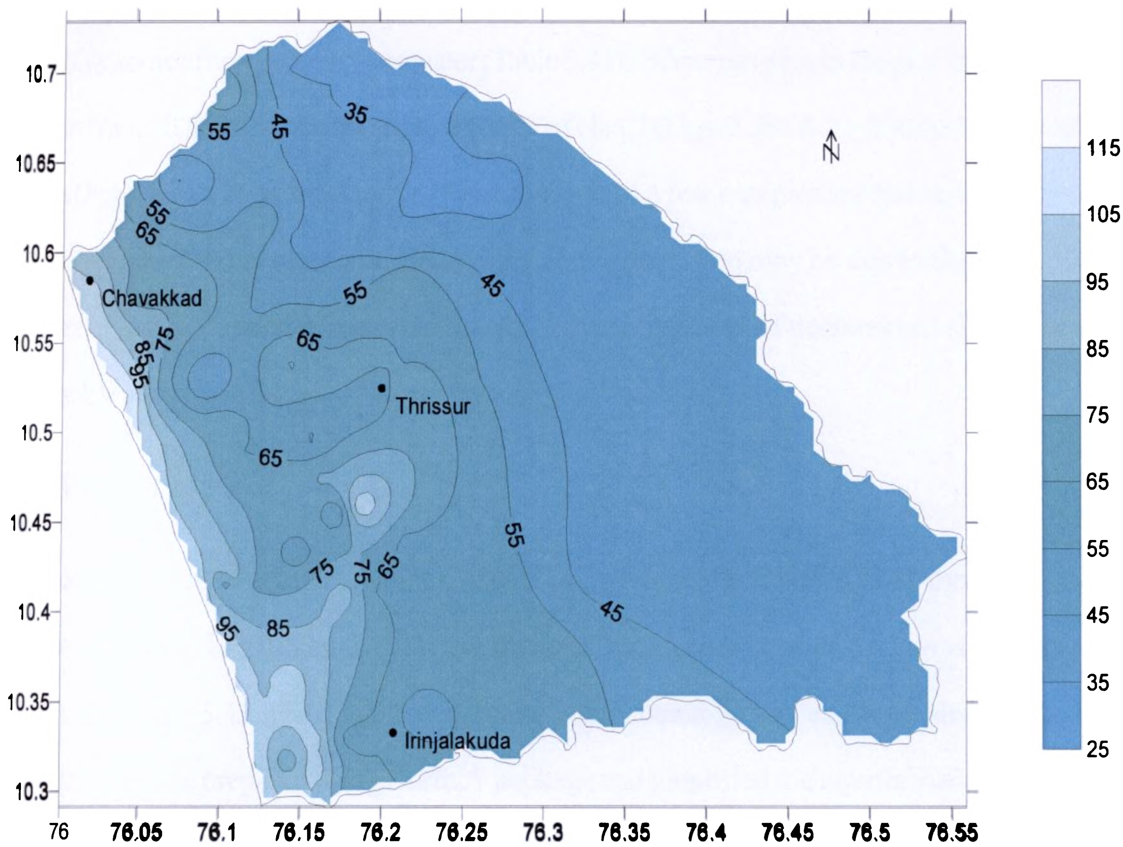


Fig. 5.45 Map indicating aquifer vulnerability to seawater intrusion assessed in phreatic aquifer of Palaeo-lagoon (Kole land basin) by GALDIT method.

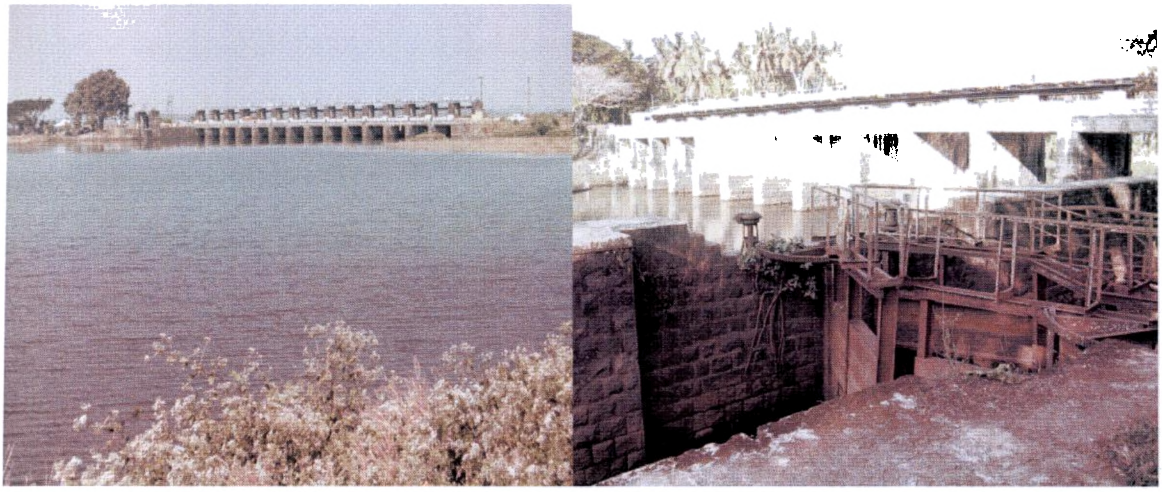


Plate. 5.3 A view of Enammavu and Illikkal regulators constructed across Chetwai and Karuvannur rivers to prevent seasonal saline water ingress.

basin show some affinity towards seawater (Table 5.41). Some samples in the plot fall in the field of seawater (ratio: 0.5526) in the bivariate diagram of Na/Cl (Figs. 5.39a & b). Similarly in the plots of Mg/Ca (Figs. 5.42a & b) and Mg/Na (Figs. 5.43a & b) a few samples are fall in the fields 3.375 and 0.1286; the field of seawater. Reason for above deviation may be due to the freshening or presence of trapped seawater in layered aquifer or interconnection of fractures and shallow aquifers with back water channels.

5.5.1 GALDIT method

The vulnerability of the aquifer towards saline intrusion was analysed by GALDIT method (Chachadi and Lobo Ferreira, 1999). The GALDIT score for 95 locations within the basin was calculated and presented in Table 5.42. The contour map for aquifer vulnerability index values along with x and y co-ordinates were prepared using Surfer.7 package and identified the aquifer vulnerable areas to seawater intrusion in the palaeo-lagoon (Fig. 5.45).

The GALDIT score of the basin varies from 32 (Kundannur) to 121 (Kadappuram). As per the norms of GALDIT it is found that the coastal areas and some low land connected with backwaters are vulnerable areas of phreatic aquifer to saline intrusion in the basin (GADIT index >100, Fig. 5.46). The salinity distribution along the Chetwa- Kottapuram during the summer months from February to May have been observed and are directly proportional to tidal changes, i.e., salinity is more at high tide and less at low tide (Ahamadali et al., 1987). The major regulators at Enamakkal and Kuttankottvalavu are preventing the inflow of seawater into inland via estuaries. Due to lack of sufficient data, it was not possible to evaluate aquifer vulnerability to saline intrusion in semi-confined deep aquifers of the basin.

CHAPTER 6

STRATIGRAPHY

6.1 Introduction

Stratigarphical geology has, as its aim, the description and classification of rocks with a view to arranging them in a chronological order in which they laid down on the surface of earth. Of the three groups of rocks namely igneous, metamorphic and sedimentary only the sedimentary rocks are easily amenable to such an arrangement, since they have deposited bed by bed and contain the remains of organism which flourished while they were formed. The lithological characters of units or formations and particularly their fossil content have been invaluable for determining the chronology of the materials of the earth's crust. Each formation has not only distinct petrological characters but also encloses a fossil assemblage, which is characteristic and different from that of the underlying and overlying formations. Fossil assemblages of the same age are not necessarily identical, for the species in them will depend on the conditions of environment and development of each area of sedimentation. If the environment was the same or very similar, the species may be identical or closely allied, as is often in the case with marine fauana; if the environment were different, as in the case of esturine and lacustrine deposits, the elements of the fauna will be different but will show the same stage of evolution or development in relation to each other and in comparison with the parallel faunas of other areas. In comparing the faunas or floras of two areas, the lithological as well as environmental facies will have to be fully taken in to account.

The study area consists of coastal plain and associated palaeo-lagoon, laterite uplands and other crystalline terrains (plates 6.1- 6.4). The palaeo-lagoon covers an area about 300 km^2 lies 0.5 to 1.50 m below mean sea level. This low lying tract; Palaeo-lagoon, which invariably gets water logged throughout the monsoon season (June to September) and separated from the sea by a sandy belt. The crystalline area is least important while considering the stratigraphy of the whole basin, in which topsoil or weathered rock of limited thickness is overlying them. The coastal plain including palaeo-lagoon is characterized by depositional landforms. Landforms of the coastal plain area are divisible into different geomorphic units in view of their morphological characters, lithological assemblage and environment of formation. A geomorphic unit is characterized by a particular

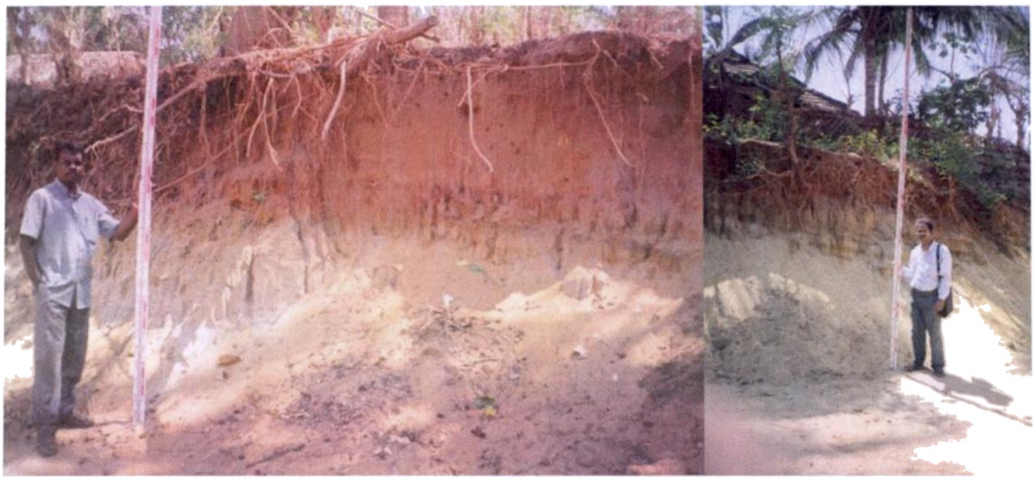


Plate 6.1 A section of palaeo-ridges in the coastal plain area showing different layers (Engadiyoor)

Plate 6.2 Laterite cappings in the eastern side of the Palaeo-lagoon (Vilangankunnu)

morphology and lithology and which are formed under a particular environment and are mapped as morphostratigraphic surfaces. The various morphostratigraphic surfaces initially identified in Kerala by Krishana Nair (1985) during the course of investigation and named after the local villages around which they were seen developed best are given in Table 1.5. All morphostratigraphic units mentioned in Table 1.5 except Periyar and Ponnani surfaces are identified in the study area.

6.2 Stratigraphy of Palaeo-lagoon

The Palaeo-lagoon is the northern most extension of the South Kerala Sedimentary Basin (SKSB) (area between Eriyad and Edakazhiyur in Fig. 1.7). It is underlain by the rocks of Archaean metamorphic complex. They include the granitic gneisses and charnockite. Dolerite and gabbro dykes trending NW-SE and E-W are seen in a few places. Laterite seen as cap rock ranges in thickness from less than a meter to about twenty meters.

The palaeo-lagoon (Kole land basin) of the present study area covers the regions of both the sedimentary terrain of the coastal plain with an areal extend of 516 km^2 in the west and the mid and high land region in the east (1174 km^2). The area comprised of both depositional and denudatonal landforms. Fig. 6.1 describes the geomorphology of the study area. Out of 1690 km^2 area of the basin, about 682 km^2 area include in midland and 489 km^2 area include by highland. The western part of the area is covered by Palaeo-lagoon and coastal plain respectively in 300 km^2 and 216 km^2. The Tertiary and Quaternary deposits having thickness varies from 2 m bgl (east of Kole land) to 80 m bgl (near shore line) are confined to the coastal plain and Palaeo-lagoon of the basin. The laterite capping of the crystalline terrain varies from 2m bgl to 20 m bgl.

The Fig. 6.2 shows the bedrock distribution of the basin below ground level. The map is prepared using the borewell/tubewell/filterpoint well drilling data in 57 locations of the basin. The depth to bed rock in midland and highland region varies from 0 m (rock exposure) to 15 mbgl. In sedimentary terrain it varies from 15 mbgl (east of palaeo-lagoon) to 80 mbgl (near beach). A sudden change in depth to bedrock from 30 mbgl to 80 mbgl is recorded within 1 to 2 km from shoreline. This deep portion of the basin is completely occupied by Tertiary deposits (Vaikom formation), in which most of the tube wells of the area are constructed.

The geology of the area is depicted in the Fig. 6.3. The western part of the basin is mainly occupied by alluvium. The coastal plain is covered by coastal alluvium while the palaeo-lagoon area is covered partly by coastal alluvium on the west and riverine alluvium in the east. The alluvium of the sedimentaries

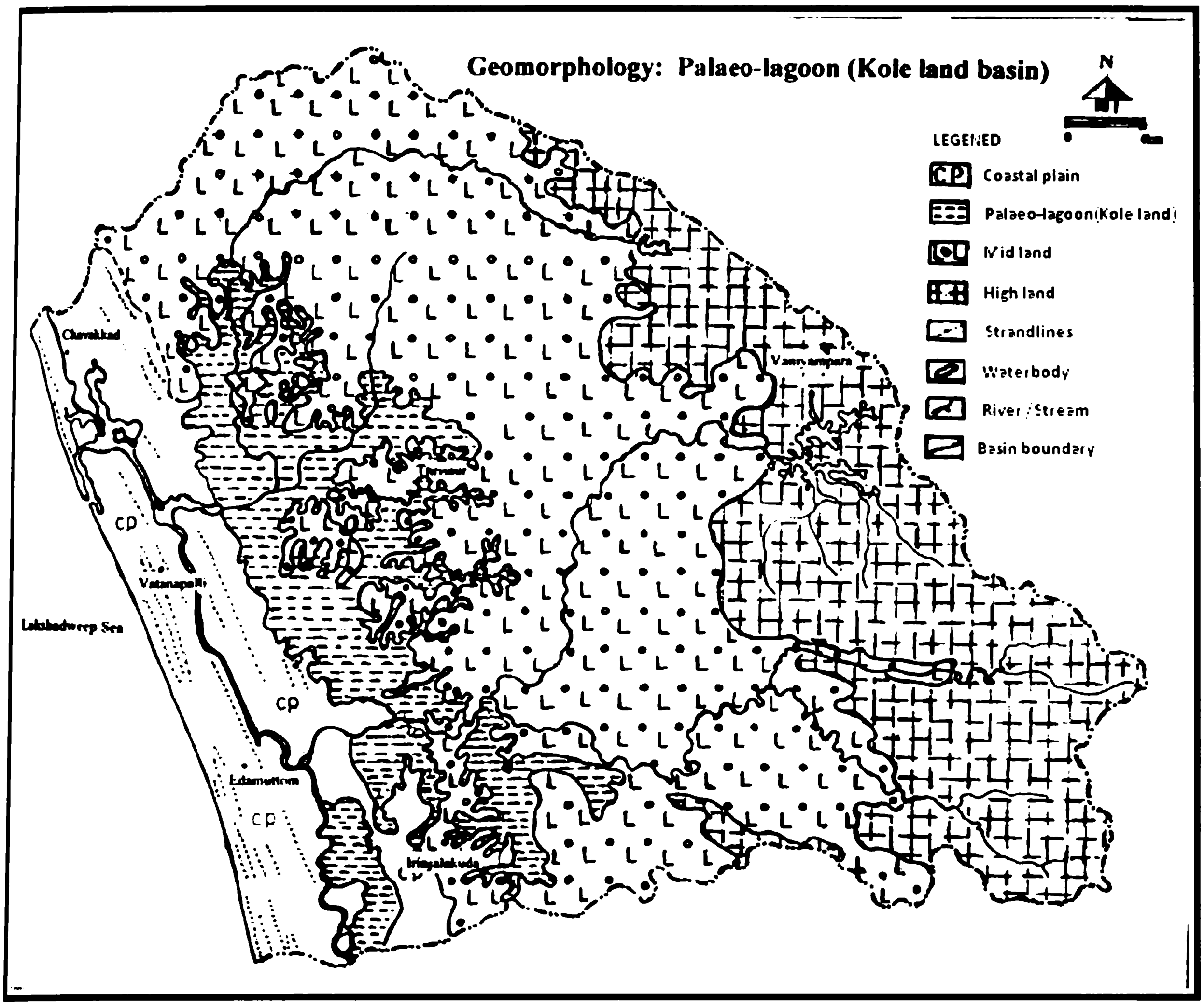


Fig. 6.1 General geomorphology of Palaeo-lagoon (Kole land basin)

Plate 6.3 A view of residual laterite seen as isolated patches within in Palaeo-lagoon (coconut planted area, Alappad and Pullu).

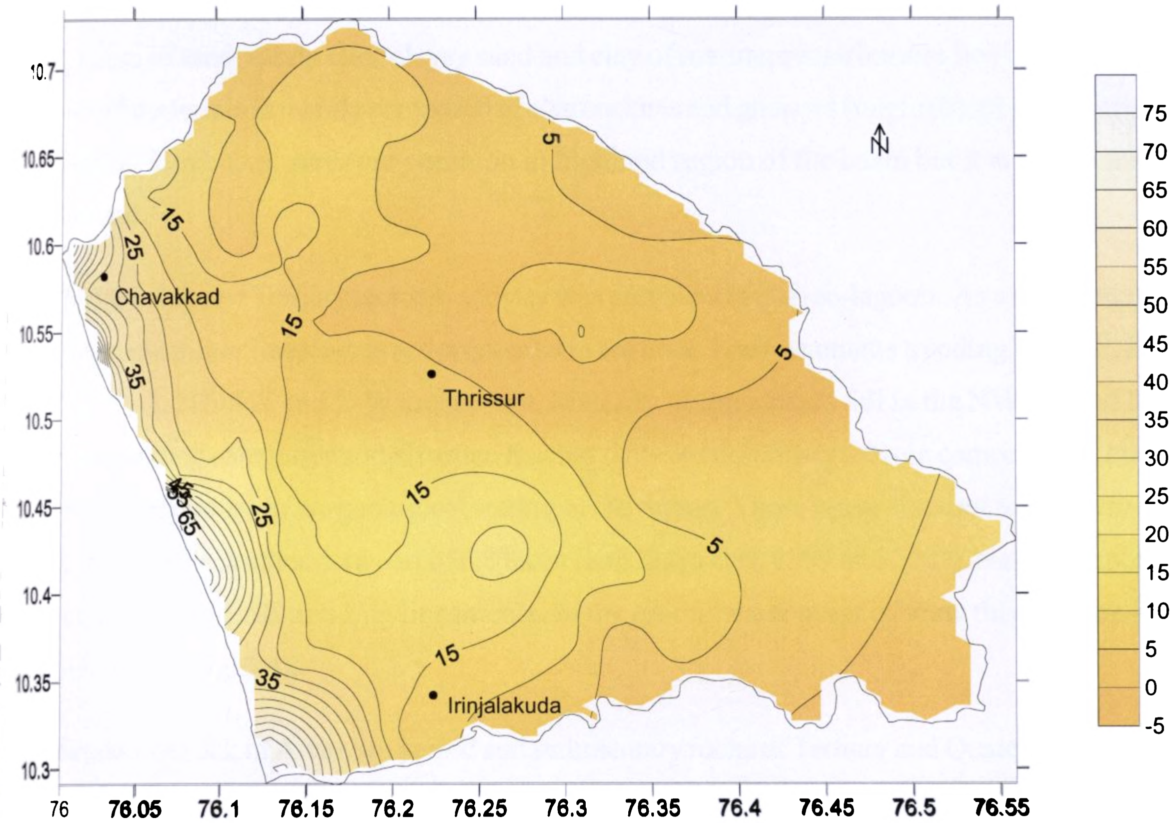


Fig. 6.2 Depth to bed rock of Palaeo-lagoon (Kole land basin)

Plate 6.4 A view of laterite uplands within Palaeo-lagoon (Puzhakkal and Kanimangalam areas)

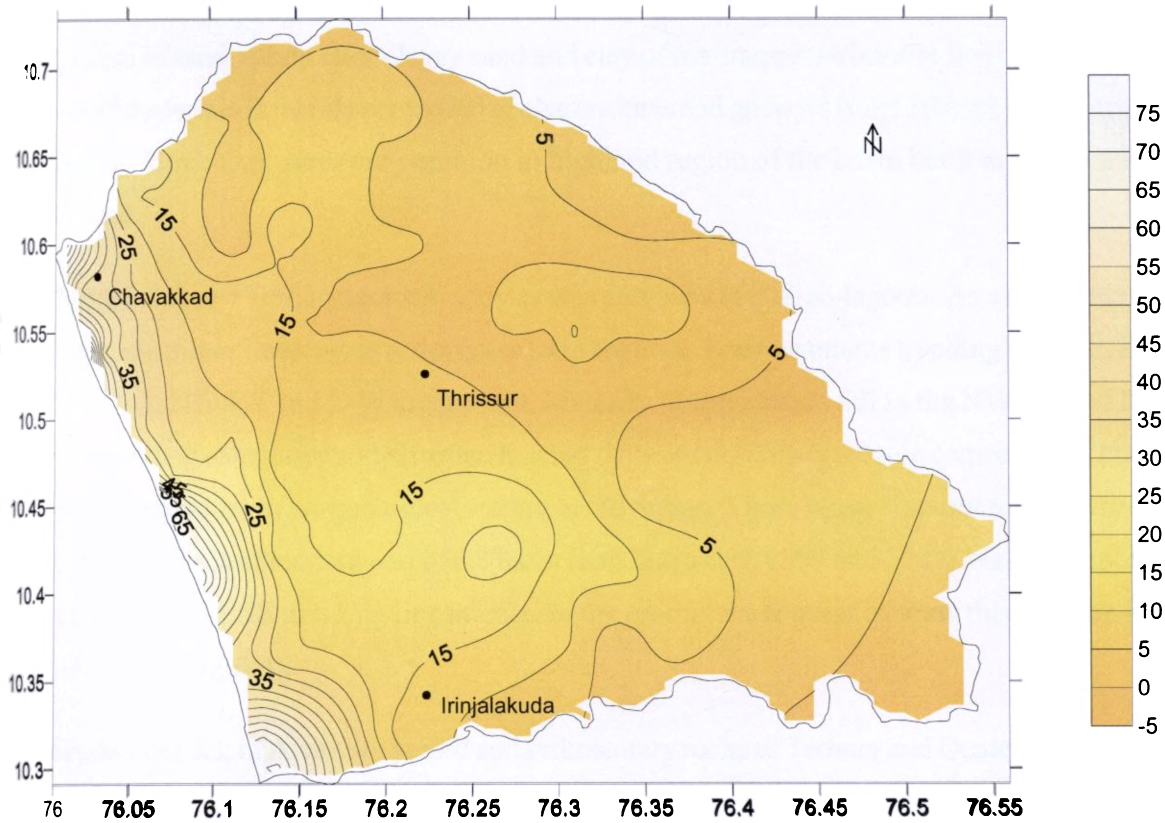


Fig. 6.2 Depth to bed rock of Palaeo-lagoon (Kole land basin)

Plate 6.4 A view of laterite uplands within Palaeo-lagoon (Puzhakkal and Kanimangalam areas)

consists of sand, sandy clay, clayey sand and clay of marine, estuarine and fluvial in origin. The crystalline terrain is mainly composed of charnockites and gneisses (migmatised) and is capped by laterite. Rock exposures are common in highland region of the basin but it is rare in mid and lowland.

Precambrian and Tertiary tectonic activity was prevalent in Palaeo-lagoon. As a result numerous major and minor lineaments are originated in the area. The lineaments trending NW-SE, NNW-SSE, N-S, NE-SW and E-W are present. Majority of lineaments fall in the NW-SE and NNW-SSE trending categories and are often hosting dykes of dolerite /gabbroic composition, having a definite signature in the geological setting of the region. These linear fracture zones form major aquifers in the northeastern part of the basin (Kukillaya et al. 1999 and 2002). Next in importance are the WNW-ESE trending lineaments. In the groundwater point of view this fracture is also productive (Fig. 6.4).

Crystalline rock of Archaean period and sedimentary rocks of Tertiary and Quaternary period are noticed in the study area. The crystalline rocks are charnockites and gneisses and are mainly confined to the eastern parts of the basin. The western part of the area represents the sedimentary formations predominantly of Quaternary period. The details of litho-logs collected from various parts of the basin are given in Table 6.1 (attached as appendix). Sedimentary formation of upper Tertiary period (Lower Miocene) known as Vaikom formation is seen in the western periphery of the area mapped. The sedimentary formation of the coastal plain has an average thickness of 80 m, out of which top 25 to 30 m is Quaternary deposits. A systematic study based on available radio carbon dates was done in the subsurface Quaternary sediments to bring out the various chronstratigraphic units of the area. The stratigraphic succession of the area based on lithologs, radio carbon dating and the morpho stratigraphic surfaces is given in the Table 6.2 and Fig. 6.5a-b. The description of each stratigraphic unit of the basin is given as follows.

Archaean: The basement rock of the basin is charnockite and associated gneisses of Archaean age and occupies a major part of the highlands and the midland regions of the basin, especially in eastern part. The charnockites and gneisses are unconformably overlain by Vaikom formation in the west (1 to 1.5 km from shoreline) and laterites in the east of the Palaeo-lagoon.

Intrusive phase within basin region includes sporadic occurrence of basic and ultrabasic bodies and dykes belonging to Lower-Middle Proterozoic age, pegmatites of Middle Proterozoic age, a host of younger granites (Late Precambrian-Early Palaeozoic age) with associated pegmatites, and later

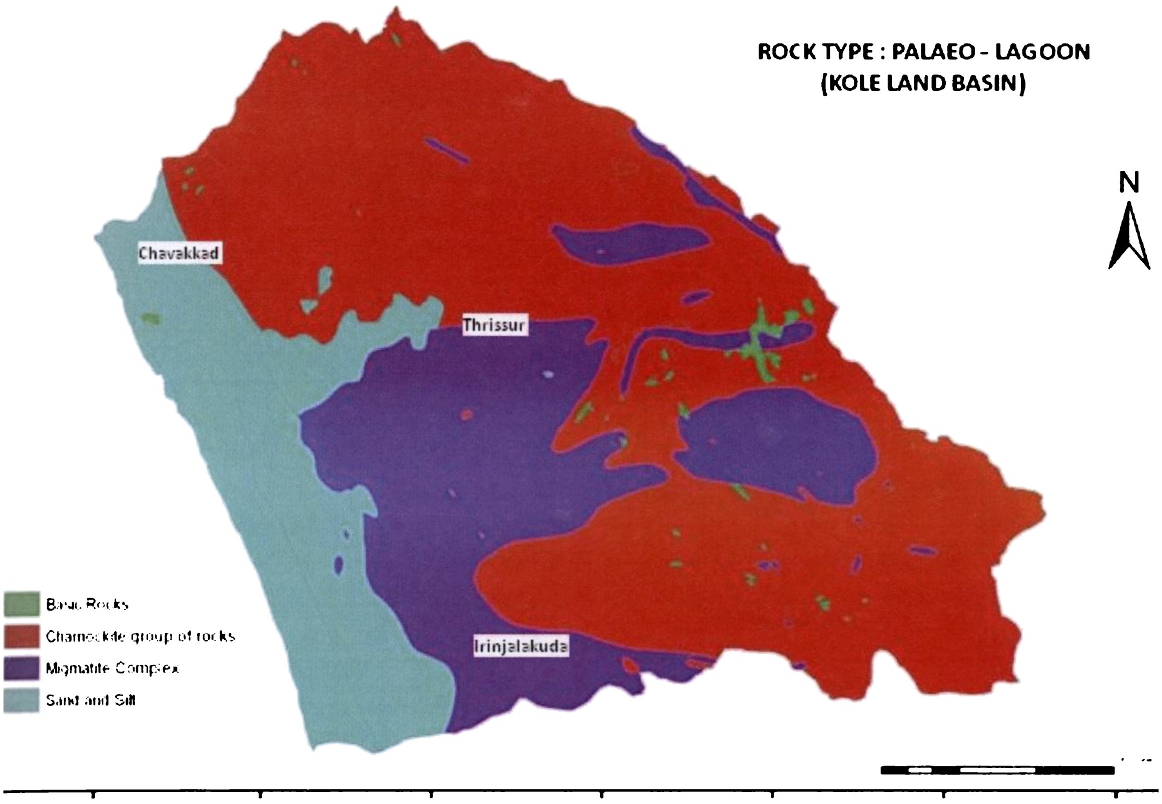


Fig. 6.3 Geology of palaeo-lagoon (Kole land basin)

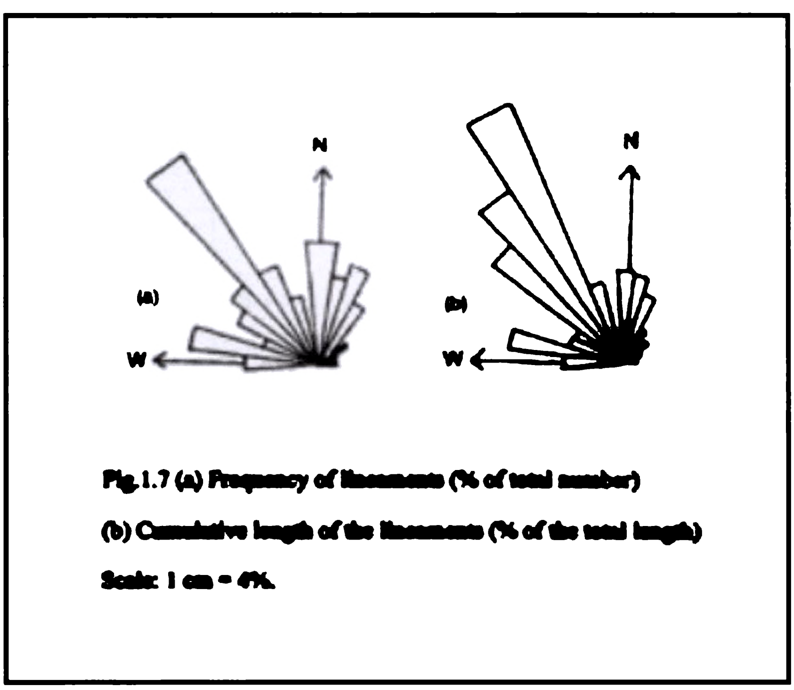


Fig. 6.4 Rose diagram for lineaments in Palaeo-lagoon (Kole land basin) (Kukillaya, 2007)

Table 6.2 Stratigraphic succession of Palaeo-lagoon (Kole land basin)

Time unit	Period	Age (yrs.B.P)	Environment of deposition	Stratigraphic unit	Lithology	Maximum thicknes (m)	Remarks
Quaternary	Late Holocene	2520 ± 70 to 3160 ± 110	Marine	Kadappuram beds	Coarse to fine grained sand	15	Exposed in western part of the basin
	Unconformity						
	Middle to Early Holocene	5160 ± 130 to 8820 ± 120	Fluvio-marine	Viyyam beds	Clay and mud (Greenish black to black in colour)	25	Exposed in well cuttings of Palaeo-lagoon
	Unconformity						
	Middle to Late Pleistocene	24700 ± 1890 to 35060 ± 5570	Marine	Guruvayur beds	Ferrugenous clay, clayey sand, coarse to medium sand and molluscan shells	10	Exposed in well cuttings of Palaeo-lagoon
	Unconformity						
Tertiary	Pliocene	> 40000	Erosional	Kunnamkulam beds	Laterite	20	Exposed in easten part of the basin
	Unconformity						
	Lower Miocene	NA	Marine	Vaikom formation	Coasrse sand and gravel	60	Not exposed
	Unconformity						
Archaean	Archaean	NA	Basement	Basement	Charnockite and gneisses	NA	Exposed in midland & highland regions of the basin

NA: Not analysed

dolerite dykes, contemporaneous with Cretaceous-Palaeocene Deccan basalt magmatism. Of these, the younger granites and associated pegamatites constitute the bulk of the intrusive rocks, and are contemporaneous with the Pan-African tecto-magmatic event. Within the charnockite domain, granite, gabbro-granophyre predominates.

Tertiary deposits: Tertiary deposits of the basin belonging to Vaikom formation consists of the coarse sands and gravels of Vaikom formation and the primary laterites seen over it. The younger formations such as Quilon and Warkallai are not seen in the area.

Vaikom formation: Vaikom formation of the basin is confined to western periphery of the basin, close to coast and having 1 to 1.5 km width. This is underlain by crystalline rocks and unconformably overlain by Pleistocene deposits (Ferrugenous clay, clayey sand, coarse to medium sand and molluscan shells) of Guruvayur formation in the west and Pliocene laterites of Kunnamkulam formation in the east. The ^{14}C dating of samples from this formation gives an age of > 40000 yrs.BP. The thickness of the formation varies from 50 to 60 m. This is the only deep confined aquifer of the basin (Fig. 6.5a-b). The granular zones constitute about 50 % of the total sediments. The thickness of granular unit in this aquifer ranges from 15 to 65 m and the yield of the wells in this formation ranges 0.73 to 26.82 lps. The grain size particulars of this formation are given the Table 6.3.

Table 6.3 Grain size particulars of Vaikom formation (CGWB, 1984)

Effective grain size	0.13 to 0.78 mm
Coeff. of uniformity	1.75 to 10.00
Median	0.3 to 2.30
Skewness	0.01 to 1.70

Kunnamkulam beds: This is the lithounit typically exposed in Kunnamkulam area, comprised of the primary laterite and or the lateritic soils (Plate 6.2). This is a surface of erosional origin. The entire midland and highland region of the basin are occupied by laterite and lateritic soil (Fig. 6.1). To the east of coastal plain, laterite capped upland knolls, generally of 20 m or more in elevation are very common. The elevation increases progressively towards east. At the eastern part, the surface is developed on charnockite and gneisses and is underlain by Vaikom formation on the west. This is unconformably overlain by Guruvayur beds in the west. Laterite is seen as capping the hillocks, when exposed it is very hard and massive with vesicles on top that is formed due to leaching of clay. It is reddish brown in colour and ferruginous composition. The top hard layer grades down to a soft vermicular zone with clay pockets. It is further grades down to a layer of lithomarge, which in turn is

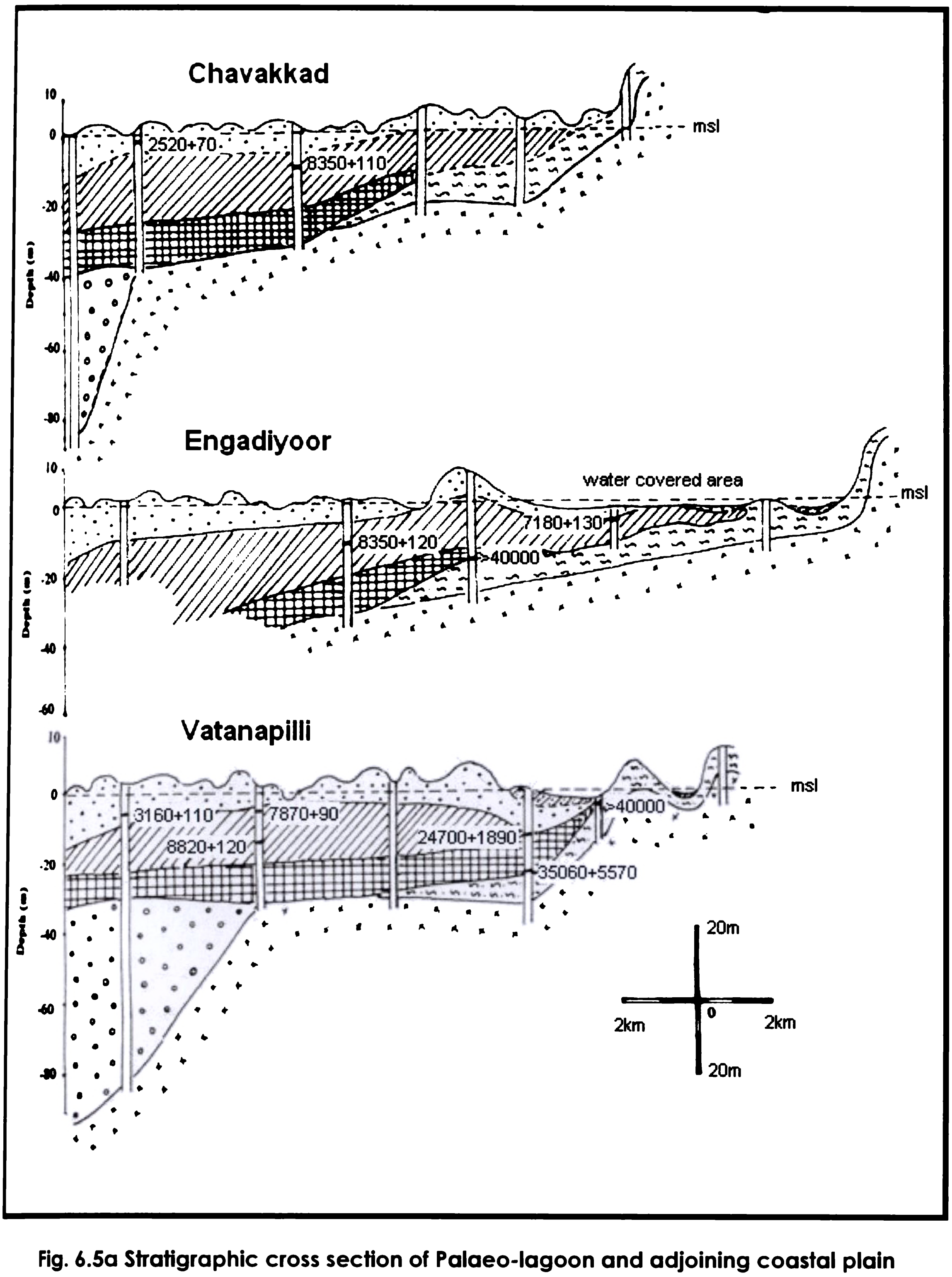


Fig. 6.5a Stratigraphic cross section of Palaeo-lagoon and adjoining coastal plain

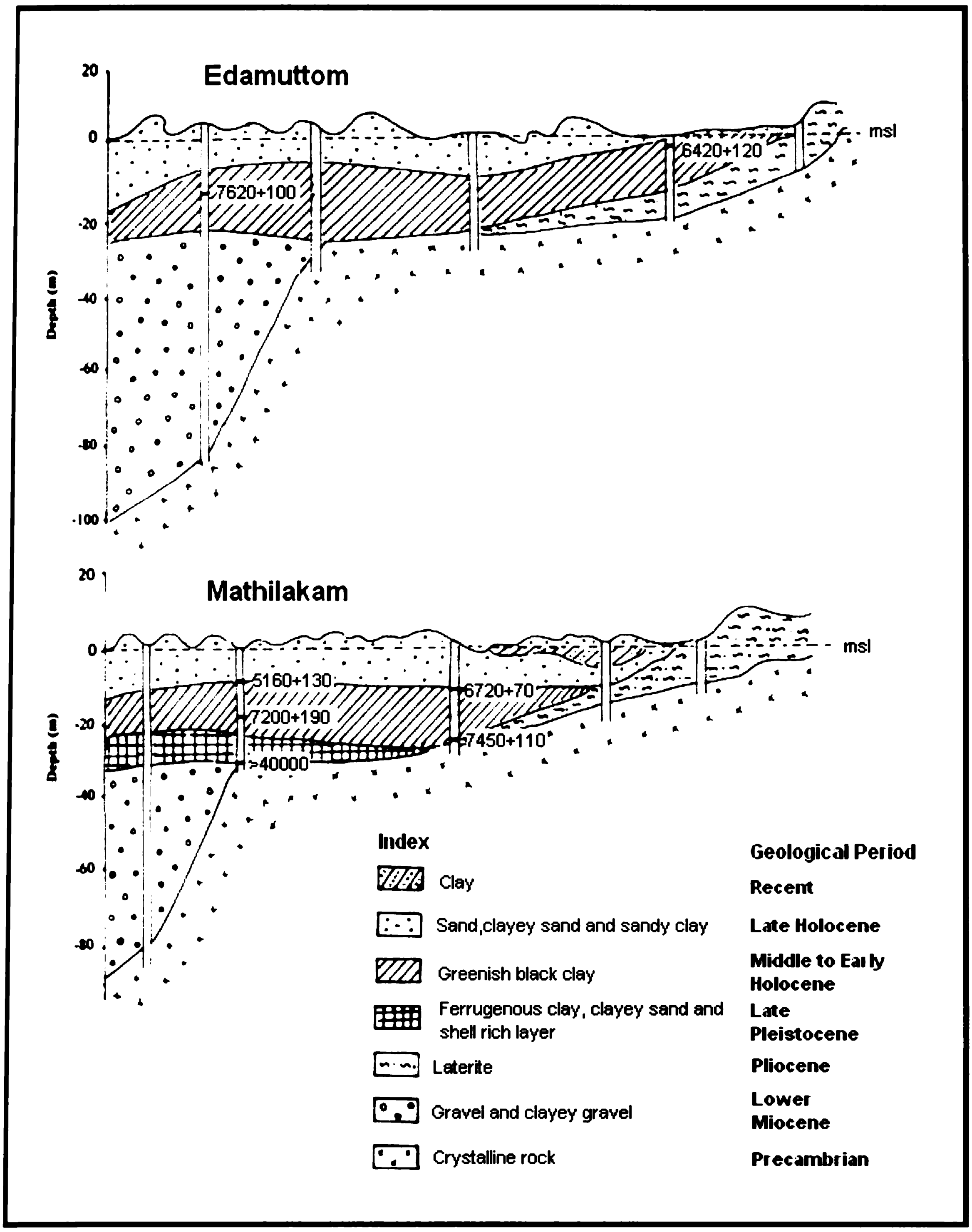


Fig. 6.5b Stratigraphic cross section of Palaeo-lagoon and adjoining coastal plain.

underlain by crystalline or sedimentary rocks. The thickness of this formation varies from 10 to 20 m including lithomarge. It is believed that laterite capped flat topped hills the 'vestiges' of an extensive pedeplain, and later dissected intensively. The dateable material was absent in the formation. The fossil shell seen encrusted on the top of laterite formation gives a ^{14}C date > 40000 yrs.BP and it suggests Pliocene age for laterites.

Quaternary deposits: The quaternary deposits of the area consist of ferruginous clay, clayey sand with molluscan shells of Pleistocene age and greenish black clay and medium to fine sands of Holocene age.

Pleistocene deposists: The Pleistocene deposits of the basin is seen as two separate patches (i) northern part of the basin between Chavakkad and Vatanapilli and (ii) in southern part of the basin around Mathilakam. There is no continuity of this layer is seen in the places in between. This shows that the depositional basin of Pleistocene time was not continuous one in the Palaeo lagoon. The Pleistocene deposits of the area are named as Guruvayur formation by Krishnan Nair (1988).

Guruvayur beds: It is underlain by Vaikom formation in the west of Palaeo-lagoon and laterites in the east (Fig. 6.5). These are unconformably overlain by 20-30 thick greenish black to black clay deposit known as Viyyam beds. In the north as well as in south, the Pleistocene unit overlies mainly the laterite in the middle and eastern part of the basin. In the western part it overlies Vaikom formations of Tertiary age. It has a maximum thickness ~ 10m. The bottommost part is made up of a matrix of white and yellow clay. This horizon is overlain by ferruginous clay and clayey sand. This unfossiliferous sequence is overlain by a coarse to fine sand layer, which is passes upward into a shell rich layer. This layer is characterised by molluscan fauna. The sand is essentially composed of quartz grains and is medium to fine grained, well rounded to sub rounded. Thin layerings are also observed for the deposits. Radiocarbon dating of the shell fragments from Mathilakam at a depth of 17 m bgl, yielded a ^{14}C date > 40000 yrs.BP. The sediment samples from Palaeo-lagoon (near Kanjani - northern part of the basin) at depths of 20.50 m and 13 m bgl yielded ^{14}C dates 35060 ± 5570 and

24700 ± 1890 yrs.BP respectively. The ^{14}C dating of the samples from the formation gives an age between 35060 ± 5570 and 24700 ± 1890 Yrs.BP. The ^{14}C dates suggest Middle Pleistocene to Late Pleistocene age for these beds (Figs. 6.5a-b).

Holocene: The Holocene deposits of the basin are seen as two separate units (i) the older greenish black sticky clay deposits and (ii) younger coarse to fine sand. The Holocene deposits of the area are named as Viyyam formation (Greenish black clay) and Kadappuram formation (coarse to fine sand) by Krishnan Nair (1988).

Viyyam beds: This bed represents the tidal and fluvio-marine deposits of the area. It is very extensively developed in the study area especially west of Palaeo-lagoon and coastal plain. Deposit is predominantly greenish black to black clay and mud. A mixture of sand and silt are also noticed in the eastern side of Palaeo-lagoon. The clay is plastic and sticky when it is wet but very hard when dried. Decayed and partially decayed wood pieces and shells are seen associated with this clay deposits. The chemical analysis of the clay samples shows that they are predominantly oxides of Si, Fe and Al (Krishnan Nair, 1988). Nodules with size varying from 5 to 15 cm are seen associated with this clay deposits in Padiyoor and Edathiriji areas. The thickness of the formation varies from 5 to 30 m. Maximum thickness is observed about 1.5 to 2 km east of the shoreline. Clay layer is tapering towards east of the Palaeo-lagoon. Viyyam bed is underlain by Guruvayur bed in the west of Palaeo-lagoon and laterits of Kunnamkulam formation in the east. It is unconformably overlain by younger Kadappuram beds of Late Holocen age. The ^{14}C dating of the samples from the formation gives an age between 8820 ± 120 and 5160 ± 130 yrs.B.P. The ^{14}C dates suggest Early to Middle Holocene age to these beds (Figs. 6.5a-b).

Kadappuram beds: The present day beach deposit represents the Kadappuram beds (Plate 6.5). Beach deposit is coarse to fine sand mosly of quartz. Black opaque minerals like ilmenite, pyroxene, hornblende and magnetite are also noticed. Flakes of muscovite and biotite are common. Ilmenite, garnet and rutile are the heavy minerals identified. The sand grains are well rounded to sub rounded and they are moderately sorted. The Kadappuram bed is unconformably overlain to Viyyam beds in the basin. But in the eastern part of the Palaeo-lagoon thin clay layer is overlaying the Kadappuran sands. These are fluvial in origin and slightly younger to Kadappuram sands. The thickness of Kadappuram beds varies from 2 m to 15m. Maximum thickness observed near shore and it is gradually decreasing and tapered out at east of Palaeo-lagoon (Fig. 6.5). The ^{14}C dating of the samples from the formation gives an age between 2520 ± 70 and 3160 ± 110 Yrs.BP and it suggests Late Holocene age to this formation.

The deposits in lowlands along the coast comprising tidal flats/mudflats and sand ridges are grouped under Quaternaries. The development of spit along the bay mouth is seen in Chetwai area and point bars also seen in parts of Chetwai and Karuvannur rivers of the basin (Plate 6.1). They are the result of fluvio-marine processes operating in the coastal tract. In spite of numerous rivers draining towards west, it is surprising that no delta is developed along the west coast. The transportation of riverine materials to deep sea by marine process along this high energy coast is to be reason for their absence (Ahamad, 1972). Braided character of the rivers and passive deltaic sequences seen in the Palaeo-lagoon are the indication of premature delta. Most part of these surface lies below mean sea level (Figs. 7.3 & 7.4).

6.3 Texture of sediment

The mechanism of transportation and deposition of unconsolidated sediments can be deciphered from the granulometric studies. Hence exhaustive research has been carried out on grain size characteristics for the past six to seven decades from different parts of the globe. A significant correlation between size frequency distribution and depositional processes has been brought out. Proper selection and combination of statistical parameters can excellently be used to discriminate various environments of deposition of ancient as well as recent sediments (Folk, 1966; Friedman, 1967; Hails and Hoyt, 1969). Apart from environmental implications, the particle size distribution is related to the source materials, processes of weathering, abrasion and corrosion of the grains and sorting processes during transport and deposition (Mishra, 1969; Patro et al., 1989; Williams et al., 1978; Forstner and Wittmann, 1983; Seralathan, 1979, 1988; Samsuddin, 1990; Padmalal and Seralathan, 1991; Padmalal, 1992; Joseph et al., 1997; Majumdar and Ganapathi, 1999; Rajamanickam and Gujar, 1984, 1985, 1997; Rajaguru et al., 1995). Hence, an attempt has been made to understand the particle size distribution of the coastal plain sediments of the Mathilkam - Chavakkad area of Palaeo-lagoon so as to have a proper insight of its influence on the mineralogy and evolution.

The size distributions of clastic sediments have revealed the existence of a strong statistical relationship between the different size parameters such as mean size, sorting (standard deviation), skewness and kurtosis. The relation between mean size and sorting is particularly well established and many studies have shown that the best-sorted sediments are generally those with mean size in the fine sand grade (Pettijohn, 1957; Griffiths, 1967; and Allen, 1970). Several attempts have been made to differentiate various environments from size spectral analysis, as particle distribution is highly sensitive to the environment of deposition (Mason and Folk, 1958; Friedman, 1961, 1967; Griffiths, 1962; Moiola et al., 1974; Stapor and Tanner, 1975; Nordstrom, 1977; Goldberg, 1980; Sly et al., 1982; Seralathan, 1988). Friedman (1961, 1965) has analyzed the fine-grained sands collected from many different localities around the world from dunes, beaches and rivers. A scatter diagram of moment standard deviation (sorting) versus moment skewness shows the most effective distinction of sands from these three environments. Visher (1969), based on the log normal distribution of grain size has identified three types of populations such as rolling, saltation and suspension, which indicate distinct modes of transportational and depositional processes. Passega (1957, 1964) has established a relationship between texture of sediments and process of deposition rather than between texture and environment as a whole. The study indicates that the finest fractions are transported independently and the coarser particles exhibit a logarithmic relation between the first percentile (C) and median (Md) of clastic sediments.

The statistical parameters such as mean size (Mz), Median (Md), Standard deviation (ó1), Skewness (Ski), Kurtosis (KG) and first percentile(C) were determined for the sediment samples collected (Fig. 6.6) by using graphic method (Folk and Ward, (1957) are given in the Tables 6.4 to 6.9. The various statistical parameters such as mean size; standard deviation, skewness and kurtosis have been plotted against each other (Figs. 6.7 to 6.13). Several investigators (Folk and Ward, 1957; Sahu, 1964; Friedman, 1965 and Abed, 1982) have observed significant trends. The mean size of clastic sediments is the statistical average of grain size. Standard deviation or sorting value indicates the particle spread on either side of the average (Folk and Ward, 1957; McKinney and Friedman, 1970). The sediment sorting is good if the spread sizes are relatively narrow. Skewness of sediments in a measure of symmetry of grain size population and reflects environment of deposition (Folk and Ward, 1957; Folk, 1968). In textural analysis skewness is considered as an important parameter because of its extreme sensitivity in subpopulation mixing. Well-sorted unimodal sediments are usually symmetrical with zero skewness. In a fine skewed sediment population, the distribution of grains will be from coarser to finer and the frequency curve chops at the coarser end and tails at the finer. The reverse condition is characteristic of coarse skewed sediments.

Mean size: The mean size of the sediment of the study area varies from 1 to 2.5 ϕ. Medium sand is seen in Chavakkad and Engadiyoor area. But the grain size is gradually decreasing towards south of the basin (1 to 2.5 ö) and become medium to fine sand near Edamuttom and Mathilakam. The variation of mean size with depth is given in the Figs. 6.7a-f. The grain size up to 2 m depth is uniform with phi mean size is just above 1.5 in Chavakkad, Engadiyoor, Edamottom and Mathilakam. A different trend is seen in Vatanapilli and Nattika. All the places of the basin except Edamuttom, shows a coarsening downward trend up to the depth 3 to 6 mbgl. But in the Edamuttom area, a coarsening upward trend is seen (Fig. 6.7e). The Vatanapilli area shows uniform character (medium to fine sand) through out the analyzed depth. The grain size becomes coarse at 5m bgl in Chavakkad, 4.5 mbgl and 8 m bgl at Engadiyoor, 3m bgl at Mathilakam. This may be due to the influence of Karuvannur, Kecheri and Chetwai rivers (flooding) along with sea level oscillation.

Sorting: The degree of sorting is a reflection of the energy level in the environment of deposition. Based on the degree of sorting, the sediment can be easily classified into three classes (i) well sorted, (ii) moderately sorted and (iii) poorly sorted.

The average standard deviation of the sediments of the basin varies from 0.82 to 1.34 ö and the sorting is generally decreases towards southern side of the basin. Majority of the sediments are moderately sorted to poorly sorted. The poorly sorted nature in the southern side of the basin shows the fluvial influence in deposition. The moderately to poorly sorted sediments are seen as alternate layered sequence with depth.

The phi mean versus standard deviation shows an almost linear relation (Fig. 6.8). The sorting worsens as the phi mean size decreases. But a reverse trend is seen in Nattika area (Fig. 6.8d). The medium and fine sands show moderate to moderately well sorted nature. It is difficult to demarcate the palaeo-ridge sediments from the recent ridge sediments possibly due to the presence of coarse as well as fine sediments in both the ridges.

Skewness: Most of the sediments of the study area with moderately sorted to poorly sorted nature are near symmetrical with respect to skewness (except Nattika area) even though there is a significant variation in phi mean size of sediments (Tables 6.4 to 6.9 and Fig. 6.13). It is significant to note that if the standard deviation is a function of phi mean size, sorting and skewness will bear a mathematical relationship to each other (Folk and Ward, 1957). Symmetrical curve can be obtained either in a unimodal sediments with good sorting or equal mixtures of two modes which have the poorest mode of sorting. With one mode dominant and other subordinate, the sediments exhibit moderate sorting but give extreme values of skewness (Folk and Ward, 1957; McKinney and Friedman, 1970) as observed in most of the sediment samples of the study area.

Perfectly sorted, unimodal sediments have a skewness value zero and very slight deviation on sorting results in near symmetrical skewness. Friedman (1967) and Cronan (1972) have indicated that the polymodal sediment can show variable skewness values depending on the specific proportion of subpopulation abundance.

Kurtosis: The kurtosis of the samples of the basin varies from 0.947 to 2.79. Sediments of all locations except Engadiyoor area show from leptokurtic to very leptokurtic nature. But the sediments at Engadiyoor area show meosokurtic nature (Tables 6.4 to 6.9 and Fig. 6.13). The sub samples of the sediments of the ridge are mostly leptokurtic to very leptokurtic nature. As the sediments are

Table 6.4 Statistical parameters of grain size in coastal plain sediment of Chavakkad area in Palaeo-lagoon (Kole land basin)

Sl.No	Depth (mbgl)	Mean size Phi (Mz)	Median (phi) (Md)	Standard deviation (phi) (σ1)	Skewness (Ski)	Kurtosis (KG)	First percentile (C)
1	0.30	1.61	1.78	0.63	0.00	0.95	-0.32
2	0.60	1.63	1.79	0.62	0.00	0.96	0.00
3	0.90	1.62	1.80	0.61	-0.02	0.95	0.00
4	1.20	1.64	1.82	0.62	-0.02	0.94	0.00
5	1.50	1.53	1.75	0.80	-0.07	1.16	0.01
6	1.80	1.19	1.46	0.60	-0.06	0.91	-0.36
7	2.10	1.28	1.50	0.70	0.05	0.86	-0.36
8	2.40	1.71	1.73	0.72	0.15	0.84	0.00
9	2.70	1.67	1.82	0.62	0.14	1.79	0.52
10	3.00	1.63	1.80	0.56	-0.01	0.98	0.21
11	3.30	1.55	1.63	0.55	0.02	1.34	0.51
12	3.60	0.82	0.95	0.61	0.22	0.99	-0.76
13	3.90	0.81	1.00	0.71	0.15	1.49	-0.49
14	4.20	0.44	0.63	0.83	-0.07	0.91	-1.40
15	4.50	1.13	1.35	0.87	-0.09	0.98	-1.36
16	4.80	0.19	0.45	0.93	-0.02	0.88	-1.98
17	5.10	0.46	0.68	0.74	-0.15	0.94	-1.00
18	5.40	0.11	0.24	0.64	0.02	0.88	-1.46
19	5.70	0.60	0.80	0.94	-0.04	1.11	0.09
20	6.00	1.13	1.35	0.72	-0.10	1.10	0.13
21	6.30	0.72	1.21	1.10	-0.05	0.49	0.03
22	6.60	0.74	1.74	1.28	-0.45	0.87	0.02
23	6.90	1.16	1.67	1.26	-0.14	0.92	0.13
24	7.20	1.74	1.92	0.86	-0.11	1.28	0.12
25	7.50	1.95	2.19	0.74	-0.21	1.01	-0.94
26	7.80	1.67	1.98	0.94	-0.20	1.15	-1.38
27	8.10	1.24	1.40	1.14	0.03	0.90	-1.76
28	8.40	1.18	1.40	1.41	0.29	0.95	0.04

Table 6.5 Statistical parameters of the grain size in coastal plain sediment of Engadiyoor area in Palaeo-lagoon (Kole land basin)							
Sl.No.	Depth in (m) bgl	Mean size (Phi) (Mz)	Median (phi) (Md)	Standard deviation (phi) (σ1)	Skewness (Ski)	Kurtosis (KG)	First percentile (C)
1	0.30	1.59	1.69	0.62	0.07	0.86	0.02
2	0.60	1.60	1.66	0.61	0.06	0.86	0.05
3	0.90	1.61	1.73	0.61	0.06	0.85	0.09
4	1.20	1.69	1.95	0.58	0.00	0.86	0.52
5	1.50	1.63	1.79	0.56	0.00	0.87	0.25
6	1.80	1.57	1.61	0.56	0.07	0.85	0.19
7	2.10	1.60	1.69	0.50	0.15	0.68	0.54
8	2.40	1.63	1.77	0.55	0.02	0.86	0.53
9	2.70	1.03	1.08	0.55	0.05	1.42	-0.31
10	3.00	1.10	1.20	0.62	0.16	1.67	-0.28
11	3.30	1.44	1.64	0.82	-0.25	1.21	-1.26
12	3.60	1.50	1.74	0.75	-0.17	0.97	-0.36
13	3.90	0.72	0.80	0.75	0.18	1.03	-0.91
14	4.20	0.58	0.69	0.92	0.05	1.08	-1.38
15	4.50	-0.06	0.06	0.77	-0.12	1.09	0.11
16	4.80	1.07	1.15	0.97	0.03	1.14	0.22
17	5.10	0.70	0.67	0.75	0.24	1.05	-1.38
18	5.40	1.26	1.68	1.13	-0.39	1.08	-1.98
19	5.70	1.92	2.20	0.84	-0.31	0.93	-1.34
20	6.00	1.73	2.15	1.13	-0.54	1.16	0.14
21	6.30	0.98	1.45	1.31	-0.24	0.82	0.20
22	6.60	1.02	1.58	1.27	-0.23	0.83	0.12
23	6.90	0.62	0.94	1.48	-0.03	0.72	0.08
24	7.20	0.90	1.92	1.47	-0.19	0.36	0.02
25	7.50	-0.03	-0.24	1.49	0.33	0.81	0.05
26	7.80	1.30	1.92	1.19	-0.19	0.75	0.02
27	8.10	1.99	2.47	1.13	-0.20	0.98	-0.86
28	8.40	2.48	2.27	3.11	0.39	0.74	0.03

Table 6.6 Statistical parameters of the grain size in coastal plain sediment of Vatanapilli area in Palaeo-lagoon (Kole land basin)

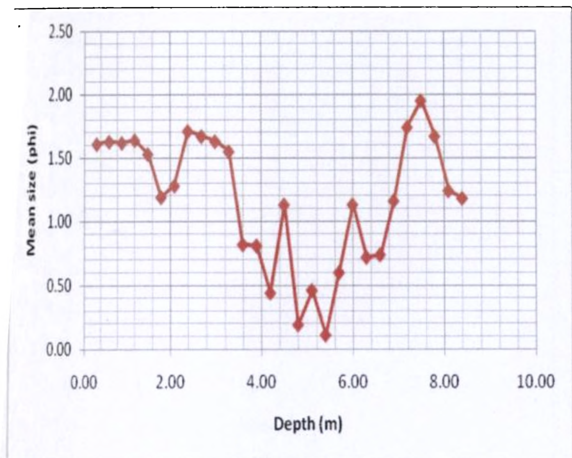
Sl.No.	Depth in (mbgl)	Mean size (Phi) (Mz)	Median (phi) (Md)	Standard deviation (phi) (σ1)	Skewness (Ski)	Kurtosis (KG)	First percentile (C)
1	0.30	2.37	2.35	1.69	0.32	2.17	0.17
2	0.60	2.42	2.45	1.84	0.36	1.53	0.20
3	0.90	1.75	2.24	1.63	-0.14	2.15	0.09
4	1.20	1.76	2.23	1.31	-0.16	1.45	0.08
5	1.50	2.11	2.43	1.34	0.11	1.91	0.09
6	1.80	1.77	2.28	1.94	0.10	2.92	-0.99
7	2.10	1.78	2.36	2.07	0.02	3.23	-1.89
8	2.40	2.49	2.50	2.61	0.39	1.91	-0.95
9	2.70	2.16	2.48	2.06	0.23	1.51	-0.95
10	3.00	1.42	1.89	1.68	0.43	1.23	0.02
11	3.30	1.13	1.70	1.14	-0.02	0.83	-0.99
12	3.60	1.44	2.10	1.16	-0.60	0.85	0.22
13	3.90	2.43	2.67	0.72	0.57	7.09	
14	4.20	2.40	2.59	0.58	0.38	5.25	-0.88
15	4.50	2.12	2.52	0.21	-0.38	3.10	0.18
16	4.80	2.13	2.53	0.37	0.02	5.53	0.08
17	5.10	1.83	2.43	0.57	-0.40	4.84	0.06

Table 6.7 Statistical parameters of grain size in coastal plain sediment of Nattika area in Palaeo-lagoon (Kole land basin)							
Sl.No	Depth (mbgl)	Mean size (Phi) (Mz)	Median (Phi) (Md)	Phi Standard deviation (phi) (σ1)	Skewness (Ski)	Kurtosis (KG)	First percentile (C)
1	0.30	2.09	2.34	1.62	0.23	2.56	0.07
2	0.60	2.02	2.19	1.11	-0.02	1.47	0.06
3	0.90	2.11	2.48	1.60	0.21	1.56	0.18
4	1.20	2.19	2.81	1.87	0.29	3.25	0.03
5	1.50	1.87	2.62	2.13	0.13	1.89	0.05
6	1.80	1.84	2.45	2.14	0.14	1.88	0.06
7	2.10	1.82	2.38	2.14	0.15	1.88	0.06
8	2.40	1.15	1.57	1.58	0.23	1.44	0.19
9	2.70	1.15	1.54	1.44	0.20	1.25	0.20
10	3.00	1.07	1.17	1.14	0.07	1.50	-0.98
11	3.30	1.65	1.92	0.92	0.02	1.08	-0.36
12	3.60	1.13	1.19	0.96	0.10	1.09	-0.49
13	3.90	1.11	1.14	0.99	0.08	1.09	0.18
14	4.20	0.81	0.92	0.88	0.23	1.17	-1.35
15	4.50	1.10	1.14	1.04	0.13	1.15	-0.95
16	4.80	0.94	1.00	0.96	0.28	0.95	-0.94
17	5.10	1.08	1.10	0.96	0.08	1.12	-0.93
18	5.40	0.96	1.05	0.99	0.29	0.93	0.15
19	5.70	1.13	1.15	1.26	0.27	1.35	0.19
20	6.00	0.94	0.98	0.97	0.30	0.98	-0.90
21	6.30	0.92	0.89	0.95	0.33	1.22	-0.85
22	6.60	0.85	1.00	0.84	0.23	1.18	-0.76
23	6.90	0.94	1.03	0.95	0.27	0.95	-0.97

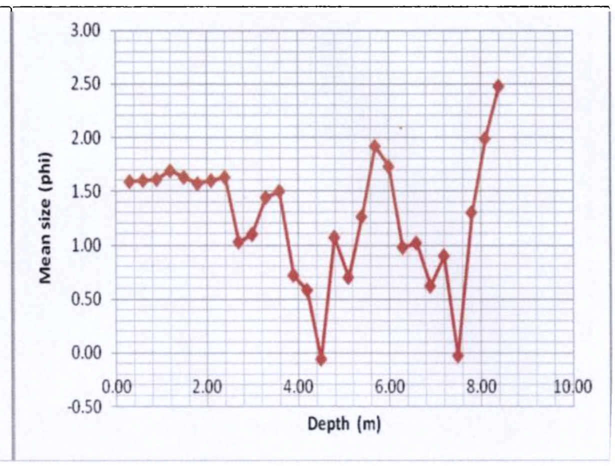
Table 6.8 Statistical parameters of grain size in coastal plain sediment of Edamuttom area in Palaeo-lagoon (Kole land basin)

Sl.No.	Depth (mbgl)	Mean size (Phi) Mz	Median (phi) (Md)	Standard deviation (phi) ($\sigma 1$)	Skewness (Ski)	Kurtosis (KG)	First percentile (C)
1	0.30	1.49	1.76	0.80	-0.14	0.97	-0.45
2	0.60	1.46	1.63	0.79	-0.12	0.99	-0.45
3	0.90	1.46	1.62	0.77	-0.12	0.97	-0.45
4	1.20	1.46	1.63	0.79	-0.13	0.97	-0.45
5	1.50	1.51	1.80	0.78	-0.16	0.99	-0.48
6	1.80	1.35	1.55	0.78	0.17	0.99	-0.45
7	2.10	1.47	1.59	0.74	-0.10	1.02	-0.40
8	2.40	1.12	1.21	0.69	0.00	1.10	-1.27
9	2.70	1.47	1.65	0.89	-0.03	1.18	0.19
10	3.00	1.16	1.40	1.01	0.00	0.85	-1.33
11	3.30	1.36	1.48	0.86	0.23	1.15	-0.90
12	3.60	2.10	2.33	0.66	-0.15	1.07	-0.89
13	3.90	1.32	1.44	0.92	0.15	0.99	-0.86
14	4.20	1.98	2.35	0.86	-0.32	1.23	-0.95
15	4.50	2.55	2.66	0.67	-0.04	1.70	0.10
16	4.80	2.36	2.58	0.82	-0.30	1.91	-0.43
17	5.10	1.84	2.43	1.13	-0.36	1.10	-0.48
18	5.40	2.52	2.77	0.83	-0.25	1.40	-0.42
19	5.70	2.81	2.95	0.89	0.07	0.94	-0.34
20	6.00	2.82	2.94	0.86	0.11	0.94	0.09
21	6.30	2.79	2.90	0.89	0.07	0.96	0.01
22	6.60	1.13	1.56	1.15	0.03	0.87	0.18
23	6.90	1.41	1.60	1.49	0.25	1.05	0.19
24	7.20	1.13	1.50	1.14	0.03	0.87	0.18
25	7.50	2.27	2.64	1.30	-0.16	0.60	0.17
26	7.80	2.65	2.91	0.95	-0.05	0.87	-0.41
27	8.10	2.49	2.79	0.81	-0.20	1.05	-0.40
28	8.40	2.86	3.04	0.81	0.16	0.98	0.59

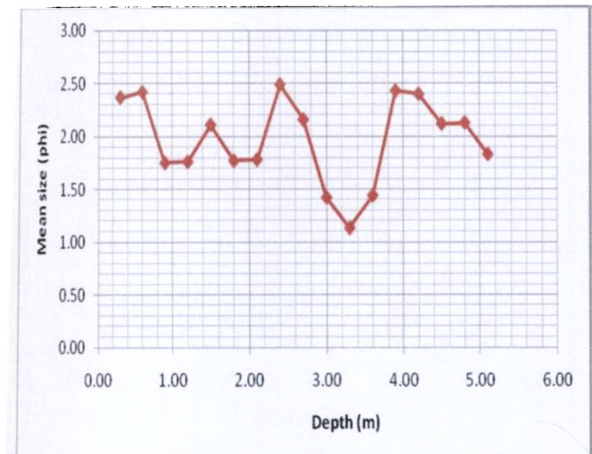
Table 6.9 Statistical parameters of grain size in coastal plain sediment of Mathilakam area in Palaeo-lagoon (Kole land basin)							
Sl.No	Depth (mbgl)	Mean size (Phi)(Mz)	Median (phi) (Md)	Standard deviation (phi) ($\sigma 1$)	Skewness (Ski)	Kurtosis (KG)	First percentile (C)
1	0.30	1.63	1.809	0.84	-0.04	0.95	-0.38
2	0.60	1.64	1.84	0.88	0	1.05	-0.37
3	0.90	1.77	1.97	0.78	0.12	0.95	-0.33
4	1.20	1.79	2.046	0.77	0.08	0.95	-0.29
5	1.50	1.64	1.805	0.61	0.02	0.88	0.04
6	1.80	1.67	1.886	0.59	0.01	0.89	0.17
7	2.10	1.66	1.849	0.61	0.01	0.86	0.09
8	2.40	1.62	1.832	0.69	-0.07	0.99	-0.4
9	2.70	1.6	1.818	0.95	-0.17	1.16	0.17
10	3.00	1.97	2.444	0.94	-0.38	1.31	-1.29
11	3.30	0.46	0.427	1.32	0.28	1.01	-1.9
12	3.60	1.15	1.671	1.38	-0.06	0.69	0.16
13	3.90	2.8	2.822	1.13	-0.02	1.93	0.05
14	4.20	1.96	2.412	1.06	-0.35	1.26	-0.97
15	4.50	2.36	2.421	1.31	0.05	1.71	-0.96
16	4.80	2.63	2.772	0.53	0.05	3.61	0.61
17	5.10	2.01	2.391	0.89	-0.09	1.3	-0.28
18	5.40	2.15	2.368	0.56	-0.05	0.94	0.57
19	5.70	1.61	1.775	0.77	0.05	0.84	-0.35
20	6.00	1.78	2.261	0.77	-0.48	1.2	-0.9
21	6.30	1.54	2	1.98	0.49	2.68	0.06
22	6.60	1.51	1.927	1.96	0.39	1.62	-0.97
23	6.90	1.15	1.613	1.61	0.22	1.46	-0.99
24	7.20	1.14	1.501	1.76	0.27	1.66	-0.98
25	7.50	1.17	1.691	1.73	0.26	1.66	-0.97
26	7.80	1.49	1.774	2.10	0.43	1.83	-0.97



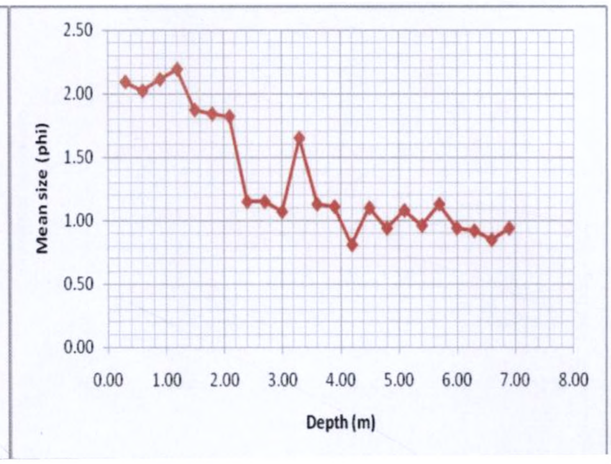
(a)Chavakkad



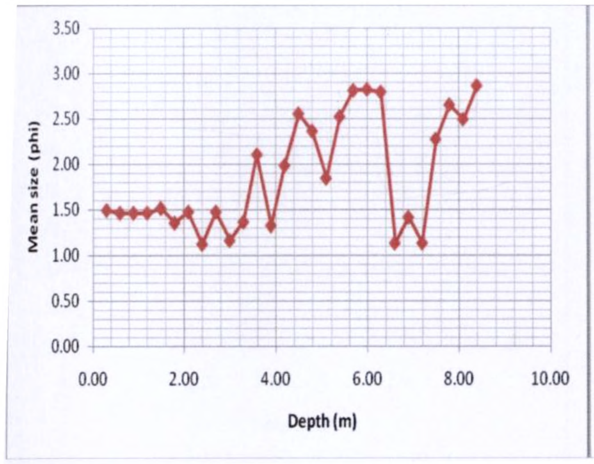
(b) Engadiyoor



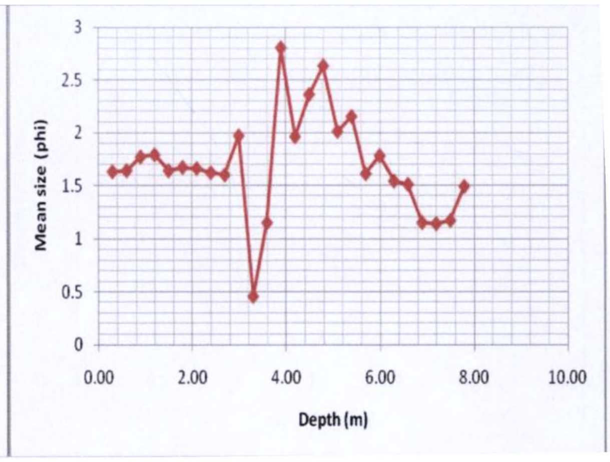
(c) Vatanapilli



(d) Nattika

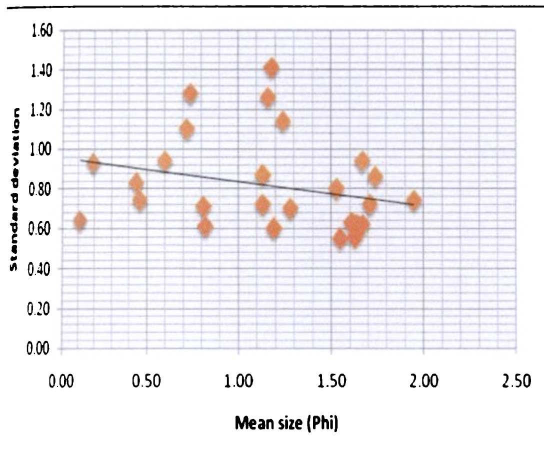


(e) Edamuttom

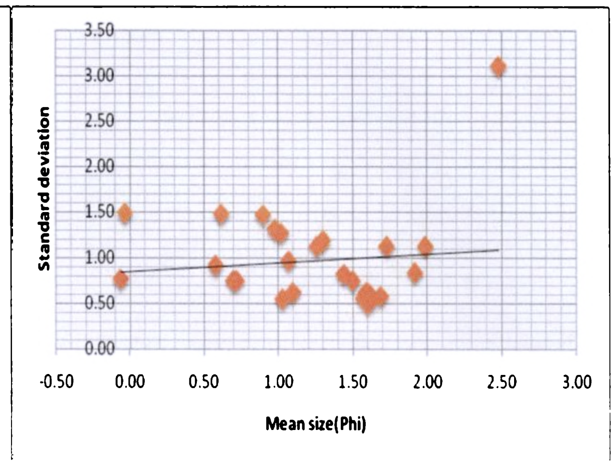


(f) Mathilakam

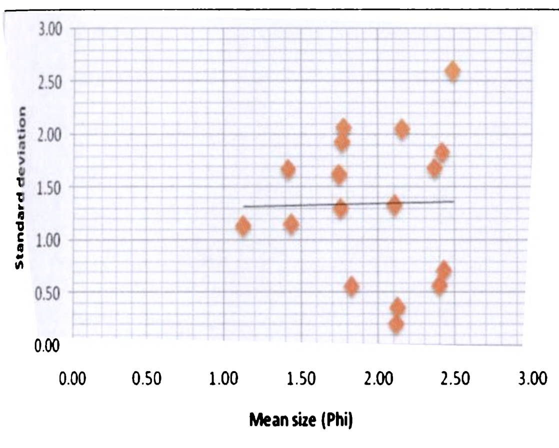
Fig. 6.7 Bivariate Plot of depth Vs Phi Mean size in coastal plain region of Palaeo-lagoon



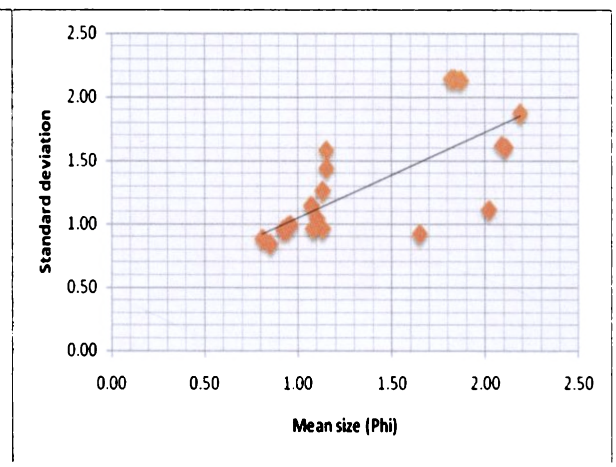
(a)Chavakkad



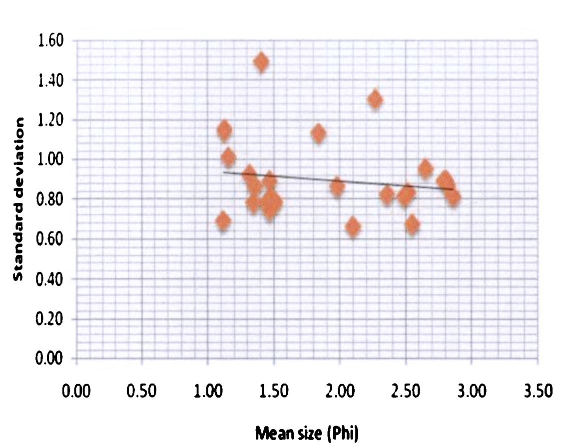
(b) Engadiyoor



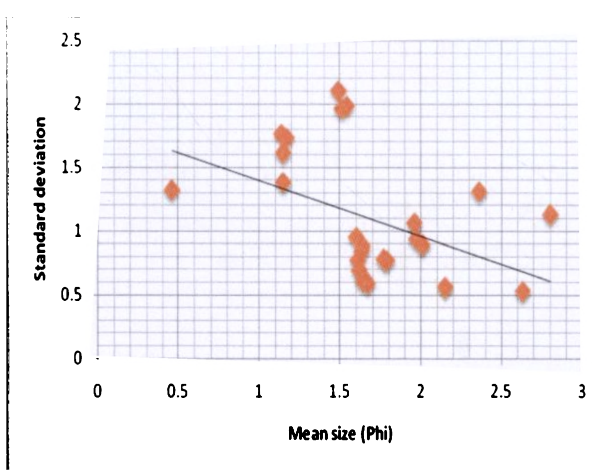
(c) Vatanapilli



(d) Nattika

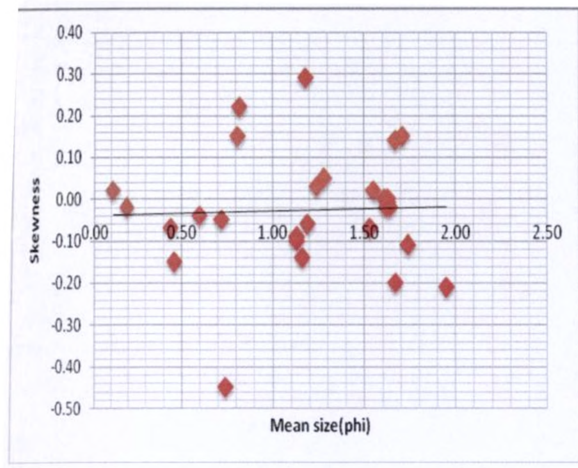


(e) Edamuttom

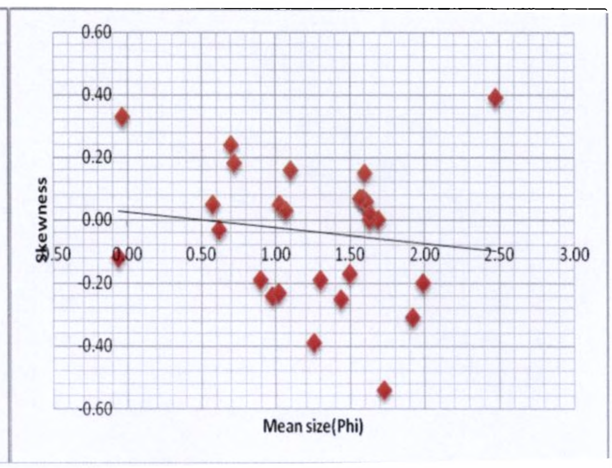


(f) Mathilakam

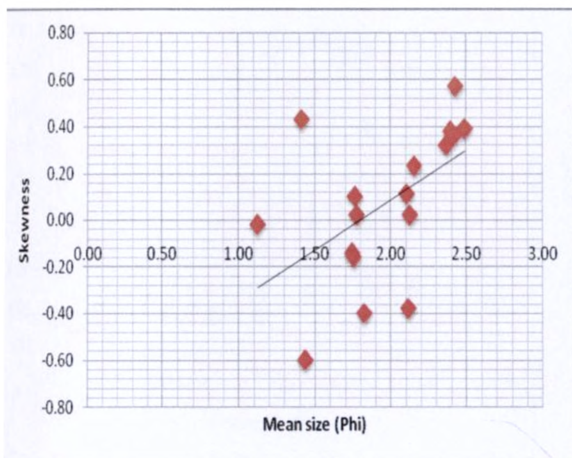
Fig. 6.8 Bivariate Plot of Phi Mean size Vs Standard deviation in coastal plain region of Palaeo-lagoon



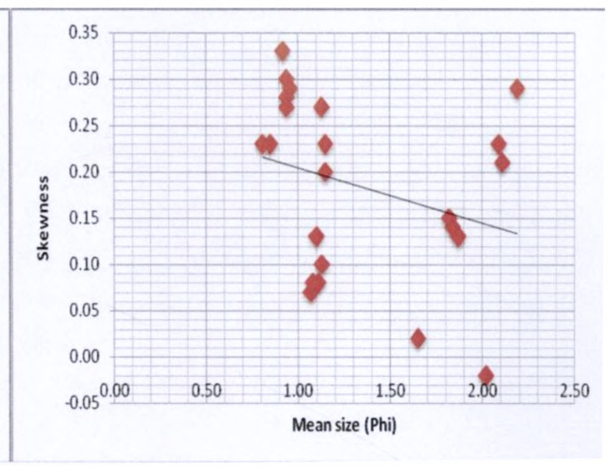
(a)Chavakkad



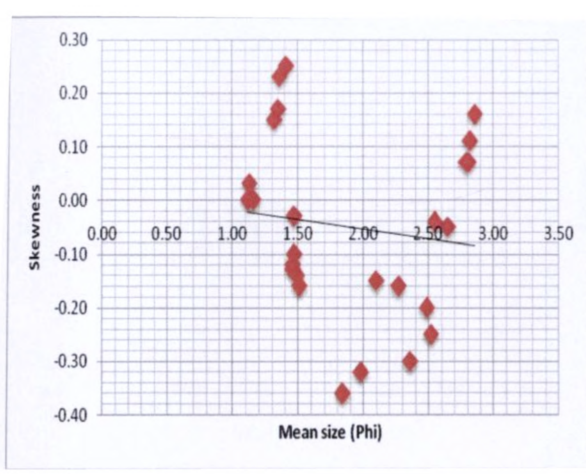
(b) Engadiyoor



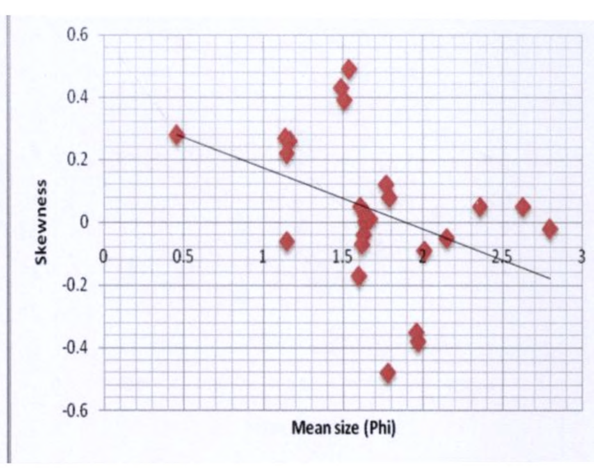
(c) Vatanapilli



(d) Nattika

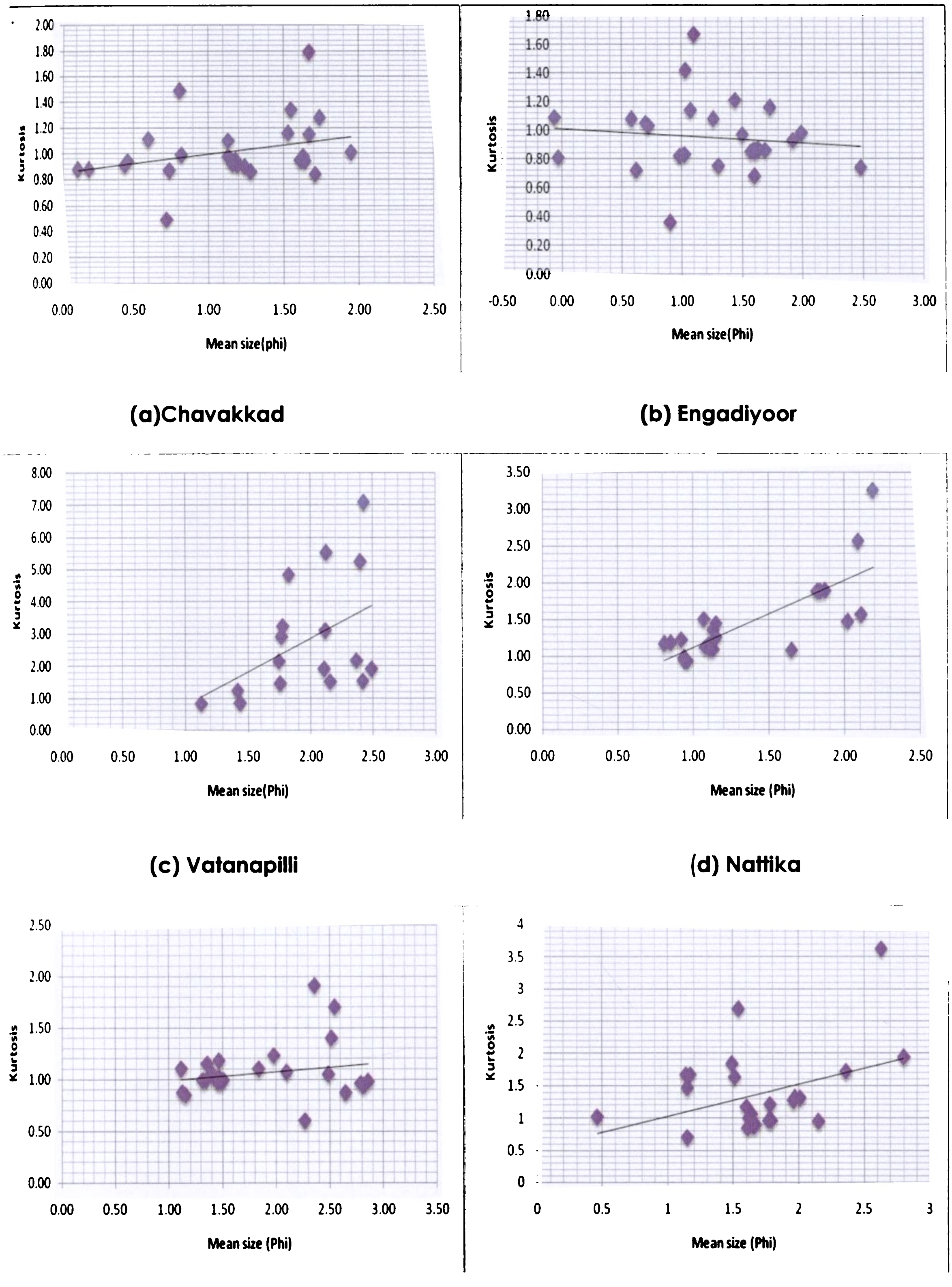


(e) Edamuttom



(f) Mathilakam

Fig. 6.9 Bivariate Plot of phi Mean size Vs Skewness in coastal plain region of Palaeo-lagoon

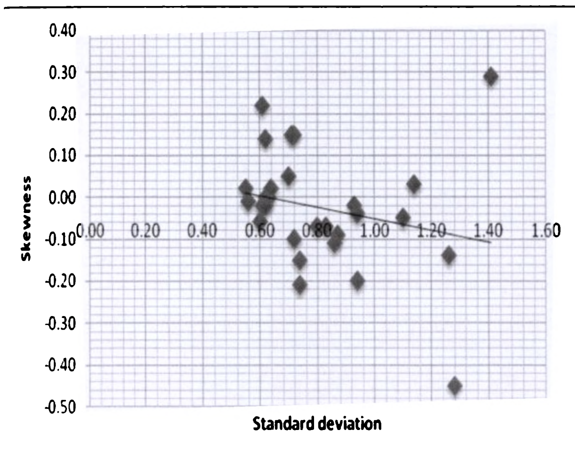


(a)Chavakkad **(b) Engadiyoor**

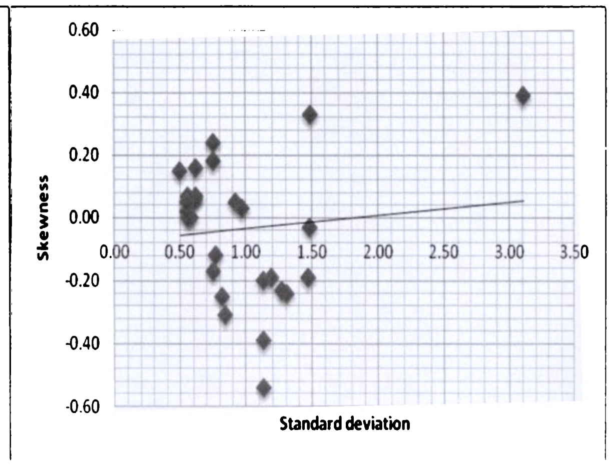
(c) Vatanapilli **(d) Nattika**

(e) Edamuttom **(f) Mathilakam**

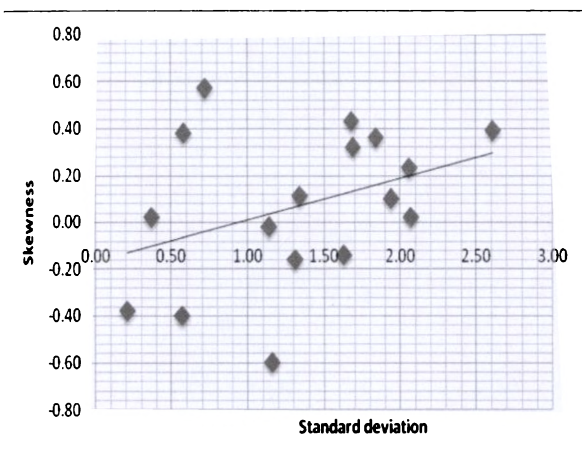
Fig. 6.10 Bivariate Plot of Phi Mean size Vs Kurtosis in coastal plain region of Palaeo-lagoon



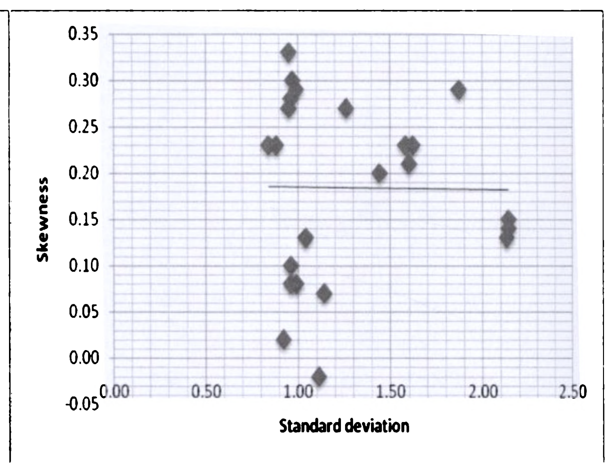
(a)Chavakkad



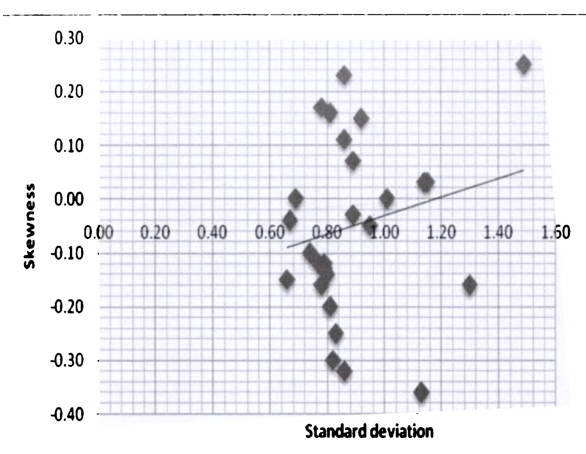
(b) Engadiyoor



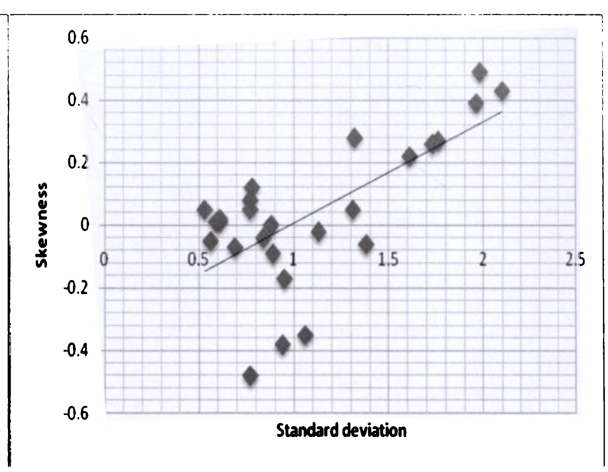
(c) Vatanapilli



(d) Nattika

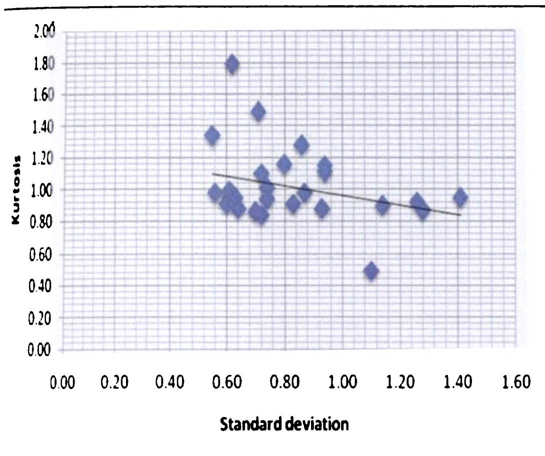


(e) Edamuttom

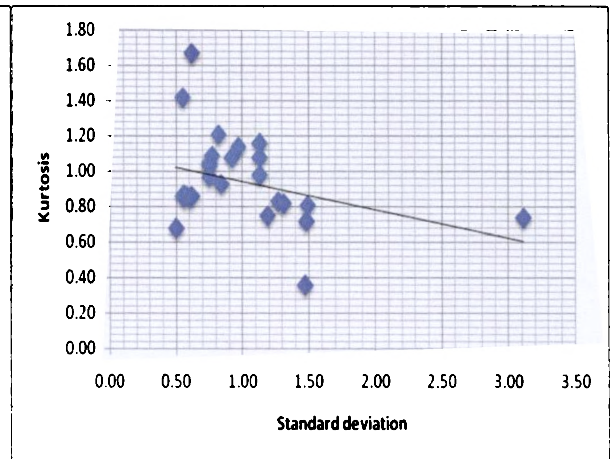


(f) Mathilakam

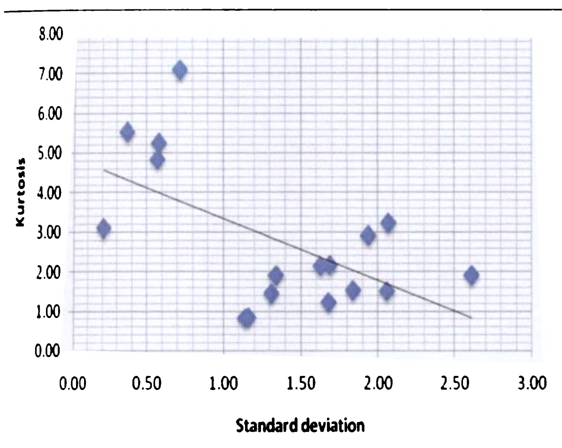
Fig. 6.11 Bivariate Plot of Standard deviation Vs Skewness in coastal plain region of Palaeo-lagoon



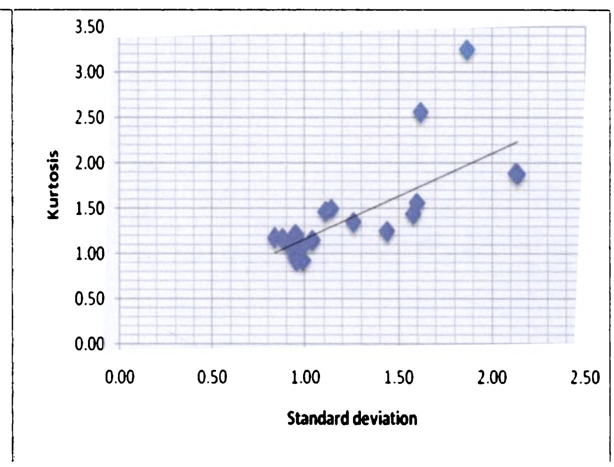
(a)Chavakkad



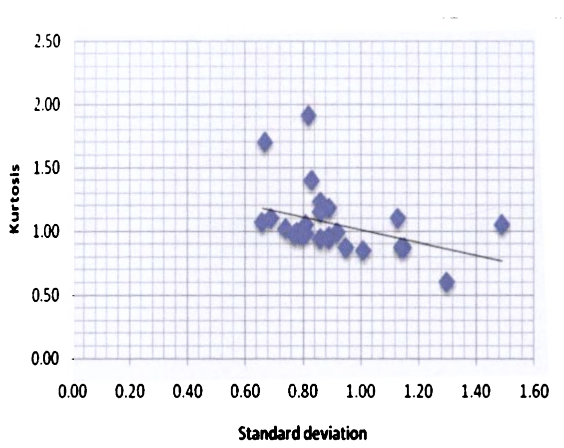
(b) Engadiyoor



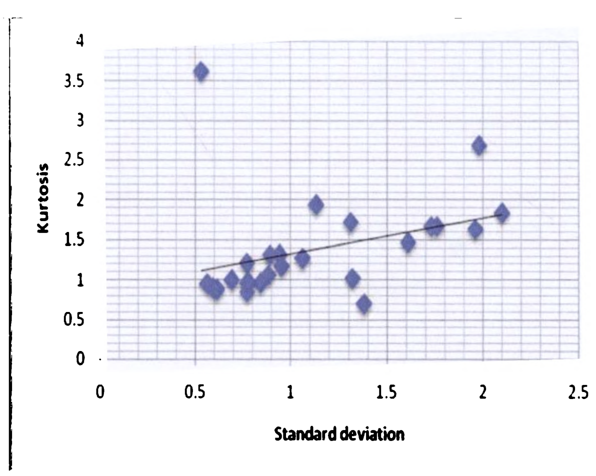
(c) Vatanapilli



(d) Nattika



(e) Edamuttom



(f) Mathilakam

Fig. 6.12 Bivariate Plot of Standard deviation Vs Kurtosis in coastal plain region of Palaeo-lagoon

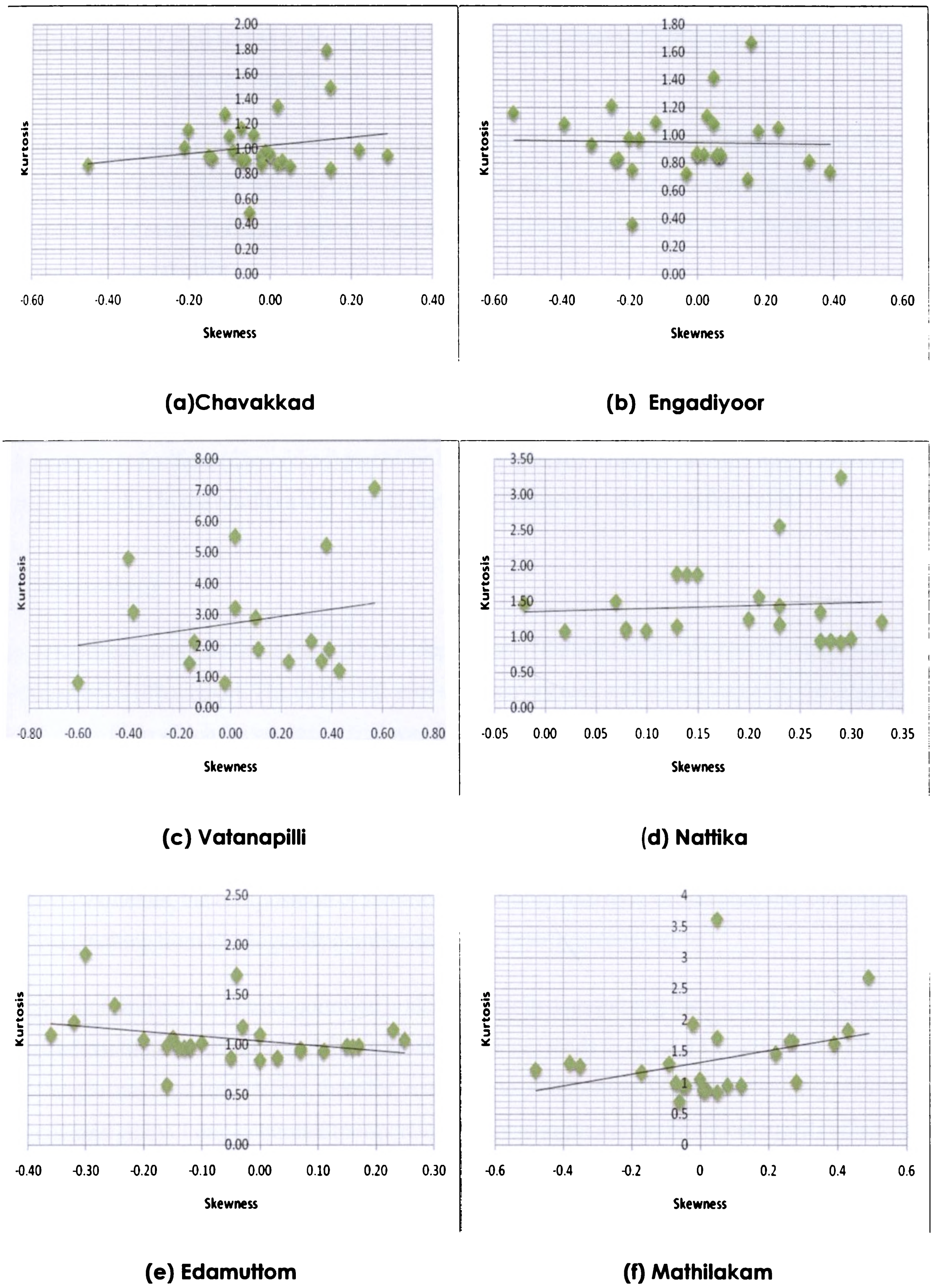


Fig. 6.13 Bivariate plot of Skewness Vs Kurtosis in coastal plain region of Palaeo-lagoon

Table 3.7 Long term trend of groundwater level in bore wells of semi-confined aquifer for the period from 01.01.1997 to 01.01.2007 in Palaeo-lagoon (Kole land basin)

Well No	Location	Number of data analysed	All data		Pre monsoon		Post monsoon	
			Water level rise (m/year)	Water level fall (m/year)	Water level rise (m/year)	Water level fall (m/year)	Water level rise (m/year)	Water level fall (m/year)
BW-1	Kaduppassery	86	0.292	-	0.25	-	0.29	-
BW-2	Mattathur	86	0.016	-	0.01	-	-	0.04
BW-3	Nellai	88	0.045	-	0.04	-	0.02	-
BW-4	Tholur	87	-	0.017	-	0.20	0.10	-
BW-5	Trikkur	87	0.200	-	0.17	-	0.09	-
BW-6	Choondel	90	-	0.063	-	0.36	0.10	-
BW-7	Madakkathara	89	0.064	-	0.08	-	0.06	-
BW-8	Pananchery	87	0.140	-	0.16	-	0.13	-
BW-9	Kolazhy	73	-	0.031	0.10	-	-	0.04
BW-10	Athani	86	0.352	-	0.19	-	0.37	-
BW-11	Chengalur	88	0.027	-	0.08	-	-	0.00
BW-12	Muppliyam	88	-	0.157	-	0.19	-	0.15
BW-13	Mudicode	89	0.068	-	0.09	-	0.04	-
BW-14	Velapaya	87	0.154	-	0.07	-	0.10	-
BW-15	Kaiparambu	89	0.050	-	-	0.05	0.08	-
BW-16	Peechi	90	0.004	-	-	0.04	0.03	-
BW-17	Chittilappilly	86	0.234	-	0.05	-	0.32	-
BW-18	Nelluvayi	91	0.039	-	-	0.09	0.07	-
BW-19	Kandanissery	79	-	0.173	-	0.34	0.14	-
BW-20	Aloor	84	0.182	-	-	0.10	0.15	-
BW-21	Vellangallur	87	0.090	-	-	0.04	0.02	-
BW-22	Wadakkancherry	65	-	0.130	-	0.15	-	0.163
BW-23	Varavur	64	-	0.081	-	0.46	0.08	-
BW-24	Arthat	64	-	0.142	-	0.76	0.15	-

mostly moderately well sorted to poorly sorted, the predominance of fine population makes the sediments leptokurtic to very leptokurtic.

The scatter diagram of mean size Vs skewness (Figs. 6.14 and 6.15) gives an idea about palaeo-environment of deposition. Most of the samples plotted fall in the field of beach and inland. Very little samples are seen in offshore region. There is not much variation is observed in the above along or across the coastal plain.

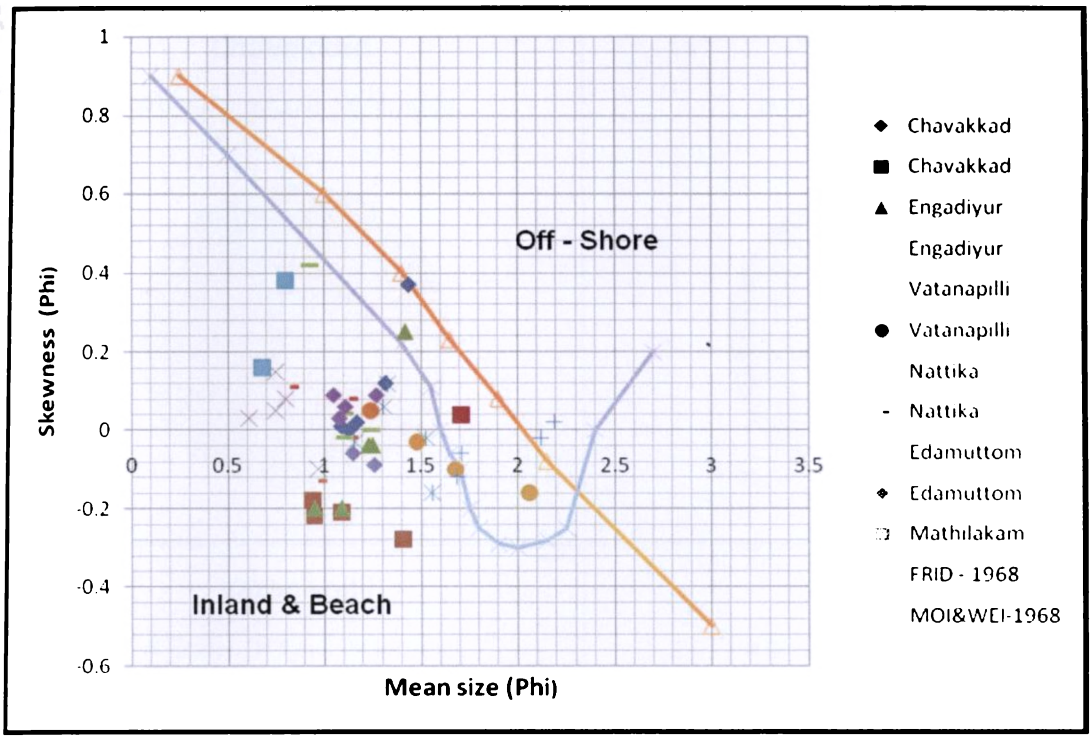
The gravel, sand and silt/mud content in the sediment samples of the study area were analyzed and are given in the Tables 6.10 to 6.12. The sand content in the samples varies from 85 (Vatanapilli) to 99% (Mathilakam). The clay content in the samples shows an increasing trend from southern (Mathilakam) to northern (Chavakkad) part of the basin (Fig. 6.16). This indicates the fluvial influence during deposition in the northern and central part of the basin was more than the south.

6.4 Mineralogy

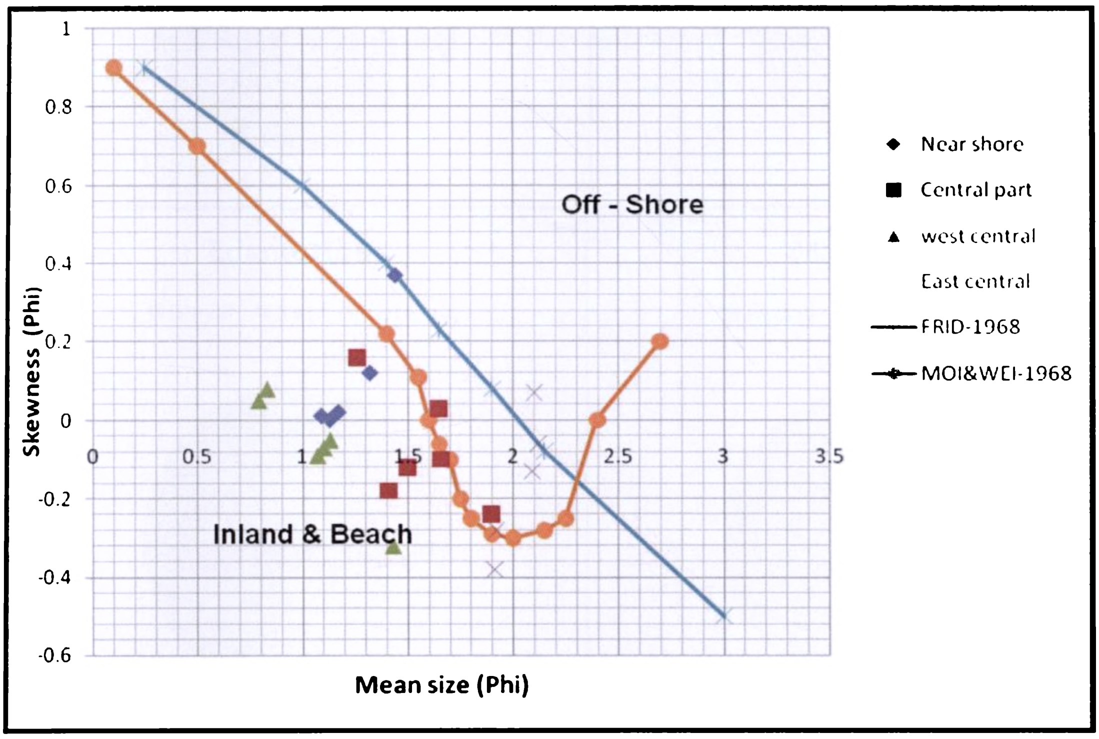
The sedimentary rocks are those formed by the deposition of the solid materials carried in suspension by the agencies of transport. The composition of sedimentary rock will depend upon (i) the original source rocks from which the waste material was derived; (ii) the chemical and mechanical resistance of each mineral component during transport; and (iii) the distance travelled. The mineral composition also depends on the nature of the rocks forming material. If the country rock consists mainly of some mineralogically uniform rock such as quartzite and granite which are poor in ferromagnesian and accessory minerals, the composition of sediments resulting from their denudation will be simpler than that resulting from lithologically or mineralogically heterogeneous region.

The duration and nature of transportation is also a factor in determining the mineral composition. Long and continued drifting to and fro by wind or by water tends to effect a separation of particles according to mass and surface area, there for, according to composition. Wind is particularly efficient sorter of sand grains. Long-continued transport in rivers or alongshore may be almost equally effective in producing clean, graded and uniform deposits.

The vicissitudes of transport tend to destroy the softer, more cleavable, and brittle mineral grains and thus to produce greater mineral uniformity in the final material. Feldspars are more altered and softer, and are consequently more easily broken down to silt and clay grade than the hard and intractable quartz. The waves of the sea are still more effective in eliminating the feldspar from sands.



ig. 6.14 Scatter diagram showing north-south variation of Mean size Vs Skewness in coastal plain between Mathilakam and Chavakkad of Palaeo-lagoon.



ig. 6.15 Scatter diagram showing east-west variation of Mean size Vs Skewness in coastal plain between Mathilakam and Chavakkad of Palaeo-lagoon.

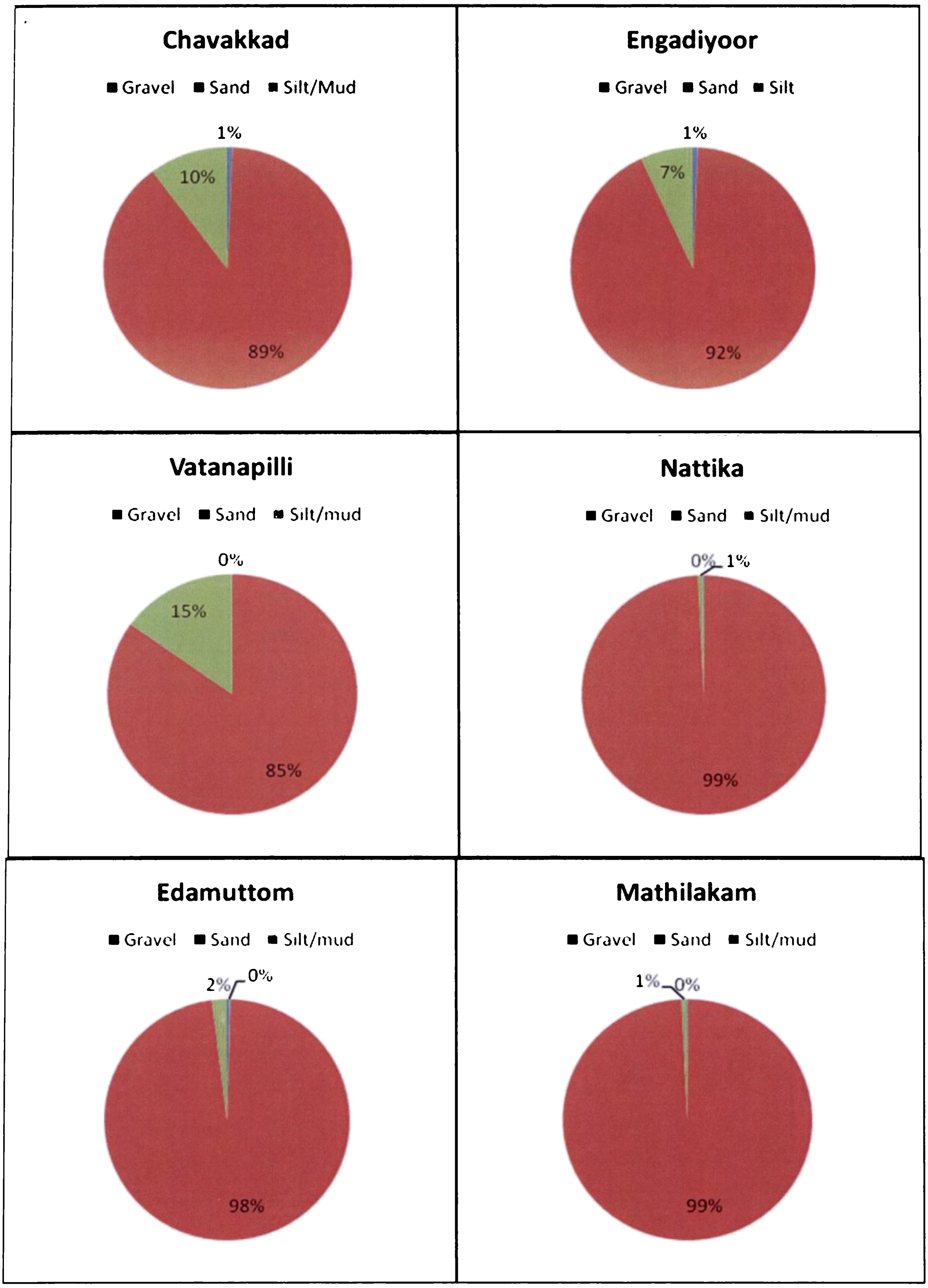


Fig.6.16 Variation of Gravel, sand and silt/mud percentages in sediments of the study area.

Table 6.10 Gravel, sand, silt/mud and clay percentages of the coastal plain sediments in Palaeo-lagoon (Kole land basin)							
Sl.No.	Depth (m) bgl	Chavakkad			Engadiyoor		
		Gravel (%)	Sand (%)	Silt/mud (%)	Gravel (%)	Sand (%)	Silt/mud (%)
1	0.30	2.065	84.460	13.500	0.067	99.170	0.760
2	0.60	1.567	80.308	18.125	0.000	99.260	0.738
3	0.90	3.580	87.570	8.850	0.000	99.275	0.724
4	1.20	0.000	94.925	5.075	0.052	97.334	2.613
5	1.50	0.000	85.825	14.175	0.085	99.720	0.197
6	1.80	0.860	90.065	9.075	0.000	99.840	0.165
7	2.10	1.554	84.146	14.300	0.057	99.650	0.299
8	2.40	0.247	66.795	32.959	0.154	99.639	0.206
9	2.70	0.000	52.150	47.850	1.505	98.270	0.223
10	3.00	0.000	71.597	28.400	0.139	98.450	0.410
11	3.30	0.428	82.346	17.227	8.260	91.640	0.097
12	3.60	0.991	82.970	16.038	4.787	95.010	0.196
13	3.90	0.173	89.424	10.404	0.000	99.470	0.530
14	4.20	0.092	90.508	9.400	0.399	99.600	0.000
15	4.50	0.000	89.450	10.550	0.389	99.450	0.162
16	4.80	0.055	93.070	6.875	0.031	99.339	0.630
17	5.10	0.000	96.500	3.500	0.210	99.390	0.399
18	5.40	0.719	92.806	6.475	0.000	99.740	0.259
19	5.70	1.028	98.543	0.429	0.239	99.679	0.081
20	6.00	0.210	99.341	0.449	0.085	92.990	6.922
21	6.30	1.685	97.927	0.388	0.000	80.699	19.300
22	6.60	0.000	99.577	0.423	0.200	82.422	17.370
23	6.90	1.616	97.964	0.420	0.700	83.500	15.798
24	7.20	1.212	98.731	0.057	0.226	80.687	19.080
25	7.50	0.057	99.843	0.100	0.319	67.840	31.840
26	7.80	0.055	99.917	0.028	0.310	65.850	33.840
27	8.10	0.000	99.839	0.161	0.300	64.890	34.840

Table 6.11 Gravel, sand, silt/mud and clay percentages of the coastal plain sediments in Palaeo-lagoon (Kole land basin)							
Sl.No	Depth (m) bgl	Vatanapilli			Nattika		
		Sand (%)	Mud/silt(%)	Clay %	Gravel (%)	Sand (%)	Mud/silt (%)
1	0.30	85.560	9.375	5.075	0.385	99.373	0.242
2	0.60	81.750	10.450	7.675	0.308	99.470	0.220
3	0.90	91.150	5.200	3.650	0.000	99.980	0.018
4	1.20	94.925	3.550	1.525	0.000	99.900	0.099
5	1.50	85.825	7.070	7.100	0.000	99.916	0.084
6	1.80	90.925	0.825	8.250	0.041	99.880	0.077
7	2.10	85.700	7.275	7.025	0.074	99.866	0.060
8	2.40	67.550	7.468	24.981	0.499	99.450	0.051
9	2.70	52.150	42.725	5.125	0.127	99.760	0.113
10	3.00	72.890	22.050	5.064	0.377	99.509	0.114
11	3.30	83.113	15.050	1.840	0.000	99.870	0.127
12	3.60	84.030	1.125	14.854	0.093	99.554	0.353
13	3.90	89.690	1.950	8.364	0.000	98.251	1.748
14	4.20	90.600	1.575	7.825	0.000	98.805	1.195
15	4.50	89.450	1.325	9.225	0.000	98.793	1.207
16	4.80	93.125	1.525	5.350	0.000	99.110	0.890
17	5.10	96.500	1.300	2.200	0.000	97.695	2.305
18	5.40	93.525	0.975	5.500	0.000	98.131	1.869
19	5.70				0.708	97.544	1.748
20	6.00				0.060	99.036	0.904
21	6.30				0.093	99.080	0.827
22	6.60				0.000	99.067	0.934
23	6.90				0.000	98.461	1.539

Table 6.12 Gravel, sand, silt/mud and clay percentages of the coastal plain sediments in Palaeo-lagoon (Kole land basin)

Sl.No.	Depth (m) bgl	Edamuttom			Mathilkam		
		Gravel (%)	Sand (%)	Silt/mud (%)	Gravel (%)	Sand (%)	Silt/mud (%)
1	0.30	0.502	98.902	0.596	0.345	99.513	0.142
2	0.60	0.000	99.710	0.290	0.317	99.563	0.120
3	0.90	0.000	99.843	0.157	0.000	99.982	0.018
4	1.20	0.000	99.959	0.041	0.000	99.901	0.099
5	1.50	0.300	99.627	0.073	0.000	99.916	0.084
6	1.80	0.062	99.847	0.092	0.041	99.882	0.077
7	2.10	0.065	99.871	0.064	0.054	99.847	0.099
8	2.40	0.131	99.838	0.031	0.399	99.327	0.275
9	2.70	0.125	99.829	0.046	0.127	99.760	0.113
10	3.00	0.000	99.809	0.191	0.277	99.610	0.114
11	3.30	0.304	99.410	0.287	0.000	99.873	0.127
12	3.60	0.567	99.161	0.271	0.093	99.554	0.353
13	3.90	0.921	98.980	0.098	0.000	98.272	1.728
14	4.20	0.228	99.674	0.097	0.000	98.895	1.105
15	4.50	0.166	99.706	0.128	0.000	98.793	1.207
16	4.80	0.000	99.556	0.444	0.000	98.795	1.205
17	5.10	0.226	99.267	0.507	0.360	97.771	1.869
18	5.40	0.734	98.814	0.452	0.708	97.554	1.738
19	5.70	1.489	98.016	0.495	0.050	99.046	0.904
20	6.00	3.765	95.705	0.530	0.093	99.080	0.827
21	6.30	1.390	98.252	0.358	0.000	99.066	0.934
22	6.60	0.242	99.491	0.267	0.000	98.481	1.519
23	6.90	1.019	98.606	0.375	0.000	98.561	1.439
24	7.20	0	91.92	8.08	0.000	98.521	1.479
25	7.50	0	92.15	7.85			
26	7.80	0	91.33	8.66			
27	8.10	0	88.36	11.64			
28	8.4	0	87.43	12.57			

Minerals are integral part of rocks and sediments. Assemblage of heavy and light minerals in sedimentary deposits has been used for many years to unravel the sources and transportation history of sediments. Worldwide, the mineralogical make up of sediments is used for the evaluation of various physicochemical processes involved during weathering, transportation and deposition. The knowledge of relative abundance of heavy fractions renders valuable information on the nature of contribution, longshore transport direction and energy conditions of the depositing medium.

The minerals of sedimentary rocks fall into two classes (i) the insoluble residues of rock decomposition; and (ii) the comparatively durable minerals derived from pre-existing rocks. Amongst the former are the groups of (a) the clay minerals, such as kaolinite, halloysite etc; (b) the micaceous minerals, including the hydromicas and chlorite; (c) the aluminum hydroxides, bauxite, gibbsite etc; and (d) the ferric oxides and hydroxides. A large number of mineral species are found in the second class. Resistant mineral such as quartz is common constituent of sedimentary rocks, and some rare minerals such as garnet, rutile zircon, tourmaline, kyanite, magnetite etc. are frequently present in sediments. Feldspar is less resistant, but is so common that it is a major constituent of some sedimentary rocks.

6.5 Heavy and light minerals

In India, detailed studies on heavy mineral assemblages of the beach sands, teri sands, beach ridges and dunes have been carried out since 1950. Jacob (1956) made a detailed study on the heavy minerals of the beach sands of Thirunelveli, Ramanadhapuram and Thanjavur districts of Tamil Nadu. Several workers have investigated the heavy mineral assemblages of Tamil Nadu beach and coastal plain regions. Investigators like Aswathanarayana (1964), Prabhakara Rao (1968), Mallik (1986), Unnikrishnan (1987), Purandara et al. (1987), Sasidharan and Damodaran (1988), Purandara (1990) and Krishnan et al. (2001) have studied the heavy mineral suite of the beach sands of Kerala. Rajendran et al. (1996) have investigated the heavy mineral composition of lower Bharathapuzha river sediments and their influence on the geochemical constituents of bed sediments. Babu and Seralathan (2005) have made a detailed study on the buried placer deposits of the central Kerala coast between Periyar and Bharathapuzha rivers. Padmalal et al. (1998) made a detailed account of mineral suites of Muvattupuzha river and Vembanad estuary. They have suggested that heavy mineral assemblages of sediments indicate mixed igneous and metamorphic provenance. Detailed geological and geophysical surveys conducted along the Konkan coast by Gujar et al. (1989) revealed the occurrences of several promising isolated placer deposits.

Table 6.13 Variation of heavy minerals at different depths (count %) in northern part of the coastal plain region (Engadiyoor in Keecheri basin) of Palaeo-lagoon (Kole land basin)

Total heavy mineral (%)	4.08	11.52	12.19	12.59	25.56	40.34
Mineral	**Depth 0 to 0.50 m bgl.**			**Depth 0.5 to 1.0 m bgl.**		
	Medium sand	Fine sand	Very fine sand	Medium sand	Fine sand	Very fine sand
Actinolite	0.00	1.00	6.00	0.67	3.00	1.00
Tremolite	0.00	5.33	4.00	0.00	0.00	0.00
Hornblende	0.00	4.67	0.33	1.67	1.33	0.67
Glaucophane	18.67	17.00	10.67	20.33	4.00	1.00
Hypersthene	6.00	9.67	19.67	8.67	12.67	2.33
Biotite	5.00	7.00	10.00	1.67	10.67	5.67
Chlorite	49.00	26.67	9.67	29.00	27.00	2.67
Epidote	6.67	2.67	1.00	3.33	0.67	0.00
Garnets	8.67	17.00	27.67	6.67	29.33	3.67
Monazite	0.00	0.00	0.00	0.00	0.00	3.00
Rutile	0.00	0.00	0.00	0.00	0.00	3.33
Sillimanite	0.00	3.00	2.67	0.00	0.00	0.00
Topaz	0.00	0.00	1.00	1.67	2.67	0.00
Tourmaline	5.33	3.67	0.67	1.67	4.00	0.00
Zircon	0.00	1.00	3.00	0.00	3.33	9.67
Opaques	0.67	1.33	3.67	24.67	1.33	67.00

Total heavy mineral (%)	19.05	31.59	52.17	24.01	52.15	69.23
Mineral	**Depth 1 to 1.50 m bgl.**			**Depth 1.5 to 2.0 m bgl.**		
	Medium sand	Fine sand	Very fine sand	Medium sand	Fine sand	Very fine sand
Actinolite	0.67	4.00	2.67	0.67	3.00	1.00
Tremolite	0.00	0.00	0.00	0.00	0.00	0.00
Hornblende	2.33	1.67	0.67	1.67	0.00	1.33
Glaucophane	19.67	4.00	1.00	15.67	0.67	20.00
Hypersthene	6.67	12.00	2.33	6.67	2.33	6.67
Biotite	1.67	10.33	5.67	1.67	0.00	1.67
Chlorite	31.00	26.33	3.00	33.33	5.33	26.67
Epidote	3.67	0.67	0.00	3.33	0.00	0.00
Garnets	3.67	29.67	3.67	3.33	8.33	7.00
Monazite	0.00	0.00	2.33	0.00	0.00	6.67
Rutile	0.00	0.00	3.67	0.00	0.00	1.67
Sillimanite	0.00	0.00	0.00	0.00	0.00	0.00
Topaz	1.67	2.00	0.00	1.67	1.33	1.33
Tourmaline	2.33	4.00	0.00	1.67	5.33	1.33
Zircon	0.00	3.67	9.33	0.00	8.00	0.00
Opaques	26.67	1.67	65.67	30.33	65.67	24.67

Table 6.14 Variation of heavy minerals at different depths (count %) in southern part of the coastal plain region (Edamuttom in Karuvannur basin) of Palaeo-lagoon (Kole land basin)

Total heavy mineral (%)	7.13	12.34	19.38	11.14	29.23	52.49
Mineral	**Depth 0- 0.5 m bgl.**			**Depth 0.5 to 1.0 m bgl.**		
	Medium sand	Fine sand	Very fine sand	Medium sand	Fine sand	Very fine sand
Actinolite	0.69	1.63	5.00	0.67	2.33	1.67
Tremolite	0.89	5.12	4.00	0.33	0.33	0.00
Hornblende	0.85	5.17	0.33	1.67	1.67	1.00
Glaucophane	16.03	19.50	10.67	21.00	5.00	2.00
Hypersthene	9.25	9.50	20.00	7.33	13.67	2.67
Biotite	6.54	6.49	9.00	2.00	10.00	4.67
Chlorite	47.25	27.32	8.67	26.33	26.00	2.33
Epidote	4.43	2.10	0.67	3.33	0.33	0.33
Garnets	7.82	16.64	29.33	6.33	29.00	3.67
Monazite	0.00	0.21	0.00	0.00	0.00	2.00
Rutile	0.00	0.00	0.00	0.00	0.00	4.33
Sillimanite	0.00	2.21	2.00	0.00	0.33	0.00
Topaz	0.00	0.00	0.67	1.33	2.00	0.33
Tourmaline	4.75	2.33	1.00	2.00	4.00	0.33
Zircon	0.00	0.23	3.00	0.00	3.00	8.67
Opaques	1.50	1.57	5.67	27.67	2.33	66.00

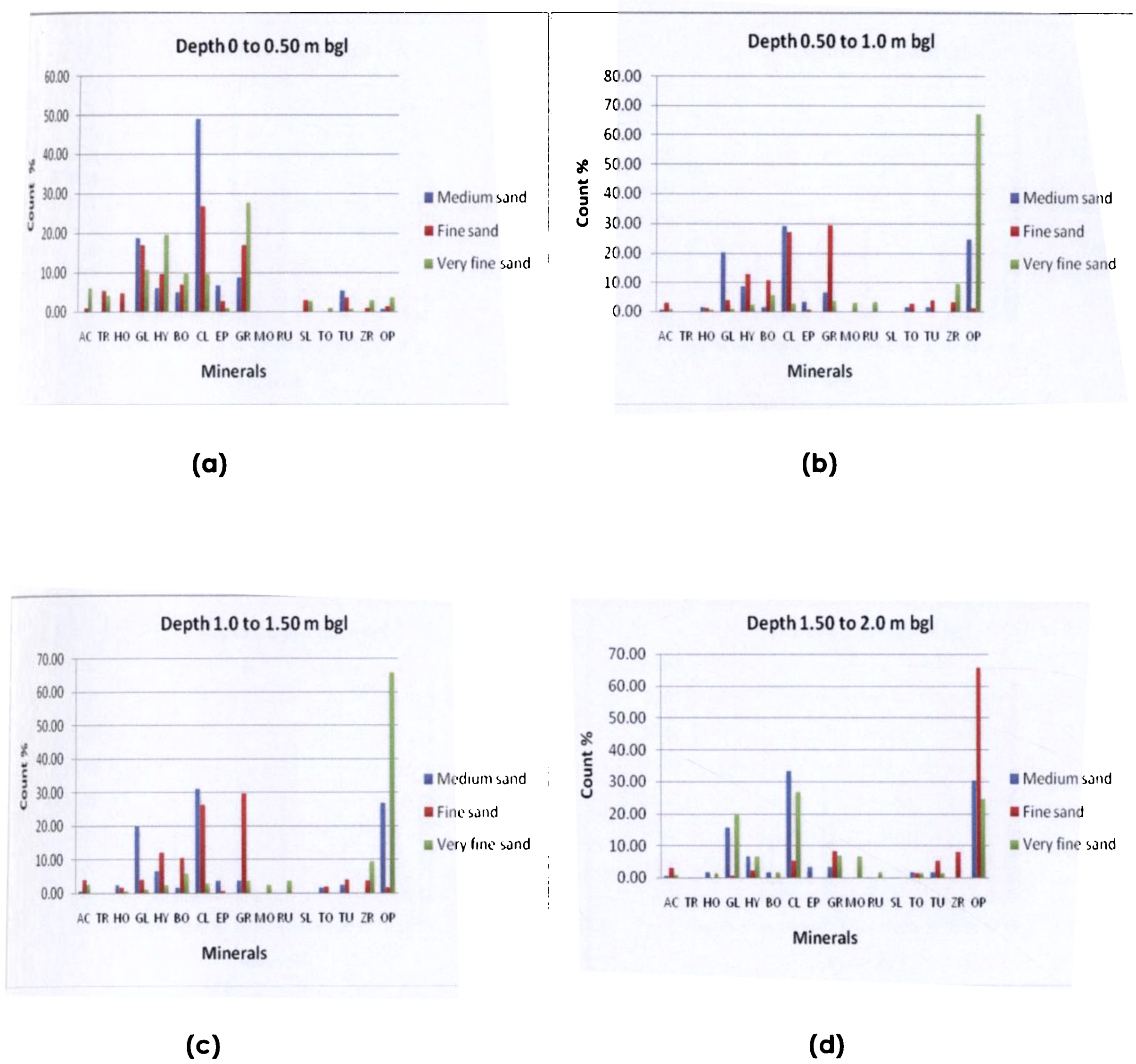
Total heavy mineral (%)	35.27	51.85	69.12	35.12	61.14	77.52
Mineral	**Depth 1 to 1.50 m bgl.**			**Depth 1.5 to 2.0 m bgl.**		
	Medium sand	Fine sand	Very fine sand	Medium sand	Fine sand	Very fine sand
Actinolite	0.67	3.67	2.67	0.67	2.67	0.67
Tremolite	0.00	0.00	0.00	0.00	0.00	0.00
Hornblende	2.00	1.33	0.67	1.67	0.00	1.33
Glaucophane	19.67	4.00	1.33	15.33	1.00	20.33
Hypersthene	6.67	12.33	2.33	6.67	2.33	7.00
Biotite	1.00	11.33	5.67	2.00	0.00	2.67
Chlorite	30.33	25.33	3.00	35.33	5.33	24.33
Epidote	3.33	0.67	0.00	2.33	0.00	0.00
Garnets	3.00	31.33	3.33	3.33	8.67	6.67
Monazite	0.00	0.00	2.67	0.00	0.00	6.00
Rutile	0.00	0.00	3.33	0.00	0.00	1.67
Sillimanite	0.00	0.33	0.00	0.00	0.00	0.00
Topaz	1.33	2.00	0.00	1.00	1.33	1.67
Tourmaline	2.00	3.00	0.00	1.00	5.00	1.67
Zircon	0.00	3.33	8.67	0.00	7.67	0.00
Opaques	30.00	1.33	66.33	30.67	66.00	26.00

Heavy minerals: The total heavy mineral content from beach ridge in different size classes at four depth-ranges namely 0 to 0.5 m, 0.5 m to 1.0 m, 1.0 m to 1.5 m and 1.5m to 2.0 m levels are given in Tables 6.13 and 6.14. Below a depth of 2.0 m, the concentration of heavy mineral is very negligible. The heavy minerals have been studied in two core samples one in the northern (Kecheri basin) and another in the southern (Karuvannur basin). The heavy minerals in the sediments are found to be primarily opaques, garnets, hypersthene, glaucophane, biotite and actinolite in very fine sands whereas chlorite, glaucophane, garnets and opaques are found in fine and medium fractions. The individual mineral species identified in the Engadiyoor samples of Kecheri basin and the Edamuttom sample in Karuvannur basin at different depths under different size classes and their distributions are present in Figs. 6.17 and 6.18.

Engadiyoor in Kecheri basin: Total heavy mineral content in medium sand of Engadiyoor sample in 0-0.5 m, 0.5-1.0 m, 1.0-1.5 m and 1.5-2.0 m depth zones are 4.08%, 12.59%, 19.05% and 24.01% respectively. In the fine sand the concentration in the four depth zones are11.52%, 25.56%, 31.59% and 52.15%. Down core variation in the total heavy mineral content in the very fine sand from 0-0.5 m, 0.5-1.0m, 1.0-1.5 m and 1.5 -2.0 m depth zones are12.19%, 40.34%, 52.17% and 69.23 % (Table 6.13).

Edamuttom in Karuvannur basin: The heavy mineral content, in medium sand of Edamuttom sample in 0-0.5 m, 0.5-1.0 m, 1.0-1.5 m and 1.5-2.0 m depth zones are 7.13%, 11.14%, 32.27% and 35.12% respectively. In the fine sand the concentrations from the four depth zones are 12.34%, 29.23%, 51.85% and 61.14%. Down core variation in the total heavy mineral content observed in the very fine sand from 0-0.5 m, 0.5-1.0 m, 1.0-1.5 m and 1.5-2.0 m depth zones are 19.38%, 52.49%, 69.12% and 77.52% (Table 6.14).

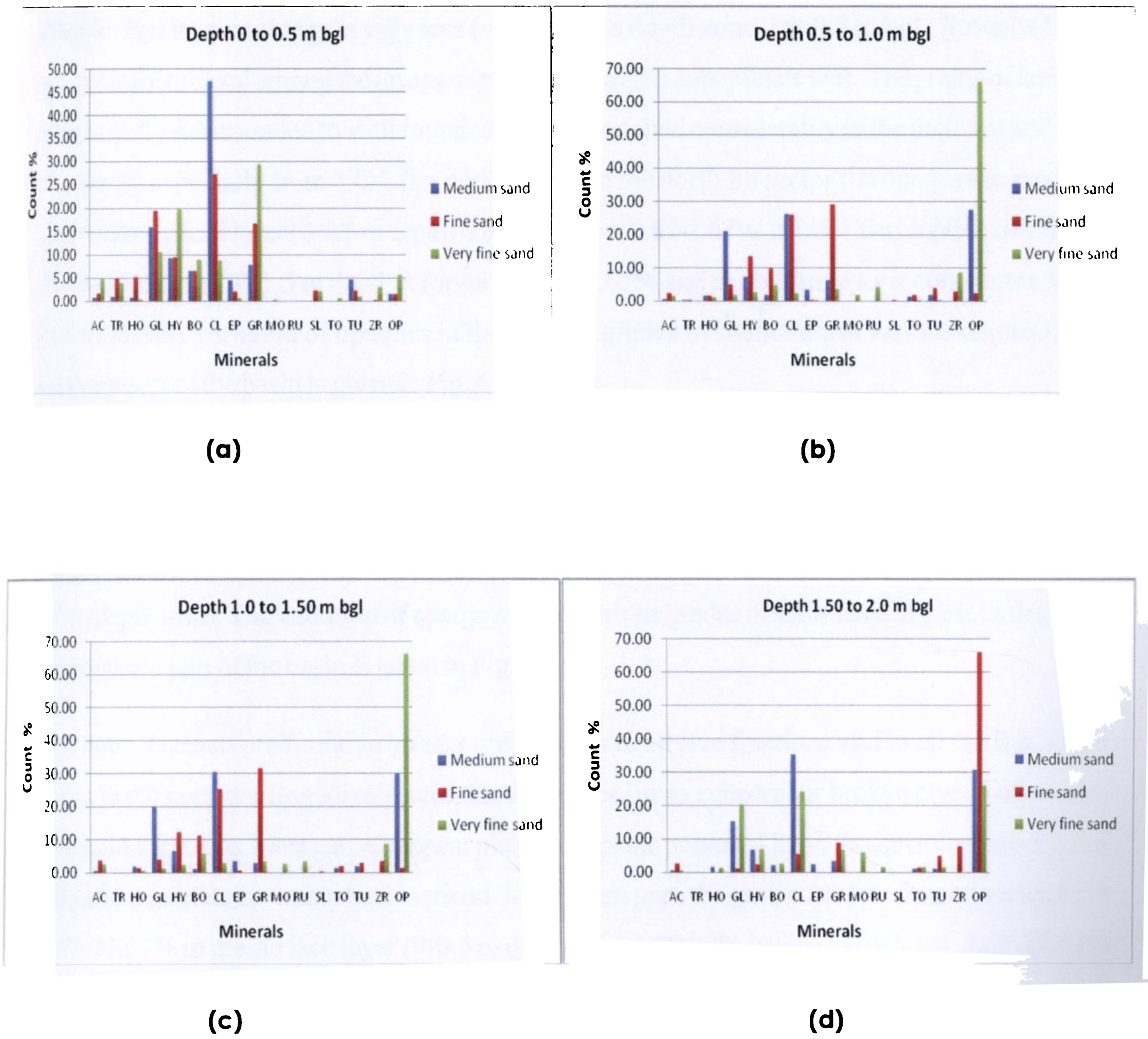
Heavy mineral assemblage: The heavy mineral suite of the coastal plain sediments of Palaeo-lagoon (Kole land basin) shows considerable variation between northern and southern part of the basin. The concentration at different depth zones is presented in Figs. 6.17 and 6.18 and the spectrum of minerals identified with their characteristic features is described below.



Legened

AC: Actinolite, **TR**: Tremolite, **HO**: Hornblende, **GL**: Glaucophane, **HY**: Hypersthene, **BO**: Biotite, **CL**: Chlorite, **EP**: Epidote, **GR**: Garnet, **MO**: Monazite, **Ru**: Rutile, **SL**: Sillimanite, **TO**: Topaz, **TU**: Tourmaline, **Zr**: Zircon, **OP**: Opaques.

Fig. 6.17 Distribution of heavy minerals in different depth zones and different size grades in northern part of the coastal plain region (Engadiyoor in Kecheri basin) of Palaeo-lagoon.



Legened

AC: Actinolite, **TR**: Tremolite,**HO**: Hornblende, **GL**: Glaucophane, **HY**: Hypersthene, **BO**: Biotite, **CL**: Chlorite, **EP**: Epidote, **GR**: Garnet, **MO**: Monazite, **Ru**: Rutile, **SL**: Sillimanite, **TO**: Topaz, **TU**: Tourmaline, **Zr**: Zircon, **OP**: Opaque.

Fig. 6.18 Distribution of heavy minerals in different depth zones and different size grades in southern part of the coastal plain region (Edamuttom in Karuvannur basin) of Palaeo-lagoon.

Opaques: Opaques are considerably enriched in all the size grades in the northern Engadiyoor sample. But its percentage is very less (< 5%) in the depth zone 0 to 0.5 m bgl. Ilmenite is the predominant mineral among the opaques while magnetite is subordinate to it. The grains of ilmenite are generally sub-rounded to well rounded and are enriched considerably in the medium and very fine sands, especially from 1.0-2.0m depth level. In the northern sector the opaques in medium sand in the surficial layer (0-0.5 m depth) constitute from 0.67-3.67%. In 0.5-1.0 m depth it constitutes 24.67-67.0%. In 1.0-1.5 m depth it forms 26.67-65.67% and in bottom layer it constitutes 30.33 - 65.67%. The variation of opaques in the various grades of sediments at various depths in the northern part of the basin is given in Fig. 6.17.

In the southern Edamuttom sample (Table 6.14), opaques constitute in notable amount among heavies in all the size fractions and in all the four layers. The opaques constitute 1.5 -5.67% of heavies in surface layer; 2.33-66.0% in 0.5-1.0m depth; 1.33-66.33 % in 1.0-1.5 m and 26.0-66.0% in 1.5-2.0 m depth level. The variation of opaques in the various grades of sediments at various depths in the southern part of the basin is given in Fig. 6.18.

Garnets: Garnets are found in greater proportions in all size fractions and in all the four depth zones in the northern Engadiyoor sample. Garnets occur as euhedral or broken crystal often with conchoidal fracture. Most garnets appear pink under plane polarised light, though minor amounts of colourless garnets have also been noticed. In northern part, the garnet content in sand varies from 8.67-27.67% in the surface layer (0-0.5 m depth), 3.67-29.33% in 0.5-1.0 m level, 3.67-29.67% in 1.0-1.5 m level and 3.33-7.0% in the bottom most layer. The variation of garnet in the various grades of sediments at various depths is given in Table 6.13 and Fig. 6.17.

Garnets constitute a considerable proportion of heavy minerals in the southern Engadiyoor sample. They are found in considerable proportions in all size fractions, in all four layers. The amount of garnet in the sand varies between 7.82 and 29.33% in surface layer (0-0.5 m depth), between 3.67 and 29.0% in 0.5-1.0 m depth, between 3.0 and 31.33% in 1.0-1.5 m depth and between 3.33 and 8.67% in the bottom layer. The variation of garnet in the various grades of sediments at various depths in the southern part of the basin is given in Table 6.14 and Fig. 6.18.

Chlorite: Chlorite is found in significant amount in all the four depth zones of northern Engadiyoor sample (Table 6.13). Chlorite is seen as tabular crystals with green, pale green in colour and well developed cleavages. Under microscope it is identified by its colour, cleavage and pleochroism.

Chlorite in the sand ranges from 9.67-49% in the surface layer (0-0.5 m), 2.67-29% in 0.5 m-1.0 m depth, 3.0-31% in 1.0-1.5 m depth and 5.33-33.33% in 1.5-2.0 m depth. The variation of chlorite in the various grades of sediments at various depths in the northern part is given in Fig. 6.17.

Chlorite is found in greater proportions in all the size fractions and in all four depth zones of the southern Edamuttom sample (Table 6.14). In the surface layer (0-0.5m) chlorite ranges from 8.67-47.25 %, 2.33 -26.33 % in 0.5-1.0 m depth, 3-30.33 % in 1.0-1.5 m and 5.33-35.33% in 1.50-2.0 m depth. The variation of chlorite in the various grades of sediments at various depths in the southern sample is given in Table 6.14 and Fig. 6.18.

Glaucophane: In northern Engadiyoor sample, glaucophane is found in considerable proportions in all size fractions and in all the four levels (Table 6.13 and Fig. 6.17). It appears fresh and occurs as angular to subangular crystals. Under microscope it is identified by its colour, cleavage and pleochroism. In northern part, glaucophane content in the sand varies from 10.67-18.67% in surface layer (0-0.5 m depth), in 0.5 -1.0 m depth from 1.0-20.33%, in the 1.0-1.5 m depth it varies from 1 to 19.67% and in bottom most layer from 0.67-20%.

Glaucophane is seen in considerable quantity in the southern part. They are more common in the medium sands of the top layer (Table 6.14 and Fig. 6.18). Glaucophane content in the sand varies from 10.67-19.5% in surface layer (0-0.5 m depth), in 0.5 -1.0 m depth from 2-21%, in the 1.0-1.5 m depth, in the 1.5 to 2.0 m it varies from 1.33-19.67% and in bottom most layer from 1-20.33%.

Hypersthene: In northern sample of the study area hypersthene is present in all size fractions and in all the four depth zones (Table 6.13 & Fig. 6.17). In the surface layer (0-0.5 m depth) it varies from 6-19.67% in sand, 2.33-12.67% in 0.5-1.0 m depth, 2.33-12% in 1.0-1.5 m layer and 2.33-6.67% in the bottom most layer.

In southern part of the study area hypersthene is common in all size fractions and in all four depth zones. In the sand fraction it ranges from 9.25-20% in surface layer (0-0.5 m depth); 2.67-13.67% in 0.5 -1.0 m depth; 2.33-12.33% in 1.0-1.5 m depth and 2.33-7.0% in the bottom most layer. The variation of hypersthene in the various grades of sediments at various depths in the southern sample of the basin is given in Table 6.14 and Fig 6.18.

Epidote: Epidote is seen as elongated prismatic crystal with shades of green colours. In northern samples and present considerably. Fig. 6.17 gives size wise distribution of epidote in this part of study area.

Epidote is an important heavy mineral fraction of the southern part of the study area. In the surface layer (0-0.5 m) the amount epidote in the sand fraction ranges between 0.67-4.43%; in 0.5-1.0 m depth it ranges between 0.33-3.33% and in 1.0-1.5 m depth it ranges between 0-3.3% and at the 1.5-2.0 m column it values vary between 0-2.33.The concentration epidote in the basin is decreases with in creasing depth (Table 6.14 and Fig. 6.18).

Biotite: Biotite occurs as platy crystals, lath-like cross section with cleavage and found in notable amount in all the size fractions and in all the four depth zones of the northern sample (Table 6.13). In the surface layer (0-0.5 m), biotite ranges between 5 -10 %. In 0.5 -1.0 m depth it varies from 1.67 to10.67% and in 1.0-1.5 m depth the biotite content is from1.67 to10.33%. At the bottom layer the range is from 0 to1.67%.

In the southern part of the study area, biotite shows same pattern as north (Table 6.14 & Fig. 6.18). Among sand fraction it varies from 6.54 to 9% in surface layer, 2 to 10% in 0.5-1.0 m depth, 1 to 11.3% in 1.0 to 1.5 m and 0 to 2.67% in the bottom most layer.

Hornblende: Hornblende is seen as prismatic, elongated crystals with shades of green and brown colours. In sand fraction of northern sample, it constitutes 0.33 to 5.17%, 1.0 to 1.67%, 0.67 to 2% and 0 to 1.67% in 0-0.5 m, 0.5-1.0 m, 1.0-1.5 m and 1.5-2.0 m depth respectively. The variation of hornblende in the various grades of sediments at various depths in the southern sample of the basin is given in Table 6.13 and Fig. 6.17.

In the southern sample in the surface layer (0-0.5 m) hornblende ranges from 0 to 4.67%, from 0.67-1.67 % in 0.5-1.0 m depth, from 0.67- 2.33% in 1.0-1.5 m and from 0- 1.67 % in 1.50-2.0 m depth. The variation of hornblende in the various grades of sediments at various depths in the southern sample of the basin is given in Table 6.14 and Fig. 6.18.

Zircon: Zircon is found negligible in the northern and southern samples of the basin, especially in the very fine sand (Table 6.13 and 6.14). Grains are mostly colourless and sometimes with brownish tint and pink varieties. The different nature, shapes and features of zircon were observed in the study area are euhedral, rounded, broken as identified by their high relief, straight extinction and high order, white, colour. Zoning, fracture lines and inclusions are exhibited by some of these grains suggesting the possibility their derivation from the granites and gneisses (Murthy, 1969). These are seen mainly associated with fine and very fine sands and its concentration varies from 1 to 3% in 0-0.5 m depth, 3.33 to 9.67% in 0.5 to 1.0 m depth, 3.67 to 9.33% in 1.0 to 1.5 m depth and 0 to 8% in 1.5 to 2.0 m depth in northern sample (Fig. 6.17).

In southern sample, its concentration varies from 0.23 to 3% in 0-0.5 m depth, 3.33 to 8.67% in 0.5 to 1.0 m depth, 3.33 to 8.67 % in 1.0 to 1.5 m depth and 0 to 7.67% in 1.5 to 2.0m depth in southern sample (Fig. 6.18).

Tourmaline: Tourmaline seen as triangular elongated prismatic crystals and some crystals are showing pleochroism. These are seen mainly associated with fine and medium sands and its concentration varies from 0.67 to 5.33% in 0-0.5 m depth, 1.67 to 4% in 0.5 to 1.0 m depth, 2.33 to 4% in 1.0 to 1.5 m depth and 1.33 to 5.33 % in 1.5 to 2.0m depth in northern sample (Fig. 6.17).

In southern sample, its concentration varies from 1 to 4.75 % in 0-0.5 m depth, 0.33 to 4% in 0.5 to 1.0 m depth, 2 to 3 % in 1.0 to 1.5 m depth and 1 to 5% in 1.5 to 2.0 m depth in southern sample (Fig. 6.18).

In addition to the above mentioned minerals, monazite, rutile, sillimanite, tremolite, topaz etc. are seen in very negligible concentrations in various depths. Details are given in Table 6.13 and 6.14.

Mechanism of heavy mineral concentration: Heavy minerals concentrate such as ilmenite, rutile, monazite, zircon and garnets from the coastal deposits of both ancient and modern age are major economic resources in India as well as Kerala. However, information on the sedimentological, stratigraphical, hydrodynamical and geomorphological aspects is rather limited in India to document the distributions and mechanisms of concentration of heavy minerals within a coastal plain system.

The heavy minerals in the present study area are the result of processes operating at different temporal and spatial scales. As the heavy minerals in the central Kerala form part of the Late Holocene regressive coastal plain sequences and to a little extend in modern environment, the sea level changes has a significant role in the heavy mineral concentration, preservation or alteration. In general the heavy mineral occurrence in the coastal plain areas is the result of several processes such as segregation due to differential entrainment in the swash zone, differential transport, shear sorting and longshore and onshore sediment transport, all contribute cumulatively or singularly to the concentration of certain heavy minerals (Hamilton and Collins, 1998). The coastal plain evolution and seasonal variation in wave energy have also played a major role in the above mechanism of concentration.

and pegmatites; basic type- gabbro and dolerite) igneous rocks (Ravindrakumar et al., 1985, Soman, 1998). Laterites occupy the lower reaches of the river courses such as Chalakudi, Karuvannur, Keecheri and Bharathapuzha rivers. Denudation of rocks occupying these drainage basins could be the prime source for the high content of blue-green hornblende in the basin. Ilmenite is the second dominant mineral in the basin and thus its source lie in the metamorphic rocks of the study area. A considerable portion of the ilmenite could be derived from laterites, which occupy a considerable aerial extent of the drainage. Colourless and pink garnets might have derived from charnockites. Mallik (1981) and Purandara (1987) have stated that the charnockites of the Western Ghats are characterized by colourless and pink garnets. Charnockites are also the prime contributors for the enrichment of hypersthene in the study area. The igneous suites of rocks such as granites and pegmatites contribute considerably to the enrichment of monazite, rutile and tourmaline. Low grade metamorphic rocks and basic igneous rocks rich in calcic -plagioclase are the sources of epidote. Alkali granite is the source rock of glaucophane in the study area.

The presence of rounded zircon in the study area suggests that the zircon has been subjected to reworking in the nearshore environment by waves and currents before it got settled in the coastal plain environment. Occurrence of rounded zircon in the beach sediments of the central Kerala (Mallik, 1986) and in the Vembanad estuarine sediments (Padmalal, 1992, Padmalal et al., 1998) has been reported. Zoning, fracture lines and dust inclusions are exhibited by some of the zircon grains suggesting the possibility their derivation from the granites and gneisses (Murthy, 1969).

In southern samples the predominant minerals are hypersthene, biotite, chlorite, epidote, opaques and garnets. Percentage of chlorite and glaucophene indicates that these minerals belong to Periyar provenance. Presence of considerable amount of hornblende in the samples, which is absent in north abundant in south, indicates that the sediments of mixed origin.

In the northern samples the dominant heavy minerals are opaques, chlorite, garnets, hypersthene, glaucophane, biotite and actinolite. In the medium and fine fractions chlorite, glaucophane, garnets and opaques are enriched while in very fine sands opaques, hypersthene, glaucophane, biotite and actinolite predominate over others. Such concentration levels are recorded by Babu and Seralathan (2005) in the buried beach placers between Bharathapuzha and Periyar rivers. Rajendran et al. (1996) reported that the heavy minerals from the Bharathapuzha river are predominated by hornblende, pyroxene, opaques and garnets. Similarly the predominant minerals in Periyar river sediments are opaques, chlorite, garnet, hypersthene, biotite, glaucophane and tourmaline

(Maya, 2005). One of the predominant minerals in the southern sector is chlorite, which affirms to a provenance in metamorphic terrain. Presence of opaques in relatively higher proportions in the study area shows that they are being derived from the crystallines of Western Ghats by Bharathapuzha, Kecheri, Karuvannur, Chalakudi and Periyar rivers. Mallik et al. (1987) have stated that charnockites and retrograde charnockites are the sources for hypersthenes and hornblende respectively for the opqaque minerals of the Central Kerala coast. Baba (1980) has attributed that the NNW oriented waves were responsible for the selective transportation of hornblende-hypersthene from hornblende-hypersthene province recognized by Mallik et al. (1987).

High concentration of heavies in the fine and very fine samples near the mouths of Bharathapuzha, Chetwai and Periyar rivers implies the contribution by the river systems. Marine process such as waves and currents played a considerable role in sorting, transportation and deposition of heavy mineral along the beach. The distribution also reveals that these minerals are derived from the chanockite-gneiss-khondalite suits of the Western Ghats and from adjoining shelf areas.

6.6 Clay Mineralogy

The study of clay minerals is an important area of research in the recent years as it throws light on weathering, provenance etc. The clay minerals constitute a major part of the finer fractions of the aquatic sediments and are reactive geological materials or particulates which serves as an indicators of the over all physico-chemical environment of deposition (White house et al., 1960). According to Biscaye (1965) and Grim (1968) the composition and distribution of clay minerals are good indicators of sediments dispersal in the marine environment. This is mainly because the clay mineral composition of sediments mainly depends on the climatic condition, provenance and rock types of the region.

Kaolinite, illite, chlorite and montmorillonite are the clay minerals recorded in the area.

CHAPTER 7

EVOLUTION OF PALAEO-LAGOON

7.1 Introduction

Sedimentary basins are areas of prolonged subsidence of Earth's crust. The driving mechanism of subsidence is ultimately related to process within relatively rigid, cool thermal boundary layer of the Earth. In a broad sense, these are areas in which sediments can accumulate to a considerable thickness and are preserved for long geological time periods. The shape of the sedimentary basins may vary from place to place. Some may be circular or elongate depressions, troughs or embayment, and often they have quite irregular boundaries. Even an alluvial plain can also act as a sedimentary trap. The size of the sedimentary basin is highly variable, and will be usually 100 km long and tens of kilometres wide.

The present study area forms a part of Kerala-Konkan offshore basin. It has a narrow stretch of Neogene sedimentary tract on land which is delimited to the east by the Precambrian rocks of the shield area, and to the west by the Laccadive ridge bounded by N-S fault/lineaments between Lat. 8°N, and 14°N and appears to be dissected into NNW trending horsts and grabens (Soman, 1997). The South Kerala Sedimentary basin (SKSB) extends along the coast between Kollam and Kodungallur. The Palaeo-lagoon (Kole and basin) is the northern most extension of South Kerala Sedimentary Basin (SKSB).

7.2 Radiocarbon (^{14}C) ages of Kerala coastal plain

In the stratigraphic history of India, the palaeo-environments suitable for carbonaceous deposits like coal, lignite and peat were (i) Permian-carboniferous period, (ii) Mio-Pliocene period, (iii) Early to Middle Pleistocene and (iv) Late to Middle Holocene. Abundant peat and shell deposits were identified at many onshore locations adjacent to the present shoreline along the west coast of India (Kale et al., 1983; Rajendran et al.1989; Narayana et al., 2001). The available ^{14}C dates of the various locations of the Kerala Konkan Basin are given in Table 7.1. Quaternary sediments of KKB shows that it fall in two ranges of age groups viz (i) 24450 ± 710 to 42490 ± 860 yrs.BP and (i)

Table 7.1 Radiocarbon dates of coastal sediments from the onland of Kerala-Konkan basin (KKB)

Sl.No	Location	Dating material	Depth of samples (mbgl)	^{14}C dates (Yrs.BP)	References
1	Ramapuram	Wood	3.00	2460 ± 120	Nair et al. (2006)
2	Ramapuram	Shell	7.60	24450 ± 710	Nair et al. (2006)
3	Ramapuram	Shell	12.00	39370 ± 1000	Nair et al. (2006)
4	Muthukulam	Shell	1.27	3662 ± 114	Nair et al. (2006)
5	Muthukulam	Shell	2.07	6276 ± 112	Jayalakshmi (2001)
6	Muthukulam	Shell	2.69	7176 ± 82	Jayalakshm (2001)
7	Pacha	Shell	8.50	6990 ± 160	Nair et al. (2006)
8	Kalarkod	Sediment	8.45	6740 ± 120	Nair et al. (2006)
9	Kalarkod	Sediment	40.00	20380 ± 490	Nair et al. (2006)
10	Eruva	Shell	4.03	39193 ± 923	Nair et al. (2006)
11	Eruva	Shell	6.64	42490 ± 860	Jayalakshmi (2001)
12	Kavanar	Shell	9.50	7090 ± 100	Jayalakshmi (2001)
13	Kavanar	Sediment	6.50	2180 ± 70	Nair et al. (2006)
14	Haripad	Reworked shell	19.50	>45000	Nair et al. (2006)
15	Parayakadavu	Shell	6.50	4610 ± 100	Nair et al. (2006)
16	Ernakulam (Lagoon)*	Sediment	7.50	3800 ± 80	Nair et al. (2006)
17	Ernakulam (Lagoon)*	Sediment	21.50	8330 ± 110	Nair et al. (2006)
18	Pathiyoor	Wood	1.00	7510 ± 100	Nair et al. (2006)
19	Payyannur	Shell	1.0 to 1.5	4370 ± 100	Nair et al. (2006)
20	Payyannur	Shell	1.0 to 1.5	4490 ± 90	Rajendan et al. (1989)
21	Vechoor	Shell	1.0 to 1.5	3710 ± 90	Rajendan et al. (1989)
22	Muhamma	Shell	1.0 to 1.5	3130 ± 100	Rajendan et al. (1989)
23	Thalasseri	Peat	2.00	7230 ± 120	Rajendan et al.(1989)
24	Valoor	Peat	2.00	3390 ± 110	Shajan (1998)
25	Valoor	Peat	3.00	5520 ± 160	Shajan (1998)
26	Kaloor	Peat	18.00	25610 ± 840	Shajan (1998)
27	Kaloor	Peat	36.00	>40000	Shajan (1998)
28	Ernakulam Jn	Peat	24.00	29930 ± 840	Shajan (1998)
29	Puthenvelikkara	Shell	2.50	6300 ± 160	Nair et al. (2006)
30	Willington Island	Peat	16.75	8315 ± 125	Agarwal et al. (1970)
31	Vembanad Lake*	Decayed wood	NA	8785 ± 135	Agarwal et al. (1975)
32	Cochin harbour	Decayed wood	NA	8795 ± 115	Agarwal et al. (1975)
33	Vembanad Lake*	Peat	40.00	>40000	Narayana et al. (2001)
34	Chenganacherry	Peat	6.00	7050	Powar et al. (1983)
35	Periyar river	Peat	24.00	8460 ± 130	Narayana (2007)
36	Goa	Peat	2.50	6430	Kale et al. (1983)

*Depth measurements were made with reference to mean sea level

2180 ± 170 to 8820 ± 120 yrs.BP. The bivariate plot of depth of the samples Vs ^{14}C age also shows a grouping of data points between the age 25000 to 42000 yrs.BP and 2000 to 9000 yrs.BP. Thus a sedimentation gap for over 10000 years seen between these two groups of samples, is a clear indication of an unconformity may be either erosional or nondepositional (Fig. 7.1). From the above it is clear that first age group belongs to Middle to Late Pleistocene while the second group belongs to Holocene period. But the ^{14}C dates from Quaternary sediments of the Palaeo-lagoon area shows three ranges of age groups viz. (i) 24700 ± 1890 to 35060 ± 5570 Yrs.BP (ii) 5160 ± 130 to 8820 ± 120 yrs.BP and (iii) 2180 ± 170 to 3160 ± 110 yrs.BP (Table 7.2). The bivariate plot of depth of the samples Vs ^{14}C age also shows a grouping of data points between the age 25000 to 40000 yrs.BP, 6000 to 9000 yrs.BP and 2000 to 4000 yrs.BP. A sedimentation gap for about 10000 years is seen between (iii) and (ii), for about 1000 years between (ii) and (i) groups of samples respectively (Fig. 7.2). From the above it is clear that there exist unconformities between these three beds. Radiocarbon dates suggests Middle to Late Pleistocene period for group (I), Early to Middle Holocene period for group (ii), and Late Holocene period for group (iii). Lithostratigraphic succession of the area shows a good correspondence with radiocarbon dates (Table 6.5).

In addition to the above palynoflora, Molluscan shells are also seen associated with the Quaternary sediments of the Palaeo-lagoon. Recorded molluscan shells are Dentalium Cerithium, Conus , Crepidula, Fusus), Littorina, Murex, Natica, Turitella, Cypraea, Oliva, Falsifusus, Terebra and Venericardia planicoasta (Plate 7.1).

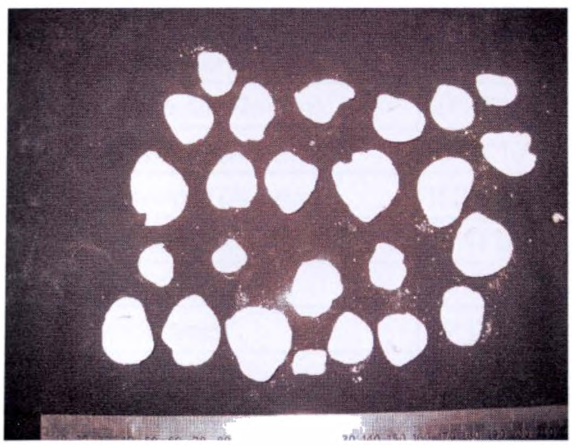
7.3 Evolutionary history of Palaeo-lagoon

The evolution of the Palaeo-lagoon is related to the formation of Kerala -Konkan basin and the uplift of Western Ghats in Late Cretaceous to Early Palaeocene period. The basement profile of the palaeo-lagoon (Kole land basin) shows two sudden abnormal changes in slope (i) is very close to the sea between 1.5 and 2 km away from the present shoreline and (ii) in the eastern boundary of the palaeo-lagoon (about 7 to 10 km away from the present shoreline). These are considered as faults, which control the evolutionary history of the basin very much. Based on the present investigation and available secondary data, the evolutionary changes may be summarised as follows.

Tertiary Period: The uplift of Western Ghats created a number of swift west flowing rivers in the west coast. The intensive phase of erosion causes the deposition of clastic sediments in offshore over Archaean basement. Clastic sediments known as Vaikaom formation unconformably overlay

(a) Location: Venkitangu (11 to 13 mbgl

(b) Location: Kalpamangalam (20 to 60 mbgl)



(c) Location: Alappad & Kattoor (1.8 to 2 mbgl)

(d) Location: Ayyappankavu, (8 to 11mbgl)

(e) Location: Vatanapilli (5.8 to 6.5 mbgl)

(f) Location: Chavakkad (6 to 7 mbgl)

Plate 7.1a-f Photgraphs of shells recovered from Palaeo-lagoon

Table 7.2 Radiocarbon dates of coastal sediments from Palaeo-lagoon (Kole land basin)

Sl.No	Location	Lattitude	Longitude	Dating material	Depth of samples (mbgl)	^{14}C date (Yrs. BP)
1	Edamuttom	10°22'08"	76°07'00"	Peat	16.50	7620 ± 100
2	Chavakkad	10°34'30"	76°01'10"	Peat	1.50	2520 ± 70
3	Irmbrnellur	10°00'30"	76°07'30"	Peat	1.20	7180 ± 130
4	Kanjani north	10°28'45"	76°07'00"	Peat	6.50	> 40000
5	Venkitangu	10°01'00"	76°05'45"	Shell	11.00	> 40000
6	Vatanapilli (Almavu)	10°28'10"	76°05'10"	Peat	14.00	8820 ± 120
7	Vatanapilli (Almavu)	10°28'10"	76°05'10"	Peat	11.00	8350 ± 110
8	Vatanapilli (Almavu)	1028'10"	76°05'10"	Peat	8.00	7870 ± 90
9	Mathilakam	10°17'55"	76°08'15"	Peat	17.00	> 40000
10	Mathilakam	10°17'55"	76°08'15"	Peat	15.50	> 40000
11	Mathilakam	10°17'55"	76°08'15"	Sediment	11.50	7200 ± 190
12	Mathilakam	10°17'55"	76°08'15"	Sediment	8.50	5160 ± 130
13	Thalikulam	10°27'42"	76°04'30"	Sediment	14.50	7450 ± 110
14	Thalikulam	10°27'42"	76°04'30"	Sediment	9.50	3160 ± 110
15	Kanjani(Palaeo-lagoon)	10°28'41"	76°07'02"	Sediment	20.50	35060 ± 5570
16	Kanjani(Palaeo-lagoon)	10°28'41"	76°07'02"	Sediment	13.00	24700 ± 1890
17	Thanissry(Irinjalakuda)*	NA	NA	Peat	2.00	6420 ± 120
18	Poovathumkadavu**	NA	NA	Peat	6.50	6720 ± 70
19	Poovathumkadavu**	NA	NA	Peat	24.00	7450 ± 110

*Rajendran et al. (1989);**Shajan (1998); all other details from Prof.P.Seralathan, CUSAT; NA: Not available

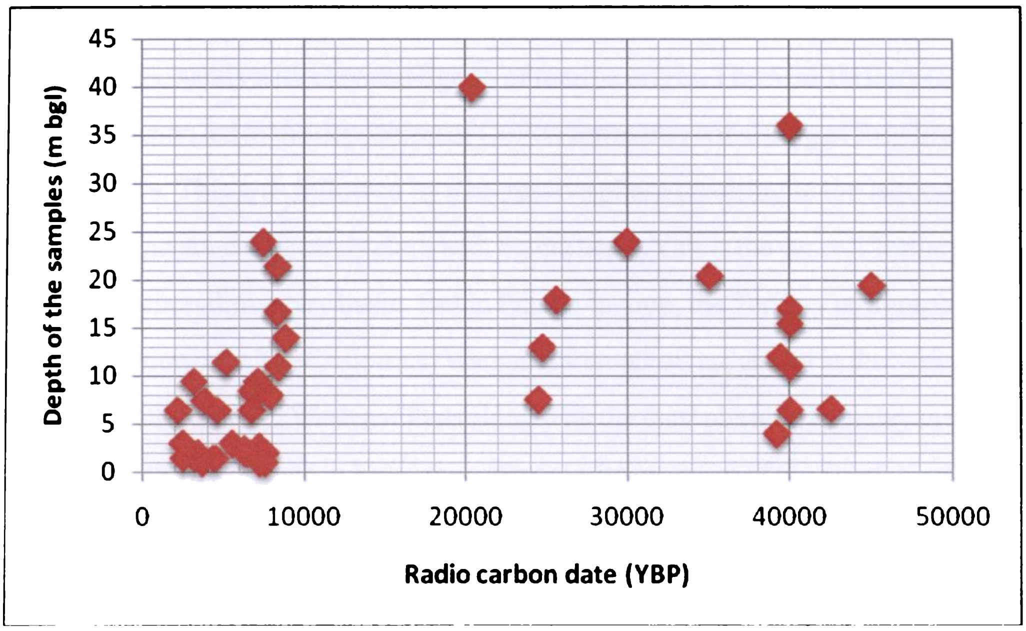


Fig. 7.1 Bivariate diagram of ^{14}C date Vs Depth of the samples in Quaternary sediments of Kerala Konkan Basin.

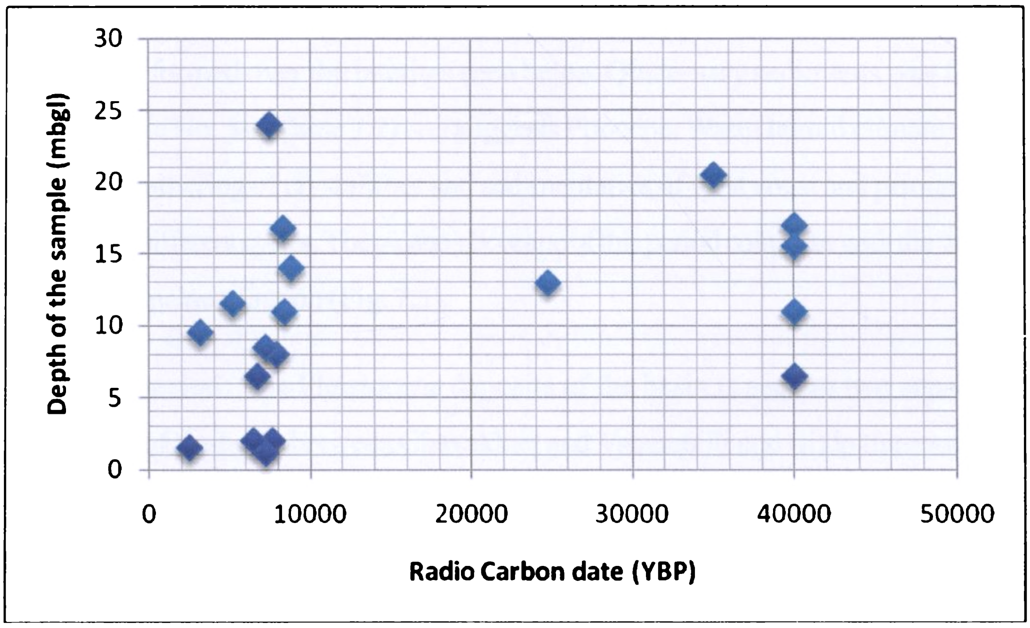


Fig. 7.2 Bivariate diagram of ^{14}C date Vs Depth of the samples in Quaternary sediments of Palaeo-lagoon.

the Crystallines. The thickness of the Vaikom formation in the Palaeo-lagoon area varies from 40 to 60m and are not exposed any where in the basin (Figs. 6.5a &b) The Vaikom bed mainly comprises of gravel, coarse sands with clay and lignite of marine origin. The Mid Tertiary (Burdigalian) sea level transgression led to the deposition of Quilon formation consisting of fossiliferous limestone, sands and clays. This was followed by a regressive phase resulting in the lagoonal formation of Warkallais (Sandstone with sandy clays with lignite beds). This is the general Tertiary stratigraphy of the South Kerala sedimentary basin. But in Palaeo-lagoon, the Tertiary strtigraphy is confined to Vaikom formation only. The Quilon and Warkallai formations are absent in the basin. The faulting of west coast and the uplift of Western Ghats along with the third phase of Himalayan upheaval during Middle Miocene might have reduced the accommodation space of the South Kerala Sedimentary Basin beyond palaeo-lagoon due to the initiation of uplift. This accounts the reason for non deposition of Quilon and Warkallai beds in Palaeo-lagoon of South Kerala Sedimentary Basin.

Laterites succeed the Vaikom formation in Palaeo-lagoon. These are not capping the Vaikom formation any where in the basin. But it underlay the Quaternary sediments and overlay the crystallines in the western part of the basin (Fig. 6.5a-b). Exposed laterites are seen as escarpments in the eastern part on the Palaeo-lagoon and capped the crystalline rock (Plate 6.2). The escarpment along the eastern fringes of Palaeo-lagoon is an indication of down faulting (Soman, 1997). The shell encrustations formed over the laterites seen below Quaternary sediments was formed > 40000 yrs.BP (Sample No. 5 of Table 7.2) and suggests Pliocene. Warm humid climate during Pliocene lead to the weathering of crystallines and sedimentaries of west coast and primary laterites were formed under different cycles. The palaeo-shoreline of this period coincides with the western boundary of the Present palaeo-lagoon (Fig. 7.5).

Pleistocene period: The Pleistocene deposits of the basin is seen as two separate patches (i) northern part of the basin between Chavakkad and Vatanapilli and (ii) in the southern part of the basin around Mathilakam. There is no continuity of this layer in between the places. This shows that the depositional basin of Pleistocene time was not a continuous one in the Palaeo-lagoon (Kole land basin). Radiocarbon dating of the peat from Mathilakam at a depth of 17 and 15.5 mbgl, yielded a ^{14}C date > 40000 yrs.BP(Sample nos. 9 & 10, Table 7.2), The sediment samples from Palaeo-lagoon (near Kanjani -northern part of the basin) at a depths of 20.5 m and 13 m bgl yielded ^{14}C dates of 35060 ± 5570 and 24700 ± 1890 yrs.BP respectively (Sample nos. 15 & 16, Table 7.2).

Another set of samples shell (Cypraea) and peat from Venkitngu (near Chavakkad) and north of Kanjani at a depth 11m and 6.50 mbgl gave a ^{14}C date > 40000 yrs.BP (Sample nos. 4 & 5, Table 7.2). The molluscan fauna of this layer includes Venus, Turbo, Turitella, cerithium, fusus , Cypraea etc. (Plate 7.1).

The Pleistocene deposits of the area are inferred as shallow nearshore or continental without much organic content. The uplift of the northern block of SKSB might have continued up to Middle to Later Pleistocene leading to the formation of shallow basin of deposition, which was not continuous in Palaeo-lagoon area. The molluscan shells, which are seen associated with the Pleistocene deposits, might be littoral or lagoonal in origin. The Pleistocene marine transgression in SKSB which took Place H+ 40000 to 42000 yrs.BP, created a littoral zone in the uplifted northern part of SKSB resulting in the deposition of sediments within the littoral zone. The marine-brackish waters of this transgression did not cover the entire basin uniformly due to the palaeo-topographic differences.

Holocene period: The Holocene deposits of the basin are seen as two separate litho-units of two age groups. (i) The lower lithounit consists of greenish black clay layer with peat beds, ranging in thickness from <1 m to 25 m and (ii) the upper lithounit consists of sandy clay, clayey sand and sand with shell fragments and decayed wood. The lower sequence of the Holocene deposits of the basin is clay dominated while the upper sequence is sand dominated.

The Lower to Middle Holocene (Viyyam bed) is well developed throughout the basin. The maximum thickness (H+ 25 m) is seen around Chetwai, north central part of the basin, where the Palaeo-lagoon is connected to the sea. This layer is starting with greenish black to black clay and mud with shell and peat intercalations at lower part. Sand content increases towards top of this layer. The radio carbon dating of the peat samples from this formation gives an age ranging between 8820 ± 120 yrs.BP and 5160 ± 130 yrs.BP. The peat samples form Vatanapilli (Almavu-in the central part of the basin) at a depth 8 mbgl yielded a ^{14}C date 7870 ± 90 yrs.BP (sample no. 8, Table 7.2), at a depth 11 mbgl yielded 8350 ± 110 yrs.BP(sample no. 7, Table 7.2) and at a depth 14 mbgl yielded 8820 ± 120 yrs.BP (sample no. 8, Table 7.2). The samples from the lower Holocene clay deposits of the eastern part of the lagoon (Irimbranellur) yielded a ^{14}C date of 7180 ± 130 yrs.BP at a depth of 1.2 mbgl (sample no. 3, table 7.2). The reported dates from Thanissery (Rajendran et al. 1989) and Poovathumkadavu (Shajan, 1998) areas of the basin also show ages 6420 ± 120 yrs.BP and 7450 ± 10 yrs.BP respectively (Table 7.2).

The lithology and associated vegetal debris and shells from this formation attribute marine condition of deposition. The Holocene marine transgression took place in a series of continental depressions where organic rich clay was deposited. This transgression, datedH+ 7000 to 8000 yrs.BP was a faster event, covering all the parts of SKSB resulted in the submergence of the basin and sea was stand still till around 5000 yrs.BP. The palaeo-shoreline coincides with the eastern boundary of the present Palaeo-lagoon (Fig. 7.5). The whole part of the basin was under water through out this period. The entire thickness of Viyyam beds might have deposited during the period from 9000 to 4000 yrs.BP. The sandy deposits on the eastern side of Palaeo-lagoon, in places like Thanissery, Korumbisseri etc. are marine (Rajendran et al. 1989). The regression that followed left behind a vast lagoonal water body (mega lagoon), that might be extending southward upto Vembanadu Lake or the present Kuttanad, Kayamkulam lagoon in the Southern Kerala (Jayalakshmi et al. 2005). The marine influence in this water body differs from place to place. Silting up of this vast lagoon resulted in the isolation of Kayamkulam lagoon and conversion of vast areas into shallow seasonal perennial wetlands used for raising paddy crops. The spectacular ridge and runnel topography might have developed during this regression. Limeshell from the bottom of Vembanad Lake yielded ages of 3710 ± 90 and 3130 ± 120 yrs.BP (Soman, 1997). This shows that the regressive phase of Holocene transgression started around 4000 to 5000 yrs.BP. The first ridge, which was developed during the regressive phase, has maximum elevation of around 14 m above msl near Venkitangu in the study area (about 7 km from present shore) is an indication of farthest marine advancement and prolonged stand still condition (Fig. 7.4 and Plate 7.2). The younger clay and sand deposits over the Viyyam beds in the eastern part of palaeo-lagoon is of fluvial origin (from the Karuvannur and Kechery rivers), which was deposited in the lagoon formed during the regressive phase (Figs. 6.5a-b and 7.3). It is quite possible that during Early Holocene time there would have some neotectonic activity due to which, part of the coastal plain (Vembanad lagoon, present Palaeo- lagoon and other low lying areas east of it) were subsided and the coastal plain west of the Vembanadu and palaeo-lagoon was elevated (Fig. 6.5).

The profiles across the coastal plain of the Palaeo-lagoon show at least ten major ridges, indicating successive phases of still- stand while receding (Fig. 6.9). There have been periods of abnormally high, normal and deficient rainfall during Late Holocene. The highly wet spell from 10000 to 4000 yrs.BP has been followed gradually by a period of reduced precipitations. During the period 5000 to 4000 yrs.BP the sea started receding to the present level at about 3000 to 2500 yrs.BP. The presence of a layer of palaeosole or oxidised horizon in the inland ridges shows the period of very low precipitation in Late Holocene.

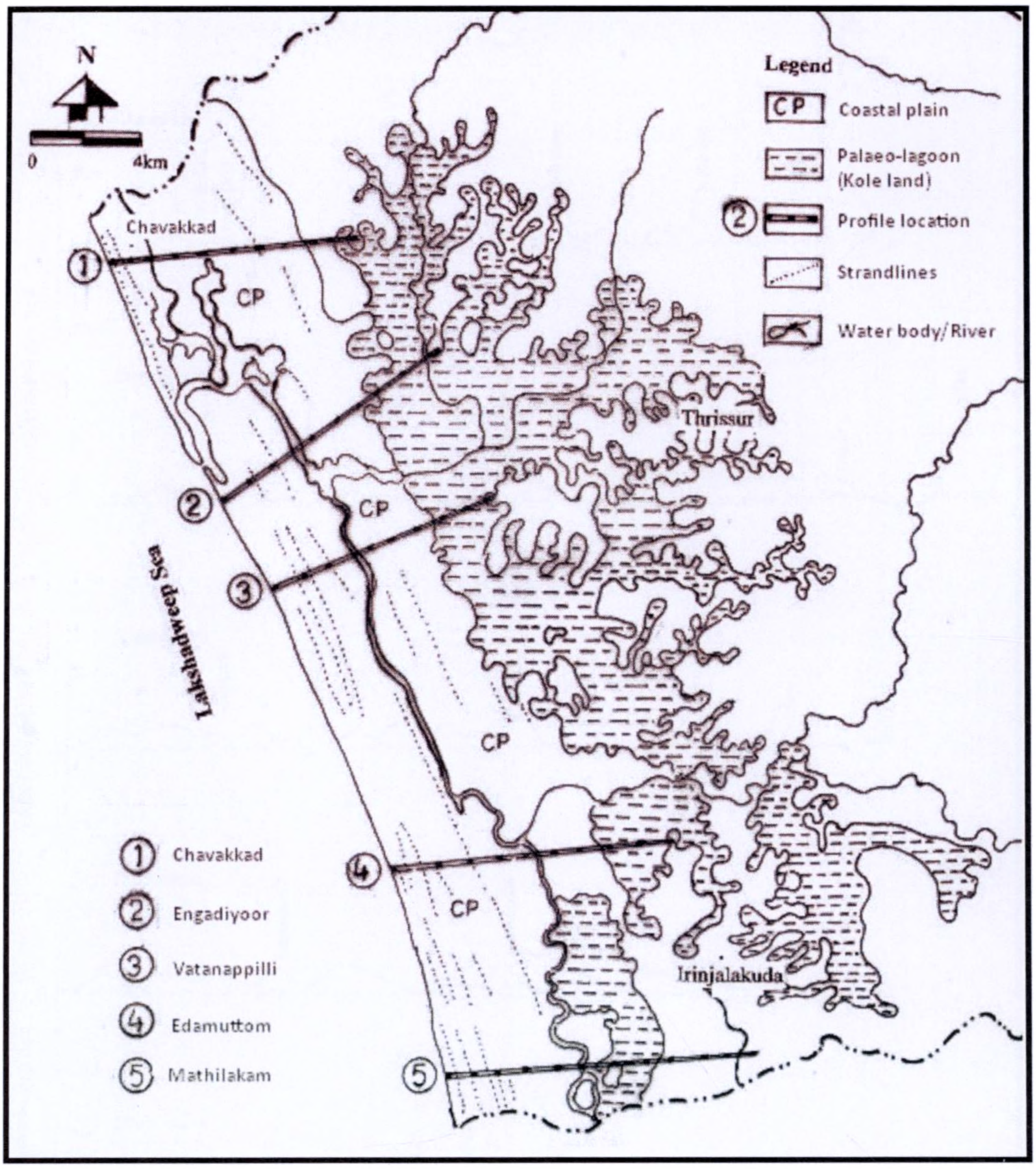


Fig. 7.3 Cross-shore profile locations in coastal plain Palaeo-lagoon.

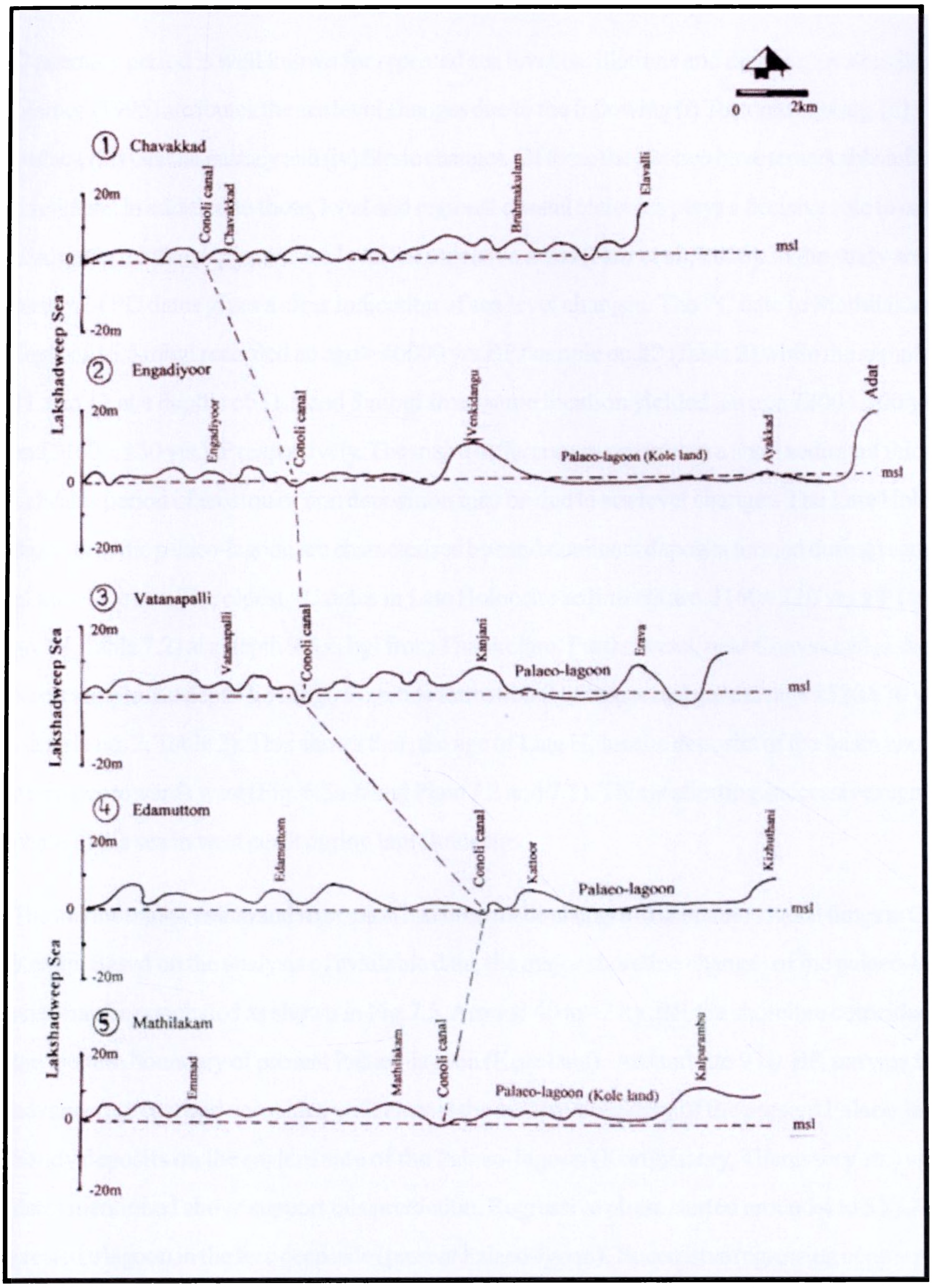


Fig. 7.4 Profile variation across palaeo beach-ridges in the Palaeo-lagoon (Kole land basin)

7.4 Palaeoshorelines and rate sedimentation.

Quaternary period is well known for repeated sea level oscillations and drastic climatic changes. Morner (1995) attributes the sea level changes due to the following (i) Tectonic eustacy, (ii) Geoid eustacy, (iii) Glacial eustacy and (iv) Steric changes. Of these the last two have remarkable influence on climate. In addition to these, local and regional coastal tectonics plays a decisive role in causing changes in relative /apparent sea level in respective areas (Nair et al., 2006). In the study area, the pattern of ^{14}C dates gives a clear indication of sea level changes. The ^{14}C date in Mathilakam at a depth of 15.5 mbgl recorded an age > 40000 yrs.BP (sample no.10 ,Table 2) while the sample nos. 11 and 12 at a depths of 11.5 and 8 mbgl from same location yielded an age 7200± 200 yrs.BP and 5160 ± 130 yrs.BP respectively. The major difference in age within a short sediment thickness indicates period of erosion or non deposition may be due to sea level changes. The Late Holocene deposits of the palaeo-lagoon are characterised by sand dominant deposits formed during regressive phase of the sea. The oldest ^{14}C dates in Late Holocene sediments are 3160± 120 yrs.BP (sample no. 14, Table 7.2) at a depth 9.5 m bgl from Thalikulam. Further west, near Chavakkad, a decayed wood sample at a depth 1.5 mbgl, from this formation (Kadappuram) gave an age 2520± 70 yrs.BP (sample no. 2, Table 2). This shows that, the age of Late Holocene deposits of the basin gradually decreases towards west (Fig. 6.5a-b and Plate 7.2 and 7.3). This is attesting successive regressive phase of the sea in west coast during late Holocene

The marine transgression and regression had been made changes of shoreline several times in Central Kerala. Based on the analysis of available data, the major shoreline changes of the palaeo-lagoon area may be concluded as shown in Fig.7.5. Around 40 to 42 ky .BP, the shoreline coincided with the western boundary of present Palaeo-lagoon (Kole land). Around 7 to 9 ky. BP, sea was further advanced to east and coincides with almost the eastern boundary of the present Palaeo-lagoon. Sandy deposits on the eastern side of the Palaeo-lagoon (Korubissery, Thanissery etc) and ^{14}C dates mentioned above support this prediction. Regressive phase started around 4 to 5 ky.BP and created a lagoon in the fore deep side (present Palaeo-lgoon). Successive regression continued and become stand still for a couple of time around 2 to 3 ky.BP at the western side of Conoly canal (coincides with Conoli canal). Further regression around 1ky.BP caused the formation of present day coast and Conoli canal parallel to it (Fig. 7.3 &7.4).

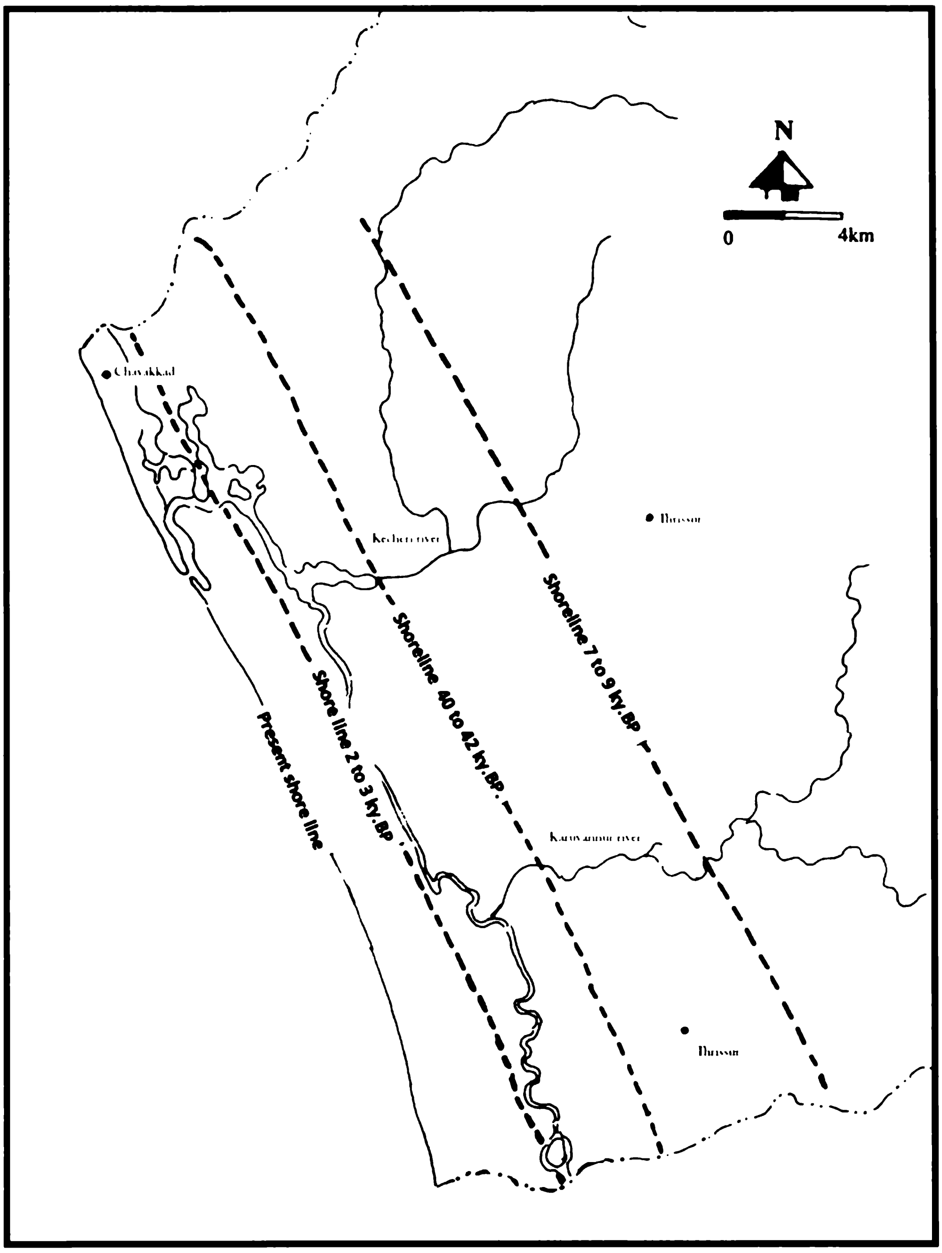


Fig. 7.5 Shoreline changes in Palaeo-lagoon area of Central Kerala

Plate 7.2 A view of beach ridge plain in Kurikuzhi area of Plaeo-lagoon (Remanents of former seawall also seen).

Plate 7.3 A view of sand dunes in Chetwai and Moonnupeedika area of the Palaeo-lagoon.

Rate of sedimentation: The rate of sedimentation of each period of the Palaeo-lagoon is calculated by using thickness of the sediments and available ^{14}C dates. The calculated rate of sedimentation in the basin during Pleistocene period is $\sim$ 1 m/ 1000 years. The average rate of sedimentation in the basin during Holocene period is $\sim$ 3 m/1000 years. This shows that the availability of depositional material was higher in Holocene period than it compared with Pleistocene period. The details of rate deposition of the various places of the basin are given in Table 7.3.

Table 7.5 Rate of sedimentation in Palaeo-lagoon (Kole land basin)

Sl.No	Location	Depth of the sample (mbgl)	Radio carbon date (Yrs.BP)	Rate of sedimentation (m/ KY)	Formation
1	Kanjani	13	24700		Pleistocene
	Knjani	20.5	35060	0.72	(Gururvayur)
2	Thalikulam	9.5	3160		Holocene
	Thalikualm	14.5	7450	1.16	(Viyyam)
3	Vatanapilli	8	7870		
	Vatanapilli	11	8350		Holocene
	Vatanapilli	14	8820	6.00	(Viyyam)
4	Mathilakam	8.2	5160		
	Mathilakam	11	8350		Holocene
	Mathilakam	14	8820	1.61	(Viyyam)

CHAPTER 8

SUMMARY AND CONCLUSION

The present investigation on "Hydrogeology, stratigraphy and evolution of the Palaeo-lagoon (Kole land basin) in the Central Kerala coast, India" is an integrated approach based on hydrogeological, geophysical, hydrochemical and stratigraphic aspects. A strong scientific data base of the study area is generated using interpretation of well observation and water quality analysis. The salient findings of the present study are given to provide a holistic picture on the hydrogeology (including groundwater resource and its quality), stratigraphy and evolution of the Palaeo-lagoon.

The aquifer parameters such as specific capacity, transmissivity, storativity, hydraulic diffusivity, drainage factor and optimum yield of phreatic as well as semi confined aquifers were determined by Slug test (ST), Step drawdown test (SDT) and Aquifer performance test (APT).

The results show that the specific capacity of phreatic aquifer of the basin varies from 65.33 lpm/m (Adichira-Chelakkara) to 521.74 lpm/m (Paluvaya-Chavakkad). The average specific capacity of the phreatic aquifer is 247.82 lpm/m.

The transmissivity (T) of the phreatic aquifer of the basin varies from 20 m^2/day (Paruthipra-Mulloorkara) to 138 m^2/day (Irinjalakuda). The average transmissivity of the basin is 91.925 m^2/day. T value ranges from 20 m^2/day (Paruthipra) to 94 m^2/day (Prabhathnagar-Velur) in Jacob's - Theis's straight line method, while it ranges 92 m^2/day (Prabhathnagar) to 138 m^2 /day (Irinjalakuda) in Papadopulos-Cooper curve matching method. The average T value of the basin during Jacob's-Theis's and Papadioulos-Cooper are 48.85 m^2/day and 135 m^2/day respectively. A marginal increase in transmissivity with increasing well yield is observed.

The storativity of the basin varies from 4.5 x 10^{-5} (Paruthipra-Mulloorkara) to 1.1 x 10^{-3} (Adichira-Chelakkara) in Jacob's-Theis's method and 3.4 x 10^{-5}(Padiyoor) to 5.9 x 10^{-3} (Choolissery) in Papadopulose-Cooper method. The average storativity of phreatic aquifer of the basin is 1.08 x 10^{-3}.

The hydraulic diffusivity of the basin varies from 3000 m^2/day (Adichira-Chelakkara) to 367647 m^2/day (Padiyoor). The average hydraulic diffusivity of the basin is 81491 m^2/day,while the drianage factor varies from 1.37 m (Adichira-Chelakkara) to 8.83m (Choolissery). The average drainage factor of the basin is 4.77 m. The high drianage factor indicates fast drainage of the aquifer. The optimum yield of the dug wells in the phreatic aquifer varies from 500 lph to 5000 lph in coastal plain. In mid and highland it varies from dry to 25000 lph.

The specific capacity of semi-confined aquifer of the basin varies from 3.22 lpm/m (Koorkamattom-Kodassery G.P) to 208.90 lpm/m (Choolissery - Avannur G.P). The average specific capacity of the aquifer is 38.98 lpm/m, while the specific drawdown varies from 0.0047 m/lpm (Choolissery - Avannur G.P) to 0.4705 m/lpm (Melillam -Thekkumkara GP). The average specific drawdown of the basin is 0.072 m/lpm. The formation loss of the aquifer varies from 0.57 m (Parappuram - Kaiparambu G.P) to 27.22 m (Kannara-Peechi), while the well loss shows a variation from 0.09 m (Kunnetheri – Erumapetti GP) to 23 m (Kumaranellur-Mulloorkara G.P). The average formation loss and well percentage of the basin is 57.66 and 41.65 respectively. The formation loss of the basin varies from 18% (Gramela-Avannur GP) to 94% (Kannara-Peechi), whereas the well loss varies from 6% (Kunnetheri – Erumapetti GP) to 82% (Gramela-Avannur GP).

The trasmissivity (T) of the semi-confined aquifer of the basin vary from 0.38 m^2/day (Padavaradu) to 485.05 m^2/day (Choolissry). The average transmissivity of the basin is 61.05 m^2/day. T value ranges from 0.38m^2/day (Padavarau) to 485.05m^2/day (Choolissery) in pumping phase and 2 m^2/day (Thuruthiparambu) to 369 m^2 /day (Choolissery) during recovery phase. The average T value of the basin in pumping and recovery phase are 58.46 m^2/day and 63.64 m^2/day respectively. Transmissivity of the semi-confined deep aquifer in the sedimentary area (Tube wells) vary from 22 m^2/day (West Mathilakam) to 104 m^2/day (Nattika).There is an increase in transmissivity with well yield is observed in the area. The initial flow is not only from bore well storage but also from the fractures.

The storativity of semi-confined aquifers at Adichira-Chelakkara and Prabathnaga - Velur is 6.4 x10^{-4} and 1.1 x 10^{-4} respectively. In sedimentary (tube wells) area it varies from 1.07 x 10^{-3} (Nattika) to 4.04 x 10^{-3} (Chavakkad). The optimum yield of the bore wells varies from 1000 lph to 41700 lph. The yield of tube wells in the sedimentary area of the basin varies from 12000 lph to 115000 lph.

Drawdown - recovery analysis of phreatic as well as semi-confined aquifers were done by using the pumping test data. The following chateracteristics of the aquifers during pumping and recovery phase of the area are noted.

In phreatic aquifer the maximum observed drawdown vary from 0.46m (Paluvaya-Chavakkad) to 3.42m (Paruthipra-Mulloorkara). The average drawdown of the basin is 1.79m. The percentage of drawdown in 1st minute since pumping stopped varies from 0.00 (Choolissery-Avanur) to 13 (Padiyoor). The average drawdown percentage in 1st minute since pumping started is 1.79. The percentage of recovery in 1st minute since pumping stopped varies from 0.00 (Choolissry, Paluvaya) to 1(Edamuttom, Padiyoor, Irinlalakuda and Prabhathnagar). The average percentage recovery of the basin in 1st minute since pumping stopped is 0.63.

In semi-confined aquifer, the observed drawdown vary from 0.77m (Thippallur-Erumapetti) to 43.05m (Adichira-Chelakkara). The average drawdown of the basin is 16.70m. The percentage of drawdown in 1st minute since pumping started varies from 7.2 (Padavaradu-Puthur) to 87 (Gramela-Avanur). The average drawdown in percentage of the basin in 1st minute since pumping started is 38.60. The percentage of recovery in 1st minute since pumping stopped varies from 5 (Padavaradu-Puthur) to 87 (Gramela-Avanur). The average percentage recovery of the basin in 1st minute since pumping stopped is 42.29.

The other main characters of the aquifer reflected in drawdown- recovery analysis of the basin are (i) responses similar to double porosity model, (ii) linear fracture zone with barrier (no-flow) boundaries, (iii) connectivity of semi-confined fracture aquifer with phreatic aquifer, (iv) drawdown curve shows slope change due to heterogeneity of the aquifer (v) depth wise interconnection between fractures and (vi) apparently homogenous response during pumping.

The average water level of dug wells in coastal plain region varies from 0.79 m bgl (Nattika) to.2.46 m bgl (Mathilakam) while it varies from 2.73 m bgl (Mannuthi) to 10.83 m bgl (Cherpu) in midland and highland regions of the basin. The long term rise of groundwater level varies from 0.22 m/year (Chavakkad) to 0.532 m/year (Kunnamkulam). The maximum long term fall of groundwater level is in Puthur (0.008 m /year).

The average piezometric surface in coastal plain varies from 0.79 m bgl (Nattika) to 2.46 m bgl (Mathilakam), while the average piezometric surface varies from 2.22 m bgl (Madakathara) to 22.58 mbgl (Kandanissery) in midland and highlands. The long term rise of groundwater level of bore wells varies from 0.016m/year (Mattahtur) to 0.352m/year (Athani). The long term fall of groundwater level varies from 0.017m/year (Tholur) to 0.173 m/year (Kandanissery). A falling trend in water level during pre-monsoon indicates that there is an increase in groundwater development in the area. As long as the same trend is not observed in the post monsoon water level, it is a positive indication for optimum development. A falling trend of water level in the post-monsoon indicates that the rainfall is not sufficient to recharge the aquifer to the required level or an increase in groundwater draft/out flow.

The rising water levels in both phreatic and semi-confined aquifers are closely related to increase in rainfall and vice-versa. Rainfall has a major control over the water level fluctuation in the basin but in semi-confined aquifers, structure and geology of the area are the main controlling factors.

The major recharge areas of the basin are Pattikkad, Ottuppara. Chelakkara, Vaniyampara and Wadakkancherry fall on eastern and north eastern part of the basin. In addition to the above, two local pockets of recharge are seen around Irinjalakuda in Karuvannur basin and Kunnamkulam in Kechery basin; which lies in south central and north western part of the Palaeo-lagoon (Kole land basin) respectively. The discharge zone lies in the western part of the basin covering more than 45% of the terrain. The groundwater flow direction of the basin more or less coincides with the grid deviation map suggesting that topography play a considerable role in groundwater movement.

As per the norms of GEC-97, the estimated annual ground water availability of the basin is as follows: (i)recharge from rainfall during monsoon season-305.88MCM, (ii) recharge from rainfall during non monsoon season-131.93MCM, (iii) recharge from other sources during non monsoon season-128.20MCM, (iv) total annual groundwater recharge- 566.01MCM, (v) natural discharge during non monsoon season-52.99MCM, (vi) net annual ground water availability- 513.03MCM, (vii) existing gross groundwater draft for all uses- 222.09 MCM and (viii) stage of groundwater development of the basin- 50.07%. The areas such as Wadakkancherry, ollukkara, Thalikulam, Mathilakam and Mala are found semi-critical with a stage of groundwater development between 70 and 90%. All other areas are found safe with groundwater development less than 70%. No areas of the basin is found critical and over exploited.

Groundwater occurs as three layered sequence in the basin; (i) Overburden portion (10 to 20 m thick) including clay and laterite above crystalline rock (first layer), (ii) between 30 and 50 mbgl (fractured rock; second layer) and (iii) between 60 and 90 m bgl (fractured rock; third layer). The p1 (resistivity of the first layer) of this basin ranges from 5 ohm-m (Vatanapilli) to as high as 3400 ohm-m (Peechi). Thickness of this layer varies from 5 to 50m. The average resistivity of this layer is 643 ohm-m. The resistivity of the second layer (p2) ranges from 25 (Pulavaya) to 1200 ohm-m (Alur) which are weathered or fractured rocks, that may or may not be saturated with water. The thickness of this layer varies from 12 to 70 m and the average resistivity is 397 ohm-m. The resistivities of the third layer (p3) range from 20 to 1600 ohm-m which are fractured rocks associated with major and minor lineaments. The average resistivity of this layer is 414 ohm-m. The low resistivity values, below 50 ohm-m, in the places like Chittilapilli, Venkidangu, Adat, Penagam etc. are due to the occurrence of brackish water in fractured hard rock aquifers of the area that is in contact with saline water. Overabstraction of groundwater from bore wells of these places may cause saline water incursion since the fractures are connected to brackish water.

The percentage of geophysical curve types in the area are 35% (H type), 26% (A type), 21% (Q type) and 18% (K type) respectively. H type curve is common for mid and highland while it is Q and A in coastal plain.

The groundwater of both phreatic (dug wells) and semi-confined (bore wells) aquifers of the basin is suitable for domestic, agricultural and industrial uses. In phreatic aquifer (dug wells) pH varies from 5 to 8.74. The maximum pH is recorded along coastal plain (Chavakkad) and the minimum in the northeastern (Wadakkancherry) part of the basin. Electrical conductivity (EC) ranges from 29 µmhos/cm to 980 µmhos /cm at 25°C (northwest of the basin). TDS ranges from 24 mg/l (M.G.Kavu) to 696 mg/l (Chavakkad) and total hardness from 9 mg/l (M.G.Kavu) to 305 mg/l (Chavakkad). Fluoride ranges from 0 mg/l to 1.26 mg/l (Vaniyampara), Ca^{2+} from 0 mg/l to 94mg/l (Chavakkad), Mg^{2+} from 0 mg/l to 28 mg/l (Chavakkad), Na^{+} from 2 mg/l to 86.5 mg/l (Chavakkad), K^{+} from 0.7 mg/l to 34.3 mg/l (Chavakkad), Fe^{+} varies from 0 mg/l to 3.86 mg/l (Ottuppara), Cl^{-} from 8 mg/l (M.G.Kavu) to 195.9 mg/l (Chavakkad), CO_3^{-} from 0 mg/l to 37.5 mg/l (Engadiyoor), HCO_3^{-} from 7.17 mg/l (Kodakara) to 199.8 mg/l (Chavakkad) SO_4^{-} from 0.0 mg/l (Pazhanji) to 81 mg/l (Chavakkad) and NO_3^{-} from 0.28 mg/l to 8.62 mg/l (Irinjalakuda).

In semi-confined deep aquifer (bore wells), pH varies from 5.5 to 8.8. The maximum pH is noted in the south and central part and the minimum in southwestern part of the basin. Electrical conductivity ranges from 10µmhos/cm to 930µmhos /cm at 25°C (northeast of the basin). TDS ranges 48 mg/l(Vellangallur) to 630 mg/l (Wadakkancherry), total hardness varies from 15 mg/l (Aloor) to 445 mg/l (Wadakkancherry), fluoride from 0 mg/l to 1.18 mg/l (Pananancherry), Ca^{2+} from 2 mg/l to 100.4 mg/l (Mattathur), Mg^{2+} from 0 mg/l to 56.8 mg/l (Wadakkanchery), Na^{+} from 1 mg/l to 158.7 mg/l (Nellai), K^{+} from 0.4 mg/l to 11.9 mg/l (Aloor), Fe^{+} from 0 mg/l to 6.658 mg/l (Kaiparambu), Cl^{-} from 7 mg/l (Kaiparambu) to 111.6 mg/l (Nellai), CO_3^{-} from 0 mg/l to 46.5 mg/l (Tholur), HCO_3^{-} from 1 mg/l (Choondal) to 225.7 mg/l (Wadakkancherry), SO_4^{-} from 0.87 mg/l (Tholur) to 125 mg/l (Wadakkancherry) and NO_3^{-} from 0mg/l to 8.58 mg/l (Velapaya).

Bacteriological analysis of water samples indicates that, almost all the dug wells in the study area are contaminated with coliforms and E.coli, while in bore wells contamination percentage of E.coli is less than 50% in comparison with dug wells. E.coli contamination is higher in urban areas such as Thrissur, Chavakkad, Irinjakuda and Kunnamkulam than the rural areas.

The groundwater of the basin is generally potable, even though some variations are seen in some pockets. The pH of groundwater is above permissible limit for drinking in the places like Pudukkad, Chelakkara and Chavakkad. Fluoride content is above desirable limit and below permissible limit for drinking (1 to 1.5 mg/l) in the water samples of Vaniyampara, Mathilakam and Ottuppara. The iron concentration is above permissible limit for drinking (> 1mg/l) in ground water samples of Pattikkad, Pudukkad , M.G.Kavu, Ottuppara, Chelakkara, Kunnamkulam and Edamuttom. The source of iron in the groundwater is from laterite, which covered major portion of the basin, that is due to leaching under low pH condition.

Evaluation based on the concentration of Na%, electrical conductivity and total dissolved solids indicates the groundwater of the basin is generally good for irrigation. Some precaution is necessary while using the ground water particularly for sensitive crops from bore wells of Avanur, Chittilapilli, Adat and Wadakkancherry areas and tube wells of sedimentary (coastal) areas.

The Wilcox and U.S.S.L diagram for the water samples shows that, almost all samples of phreatic (dug wells) and semi-confined deep aquifer (bore wells) belong to C1 and C2 types. The EC of water samples of phreatic aquifers at Chavakkad and Irinjalakuda and semi-confined deep aquifer at Velapaya, Chittilapilli and Wadakkancherry shows an EC greater than 750 imhos/cm and are C3 type. The SAR values of phreatic aquifer of the basin vary from 0.32 (Mathilakam) to 2.35 (Elavally). The average SAR of basin is 0.95. The SAR values of semi-confined deep aquifer of the basin vary from 0.35 (Chengaloor) to 6.32 (Nellayi). The average SAR of deep aquifer is 0.86. The water samples at Nellayi, Choondal and Arthat shows an SAR more than six during the period of investigation. Almost all samples of both phreatic and semi-confined aquifers of the basin belong to CS1 and C2S2 type, which is suitable for irrigation. Only very few samples show medium suitability for irrigation.

The spatial variation of the residual sodium carbonate (RSC) of the phreatic aquifer of the basin varies from -3.14 meq/l (Thrissur) to 1.11meq/l (Chavakkad). The average RSC of the basin is -0.39meq/l. The RSC values of semi-confine deep aquifer of the basin vary from -4.49meq/l (Wadakkancherry) to 2.93 (Nellayi). The average RSC of deep aquifer is -0.32. The RSC concentration of the all water samples of the basin is <1.25 mg/l, and hence it is suitable for irrigation.

The permeability index (PI) of phraeatic aquifer of the basin varies from 32.22 (Pattikkad) to 172.42 (M.G kavu). The average permeability index of phreatic aquifer of the basin is 89.00. Out of 240 water samples analysed, 39% shows a permeability index $\leq$ 75(Class I & Class II) and 62% shows a PI between 75 and 172 (Class III). The permeability index of semi-confined deep aquifer of the basin varies from 27.83(Wadakkancherry)) to 172.18(Chittilapilli). The average permeability index of semi-confined deep aquifer of the basin is 79.60. About 51% of water samples show a permeability index $\leq$ 75 (Class I and Class II) and 49% shows a PI between 75 and 172 (Class-III). The class I and II are suitable for irrigation while the Class III is not suitable.

The magnesium ratio of phreatic aquifer of the basin varies from 12.53 (Engadiyoor) to 59.07 (Puthur). The average magnesium ratio of phreatic aquifer of the basin is 36.74. About 92% of water samples show a magnesium ratio $\leq$ 50 and 8% shows a MR between 50 and 59. In semi-confined deep aquifer of the basin it varies from 23.24 (Mudicode) to 59.78 (Athani). The average magnesium ratio of semi-confined deep aquifer of the basin is 44.71. Hence the groundwater of shallow and deep aquifers of the basin is suitable for irrigation.

The water sample of both shallow and deep aquifer shows a pH and TDS (as $CaCO_3$) below the maximum allowable limit for industry (pH 6.4 to 8.5 & TDS 50 to 3000mg/l and is generally suitable for industries. The corrosivity ratio of waters of both shallow and deep aquifers of the basin is <1 (CR, 1) and considered under safe category.

In Gibbs diagram, density of sample points are maximum in precipitation dominance area (79%), while in the case of phreatic shallow aquifer only few points fall (21%) in the rock dominance area. The clustering of points in precipitation domain indicates the rock chemistry of the phreatic aquifer is not a major factor in controlling the groundwater chemistry of the basin, but precipitation. But the situation is different in semi-confined deep aquifer of the basin. 77% data points fall in rock dominance area and only 23% data points fall in precipitation dominance area. The clustering of data points in rock domain indicates that the rock chemistry of the semi-confined deep aquifer is a major factor in controlling the groundwater chemistry of the basin not precipitation.

The Hill-Piper plot of phreatic and semi-confined aquifer indicate that, about 70% of the samples fall in the Field 1 (alkaline earth exceeds alkalies) and the water belong to Ca-Mg-HCO_3 facies. Calcium and magnesium are the major cations and bicarbonate is the major anion in the study area. Total hydrochemistry of the area is dominated by alkaline earths and weak acids.

Three hydrochemical facies identified for the water samples of phreatic aquifer of the area are (i) Ca^{2+}-Mg^{2+} - HCO_3^- facies (Field I), (ii) Na^+-K^+-Cl^- - SO4 facies (Field 3) and (iii) Ca^{2+}-Mg^{2+}-Cl^- - SO_4^{2-} facies (Field 4). The post monsoon samples are enriched with bicarbonate and sodium. The calcium and magnesium are the major cations (about 70 to 75%) and bicarbonate is the major anion (60 to 65%) of the basin. This indicates the influence of rainfall on ground water chemistry of phreatic aquifer of the basin rather than geology. The hydrochemical facies for the water samples of semi-confined deep aquifer of the basin are (i) Ca^{2+}-Mg^{2+}-HCO_3^- facies (Field I) and (ii) Na^+-K^+-Cl^- -SO_4 facies (Field 3). The calcium and magnesium are the major cations (about 60 to 65%) and bicarbonate is the major anion (70 to 75%) of the basin. Facies changes during pre and post monsoon indicates that, the geology of the area plays a major role in controlling the ground water chemistry of semi-confined deep aquifer of the basin rather than rainfall.

The DRASTIC score for groundwater vulnerability towards pollution of the basin varies from 110 (Tholur) to 176 (Kuttichira). As per the norms of DRASTIC it is found that the groundwater in phreatic aquifer of the entire basin area is highly vulnerable to pollution.

GALDIT score for vulnerability of shallow aquifer towards saline intrusion of the basin varies from 32 (Kundannur) to 121 (Kadappuram). As per the norms in GALDIT it is found that the coastal areas and some low land connected with back waters and sea are vulnerable areas of phreatic aquifer to saline intrusion in the basin (GADIT index >100. Range of EC values, hydrochemical facies diagram, Ionic ratios of major cation and anions, TDS etc. of the samples of the coastal area rejects the possibility of saline intrusion in the basin.

The groundwater potential of the basin has been demarcated by conducting hydrogeologial, geophysical investigations and other available secondary data. The midland region of the basin gives potential aquifer with good quality. Groundwater potential of the coastal plain region is also high but shows seasonal chemical variations especially in semi-confined deep aquifers and shallow aquifer in contact with channels connected to sea. Phreatic aquifer of the highland region of the basin shows only a low to moderate ground water potential. Deep semi-confined aquifers of the northwest, northeast and southern part of the basin show moderate to high groundwater potential. The deep aquifers at the central and western part of the basin are productive but show quality variation (high EC) if the withdrawal is in higher quantities. A narrow strip of Tertiary sediments (width less than 1000m from the coast) of Vaikom formation, along the coast of the basin, is productive with moderate potable quality.

The stratigraphical analysis of the basin gives a clear picture about the origin and evolution of palaeo-lagoon (Kole land basin). The ^{14}C ages and shell assemblage help to separate the different lithological units. Charnockites, gneisses and intrusives (Precambrian), laterites and gravels (Tertiary), ferruginous clay, clayey sand, coarse to medium sand and molluscan shells (Pleistocene), greenish black/grey clay, sand and sandy clay interbeded with thin layers of clay (Holocene) and clay, sandy clay, silt, loam (Recent) are the major stratigraphic units identified in the basin. The ^{14}C dates from Quaternary sediments of the Palaeo-lagoon area shows three ranges of age groups viz. (i) 24700 ± 1890 to 35060 ± 5570 Yrs.BP (ii) 5160 ± 130 to 8820 ± 120 Yrs.BP and (iii) 2180 ± 170 to 3160 ± 110

Yrs.BP. A sedimentation gap for 10000 years is seen between (iii) and (ii), for 1000 years between (ii) and (i) groups of samples respectively indicating a break in deposition. Radiocarbon dates suggests Middle to Late Pleistocene period for group (i) Early to Middle Holocene period for group (ii) and Late Holocene period for group (iii).

The sediments of the beach ridges range from medium to very fine sand, moderately sorted to poorly sorted, near symmetric skewness and meso to leptokurtic nature and show coarsening downward sequences in the bottom most layers. In the middle part of the basin fining upward sequences have been observed.

The average standard deviation of the sediments of the basin varies from 0.82 to 1.34 ö and the sorting is generally decreases towards southern side of the basin. The poorly sorted nature in the southern side of the basin shows the fluvial influence in deposition. The sorting worsens as the phi mean size decreases. But a reverse trend is seen in Nattika area. The medium and fine sands show moderate to moderately well sorted nature. It is difficult to demarcate the palaeo-ridge sediments from the recent ridge sediments due to the presence of coarse as well as fine sediments in both the ridges.

Bivariate plots of the textural data indicate beach and inland environment for the sediments in the area. There is not much variation in the environments along and across the coastal plain. The beach ridges of the study area would have been formed from near shore sand supply.

The sand content in the samples varies from 85 (Vatanapilli) to 99% (Mathilakam). The clay content in the samples is increasing from southern (Mathilakam) to northern (Chavakkad) part of the basin. This indicates the fluvial influence during deposition in the northern and central part of the basin was more than the south.

The heavy minerals in the sediments are primarily opaques, garnets, hypersthenes, glaucophane, biotite and actinolite in very fine sands whereas chlorite, glaucophane, garnets and opaques are found in fine and medium fractions. The heavy mineral distribution shows that the concentration decreases towards central part of the study area. The source for the mineral assemblage is the drainage basins of Chalakudi, Karuvannur, Kecheri and Bharathapuzha rivers.

The predominant clay minerals found in the study area are kaolinite, illite, chlorite, and montmorillonite.

The approximate evolutional history of the area that, around 40 to 42 ky .BP, shoreline coincided with the western boundary of present Palaeo-lagoon (Kole land). Around 7 to 9 ky.BP, sea was further advanced to east and coincides with almost the eastern boundary of the present Palaeo-lagoon. A wide littoral zone was created by transgression while the lagoonal water bodies and the ridge-runnel topography developed during regression. Regressive phase was started from around 4 to 5 ky.BP and created a lagoon in the foredeep side (present Palaeo-lgoon). Successive regression was continued and became standstill for a couple of time around 2 to 3 ky.BP at the western side of Conoly canal (coincides with Conoli canal). Further regression around 1ky.BP caused the formation of present day coast and Conoli canal parallel to it. The earlier deposits in the basin show marine/ lagoonal character but later deposition shows fluvial character.

The major conclusions of the study are:

- Based on the aquifer parameters analysis most of the areas of the basin are found suitable for groundwater prospecting. The main groundwater zones of the study area are (i) sedimentaries in the west and (ii) laterites and crystalline rocks in the east of palaeo-lagoon. Coastal area of the basin is suitable for tube wells, filter points and shallow dug wells, while the midland region is suitable for large diameter dug wells with moderate to high yield and the highlands are desirable for construction of low yielding dug wells. The north, northeast and southeast portion of the basin is very much suitable to moderate to high yielding bore wells.

- The movement of groundwater is mainly controlled by topography and lithology in phreatic aquifer, but lineaments and structure in semi-confined aquifer. The average drawdown is 1.79 m in phreatic aquifer and 16.70 m in semi-confined aquifer of the basin.

- Groundwater occurs as three layered sequence in the basin viz. (i) 10 to 20 mbgl (including clay and laterite above crystalline rock), (ii) between 30 and 50 mbgl (fractured rock) and (iii) between 60 and 90 m bgl (fractured rock associated with lineaments).

- Geochemically the groundwater is generally potable and suitable for irrigation and industry.

- The groundwater in phreatic aquifer of the entire basin is highly vulnerable to pollution as deduced by DRASTIC method.

- The phreatic aquifer of the coastal area and some lowland region connected either to back waters or sea is vulnerable to saline intrusion. Overabstraction of groundwater by tube wells along coastal plain and bore wells in places like Chitilapilli, Velapaya, Arthat, Puzhakkal, Penagam etc. may cause saline water incursion through the fractures that cut across the brackish water.

- Laterites and gravels (Tertiary), ferruginous clay, clayey sand, coarse to medium sand and molluscan shells (Pleistocene), greenish black/grey clay, sand and sandy clay interbeded with thin layers of clay (Holocene) and clay, sandy clay, silt, loam (Recent) are the major stratigraphic units identified in the basin.

- Three statigraphic breaks have been observed in the depositional history of the basin viz. (i) above 42000 Yrs. BP, (ii) between 20000 and 10000 yrs. BP and (iii) between 3000 to 2000 yrs. BP. This may be due to the break in sedimentation related to sea level oscillations.

- The heavy minerals in the sediments are found to be primarily opaques, garnets, hypersthenes, glaucophane, biotite, actinolite chlorite, glaucophane garnets etc. and the source for the mineral assemblage is the drainage basins of Chalakudi, Karuvannur, Kecheri and Bharathapuzha rivers.

Areas such as Wadkkancherry, Ollur, Mala and Thalikulam are found semi-critical as far as groundwater development (between 70-90%) is concerned. Proper groundwater management and schemes for artificial recharge are necessary in these areas to overcome the further groundwater depletion. Geochemically groundwater of the basin is good for all domestic, irrigational and industrial, even though some red signal are given by coastal areas regarding aquifer vulnerability and saline intrusion. Further intervention in the coastal aquifers of the basin should be cautiously managed. High resoultion dating has to be carried out in the area to correlate the various lithostratigraphic units of the Central Kerala.

REFERENCES

Abed, A. (1982). Depositional environments of the early Cretaceous Kurnub (Hathira) Sandstones, north Jordan. Sed. Geol., v. 31, pp. 267-79.

Acharya, B., Panigrahy, P.K., Nayak, B.B., and Sahoo , R.K. (1998). Heavy mineral placer deposits of Ekakula beach, Gahiramatha coast, Orissa, India, Resource Geology, v.48, pp.125 – 136.

Adayalkar, P.G. and Mani, V.V.S. (1972). An attempt at estimating the transmissibility of trappean aquifers from specific capacity values, Jour. Hydrol., v. 17, pp. 237-241.

Ahamedali, K., James, E.J and Nabuthiripad, K.D (1987). Salinity intrusion in to Chetwa-Kottppuram sound of the Trichur Kole lands, Proc. Natn. Sem. Esturine Management, Trivandrum, pp 83.87.

Ahmad, E. (1972). Coastal Geomorphology of India. Orient Longman, New Delhi. 222p.

Allen, J. R.L., (1970). Physical process of sedimentation. George Allen and Unwin Ltd., Unwin University Books, London, 248 p.

Aller, L., Bennet, T., Leher, J. H. and Pretty, R.J (1987). "DRASTIC: a standardized system for evaluating groundwater pollution potential using hydrogeologic settings", U.S.EPA Report 600/2-85/018.

Alter, L., Bennet, T, Lehr, J.H. and Pety, R.J. (1987).DRASTIC: a standardised system for evaluating groundwater pollution using hydrogeological settings. United States Environmental Protection Agency, Washington. Report 600/2-85/018.

Angusamy, N. and Rajamanickam, G (2000) Beach morphology and inferences from heavy mineral assemblage of Mandapam to Kanyakumari coast, South East coast of India, Indian Jour. Marine. Sciences, v.29, pp.283-294.

Angusamy, N., and Rajamanickam, G. (2000). Distribution of heavy mineral along the beach from Mandapam to Kanyakumari , Tamilnadu , Jour. Geol. Soci. India , v. 56, pp. 199-211.

Anon (1974). Water Resources of Kerala. Government of Kerala Publ., 110p.

Anthony, E. J. (1995). Beach ridge development and sediment supply- examples from west Africa. Jour. Mar. Geol. V. 129, pp. 175-186

Anthony, E. J. (1991a). Beach ridge plain development; Sherbro Island Sierra Leone. Z. eomorphol. N.F Suppl., v. 81, pp. 85-98

APHA (1985). Standard Methods for the Analysis of Water and Waste Water (16th edn.), American Public Health Association, Washington. D.C.

Applin, K.R. and Zhao, N. (1989). The kinetics of Fe (II) oxidation and well screen encrustation. Ground Water, v. 27 (2), pp. 168-174.

Aravindan, S. (1999). Integrated hydrogeological studies in hard rocks aquifer system of Gadilam river basin, Tamil Nadu, India, p.110 (Unpublished Ph.D thesis, Bharathidasan University), p. 110.

Aswathanarayana, U. (1964). Origin of heavy mineral beach sand deposit of southwest coast of India. Advance frontiers in Geology and Geophysics, Indian Geophysical Union, pp. 481-489.

Babva, A. (1980). Geochemistry of interstitial water of Vembanadu estuary. Thesis submitted to Cochin University of Science and Technology.

Babu, N. and Seralathan, P. (2005). Distribution of heavy minerals in the buried placers, Central Kerala coast, India. National seminar on development planning of coastal placer minerals 2005, Ed Lorson V.J, Chandrasekar. N. and Sinha .A. Allied publishers Pvt .Ltd. Chennai, pp. 40-49.

Back, W. and Hanshaw, B.B. (1965). Chemical Geohydrology, Adv. Hydro Science, v. 1, pp. 49-109.

Badrinath, S.D., Raman, V., Gadkari, S.K., Mahaisalkar, V.A. and Deshpande, V.P. (1984). Evaluation of calcium carbonate stability indices for Sabarmati river water. Ind.Water. Ass., v. 16(1), pp.163-168

Balakrishna, S., Subramanyam, K., Gogte, B.S., Sharma, S.V.S. and Venkatanarayana, B. (1984). Groundwater investigations in the Union Territory of Dadra, Nagar and Haveli, Geophysical Research Bull., v. 21 (4), pp. 346- 359.

Balasubramanian, A. (1986). Hydrogeological investigations in the Tambraparani river basin, Tamil Nadu. Unpublished Ph.D, Thesis (University of Mysore), 349 p.

Balasubramanian, A., Sharma, K.K. and Sastri, J.C.V. (1985). Geoelectrical and hydrogeochemical evaluation of coastal aquifer Tambraparani basin, Tamil Nadu, Geophysical Research Bull., v. 23 (4), pp. 203- 209.

Ballukraya, P.N. (1996). Differentiating conductives and resistive inhomogeneities: A new approach in groundwater exploration. Current Science, v. 71, pp. 130-150.

Ballukraya, P..N., Sakthidivel, R. and Baratan, R. (1981). Inadequacies in the techniques of resistivity methods for the location of sites in hard rock areas. Nordic Hydrology, v. 12, pp. 185-192.

Banerjee, P. K. (2000). Holocene and Late Pleistocene relative sea level fluctuations along the east coast of India. Mar. Geol. v. 167, pp. 243-260.

Banerjee, P. K., Goswami, S. and Chatterjee, S. (1997). A genetic reinterpretation of the shore parallel sand ridges along the Digha-Chandipur coast, West Bengal and Orissa. Jour. Geol. Soc. India, v.49, pp. 687-692.

Basak, P. and Nazimuddin, M. (1987). Sea water intrusion in coastal unconfined aquifers of the south western Peninsula- A case study. Jal Vigyan Sameekha- a Publication of high-level technical committee on hydrology, v. 11(1), pp. 72-80.

Basak, P. and Nazimudidin, M. (1986). Groundwater in the coastal belt: Thrissur district, Technical report GW/R-163/86 of Centre for Water Resources Development and Management, Kozhikode.

Basak, P. and Sabu Abraham (1983). Salt water intrusion in Coastal aquifer of Malappuram district,Technical report GW/R-54/83 of Centre for Water Resources Deveopement and Management, Kozhikode.

Bhattacharya, A.K., Kurian, T.K., Krishnanunni, K. and Sethi, D.L (1979). Geomorphic mapping in parts of Kerala state. Jour. Indian Soc. Rem. Sens., v. 7(1), pp. 1-9.

Bhimashankaram, V. L.S. and Gaur, V.K. (1977). Lectures on Exploration geophysics for Geologists and Engineers, AEG Publi., Osmania Uni. Hyderabad, 449 p.

Biscaye, P. E. (1965). Mineralogy and sedimentation of recent deep sea clays in the Atlantic Ocean. Geol. Soc. Amer. Boll. V. 76, PP. 803-832.

Biscaye, P. E. (1964). Distribution of Kaolinite and chlorite in recent sediments. Amer. Mineral., v.49, pp. 803-832

Biswas, S. K. (1988). Structure of Western Continental Margin of India and related igneous activity. In: K.V. Subbarao, (Ed.), Deccan Flood Basalts, Mem. Geol. Soc. India, No. 10, pp. 372-390.

Black, J. H. and Kipp, K.L. (1977). Observation well response time and its effect upon aquifer test results. Jour. Hydrol., v. 34, pp. 297- 306.

Blatt, H. (1995) Provenance study and mud rock . Jour. Sed. Petrol. v.55, pp. 59-75.

Boehmer, W. K. (1993). Secondary type aquifers and the value of pumping tests for the evaluation of groundwater potential, in Mem. 24th Congress of IAH, Oslo, pp. 159-68.

Bose, R. N., Kartha, T. D. G., and Padmanabhan, K. (1976). Geophysical investigations in the coastal basin of Kerala. Paper presented to the Workshop on Coastal Sedimentaries of India south of 18°N ONGC, Madras.

Boulton, N. S. and Streltsova, T.D. (1976). The drawdown near an abstraction well of large diameter under non-steady conditions in an unconfined aquifer, Jour. Hydrol., v. 30, pp. 29-46.

Bradley, J. S. (1957). Differentiation of marine and subaerial sedimentary environments by volume percentage of heavy minerals, Mustang Island, Texas. Jour. Sed. Petrol., v.27, pp. 116-125.

Briggs, L.I. (1965). Heavy minerals correlation and provenances. Jour. Sed. Petrol., v.35, pp. 939-955.

Bruckner, H. (1989) Late Quaternary shorelines in India. In: D.B. Scot, P.P. Pirazzoli and C.A. Honig (Eds.), Late Quaternary Sea-Level Correlation and application. Walter S.Newman Memorial Volume, NATO ASI Series C-256, Kluwer Academic Publishers, Dordrecht, pp. 169-194.

Campanile, D., Nambiar, C.G, Bishop, P., Widdowson, M. and Brown, R. (2008). Sedimentation record on the Konkan_kerala Basin: Implications for evolution of the Western Ghats and the western Indian passive margin, Basin research (2008) 20, 3-22.

Canter, L.W. (1988). Methods for the assessment of groundwater pollution potential. In. Groundwater quality (ed. C.H. Ward, W. Giger and P.L. Mc Corty). John wiley, Newyork, pp. 270-306.

Carver, R.E. (1971). Procedures in sedimentary petrology. Wiley Inter Science, New York, pp.427-478.

CESS (1984). Resource atlas of Kerala, Centre for Earth Science Studies, Thiruvananthapuram, Kerala.

CGWB (1982). Manual of evaluation of aquifer parameters, Ministry of water resources Govemenment of India.

CGWB (2002). Groundwater balance. Mass awareness programme in Ernakulam district on January 5th 2002 by CGWB, Kerala region, Thiruvananthapuram, Kerala.

CGWB (2003). A study on seawater ingress in the coastal aquifers in parts of Alleppey and Ernakulam districts, Kerala, Technical report, AAP 2000-2001, 29p.

CGWB. (1992). Tchnical report of SIDA assisted coastal groundwater project,Un.pub.

Chachadi, A.G and Lobo Ferreira, J.P. (2001). Sea water intrusion vulnerability mapping of aquifers using Galdit method, Modelling in hydrology,L.Elango and R.Jayakumar (eds) pp143-155.

Chandrasekar, N. (1992). Beach placer mineral exploration along the central Tamil Nadu coast. Ph.D. thesis (unpublished), Madurai Kamaraj University, Madurai. 293 p.

Chandrasekar, N., Anil Cheriyan., Rajamanickam, M. and Rajamanickam, G.V. (2003). Ilmenite and magnetite ratio in the beaches between Kallar and Vembar coast Tamilnadu;Implication and distribution with other heavy minerals, Jour.Indian .Asso.

Chandrasekhar, N. and Rajamanickam, G. (1997). Zircon placer deposits along the beaches of central Tamilnadu , India. Geol. Survey and Mines bureau, Sri Lanka, vol. 7, pp.337-348.

Chandrasekharam, D. (1989). Anomalous SO_4- CI groundwater in coastal aquifer, Kerala, Proc. Ind. Acad. Sci.,v.98 (3), pp. 287-295.

Chandrashekar, N., Rajamanickam, G.V.(2001). Nature of distribution of heavy minerals along the beaches of Central Tamilnadu Coast, Jour Indian Associ.Sedimentologist, v.20,pp.167-180.

Chebotarev, I. (1950). Metamorphism of natural waters in the crust of weathering. Geochim. Cosmochim. Acta, v. 8, pp 22-48

Cohen, A.J.B.,Karasaki,k.,Benson,s.,Bodavarsson,G.,Freifeld, B.,Beneito,P.,Cook,p.,Zawislanski,P. (1996). Hydrogeologic characterization of fractured rock formations: A guide for groundwater remediators,EPA project summary.

Collins, L. B. and Hamilton, N. T. M. (1989). Holocene sedimentation and Heavy minerals accumulation, Minninup shoreline, WA minerals and energy research institute of Western Australia, report 42.

Cooper, H.H. and Jacob, C.E. (1946). A generalized graphical method for evaluating formation constants and summarizing well field history. Amer. Geophy. Union Trans., v. 27, pp. 526- 534.

Crawford, A.R. (1969). Reconnaissance Rb-Sr dating of the Precambrian rocks of southern Peninsular India. Jour. Geo.Soci. India, v.10, pp. 117-166.

Cronan, D.S. (1972) Skewness and kurtosis in polymodal sediments. Jour. Sed. Petrol., v.42, pp. 102-106.

Curray, J.R., Emmel, F.J. and Crampton, P.J.S. (1969). Holocene history of a strand plain lagoonal coast, Nayarit, Mixico. In. A.A. Castanares and F.B.Pflerger (Editors), Lagunas Costeras, Un simposio. UNAM- UNESCO, pp. 63-100

Davies, J. (1994). The hydrogeochemistry of alluvial aquifers in central Bangladesh. Groundwater Quality, 17th special report, ed. By H. Nash and G.J.H. McCall, Chapman and Hall pub., pp. 9-18.

Davies, J. L. (1980). Geographical variation in Coastal development, 2nd edition, New York:,212 p.

Davis, S. N. and De Wiest, (1960). Hydrogeology, John Wiley Inc., New York, 463p.

Davis, S. N. and Turk, L.J. (1964). Optimum depth of wells in crystalline rocks. Ground water, v. 2, pp. 6-11.

Desikachar, S. V. (1976). Geology and the hydrocarbon prospects of the Kerala west coast basin. Paper presented to the Workshop on Coastal Sedimentaries of India south of 18°N ONGC, Madras.

Desikachar, S. V. and Subramanyam, M. (1959). Progress report (Part II) on subsurface geology of parts of coastal Kerala. Madras and Kerala party 1968-59, ONGC Report, Unpublished.

Dissanayake, C.B.(1991). The fluoride problem in the groundwater of Sri Lanka-environmental management and health. Int. Jour. Env. Studies, v. 38, pp.137-156.

Donnen, L. D. (1964). Notes on water quality in Agriculture. Published as water science and engineering paper 4001. Dept. of Water Sciences and Engineering, University of California.

Dora, Y. L. (1978). Certain aspects of provenance and sedimentation of the modern sediments of the Godavari river and Vasishta-Godavari distributary, India. Ph.D. Thesis (unpublished), Andhra University, Andhra Pradesh.

Dryden, A. L. and Dryden, C. (1946). Comparative rates of weathering of some common heavy minerals. Jour. Sed. Petrol., v.16, pp. 91-96.

Eagon, H.B. and Johe, D.E. (1972). Practical solutions for pumping tests in carbonate rock aquifers. Ground Water, v. 10, pp. 6-13.

Edmunds, W.M. (1994). Groundwater chemistry and development. Groundwater quality, eds. Nash,H. and McCall.G.J.H. Chapman and Hall.

Ewing, J. and Ewing, M. (1976) Sediment distribution on the midoceanic ridges with respect to spreading of sea floor. Science ,156, pp.251-266.

Flores, R.M. and Shideler, G.L. (1978). Factors controlling heavy mineral variations on the South Texas outer continental shelf, Gulf of Mexico. Jour. Sed. Petrol., v.48, pp. 69-80.

Folk, R.L. (1966). A review of grain size parameters. Sedimentology. v.6, pp. 73-96.

Folk, R.L. (1968). Petrology of sedimentary rocks. Hemphill's, Texas, 170 p.

Folk, R.L. and Ward, W. (1957). Brazos river bar: A study in the significance of grain size parameters. Jour. Sed. Petrol., v.27, pp. 3-26.

Folk, R.L. Andrews, P.B. and Lewis, D.W. (1970). Detrital sedimentary rock classification and nomenclature for use in New Zealand. New Zealand Jour. Geol. and Geophy., v.13, pp. 937-968.

Foote, R. B. (1883). On the geology of South Travancore. Rec. Geol. Surv., v.6 (1), pp.90-35.

Forstner, U. and Wittmann, G.T.W. (1983) Metal pollution in the aquatic environment. Springer-Verlag, New York, 486 p.

Friedman, G.M. (1961). Distinction between dune, beach and river sands from their textural characteristics. Jour. Sed. Petrol., v.31, pp. 514-529.

Friedman, G. M. (1962). On sorting coefficient and the log normality of grain size distribution in sandstones. Jour. Geol., v.70, pp. 737-753.

Friedman, G. M. (1965) Relationship between statistical parameters derived from size frequency distribution of sands and environment of deposition. Amer. Geophy. Union, Transactions, v.46, 108p

Gansser, A. (1964). Geology of the Himalayas: Interscience, Newyork,289p.

Ghosh, B. N. and Zutshi, P.L. (1989). Indian West coast shelf break tectonic features, geol. Surv. India. Spl.Pub. No.24,pp.309-318.

Gibbs, R. J. (1968). Clay mineral mounting techniques for X-ray diffraction analysis: A discussion. Jour. Sed. Petrol., v.38, pp. 242-244.

Gibbs, R.J. (1970). Mechanism controlling World's water chemistry. Science, v.170, pp. 1088-1090.

Gilkcson, R.H. and Wright, K.C. (1983). The application of surface electrical and shallow geothermic methods in monitoring network design. Groundwater monitoring RCV., v. 3 (3), pp. 30-42.

Girish Gopinath (2003). An intergrated hydrogeological study of Muvattupuzha river basin, Kerala, India, Ph.D theisis submitted to the Cochin University of Science and Technology,Kerala, India.

Goldberg, R. (1980) Use of grainsize frequency data to interpret the depositional environments of the Pleistocene pleshet formation Beer Sheva, Israel. Jour. Sed. Petrol., v.50, pp. 843-856

Goldschmidt, V. M. (1958). Geochemistry, Oxford University press, Amen house, London, ECA, edited by Alex Muir, 730 p.

Goyal, R. S. and Jain, B.L. (1982). Use of gypsum modifying crustal conductive conditions in saline water irrigated soils. Jour. Ind. Soc. Soil Sci., v. 30 (4), pp. 447- 454.

Gregg, D. O. (1996). Analysis of groundwater fluctuations caused by ocean tides in Glynn country, Georgia, Groundwater, v. 4 (3), pp. 24-32.

Griffiths, J. C. (1962) Grain size distribution and reservoir rock (Sci) characteristics. Bull

Griffiths, J. C. (1967) Scientific methods in analysis of sediments. New York, McGraw-Hill Book Com., 508 p

Grim, R. E. (1968). Clay mineralogy. McGraw Hill, Newyork, 384p.

GSI (1995). Geological and Mineral map of Kerala. Hyderabad, India: Geological Survey of India, Scale 1:500,000, 1 sheet.

Gujar, A.R., Ramana, M.V. and Rajamanickam, G.V. (1989). Exploration of nearshore placers of Konkan coast, West Coast of India. Proc. Offshore Technology Conference, Texas. pp. 569-577.

Gupta, I. C. (1987). The scope of utilising saline groundwater for supplemental irrigation in arid and semi arid zones. In dry land Agriculture in India, eds. Mohammed Shafi and Mehdi Raza, Rawat Publications, Jaipur, pp. 124-134.

Hails, J. R. and Hoyt, J.H. (1969). The significance and limitations of statistical parameters for distinguishing ancient and modern sedimentary environments of the lower Georgia coastal plain. Jour. Sed. Petrol., v.39, pp. 559-580.

Handa, B. K. (1964). Modified classification procedure for rating irrigation waters. Soil Sci., v. 98, pp. 264 -269.

Handa, B. K. (1965). Modified Hill-Piper diagram for presentation of water analysis data., Curr. Sci, v. 34, pp. 313-314.

Hantush, M.S. (1964).Hydraulics of well . Advances in hydroscience, Academic press, vol., 442pp,Newyork.

Harbinson, R. N. and Bassinger, B.G. (1970). Seismic Refraction and magnetic study off Bombay, India. Geophysics, vol.35,pp.603-612.

Hashimi, N. H., Nigam, R., Nair, R.R. and Rajagopalan, G. (1995). Holocene sea level fluctuations on Western Indian Continental Margin: An Update. Jour. Geol. Soc. India, v. 46, pp. 157-162.

Hashmi, N. H, and Nair, R. R (1981). Surficial sediments of the continental shelf off Karnataka. Jour. Geol. Soc. Ind., V. 22, PP 226-273.

Hashmi, N.H. and Nair, R.R. (1986). Climatic aridity over India 11,000 years ago: Evidence from feldspar distribution in shelf sediments. Paleogeorgr. Paleoclimat. Paleoecol., v. 53, pp. 309-320.

Hem, J. D. (1959). Study and interpretation of the chemical characteristics of natural water. USGS, water supply paper, 1935-C, p17.

Hill, R. A. (1940). Geochemical patterns in Coachella valley, California, Am. Geophy. Union. Trans., v. 21, pp. 46-53.

Hong, Y.T. and Forstner, U (1984). Speciation of heavy metals in yellow river sediments. In : proc. Symposium on, heavy metals in environment., Heidelberg .CEP Consultants/Edinburgh. pp.872-875.

Houk, I. E. (1951). Irrigation Engineering Vol.1. Agricultural and hydrological phases. John Wiley and Sons Inc.

ISI (1983). Indian standard methods of sampling and test (Physical and Chemical) methods for water used in industry, 122p.

IWRS (1996). Interbasin transfer of water for natural resources development-problems and prospects. Indian water resources society, Roorkee, p.35.

Jacob, C.E.(1946) Radial flow in leaky artisian aquifer,trans. Amer,Geophysical union,vol.27,pp.198—208.

Jacob, K. (1956). Illmenite and garnet sands of Chowghat, (West coast), Tinnevely, Ramnad and Tanjore coasts (East coast). Rec. Geol. Sur. Ind., v.82, pp. 567-692.

Jacob, K. and Sastri V. V. (1952). Miocene foraminifera from Chavara near Quilon, Travancore. Rec. Geol. Surv. Ind., v. 82(2), pp. 342-459.

Jacob,C.E. (1950). Flow of groundwatet ,in engineering hydraulics(H. Rouse,ed)John wiley and sons, Newyork,pp.321-386.

Jahan, C.S., Majumder, T.K. and Roy, M.K. (1990). Sedimentary environmental discrimination using grain size analysis. Jour. Geol. Soc. Ind., v.35, pp. 529-534.

Jayalakshmi, K., Kumaran, K.P.N., Nair,K.M. and Padmalal, D. (2005). Late Quaternary environmental changes in South Kerala Sedimentary basin, South western India, Geophytology 35(1&2):25-31.

Jenne, E.A. (1968). Controls on Mn, Fe, Ni, Cu and Zn concentration in soil and water; the significant role of hydrous Mn and Fe oxides. Adv. in chemist. V.73, pp. 337-387.

Johansen, H. K. (1975). Interactive computer- graphic - display- terminal system for interpretation of resistivity sounding, Geophy. Prosp., v. 23, pp. 449-58.

Johnson, J. H. (1975). Hydrogeochemistry in groundwater exploration. Groundwater symposium, Bulawano.

Johnston, C. D. (1987). Distribution of environmental chloride in relation to subsurface hydrology. Jounl. Hydrology, v. 94, pp. 67-88.

Johnston, J.W., Baedke, S.J., and Thompson, T.A. (2002). Beach-Ridge Architecture, Lake-Level Change, and Shoreline Behavior in the Au Train Bay Embayment, Au Train, Michigan, In Loope, W. L, and Anderton, J.B. (eds.), A field guide for the 48th Midwest Friends of the Pleistocene field conference: Deglaciation and Holocene landscape evolution in eastern upper Michigan, Grand Marais and Munising, Michigan, 49-55.

Josanto, V. (1971b). On the grain size distribution of the Cochin backwater sediments. Bull. Dept. Mar. Bio. Oceanogr. , v..5, pp. 109-122.

Joseph, S. and Thrivikramaji, K.P. (2002). Kayals of Kerala coastal land and implication to Quaternary sea level changes. In: Narayana, A.C. (Ed.), Late Quaternary Geology of India and Sea level changes, Memoir Geol. Soc. of India, pp. 51-64.

Joseph, S., Thrivikramaji, K.P. and Anirudhan, S. (1997). Textural parameters, discriminant analysis and depositional environments of Teri sands, Southern Tamil Nadu. Jour. Geol. Soc. Ind., v.50, pp. 323-329.

Joseph, S. and Nambiar,C.G(1996). Alkaline nature and tephrogenetic affinity of felsic volcanic rocks of st.Mary's islands off Mangalore coast, Current science,70.99.858-860.

Junge, C. E and Wrby, R.T. (1958). The concentration of chloride, sodium, potassium, calcium and sulphate in rainwater over the United States. Jour. Meteorol., v.15, pp. 417- 25.

Kaehler, C.A. and Hsieh, P.A. (1994). Hydraulic properties of fractured rock aquifers, Lee Valley, San Diego Country, California. US. Geol. Surv. Water Supply Paper, v. 2394, pp. 64.

Kale, V. S. and Rajaguru S. N. (1983) Neogene and Quaternary transgressional and regressional history of the west coast of India – An overview. Bull. Deccan College Res. Inst., v. 44, pp. 153-165.

Kale, V.S. and Rajaguru S.N. (1985). Neogene and Quaternary transgressional and regressional history of the west coast of India – An overview. Bull. Deccan College Res. Inst., v. 44, pp. 153-165.

Karanth, K.R. (1987). Groundwater assessment development and management. Tata Mc Graw-Hill, New Delhi, 720p.

Karasaki, K., Freifeld, Cohen. A., Grossenbacher, K., Cook, P. and Vasco, D. (2000). A multidisciplinary fractured rock characterization study ar Raymond field site Raymond,CA, Journal of Hydrology,Vol.236,pp 17-34.

Keller, G.V. and Frisehknecht, F.C. (1966). Electrical methods in geophysical prospecting. Pergamon Press. New York.

Kelley, W.P. (1940). Permissible Composition and concentration of irrigation waters, Proc. A.S.C.E., v. 66, 607p.

Kerala State Land use Board (2000). Report of the resource mapping of Thrissur district.

King, W. (1882). The Warkalli beds and associated deposits at Quilon in Travancore. Rec. Geol. Surv. Ind., v. 15(2), pp.93-102.

Klein, M. and Kaser (1963). A statistical analysis of groundwater levels in twenty selected observation wells in Ohio, Tech-Rept. 5, Ohio Dept. Natural Resource, Div. of water, Columbus, pp. 124.

Knopman, D.S and Hollyday, E.F. (1993). Variation in specific capacity in fractured rocks, Pennsylvania. Ground Water, v. 31(1), pp. 135-145.

Koefoed, O. (1979). Geosounding Principles, (1) Resistivity sounding measurements, Elsevier, Amsterdam , 276p.

Krishanan Nair. (1996). Coastal geomorphology of Kerala, Geol. Surv. Ind. Spl. Pub. No. 40,1996,pp83-94.

Krishnamurthy, J. and Srinivas, G (1995). Role of geological and geomorphological factors in groundwater exploration. A study using IRS LISS II data. Int., Jourl. of Rem. Sens., v. 16 (14). pp. 2595.

Krishnan Nair, K. and Gopala Rao, V. (1988). Quaternary geological and geomorphological mapping in coastal tracts Kerala in Ernakulam, Alleppey and Kottayam districts, GSI progress report fro the field season 1986-87.

Krishnan, M. S. (1982). Geology of India and Burma, CBS publishers and distributors, New Delhi.

Krishnan, S., Viswanathan, G and Balachandran, K. (2001). Heavy mineral sand deposits of Kerala. Explo. Res. Atm. Min. v. 13, pp. 111-146.

Krumbein, W.C. and Pettijohn, F.J. (1938). Mauanl of Sedimentary Petrology. Appleton-Centnary-Crofts Inc., New York, 549p.

Krumbein, W. C. and Slack, H.A. (1934). Size frequency distribution of sediments Jour. Sed. Petrol., v.4, pp. 65-77.

Kruseman, G.P. and de Ridder, N.A. (1970). Analyses and evaluation of pumping test data, Int. Inst, for land reclamation and improvement, Bull. 11, Wageringen, 200 p.

Kruseman, G.P. and de Ridder, N.A. (1990). Analyses and evaluation of pumping test data, 2nd edn, Int. Inst, for land reclamation and improvement, Publ. 47, Wageringen, 377 p.

Krynine, P. D. (1942). Provenance versus mineral stability as a controlling factor in the composition of sediments. Geol. Soc. America Bull., v.53, pp. 1850-1851.

Kukillaya, J. P.(2007). Characteristic responses to pumping in hard rock fracture aquifers of Thrissur,Kerala and their hydrogeological significance,Jurnal of Geological Society of India, Special section on groundwater, Vol.69, pp1055-1067.

Kukillaya, J. P., Padamanabhan, K. and Radhakrishana, K. (2004). Occurrence of brackish water in fractured hard rock aquifers of Puzhakkal-avannur area in Thrissur ,Kerala,Journal of Geological Society of India,Vol.64, pp 32-42.

Kukillaya, J. P., Padmanabhan, K. and Krishanan, E. (1999). Use and limitations of short and medium duration pumping tests in understanding hard rock fracture aquifers-an example from Kerala, Journal of Geological Soc. of India, Vol.54,pp 267-277.

Kukillaya, J.P., Padmanabhan, K., Krishanan, E. and Radhakrishnan, K.(2002). Characterization of Hard rock fracture aquifer-The Kalleppadam-Oralassery fracture zone in Thrissur,Kerala, Journal of Geological Society of India,Vol.59,pp 59-67.

Kumar, A. and Srivatsava, S.K. (1991). Geomorphological units, their geohydrological characteristics and vertical electrical sounding response near Munger, Bihar, Jour. Ind. Soc. Rem. Sensing, v. 19(3), pp. 205-212.

Kumar, S. (1977) Textural analysis of the beach on Anjidiv Island near Karwar. Jour. Geol. Soc. Ind. v.18, pp. 178-183.

Kumaran, K.P.N., Nair, K.M., Mahesh Shindikar., Ruta. B.Limaya. and Padmalal, D. (2004). Stratigraphical and playnological appraisal of the Late Quaternary mangrove deposits of the west coast of India,Quaternary research 64,pp 418-431.

Langmuir, D. (1997). Aqueous environmental chemistry, Prentice-Hall, Inc, New Jersey

Lewis, D.W. (1984) Practical Sedimentology, Stroudsburg Pennsylvania, Hutchinson Ross., 229 p.

Lloyd, J.W. and Heathcote, J.A. (1985). Natural inorganic hydrochemistry in relation to ground water-An Introduction, Clarendon Press Oxford, 296p.

Loveson, E. J. (1994). Geological, geomorphological investigation related to sea level variation and heavy mineral accumulation along the southern Tamilnadu beaches, Ph.D. thesis, Maduai Kamaraj University, India.

Loveson,V.J. and Rajamanickam, G.V. (1987). Coastal geomorphology of the southern Tamil Nadu, India. Proc. Natl. Symp; Remote sensing in Land transformation and management, NRSA, Hyderabad. pp. 115-128.

Mahadevan, T.M. (1964). Systematting mapping in Trichur district, Kerala State, F.S.1962-63 Unpublished report, G.S.I.

Mahadevan, T.M. (1964). The origin of charnockite suite of rocks forming part of the Western Ghats in Kerala. India, Proc. Int. Geol. Congress, 22^{nd} session, (13), pp. 87-96.

Majumdar, P. and Ganapathi. (1998) Grain-size frequency distribution in ancient depositional environment- A case study from Lower Gondwana sediments, Pranhita Godavari basin, Andhra Pradesh. Jour. Geol. Soc. Ind., v.52, pp. 219-228.

Mallik, T. K. (1981). Heavy mineral placers in the beaches and offshore areas-their nature, origin, economic potential and exploration. Indian Minerals, v.28, pp. 39-46.

Mallik, T. K. (1986). Micromorphology of some placer minerals from Kerala beach, India. Mar. Geol., v.71, pp. 371-381.

Mallik, T. K. (1987) Micromorphology of some placer minerals from Kerala beach, India. Mar. Geol., v.71, pp. 371-381.

Manivel, M and Aravindan, S. (1997). Groundwater pollution in and around Sempattu area, Tiruchirappalli, Tamil Nadu. The geography teachers, India, v. 4(2), pp. 22-23.

Mathai, T. and S.B. Nair. (1988). The stages in the emergence of the Cochin-Kodungallur Coast – Evidence for the interaction of marine and fluvial process. Proc. of Ind. Nat. Sc. Academy 54 A (3), 439-447.

Matthess, G. (1982). The properties of Groundwater, John Wiley, New York, 406p.

Matthess, G. (1982). The properties of Groundwater, John Wiley, New York, 406p.

Matthess, G. and Pekdeger, A. (1981). Concepts of a survival and transport model of pathogenic bacteria and virus in groundwater. Proc. Intl. Sympo. on quality of groundwater, Amsterdam.

Maya, K. (2005). Studies on the nature and chemistry of the sediments and water of Periyar and Chalakkudy rivers, Kerala, India. Ph.D (Unpublished) Cochin University of Science and Technology.

MC Kenzie, D. and Scalter, J.C.(1971). The evolution of the Indian Ocean since the Late Cretaceous .Geophy.Jour.Royal.Astro.Soc.25,pp.437-528.

McElwee, C.D. (1980a). Theis's parameter evaluation from pumping tests by sensitivity analysis. Groundwater, v. 18 (1), pp. 56 - 60.

McElwee, C.D. (1980b). The Theis equation; evaluation, sensitivity to storage and transmissivity, and automated fit of pump test data, Kansas Geol. Surv. Groundwater, v.3, pp. 39.

McFarlane, M.J., Chiloton, P.J. and Lews, M.A. (1992). Geomorphological controls on borehole yields: a statistical study in an area of basement rocks in central Malawi ,in The hydrogeology of crystalline basement aquifers in Africa (eds. E.P.Wright and W .G Burgess). Geol.Soc .Spl. Publ.No.66, pp. 131 -54.

McKinney, T.F. and Friedman, G.M. (1970) Continental shelf sediments of Long Island, New York. Jour. Sed. Res., v.40, pp. 213-245.

Menon, G S (1988). Hydrogeological studies in the Kole lands basin, Un.pub, report No.22 CKGW Project, C.G.W.B.

Merh, S.S. (1992). Quaternary sea level changes along Indian coast. Proc. Indian Natl. Sci. Acad ., v. 58A, No. 5, pp. 461-472.

Mishra, G.C. and Chachadi, A.G (1985). Analysis of flow to a large diameter well during th erecovery period, Groundwater,v.23(5), pp.646-651.

Mohan, P.M. (1990). Studies on texture, mineralogy and geochemistry of the modern sediments of Vellar estuary. Ph.D. Thesis (unpublished), Cochin University of Science and Technology, Kochi.

Mohan, P.M., Rajamanickam ,G (2000). Buried placer mineral deposits along the east coast between Chennai and Pondicheri , Jour. Geo .Soci Ind,v.56, pp.1-13.

Moiola, R.J. Spencer, A.B. and Weiser, D. (1974) Differentiation of modern sand bodies by linear discriminant analysis. Trans. Gulf Coast Ass. Geol. Soc., v.57, pp. 324-332

Moony, H.L. (1980). Handbook of Engineering Geophysics, v.2, Electrical Resistivity, bison Instrument, Minneapolis, Minn.

Morton, A.C. (1986) Influences of provenance and diagenesis on detrital garnet suites in the Palaeocene forties sandstone, Central North Sea. Jour. Sed. Petrol., v.57, pp.

Mukhopadhyay, A. (1985). Automated derivation of parameters in a non-leaky confined aquifer with transient flow. Groundwater, v. 23 (6), pp. 806-811.

Murthy, P.S.N. and Veerayya, M. (1981). Studies on the sediments of Vembanad lake, Kerala. Part IV – Distribution of trace elements. Ind. Jour. Mar. Sc., v.10, pp. 165-172.

Murty, C.S., Sastry, J.S. and Varadachari, V.V.R. (1980). Shoreline deformations in relation to shore protection structures along Kerala coast. Indian Jour. Mar. Sci., v.9, pp.77-81.

Murty, P.S.N. and Veerayya, M. (1972a). Studies on the sediments of Vembanad lake, Kerala state: Part I- distribution of Organic matter. Ind. Jour. Mar. Sci., vol.1, pp.45-51.

Murty, Y. G. K., Varadan, G. N., Nair, K. B. Gopalakrishnan, L. S. and Chauhan, R. P. S. (1976). A review of the sedimentary formations of Kerala. Paper presented to the Workshop on Coastal Sedimentaries of India south of 18°N ONGC, Madras.

Nair, K.M. (1998) Quaternary aquifers and Kerala's drinking water problems. In: proceedings of the workshop on groundwater regime monitoring in Keral. Central Ground Water Board, Thiruvananthapuram.

Nair, K.M. and Rao, M.R. (1980) Stratigraphic analysis of Kerala Basin. Symp. on Geology and Geomorphology of Kerala, Spl. Publ. No.5, Geol. Sur. India, pp.1-8.

Nair, K.M., Padmalal, D. and Kumaran, K.P.N. (2006). Quaternary geology of South Kerala Sedimentary basin-An out line, journal of Geological society of India, Vol.67, pp165-180.

Nair, K.M., Padmalal, D. and Kumaran, K.P.N. (2007). Response of Post Middle Miocene tectonics on stratigraphy and geomorphology of offshore-onshore regions of SW coast of India, Paper presented in International work shop on Fluvial and marine process of Cenozoic and formation of placers organized by Centre for Earth Science Studies, Thiruvanathapuram in Nov-2007.

Nair, M.M. (1987). Coastal geomorphology of Kerala. Jour. Geol. Soc. India, v.29, pp.450-458.

Nair, P.K.R and Nair, E.V. (1980). Superposed folding of Precambrian rocks around Ottapalam, Palghat district, Keral. Proc. Semi. On Geology and Geomorphology of Keral, Spl.publ. No.5, Geol. Sur. India, pp.15-18.

Nair, S.K. (1987). Hydrometerological studies of Kerala state in relation to Western Ghats, Ph.D Thesis (unpublished), Cochin University of Science and Technology.

Nair. K.M. and Rao. M.R. (1986). Stratigraphical analysis of Kerala basin,GSI,Spl.pub.No.5.

Najeeb, K.M. (1985). Reappraisal studies in parts of Ernakulam district. Unpub. Rep.CGWB.

Najeeb, K.M. (1999). Groundwater Exploration in Kerala as on 31-3-1999. Central Groundwater Board, Kerala Region, Trivandrum (Unpubl. Report).

Nambiar,C.G, Bhaskara Rao,B.,Parthasarathy,R. and Fedkin,v.v.(1991). Geochemistry and gneisses of charnockites and associated gneisses from northern Keral,India.In:high- grade Metsamorphics.Theiphratue Pub.S.A.,Greece,pp.187-215.

Narasimhan, T.N. (1965). On testing open wells, India, Geohydrology, v. I, pp. 101-105.

Narayana, A.C and Priju.C.P (2006), Landform and shoreline changes inferred from satellite images along the Central Kerala coast, Journal of Geological Society of India,Vol.68,pp35-49.

Narayana, A.C. (2007). Peat deposit of the West coast of India: Implications for environmental and climate changes during Late Quaternary, Journal of coastal research, Special issue 50, pp 683-687.

Narayana, A.C., Priju, C.P. and Chakrabarti, A. (2001). Identification of paleodelta near the mouth of Periyar River in Central Kerala. Jour. Geol. Soc. India, v.57, pp. 545-547.

Narayana. A.C and Priju. C.P. (2002). Late Quaternary peat deposits from Vembanadu lake(lagoon), Kerala, SW coast of India, Current Science,Vol.83,No.3,10.

Narayanan, K. (1958). Report on the geological reconnaissance of Kerala. ONGC Report, Unpublished.

Narayanaswami, S.(1976). Structure and tectonics of Archaean crystalline rocks of Kerala. Proc.Symp. on Geology and Geomorphology of Keral,GeolSyrv.India.

Nayak, G.N. and Chavadi, V.C.(1989). Distribution of heavy minerals in the Beach sediments around Kali River, Karwar, west Coast of India, Geol.Surv.Ind, v.24,pp.241-245.

Nazimudidin.M and Prabhasankar, P.N (1984). Extent and pattern of groundwater use in the coastal belt of Thrissur district-A case study, Technical report GW/R-103/84 of Centre for Water Resources Deveopement and Management, Kozhikode.

Nightingale, H. I. and Binachi, W.C. (1980). Well-water quality changes correlated with well pumping time and aquifer parameters-Fresno, California, Groundwater, v. 18 (3), pp. 274-280.

Nordstrom, E. F. (1977) The use of grain size statistics to distinguish between high and moderate energy beach environments. Jour. Sed. Petrol., v.47, pp. 1281-1294.

Oreelana, E and Mooney, H.M. (1966). Master curves and tables for vertical electrical soundings overlayered structures. Interciencia, Madrid.

Padmalal, D. (1992), Mineralogy and geochemistry of the sediments of the Muvattupuzha river and central Vembanad estuary, Kerala, India. Ph.D Thesis (unpublished), Cochin University of Science and Technology, 122 p.

Padmalal, D. (1992), Mineralogy and geochemistry of the sediments of Muvattupuzha river and Central Vembanad estuary, Kerala, India. Ph.D. Thesis, Cochin University of Science and Technology, Cochin.

Padmalal, D. and Seralathan, P. (1991). Interstitial water-sediment geochemistry of P and Fe in the sediments of Vembanad lake, west coast of India. Ind. Jour. Mar.Sci., vol. 20, pp. 263-266.

Padmalal, D., Ramachandran, K.K. and Seralathan, P.(1998). Significance of heavy mineral suite in riverine and estuarine sediments in south west coast of India – A case study , Indian. Jour. Mar. Sci. v. 27, pp. 185-189.

Palacky, G, J and Jagodis, F.L. (1975). Computer data processing and quantitative interpretation of airbone resistivity surveys. Geophysics, v. 40, pp. 818 -30

Palacky, G.J., Ritsema I.L. and deJong, S.J. (1981). Electromagnetic prospecting for groundwater in Precambrian terrains in the Republic of Upper Volta (Burkino Faso). Geophysical Prospecting, v. 29, pp 932-955.

Paliwal, B. S. and Khilnani, M. (2001). Electrical resistivity data to assess aquifer parameters for better interpretations of hydrogeology: A study of the Nagaur region Rajasthan, eds. Bhu. H and Agrawal. Proc. of the National Seminar on ground water resources, Dept. of geology, MLS University, Udayapur, pp. 48-67.

Paliwal, K.V. and Yadav, B.R. (1976). Irrigation water quality and crop management in the Union Territory of Delhi. Water Tech. Center, Indian Agricultural Research Institute, New Delhi.

Pandarinath, K., Shankar, R. and Yadava, M.G. (2001). Late Quaternary changes in sea level and sedimentation rate along the SW coast of India: Evidence from radiocarbon dates. Curr. Sci ., v. 165, pp. 594-600.

Pandian. K and Sankar. K (2007). Hydrochemistry and groundwater quality in Vaippar River basin,Tamil Nadu, Journal of Geological society of India, Special section on groundwater, Vol.69, pp 970-983.

Pant, R. K. and Juyal, N. (1993). Late Quaternary coastal instability ans sea level changes: New evidence from Saurashtra coast, Zetishrift. Geomorphol., v. 37, pp. 9-40.

Papadopulos, I. S. and Cooper, H.H. Jr. (1967). Drawdown in a well of large diameter. Wat. Res., v. 3, pp. 241- 244.

Passega, R. (1957) Texture as a characteristic of clastic deposition. Bull. Amer. Assoc. Petrol. Geol., v.14, pp. 1952-1984.

Passega, R. (1964) Grain size representation by CM patterns as a geologic tool, Jour. Sed. Petrol., v.34, pp. 830-837.

Patangay, N. S. and Murali, S. (1984). Geophysical Surveys to locate groundwater prospecting - lectures, on Exploration Geophysics for geologist and engineers (eds. Bhimasankaram, V.L.S and Gaur, V.K., Pub. AEG, Hyderabad), pp. 375- 404.

Patro, B.C., Sahu, B.K. and Guru, S. (1989) A study of heavy mineral sands of Gopalpur beach, Orissa. Jour. Geol. Soc. India, v.33, pp. 243-252.

Paulose, K.V. and Narayanaswami, S. (1968). The Tertiaries of Kerala coast. Mem. Geol. Soc. India., no.2, pp.300-308.

Pettijohn, F.J. (1941). Persistence of heavy minerals and geological age. Jour. Geol., v.49, pp.610-625.

Pettijohn, F.J. (1957). Sedimentary rocks. Harper and Row, New York, 718 p.

Piper, A.M. (1944). A graphic procedure in the geochemical interpretation of water analyses, Trans. Am. Geophy. Union, v. 25, pp. 914 - 928.

Pisharody, P.R. (1992). Keralathile Kalavasta (Climate in Kerala). State Institute of Language Publ. 26p. (in Malayalam).

Prabhakara Rao, G. (1968). Sediments of the nearshore region of Neendakara coast and the Ashtamudi and Vetta estuaries, Kerala, India. Bull. Natl. Inst. Sc., v.30, pp. 513-551.

Pradeep, K. Naik and Arun, K. Awathi (2007). Estimation of shallow aquifer parameters from large diameter wells in Basalts, Journal of Geological society of India, Special section on groundwater, Vol.69, pp 949-959.

Purandara B K (1993). Texture and mineralogy of Periyar river, (South- west coast of India). Indian Jour. Mar. Sci. vol.2, PP 78-80.

Purandara, B.K. (1990). Provenance, sedimentation and geochemistry of the modern sediments of the mud banks of the Central Kerala coast, India. Ph.D. Thesis (unpublished), Cochin University of Science and Technology, Kochi.

Purandara, B.K., Unnikrishnanan , V.P., Gupta, C.S. and Dora, Y.L. (1987). Textural and mineralogical studies on the beach sands from Fort Cochin to Chellanum. Jour. Geol. Soc.India, v.30, pp. 524-531.

Radhakrishana, T., Joseph, M., and Tambi, P.K (1990). Phanerozoic mafic dyke intrusion from the high grade terrain of south western India: K-Ar isotope and geochemical implications. In: Mafic dykes and emplacement mechanism,(Eds) parker,Rickwood and Tucker, Balkema, Roterdam, pp.336-372.

Raghava Rao, G. (1976). Groundwater Exploration, Development and long term aquifer management in Kerala. Proc. Symp. Mineral Resources of Kerala and their utilization, Trivandrum, Oct 18-19, 1975. Pp.30-36.

Raghunath, H.M. (1987). Geochemical surveys and water quality. Groundwater, Wiley Eastern Limited, New Delhi, pp. 343- 347.

Rajagopalan, P.T., Abhram, S. and Prabha Sanker, P.N. (1983). Pumping tests and analysis of test data from open wells in the coastal tract of Trivandrum Dist. Rrp. GW/R-92/83, Ground Water Division, CWDRM, Calicut.

Rajaguru, S.N., Gupta, A., Kale, V.S., Mishra, S., Gangoo, R.K., Eli, L.L., Enzel, Y. and Baker, V.R. (1995) Channel forms and processes of the flood dominated Narmada River, India. Earth Surface Processes and Landforms, v.20, pp. 407-421.

Rajamanickam, G.V. (1983). Geological investigation of offshore heavy mineral placers of Konkan coast, Maharashtra, India.. Ph.D. Thesis, Department of Applied Geology, Indian School of Mines, Dhanbad, Bihar, India.

Rajamanickam, G.V. and Gujar, A.R. (1985). Indications given by the median distribution and CM patterns on clastic sedimentation in Kalbadevi, Mirya and Ratnagiri bays, Maharashtra, India. Gordanale di Geologia. v.47, pp. 237-251.

Rajamanickam, G.V., and Gujar, A.R. (1984). Sediment depositional environment in some bays in central west coast of India. Ind. J. Mar. Sci., v. 13, pp. 53-59.

Rajamanickam, G.V., and Gujar, A.R. (1997). Grain size studies on the nearshore sediments of Jaigad, Ambwah and Varvada Bays, Maharashtra. Jour. Geol. Soc. Ind., v.49, pp. 567-576.

Rajamanickam,G. Victor., Verma. O.P, and Gujar. A.R. (1986). Grain size studies from the near shore sediments off Joigad, Maharastra, Indian Association of sedimentologist, convection VI, Abstracts. V. 7, pp. 70-71.

Rajan, R.V. (2006). Texture, Mineralogy and Geochemistry of sediments from the coastal plains between Kodungallur and Chellanam, Central Kerala, India, Ph.D thesis submitted to the Cochin University of Science and Technology, Kerala, India.

Rajendran, C.P,Rajagopalan,G and Narayanswamy (1989). Quaternaru geology of Keral: evidence from radiocarbon dates,jour.Geo.Soc.India,v.33,pp-218-322.

Rajendran, S., Karthikeyan, P., Seralathan, P. (1996). Heavy mineral and geochemical studies of lower Bhrathapuzha sediments, Kerala, Jour. Geol. Soci. India. v. 48, pp. 319-324.

Rajesh Raghunath., Sreedhara Murthy, T.R. and Raghavan, B.R. (1999). Aquifer parameter evaluvation of Nethravathi river basin, Karnataka state, India, Jour. App. Hydr., v. XII (1), pp. 46-51.

Rajesh Raghunath., Sreedhara Murthy, T.R. and Raghavan, B.R. (2001). Spatial distribution of pH, EC and total dissolved solids of Nethravathi river basin, Karnataka state, India, Pollu. Res., v. 20 (3), pp. 413-418.

Raju, T.S. and Raghava Rao, K.V. (1967). New approach to the analysis of pump test data of an open well. Paper presented at Symp. on Ground and Lake water resources of India., Hyderabad.

Ramanujachary, K.R and Balakrishna, S. (1985). Resistivity investigations in different geological terrains, Groundwater news, NGRI, pp. 1-14.

Rao, B. R. J. and Datta, P. M. (1976). Foraminiferal and Ostracod Fauna of the early Miocene beds of Kerala coast and their stratigraphic significance. Paper presented to the Workshop on Coastal Sedimentaries of India south of 18°N ONGC, Madras.

Rao, P. S. (1974). Some aspects of structure and Tectonics of the Keral region and related mineralization. Proc. Symp. On Tectonics amd Metallogeny of DSouth East Asia and far east. Geo. Surv. India, Misc. publ.34, part 3, pp.51-64.

Rao, V. P., Veerayya, M., Thamban, M. and Wagle, B.G. (1996). Evidences of Late Quaternary neotectonic activity and sea level changes along the western continental margin of India. Curr. Sci., v. 71, pp. 213-219.

Rao, R. P. and Talukdar, S.N. (1980). Petroleum geology of Bombay high field India, In: M.T. Halbouty(Ed) Giant oil and gas fields of decade,AAPG Mem.30,pp.487-505.

Rasheed, K., Joseph, K.A. and Balchand, A.N. (1995). Impacts of harbour dredging on the coastal shoreline features around Cochin. Proceedings of the international conference on 'Coastal Change 95' (Bordomer-IOC, Bordeaux, France). pp. 943-948.

Rashid Umar, Izrar Ahamed and Fakhre Alam. (2009). Mapping of groundwater vulnerable zones using modified DRASTIC approach of an alluvial aquifer in parts of Central Ganga Plain, Western Uttar Pradesh. Jour.geo.Soc. India, vol. 73,pp.193-201.

Ravindrakumar G. R., Srikanthappa, C. and Handsen, E. C. (1985). Charnockite formation at Ponmudi, Southern India, Nature. V. 313, PP 207-209.

Rayner, F. A. (1980). Pumping test analysis with a handheld calculator. Groundwater, v. 18 (6), pp. 562- 568.

Reddy. K.S.N., Lakshmi Prasad .M and Babu Rao.N. (2007). Relationship of heavy mineral distribution in different micro-environment to seasonal changes of beach process in an embayment beach of Yarada-Gangavaram, north coastal Andrapradesh, Journal of Geological society of India, Vol.70, pp 963-975.

Rengarajan, R. and Balasubramanian, A. (1990). Corrosion and scale formation characteristics of groundwater in and around Nangavalli, Salem district, Tamil Nadu, Jour. App. Hydro., v. 3 (2), pp.15- 22.

Report of the groundwater resource estimation committee (1997). Groundwater resource estimation methodology-1997, Ministry of water resources, Government of India, New Delhi.

Rittenhouse, G. (1943). Transportation and deposition of heavy minerals. Geol. Soc. Amer. Bull., v.54, pp. 1725-1780.

Rojas, R., Howard and Bartram, J. (1993). Bacteriological groundwater quality of Lima water supply. Groundwater Quality, 17th special report, eds. H. Nash and G.J.H. McCall, Chapman and Hall pub., pp.159-167.

Romani, S (1987). Application of Papadopulose –Cooper method for analysis of pumping test data of large diameter wells, Bhujal, vol.2, No.1.

Ruston, K.R. and Singh, V.S. (1983). Drawdowns in large diameter wells due to decreasing abstraction rates. Groundwater, v. 21 (6), pp. 670- 677.

Ruta, B.Limaya., Kumaran, K.P.N., Nair, K.M. and Padmalal, D.(2007). Non pollen poly nomorphs as potential palaeoenvironmental indicators in the Late quaternary sediments of the west coast of India, Current science, Vol.92, No.10.

Sabu Joseph and Thrivikramaji, K. P. (2002). Kayals of Kerala Coastal Land and Implication to Quaternary Sea Level Changes In: A.C. Narayana, (Ed.), Late Quaternary Geology of India and Sea Level Changes, Mem. Geol. Soc. India, No. 49, pp. 51-64.

Sahu, B. K. (1964). Depositional mechanism from the size analysis of classic sediments. Jour. Sed. Petrol., v.36, pp. 73-83.

Sakthimurugan, S. (1995). Hydrogeological studies and simulation of contaminant migration in and around Dindigul, Anna district, Tamil Nadu, Ph.D Thesis (unpublished), M.S. University, Tirunelveli, 214p.

Sakthimurugan, S. and Balasubramanian, A. (1991). Resistivity measurement over granular porous media saturate with fresh and salt water, Regional Sem. Groundwater Development problems in Southern Kerala, pp. 43- 53.

Saleem, Z. A. (1970). A computer method for pumping test analysis, Groundwater, v. 8 (5), pp.21-24.

Sallenger Jr., A.H. (1979). Inverse grading and hydraulic equivalents in grain flow deposits. Jour. Sed. Petrol. V. 49, pp. 553-562.

Sammel, E. A. (1974). Aquifer tests in large diameter wells in India, Groundwater, v. 12, pp. 265-272.

Sampath, S. and Vinayak, P.V.S.S.K.(1989). Rainfall in Kerala. Report, CESS, Thiruvanathapuram, 17p.

Samsuddin, M. (1986). Textural differentiation of offshore and breaker zone sediments on the northern Kerala coast, India. Sed. Geol., v.46, pp. 130-145.

Samsuddin, M. (1990). Sedimentology and mineralogy of the beach, strand plain and inner shelf sediments of the northern Kerala coast. Ph.D. Thesis, Cochin University of Science and Technology, Cochin.

Sankar, K. (2002). Evaluation of groundwater potential zones using remote sensing data in Upper Vaigai river basin, Tamil Nadu, India, Jour. Indian Soc. Rem. Sens., v. 30 (3), pp. 119-129.

Sankar, K., Jegatheesan, M. S. and Balasubramanian, A. (1996). Geoelectrical resisitivity studies in the Kanayakumari district, Tamil Nadu. Jour. App. Hydro., v. IX, (1&2), pp. 83-90.

Sankaranarayanan, V. N., Udayavarma, P., Balachandran, K.K., Pylee, A. and Joseph, T. (1986). Estuarine characteristics of the lower reaches of the river Periyar (Cochin backwater). Indian Jour. Mar. Sci., v.15, p.166-170.

Santhosh, M and Drury S A (1988). Alkali Granite with Pan African affinities from Kerala, South India. Jour. Geol. Ind. V. 96, PP 616-626.

Santschi, P, Hohener,P,Binoit,G,and Brink,M.B.(1990).Chemical processes at the sediment-water interface.Mar.Chem.v.30,pp.269-315.

Sarma, J.V. V. and Sarma, N.K. (1982). Geomorphometric studies of Upper Sarada river basin, Proc. Sem. hydrological investigations during the last 25 years in India, pp. 217-224.

Sarma, R. K. and Sharma, T.K. (1987). Groundwater and tube well irrigation, A text book on Hydrology and water resources, Dhanpet Rai and Sons, New Delhi.

Sasidharan, K. and Damodaran, K.T. (1988). Texture and mineralogy of the beach sands of northern part of Kerala coast. Mahasagar, v.21, pp. 209-218.

Sastri, J. C.K. (1976). Chemical quality of waters from different lithological units in Karnataka tate, Nat. Symp. v. HPDPI, Kanpur, C11 pp 1-6.

Sathiyamoorthy, K. and Banerjee, B. (1985). Resistivity surveys locating brine pockets in the Little Rann of Kutch, Gujarat, Jour. Assoc. Exploration Geologists, v. 5 (3), pp. 8 -14.

Satyanarayana, K. (1973). Studies on some aspects of the modern deltaic sediments of the Mahanadi river, India. Ph.D. Thesis (unpublished), Andhra University, Waltair.

Seetharamaiah, J., Gandhi., M.S., Bhagavan., K.V.S and Bhanumurthy,.P.(2000). Environment and lithology of barrier-lagoon system south of Nilarevu river, East Godavari district, AP, Vishaka Science journal, Vol.4, pp 125-132.

Seetharamaswamy, A. (1970). Studies on some aspects of modern deltaic sediments of the Krishna river, India. Ph.D. Thesis (unpublished), Andhra University, Waltair.

Sengupta, R., Bhattacharya, S. Rana, R.S., Mitra, S.K. and Jain, V.K. (1990). Preliminary studies of offshore heavy mineral placers, Gopalpur-Chatarapur Coast, Orissa. Ind. Jour. Geol. V. 62. pp. 27-37.

Seralathan, P. (1979). Studies on texture, mineralogy and geochemistry of the modern deltaic sediments of Cauvery river, India. Ph.D. Thesis (unpublished), Andhra University, Waltair.

Seralathan, P. (1984). Use of textural (CM) pattern for identification of depositional processes and environment of sediments of Cauvery delta. Bull. Dept. Mar. Sci., University of Cochin, v.14, pp. 17-26.

Seralathan, P. (1987).Trace element geochemistry of modern deltaic sediments of the Cauvery river.east coast of India.Ind,.jour.mar.Sci.v.16,pp.31-38.

Seralathan, P. (1988). Use of textural (C.M) pattern for identification of depositional process in the sediments of the cauvary delta. Bull. Dept.Mar.Sci., V.14, pp.17-26

Seralathan, P. and Padmalal, D. (1993). Heavy metal contents in suspended particulates and bed sediments of a tropical perennial river and estuary, central Kerala, Jour. Geol. Soc. Ind., v.42, pp. 349-355.

Seralathan, P. and Padmalal,D. (1993). Heavy metal contents in suspended particulates and bed sediments of a tropical perennial river and estuary, central Kerala, Jour. Geol. Soc. Ind., v.42, pp. 349-355.

Sharma, G. S., (1978). Upwelling off the southwest coast of Indian Journal of Marine Sciences, v. 7(4), pp. 209-218.

Short, A. D, Buckley, R.C and Fotheringham, D.G (1991). Preliminary investigation of beach ridge progradation on Eyre Peninsula and Kangaroo Island. Trans.R.Soc. Aust., v.113, pp .145-161.

Siddique, H.N., Rajamanickam, G.V., Almeida, F. (1979). Offshore ilmenite placers of Ratnagiri, Konkan coast, Maharashtra, India. Mar. Mining., v.2, pp. 91-118.

Singerland, R.L. (1984). The role of hydraulic sorting in the origin of fluvial placers. Jour. Sed. Petrol. V. 54, pp.137-150

Singerland, R.L. (1984). The role of hydraulic sorting in the origin of fluvial placers. Jour. Sed. Petrol. V. 54, pp.137-150.

Singh, S.N. and Mesh A.J. (1982). Groundwater conditions along coastal areas of Saurashtra with special reference to the problem of salinity in Mangrol-Kodinar area. First National seminar on Quaternary environment (Recent researches in Geology vol. 9). (ed. S.S. Mesh) Hindustani Publishing Corp. India, pp. 61-74.

Singh, V.S. and Thangarajan, M. (1998). Estimation of parameters of crystalline rocks aquifers: A case study, Jour. Geol. Soc. India, v.52, pp. 333-336.

Singhal, B.B.S. (1973). Some observations on the occurrence, utilisation and management of groundwater in the Deccan trap areas of central Maharashtra, India, Proc. Int. Nat. Sym. Development of groundwater resources, Madras, India, v.3, pp.75-81.

Singhal, B.B.S. and Gupta R.P. (1999). Applied Hydrogeology of fractured rocks, Kulwer Academic Publishers, The Netherlands, 400 p.

Singhal, D.C. (1984). An integrated approach for groundwater investigation in hard rock areas. A case study; International workshop on rural hydrogeology and hydraulics in fissured basement area, pp. 87- 93.

Sivaganam, N and Kumaraswamy, K. (1983). Ground water quality in Vaippar basin, South India, The Indian Geographical Jour., v. 58 (2), pp. 127-140.

Slichter, C.S. (1906). The under flow in Arkansas valley in Western Kansas, USGS water supply paper 153, 61 p.

Sly, P.G., Thomas, R.L. and Pelletier, B.R. (1982). Comparison of sediment energy texture relationships of light and heavy minerals in sand. Jour. Sed. Petrol., v.47, pp. 753-770.

Smedly, P.L. (1992). Relationship between trace elements in water and health ,with special reference to developing countries . Interim Report 1992 BGS. Tech., Report WD/92/3933p.

Soils of Kerala. (1978). Soil survey branch, Department of Agriculture, Govt, of Kerala.

Soman, K., (1997). Geology of Kerala: Geological society of India, Bangalore, India, 336p.

Soman, K., Machado, T., (1986). Original and depositional environment of the china clay deposits of south Kerala. Proce. Ind. Acad. Sci. (Earth.Planet.Sci.) V. 95, PP 285-292.

Sreekumar, S and John Thomas, K. (2004). Metamorphism of Muriyad kayal with in Vembanad-Kol wet land system due to human intervension, Nature Environment and Pollution Technology,Technosicence publications,Vol.3, pp 179-184.

Sridharan, K., Mohan Kumar, M.S. and Sekhar, M. (1995). Groundwater flow and storage in hard rocks aquifers, Proc. workshop on artificial recharge of groundwater in granite terrain, CGWB, pp. 86-107.

Stapor, F.W, Mathews. T..D, and Lindefors-Kearns.F.E (1991). Barrier island progradation and Holocene sea level history in south west Florida. Jour. Coastal. Res., v. 77, pp. 815-838

Stapor, F.W. and Tanner, W.F. (1975). Hydrodynamic implications of beach, beach ridges and dune grain size studies. Jour. Sed. Petrol., v.45, pp. 926-931.

Stewart, M.T., Michael Layton and Theodore Linazec (1983). Application of resistivity surveys to regional hydrogeologic reconnaissance. Groundwater, v.21(1), pp.42-48.

Stiff, H.A. Jr. (1951). The interpretation of chemical water analysis by means of patterns, Jour. Petrol. Tech., v. 3 (10), Tech., Note 84, pp. 15- 16.

Strahler, A.N. (1957). Quantitative analysis of watershed geomorphology, Am. Geophy. Union. Trans.,v.38, pp. 913-920.

Streltsova, T.D. (1974). Drawdown in compressible unconfined aquifer, Jour. Hydraul. Div. Am. Soc. Civil Engg., v. 100 (HY 8), pp. 1601- 1616.

Subrahmanya, K.R. (1996). Tectonic, eustatic and isostatic changes along the Indian coasts, In: J.D. Millman and B.U. Haq (Eds.), Sea level rise and coastal subsidence, Kluwer Acad. Publishers, Boston, USA, v.1, pp. 193-199.

Subramanian, S. (1994). Hydrogeological studies of the coastal aquifers of Tiruchendur, Tamil Nadu, Unpublished Ph.D. Thesis (Manonmaniam Sundaranar University, Tirunelveli), 308p.

Subramanian, V., Vant Dack, L and Van Gricken, R, (1985) Chemical composition of river sediments from the Indian subcontinent. Chem.Geol.v.49, pp. 271-279.

Subramanyan, A. (1975). Specific capacity of wells in hard rocks -A study, Sym. Hydrology Roorkee., v. 8, pp. 16- 49.

Summers, W.K. (1972). Specific capacity of wells in crystalline rocks. Groundwater, v. 10 (6), pp. 37- 47.

Sundaresan Pillai, J. (1989). Studies on siltation in Cochin harbour-Dynamics of suspensate. Ph.D. Thesis, Cochin University of Science and Technology, Cochin.

Tanner, W.F and Demirpolat.S., (1988). New beach ridge type. Severely limited Fetch, very shallow water. Trans. Gulf coast. Assoc. Geol. Soc., v. 38, pp. 367-373.

Tanner, W.F, (1988). Beach ridge data and sea level history from the Americas. Jour. Coastal. Res., v. 4, pp. 81-91.

Tanner, W.F., (1987). Spatial and Temporal factors controlling over topping of coastal ridges. In: V.P.Singh (Editor), Flood Hydrology. Klauwer, Dordrecht, pp.241-248.

Taylor, G.C. and Oza, M.M. (1984). Geology and Groundwater of the Dudhai area, Eastern Kutch (India), Geol. Surv. Ind. Bull., Ser. B (5), pp.35-75.

Taylor, R.G. and Howard, K.W.F. (1994). Groundwater quality in rural Uganda: hydrochemical consideration for the development of aquifers within the basement complex of Africa Groundwater Quality, 17th special report, eds. H. Nash and G.J.H. McCall, Chapman and Hall pub., pp. 31-43.

Telford, W.M., Geldart, L.P., Sheiff, R.E. and Keys, D.A. (1990). Applied Geophysics. Cambridge University press, 770 p.

Theis, C. V. (1935). The relation between the lowering of the piezometric surface and the rate and the duration of discharge of a well using groundwater storage Am. Geophy. Union Trans., v. 16, pp. 519- 524.

Thom,B.G; Bowman, G M., Gillespie, R, Temple, R.and Barbetti, M., 1981. Radiocarbon dating of Holocene beach ridge sequences in south west Australia. Mar.Geol.,V.56:, pp.137-158.

Thrivikramaji, K.P. (1987). On the evolution of the estuary barrier system between N. Lats. 12° 5¢ and 12° 15¢, Cannanore district, Kerala. Jour. Geol. Soc. India, v.29, pp.405-411.

Tipper, G H. (1914). The monazite sands of Travancore. Rec. Geol. Sur. Ind., v. 45, pp. 186-195.

Todd, D.K. (1980). Groundwater Hydrology, 2nd edn. John Wiley New York, 535p.

Tomas, A., Sharma, A.K., Manoj, K.S. and Anil Sood. (1999). Hydrogeomorphological mapping in assessing groundwater by using remote sensing data- A case study in Lehra Ganga block, Sangrur district, Punjab. Jour. Indian Soc. Rem. Sens., v. 27 (1), pp. 31-42.

Trilochan Dass (1972). Determination of transmissibility and storage coefficient in shallow open wells in hard rock terrain. Paper presented at Sem. on problems in ground development, Madras.

Trivedi, R.K. and Goel, P.K. (1986). Chemical and biological methods for water pollution studies. Environmental publication, Karala.

U.S. Salinity Laboratory (1954). Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agri. Hand book, 160pp.

UNESCO, (1979). Water in crystalline rocks SC-77/WS/71,UNESCO, Paris, 344 p.

UNESCO/ IAHS, (1967). Proceedings Dubrovnik symposium on hydrogeology of fractured rocks, v. I & II, UNESCO, Louvain, Belgium.

Unnikrishnan, V.P. (1987). Texture, mineralogy and provenance of the beach sands of south Kerala. Ph.D. Thesis, Cochin University of Science and Technology, Kochi.

Vaidyanathan, R. (1964). Geomorphology of Cuddapah basin. Jour. Indian Geosciences Assoc, v. 4, pp. 29-36.

Varadarajan, K. and Balakrishnan, M. K. (1976). Geomorphology of the Kerala Coastal Belt. Paper presented to the Workshop on Coastal Sedimentaries of India south of 18°N ONGC, Madras.

Venugopal, T.N. (1998). Hydrogeological investigation in the Arkavathi river basin -A tributary of Cauvery river, Karnataka, Ph.D Thesis (unpublished), Mysore University, p. 224

Verma, R.K, Rao, M.K. and Rao, C.V. (1980). Resistivity investigation for groundwater in Metamorphic areas near Dhanbad, India, Groundwater, v. 18 (1), pp. 46-55.

Visher, G. S. (1969) Grain size distributions and depositional processes. Jour. Sed. Petrol., v.39, pp. 1074-1106.

Viswanathiah, M.N. and Sastri, J.C.V. (1973). Hydrogeochemistry of the Precambrian graywackes and chloriteschists of certain areas of Mysore state. Proc. Sem. v.6. Water well drilling in hard rock areas of India, Bangalore, pp. 155-169.

Viswanathiah, M.N., and Sastri, J.C.V. and Ramegowda, B. (1978). Specific capacity of wells in some hard rocks of Karnataka, Jour. Geol. Soc. India, v.19, pp. 426-430.

Vredenberg, E.W.(1906) Pleistocene movement in Indain peninsula,Rec.Geol.Surv.India,v.33, part-1,pp-1-64.

Wagle, B.G., Vora, K.H., Karisiddiah, S.M., Veerayya, M. and Almeida, F. (1994). Submarine terraces on the western continental shelf of India: Implications for sea level changes. Mar. Geol., v.117, pp. 207-225.

Walton, W. C. (1962). Selected analytical methods of well and aquifer evaluation, Illinois State Water Sur. Bull., v. 49, 31 p.

Walton, W.C. (1970). Comprehensive analysis of water table aquifer test data. Groundwater, v. 16, pp. 311-317.

White, A.F., Benson, S.M., Yee, A.W., Woiienberg, H.A. and Flexser, S. (1991). Groundwater contamination at Kesterson reservoir, California- geochemical parameters influencing selenium mobility. Water Resource, Res., v. 27, pp.1085-1098.

WHO (1984). Guide lines for drinking water quality, V.I. Recommendations, Geneva.

Wilcox, L.V. (1955). Classification and use of Irrigation waters, U.S. Department of Agriculture circle, Washington, 969 p.

Williams, S.C., Simpson, H.J., Oslen, C.R. and Bopp, T.P. (1978). Sources of heavy metals in sediments of the Hudson river estuary. Mar. Chem., v.6, pp. 195-213.

Wong, F.L. (2002) Heavy mineral provinces of the Palos Verdes margin, Southern California. Continent. Shelf. Res, v.22, pp. 899-910.

Woods, L. (1990). Groundwater quality in the Nore River Bain, Republic of Ireland. M.Sc. dissertation (unpublished), University College, London.

Worthington, P. F. (1977). Geophysical investigation of groundwater resources in Kalahari Basin, Geophysics, v. 42 (4), pp. 838- 849.

Wright, E.P. and Burgess, W.G. (eds) (1992). The Hydrogeology of crystalline basement aquifers in Africa, Geol. Soc. Special Pub. No. 66, The Geological Society , London , 264p.

Yeh, H.D. (1987). Theis solution by non-linear least squares and finite difference Newton's method. Groundwater, v. 25, pp. 710-115.

Zaporozec, A. (1972). Graphical interpretation of water quality data. Ground Water, v. 10(2), pp. 32-43.

Zhdankus, N.T. (1974). Analysis of shallow hard rock well pumping and recovery test data, Groundwater, v.12, pp. 310-317.

Zhu, Z. and Evans, D.L. (1994). U.S. forest type and predicted prevent forest cover from AVHRR data: Photogrametric Engg. Rem. Sens., v. 60, pp.525-531.

Zohdy, A.A.R., Eaton, G.P. and Mabey, D.R. (1974). Application of surface Geophysics to groundwater investigations, USGS, chapter 1, 116 pp.

APPENDIX

Table 5.6 Chemical characteristics of groundwater in dug wells (phreatic shallow aquifer) of Palaeo-lagoon (Kole land basin) for the period 01.01.2000 to 31.12.2006.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Well No	Location	Sampling date	pH	EC (µmhos/ cm)	TDS (mg/l)	TH (mg/l)	Alk (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	F mg/l)	Fe (mg/l)	Si (mg/l)	Cl (mg/l)	SO4 (mg/l)	CO3 (mg/l)	HCO3 (mg/l)	NO3 (mg/l)
OW-1	Thrissur	23/10/2001	8.10	130.00	72.00	50.00	20.00	12.00	4.80	8.00	5.70	0.00	0.00	20.00	23.00	4.00	0.00	24.40	2.20
OW-1	Thrissur	20/07/2002	7.20	210.00	126.00	35.00	11.76	10.00	2.41	17.70	7.60	0.00	0.74	NA	26.30	46.00	0.00	14.34	7.97
OW-1	Thrissur	11/08/2003	7.20	190.00	114.00	34.00	14.60	2.20	0.00	16.20	7.50	0.80	0.03	NA	24.50	1.39	0.00	21.80	7.30
OW-1	Thrissur	07/05/2005	7.10	200.00	120.00	40.00	12.00	12.10	2.46	13.00	7.00	0.26	0.30	NA	31.00	2.80	0.00	14.60	8.60
OW-1	Thrissur	07/02/2006	8.09	270.00	162.00	94.30	58.00	31.16	4.00	10.50	7.80	0.22	0.20	NA	19.20	2.25	2.40	65.88	8.60
OW-2	Mannuthi	27/09/2002	7.70	80.00	48.00	20.00	17.60	6.00	1.20	6.70	3.20	0.22	0.10	NA	12.80	4.20	0.00	21.50	1.40
OW-2	Mannuthi	11/08/2003	7.20	70.00	42.00	20.00	9.80	3.20	0.00	7.80	2.80	0.64	0.03	NA	13.60	1.62	0.00	14.50	2.64
OW-2	Mannuthi	21/11/2003	7.20	60.00	36.00	15.00	9.80	4.00	1.20	9.00	2.80	0.12	0.10	NA	12.00	3.30	0.00	11.96	1.54
OW-2	Mannuthi	01/03/2004	7.30	80.00	48.00	15.00	10.00	2.00	2.40	5.80	2.70	0.78	0.20	NA	11.00	3.90	0.00	12.20	BDL
OW-2	Mannuthi	14/05/2004	7.10	90.00	54.00	15.00	20.00	6.00	0.00	6.40	2.50	0.00	0.01	NA	10.00	2.00	0.00	24.40	2.98
OW-2	Mannuthi	13/08/2004	7.20	70.00	42.00	22.00	9.00	1.70	4.20	5.80	2.70	0.00	0.20	NA	11.00	5.60	0.00	10.90	2.20
OW-2	Mannuthi	15/02/2005	7.90	110.00	66.00	35.00	31.00	10.10	2.50	7.80	2.70	0.00	0.24	NA	15.00	2.00	0.00	37.80	0.87
OW-2	Mannuthi	04/05/2005	7.30	73.00	43.80	20.00	12.00	4.04	2.46	5.10	2.50	0.41	0.19	NA	16.50	2.00	0.00	14.60	2.10
OW-2	Mannuthi	02/09/2005	7.40	80.00	48.00	25.00	13.30	6.10	2.50	3.30	3.10	0.56	0.08	NA	12.50	2.10	0.00	16.25	1.94
OW-2	Mannuthi	07/02/2006	7.91	184.00	110.40	61.50	50.00	21.32	2.00	2.40	3.50	0.22	0.30	NA	9.60	1.00	0.00	61.00	2.70
OW-3	Pttikkad	27/09/2002	8.40	220.00	132.00	70.00	58.80	22.00	3.70	8.00	5.20	0.47	0.15	NA	12.80	6.40	0.00	71.70	1.70
OW-3	Pttikkad	11/02/2003	7.70	120.00	72.00	48.00	35.80	5.12	3.90	15.80	3.20	0.00	1.20	NA	8.20	4.20	0.00	53.30	3.20
OW-3	Pttikkad	26/02/2004	7.90	220.00	132.00	59.00	40.00	17.70	3.60	6.80	4.20	0.62	0.50	NA	13.00	2.60	0.00	48.80	2.00
OW-3	Pttikkad	16/08/2004	8.30	190.00	114.00	82.00	70.20	25.80	4.20	6.10	4.20	0.20	0.79	NA	11.00	7.30	2.20	81.30	2.40
OW-3	Pttikkad	03/11/2004	8.20	170.00	102.00	70.00	60.80	20.00	4.90	7.70	3.90	0.70	0.43	NA	12.00	4.40	4.50	64.90	2.08
OW-3	Pttikkad	09/02/2005	8.10	130.00	78.00	41.00	46.60	8.10	4.90	8.00	3.70	0.77	0.41	NA	14.00	3.30	2.30	52.10	0.40
OW-3	Pttikkad	02/09/2005	8.34	200.00	120.00	71.00	59.90	18.20	6.20	6.50	4.30	0.84	0.32	NA	12.50	6.80	2.67	67.71	1.88
OW-3	Pttikkad	07/02/2006	8.02	133.00	79.80	41.00	36.00	0.00	10.00	4.90	4.20	0.40	0.98	NA	7.68	3.50	0.00	43.92	BDL
OW-4	Pudukkad	17/07/2002	4.90	110.00	66.00	20.00	11.76	2.00	3.62	13.60	1.80	1.00	0.51	NA	22.70	5.00	0.00	14.30	4.41
OW-4	Pudukkad	14/08/2003	6.90	110.00	66.00	20.00	14.60	2.40	1.20	13.20	2.20	0.78	0.02	NA	19.10	1.27	0.00	21.80	4.46
OW-4	Pudukkad	07/11/2003	7.00	160.00	96.00	20.00	9.80	4.00	2.50	14.80	2.40	0.88	0.50	NA	22.00	2.40	0.00	11.90	4.72
OW-4	Pudukkad	01/03/2004	7.10	150.00	90.00	20.00	10.00	5.90	1.20	12.30	2.40	0.96	0.20	NA	21.00	1.70	0.00	12.20	4.56
OW-4	Pudukkad	17/05/2004	7.60	160.00	96.00	50.00	30.00	18.00	1.20	10.70	1.70	0.07	0.02	NA	18.00	- 3.20	0.00	36.60	3.75
OW-4	Pudukkad	04/11/2004	6.90	110.00	66.00	15.00	5.70	2.00	2.40	12.80	2.20	0.68	0.14	NA	21.00	1.30	0.00	6.90	5.60
OW-4	Pudukkad	16/02/2005	7.40	140.00	84.00	15.00	7.80	4.10	1.20	15.20	2.70	0.00	0.32	NA	21.00	3.00	0.00	9.40	4.40
OW-4	Pudukkad	03/05/2005	8.20	187.00	112.00	35.00	22.00	4.04	6.16	14.30	2.50	0.20	1.01	NA	26.20	3.00	0.00	26.80	5.18

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
OW-4	Pudukkad	06/09/2005	5.90	107.00	64.20	20.00	2.20	6.10	1.20	5.30	1.20	0.20	0.08	NA	17.30	2.00	0.00	2.70	4.48
OW-4	Pudukkad	08/02/2006	7.12	157.00	94.20	24.60	10.00	0.00	6.00	10.70	3.60	0.58	0.33	NA	20.16	2.50	0.00	12.20	2.70
OW-5	Kodakara	17/07/2002	6.40	220.00	132.00	25.00	5.88	6.00	2.41	26.50	9.90	0.00	0.10	NA	44.40	24.00	0.00	7.17	6.43
OW-5	Kodakara	12/08/2003	6.90	210.00	126.00	29.00	9.80	4.64	0.00	21.50	10.70	0.64	0.04	NA	40.90	2.44	0.00	14.50	6.28
OW-5	Kodakara	19/05/2004	6.70	240.00	144.00	40.00	10.00	8.00	4.90	20.70	10.80	0.28	0.00	NA	43.00	1.75	0.00	12.20	8.04
OW-5	Kodakara	21/08/2004	6.60	200.00	120.00	34.00	5.40	8.60	3.10	17.50	9.90	0.35	0.11	NA	41.00	2.20	0.00	6.60	6.20
OW-6	Irinjalakuda	20/07/2002	7.90	570.00	342.00	104.00	35.28	35.60	3.62	58.90	18.40	0.00	0.04	NA	97.00	31.00	0.00	43.40	BDL
OW-6	Irinjalakuda	22/02/2003	7.40	730.00	438.00	185.00	20.40	22.00	11.60	72.40	22.80	0.20	0.05	NA	139.00	13.20	0.00	30.40	9.30
OW-6	Irinjalakuda	06/08/2003	8.00	500.00	300.00	118.00	43.90	15.68	4.80	28.00	19.40	0.72	0.03	NA	74.50	14.30	0.00	65.40	6.90
OW-6	Irinjalakuda	13/02/2004	7.60	640.00	384.00	128.00	35.00	39.40	7.20	52.80	20.30	0.75	0.10	NA	116.00	27.00	0.00	42.70	8.40
OW-6	Irinjalakuda	19/05/2004	7.30	440.00	264.00	80.00	20.00	26.00	3.70	36.40	13.00	0.25	0.00	NA	70.00	28.80	0.00	24.40	5.73
OW-6	Irinjalakuda	25/08/2004	7.50	280.00	168.00	82.00	18.00	22.40	6.30	17.20	14.90	0.15	0.10	NA	44.00	29.30	0.00	21.90	5.02
OW-6	Irinjalakuda	10/02/2005	7.30	800.00	480.00	117.00	21.30	46.60	0.00	53.60	20.50	0.02	0.12	NA	148.00	28.00	0.00	26.00	BDL
OW-6	Irinjalakuda	02/05/2005	7.80	950.00	570.00	207.00	50.00	56.50	16.00	58.00	13.50	0.66	1.49	NA	195.90	32.00	0.00	61.00	8.62
OW-6	Irinjalakuda	05/09/2005	7.41	400.00	240.00	91.00	17.80	26.30	6.20	27.70	17.40	0.64	0.02	NA	69.10	28.50	0.00	21.67	6.60
OW-6	Irinjalakuda	06/02/2006	7.50	800.00	480.00	164.00	20.00	49.20	10.00	54.10	26.90	0.35	0.14	NA	150.72	24.52	0.00	24.40	8.16
OW-7	M.G.Kavu	22/07/2002	7.60	50.00	30.00	10.00	11.76	4.00	0.00	10.50	0.70	1.00	0.05	NA	18.10	5.00	0.00	14.30	0.65
OW-7	M.G.Kavu	28/09/2002	7.80	50.00	30.00	20.00	11.70	4.00	2.50	6.70	1.00	0.00	0.21	NA	11.00	1.70	0.00	14.30	0.62
OW-7	M.G.Kavu	26/11/2002	7.70	50.00	30.00	21.00	15.36	4.00	2.50	7.00	0.80	0.50	0.06	NA	10.20	1.50	0.00	18.70	BDL
OW-7	M.G.Kavu	07/08/2003	7.50	40.00	24.00	15.00	9.80	1.60	1.20	5.70	0.80	0.78	0.16	NA	8.20	1.51	0.00	14.50	0.60
OW-7	M.G.Kavu	22/05/2004	7.50	80.00	48.00	30.00	25.00	2.00	6.10	6.20	1.40	0.22	0.09	NA	9.00	2.50	0.00	30.50	0.64
OW-7	M.G.Kavu	23/08/2004	7.50	40.00	24.00	17.00	12.60	1.70	3.10	3.00	0.80	0.00	0.35	NA	8.00	2.20	0.00	15.40	0.52
OW-7	M.G.Kavu	10/02/2005	7.90	80.00	48.00	20.00	23.30	6.10	1.20	6.80	1.50	0.00	1.23	NA	9.00	2.10	0.00	28.40	BDL
OW-7	M.G.Kavu	06/05/2005	8.20	133.00	79.80	30.00	32.00	8.08	2.46	8.60	1.30	0.60	2.21	NA	16.50	5.00	0.00	39.00	BDL
OW-7	M.G.Kavu	19/09/2005	7.60	60.00	36.00	25.00	20.00	4.00	3.70	1.60	1.00	0.82	0.32	NA	7.70	2.00	0.00	24.38	0.82
OW-7	M.G.Kavu	06/02/2006	7.70	82.00	49.20	28.70	22.00	0.00	7.00	2.00	2.00	0.33	2.46	NA	7.68	0.00	0.00	26.84	BDL
OW-8	Ottupara	22/07/2002	7.70	240.00	144.00	40.00	23.52	10.00	3.62	22.30	4.50	0.86	0.13	NA	33.60	38.00	0.00	28.67	5.28
OW-8	Ottupara	28/09/2002	8.00	180.00	108.00	35.00	23.50	10.00	2.50	16.70	4.20	0.00	0.06	NA	23.80	5.80	0.00	28.67	3.20
OW-8	Ottupara	05/08/2003	7.60	180.00	108.00	44.00	24.40	5.44	2.40	16.60	4.10	0.80	0.04	NA	22.70	10.66	0.00	36.40	5.30
OW-8	Ottupara	29/11/2003	7.50	130.00	78.00	40.00	24.40	10.00	3.70	10.00	3.00	0.82	0.10	NA	19.00	6.50	0.00	29.80	2.10
OW-8	Ottupara	22/05/2004	7.50	210.00	126.00	45.00	20.00	6.00	7.30	15.20	3.20	0.00	0.00	NA	28.00	3.10	0.00	24.40	5.72
OW-8	Ottupara	23/08/2004	7.90	230.00	138.00	60.00	39.60	15.50	5.20	21.90	4.90	0.00	0.04	NA	30.00	13.40	0.00	48.30	5.20
OW-8	Ottupara	17/11/2004	8.30	370.00	222.00	110.00	87.40	24.00	12.20	24.60	23.00	0.93	3.86	NA	47.00	13.40	9.10	88.00	1.70
OW-8	Ottupara	10/02/2005	7.90	140.00	84.00	30.00	25.20	6.10	3.70	12.70	2.70	0.34	0.10	NA	18.00	4.00	0.00	30.70	0.70
OW-8	Ottupara	05/05/2005	8.20	170.00	102.00	40.00	32.00	8.08	4.93	13.30	3.80	0.00	0.23	NA	24.30	4.20	0.00	39.00	1.50
OW-8	Ottupara	19/09/2005	8.30	260.00	156.00	71.00	62.20	20.20	4.90	18.60	5.30	1.02	0.18	NA	25.00	4.00	2.67	70.42	4.80

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
OW-8	Ottupara	06/02/2006	7.83	128.00	76.80	36.90	28.00	0.00	9.00	7.30	4.10	0.27	0.25	NA	13.40	3.00	0.00	34.16	BDL
OW-9	Chelakkara	28/09/2002	8.70	400.00	240.00	121.00	111.70	32.00	9.80	18.20	12.40	0.86	0.04	NA	28.40	12.70	14.10	107.60	0.84
OW-9	Chelakkara	26/11/2002	8.60	350.00	210.00	119.00	97.28	31.20	10.10	20.10	11.20	0.37	0.12	NA	26.80	15.70	12.30	93.70	1.26
OW-9	Chelakkara	19/02/2003	8.70	420.00	252.00	180.00	122.80	13.60	23.20	25.10	2.80	0.80	0.10	NA	40.30	3.60	11.00	137.00	1.80
OW-9	Chelakkara	27/11/2003	8.40	360.00	216.00	136.00	97.60	32.00	13.60	18.10	11.50	1.00	0.10	NA	34.00	3.30	23.40	71.50	0.52
OW-9	Chelakkara	27/02/2004	8.60	430.00	258.00	148.00	135.00	39.40	12.00	23.60	4.90	0.90	0.30	NA	41.00	14.20	12.00	140.30	0.50
OW-9	Chelakkara	22/05/2004	8.30	380.00	228.00	155.00	110.00	40.00	13.40	20.60	5.90	0.60	0.00	NA	35.00	15.10	12.00	109.80	0.88
OW-9	Chelakkara	16/08/2004	8.50	390.00	234.00	172.00	133.20	27.50	25.20	15.80	10.50	0.75	0.06	NA	42.00	16.20	8.60	144.90	0.98
OW-9	Chelakkara	09/12/2004	8.50	380.00	228.00	170.00	117.80	42.00	15.90	21.60	10.70	0.81	0.00	NA	41.00	14.20	13.60	115.90	0.51
OW-9	Chelakkara	10/02/2005	8.70	400.00	240.00	127.00	130.00	26.40	14.80	20.80	10.20	0.74	0.13	NA	40.00	14.00	9.30	139.60	0.26
OW-9	Chelakkara	04/05/2005	8.50	380.00	228.00	182.00	162.00	38.30	20.90	24.50	10.30	0.74	0.19	NA	46.60	15.30	14.40	168.30	0.16
OW-9	Chelakkara	22/09/2005	8.55	420.00	252.00	162.00	146.50	38.40	16.00	16.10	11.40	0.94	0.05	NA	42.20	14.00	13.30	151.67	0.92
OW-9	Chelakkara	06/02/2006	8.66	430.00	258.00	188.60	134.00	39.36	22.01	17.50	12.90	0.87	0.42	NA	33.60	17.29	16.80	129.32	BDL
OW-10	Kunnamkulam	24/07/2002	8.40	260.00	156.00	74.00	64.68	29.60	0.00	18.70	2.10	0.27	0.03	NA	34.50	11.00	7.00	64.60	0.65
OW-10	Kunnamkulam	30/09/2002	8.25	290.00	174.00	60.00	52.92	24.00	0.00	25.60	2.50	0.13	0.28	NA	38.50	5.70	0.00	64.60	3.98
OW-10	Kunnamkulam	19/02/2003	8.40	410.00	246.00	127.00	66.50	14.40	9.00	35.90	6.70	0.30	3.30	NA	68.60	4.30	3.67	83.80	2.20
OW-10	Kunnamkulam	17/11/2003	8.50	380.00	228.00	116.00	83.00	40.40	3.70	21.10	2.50	0.62	0.20	NA	28.00	5.40	11.70	77.30	7.00
OW-10	Kunnamkulam	17/02/2004	8.30	350.00	210.00	84.00	70.00	31.60	1.20	31.70	3.70	0.57	2.50	NA	53.00	1.70	6.00	73.20	1.30
OW-10	Kunnamkulam	15/05/2004	8.16	340.00	204.00	105.00	75.00	38.00	2.40	24.20	3.90	0.25	0.00	NA	43.00	2.00	6.00	79.30	2.86
OW-10	Kunnamkulam	23/08/2004	8.30	250.00	150.00	99.00	72.00	27.50	7.30	14.50	1.80	0.26	0.16	NA	29.00	6.86	2.20	83.40	1.52
OW-10	Kunnamkulam	16/11/2004	8.20	270.00	162.00	90.00	62.70	32.00	2.40	22.70	2.00	0.48	0.22	NA	42.00	4.30	2.30	71.80	2.10
OW-10	Kunnamkulam	09/02/2005	8.40	450.00	270.00	101.00	85.40	24.30	9.90	43.00	5.00	0.00	3.00	NA	81.00	2.30	4.60	94.60	1.00
OW-10	Kunnamkulam	05/05/2005	8.30	520.00	312.00	116.00	96.00	30.30	9.86	50.00	2.90	0.71	1.53	NA	111.60	3.00	2.40	112.00	4.30
OW-10	Kunnamkulam	05/09/2005	8.30	360.00	216.00	96.00	71.00	32.30	3.70	31.00	3.10	0.85	0.07	NA	59.50	3.00	2.67	81.25	3.28
OW-10	Kunnamkulam	01/02/2006	8.20	620.00	372.00	118.90	74.00	31.16	10.00	63.20	6.40	0.59	0.60	NA	112.32	1.63	7.20	75.64	8.32
OW-11	Chavakkad	20/07/2002	8.90	880.00	528.00	232.00	164.64	79.20	8.44	74.50	39.00	0.50	0.02	NA	124.30	81.00	21.20	157.80	BDL
OW-11	Chavakkad	30/09/2002	8.90	930.00	558.00	236.00	206.00	94.40	0.00	61.20	47.00	0.63	0.05	NA	89.00	34.00	42.60	164.70	5.80
OW-11	Chavakkad	22/02/2003	8.70	820.00	492.00	249.00	128.00	30.40	14.20	64.70	31.30	0.40	0.09	NA	102.50	16.70	11.00	144.70	9.10
OW-11	Chavakkad	07/08/2003	8.60	770.00	462.00	211.00	146.40	28.20	8.40	52.20	33.10	0.70	0.05	NA	15.40	28.67	10.60	174.20	6.36
OW-11	Chavakkad	13/02/2004	8.70	820.00	492.00	207.00	155.00	73.00	6.00	61.70	31.10	0.00	0.10	NA	91.00	31.00	24.00	140.30	7.66
OW-11	Chavakkad	15/05/2004	8.30	1160.00	696.00	305.00	200.00	82.00	24.40	86.50	22.00	0.25	0.07	NA	169.00	67.70	36.00	170.80	3.34
OW-11	Chavakkad	23/08/2004	8.70	810.00	486.00	258.00	192.60	56.80	28.30	58.80	5.20	0.74	0.04	NA	87.00	60.10	17.30	199.80	6.14
OW-11	Chavakkad	06/11/2004	8.50	720.00	432.00	255.00	191.90	68.00	20.70	48.50	26.00	1.00	0.09	NA	74.00	32.60	25.00	183.10	6.60
OW-11	Chavakkad	12/8/2005	8.80	770.00	462.00	177.00	186.20	60.80	6.20	50.50	27.60	0.00	0.12	NA	80.00	32.00	18.60	189.30	7.06
OW-11	Chavakkad	02/05/2005	8.50	810.00	486.00	242.00	206.00	52.50	27.10	59.00	25.40	0.15	0.15	NA	103.80	55.00	19.20	212.00	7.00
OW-11	Chavakkad	05/09/2005	8.67	700.00	420.00	197.00	173.20	60.60	11.10	48.30	27.00	0.00	0.06	NA	73.90	32.00	21.30	167.90	5.90

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
OW-11	Chavakkad	01/02/2006	8.74	660.00	396.00	205.00	162.00	70.52	7.00	45.70	34.30	0.68	0.23	NA	59.60	31.33	19.20	158.60	8.60
OW-12	Pazhanji	24/07/2002	6.80	190.00	114.00	20.00	11.76	6.00	1.21	22.40	4.00	0.00	0.05	NA	30.80	4.00	0.00	14.30	BDL
OW-12	Pazhanji	07/08/2003	7.10	170.00	102.00	25.00	9.80	3.20	1.20	19.20	4.00	0.50	0.02	NA	26.20	4.18	0.00	14.50	6.40
OW-12	Pazhanji	17/02/2004	7.30	220.00	132.00	35.00	15.00	3.90	6.00	22.80	5.10	0.87	0.20	NA	33.00	3.00	0.00	18.30	7.92
OW-12	Pazhanji	18/05/2004	7.00	200.00	120.00	20.00	10.00	6.00	1.20	22.40	3.60	0.10	0.00	NA	30.00	3.87	0.00	12.20	8.40
OW-12	Pazhanji	05/05/2005	7.40	270.00	162.00	45.00	30.00	12.10	3.70	23.60	4.30	0.44	0.12	NA	37.80	3.60	0.00	36.60	6.60
OW-13	Nattika	20/07/2002	8.70	300.00	180.00	119.00	111.72	47.60	0.00	12.00	3.30	0.13	0.16	NA	20.00	13.00	7.10	121.96	2.35
OW-13	Nattika	30/09/2002	8.60	260.00	156.00	111.00	94.00	44.40	0.00	5.80	2.10	0.00	0.04	NA	11.00	7.70	7.02	100.40	0.70
OW-13	Nattika	22/11/2002	8.50	230.00	138.00	114.00	87.04	37.20	5.10	7.40	1.80	0.80	0.03	NA	10.20	6.20	12.30	81.20	BDL
OW-13	Nattika	22/02/2003	8.20	190.00	114.00	111.00	51.20	12.60	7.70	18.20	1.90	0.50	0.07	NA	13.70	7.10	0.00	76.30	3.00
OW-13	Nattika	18/11/2003	8.30	260.00	156.00	106.00	73.20	13.60	4.90	6.00	1.80	0.87	0.09	NA	10.00	5.40	7.00	65.50	0.70
OW-13	Nattika	13/02/2004	8.10	210.00	126.00	84.00	55.00	33.50	0.00	6.60	1.90	0.50	0.06	NA	16.00	13.50	6.00	54.90	1.12
OW-13	Nattika	17/08/2004	8.30	270.00	162.00	129.00	81.00	46.40	3.10	3.30	1.70	0.23	0.04	NA	12.00	41.10	2.20	94.40	1.66
OW-13	Nattika	06/11/2004	8.30	220.00	132.00	125.00	79.20	42.00	4.90	5.30	1.60	0.45	0.07	NA	10.00	19.10	6.80	83.40	0.92
OW-13	Nattika	07/02/2005	8.30	220.00	132.00	86.00	56.30	28.40	3.70	8.00	1.70	0.07	0.07	NA	14.00	18.60	2.30	63.90	0.76
OW-13	Nattika	02/05/2005	8.30	280.00	168.00	111.00	74.00	36.30	4.90	15.80	1.90	0.00	0.12	NA	30.10	36.00	2.40	85.40	1.66
OW-13	Nattika	05/09/2005	8.50	330.00	198.00	167.00	126.50	54.50	7.40	1.70	2.30	0.87	0.03	NA	13.40	35.00	13.30	127.29	0.72
OW-13	Nattika	01/02/2006	8.26	220.00	132.00	102.80	56.00	31.16	6.00	3.20	2.80	0.00	0.23	NA	12.48	18.90	2.40	63.40	1.10
OW-14	Edamuttam	20/07/2002	8.60	290.00	174.00	89.00	99.96	31.60	2.41	20.00	6.00	0.29	0.24	NA	33.50	13.00	14.30	107.60	BDL
OW-14	Edamuttam	30/09/2002	8.50	250.00	150.00	70.00	71.00	28.00	0.00	13.00	7.00	0.50	0.35	NA	19.00	6.00	0.00	86.60	
OW-14	Edamuttam	22/11/2002	8.50	220.00	132.00	78.00	76.80	24.80	3.80	14.50	6.60	0.00	0.30	NA	15.70	2.70	6.14	81.20	BDL
OW-14	Edamuttam	22/02/2003	8.50	310.00	186.00	153.00	87.00	15.20	14.20	19.20	6.60	0.00	1.20	NA	25.60	5.80	6.12	114.30	3.20
OW-14	Edamuttam	13/02/2004	8.50	330.00	198.00	128.00	95.00	47.30	2.40	13.70	6.30	0.30	0.80	NA	31.00	10.10	6.00	103.70	BDL
OW-14	Edamuttam	15/05/2004	8.30	280.00	168.00	100.00	75.00	38.00	1.20	16.50	3.80	0.15	0.04	NA	27.00	19.45	6.00	79.30	0.70
OW-14	Edamuttam	17/08/2004	8.40	270.00	162.00	116.00	97.20	37.80	5.20	14.30	5.40	0.49	0.94	NA	22.00	7.70	4.30	109.80	0.10
OW-14	Edamuttam	06/11/2004	8.40	250.00	150.00	120.00	93.10	36.00	7.30	12.00	5.60	0.55	0.89	NA	19.00	7.10	11.40	90.40	BDL
OW-14	Edamuttam	09/02/2005	8.60	300.00	180.00	96.00	100.90	28.40	6.20	15.20	6.80	0.06	1.30	NA	28.00	7.00	6.90	108.80	BDL
OW-14	Edamuttam	02/05/2005	8.40	330.00	198.00	126.00	150.00	24.20	16.00	22.00	5.60	0.66	1.19	NA	41.70	10.00	14.40	153.70	0.46
OW-14	Edamuttam	05/09/2005	8.41	280.00	168.00	101.00	106.60	36.40	2.50	11.80	5.40	0.84	0.29	NA	22.10	7.00	5.32	119.10	BDL
OW-14	Edamuttam	01/02/2006	8.40	380.00	228.00	143.50	126.00	42.64	9.00	12.60	8.10	0.66	1.11	NA	24.00	5.63	9.60	134.20	0.30
OW-15	Mathilakam	20/07/2002	8.30	180.00	108.00	79.00	47.04	23.60	4.82	9.20	2.00	0.61	0.06	NA	15.40	15.00	0.00	57.40	1.87
OW-15	Mathilakam	22/11/2002	8.20	140.00	84.00	57.00	51.20	22.80	0.00	6.00	1.10	0.30	0.11	NA	9.20	14.10	0.00	62.50	0.26
OW-15	Mathilakam	18/11/2003	8.10	180.00	108.00	76.00	43.90	24.00	3.70	9.20	1.20	0.87	0.30	NA	17.00	15.30	0.00	53.60	0.80
OW-15	Mathilakam	13/02/2004	7.80	150.00	90.00	49.00	30.00	19.70	0.00	6.20	0.80	0.78	0.20	NA	10.00	9.80	0.00	36.60	1.20
OW-15	Mathilakam	15/05/2004	7.50	150.00	90.00	60.00	20.00	20.00	2.40	2.60	0.80	0.25	0.00	NA	13.00	14.60	0.00	24.40	3.20
OW-15	Mathilakam	18/08/2004	8.50	280.00	168.00	151.00	100.80	48.20	7.30	6.70	5.70	0.56	0.11	NA	14.00	22.40	6.50	109.80	0.94

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
OW-18	Varandarapilli	04/11/2004	8.13	160.00	96.00	55.00	47.50	22.00	0.00	6.40	11.20	0.52	0.16	NA	12.00	8.50	0.00	57.00	1.58
OW-18	Varandarapilli	10/02/2005	7.30	120.00	72.00	20.00	19.40	4.10	2.50	9.50	13.40	0.20	0.13	NA	16.00	11.00	0.00	23.60	1.08
OW-18	Varandarapilli	03/05/2005	7.60	120.00	72.00	30.00	30.00	6.06	3.70	9.60	12.80	0.11	0.53	NA	18.40	13.00	0.00	36.60	1.32
OW-18	Varandarapilli	06/09/2005	7.95	139.00	83.40	40.00	33.30	12.10	2.50	6.00	9.70	0.47	0.15	NA	11.50	10.00	0.00	40.63	1.78
OW-18	Varandarapilli	08/02/2006	7.65	113.00	67.80	16.40	16.00	0.00	4.00	5.80	15.90	0.57	0.21	NA	10.56	8.29	0.00	19.52	2.16
OW-19	Cherpu	20/10/2001	7.70	410.00	226.00	115.00	62.00	40.00	3.60	25.00	30.00	0.15	0.00	17.00	81.00	11.00	0.00	75.64	9.00
OW-19	Cherpu	02/05/2005	7.70	450.00	270.00	96.00	46.00	30.30	4.93	33.00	20.10	0.34	0.54	NA	74.70	1.60	0.00	56.10	8.68
OW-20	Puthur	16/10/2001	6.30	70.00	39.00	25.00	64.00	10.00	20.00	3.00	1.30	0.00	0.00	5.00	23.00	4.00	9.60	58.56	2.70
OW-20	Puthur	23/07/2002	7.50	60.00	36.00	10.00	11.76	4.00	0.00	8.30	4.50	0.13	0.03	NA	11.80	13.00	0.00	14.34	1.36
OW-20	Puthur	27/09/2002	8.09	150.00	90.00	55.00	5.88	14.00	4.90	6.20	3.90	0.31	0.02	NA	9.20	2.10	0.00	7.20	0.80
OW-20	Puthur	11/08/2003	7.10	70.00	42.00	15.00	9.80	6.00	0.00	8.00	3.90	0.58	0.02	NA	10.30	5.42	0.00	11.90	1.50
OW-20	Puthur	01/04/2004	6.80	160.00	96.00	25.00	10.00	3.90	3.60	14.30	6.70	0.40	0.10	NA	37.00	1.80	0.00	12.20	1.70
OW-20	Puthur	21/08/2004	7.20	70.00	42.00	17.00	12.60	3.40	2.10	5.50	4.00	0.36	0.07	NA	14.00	5.10	0.00	15.40	1.12
OW-20	Puthur	03/11/2004	7.40	60.00	36.00	15.00	11.40	0.00	3.70	5.20	3.60	0.44	0.11	NA	10.00	1.20	0.00	13.90	1.02
OW-20	Puthur	08/02/2005	7.70	90.00	54.00	15.00	15.50	4.10	1.20	9.10	4.20	0.00	0.24	NA	17.00	2.00	0.00	18.90	0.30
OW-20	Puthur	03/05/2005	7.40	122.00	73.00	30.00	16.00	4.00	4.93	5.60	4.10	0.52	0.30	NA	25.20	3.20	0.00	19.50	2.30
OW-20	Puthur	23/09/2005	7.30	82.00	49.20	15.00	13.30	2.00	2.50	7.00	4.40	0.50	0.02	NA	13.40	1.50	0.00	16.25	1.14
OW-20	Puthur	07/02/2006	7.37	96.00	57.60	16.40	12.00	0.00	4.00	5.10	6.30	0.54	0.28	NA	19.20	1.13	0.00	14.64	0.80
OW-21	Elavally	11/10/2001	6.50	410.00	226.00	110.00	0.00	34.00	6.10	27.00	20.70	0.00	0.00	11.00	123.00	20.00	0.00	0.00	9.00
OW-21	Elavally	24/09/2002	7.38	480.00	288.00	50.00	41.16	8.00	7.40	44.10	13.70	0.00	0.09	NA	59.60	33.30	0.00	41.16	8.00
OW-21	Elavally	07/08/2003	7.00	420.00	252.00	44.00	4.90	15.60	1.20	40.30	12.30	0.96	0.01	NA	62.70	15.18	0.00	5.95	7.74
OW-21	Elavally	13/02/2004	7.20	330.00	198.00	35.00	15.00	9.90	2.40	38.30	9.60	0.00	0.09	NA	58.00	8.40	0.00	18.30	8.00
OW-21	Elavally	18/05/2004	7.40	280.00	168.00	35.00	20.00	10.00	2.40	29.30	8.50	0.22	0.00	NA	50.00	10.30	0.00	24.40	4.90
OW-21	Elavally	07/02/2005	7.60	310.00	186.00	35.00	15.50	6.10	4.90	33.70	8.70	0.26	0.08	NA	51.00	7.20	0.00	18.90	4.84
OW-21	Elavally	05/05/2005	7.80	280.00	168.00	56.00	48.00	10.10	7.39	40.00	9.00	0.33	0.21	NA	54.30	8.90	0.00	58.50	1.74
OW-21	Elavally	09/09/2005	7.25	350.00	210.00	40.00	13.30	10.10	3.70	38.60	10.40	0.67	0.04	NA	59.50	10.00	0.00	16.25	6.76
OW-21	Elavally	04/02/2006	7.44	280.00	168.00	36.90	14.00	0.00	9.00	31.40	10.60	0.03	0.18	NA	48.96	7.81	0.00	17.08	8.60
OW-22	Kadangode	10/10/2001	6.60	290.00	160.00	55.00	16.00	14.00	4.80	21.00	22.00	0.00	0.41	9.00	74.00	4.00	0.00	19.52	9.00
OW-22	Kadangode	30/09/2002	8.07	110.00	66.00	20.00	29.40	4.00	2.50	7.30	3.10	0.00	0.45	NA	10.10	6.70	0.00	35.90	0.33
OW-22	Kadangode	25/11/2002	7.90	90.00	54.00	26.00	30.72	6.40	2.50	6.30	2.60	0.30	1.34	NA	8.30	3.60	0.00	37.50	0.36
OW-22	Kadangode	17/11/2003	7.50	90.00	54.00	30.00	24.40	6.08	3.70	5.70	2.80	0.91	0.30	NA	18.00	2.90	0.00	29.80	0.40
OW-22	Kadangode	27/02/2004	7.90	100.00	60.00	20.00	35.00	3.90	2.40	8.40	3.30	0.40	0.20	NA	8.00	2.90	0.00	42.70	0.52
OW-22	Kadangode	08/12/2004	7.90	130.00	78.00	35.00	34.20	4.00	6.10	14.60	2.80	0.67	0.00	NA	24.00	1.60	0.00	41.70	0.34
OW-22	Kadangode	08/02/2005	8.10	110.00	66.00	25.00	42.70	4.10	3.70	10.60	3.30	0.13	0.48	NA	9.00	2.30	0.00	52.00	BDL
OW-22	Kadangode	19/09/2005	7.72	84.00	50.50	25.00	24.40	2.00	4.90	5.00	1.70	0.47	0.13	NA	11.50	2.30	0.00	29.79	BDL
OW-22	Kadangode	04/02/2006	7.96	106.00	63.60	28.70	38.00	0.00	8.00	4.70	4.60	0.50	0.63	NA	6.72	0.88	0.00	46.36	0.28

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
OW-23	Wadakanchery	08/10/2001	5.00	220.00	121.00	45.00	8.00	10.00	4.80	18.00	11.80	0.00	0.00	13.00	67.00	4.00	0.00	9.76	8.00
OW-23	Wadakanchery	28/09/2002	7.72	120.00	72.00	25.00	17.64	4.00	3.70	10.40	5.80	0.76	0.02	NA	15.60	2.70	0.00	21.50	2.00
OW-23	Wadakanchery	29/11/2003	7.70	130.00	78.00	35.00	29.30	12.00	1.20	8.00	4.90	0.80	0.40	NA	14.00	7.10	0.00	35.70	0.97
OW-23	Wadakanchery	27/02/2004	7.50	100.00	60.00	25.00	20.00	5.90	2.40	6.80	4.20	0.80	0.50	NA	12.00	3.10	0.00	24.40	0.74
OW-23	Wadakanchery	23/08/2004	7.70	110.00	66.00	34.00	27.00	5.20	5.20	7.30	4.00	0.00	0.19	NA	14.00	4.70	0.00	32.90	1.02
OW-23	Wadakanchery	07/02/2005	7.80	90.00	54.00	15.00	17.50	4.10	1.20	7.90	3.20	0.07	0.17	NA	13.00	1.30	0.00	21.30	0.67
OW-23	Wadakanchery	06/05/2005	7.40	60.00	36.00	25.00	16.00	4.00	3.70	7.00	3.50	0.63	0.19	NA	15.50	2.00	0.00	19.50	0.68
OW-23	Wadakanchery	22/09/2005	7.60	100.00	60.00	25.00	24.40	4.00	3.70	7.00	4.10	0.38	0.13	NA	14.40	4.00	0.00	29.79	1.04

BDL:Below detectable level

NA: Not analysed

Table 5.7 Chemical characteristics of groundwater in bore wells (semi-confined deep aquifer) of Palaeo-lagoon (Kole land basin) for the period 01.01.2000 to 31.12.2006.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Well No	Location	Sampling Date	pH	EC (µmhos/ cm)	TDS (mg/l)	TH (mg/l)	Alk (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	F mg/l)	Fe (mg/l)	Si (mg/l)	Cl (mg/l)	SO4 (mg/l)	CO3 (mg/l)	HCO3 (mg/l)	NO3 (mg/l)
BW-1	Kaduppassery	26/05/2001	8.10	210	126	105.00		36.00	3.60	19.00	3.20	0.00	BDL	NA	39.70	22.00	4.80	50.40	BDL
BW-1	Kaduppassery	26/09/2002	8.71	460	276	171.00	129.36	44.40	14.70	11.40	7.70	0.00	0.09	NA	14.70	36.40	21.17	112.90	0.89
BW-1	Kaduppassery	27/11/2002	8.70	390	234	197.00	128.00	43.60	21.50	10.70	6.80	0.80	0.36	NA	15.70	44.00	12.29	129.00	BDL
BW-1	Kaduppassery	22/02/2003	8.50	370	222	180.00	108.00	14.40	21.90	23.90	6.40	0.00	0.40	NA	11.00	35.90	11.10	112.40	1.60
BW-1	Kaduppassery	16/02/2004	8.40	380	220	163.00	95.00	35.50	18.00	10.00	6.40	0.30	0.50	NA	16.00	50.00	12.00	91.50	0.50
BW-1	Kaduppassery	25/08/2004	8.70	430	258	215.00	129.60	46.40	24.10	10.80	6.20	0.11	0.23	NA	14.00	78.70	4.30	149.30	0.40
BW-1	Kaduppassery	05/11/2004	8.50	420	252	230.00	159.60	60.00	19.50	10.00	6.40	0.40	0.10	NA	13.00	55.20	9.10	176.10	0.28
BW-1	Kaduppassery	07/02/2005	8.70	440	264	162.00	124.20	26.40	23.50	14.50	6.10	0.46	0.24	NA	13.00	46.00	9.30	132.50	BDL
BW-1	Kaduppassery	07/05/2005	8.70	480	288	237.00	194.00	50.50	27.10	11.20	6.00	0.35	0.37	NA	16.50	50.00	19.20	197.60	0.48
BW-1	Kaduppassery	23/09/2005	8.60	500	300	242.00	173.20	38.40	35.70	9.80	6.30	0.88	0.07	NA	15.40	58.00	10.65	189.59	BDL
BW-1	Kaduppassery	02/02/2006	8.52	510	306	237.80	132.00	50.84	27.01	11.50	7.10	0.15	0.45	NA	21.10	65.50	12.00	136.60	0.86
BW-2	Mattathur	18/05/1999	8.40	335	176	175.70	NA	100.40	18.40	9.10	4.10	0.16	BDL	NA	19.70	26.10	27.80	271.00	BDL
BW-2	Mattathur	01/03/2004	8.30	350	210	128.00	75.00	29.60	13.20	17.80	6.20	0.50	0.30	NA	34.00	30.70	6.00	79.30	BDL
BW-2	Mattathur	17/05/2004	8.10	340	204	135.00	80.00	54.00	0.00	16.40	5.70	0.47	0.18	NA	31.00	31.20	12.00	73.20	0.00
BW-2	Mattathur	25/08/2004	8.60	350	210	163.00	90.00	27.50	23.10	17.80	5.60	0.16	0.19	NA	34.00	40.80	6.50	96.60	BDL
BW-2	Mattathur	04/11/2004	8.40	350	210	140.00	95.00	30.00	15.90	18.30	5.60	0.26	0.06	NA	35.00	26.30	6.80	101.90	0.10
BW-2	Mattathur	08/02/2005	8.60	370	222	122.00	100.90	22.30	16.10	18.10	5.60	0.64	1.23	NA	31.00	28.00	13.90	94.60	BDL
BW-2	Mattathur	03/05/2005	8.40	350	210	126.00	118.00	26.60	14.70	19.50	5.50	0.65	0.43	NA	36.90	26.00	12.00	119.50	0.10
BW-2	Mattathur	06/09/2005	8.47	350	210	131.00	106.60	30.30	13.60	16.50	5.70	0.85	0.14	NA	31.70	27.00	10.65	108.34	BDL
BW-2	Mattathur	08/02/2006	8.52	370	222	143.50	86.00	27.88	18.00	15.80	6.70	0.21	0.87	NA	29.76	29.04	7.20	90.29	BDL
BW-3	Nellai	29/05/2001	8.30	400	240	150.00	NA	42.00	10.90	27.80	5.10	0.00	BDL	NA	55.60	32.00	7.20	70.80	BDL
BW-3	Nellai	25/09/2002	8.37	860	516	55.00	152.88	14.00	4.90	120.00	5.70	0.90	0.25	NA	100.00	30.30	7.06	172.20	BDL
BW-3	Nellai	29/11/2002	8.70	730	438	62.00	133.12	10.40	8.80	131.60	5.10	1.00	0.80	NA	97.10	34.20	30.72	99.90	BDL
BW-3	Nellai	21/02/2003	8.40	730	438	69.00	138.00	5.92	7.70	95.20	5.00	0.85	0.30	NA	97.00	29.00	18.42	131.15	1.30
BW-3	Nellai	12/08/2003	8.70	730	438	59.00	131.80	5.44	6.00	106.90	4.80	1.00	0.15	NA	101.70	35.20	10.50	152.50	BDL
BW-3	Nellai	01/03/2004	8.60	730	438	59.00	135.00	15.80	4.80	140.00	5.00	1.00	1.00	NA	98.00	32.20	12.00	140.30	BDL
BW-3	Nellai	19/05/2004	8.30	770	462	65.00	135.00	16.00	6.10	115.00	4.00	0.81	0.22	NA	95.00	34.20	30.00	103.70	0.00
BW-3	Nellai	25/08/2004	8.80	710	426	65.00	156.60	13.80	7.30	140.20	4.70	0.18	0.36	NA	96.00	42.20	15.10	160.30	BDL
BW-3	Nellai	10/11/2004	8.60	710	426	70.00	157.70	16.00	7.30	132.00	4.90	0.91	0.54	NA	97.00	32.20	22.80	146.00	BDL
BW-3	Nellai	07/02/2005	8.80	730	438	56.00	161.00	18.30	2.50	158.70	4.70	0.06	1.02	NA	104.00	32.00	13.90	168.00	BDL
BW-3	Nellai	07/05/2005	8.70	750	450	56.00	202.00	14.10	4.90	140.00	4.70	0.89	0.76	NA	111.60	33.30	21.60	202.50	BDL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BW-3	Nellai	08/02/2006	7.98	184	110.4	32.80	34.00	4.92	5.00	13.00	3.60	0.13	0.24	NA	17.28	10.16	0.00	41.48	1.56
BW-4	Tholur	24/09/2002	7.55	100	60	15.00	17.64	4.00	1.20	9.90	3.40	0.30	0.06	NA	12.80	11.00	0.00	21.50	2.46
BW-4	Tholur	25/11/2002	7.70	100	60	26.00	20.48	4.00	3.80	10.00	3.40	0.20	0.06	NA	13.00	1.06	0.00	24.98	2.80
BW-4	Tholur	05/08/2003	7.60	100	60	25.00	19.52	1.60	3.60	8.00	3.20	0.40	0.10	NA	12.70	2.10	0.00	29.10	3.00
BW-4	Tholur	19/11/2003	7.60	160	96	20.00	34.20	4.00	2.50	10.00	3.00	0.58	0.20	NA	13.00	1.51	0.00	41.70	2.90
BW-4	Tholur	17/02/2004	7.50	100	60	25.00	15.00	5.90	2.40	8.80	3.10	0.50	0.10	NA	14.00	2.90	0.00	18.30	3.10
BW-4	Tholur	16/11/2004	7.70	100	60	20.00	13.30	2.00	3.70	8.80	3.00	0.39	0.12	NA	15.00	1.30	0.00	16.00	3.60
BW-4	Tholur	16/02/2005	7.70	110	66	15.00	13.60	4.10	1.20	10.40	3.00	0.00	0.13	NA	14.00	1.90	0.00	16.50	3.20
BW-4	Tholur	05/05/2005	7.80	110	66	20.00	18.00	4.00	2.46	9.30	3.10	0.00	0.29	NA	17.50	2.00	0.00	21.90	3.68
BW-4	Tholur	09/09/2005	7.50	107	64.2	25.00	13.30	4.00	3.70	6.80	3.20	0.36	0.09	NA	15.40	1.60	0.00	16.20	3.32
BW-4	Tholur	04/02/2006	7.48	117	70.2	16.40	12.00	3.28	2.00	6.70	4.40	0.46	0.38	NA	12.48	0.87	0.00	14.64	8.60
BW-5	Trikkur	18/10/2001	8.30	380	209	190.00	188.00	44.00	17.00	14.00	5.10	0.10	0.57	84.00	19.00	5.00	31.20	165.90	0.80
BW-5	Trikkur	27/09/2002	8.37	200	120	55.00	70.56	14.00	4.90	10.00	4.10	0.02	0.39	NA	13.00	3.00	7.06	71.70	0.12
BW-5	Trikkur	01/03/2004	8.30	180	108	74.00	65.00	13.80	9.60	10.00	3.90	0.50	0.10	NA	13.00	4.10	6.00	67.10	BDL
BW-5	Trikkur	14/05/2004	8.10	190	114	70.00	65.00	16.00	7.30	12.20	3.70	0.33	0.00	NA	10.00	3.70	0.00	79.30	0.00
BW-5	Trikkur	25/08/2004	8.50	180	108	82.00	77.40	15.50	10.50	11.00	3.80	0.42	0.25	NA	12.00	3.80	0.00	94.40	BDL
BW-5	Trikkur	03/11/2004	8.30	180	108	70.00	74.10	18.00	6.10	11.70	3.80	0.93	0.16	NA	12.00	1.80	2.20	85.70	BDL
BW-5	Trikkur	09/02/2005	8.50	190	114	61.00	79.50	12.20	7.40	13.10	3.70	0.13	0.33	NA	11.00	3.60	4.60	87.50	BDL
BW-5	Trikkur	23/09/2005	8.30	190	114	66.00	82.10	16.20	6.20	8.00	4.10	0.43	0.03	NA	12.50	3.60	5.32	89.38	BDL
BW-5	Trikkur	07/02/2006	8.25	200	120	73.80	86.00	18.04	7.00	8.00	4.70	0.20	0.23	NA	10.56	1.00	4.80	95.16	BDL
BW-6	Choondel	11/10/2001	7.90	230	127	60.00	50.00	18.00	3.60	21.00	7.60	0.00	1.00	NA	54.00	7.00	0.00	61.00	2.10
BW-6	Choondel	27/03/2002	8.00	240	144	44.80	0.00	8.00	6.08	23.00	9.30	0.00	0.79	NA	62.30	7.00	0.00	0.00	BDL
BW-6	Choondel	24/09/2002	7.84	280	168	40.00	29.40	8.00	4.90	24.70	10.60	0.23	0.12	NA	37.60	32.00	0.00	35.90	3.51
BW-6	Choondel	20/02/2003	7.30	250	150	53.00	15.30	6.64	2.60	24.90	9.50	0.80	0.10	NA	41.20	6.40	0.00	22.80	9.10
BW-6	Choondel	05/08/2003	7.90	270	162	44.00	29.30	6.00	1.20	25.50	10.00	0.98	0.05	NA	43.60	7.00	0.00	43.60	3.40
BW-6	Choondel	17/11/2003	8.00	270	162	61.00	34.20	16.00	4.90	25.30	8.40	0.76	0.36	NA	48.00	8.00	0.00	41.70	3.12
BW-6	Choondel	17/02/2004	7.70	310	186	54.00	30.00	13.80	4.80	27.00	9.80	0.90	0.20	NA	52.00	6.60	0.00	36.60	3.84
BW-6	Choondel	18/05/2004	7.70	300	180	55.00	30.00	12.00	6.10	26.40	10.70	0.59	0.05	NA	48.00	6.60	0.00	36.60	3.34
BW-6	Choondel	12/08/2004	8.00	280	168	60.00	30.60	15.50	5.20	29.20	9.80	0.25	0.15	NA	53.00	4.00	0.00	37.30	2.48
BW-6	Choondel	16/11/2004	8.00	300	180	65.00	39.90	16.00	6.10	29.10	9.30	0.54	0.26	NA	56.00	5.20	0.00	48.60	3.30
BW-6	Choondel	16/02/2005	8.00	320	192	46.00	31.00	12.20	3.70	27.10	9.60	0.30	0.12	NA	59.00	5.60	0.00	37.80	2.64
BW-6	Choondel	05/05/2005	7.80	290	174	51.00	34.00	14.10	3.70	29.00	9.90	0.49	0.41	NA	63.00	4.60	0.00	41.40	2.82
BW-6	Choondel	09/09/2005	7.80	310	186	56.00	35.50	12.10	6.20	26.20	11.30	0.30	0.39	NA	63.40	4.30	0.00	43.30	2.92
BW-6	Choondel	04/02/2006	7.98	310	186	69.70	32.00	13.12	9.00	28.50	11.90	0.49	0.29	NA	54.70	5.52	0.00	39.04	4.28
BW-7	Vellanikkara	29/05/2001	8.00	480	288	175.00	NA	56.00	8.50	33.80	8.90	0.00	BDL	NA	58.90	21.00	12.00	104.90	BDL
BW-7	Vellanikkara	16/10/2001	8.30	410	226	240.00	198.00	52.00	27.00	19.00	3.70	0.30	0.48	97.00	16.00	21.00	38.40	163.50	3.40

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BW-7	Vellanikkara	02/04/2002	8.70	440	264	218.90	205.00	51.60	29.84	16.10	3.90	0.00	0.25	NA	30.50	32.00	39.00	170.80	BDL
BW-7	Vellanikkara	27/09/2002	8.71	430	258	201.00	182.28	42.40	23.30	15.00	4.30	0.48	0.02	NA	20.20	22.20	28.22	164.90	0.36
BW-7	Vellanikkara	18/11/2002	8.70	420	252	192.00	168.96	47.60	17.70	18.30	4.10	0.20	0.00	NA	12.90	37.20	24.58	156.16	0.40
BW-7	Vellanikkara	11/02/2003	8.60	380	228	185.00	143.00	12.64	25.80	25.50	4.10	0.40	0.03	NA	10.10	28.90	11.00	167.50	1.10
BW-7	Vellanikkara	21/11/2003	8.70	370	222	177.00	141.50	34.00	22.20	13.10	3.40	0.22	0.15	NA	14.00	23.80	29.30	113.00	0.52
BW-7	Vellanikkara	26/02/2004	8.60	380	220	168.00	125.00	25.60	25.30	14.70	3.70	0.40	0.20	NA	12.00	30.00	12.00	128.10	0.52
BW-7	Vellanikkara	14/05/2004	8.30	380	228	175.00	135.00	46.00	14.60	12.70	3.30	0.38	0.00	NA	13.00	28.20	18.00	128.10	0.59
BW-7	Vellanikkara	16/08/2004	8.80	380	228	176.00	160.20	34.40	22.00	13.80	3.70	0.00	0.04	NA	11.00	33.00	15.10	164.70	0.84
BW-7	Vellanikkara	03/11/2004	8.50	390	234	185.00	159.60	40.00	20.70	14.90	3.40	0.26	0.07	NA	12.00	27.60	13.60	166.80	0.64
BW-7	Vellanikkara	09/02/2005	8.90	390	234	147.00	159.10	20.30	23.50	18.10	3.70	0.24	0.27	NA	9.00	28.60	16.20	160.90	0.00
BW-7	Vellanikkara	02/09/2005	8.73	460	276	207.00	219.80	38.40	27.10	16.00	4.40	0.75	0.07	NA	12.50	28.00	29.30	208.50	0.48
BW-7	Vellanikkara	07/02/2006	8.67	410	246	184.50	160.00	22.96	31.01	16.10	5.00	0.46	1.07	NA	9.60	35.43	21.60	151.28	0.54
BW-8	Pananchery	11/02/2003	8.10	400	240	185.00	66.50	19.52	15.50	24.10	4.10	0.60	0.10	NA	9.20	52.10	0.00	98.90	6.20
BW-8	Pananchery	11/08/2003	8.50	470	282	221.00	83.00	23.52	17.90	13.30	4.40	0.90	0.04	NA	9.10	88.19	3.48	108.90	0.66
BW-8	Pananchery	14/05/2004	8.10	410	246	190.00	80.00	54.00	13.40	8.00	4.00	0.41	0.35	NA	11.00	94.10	12.00	73.20	0.67
BW-8	Pananchery	16/08/2004	8.50	390	234	176.00	93.60	48.20	13.60	8.20	4.20	0.33	0.15	NA	11.00	90.00	8.60	96.60	0.88
BW-8	Pananchery	03/11/2004	8.40	370	222	170.00	91.20	52.00	9.80	9.30	4.00	0.70	0.08	NA	12.00	59.90	6.80	97.30	0.94
BW-8	Pananchery	09/02/2005	8.60	380	228	142.00	95.10	34.50	13.60	11.10	3.80	0.62	0.16	NA	17.00	65.00	11.60	92.30	0.40
BW-8	Pananchery	04/05/2005	8.40	380	228	167.00	116.00	36.30	18.40	9.50	4.10	0.48	0.25	NA	17.50	68.30	7.20	126.80	1.14
BW-8	Pananchery	02/09/2005	8.48	440	264	187.00	106.60	50.50	14.80	7.60	4.50	1.18	0.13	NA	14.40	89.00	15.98	97.50	0.64
BW-9	Kolazhy	20/11/1999	8.40	270	138	148.00	NA	89.00	14.00	18.00	4.00	0.60	BDL	NA	32.00	7.30	54.00	219.00	BDL
BW-9	Kolazhy	02/04/2002	8.50	290	174	119.40	102.00	24.00	14.57	13.60	3.10	0.00	2.10	NA	33.90	18.00	10.80	102.50	BDL
BW-9	Kolazhy	28/09/2002	8.58	460	276	136.00	105.84	34.00	12.30	19.60	5.00	0.65	1.49	NA	35.80	20.80	14.11	100.00	BDL
BW-9	Kolazhy	26/11/2002	8.60	390	234	150.00	112.64	33.20	16.40	21.00	4.80	0.90	0.44	NA	37.90	19.50	18.40	99.90	BDL
BW-9	Kolazhy	20/02/2003	8.50	340	204	148.00	92.00	12.64	16.80	20.60	4.30	0.80	1.00	NA	27.50	9.20	7.30	106.60	2.30
BW-9	Kolazhy	28/02/2004	8.60	280	168	118.00	80.00	31.60	9.60	14.70	3.60	1.10	2.40	NA	23.00	18.60	6.00	85.40	0.56
BW-9	Kolazhy	22/05/2004	8.13	260	156	95.00	70.00	22.00	9.80	15.00	3.00	0.50	0.04	NA	21.00	14.20	0.00	85.40	0.57
BW-9	Kolazhy	26/08/2004	8.70	390	234	189.00	124.20	31.00	27.30	18.90	4.40	0.32	2.86	NA	35.00	20.10	6.50	138.30	0.08
BW-9	Kolazhy	17/11/2004	8.50	390	234	155.00	117.80	34.00	17.10	20.80	4.50	0.69	0.43	NA	40.00	13.50	22.80	97.30	0.00
BW-9	Kolazhy	15/02/2005	8.70	370	222	132.00	135.80	26.40	16.10	18.00	4.00	0.00	1.40	NA	31.00	14.70	18.60	127.80	BDL
BW-9	Kolazhy	06/05/2005	8.40	270	162	106.00	114.00	20.20	13.50	16.00	4.10	0.15	0.48	NA	30.10	16.20	7.20	124.40	0.48
BW-9	Kolazhy	19/09/2005	8.60	400	240	167.00	135.40	34.30	19.70	15.20	4.70	0.79	1.40	NA	41.30	14.00	15.98	132.70	BDL
BW-9	Kolazhy	06/02/2006	8.59	400	240	147.60	118.00	34.44	15.00	15.50	5.70	0.65	5.42	NA	29.76	13.46	14.40	114.68	0.80
BW-10	Athani	20/03/2000	7.70	276	149	124.80	NA	59.90	15.80	12.40	4.30	0.24	BDL	NA	13.06	18.50	0.00	232.00	BDL
BW-10	Athani	28/09/2002	8.01	160	96	35.00	23.52	4.00	6.10	12.80	5.20	0.22	0.16	NA	17.40	25.00	0.00	28.69	2.44
BW-10	Athani	28/02/2004	8.60	280	168	108.00	85.00	21.70	13.20	12.50	5.70	0.76	0.80	NA	24.00	13.30	12.00	79.30	0.20

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BW-10	Athani	22/05/2004	7.30	100	60	25.00	15.00	2.00	4.90	9.60	4.10	0.10	0.00	NA	15.00	5.00	0.00	18.30	2.62
BW-10	Athani	02/09/2004	7.60	110	66	26.00	16.20	3.40	4.20	10.20	4.20	0.09	0.26	NA	16.00	5.00	0.00	19.70	2.52
BW-10	Athani	17/11/2004	7.60	120	72	25.00	17.10	6.00	2.40	11.00	4.70	0.11	0.15	NA	21.00	2.90	0.00	20.80	3.04
BW-10	Athani	06/05/2005	8.40	310	186	116.00	116.00	22.20	14.70	22.00	4.20	0.43	0.58	NA	39.80	12.00	12.00	117.00	BDL
BW-10	Athani	19/09/2005	7.77	110	66	25.00	15.50	2.00	4.90	6.40	4.30	0.36	0.15	NA	16.30	6.00	0.00	18.90	2.06
BW-10	Athani	06/02/2006	8.00	180	108	61.50	36.00	8.20	10.00	7.70	6.50	0.61	0.57	NA	18.24	6.83	0.00	43.92	3.18
BW-11	Chengalur	18/05/1999	8.30	336	176	180.70	NA	85.30	23.20	4.70	2.90	0.24	BDL	NA	6.90	10.80	48.70	348.00	BDL
BW-11	Chengalur	18/10/2001	8.10	230	127	110.00	104.00	30.00	8.50	6.00	6.50	0.40	0.59	18.00	18.00	5.00	12.00	102.50	0.80
BW-11	Chengalur	21/02/2003	8.40	220	132	101.00	76.80	14.40	2.60	17.40	5.30	0.10	0.10	NA	8.20	5.30	3.67	98.80	2.60
BW-11	Chengalur	21/11/2003	8.30	160	96	66.00	48.80	16.00	6.20	6.60	3.30	0.43	0.10	NA	12.00	4.30	5.90	47.60	1.00
BW-11	Chengalur	01/03/2004	8.60	230	138	89.00	80.00	33.50	1.20	5.20	4.70	0.35	0.10	NA	10.00	2.20	0.00	97.60	0.50
BW-11	Chengalur	17/05/2004	7.60	80	48	35.00	20.00	8.00	3.70	4.00	1.90	0.04	0.01	NA	10.00	4.50	6.00	12.20	1.00
BW-11	Chengalur	25/08/2004	8.40	170	102	73.00	66.60	24.10	3.10	6.90	3.20	0.00	0.15	NA	12.00	2.40	2.20	76.80	0.84
BW-11	Chengalur	04/11/2004	8.40	200	120	85.00	83.60	28.00	3.70	5.80	4.30	0.53	0.09	NA	11.00	3.50	4.50	92.70	0.60
BW-11	Chengalur	08/02/2005	8.60	200	120	81.00	89.20	20.30	7.40	6.20	4.30	0.23	0.12	NA	10.00	2.00	6.90	94.60	BDL
BW-11	Chengalur	03/05/2005	8.20	140	84	61.00	66.00	18.10	3.70	7.80	4.00	0.13	0.48	NA	14.60	1.90	0.00	80.50	1.20
BW-11	Chengalur	06/09/2005	7.90	122	73.2	35.00	28.90	10.10	2.50	4.00	2.50	0.27	0.09	NA	16.30	3.30	0.00	35.20	2.06
BW-11	Chengalur	08/02/2006	8.06	131	78.6	45.10	38.00	9.84	5.00	2.00	4.00	0.10	0.24	NA	8.64	2.60	0.00	46.36	1.80
BW-12	Muppliyam	29/05/2001	8.00	410	246	160.00	NA	22.40	4.80	19.60	4.10	0.00	BDL	NA	57.80	22.00	4.32	41.70	BDL
BW-12	Muppliyam	13/03/2002	8.60	360	216	179.10	182.00	34.00	23.06	10.50	2.40	0.00	1.31	NA	31.60	10.00	28.20	164.70	BDL
BW-12	Muppliyam	27/09/2002	8.75	430	258	176.00	170.52	32.00	23.30	9.00	3.80	0.00	0.73	NA	12.80	11.60	7.02	193.70	BDL
BW-12	Muppliyam	19/11/2002	8.80	370	222	186.00	168.96	33.20	25.30	7.10	3.80	0.70	0.43	NA	9.20	10.50	36.90	107.52	BDL
BW-12	Muppliyam	21/02/2003	8.60	350	210	175.00	158.70	14.40	20.70	25.20	3.30	0.10	1.70	NA	7.30	10.10	18.40	159.80	0.70
BW-12	Muppliyam	26/11/2003	8.70	350	210	187.00	151.30	30.00	27.10	7.30	3.10	0.75	1.40	NA	10.00	10.40	29.30	125.10	0.52
BW-12	Muppliyam	17/05/2004	8.40	370	222	185.00	170.00	38.00	22.00	12.30	3.20	0.35	0.00	NA	10.00	10.20	24.00	158.60	0.04
BW-12	Muppliyam	25/08/2004	8.80	370	222	194.00	189.00	39.60	23.10	12.10	3.20	0.49	0.14	NA	11.00	11.70	2.20	226.20	BDL
BW-12	Muppliyam	04/11/2004	8.50	350	210	180.00	180.50	34.00	23.20	12.30	3.30	0.36	0.21	NA	7.00	3.80	27.40	164.50	0.01
BW-12	Muppliyam	08/02/2005	8.90	350	210	142.00	180.40	22.30	21.00	14.60	3.20	0.66	2.10	NA	8.00	10.00	32.50	153.80	BDL
BW-12	Muppliyam	06/09/2005	8.60	330	198	157.00	186.50	28.30	20.90	8.00	3.20	0.16	0.65	NA	9.60	10.00	26.60	173.30	0.26
BW-12	Muppliyam	08/02/2006	8.77	350	210	184.50	170.00	34.44	24.00	8.00	4.20	0.47	4.19	NA	9.60	9.27	24.00	158.60	BDL
BW-13	Mudicode	29/05/2001	7.10	250	150	130.00	NA	40.00	7.30	23.20	4.50	0.00	BDL	NA	47.60	15.00	7.20	92.70	BDL
BW-13	Mudicode	16/10/2001	8.10	250	138	105.00	90.00	32.00	6.10	8.00	2.80	0.01	0.30	71.00	14.00	8.00	19.20	70.76	1.90
BW-13	Mudicode	19/03/2002	8.50	220	132	99.50	98.00	30.00	6.08	7.00	1.50	0.00	0.37	NA	21.50	9.00	16.80	85.40	BDL
BW-13	Mudicode	28/09/2002	8.53	240	144	85.00	88.20	32.00	1.20	9.70	2.50	0.37	0.08	NA	14.70	8.40	14.10	78.90	BDL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BW-13	Mudicode	18/11/2002	8.50	240	144	104.00	81.92	26.80	8.80	8.00	2.40	0.30	0.03	NA	11.10	8.80	12.30	74.90	BDL
BW-13	Mudicode	11/02/2003	8.30	210	126	101.00	71.60	12.60	5.20	21.90	2.40	0.70	0.05	NA	8.20	2.60	7.30	76.25	2.78
BW-13	Mudicode	21/11/2003	8.40	240	144	96.00	68.30	36.00	1.20	7.50	2.00	0.15	0.10	NA	12.00	7.80	11.70	59.50	BDL
BW-13	Mudicode	26/02/2004	8.40	220	132	89.00	70.00	29.60	3.60	6.70	2.20	0.91	0.07	NA	10.00	7.30	6.00	73.20	BDL
BW-13	Mudicode	14/05/2004	8.30	210	126	85.00	70.00	32.00	1.20	7.30	1.90	0.64	0.00	NA	10.00	8.80	6.00	73.20	0.00
BW-13	Mudicode	16/08/2004	8.50	190	114	90.00	79.20	27.50	5.20	6.60	2.10	0.66	0.08	NA	13.00	9.20	4.30	87.80	BDL
BW-13	Mudicode	03/11/2004	8.30	190	114	90.00	81.70	28.00	4.90	6.90	2.20	0.56	0.08	NA	13.00	5.70	9.10	81.10	0.18
BW-13	Mudicode	09/02/2005	8.60	210	126	81.00	83.40	22.30	6.20	8.20	2.00	0.44	0.19	NA	11.00	8.30	6.90	87.50	BDL
BW-13	Mudicode	04/05/2005	8.40	190	114	91.00	100.00	22.20	8.60	7.60	2.20	0.34	0.41	NA	14.60	7.60	7.20	107.36	BDL
BW-13	Mudicode	02/09/2005	8.40	200	120	91.00	88.80	24.20	7.40	6.50	2.30	0.61	0.13	NA	12.50	7.30	10.65	86.60	BDL
BW-13	Mudicode	07/02/2006	8.37	220	132	94.30	90.00	31.16	4.00	4.00	3.20	0.46	0.37	NA	6.72	5.10	7.20	95.16	0.80
BW-14	Velapaya	20/11/1999	8.30	289	145	59.00	NA	35.00	6.00	9.00	2.70	0.30	BDL	NA	14.00	0.10	0.00	129.00	BDL
BW-14	Velapaya	24/09/2002	8.19	180	108	40.00	41.16	10.00	3.70	13.40	2.90	0.19	0.06	NA	19.30	5.70	0.00	50.20	1.60
BW-14	Velapaya	19/11/2003	7.90	190	114	51.00	34.20	14.00	3.70	12.60	2.50	0.62	0.40	NA	24.00	4.30	11.70	17.80	2.40
BW-14	Velapaya	28/02/2004	8.00	200	120	54.00	35.00	15.80	3.60	12.50	2.70	0.72	0.60	NA	24.00	5.30	0.00	42.70	2.22
BW-14	Velapaya	22/05/2004	7.90	210	126	65.00	45.00	14.00	7.30	13.90	2.50	0.06	0.00	NA	24.00	10.00	0.00	54.90	0.64
BW-14	Velapaya	26/08/2004	8.10	180	108	56.00	37.80	13.80	5.20	14.20	2.80	0.23	0.19	NA	27.00	5.00	0.00	46.10	3.10
BW-14	Velapaya	17/11/2004	8.00	190	114	60.00	34.20	14.00	6.10	14.10	2.70	0.70	0.08	NA	27.00	2.50	0.00	41.70	3.31
BW-14	Velapaya	15/02/2005	8.20	200	120	46.00	42.70	10.10	7.90	15.60	2.60	0.34	0.22	NA	24.00	3.50	0.00	52.00	1.90
BW-14	Velapaya	06/05/2005	8.30	250	150	86.00	88.00	28.20	3.70	17.00	2.70	0.19	0.92	NA	32.00	9.80	4.80	97.60	1.78
BW-14	Velapaya	19/09/2005	8.06	220	132	61.00	40.00	16.20	4.90	17.00	3.30	0.42	0.23	NA	32.60	5.00	0.00	48.75	3.78
BW-14	Velapaya	2/6/2006	8.10	230	138	65.60	40.00	14.76	7.00	14.60	4.40	0.34	0.51	NA	27.84	1.88	0.00	48.80	8.58
BW-15	Kaiparambu	12/10/2001	8.00	200	110	80.00	90.00	22.00	6.10	12.00	3.30	0.00	9.10	100.00	11.00	6.00	14.40	80.50	0.00
BW-15	Kaiparambu	19/11/2003	8.30	190	114	66.00	68.30	16.00	6.20	7.40	2.40	0.70	4.50	NA	10.00	5.70	11.70	59.53	BDL
BW-15	Kaiparambu	17/02/2004	8.30	180	108	49.00	55.00	11.80	4.80	11.60	2.80	0.88	4.30	NA	8.00	5.50	0.00	67.10	0.20
BW-15	Kaiparambu	18/05/2004	8.00	150	90	55.00	55.00	12.00	6.10	12.10	2.40	0.49	0.16	NA	7.00	4.10	6.00	54.90	0.00
BW-15	Kaiparambu	12/08/2004	8.40	150	90	60.00	72.00	10.30	8.40	11.80	2.60	0.47	2.69	NA	7.00	7.90	4.30	79.10	0.10
BW-15	Kaiparambu	09/12/2004	8.30	160	96	55.00	70.30	10.00	7.30	11.80	2.50	0.85	0.00	NA	9.00	3.20	4.50	76.40	0.08
BW-15	Kaiparambu	16/02/2005	8.40	150	90	41.00	69.80	10.10	3.70	13.70	2.50	0.49	2.73	NA	9.00	3.80	9.30	66.20	BDL
BW-15	Kaiparambu	05/05/2005	8.30	140	84	61.00	82.00	10.10	8.60	11.00	2.60	0.53	3.62	NA	10.70	4.60	2.40	95.10	BDL
BW-15	Kaiparambu	04/02/2006	8.40	170	102	53.30	68.00	8.20	8.00	9.00	3.40	0.16	6.66	NA	4.80	2.88	7.20	68.32	0.60
BW-16	Peechi	20/03/1999	7.50	157	86	59.90	NA	29.90	7.31	11.20	1.90	0.53	BDL	NA	16.08	6.90	0.00	98.00	BDL
BW-16	Peechi	24/09/2002	8.26	220	132	60.00	47.04	12.00	7.40	12.30	2.50	0.34	0.92	NA	20.20	7.60	0.00	57.40	1.10
BW-16	Peechi	20/11/2003	8.30	200	120	76.00	58.60	6.40	8.60	13.20	2.10	0.60	2.00	NA	25.00	6.80	11.70	47.58	BDL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BW-16	Peechi	26/02/2004	8.50	220	132	84.00	65.00	15.80	10.80	11.50	2.60	0.63	2.20	NA	22.00	8.10	6.00	67.10	BDL
BW-16	Peechi	14/05/2004	8.30	310	186	125.00	100.00	28.00	13.40	12.70	2.70	0.44	0.04	NA	29.00	7.70	18.00	85.40	0.00
BW-16	Peechi	16/08/2004	8.00	140	84	43.00	34.20	8.60	5.20	9.70	2.50	0.00	0.32	NA	18.00	6.40	0.00	41.70	1.16
BW-16	Peechi	03/11/2004	8.10	160	96	45.00	39.90	10.00	4.90	11.10	1.80	0.37	0.26	NA	20.00	2.80	0.00	48.60	0.42
BW-16	Peechi	09/02/2005	8.20	180	108	51.00	48.50	8.10	7.40	14.20	2.00	0.05	4.40	NA	20.00	5.00	0.00	59.20	0.30
BW-16	Peechi	02/09/2005	8.23	166	99.6	40.00	42.20	6.10	6.20	12.00	2.10	0.83	0.57	NA	23.00	6.00	0.00	51.46	0.72
BW-16	Peechi	07/02/2006	8.12	200	120	69.70	44.00	11.48	10.00	9.90	3.30	0.39	2.64	NA	24.96	3.13	0.00	53.68	2.40
BW-17	Chittilappilly	24/09/2002	8.30	140	84	20.00	47.04	6.00	1.20	17.20	3.90	0.00	0.14	NA	8.30	5.00	0.00	57.39	0.10
BW-17	Chittilappilly	19/11/2003	8.10	100	60	25.00	39.00	4.00	3.70	11.90	2.80	0.67	0.40	NA	9.00	3.50	0.00	47.58	BDL
BW-17	Chittilappilly	17/02/2004	8.10	130	78	20.00	40.00	5.90	1.20	13.70	3.00	1.00	0.40	NA	7.00	0.50	0.00	48.80	0.12
BW-17	Chittilappilly	12/08/2004	8.30	110	66	26.00	45.00	3.40	4.20	14.70	1.70	0.55	0.19	NA	8.00	3.60	2.20	50.50	BDL
BW-17	Chittilappilly	09/12/2004	8.00	110	66	20.00	47.50	4.00	2.40	14.30	2.70	0.65	0.09	NA	7.00	2.10	0.00	57.90	0.00
BW-17	Chittilappilly	16/02/2005	8.20	110	66	15.00	52.40	2.00	2.50	15.90	2.60	0.34	0.32	NA	7.00	2.50	0.00	63.90	BDL
BW-17	Chittilappilly	09/09/2005	8.37	162	97.2	51.00	75.50	14.10	3.70	11.00	3.00	0.51	0.09	NA	8.60	2.80	5.32	81.20	BDL
BW-17	Nelluvayi	07/02/2006	8.12	121	72.6	20.50	40.00	3.28	3.00	10.60	3.50	0.71	0.48	NA	5.76	0.88	0.00	48.80	0.72
BW-18	Nelluvayi	10/10/2001	8.00	320	176	160.00	160.00	40.00	14.60	13.00	4.90	0.00	9.50	61.00	25.00	21.00	24.00	146.40	BDL
BW-18	Nelluvayi	30/09/2002	8.71	370	222	151.00	123.48	34.00	15.90	12.00	4.80	0.23	0.05	NA	16.50	16.40	14.10	121.95	BDL
BW-18	Nelluvayi	25/11/2002	8.70	390	234	161.00	133.12	41.60	13.90	12.10	4.40	0.80	0.02	NA	16.70	15.10	18.40	124.90	BDL
BW-18	Nelluvayi	13/08/2003	8.50	300	180	147.00	117.10	43.20	9.60	9.80	4.10	0.72	0.07	NA	12.70	18.05	11.70	119.10	0.09
BW-18	Nelluvayi	27/02/2004	8.70	350	210	148.00	120.00	41.40	10.80	11.60	4.50	0.75	0.30	NA	12.00	17.20	12.00	122.00	BDL
BW-18	Nelluvayi	18/05/2004	8.10	200	120	70.00	65.00	16.00	7.30	11.60	4.10	0.77	0.00	NA	14.00	7.91	0.00	79.30	0.00
BW-18	Nelluvayi	02/09/2004	8.70	340	204	163.00	145.80	29.20	22.00	11.10	3.90	0.16	0.11	NA	15.00	8.90	0.00	177.80	BDL
BW-18	Nelluvayi	08/12/2004	8.40	310	186	155.00	134.90	30.00	19.40	12.30	3.60	0.08	0.00	NA	16.00	11.00	13.60	136.70	0.24
BW-18	Nelluvayi	15/02/2005	8.60	320	192	127.00	130.00	24.30	16.10	14.30	3.60	0.00	0.24	NA	14.00	7.40	13.90	130.10	BDL
BW-18	Nelluvayi	05/05/2005	8.60	310	186	146.00	184.00	30.30	17.20	14.00	3.80	0.02	0.63	NA	20.40	7.90	21.60	180.50	BDL
BW-18	Nelluvayi	19/09/2005	8.65	340	204	157.00	159.80	28.30	20.90	10.00	4.00	1.05	0.07	NA	16.30	8.00	18.64	157.09	0.42
BW-18	Kandanissery	04/02/2006	8.67	380	228	172.20	154.00	44.28	15.00	9.30	5.10	0.48	0.19	NA	14.40	13.62	21.60	143.96	0.76
BW-19	Kandanissery	11/10/2001	8.10	170	94	75.00	72.00	18.00	7.30	10.00	4.50	0.10	9.80	88.00	11.00	7.00	2.40	82.96	BDL
BW-19	Kandanissery	24/09/2002	8.44	220	132	60.00	76.44	20.00	2.50	7.00	4.50	0.59	0.24	NA	9.20	10.80	0.00	93.26	BDL
BW-19	Kandanissery	25/11/2002	8.50	210	126	83.00	81.92	18.80	8.80	8.60	4.40	0.30	0.14	NA	11.10	8.80	12.30	74.96	BDL
BW-19	Kandanissery	17/11/2003	8.40	210	126	81.00	68.30	22.00	6.20	8.30	3.80	0.20	0.20	NA	9.00	14.90	11.70	59.50	BDL
BW-19	Kandanissery	17/02/2004	8.40	180	108	64.00	60.00	19.70	3.60	8.90	3.60	0.30	1.20	NA	7.00	4.30	6.00	61.00	0.19
BW-19	Kandanissery	18/05/2004	8.10	210	126	85.00	60.00	28.00	3.70	10.20	3.80	0.30	0.11	NA	8.00	26.10	12.00	48.80	0.28
BW-19	Kandanissery	02/09/2004	8.40	210	126	103.00	79.20	20.60	12.60	9.70	4.00	0.87	0.10	NA	8.00	18.40	2.20	92.20	BDL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BW-19	Kandanissery	16/11/2004	8.40	200	120	90.00	85.50	18.00	11.10	10.10	4.10	0.48	0.32	NA	8.00	8.90	9.10	85.70	0.13
BW-19	Kandanissery	16/02/2005	8.30	169	101	51.00	60.10	12.20	4.90	11.20	3.10	0.44	1.08	NA	7.00	4.00	4.60	63.90	BDL
BW-19	Kandanissery	05/05/2005	8.30	200	120	81.00	96.00	16.10	9.86	11.30	4.00	0.74	3.59	NA	12.60	10.00	4.80	107.30	0.07
BW-19	Kandanissery	09/09/2005	8.45	250	150	96.00	93.20	24.20	8.60	7.00	4.60	0.88	0.04	NA	10.60	20.00	10.65	92.00	0.24
BW-19	Aloor	04/02/2006	8.17	141	84.6	49.20	40.00	9.84	6.00	5.80	3.60	0.75	2.57	NA	5.76	7.91	0.00	48.80	0.60
BW-20	Aloor	28/05/2001	7.10	10	6	45.00	NA	12.00	3.60	1.00	0.10	0.00	BDL	NA	1.10	0.00	0.00	51.24	BDL
BW-20	Aloor	19/10/2001	8.20	250	138	130.00	122.00	30.00	13.40	10.00	2.60	0.00	3.80	100.00	12.00	5.00	19.20	109.80	BDL
BW-20	Aloor	25/09/2002	7.72	60	36	15.00	11.76	6.00	0.00	5.30	0.30	0.00	0.14	NA	9.20	1.70	0.00	14.30	1.54
BW-20	Aloor	15/11/2003	7.70	60	36	20.00	14.60	8.00	0.00	4.90	0.50	0.20	0.10	NA	9.00	1.60	0.00	17.80	1.42
BW-20	Aloor	01/03/2004	7.60	60	36	15.00	10.00	2.00	2.40	4.20	0.50	0.90	0.20	NA	8.00	2.70	0.00	12.20	1.90
BW-20	Aloor	07/02/2005	7.50	65	39	15.00	13.60	4.10	1.20	6.00	0.40	0.59	0.13	NA	8.00	3.00	0.00	16.56	1.74
BW-20	Aloor	07/05/2005	7.40	66	39.6	15.00	10.00	4.00	1.23	7.80	0.50	0.00	0.25	NA	14.60	3.00	0.00	12.20	2.24
BW-20	Aloor	23/09/2005	7.50	66	39.6	15.00	11.10	2.00	2.50	5.60	0.50	0.87	0.02	NA	10.60	3.00	0.00	13.50	2.00
BW-20	Vellangallur	02/02/2006	7.30	68	40.8	20.50	10.00	4.92	2.00	4.00	1.30	0.17	0.24	NA	7.68	2.13	0.00	12.20	3.22
BW-21	Vellangallur	19/10/2001	8.10	200	110	90.00	88.00	20.00	9.70	10.00	6.30	0.40	9.30	91.00	14.00	6.00	9.60	87.84	BDL
BW-21	Vellangallur	16/02/2004	7.80	80	48	30.00	20.00	7.90	2.40	3.30	2.50	0.60	0.08	NA	9.00	1.80	0.00	24.40	BDL
BW-21	Vellangallur	19/05/2004	7.50	80	48	30.00	20.00	4.00	4.90	3.70	2.30	0.17	0.00	NA	10.00	4.75	0.00	24.40	0.44
BW-21	Vellangallur	25/08/2004	7.90	90	54	43.00	23.40	6.90	6.30	3.40	2.60	0.10	0.08	NA	10.00	6.60	0.00	28.50	0.62
BW-21	Vellangallur	05/11/2004	7.80	90	54	45.00	24.70	6.00	7.30	4.10	2.40	0.53	0.07	NA	11.00	5.90	0.00	30.10	0.62
BW-21	Vellangallur	07/05/2005	7.70	93	55.8	35.00	32.00	6.00	4.93	5.00	2.40	0.00	0.37	NA	14.60	6.20	0.00	39.00	0.62
BW-21	Vellangallur	23/09/2005	7.80	113	67.8	40.00	28.90	8.10	4.90	7.50	2.80	0.56	0.08	NA	14.40	5.80	0.00	35.20	0.70
BW-21	Wadakanchery	02/02/2006	7.80	118	70.8	28.70	24.00	8.20	2.00	5.70	3.40	0.52	0.20	NA	10.56	4.25	0.00	29.28	1.20
BW-22	Wadakanchery	08/10/2001	8.20	900	630	265.00	148.00	24.00	50.00	22.00	9.90	0.40	2.90	100.00	74.00	125.00	19.20	141.50	BDL
BW-22	Wadakanchery	27/03/2002	8.70	760	456	403.00	21.40	83.60	47.34	16.50	4.80	0.00	0.29	NA	106.20	49.00	39.00	181.78	BDL
BW-22	Wadakanchery	28/09/2002	8.82	850	510	347.00	199.92	76.40	38.00	21.00	7.90	0.31	0.56	NA	83.40	37.30	35.30	172.20	
BW-22	Wadakanchery	19/02/2003	8.70	720	432	365.00	184.32	21.10	56.80	37.80	7.10	0.00	0.10	NA	70.50	38.10	22.10	182.90	1.42
BW-22	Wadakanchery	27/02/2004	8.70	640	384	266.00	115.00	49.30	34.90	18.10	6.50	0.50	0.70	NA	77.00	45.80	6.00	128.10	0.24
BW-22	Wadakanchery	22/05/2004	8.30	720	432	365.00	195.00	108.00	23.20	17.40	5.90	0.30	0.00	NA	78.00	73.10	6.00	225.70	0.08
BW-22	Wadakanchery	23/08/2004	8.70	730	438	383.00	180.00	61.90	55.60	19.50	6.10	0.25	0.18	NA	76.00	65.00	21.60	175.60	0.20
BW-22	Wadakanchery	09/12/2004	8.60	830	498	445.00	220.40	112.00	40.30	23.50	6.70	0.49	0.00	NA	102.00	47.50	22.80	222.50	0.16
BW-22	Wadakanchery	15/02/2005	8.90	860	516	340.00	236.70	71.00	39.60	21.20	6.30	0.31	0.17	NA	84.00	50.00	46.50	194.10	BDL
BW-22	Wadakanchery	06/05/2005	8.60	770	462	374.00	276.00	78.70	43.10	20.00	6.50	0.20	0.29	NA	98.90	71.00	33.60	268.40	0.28
BW-22	Wadakanchery	22/09/2005	8.66	880	528	394.00	239.80	64.60	56.70	20.60	8.60	0.93	0.06	NA	97.90	70.00	18.64	254.50	BDL
BW-22	Varavur	06/02/2006	8.73	860	516	405.30	204.00	83.64	48.02	19.00	8.70	0.00	0.59	NA	88.32	66.41	33.60	180.56	0.70

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BW-23	Varavur	28/09/2002	8.80	440	264	216.00	188.00	60.40	15.90	14.30	4.20	0.25	0.10	NA	9.20	26.00	42.30	143.50	BDL
BW-23	Varavur	19/02/2003	8.70	350	210	175.00	133.12	11.80	24.50	22.60	3.90	0.90	0.10	NA	6.40	19.10	7.38	167.50	0.94
BW-23	Varavur	01/03/2004	8.90	390	234	202.00	160.00	45.40	21.70	10.50	3.50	0.70	0.50	NA	10.00	21.20	24.00	146.40	0.30
BW-23	Varavur	18/05/2004	8.31	290	174	130.00	110.00	38.00	8.50	8.50	2.40	0.38	0.00	NA	11.00	16.08	12.00	109.80	0.00
BW-23	Varavur	23/08/2004	8.70	390	234	219.00	151.20	34.40	32.50	13.20	3.70	0.36	1.83	NA	12.00	40.20	19.40	144.90	0.08
BW-23	Varavur	17/11/2004	8.40	440	264	245.00	199.50	38.00	36.60	13.60	3.70	0.77	0.09	NA	11.00	18.10	11.40	220.20	0.04
BW-23	Varavur	15/02/2005	8.90	430	258	188.00	194.00	38.50	22.30	13.70	3.40	0.89	0.27	NA	9.00	25.00	30.20	175.10	BDL
BW-23	Varavur	19/09/2005	8.67	410	246	182.00	186.50	28.30	27.00	9.00	4.50	0.75	0.48	NA	11.50	20.00	13.32	200.40	BDL
BW-23	Arthat	06/02/2006	8.60	420	252	200.90	156.00	32.80	29.01	8.90	4.60	0.52	0.72	NA	14.40	13.47	19.20	151.28	0.76
BW-24	Arthat	27/03/2002	8.20	130	78	29.90	18.00	6.00	3.66	9.80	2.20	0.00	0.47	NA	23.70	9.00	0.00	21.96	BDL
BW-24	Arthat	30/09/2002	8.39	180	108	60.00	58.80	16.00	4.90	7.00	4.10	0.00	2.16	NA	9.20	7.00	7.06	57.40	BDL
BW-24	Arthat	22/11/2002	8.30	110	66	41.00	40.96	12.40	2.50	6.00	2.90	0.30	6.30	NA	8.30	2.90	6.14	37.50	0.64
BW-24	Arthat	19/02/2003	8.10	100	60	42.00	40.90	5.90	1.30	20.60	3.40	0.30	2.40	NA	6.40	5.50	0.00	60.90	0.74
BW-24	Arthat	17/11/2003	8.30	130	78	56.00	63.40	18.20	2.50	6.00	3.10	0.88	2.80	NA	8.00	5.90	5.90	65.50	BDL
BW-24	Arthat	13/02/2004	8.20	110	66	30.00	35.00	7.90	2.40	8.20	3.20	0.92	3.30	NA	7.00	6.30	0.00	42.70	BDL
BW-24	Arthat	15/05/2004	7.70	120	72	35.00	30.00	8.00	3.70	9.00	3.10	1.09	0.01	NA	10.00	21.90	0.00	36.60	0.00
BW-24	Arthat	04/12/2004	8.20	160	96	55.00	57.00	18.00	2.40	11.00	3.20	0.09	1.00	NA	8.00	8.30	2.28	64.90	0.01
BW-24	Arthat	10/02/2005	8.20	134	80	30.00	40.70	8.10	2.50	11.50	2.90	0.03	4.50	NA	7.00	8.00	0.00	49.70	BDL
BW-24	Arthat	02/05/2005	8.20	148	88.8	35.00	52.00	8.08	3.70	13.00	3.10	0.17	2.70	NA	14.60	9.00	2.40	58.50	0.06
BW-24	Arthat	05/09/2005	8.00	124	74.4	35.00	33.30	8.10	3.70	5.40	4.00	1.10	0.73	NA	8.60	8.00	0.00	40.60	BDL
BW-24	Arthat	01/02/2006	8.19	146	87.6	45.10	48.00	8.20	6.00	5.70	4.20	0.28	0.63	NA	9.60	4.50	0.00	58.56	BDL

BDL:Below detectable level

NA: Not analysed

Table 5.35 Various ratios, percetages and indices derived from the chemical analysis date of water samples in phreatic aquifer (dug wells) of Palaeo-lagoon (Kole land basin) for the period 01.01.2000 to 31.12.2006 (ionic cocentration in meq/l)

Well No	Location	Ionic ratio	Na/Cl	HCO3/Cl	SO4/Cl	Mg/Ca	Mg/Na	HCO3/SO4	Cl/(CO3+ HCO3)	Na/(Na+ Ca+K)	SAR	Na%	Residual sodium carbonate (RSC)	Permeability index (PI)	Corosivity ratio (CR)	Mg ratio (MR)	Gibb's (Na) ratio	Gibb's (Cl) ratio
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-1	Thrissur	0.07	1.02	0.11	0.05	1.21	0.59	2.33	8.90	0.60	1.37	51.66	-0.99	63.71	0.01	54.69	0.53	0.49
OW-1	Thrissur	0.06	0.77	0.76	0.36	0.43	1.01	2.11	1.31	0.29	0.73	24.98	-2.11	47.10	0.04	29.97	0.72	0.65
OW-1	Thrissur	0.12	0.54	0.62	0.13	0.66	1.14	4.80	1.62	0.32	0.49	33.19	-0.59	73.07	0.02	39.75	0.92	0.53
OW-1	Thrissur	0.11	1.04	0.32	1.29	0.40	0.26	0.25	3.16	0.53	1.30	58.03	-0.46	85.52	0.03	28.44	0.62	0.68
OW-1	Thrissur	0.09	1.02	0.52	0.04	BDL	0.00	12.35	1.93	0.70	3.01	89.09	0.25	159.91	0.00	0.00	0.37	0.23
OW-1	Thrissur	0.08	0.65	0.27	0.07	0.34	0.36	4.10	3.65	0.42	0.89	48.01	-0.57	76.89	NA	25.11	0.62	0.37
OW-2	Mannuthi	0.03	0.81	0.98	0.24	0.33	0.34	4.03	1.02	0.43	0.65	48.39	-0.05	128.35	0.01	24.80	0.77	0.48
OW-2	Mannuthi	0.10	0.88	0.62	0.09	BDL	0.00	7.05	1.61	0.59	1.20	72.01	0.08	165.70	0.01	0.00	0.75	0.50
OW-2	Mannuthi	0.10	1.16	0.58	0.20	0.49	0.25	2.85	1.73	0.59	1.01	60.82	-0.10	120.92	0.02	33.10	0.81	0.47
OW-2	Mannuthi	0.02	0.81	0.64	0.26	1.98	0.78	2.46	1.55	0.60	0.65	51.94	-0.10	127.27	0.01	66.43	0.60	0.29
OW-2	Mannuthi	0.09	0.99	1.42	0.15	BDL	0.00	9.60	0.71	0.43	0.72	53.34	0.10	157.63	0.01	0.00	0.83	0.50
OW-2	Mannuthi	0.08	0.81	0.58	0.38	4.07	1.37	1.53	1.74	0.62	0.54	42.74	-0.25	98.86	0.02	80.29	0.51	0.28
OW-2	Mannuthi	0.01	0.80	1.46	0.10	0.41	0.61	14.88	0.68	0.37	0.57	36.52	-0.09	107.38	0.01	28.99	0.65	0.53
OW-2	Mannuthi	0.06	0.48	0.51	0.09	1.00	0.91	5.75	1.95	0.46	0.49	41.43	-0.16	113.60	0.02	50.10	0.51	0.43
OW-2	Mannuthi	0.03	0.41	0.76	0.12	0.68	1.43	6.09	1.32	0.27	0.28	30.40	-0.24	100.91	0.01	40.33	0.22	0.14
OW-2	Mannuthi	0.03	0.81	0.56	0.12	1.98	0.72	4.76	1.80	0.63	0.71	53.01	-0.11	123.95	0.00	66.43	0.37	0.15
OW-2	Mannuthi	0.03	0.39	3.69	0.08	0.15	1.58	48.02	0.27	0.08	0.13	13.63	-0.23	82.85	NA	13.40	0.79	0.13
OW-3	Pattikkad	0.05	0.96	3.25	0.37	0.28	0.87	8.82	0.31	0.22	0.42	25.54	-0.23	81.82	0.00	21.71	0.38	0.21
OW-3	Pattikkad	0.04	2.97	3.78	0.38	1.26	0.47	9.99	0.26	0.67	1.28	57.16	0.30	128.35	0.00	55.68	0.29	0.12
OW-3	Pattikkad	0.03	0.95	2.49	0.26	BDL	0.00	9.72	0.40	0.08	0.22	10.45	-2.44	32.55	0.00	0.00	0.37	0.16
OW-3	Pattikkad	0.03	1.16	3.63	0.17	0.70	1.85	21.07	0.28	0.25	0.42	22.24	-0.53	69.64	0.00	41.10	0.59	0.21
OW-3	Pattikkad	0.02	0.81	2.18	0.15	0.34	1.00	14.78	0.46	0.23	0.39	25.48	-0.38	80.67	0.00	25.12	0.37	0.16
OW-3	Pattikkad	0.03	0.86	4.29	0.49	0.27	1.30	8.77	0.22	0.16	0.29	18.58	-0.23	74.78	0.00	21.16	1.00	0.15
OW-3	Pattikkad	0.05	0.99	3.14	0.27	0.40	1.20	11.61	0.28	0.23	0.40	23.68	-0.19	78.70	0.00	28.78	0.89	0.61
OW-3	Pattikkad	0.06	0.88	2.16	0.17	1.00	1.16	12.43	0.42	0.41	0.55	35.41	0.12	110.10	0.00	49.94	0.87	0.47
OW-3	Pattikkad	0.02	0.80	3.15	0.40	0.56	1.80	7.84	0.29	0.22	0.34	21.68	-0.22	78.55	NA	35.97	0.81	0.65
OW-3	Pattikkad	0.03	0.98	3.32	0.34	BDL	3.86	9.88	0.30	0.66	0.33	28.03	-0.10	102.47	NA	100.00	0.71	0.63

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-3	Pattikkad	0.08	0.83	3.02	0.33	1.01	1.60	9.12	0.33	0.34	0.45	29.34	0.15	104.94	NA	50.14	0.41	0.33
OW-4	Pudukkad	0.01	0.92	0.37	0.16	2.98	0.50	2.25	2.73	0.80	1.33	61.59	-0.16	108.74	0.02	74.91	0.88	0.75
OW-4	Pudukkad	0.08	1.04	0.31	0.08	1.03	0.32	3.90	3.18	0.71	1.43	63.50	-0.21	103.46	0.01	50.76	0.81	0.69
OW-4	Pudukkad	0.05	0.90	0.34	0.06	0.34	0.18	5.65	2.96	0.60	1.21	60.27	-0.19	105.82	0.03	25.12	0.81	0.49
OW-4	Pudukkad	0.10	0.92	1.18	0.13	0.11	0.21	9.00	0.85	0.33	0.66	33.80	-0.40	84.79	0.02	9.91	0.52	0.86
OW-4	Pudukkad	0.05	0.94	0.19	0.05	1.98	0.35	4.18	5.24	0.78	1.44	67.34	-0.18	104.57	0.01	66.43	1.00	0.62
OW-4	Pudukkad	0.08	1.12	0.26	0.11	0.48	0.15	2.47	3.85	0.71	1.70	70.65	-0.15	109.25	0.04	32.55	0.86	0.86
OW-4	Pudukkad	0.03	0.84	0.59	0.08	2.51	0.81	7.03	1.68	0.70	1.05	49.19	-0.27	96.56	0.03	71.55	0.87	0.74
OW-4	Pudukkad	0.01	0.47	0.09	0.09	0.32	0.43	1.06	11.03	0.41	0.51	39.32	-0.36	69.58	0.01	24.49	0.80	0.78
OW-4	Pudukkad	0.10	0.82	0.35	0.09	BDL	1.06	3.84	2.84	0.83	0.94	53.03	-0.29	95.14	0.09	100.00	0.76	0.86
OW-4	Pudukkad	0.08	1.07	0.66	0.05	0.82	0.17	13.51	1.51	0.77	1.74	74.26	0.14	147.84	0.02	45.19	0.68	0.69
OW-5	Kodakara	0.02	0.92	0.09	0.40	0.66	0.17	0.24	10.66	0.68	2.31	73.85	-0.38	90.61	0.10	39.85	0.81	0.82
OW-5	Kodakara	0.03	0.81	0.21	0.04	BDL	0.00	4.68	4.85	0.65	2.75	83.93	0.01	121.94	0.04	0.00	0.75	0.53
OW-5	Kodakara	0.11	0.74	0.16	0.03	1.01	0.45	5.49	6.07	0.57	1.42	59.45	-0.60	79.14	0.05	50.25	0.65	0.73
OW-5	Kodakara	0.09	0.66	0.09	0.04	0.59	0.34	2.36	10.69	0.53	1.30	59.72	-0.58	75.42	0.09	37.28	0.66	0.74
OW-5	Kodakara	0.12	0.65	0.17	0.04	1.00	0.59	4.06	5.94	0.51	1.08	54.21	-0.63	74.17	NA	49.94	0.59	0.67
OW-6	Irinjalakuda	0.02	0.94	0.26	0.24	0.17	0.12	1.10	3.85	0.53	2.52	59.38	-1.36	73.45	0.04	14.36	0.61	0.85
OW-6	Irinjalakuda	0.09	0.80	0.13	0.07	0.87	0.30	1.81	7.87	0.65	3.11	64.52	-1.55	74.11	0.07	46.51	0.56	0.76
OW-6	Irinjalakuda	0.11	0.58	0.51	0.14	0.50	0.32	3.60	1.96	0.49	1.59	59.28	-0.11	94.07	0.02	33.55	0.63	0.76
OW-6	Irinjalakuda	0.07	0.70	0.21	0.17	0.30	0.26	1.24	4.68	0.48	2.03	52.39	-1.86	64.53	0.04	23.16	0.62	0.86
OW-6	Irinjalakuda	0.07	0.80	0.20	0.30	0.23	0.19	0.67	4.94	0.49	1.77	54.46	-1.20	69.56	0.05	19.01	0.74	0.56
OW-6	Irinjalakuda	0.09	0.60	0.29	0.49	0.46	0.69	0.59	3.46	0.33	0.83	40.83	-1.28	56.51	0.04	31.69	0.66	0.43
OW-6	Irinjalakuda	0.13	0.64	0.20	0.36	0.58	0.71	0.55	5.12	0.39	1.01	41.49	-1.59	53.32	0.09	36.87	0.66	0.35
OW-6	Irinjalakuda	0.03	0.56	0.10	0.14	BDL	0.00	0.73	9.80	0.45	2.16	55.12	-1.90	64.08	0.05	0.00	0.80	0.36
OW-6	Irinjalakuda	0.02	0.46	0.18	0.12	0.47	0.52	1.50	5.53	0.44	1.75	40.95	-3.14	52.90	0.05	31.83	0.79	0.23
OW-6	Irinjalakuda	0.07	0.62	0.18	0.30	0.39	0.42	0.60	5.49	0.41	1.26	47.51	-1.47	59.48	0.09	27.99	0.69	0.34
OW-6	Irinjalakuda	0.09	0.55	0.09	0.12	0.34	0.35	0.78	10.63	0.43	1.84	48.13	-2.88	53.02	NA	25.10	0.58	0.24
OW-7	MG Kavu	0.12	0.89	0.46	0.20	BDL	0.00	2.25	2.18	0.68	1.45	70.40	0.03	143.35	0.02	0.00	0.55	0.30
OW-7	MG Kavu	0.10	0.94	0.76	0.11	1.03	0.71	6.62	1.32	0.56	0.65	43.89	-0.17	111.31	0.01	50.76	0.39	0.24
OW-7	MG Kavu	0.05	1.06	1.07	0.11	1.03	0.68	9.81	0.94	0.58	0.68	44.50	-0.10	120.89	0.01	50.76	1.00	0.22
OW-7	MG Kavu	0.07	1.07	1.03	0.14	1.24	0.40	7.56	0.97	0.71	0.83	60.05	0.06	172.42	0.01	55.29	0.73	0.54
OW-7	MG Kavu	0.05	1.06	1.97	0.21	5.03	1.86	9.60	0.51	0.67	0.49	33.67	-0.10	112.08	0.00	83.42	0.68	0.45

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-7	MG Kavu	0.04	0.58	1.12	0.20	3.01	1.95	5.51	0.89	0.55	0.32	30.75	-0.09	134.54	0.01	75.04	0.79	0.38
OW-7	MG Kavu	0.09	1.08	1.33	0.12	1.01	0.81	11.08	0.75	0.50	0.55	42.91	-0.09	124.47	0.00	50.37	0.57	0.39
OW-7	MG Kavu	0.03	1.17	1.83	0.17	0.32	0.33	10.65	0.55	0.46	0.66	45.32	0.06	139.93	0.01	24.49	0.75	0.53
OW-7	MG Kavu	0.01	0.80	1.37	0.22	0.50	0.54	6.14	0.73	0.46	0.68	40.21	0.03	119.79	0.00	33.43	0.63	0.38
OW-7	MG Kavu	0.06	0.32	1.84	0.19	1.53	4.37	9.60	0.54	0.24	0.14	15.88	-0.10	122.32	0.00	60.40	0.66	0.35
OW-7	MG Kavu	0.06	0.40	2.03	0.00	BDL	6.62	NA	0.49	0.63	0.16	19.34	-0.14	113.16	NA	100.00	0.72	0.37
OW-8	Ottuppara	0.10	1.02	0.50	0.83	0.60	0.31	0.59	2.02	0.61	1.54	57.66	-0.33	93.70	0.02	37.38	0.68	0.38
OW-8	Ottuppara	0.08	1.08	0.70	0.18	0.41	0.28	3.89	1.43	0.55	1.22	54.20	-0.23	98.66	0.01	29.19	0.54	0.26
OW-8	Ottuppara	0.09	1.13	0.93	0.35	0.73	0.27	2.69	1.07	0.66	1.49	63.81	0.13	125.48	0.01	42.11	1.00	0.28
OW-8	Ottuppara	0.05	0.81	0.91	0.25	0.61	0.70	3.61	1.10	0.43	0.69	38.91	-0.32	91.55	0.01	37.89	0.49	0.21
OW-8	Ottuppara	0.10	0.84	0.51	0.08	2.01	0.91	6.20	1.98	0.63	0.99	45.22	-0.50	82.85	0.02	66.74	0.50	0.22
OW-8	Ottuppara	0.07	1.13	0.94	0.33	0.55	0.45	2.84	1.07	0.51	1.23	47.29	-0.41	85.53	0.01	35.62	0.67	0.23
OW-8	Ottuppara	0.07	0.81	1.09	0.21	0.84	0.94	5.17	0.76	0.37	1.02	42.96	-0.46	69.42	0.01	45.60	0.48	0.32
OW-8	Ottuppara	0.05	1.09	0.99	0.16	1.00	0.55	6.04	1.01	0.60	1.00	50.51	-0.11	108.65	0.01	50.01	0.42	0.23
OW-8	Ottuppara	0.02	0.84	0.93	0.13	1.01	0.70	7.31	1.07	0.54	0.91	45.52	-0.17	99.32	0.01	50.15	0.40	0.24
OW-8	Ottuppara	0.06	1.15	1.64	0.12	0.40	0.50	13.86	0.57	0.41	0.96	40.10	-0.17	84.83	0.01	28.57	0.49	0.22
OW-8	Ottuppara	0.06	0.84	1.48	0.17	BDL	2.33	8.96	0.68	0.75	0.52	36.32	-0.18	100.72	0.01	100.00	0.43	0.26
OW-9	Chelakkara	0.03	0.99	2.20	0.33	0.51	1.02	6.67	0.36	0.29	0.72	31.57	-0.17	66.35	0.00	33.56	0.54	0.22
OW-9	Chelakkara	0.08	1.16	2.03	0.43	0.53	0.95	4.70	0.39	0.32	0.80	32.71	-0.44	64.79	0.00	34.80	0.48	0.22
OW-9	Chelakkara	0.01	0.96	1.98	0.07	2.81	1.75	29.96	0.44	0.59	0.96	31.02	0.02	70.40	0.00	73.78	0.42	0.22
OW-9	Chelakkara	0.12	0.82	1.22	0.07	0.70	1.42	17.06	0.49	0.29	0.68	28.48	-0.76	53.38	0.01	41.21	0.44	0.21
OW-9	Chelakkara	0.01	0.89	1.99	0.26	0.50	0.96	7.78	0.43	0.33	0.84	28.06	-0.25	63.89	0.00	33.43	0.41	0.35
OW-9	Chelakkara	0.08	0.91	1.82	0.32	0.55	1.23	5.72	0.45	0.29	0.72	25.25	-0.90	56.01	0.00	35.59	0.54	0.37
OW-9	Chelakkara	0.02	0.58	2.00	0.28	1.51	3.02	7.04	0.45	0.30	0.52	21.71	-0.78	53.91	0.00	60.18	0.75	0.45
OW-9	Chelakkara	0.10	0.81	1.64	0.26	0.62	1.39	6.43	0.49	0.28	0.72	26.27	-1.05	53.36	0.01	38.44	0.37	0.27
OW-9	Chelakkara	0.04	0.80	2.03	0.26	0.92	1.35	7.85	0.43	0.36	0.80	31.50	0.06	70.27	0.00	48.04	0.53	0.42
OW-9	Chelakkara	0.01	0.81	2.10	0.24	0.90	1.61	8.66	0.41	0.33	0.79	26.80	-0.39	58.05	0.00	47.37	0.43	0.35
OW-9	Chelakkara	0.02	0.59	2.09	0.24	0.69	1.88	8.53	0.41	0.24	0.55	23.48	-0.30	57.89	0.00	40.73	0.37	0.26
OW-9	Chelakkara	0.06	0.80	2.24	0.38	0.92	2.38	5.89	0.35	0.25	0.55	22.42	-1.10	48.87	0.00	47.98	0.44	0.37
OW-10	Kunnamkulam	0.03	0.84	1.09	0.24	BDL	0.00	4.62	0.75	0.35	0.95	36.99	-0.18	80.44	0.01	0.00	0.66	0.46
OW-10	Kunnamkulam	0.01	1.03	0.97	0.11	BDL	0.00	8.92	1.03	0.47	1.44	49.58	-0.14	92.70	0.01	0.00	0.64	0.50
OW-10	Kunnamkulam	0.05	0.81	0.71	0.05	1.03	0.47	15.34	1.29	0.64	1.83	54.29	0.04	90.49	0.01	50.76	0.51	0.42

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-10	Kunnamkulam	0.06	0.96	2.32	0.49	0.17	0.20	4.76	0.39	0.44	0.84	43.69	0.62	133.97	0.00	14.32	0.69	0.60
OW-10	Kunnamkulam	0.11	1.16	1.60	0.14	0.15	0.33	11.27	0.48	0.31	0.85	29.73	-0.66	63.10	0.01	13.12	0.59	0.44
OW-10	Kunnamkulam	0.03	0.92	0.80	0.02	0.06	0.07	33.90	1.07	0.45	1.51	46.79	-0.28	81.00	0.01	5.89	0.53	0.35
OW-10	Kunnamkulam	0.07	0.87	1.07	0.03	0.10	0.19	31.21	0.81	0.35	1.03	35.50	-0.59	69.69	0.01	9.43	0.76	0.41
OW-10	Kunnamkulam	0.04	0.77	1.67	0.17	0.44	0.95	9.57	0.57	0.31	0.64	25.54	-0.53	69.13	0.01	30.45	0.75	0.08
OW-10	Kunnamkulam	0.05	0.83	0.99	0.08	0.12	0.20	13.14	0.95	0.37	1.04	36.66	-0.54	74.49	0.01	11.01	0.56	0.39
OW-10	Kunnamkulam	0.00	0.82	0.68	0.02	0.67	0.44	32.38	1.34	0.58	1.86	49.64	-0.32	79.94	0.01	40.19	0.57	0.50
OW-10	Kunnamkulam	0.06	0.69	0.58	0.02	0.54	0.37	29.39	1.64	0.58	2.02	49.19	-0.41	78.47	0.01	34.92	0.53	0.30
OW-10	Kunnamkulam	0.02	0.80	0.79	0.04	0.19	0.23	21.32	1.18	0.44	1.38	42.70	-0.50	76.65	0.02	15.89	0.52	0.29
OW-10	Kunnamkulam	0.05	0.87	0.39	0.01	0.53	0.30	36.64	2.14	0.62	2.52	55.06	-0.90	75.34	0.01	34.61	0.56	0.30
OW-11	Chavakkad	0.05	0.92	0.74	0.48	0.18	0.21	1.53	1.06	0.40	2.13	47.70	-1.35	61.48	0.01	14.95	0.62	0.33
OW-11	Chavakkad	0.07	1.06	1.08	0.28	BDL	0.00	3.81	0.81	0.31	1.73	45.06	-0.59	58.39	0.01	0.00	0.55	0.31
OW-11	Chavakkad	0.01	0.97	0.82	0.12	0.77	0.42	6.82	1.06	0.55	2.43	57.38	0.05	79.17	0.00	43.51	0.53	0.27
OW-11	Chavakkad	0.09	5.23	6.57	1.37	0.49	0.30	4.78	0.14	0.50	2.22	59.77	1.11	90.65	0.01	32.94	0.81	0.68
OW-11	Chavakkad	0.08	1.05	0.90	0.25	0.14	0.18	3.56	0.83	0.38	1.87	45.68	-1.04	61.59	0.01	11.94	0.88	0.64
OW-11	Chavakkad	0.01	0.79	0.59	0.30	0.49	0.53	1.99	1.19	0.45	2.15	41.49	-2.10	55.12	0.01	32.92	0.88	0.64
OW-11	Chavakkad	0.01	1.04	1.33	0.51	0.82	0.91	2.62	0.64	0.46	1.59	34.26	-1.31	56.57	0.01	45.10	0.81	0.71
OW-11	Chavakkad	0.08	1.01	1.44	0.33	0.50	0.81	4.42	0.54	0.34	1.32	35.25	-1.26	53.32	0.01	33.42	0.70	0.51
OW-11	Chavakkad	0.01	0.88	1.19	0.39	0.85	0.87	3.03	0.71	0.44	1.65	39.87	-0.74	59.74	0.01	45.98	0.24	0.14
OW-11	Chavakkad	0.03	1.01	1.32	0.32	0.30	0.43	4.13	0.60	0.36	1.50	41.48	-0.48	62.27	0.01	23.20	0.15	0.10
OW-11	Chavakkad	0.02	0.97	1.37	0.30	0.17	0.23	4.66	0.61	0.37	1.65	45.02	0.18	68.95	0.01	14.40	0.20	0.11
OW-11	Chavakkad	0.10	1.18	1.55	0.39	0.16	0.29	3.99	0.52	0.31	1.39	41.16	-0.86	59.19	NA	14.07	0.61	0.15
OW-12	Pazhanji	0.05	1.12	0.27	0.10	0.33	0.10	2.81	3.71	0.71	2.18	72.96	-0.16	106.20	0.03	24.96	0.36	0.13
OW-12	Pazhanji	0.01	1.13	0.32	0.12	0.62	0.12	2.73	3.11	0.76	2.32	78.39	-0.02	120.95	0.03	38.21	0.20	0.23
OW-12	Pazhanji	0.12	1.07	0.32	0.07	2.54	0.50	4.80	3.10	0.75	1.69	61.98	-0.39	91.63	0.03	71.73	0.10	0.11
OW-12	Pazhanji	0.07	1.15	0.24	0.10	0.33	0.10	2.48	4.23	0.71	2.18	72.82	-0.20	103.57	0.04	24.80	0.14	0.11
OW-12	Pazhanji	0.12	1.08	0.38	0.07	1.00	0.37	5.81	2.63	0.68	1.73	60.19	-0.42	90.28	0.02	49.94	0.25	0.18
OW-12	Pazhanji	0.05	0.96	0.56	0.07	0.50	0.30	8.00	1.78	0.59	1.52	55.58	-0.31	93.09	NA	33.52	0.33	0.26
OW-13	Nattika	0.02	0.93	3.54	0.48	BDL	0.00	7.39	0.25	0.18	0.48	20.34	-0.14	66.82	0.00	0.00	0.07	0.10
OW-13	Nattika	0.03	0.81	5.30	0.52	BDL	0.00	10.26	0.17	0.10	0.24	12.14	-0.34	62.20	0.00	0.00	0.16	0.16
OW-13	Nattika	0.07	2.05	3.24	0.38	1.01	0.80	8.46	0.31	0.54	1.00	39.96	-0.01	92.99	0.00	50.19	0.45	0.24
OW-13	Nattika	0.04	0.64	1.99	0.62	BDL	0.00	3.20	0.41	0.14	0.31	16.72	-0.57	63.09	0.00	0.00	0.42	0.18

Appendix

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-13	Nattika	0.12	0.71	0.98	0.41	BDL	0.00	2.39	1.02	0.22	0.66	25.50	-1.40	55.18	0.00	0.00	0.46	0.16
OW-13	Nattika	0.02	0.42	4.57	2.53	0.11	1.78	1.81	0.21	0.06	0.13	6.78	-0.95	51.12	0.00	9.92	0.63	0.18
OW-13	Nattika	0.10	0.82	4.85	1.41	0.19	1.75	3.44	0.18	0.10	0.21	9.80	-0.91	51.28	0.00	16.14	0.30	0.23
OW-13	Nattika	0.10	0.93	3.81	0.40	0.59	1.54	9.55	0.22	0.26	0.35	22.11	0.23	96.59	0.00	37.27	0.35	0.25
OW-13	Nattika	0.05	0.88	2.65	0.98	0.21	0.87	2.70	0.35	0.19	0.38	18.53	-0.60	66.26	0.00	17.69	0.34	0.17
OW-13	Nattika	0.03	0.81	1.65	0.88	0.22	0.59	1.87	0.57	0.27	0.65	24.94	-0.73	64.45	0.01	18.21	0.33	0.17
OW-13	Nattika	0.03	0.20	5.52	1.93	0.22	8.23	2.86	0.15	0.03	0.06	3.84	-0.80	44.63	0.00	18.29	0.44	0.20
OW-13	Nattika	0.09	0.40	2.95	1.12	0.32	3.55	2.64	0.31	0.08	0.14	9.33	-0.93	52.96	0.00	24.10	0.53	0.21
OW-14	Edamuttom	0.04	0.92	1.87	0.29	0.13	0.23	6.52	0.42	0.33	0.92	36.57	0.47	83.09	0.00	11.17	0.32	0.16
OW-14	Edamuttom	0.05	1.06	2.65	0.23	BDL	0.00	11.36	0.38	0.26	0.68	34.76	0.02	89.51	0.00	0.00	0.33	0.15
OW-14	Edamuttom	0.03	1.42	3.00	0.13	0.25	0.50	23.68	0.29	0.31	0.72	34.03	-0.01	81.82	0.00	20.17	0.32	0.21
OW-14	Edamuttom	0.01	1.16	2.59	0.17	1.54	1.40	15.51	0.35	0.47	0.85	34.25	0.15	79.79	0.00	60.64	0.24	0.13
OW-14	Edamuttom	0.01	0.68	1.94	0.24	0.08	0.33	8.08	0.46	0.19	0.53	22.84	-0.66	60.24	0.00	7.72	0.30	0.24
OW-14	Edamuttom	0.02	0.94	1.71	0.53	0.05	0.14	3.21	0.51	0.26	0.72	29.00	-0.50	68.49	0.01	4.95	0.26	0.21
OW-14	Edamuttom	0.06	1.00	2.90	0.26	0.23	0.69	11.23	0.32	0.24	0.58	24.73	-0.37	66.87	0.00	18.49	0.15	0.35
OW-14	Edamuttom	0.06	0.97	2.76	0.28	0.33	1.15	10.02	0.29	0.21	0.48	21.72	-0.54	59.58	0.00	25.06	0.20	0.11
OW-14	Edamuttom	0.04	0.84	2.26	0.18	0.36	0.77	12.24	0.39	0.29	0.67	30.23	0.09	77.13	0.00	26.47	0.19	0.16
OW-14	Edamuttom	0.10	0.81	2.14	0.18	1.09	1.38	12.10	0.39	0.41	0.85	30.36	0.47	73.08	0.00	52.16	0.33	0.19
OW-14	Edamuttom	0.05	0.82	3.13	0.23	0.11	0.40	13.39	0.29	0.21	0.51	24.36	0.11	75.35	0.00	10.17	0.38	0.37
OW-14	Edamuttom	0.04	0.81	3.25	0.17	0.35	1.35	18.78	0.27	0.19	0.46	20.84	-0.35	59.45	0.00	25.82	0.22	0.17
OW-15	Mathilakam	0.04	1.09	3.62	0.95	0.31	1.43	3.80	0.28	0.17	0.31	15.88	-0.76	63.16	0.01	23.71	0.18	0.13
OW-15	Mathilakam	0.08	0.92	2.17	0.72	0.34	0.99	3.01	0.46	0.25	0.45	22.28	-0.63	69.39	0.00	25.19	0.28	0.20
OW-15	Mathilakam	0.05	1.01	3.95	1.13	BDL	0.00	3.49	0.25	0.18	0.35	20.26	-0.11	91.02	0.01	NA	0.26	0.18
OW-15	Mathilakam	0.07	0.83	1.83	0.66	0.25	0.76	2.76	0.55	0.25	0.46	22.29	-0.62	70.31	0.01	20.27	0.37	0.29
OW-15	Mathilakam	0.07	0.96	2.13	0.72	BDL	0.00	2.94	0.47	0.21	0.38	22.79	-0.38	83.36	0.01	0.00	0.56	0.22
OW-15	Mathilakam	0.08	0.31	1.09	0.83	0.20	1.75	1.32	0.92	0.10	0.15	10.05	-0.80	56.97	0.00	16.52	0.20	0.11
OW-15	Mathilakam	0.09	0.74	4.56	1.18	0.25	2.06	3.86	0.20	0.10	0.24	12.70	-0.99	49.52	0.00	19.98	0.23	0.15
OW-15	Mathilakam	0.08	0.64	2.96	0.74	0.10	0.73	3.98	0.32	0.12	0.26	14.20	-0.77	58.76	0.00	9.43	0.16	0.09
OW-15	Mathilakam	0.05	0.82	2.48	0.74	0.14	0.43	3.35	0.40	0.23	0.36	25.34	-0.11	102.72	0.01	12.23	0.15	0.12
OW-15	Mathilakam	0.06	0.55	1.00	0.36	0.58	1.41	2.77	1.00	0.28	0.39	23.37	-0.59	72.18	0.00	36.57	0.25	0.11
OW-15	Mathilakam	0.03	0.66	2.80	0.51	0.04	0.23	5.46	0.31	0.15	0.39	17.50	-0.33	62.39	0.00	4.08	0.36	0.24
OW-15	Mathilakam	0.08	0.32	3.88	0.43	0.50	5.91	8.96	0.26	0.07	0.09	9.11	-0.39	75.88	NA	33.46	0.21	0.13

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-16	Engandiyur	0.02	0.86	2.39	0.36	0.10	0.36	6.68	0.32	0.21	0.53	22.23	-0.18	65.61	0.00	9.12	0.32	0.21
OW-16	Engandiyur	0.10	0.96	2.57	0.26	0.09	0.36	10.06	0.34	0.20	0.52	20.94	-0.66	60.39	0.00	8.50	0.59	0.30
OW-16	Engandiyur	0.00	1.19	1.46	0.35	0.13	0.29	4.21	0.35	0.31	0.94	30.45	-0.11	59.36	0.00	11.63	0.48	0.29
OW-16	Engandiyur	0.12	1.16	2.11	0.10	0.33	0.34	21.52	0.42	0.48	1.19	44.41	0.70	101.24	0.00	24.80	0.56	0.35
OW-16	Engandiyur	0.05	1.17	3.21	0.37	0.25	1.11	8.69	0.24	0.18	0.41	16.86	-0.87	53.12	0.00	20.20	0.48	0.27
OW-16	Engandiyur	0.04	0.93	4.51	0.44	0.06	0.34	10.34	0.19	0.14	0.30	15.32	-0.27	68.15	0.00	5.28	0.51	0.34
OW-16	Engandiyur	0.08	1.14	3.25	0.92	BDL	0.00	3.55	0.23	0.15	0.38	18.37	-0.60	57.83	0.00	0.00	0.44	0.23
OW-16	Engandiyur	0.02	0.80	5.87	0.69	BDL	0.00	8.46	0.15	0.09	0.22	12.10	-0.27	63.78	0.00	0.00	0.32	0.18
OW-16	Engandiyur	0.07	0.58	4.38	0.38	0.22	2.06	11.67	0.21	0.10	0.19	10.09	-0.57	58.99	0.00	18.33	0.61	0.25
OW-16	Engandiyur	0.05	0.99	4.71	0.33	0.06	0.25	14.20	0.20	0.19	0.42	20.23	0.30	83.34	0.00	5.76	0.52	0.25
OW-16	Engandiyur	0.06	0.73	1.84	0.21	0.17	0.39	8.55	0.52	0.30	0.76	28.34	-0.08	75.29	0.00	14.39	0.31	0.19
OW-16	Engandiyur	0.01	0.80	3.97	0.26	0.04	0.24	15.56	0.22	0.15	0.38	16.84	-0.11	65.02	0.00	4.08	0.53	0.25
OW-16	Engandiyur	0.07	0.93	2.14	0.31	0.19	0.56	6.95	0.41	0.24	0.64	23.95	-0.70	60.47	NA	15.70	0.78	0.44
OW-17	Vaniampara	0.12	1.08	1.51	0.52	1.35	1.37	2.93	0.66	0.45	0.70	33.49	-0.58	75.00	0.01	57.39	0.87	0.51
OW-17	Vaniampara	0.06	1.14	1.37	0.57	0.84	0.87	2.42	0.73	0.45	0.79	38.13	-0.42	83.22	0.01	45.59	0.87	0.39
OW-17	Vaniampara	0.04	1.17	1.38	0.28	0.66	0.91	4.85	0.72	0.40	0.78	33.40	-0.77	69.95	0.01	39.81	0.87	0.49
OW-17	Vaniampara	0.08	1.10	1.40	0.42	0.20	0.32	3.33	0.71	0.36	0.80	37.84	-0.40	83.66	0.01	16.80	0.85	0.37
OW-17	Vaniampara	0.08	0.80	1.06	0.33	0.87	1.04	3.18	0.94	0.42	0.73	34.94	-0.53	77.61	0.01	46.57	0.86	0.48
OW-17	Vaniampara	0.01	0.86	1.61	0.40	0.45	0.74	4.04	0.62	0.35	0.67	33.18	-0.28	84.65	0.01	30.90	0.77	0.43
OW-17	Vaniampara	0.05	0.93	1.13	0.56	0.56	0.77	2.01	0.88	0.39	0.78	35.03	-0.60	75.36	0.00	35.85	0.84	0.55
OW-17	Vaniampara	0.05	0.93	2.57	0.50	0.11	0.34	5.11	0.36	0.23	0.58	25.45	-0.25	71.61	0.01	9.91	0.44	0.17
OW-17	Vaniampara	0.04	1.07	1.75	0.54	0.66	0.61	3.26	0.57	0.48	0.94	43.06	0.07	101.77	0.01	39.84	0.85	0.40
OW-17	Vaniampara	0.09	0.72	1.72	0.48	0.88	1.26	3.57	0.55	0.38	0.65	30.69	-0.07	83.27	0.00	46.92	0.79	0.33
OW-17	Vaniampara	0.09	0.96	1.91	0.71	0.75	1.42	2.70	0.52	0.32	0.57	26.40	-0.72	67.47	0.01	42.94	0.56	0.22
OW-17	Vaniampara	0.07	0.80	2.52	0.53	0.11	0.36	4.74	0.33	0.22	0.55	24.35	0.01	70.62	NA	9.70	1.00	0.35
OW-17	Vaniampara	0.06	0.85	1.75	0.35	1.01	1.47	5.05	0.53	0.37	0.59	30.23	-0.36	76.92	NA	50.14	0.58	0.52
OW-18	Varandarapilli	0.10	0.88	0.73	1.03	0.33	0.23	0.71	1.38	0.41	0.95	64.76	-0.05	123.59	0.02	24.96	0.64	0.57
OW-18	Varandarapilli	0.06	1.11	0.92	0.58	1.03	0.42	1.59	1.08	0.46	1.09	68.41	0.00	126.16	0.02	50.76	0.30	0.28
OW-18	Varandarapilli	0.05	0.95	0.60	0.35	BDL	0.00	1.74	1.66	0.42	1.32	81.94	0.08	161.41	0.01	0.00	0.76	0.45
OW-18	Varandarapilli	0.06	0.87	0.99	0.48	1.03	0.60	2.06	1.01	0.37	0.76	64.61	-0.02	129.27	0.02	50.76	0.42	0.56
OW-18	Varandarapilli	0.05	0.81	0.63	0.38	0.51	0.26	1.64	1.60	0.40	1.01	72.63	0.01	137.37	0.01	33.66	0.66	0.46
OW-18	Varandarapilli	0.01	0.59	0.48	0.59	1.50	0.96	0.82	2.09	0.36	0.58	57.17	-0.21	105.85	0.02	60.06	0.84	0.75

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-18	Varandarapilli	0.00	0.86	0.76	0.58	BDL	0.00	1.31	1.32	0.35	0.88	68.76	0.00	138.87	0.01	0.00	0.74	0.48
OW-18	Varandarapilli	0.06	0.82	2.76	0.52	BDL	0.00	5.28	0.36	0.17	0.38	33.97	-0.16	90.46	0.02	0.00	1.00	0.42
OW-18	Varandarapilli	0.04	0.92	0.86	0.51	1.01	0.50	1.69	1.17	0.43	0.91	64.82	-0.02	125.70	0.00	50.14	0.76	0.47
OW-18	Varandarapilli	0.02	0.80	1.16	0.52	1.01	0.73	2.22	0.87	0.40	0.76	55.11	-0.01	116.36	0.01	50.17	0.71	0.56
OW-18	Varandarapilli	0.04	0.80	2.05	0.64	0.34	0.79	3.20	0.49	0.23	0.41	38.61	-0.14	100.61	0.01	25.41	0.85	0.45
OW-18	Varandarapilli	0.09	0.85	1.07	0.58	BDL	1.30	1.85	0.93	0.38	0.62	66.68	-0.01	140.67	0.01	100.00	1.00	0.57
OW-19	Cherpu	0.03	0.48	0.54	0.10	0.15	0.27	5.41	1.84	0.282424	1.02	44.72	-1.05	65.12	0.01	12.92	0.58	1.00
OW-19	Cherpu	0.09	0.68	0.44	0.02	0.27	0.28	27.60	2.29	0.41	1.47	50.41	-1.00	71.41	0.02	21.16	0.88	0.59
OW-20	Puthur	0.06	0.20	1.48	0.13	3.30	12.61	11.52	0.51	0.20	0.13	7.09	-0.87	48.79	0.02	76.73	0.77	0.91
OW-20	Puthur	0.12	1.08	0.71	0.81	BDL	0.00	0.87	1.42	0.53	1.14	70.46	0.04	150.87	0.01	NA	0.83	0.76
OW-20	Puthur	0.09	1.20	0.67	0.39	BDL	0.00	1.73	1.49	0.47	0.90	59.93	-0.10	121.97	0.02	NA	0.79	0.67
OW-20	Puthur	0.01	0.60	0.19	0.04	1.52	0.48	5.34	5.22	0.63	1.26	61.78	-0.29	96.07	0.02	60.35	0.87	0.73
OW-20	Puthur	0.06	0.61	0.64	0.27	1.02	0.72	2.38	1.56	0.47	0.58	49.93	-0.09	127.49	0.01	50.46	0.83	0.48
OW-20	Puthur	0.06	0.80	0.81	0.09	BDL	1.35	9.12	1.24	0.71	0.58	51.11	-0.08	132.57	0.04	100.00	0.83	0.79
OW-20	Puthur	0.02	0.83	0.65	0.09	0.48	0.25	7.44	1.55	0.56	1.02	62.39	0.01	136.22	0.01	32.55	1.00	0.74
OW-20	Puthur	0.09	0.34	0.45	0.09	2.03	1.67	4.80	2.22	0.44	0.44	36.53	-0.29	95.29	0.01	67.02	0.75	0.79
OW-20	Puthur	0.02	0.81	0.70	0.08	2.06	0.68	8.53	1.42	0.59	0.78	57.71	-0.04	134.52	0.01	67.33	0.72	0.22
OW-20	Puthur	0.07	0.41	0.44	0.04	BDL	1.48	10.24	2.26	0.58	0.55	53.78	-0.09	129.16	0.02	100.00	0.58	0.18
OW-21	Elavally	0.02	0.34	0.00	0.12	0.30	0.43	0.00	0.00	0.35	1.12	43.66	-2.20	34.82	0.02	22.83	0.58	0.38
OW-21	Elavally	0.02	1.14	0.40	0.41	1.53	0.32	0.97	2.49	0.72	2.70	69.23	-0.33	93.62	0.16	60.40	0.75	0.16
OW-21	Elavally	0.12	0.99	0.06	0.18	0.13	0.06	0.31	18.14	0.62	2.65	70.21	-0.78	78.52	0.05	11.26	0.81	0.37
OW-21	Elavally	0.07	1.02	0.18	0.11	0.40	0.12	1.72	5.46	0.69	2.83	73.43	-0.39	93.90	0.03	28.56	0.77	0.15
OW-21	Elavally	0.02	0.90	0.28	0.15	0.40	0.15	1.86	3.53	0.64	2.16	68.17	-0.30	96.75	0.04	28.36	0.77	0.28
OW-21	Elavally	0.10	1.02	0.22	0.10	1.32	0.28	2.07	4.64	0.74	2.46	70.47	-0.40	93.05	0.01	56.98	1.00	0.13
OW-21	Elavally	0.07	1.14	0.63	0.12	1.21	0.35	5.17	1.60	0.70	2.33	63.92	-0.15	95.34	0.05	54.68	0.75	0.87
OW-21	Elavally	0.10	1.00	0.16	0.12	0.60	0.18	1.28	6.30	0.69	2.64	70.64	-0.54	88.25	0.04	37.66	0.80	0.42
OW-21	Elavally	0.10	0.99	0.20	0.12	BDL	0.54	1.72	4.93	0.83	2.24	68.85	-0.46	89.96	0.02	100.00	0.52	0.28
OW-22	Kadagode	0.01	0.44	0.15	0.04	0.57	0.43	3.84	6.52	0.42	1.24	57.44	-0.77	73.69	0.05	36.12	0.65	0.33
OW-22	Kadagode	0.12	1.11	2.07	0.49	1.03	0.65	4.22	0.48	0.53	0.71	49.47	0.18	150.04	0.00	50.76	0.68	0.30
OW-22	Kadagode	0.04	1.17	2.62	0.32	0.64	0.75	8.20	0.38	0.42	0.53	39.34	0.09	132.40	0.00	39.18	0.73	0.38
OW-22	Kadagode	0.02	1.17	2.39	0.26	BDL	0.00	9.02	0.42	0.16	0.35	20.61	-0.93	58.96	0.01	0.00	0.72	0.44
OW-22	Kadagode	0.07	0.49	0.96	0.12	1.00	1.23	8.09	1.04	0.40	0.45	34.46	-0.12	110.63	0.00	50.09	0.74	0.33

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
OW-22	Kadagode	0.08	1.62	3.10	0.27	1.01	0.54	11.59	0.32	0.57	0.83	53.43	0.31	158.67	0.01	50.37	0.72	0.22
OW-22	Kadagode	0.00	0.94	1.01	0.05	2.51	0.79	20.52	0.99	0.70	1.07	50.18	-0.02	109.36	0.00	71.55	0.58	0.18
OW-22	Kadagode	0.02	1.82	3.36	0.19	1.49	0.66	17.80	0.30	0.61	0.91	51.73	0.34	142.69	0.01	59.81	0.79	0.67
OW-22	Kadagode	0.05	0.86	2.61	0.10	2.03	1.23	25.27	0.38	0.54	0.60	40.37	0.39	142.16	0.00	67.02	0.87	0.73
OW-22	Kadagode	0.01	0.67	1.51	0.15	4.04	1.85	10.20	0.66	0.60	0.43	34.16	-0.01	127.17	NA	80.16	0.64	0.57
OW-22	Kadagode	0.00	1.08	4.01	0.10	BDL	3.22	41.71	0.25	0.63	0.36	32.85	0.10	124.73	NA	100.00	0.30	0.28
OW-23	Wadakancery	0.07	0.41	0.08	0.04	0.79	0.50	1.92	11.82	0.49	1.17	54.82	-0.73	70.54	0.10	44.18	0.56	0.22
OW-23	Wadakancery	0.11	1.03	0.80	0.13	1.53	0.67	6.27	1.25	0.565284	0.90	54.37	-0.15	109.36	0.01	60.40	0.20	0.11
OW-23	Wadakancery	0.01	0.88	1.48	0.37	0.16	0.28	3.96	0.67	0.32	0.59	40.42	-0.11	106.44	0.01	14.16	0.68	0.69
OW-23	Wadakancery	0.05	0.87	1.18	0.19	0.67	0.67	6.20	0.85	0.42	0.60	45.04	-0.09	117.83	0.01	40.15	0.81	0.82
OW-23	Wadakancery	0.03	0.80	1.37	0.25	1.65	1.35	5.51	0.73	0.47	0.54	37.92	-0.15	104.67	0.01	62.25	0.92	0.53
OW-23	Wadakancery	0.02	0.94	0.95	0.07	0.48	0.29	12.90	1.05	0.55	0.88	58.38	0.05	144.44	0.01	32.55	0.62	0.68
OW-23	Wadakancery	0.05	0.70	0.73	0.10	1.53	1.00	7.68	1.37	0.51	0.61	43.87	-0.18	107.58	0.01	60.40	0.65	0.53
OW-23	Wadakancery	0.04	0.75	1.20	0.21	1.53	1.00	5.86	0.83	0.50	0.61	44.81	-0.02	124.08	0.01	60.40	0.51	0.43
OW-23	Wadakancery	0.04	0.44	1.21	0.10	BDL	6.31	12.57	0.83	0.50	0.20	24.25	-0.46	76.61	NA	100.00	0.22	0.14

BDL: Below detectable level

NA: Not analysed

Table 5.36 Various ratios, percetages and indices derived from the chemical analysis data of water samples in semi-confined aquifer (bore wells) of Palaeo-lagoon (Kole land basin) for the period 01.01.2000 to 31.12.2006 (ionic cocentration in meq/l)

Well No	Location	Na/Cl	HCO3 /Cl	SO4/Cl	Mg/Ca	Mg/Na	HCO3/SO4	Cl/(CO3+ HCO3)	Na/(Na+ Ca+K)	Ionic ratio	SAR	Na%	Residual sodium carbonate (RSC)	Permeability index (PI)	Corosivity ratio (CR)	Magnesium ratio (MR)	Gibb's (Na) ratio	Gibb's (Cl) ratio
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-1	Kadupassery	0.74	0.74	0.41	0.16	0.36	1.80	1.14	0.31	0.04	0.81	30.27	-1.11	59.45	0.01	14.16	0.38	0.44
BW-1	Kadupassery	1.20	4.46	1.83	0.55	2.44	2.44	0.16	0.17	0.05	0.38	16.82	-0.87	47.34	0.00	35.32	0.30	0.12
BW-1	Kadupassery	1.05	4.77	2.07	0.81	3.80	2.31	0.18	0.17	0.03	0.33	13.95	-1.42	43.52	0.00	44.85	0.29	0.11
BW-1	Kadupassery	3.35	5.94	2.41	2.51	1.73	2.46	0.14	0.54	0.06	0.93	32.31	-0.31	67.32	0.00	71.49	0.68	0.09
BW-1	Kadupassery	0.96	3.32	2.31	0.84	3.41	1.44	0.24	0.18	0.06	0.34	15.54	-1.35	45.00	0.00	45.54	0.32	0.15
BW-1	Kadupassery	1.19	6.20	4.15	0.86	4.22	1.49	0.15	0.16	0.03	0.32	12.75	-1.71	42.66	0.00	46.14	0.27	0.09
BW-1	Kadupassery	1.19	7.87	3.13	0.54	3.69	2.51	0.11	0.12	0.05	0.29	11.52	-1.41	42.39	0.00	34.89	0.21	0.07
BW-1	Kadupassery	1.72	5.92	2.61	1.47	3.07	2.27	0.15	0.30	0.05	0.49	19.48	-0.77	54.21	0.00	59.48	0.44	0.09
BW-1	Kadupassery	1.05	6.96	2.24	0.88	4.58	3.11	0.12	0.15	0.00	0.32	11.88	-0.87	43.67	0.00	46.95	0.25	0.08
BW-1	Kadupassery	0.98	7.15	2.78	1.53	6.89	2.57	0.13	0.17	0.04	0.27	10.80	-1.39	41.46	0.00	60.52	0.30	0.08
BW-1	Kadupassery	0.84	3.76	2.29	0.88	4.44	1.64	0.23	0.16	0.08	0.32	12.53	-2.12	37.96	0.00	46.70	0.27	0.13
BW-2	Mattathur	0.71	7.99	0.98	0.30	3.83	8.17	0.10	0.07	DNA	0.22	7.13	-1.16	36.18	0.00	23.21	0.12	0.07
BW-2	Mattathur	0.81	1.36	0.67	0.74	1.40	2.03	0.64	0.32	DNA	0.68	26.68	-1.06	57.36	0.01	42.38	0.45	0.30
BW-2	Mattathur	0.82	1.37	0.74	BDL	BDL	1.85	0.55	0.20	0.06	0.61	24.18	-1.09	53.07	0.01	BDL	0.29	0.30
BW-2	Mattathur	0.81	1.65	0.89	1.39	2.45	1.86	0.53	0.34	DNA	0.61	21.89	-1.47	50.22	0.01	58.08	0.46	0.26
BW-2	Mattathur	0.81	1.69	0.55	0.87	1.64	3.05	0.52	0.33	0.04	0.67	25.08	-0.91	57.99	0.01	46.64	0.44	0.26
BW-2	Mattathur	0.90	1.77	0.67	1.19	1.68	2.66	0.43	0.39	DNA	0.71	27.63	-0.42	63.02	0.01	54.35	0.52	0.25
BW-2	Mattathur	0.81	1.88	0.52	0.91	1.43	3.62	0.44	0.37	0.06	0.75	28.05	-0.18	66.40	0.00	47.68	0.48	0.24
BW-2	Mattathur	0.80	1.99	0.63	0.74	1.56	3.16	0.42	0.30	DNA	0.63	24.71	-0.50	61.22	0.00	42.53	0.42	0.23
BW-2	Mattathur	0.82	1.76	0.72	1.06	2.16	2.45	0.49	0.31	DNA	0.57	23.01	-1.15	53.48	0.01	51.57	0.45	0.25
BW-3	Nellayi	0.77	0.74	0.42	0.43	0.74	1.74	1.12	0.35	DNA	0.99	30.92	-1.59	54.41	0.01	29.97	0.44	0.44
BW-3	Nellayi	1.85	1.00	0.22	0.58	0.08	4.47	0.92	0.86	DNA	7.03	82.96	1.96	109.15	0.01	36.60	0.90	0.37
BW-3	Nellayi	2.09	0.60	0.26	1.40	0.13	2.30	1.03	0.90	DNA	7.26	82.49	1.42	100.52	0.01	58.25	0.93	0.49
BW-3	Nellayi	1.51	0.79	0.22	2.14	0.15	3.56	0.99	0.91	0.08	6.08	82.13	1.83	110.59	0.01	68.20	0.94	0.43
BW-3	Nellayi	1.62	0.87	0.26	1.82	0.11	3.41	1.01	0.92	DNA	7.52	86.18	2.08	115.06	0.01	64.52	0.95	0.40
BW-3	Nellayi	2.20	0.83	0.24	0.50	0.06	3.43	1.02	0.87	DNA	7.92	84.01	1.52	104.58	0.01	33.38	0.90	0.41
BW-3	Nellayi	1.87	0.63	0.27	0.63	0.10	2.39	0.99	0.85	0.03	6.20	79.70	1.40	100.05	0.01	38.60	0.88	0.48

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-3	Nellayi	2.25	0.97	0.32	0.87	0.10	2.99	0.87	0.88	DNA	7.60	82.83	1.84	104.49	0.01	46.59	0.91	0.37
BW-3	Nellayi	2.10	0.87	0.24	0.75	0.10	3.57	0.87	0.86	DNA	6.87	80.75	1.75	102.07	0.01	42.94	0.90	0.40
BW-3	Nellayi	2.35	0.94	0.23	0.23	0.03	4.13	0.91	0.87	DNA	9.23	86.26	2.10	106.74	0.01	18.39	0.90	0.38
BW-3	Nellayi	1.93	1.05	0.22	0.57	0.07	4.79	0.78	0.88	DNA	8.19	84.87	2.93	109.93	0.01	36.43	0.91	0.36
BW-3	Nellayi	1.16	1.39	0.43	1.68	0.73	3.21	0.72	0.63	0.03	0.99	50.02	0.02	113.71	0.01	62.63	0.77	0.29
BW-4	Tholur	1.19	0.98	0.63	0.49	0.23	1.54	1.02	0.60	0.09	1.12	63.43	0.05	140.50	0.01	33.10	0.77	0.37
BW-4	Tholur	1.19	1.12	0.06	1.57	0.72	18.55	0.90	0.60	0.10	0.86	50.47	-0.10	113.47	0.01	61.04	0.77	0.34
BW-4	Tholur	0.97	1.33	0.12	3.71	0.85	10.91	0.75	0.68	0.07	0.80	53.33	0.10	143.44	0.01	78.77	0.87	0.30
BW-4	Tholur	1.19	1.86	0.09	1.03	0.47	21.74	0.54	0.61	0.10	0.97	55.80	0.28	150.15	0.00	50.76	0.76	0.24
BW-4	Tholur	0.97	0.76	0.15	0.67	0.52	4.97	1.32	0.51	0.08	0.77	48.44	-0.19	106.37	0.01	40.15	0.67	0.43
BW-4	Tholur	0.90	0.62	0.06	3.05	0.80	9.69	1.61	0.68	0.06	0.85	53.20	-0.14	113.70	0.01	75.31	0.86	0.48
BW-4	Tholur	1.15	0.68	0.10	0.48	0.22	6.84	1.46	0.62	0.05	1.16	63.56	-0.03	128.67	0.01	32.55	0.77	0.46
BW-4	Tholur	0.82	0.73	0.08	1.01	0.50	8.62	1.38	0.59	0.04	0.90	54.62	-0.04	124.43	0.01	50.35	0.76	0.44
BW-4	Tholur	0.68	0.61	0.08	1.53	1.03	7.97	1.64	0.51	0.06	0.59	42.83	-0.24	101.40	0.01	60.40	0.71	0.49
BW-4	Tholur	0.83	0.68	0.05	1.01	0.56	13.25	1.47	0.51	0.01	0.72	55.17	-0.09	126.08	0.01	50.14	0.77	0.46
BW-5	Thrikkur	1.14	5.07	0.19	0.64	2.30	26.12	0.14	0.21	0.01	0.59	17.06	0.16	53.72	0.00	38.92	0.30	0.10
BW-5	Thrikkur	1.19	3.20	0.17	0.58	0.93	18.81	0.26	0.35	0.06	0.53	32.88	0.31	98.84	0.00	36.60	0.50	0.15
BW-5	Thrikkur	1.19	3.00	0.23	1.15	1.82	12.88	0.28	0.36	DNA	0.61	26.56	-0.18	77.53	0.00	53.43	0.50	0.16
BW-5	Thrikkur	1.88	4.61	0.27	0.75	1.13	16.87	0.22	0.37	0.10	0.45	30.89	-0.10	86.58	0.00	42.94	0.50	0.11
BW-5	Thrikkur	1.41	4.57	0.23	1.12	1.81	19.56	0.22	0.35	DNA	0.63	26.01	-0.09	81.40	0.00	52.77	0.49	0.11
BW-5	Thrikkur	1.50	4.15	0.11	0.56	0.99	37.48	0.23	0.34	DNA	0.73	30.21	0.08	88.74	0.00	35.85	0.46	0.12
BW-5	Thrikkur	1.84	4.62	0.24	1.00	1.07	19.13	0.20	0.45	DNA	0.41	35.30	0.37	98.87	0.00	50.01	0.58	0.11
BW-5	Thrikkur	0.99	4.15	0.21	0.63	1.47	19.55	0.21	0.28	DNA	0.51	25.56	0.32	93.51	0.00	38.69	0.43	0.12
BW-5	Thrikkur	1.17	5.24	0.07	0.64	1.66	74.91	0.17	0.25	DNA	0.43	24.08	0.24	87.54	0.00	39.02	0.41	0.10
BW-6	Choondal	0.60	0.66	0.10	0.33	0.32	6.86	1.52	0.46	0.08	1.18	48.12	-0.19	90.77	0.01	24.80	0.61	0.47
BW-6	Choondal	0.57	0.00	0.08	1.25	0.50	BDL	BDL	0.61	DNA	1.49	57.92	-0.90	52.66	0.01	55.62	0.80	1.00
BW-6	Choondal	1.01	0.55	0.63	1.01	0.38	0.88	1.80	0.62	0.05	1.70	62.64	-0.21	98.12	0.02	50.25	0.82	0.51
BW-6	Choondal	0.93	0.32	0.11	0.65	0.20	2.80	3.11	0.65	0.02	2.07	70.86	-0.17	104.05	0.03	39.24	0.84	0.64
BW-6	Choondal	0.90	0.58	0.12	0.33	0.09	4.90	1.72	0.67	0.10	2.49	77.42	0.32	129.67	0.01	24.80	0.86	0.50
BW-6	Choondal	0.81	0.50	0.12	0.51	0.37	4.10	1.98	0.52	0.06	1.42	52.26	-0.52	83.72	0.02	33.56	0.68	0.54
BW-6	Choondal	0.80	0.41	0.09	0.57	0.34	4.37	2.45	0.56	0.05	1.60	56.81	-0.48	86.31	0.02	36.45	0.73	0.59
BW-6	Choondal	0.85	0.44	0.10	0.84	0.44	4.37	2.26	0.57	0.08	1.55	56.37	-0.50	85.49	0.02	45.60	0.76	0.57

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-6	Choondal	0.85	0.41	0.06	0.55	0.34	7.34	2.45	0.55	0.10	1.64	55.87	-0.59	83.03	0.02	35.62	0.72	0.59
BW-6	Choondal	0.80	0.50	0.07	0.63	0.40	7.36	1.98	0.55	0.05	1.57	53.62	-0.50	84.11	0.02	38.60	0.71	0.54
BW-6	Choondal	0.71	0.37	0.07	0.50	0.26	5.31	2.69	0.58	0.02	1.74	60.93	-0.29	93.97	0.02	33.34	0.75	0.61
BW-6	Choondal	0.71	0.38	0.05	0.43	0.24	7.09	2.62	0.57	0.01	1.78	60.04	-0.33	91.88	0.02	30.20	0.73	0.60
BW-6	Choondal	0.64	0.40	0.05	0.84	0.45	7.93	2.52	0.56	0.02	1.53	56.19	-0.40	87.95	0.02	45.80	0.76	0.59
BW-6	Choondal	0.80	0.41	0.07	1.13	0.60	5.57	2.41	0.56	0.11	1.48	52.53	-0.76	77.41	0.02	53.08	0.75	0.58
BW-7	Madakkathara	0.88	1.03	0.26	0.25	0.48	3.93	0.78	0.33	DNA	1.11	32.70	-1.37	56.03	0.01	20.02	0.43	0.36
BW-7	Madakkathara	1.83	5.94	0.97	0.86	2.69	6.13	0.11	0.24	0.08	0.53	16.05	-0.86	43.65	0.00	46.13	0.30	0.09
BW-7	Madakkathara	0.81	3.25	0.77	0.95	3.51	4.20	0.21	0.21	DNA	0.44	13.72	-0.93	41.42	0.00	48.81	0.28	0.15
BW-7	Madakkathara	1.15	4.74	0.81	0.91	2.94	5.85	0.16	0.23	0.01	0.46	15.90	-0.39	49.01	0.00	47.54	0.31	0.11
BW-7	Madakkathara	2.19	7.03	2.13	0.61	1.83	3.30	0.11	0.24	0.02	0.58	19.04	-0.45	51.77	0.00	38.01	0.32	0.08
BW-7	Madakkathara	3.89	9.64	2.11	3.37	1.91	4.56	0.09	0.60	0.01	0.95	30.60	0.36	71.61	0.00	77.10	0.70	0.06
BW-7	Madakkathara	1.44	4.69	1.25	1.08	3.21	3.74	0.14	0.24	0.06	0.43	15.71	-0.69	47.17	0.00	51.85	0.33	0.11
BW-7	Madakkathara	1.89	6.20	1.85	1.63	3.26	3.36	0.14	0.32	0.08	0.49	17.93	-0.86	52.23	0.00	61.97	0.42	0.09
BW-7	Madakkathara	1.51	5.73	1.60	0.52	2.17	3.58	0.14	0.19	0.06	0.42	15.41	-0.80	49.43	0.00	34.36	0.26	0.09
BW-7	Madakkathara	1.93	8.70	2.21	1.05	3.02	3.93	0.10	0.25	0.00	0.45	16.46	-0.32	54.35	0.00	51.33	0.34	0.06
BW-7	Madakkathara	1.91	8.08	1.70	0.85	2.63	4.76	0.11	0.24	0.04	0.48	16.58	-0.51	52.94	0.00	46.05	0.31	0.07
BW-7	Madakkathara	3.10	10.39	2.35	1.91	2.46	4.43	0.08	0.42	0.03	0.65	23.04	0.23	64.57	0.00	65.62	0.52	0.05
BW-7	Madakkathara	1.97	9.69	1.65	1.16	3.20	5.86	0.08	0.26	0.04	0.48	16.32	0.25	52.55	0.00	53.79	0.35	0.06
BW-7	Madakkathara	2.59	9.16	2.72	2.23	3.64	3.36	0.08	0.35	0.04	0.52	18.30	-0.50	51.73	0.00	69.01	0.48	0.06
BW-8	PaDNAnchery	4.04	6.25	4.18	1.31	1.22	1.49	0.16	0.49	0.05	0.99	33.89	-0.63	70.39	0.00	56.70	0.59	0.09
BW-8	Panannchery	2.25	6.95	7.15	1.26	2.55	0.97	0.14	0.31	0.09	0.50	20.70	-0.75	59.36	0.01	55.66	0.43	0.08
BW-8	Panannchery	1.12	3.87	6.31	0.41	3.17	0.61	0.19	0.11	0.05	0.25	10.60	-2.20	34.82	0.01	29.04	0.18	0.13
BW-8	Panannchery	1.15	5.10	6.04	0.47	3.14	0.84	0.17	0.12	0.01	0.27	11.64	-1.65	41.61	0.01	31.75	0.20	0.10
BW-8	Panannchery	1.20	4.71	3.68	0.31	1.99	1.28	0.19	0.13	0.07	0.31	12.97	-1.58	43.81	0.00	23.71	0.20	0.11
BW-8	Panannchery	1.01	3.15	2.82	0.65	2.32	1.12	0.25	0.21	0.04	0.41	16.96	-0.94	51.54	0.01	39.40	0.30	0.16
BW-8	Panannchery	0.84	4.21	2.88	0.84	3.66	1.46	0.21	0.18	0.05	0.32	13.48	-1.01	49.61	0.00	45.53	0.27	0.12
BW-8	Panannchery	0.81	3.93	4.56	0.48	3.68	0.86	0.19	0.11	0.03	0.24	10.65	-1.61	39.20	0.01	32.58	0.19	0.13
BW-9	Kolazhi	0.87	3.98	0.17	0.26	1.47	23.62	0.17	0.15	DNA	0.47	13.67	-0.20	41.99	0.00	20.60	0.20	0.13
BW-9	Kolazhi	0.62	1.76	0.39	1.00	2.03	4.48	0.47	0.32	DNA	0.54	21.87	-0.36	63.17	0.01	50.03	0.41	0.25
BW-9	Kolazhi	0.84	1.62	0.43	0.60	1.19	3.78	0.48	0.32	DNA	0.73	26.58	-0.60	59.89	0.01	37.37	0.42	0.26
BW-9	Kolazhi	0.85	1.53	0.38	0.81	1.48	4.03	0.48	0.34	DNA	0.75	25.63	-0.76	55.95	0.01	44.89	0.44	0.28

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-9	Kolazhi	1.16	2.25	0.25	2.19	1.54	9.12	0.39	0.55	0.00	0.89	33.32	-0.02	76.23	0.00	68.67	0.66	0.21
BW-9	Kolazhi	0.99	2.16	0.60	0.50	1.24	3.61	0.41	0.28	0.08	0.59	23.61	-0.77	60.62	0.00	33.38	0.37	0.21
BW-9	Kolazhi	1.10	2.36	0.50	0.73	1.24	4.73	0.42	0.36	0.07	0.67	27.69	-0.50	71.79	0.00	42.35	0.45	0.20
BW-9	Kolazhi	0.83	2.30	0.42	1.45	2.73	5.42	0.40	0.33	0.10	0.60	19.77	-1.31	50.43	0.00	59.22	0.43	0.20
BW-9	Kolazhi	0.80	1.41	0.25	0.83	1.56	5.67	0.48	0.33	0.05	0.73	24.73	-0.75	54.08	0.01	45.34	0.43	0.29
BW-9	Kolazhi	0.90	2.40	0.35	1.01	1.69	6.84	0.32	0.36	DNA	0.68	25.10	0.07	65.11	0.00	50.14	0.45	0.20
BW-9	Kolazhi	0.82	2.40	0.40	1.10	1.60	6.05	0.37	0.38	0.09	0.68	27.43	0.16	75.45	0.00	52.43	0.50	0.19
BW-9	Kolazhi	0.57	1.87	0.25	0.95	2.45	7.46	0.43	0.27	DNA	0.51	18.99	-0.63	53.48	0.00	48.64	0.37	0.24
BW-9	Kolazhi	0.80	2.24	0.33	0.72	1.83	6.71	0.36	0.27	0.04	0.55	21.73	-0.59	56.39	0.00	41.80	0.38	0.21
BW-10	Athani	1.46	10.32	1.05	0.43	2.41	9.87	0.10	0.15	DNA	0.37	13.15	-0.49	51.56	0.00	30.31	0.22	0.05
BW-10	Athani	1.13	0.96	1.06	2.51	0.90	0.90	1.04	0.63	0.04	0.94	49.58	-0.23	98.74	0.01	71.55	0.82	0.38
BW-10	Athani	0.80	1.92	0.41	1.00	2.00	4.69	0.40	0.31	0.04	0.52	24.12	-0.47	62.07	0.00	50.08	0.46	0.23
BW-10	Athani	0.99	0.71	0.25	4.04	0.97	2.88	1.41	0.67	0.08	0.83	50.95	-0.20	104.85	0.01	80.16	0.87	0.45
BW-10	Athani	0.98	0.72	0.23	2.04	0.78	3.10	1.40	0.62	0.07	0.87	51.68	-0.19	105.52	0.01	67.07	0.81	0.45
BW-10	Athani	0.81	0.58	0.10	0.66	0.41	5.65	1.74	0.53	0.02	0.96	54.65	-0.16	108.92	0.01	39.75	0.72	0.50
BW-10	Athani	0.85	1.71	0.22	1.09	1.26	7.68	0.48	0.44	DNA	0.89	31.47	0.00	71.52	0.00	52.20	0.54	0.25
BW-10	Athani	0.61	0.67	0.27	4.04	1.45	2.48	1.48	0.57	0.02	0.56	43.57	-0.19	106.85	0.01	80.16	0.84	0.46
BW-10	Athani	0.65	1.40	0.28	2.01	2.46	5.06	0.71	0.37	0.10	0.43	28.91	-0.51	75.52	0.01	66.79	0.63	0.29
BW-11	Chengaloor	1.05	29.30	1.16	0.45	9.34	25.37	0.03	0.05	DNA	0.12	4.32	1.16	40.70	0.00	30.96	0.08	0.02
BW-11	Chengaloor	0.51	3.31	0.21	0.47	2.68	16.14	0.24	0.14	0.02	0.25	16.28	-0.12	63.36	0.00	31.85	0.29	0.15
BW-11	Chengaloor	3.27	7.00	0.48	0.30	0.28	14.68	0.13	0.47	0.08	1.11	48.90	0.81	120.13	0.00	22.94	0.61	0.08
BW-11	Chengaloor	0.85	2.30	0.26	0.64	1.78	8.71	0.35	0.25	0.08	0.35	22.11	-0.33	73.35	0.00	38.99	0.38	0.20
BW-11	Chengaloor	0.80	5.67	0.16	0.06	0.44	34.92	0.18	0.11	0.04	0.24	16.36	-0.17	74.68	0.00	5.58	0.23	0.09
BW-11	Chengaloor	0.62	0.71	0.33	0.76	1.75	2.13	0.71	0.28	0.08	0.29	24.03	-0.30	70.77	0.01	43.27	0.42	0.45
BW-11	Chengaloor	0.89	3.72	0.15	0.21	0.85	25.19	0.25	0.19	0.03	0.35	20.76	-0.13	80.90	0.00	17.50	0.30	0.14
BW-11	Chengaloor	0.81	4.90	0.23	0.22	1.21	20.85	0.19	0.14	0.00	0.27	17.55	-0.03	75.99	0.00	17.89	0.27	0.11
BW-11	Chengaloor	0.96	5.50	0.15	0.60	2.26	37.24	0.16	0.19	DNA	0.30	18.97	0.16	80.08	0.00	37.54	0.34	0.10
BW-11	Chengaloor	0.82	3.20	0.10	0.34	0.90	33.35	0.31	0.25	0.04	0.44	26.77	0.11	96.19	0.00	25.21	0.39	0.15
BW-11	Chengaloor	0.38	1.25	0.15	0.41	1.18	8.40	0.80	0.23	0.09	0.29	25.11	-0.13	105.64	0.01	28.99	0.39	0.32
BW-11	Chengaloor	0.36	3.12	0.22	0.84	4.73	14.04	0.32	0.13	0.00	0.13	17.34	-0.14	96.89	0.00	45.59	0.38	0.16
BW-12	Mupliyam	0.52	0.42	0.28	0.35	0.46	1.49	1.97	0.41	DNA	0.98	38.76	-0.69	71.00	0.02	26.11	0.51	0.58
BW-12	Mupliyam	0.51	3.03	0.23	1.12	4.15	12.97	0.24	0.21	DNA	0.34	12.60	0.05	51.83	0.00	52.80	0.28	0.16

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-12	Mupliyam	1.08	8.79	0.67	1.20	4.90	13.15	0.11	0.19	DNA	0.30	12.21	-0.11	55.64	0.00	54.56	0.29	0.06
BW-12	Mupliyam	1.19	6.79	0.84	1.26	6.74	8.06	0.09	0.15	DNA	0.23	9.80	-0.75	40.43	0.00	55.69	0.25	0.08
BW-12	Mupliyam	5.32	12.72	1.02	2.37	1.55	12.46	0.06	0.58	0.01	1.00	32.77	0.81	77.16	0.00	70.33	0.66	0.04
BW-12	Mupliyam	1.13	7.27	0.77	1.49	7.02	9.47	0.09	0.17	0.08	0.23	9.62	-0.70	43.25	0.00	59.83	0.26	0.07
BW-12	Mupliyam	1.90	9.21	0.75	0.95	3.38	12.24	0.08	0.21	0.05	0.39	14.27	-0.31	50.63	0.00	48.84	0.29	0.06
BW-12	Mupliyam	1.70	11.95	0.79	0.96	3.61	15.22	0.08	0.20	DNA	0.38	13.56	-0.10	55.68	0.00	49.03	0.28	0.05
BW-12	Mupliyam	2.71	13.65	0.40	1.13	3.57	34.08	0.05	0.23	0.04	0.40	14.66	0.00	52.58	0.00	52.95	0.31	0.04
BW-12	Mupliyam	2.81	11.17	0.92	1.55	2.72	12.11	0.06	0.35	DNA	0.53	20.15	0.76	63.95	0.00	60.83	0.44	0.05
BW-12	Mupliyam	1.29	10.49	0.77	1.22	4.94	13.64	0.07	0.19	0.08	0.28	12.07	0.60	58.43	0.00	54.91	0.28	0.05
BW-12	Mupliyam	1.29	9.60	0.71	1.15	5.68	13.47	0.08	0.16	DNA	0.26	10.98	-0.29	48.50	0.00	53.47	0.26	0.06
BW-13	Mudicode	0.88	2.94	0.42	0.31	1.44	6.96	0.22	0.17	0.03	0.34	16.66	-0.30	58.24	0.01	23.92	0.41	0.34
BW-13	Mudicode	0.75	1.13	0.23	0.30	0.60	4.87	0.76	0.32	DNA	0.89	30.21	-0.84	62.17	0.00	23.13	0.25	0.17
BW-13	Mudicode	0.50	2.31	0.31	0.33	1.64	7.47	0.31	0.17	DNA	0.30	14.65	-0.04	64.63	0.00	25.05	0.22	0.20
BW-13	Mudicode	1.02	3.12	0.42	0.06	0.23	7.39	0.24	0.20	DNA	0.46	22.27	0.07	73.63	0.00	5.82	0.28	0.16
BW-13	Mudicode	1.11	3.92	0.59	0.54	2.08	6.70	0.19	0.20	DNA	0.34	16.57	-0.42	60.43	0.00	35.13	0.28	0.13
BW-13	Mudicode	4.12	5.40	0.23	0.68	0.45	23.09	0.15	0.58	0.06	1.31	48.97	0.44	103.05	0.00	40.50	0.66	0.10
BW-13	Mudicode	0.96	2.88	0.48	0.05	0.30	6.01	0.25	0.15	DNA	0.34	16.61	-0.53	59.14	0.00	5.21	0.21	0.17
BW-13	Mudicode	1.03	4.25	0.54	0.20	1.02	7.89	0.20	0.16	DNA	0.31	16.39	-0.37	67.17	0.00	16.71	0.23	0.12
BW-13	Mudicode	1.13	4.25	0.65	0.06	0.31	6.55	0.20	0.16	0.05	0.34	17.76	-0.30	70.18	0.00	5.82	0.22	0.12
BW-13	Mudicode	0.78	3.92	0.52	0.31	1.49	7.51	0.23	0.17	DNA	0.30	15.92	-0.22	71.23	0.00	23.77	0.24	0.13
BW-13	Mudicode	0.82	3.62	0.32	0.29	1.34	11.20	0.22	0.17	0.01	0.32	16.52	-0.17	69.18	0.00	22.40	0.25	0.14
BW-13	Mudicode	1.15	4.62	0.56	0.46	1.43	8.30	0.19	0.23	DNA	0.40	20.08	0.04	78.51	0.00	31.44	0.31	0.11
BW-13	Mudicode	0.80	4.27	0.38	0.64	2.14	11.12	0.21	0.22	DNA	0.35	17.57	0.18	77.22	0.00	38.98	0.31	0.12
BW-13	Mudicode	0.80	4.03	0.43	0.50	2.15	9.34	0.20	0.18	DNA	0.30	15.83	-0.04	70.22	0.00	33.52	0.27	0.13
BW-13	Mudicode	0.92	8.23	0.56	0.21	1.89	14.68	0.11	0.10	0.01	0.18	11.96	-0.08	69.14	0.00	17.47	0.19	0.07
BW-14	Velapaya	0.99	5.35	0.01	0.28	1.26	BDL	0.19	0.18	DNA	0.37	17.05	-0.13	70.13	0.00	22.04	0.25	0.10
BW-14	Velapaya	1.07	1.51	0.22	0.61	0.52	6.93	0.66	0.50	0.02	0.92	44.99	0.02	107.47	0.01	37.89	0.62	0.28
BW-14	Velapaya	0.81	0.43	0.13	0.44	0.56	3.26	0.99	0.42	0.04	0.77	37.89	-0.32	70.16	0.01	30.35	0.52	0.57
BW-14	Velapaya	0.80	1.03	0.16	0.38	0.54	6.34	0.97	0.39	0.05	0.74	36.10	-0.38	84.76	0.01	27.31	0.49	0.36
BW-14	Velapaya	0.89	1.33	0.31	0.86	0.99	4.32	0.75	0.44	0.05	0.75	33.97	-0.40	81.58	0.01	46.23	0.54	0.30
BW-14	Velapaya	0.81	0.99	0.14	0.62	0.69	7.26	1.01	0.45	0.04	0.83	38.17	-0.36	85.74	0.01	38.32	0.55	0.37
BW-14	Velapaya	0.81	0.90	0.07	0.72	0.82	13.13	1.11	0.44	0.10	0.79	36.24	-0.52	79.39	0.01	41.81	0.55	0.39

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-14	Velapaya	1.00	1.26	0.11	1.29	0.96	11.70	0.79	0.54	0.08	0.89	39.23	-0.30	87.40	0.01	56.33	0.64	0.32
BW-14	Velapaya	0.82	1.77	0.23	0.22	0.41	7.84	0.51	0.33	0.07	0.80	32.08	0.05	81.77	0.00	17.79	0.41	0.25
BW-14	Velapaya	0.80	0.87	0.11	0.50	0.55	7.68	1.15	0.45	0.04	0.95	40.48	-0.41	83.72	0.01	33.28	0.56	0.40
BW-14	Velapaya	0.81	1.02	0.05	0.78	0.91	20.49	0.98	0.43	0.08	0.78	36.29	-0.51	78.53	0.01	43.89	0.56	0.36
BW-15	Kaiparambu	1.68	4.25	0.40	0.46	0.96	10.56	0.17	0.31	0.01	0.58	27.49	0.20	78.74	0.00	31.38	0.41	0.12
BW-15	Kaiparambu	1.14	3.46	0.42	0.64	1.58	8.22	0.21	0.27	DNA	0.40	22.65	0.06	80.32	0.00	38.99	0.38	0.14
BW-15	Kaiparambu	2.24	4.87	0.51	0.67	0.78	9.60	0.21	0.43	0.04	0.72	36.94	0.12	104.36	0.00	40.15	0.55	0.11
BW-15	Kaiparambu	2.67	4.56	0.43	0.84	0.95	10.54	0.18	0.44	0.10	0.71	34.81	0.00	90.65	0.00	45.60	0.55	0.11
BW-15	Kaiparambu	2.60	6.57	0.83	1.34	1.35	7.88	0.14	0.47	0.01	0.66	32.48	0.23	96.13	0.00	57.35	0.58	0.08
BW-15	Kaiparambu	2.02	4.93	0.26	1.20	1.17	18.79	0.18	0.48	0.01	0.69	34.42	0.30	101.20	0.00	54.62	0.59	0.11
BW-15	Kaiparambu	2.35	4.27	0.31	0.60	0.51	13.71	0.18	0.51	DNA	0.94	44.94	0.59	116.60	0.00	37.66	0.62	0.12
BW-15	Kaiparambu	1.59	5.16	0.32	1.40	1.48	16.27	0.18	0.46	DNA	0.61	31.02	0.43	102.18	0.00	58.41	0.57	0.10
BW-15	Kaiparambu	2.89	8.27	0.44	1.61	1.68	18.71	0.10	0.44	0.01	0.54	30.95	0.29	99.36	0.00	61.67	0.60	0.07
BW-16	Peechi	1.07	3.54	0.32	0.40	1.23	11.18	0.28	0.24	DNA	0.48	20.38	-0.49	67.99	0.00	28.73	0.30	0.14
BW-16	Peechi	0.94	1.65	0.28	1.02	1.14	5.95	0.61	0.45	0.03	0.69	33.15	-0.27	86.35	0.01	50.42	0.55	0.26
BW-16	Peechi	0.81	1.11	0.20	2.22	1.23	5.51	0.60	0.61	DNA	0.80	37.94	0.14	91.01	0.01	68.91	0.71	0.34
BW-16	Peechi	0.81	1.77	0.27	1.13	1.78	6.52	0.48	0.37	DNA	0.55	25.26	-0.38	71.14	0.00	52.99	0.47	0.25
BW-16	Peechi	0.68	1.71	0.20	0.79	2.00	8.73	0.41	0.27	0.02	0.49	19.91	-0.50	56.86	0.00	44.11	0.35	0.25
BW-16	Peechi	0.83	1.35	0.26	1.00	1.01	5.13	0.74	0.46	0.00	0.64	36.18	-0.17	97.63	0.01	49.93	0.59	0.30
BW-16	Peechi	0.86	1.41	0.10	0.81	0.84	13.66	0.71	0.47	0.00	0.72	36.96	-0.11	99.30	0.01	44.69	0.56	0.29
BW-16	Peechi	1.09	1.72	0.18	1.51	0.99	9.32	0.58	0.58	0.01	0.87	39.77	-0.04	98.28	0.01	60.11	0.67	0.25
BW-16	Peechi	0.80	1.30	0.19	1.68	0.98	6.75	0.77	0.59	0.08	0.82	41.41	0.03	107.77	0.01	62.63	0.70	0.31
BW-16	Peechi	0.61	1.25	0.09	1.44	1.91	13.52	0.80	0.40	0.06	0.52	26.95	-0.52	74.94	0.01	58.96	0.53	0.32
BW-17	Chittilapilly	3.20	4.02	0.44	0.33	0.13	9.04	0.25	0.65	0.01	1.68	68.05	0.54	149.87	0.00	24.80	0.78	0.13
BW-17	Chittilapilly	2.04	3.07	0.29	1.53	0.59	10.70	0.33	0.66	DNA	1.03	53.90	0.28	137.10	0.00	60.40	0.79	0.16
BW-17	Chittilapilly	3.02	4.05	0.05	0.34	0.17	76.83	0.25	0.62	0.03	1.34	63.11	0.41	150.67	0.00	25.12	0.74	0.13
BW-17	Chittilapilly	2.83	3.67	0.33	2.04	0.54	11.04	0.25	0.75	DNA	1.26	57.00	0.39	134.16	0.00	67.07	0.83	0.14
BW-17	Chittilapilly	3.15	4.81	0.22	0.99	0.32	21.70	0.21	0.70	0.04	1.40	63.51	0.55	156.62	0.00	49.74	0.81	0.11
BW-17	Chittilapilly	3.50	5.30	0.26	2.06	0.30	20.12	0.19	0.81	DNA	1.77	71.28	0.74	171.99	0.00	67.33	0.90	0.10
BW-17	Chittilapilly	1.97	5.49	0.24	0.43	0.64	22.83	0.16	0.38	DNA	0.67	35.52	0.50	109.79	0.00	30.20	0.50	0.10
BW-17	Chittilapilly	2.84	4.92	0.11	1.51	0.54	43.90	0.20	0.65	0.02	1.02	57.29	0.39	155.50	0.00	60.13	0.81	0.11
BW-18	Nelluvayi	0.80	3.40	0.62	0.60	2.12	5.49	0.22	0.21	DNA	0.45	17.77	0.00	56.19	0.00	37.57	0.31	0.15

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-18	Nelluvayi	1.12	4.29	0.73	0.77	2.51	5.85	0.19	0.22	DNA	0.43	17.67	-0.54	54.88	0.00	43.54	0.33	0.12
BW-18	Nelluvayi	1.12	4.35	0.67	0.55	2.17	6.51	0.18	0.19	DNA	0.41	16.56	-0.56	52.25	0.00	35.53	0.28	0.12
BW-18	Nelluvayi	1.19	5.45	1.05	0.37	1.85	5.19	0.15	0.16	0.06	0.35	15.28	-0.60	54.08	0.00	26.82	0.24	0.10
BW-18	Nelluvayi	1.49	5.91	1.06	0.43	1.76	5.58	0.14	0.19	DNA	0.42	17.34	-0.56	55.47	0.00	30.08	0.28	0.09
BW-18	Nelluvayi	1.28	3.29	0.42	0.75	1.19	7.89	0.30	0.36	0.04	0.60	30.34	-0.10	86.39	0.00	42.94	0.50	0.15
BW-18	Nelluvayi	1.14	6.89	0.44	1.24	3.75	15.73	0.15	0.24	DNA	0.38	15.13	-0.35	58.39	0.00	55.41	0.34	0.08
BW-18	Nelluvayi	1.19	4.96	0.51	1.07	2.98	9.78	0.17	0.25	0.05	0.43	16.86	-0.40	56.00	0.00	51.61	0.35	0.10
BW-18	Nelluvayi	1.58	5.40	0.39	1.09	2.13	13.84	0.15	0.32	DNA	0.55	21.96	0.06	65.91	0.00	52.21	0.42	0.10
BW-18	Nelluvayi	1.06	5.14	0.29	0.94	2.32	17.99	0.16	0.27	DNA	0.50	19.43	0.75	65.86	0.00	48.35	0.37	0.10
BW-18	Nelluvayi	0.95	5.60	0.36	1.22	3.95	15.46	0.14	0.22	0.02	0.35	14.64	0.06	57.18	0.00	54.91	0.33	0.09
BW-18	Nelluvayi	1.00	5.81	0.70	0.56	3.05	8.32	0.13	0.15	0.03	0.31	13.44	-0.36	50.43	0.00	35.84	0.25	0.09
BW-19	Kandanissery	1.40	4.38	0.47	0.67	1.38	9.33	0.22	0.30	DNA	0.50	26.85	-0.06	82.79	0.00	40.08	0.45	0.12
BW-19	Kandanissery	1.17	5.89	0.87	0.21	0.68	6.80	0.17	0.21	DNA	0.39	25.85	0.32	102.16	0.00	17.09	0.37	0.09
BW-19	Kandanissery	1.19	3.92	0.59	0.77	1.94	6.71	0.19	0.26	DNA	0.41	22.64	-0.02	72.80	0.00	43.56	0.41	0.13
BW-19	Kandanissery	1.87	6.70	1.70	1.01	2.46	3.94	0.14	0.27	DNA	0.42	20.25	-0.48	66.40	0.00	50.22	0.35	0.13
BW-19	Kandanissery	1.96	5.06	0.45	0.30	0.77	11.17	0.16	0.26	0.08	0.48	27.25	-0.08	83.23	0.00	23.16	0.39	0.10
BW-19	Kandanissery	1.97	3.54	2.41	0.22	0.69	1.47	0.19	0.23	0.06	0.48	24.12	-0.50	62.37	0.00	17.89	0.33	0.14
BW-19	Kandanissery	1.42	3.84	1.22	0.46	1.41	3.14	0.19	0.23	DNA	0.40	22.18	-0.24	68.49	0.00	31.73	0.40	0.08
BW-19	Kandanissery	1.95	6.22	0.82	1.02	2.08	7.58	0.13	0.30	0.05	0.46	23.10	-0.10	72.17	0.00	50.42	0.44	0.09
BW-19	Kandanissery	2.47	5.30	0.42	0.66	0.83	12.58	0.16	0.41	DNA	0.68	35.89	0.19	100.76	0.00	39.84	0.54	0.10
BW-19	Kandanissery	1.38	4.95	0.59	1.01	1.65	8.45	0.19	0.35	0.06	0.55	26.89	0.30	86.30	0.00	50.25	0.49	0.11
BW-19	Kandanissery	1.02	5.04	1.39	0.59	2.32	3.62	0.16	0.19	0.05	0.31	18.06	-0.05	69.04	0.00	36.95	0.32	0.10
BW-19	Kandanissery	1.55	4.92	1.01	1.01	1.96	4.86	0.20	0.30	0.08	0.36	25.91	-0.18	92.69	0.00	50.14	0.49	0.11
BW-20	Aloor	1.40	27.06	0.00	0.49	6.81		0.04	0.07	DNA	0.07	4.89	-0.06	102.28	0.00	33.10	0.08	0.02
BW-20	Aloor	1.29	5.32	0.31	0.74	2.53	17.29	0.14	0.22	DNA	0.38	16.17	-0.16	58.54	0.00	42.42	0.30	0.10
BW-20	Aloor	0.89	0.90	0.14	BDL	BDL	6.62	1.11	0.43	0.02	0.60	44.31	-0.07	134.86	0.01	BDL	0.48	0.39
BW-20	Aloor	0.84	1.15	0.13	BDL	BDL	8.76	0.87	0.34	0.02	0.48	36.14	-0.11	123.01	0.01	BDL	0.40	0.34
BW-20	Aloor	0.81	0.89	0.25	1.98	1.08	3.56	1.13	0.62	0.02	0.47	39.67	-0.10	131.22	0.01	66.43	0.70	0.40
BW-20	Aloor	1.16	1.20	0.28	0.48	0.38	4.35	0.83	0.55	0.01	0.67	47.21	-0.03	138.57	0.01	32.55	0.61	0.33
BW-20	Aloor	0.82	0.49	0.15	0.51	0.30	3.20	2.06	0.62	0.04	0.87	53.93	-0.10	122.86	0.02	33.65	0.67	0.54
BW-20	Aloor	0.81	0.74	0.21	2.06	0.84	3.54	1.35	0.68	0.05	0.62	45.63	-0.08	130.02	0.01	67.33	0.75	0.44
BW-20	Aloor	0.80	0.92	0.20	0.67	0.95	4.52	1.08	0.38	0.09	0.38	33.57	-0.21	106.35	0.01	40.13	0.52	0.39

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-21	Vellangallur	1.10	3.65	0.32	0.80	1.83	11.52	0.22	0.27	DNA	0.46	24.92	-0.04	73.27	0.00	44.44	0.45	0.14
BW-21	Vellangallur	0.57	1.58	0.15	0.50	1.38	10.67	0.63	0.24	DNA	0.26	25.96	-0.19	105.53	0.01	33.38	0.42	0.27
BW-21	Vellangallur	0.57	1.42	0.35	2.02	2.51	4.04	0.71	0.38	0.02	0.29	26.72	-0.20	103.87	0.01	66.89	0.60	0.29
BW-21	Vellangallur	0.52	1.66	0.49	1.51	3.51	3.40	0.60	0.26	0.09	0.23	19.90	-0.40	82.26	0.01	60.09	0.47	0.26
BW-21	Vellangallur	0.57	1.59	0.40	2.01	3.37	4.02	0.63	0.33	0.10	0.27	21.03	-0.41	81.67	0.01	66.74	0.52	0.27
BW-21	Vellangallur	0.53	1.55	0.31	1.36	1.87	4.95	0.64	0.38	0.09	0.37	28.34	-0.07	110.23	0.01	57.54	0.55	0.27
BW-21	Vellangallur	0.80	1.42	0.30	1.00	1.24	4.78	0.70	0.41	0.04	0.51	33.01	-0.23	95.78	0.01	49.94	0.56	0.29
BW-21	Vellangallur	0.83	1.61	0.30	0.40	0.66	5.42	0.62	0.33	0.01	0.46	36.86	-0.09	114.48	0.01	28.68	0.53	0.27
BW-22	Wadakanchery	0.46	1.11	1.25	3.44	4.30	0.89	0.71	0.40	DNA	0.59	18.55	-2.35	39.56	0.01	77.46	0.57	0.34
BW-22	Wadakanchery	0.24	0.99	0.34	0.93	5.43	2.92	0.70	0.14	DNA	0.36	9.44	-3.79	27.82	0.01	48.29	0.20	0.37
BW-22	Wadakanchery	0.39	1.20	0.33	0.82	3.42	3.63	0.59	0.19	DNA	0.49	13.85	-2.94	33.03	0.01	45.06	0.27	0.33
BW-22	Wadakanchery	0.83	1.51	0.40	4.44	2.84	3.78	0.53	0.57	0.07	0.97	24.17	-1.99	45.80	0.01	81.62	0.68	0.28
BW-22	Wadakanchery	0.36	0.97	0.44	1.17	3.65	2.20	0.94	0.23	0.07	0.48	15.17	-3.03	36.55	0.01	53.86	0.33	0.38
BW-22	Wadakanchery	0.34	1.68	0.69	0.35	2.52	2.43	0.56	0.12	0.04	0.40	11.06	-3.40	33.27	0.01	26.16	0.18	0.26
BW-22	Wadakanchery	0.40	1.34	0.63	1.48	5.39	2.13	0.60	0.21	0.10	0.43	11.58	-4.07	29.89	0.01	59.70	0.29	0.30
BW-22	Wadakanchery	0.36	1.27	0.34	0.59	3.24	3.69	0.65	0.15	0.10	0.48	11.82	-4.50	29.53	0.01	37.24	0.21	0.31
BW-22	Wadakanchery	0.39	1.34	0.44	0.92	3.53	3.06	0.50	0.20	DNA	0.50	13.74	-2.07	35.03	0.01	47.91	0.28	0.30
BW-22	Wadakanchery	0.31	1.58	0.53	0.90	4.08	2.98	0.51	0.18	0.07	0.45	12.18	-1.95	35.56	0.01	47.45	0.25	0.27
BW-22	Wadakanchery	0.32	1.51	0.53	1.45	5.21	2.86	0.58	0.21	DNA	0.45	12.39	-3.10	33.45	0.01	59.14	0.31	0.28
BW-22	Wadakanchery	0.33	1.19	0.55	0.95	4.78	2.14	0.61	0.16	0.07	0.41	11.43	-4.05	28.45	0.01	48.63	0.25	0.33
BW-23	Varavoor	2.40	9.06	2.09	0.43	2.10	4.34	0.07	0.17	DNA	0.42	14.44	-0.56	43.60	0.00	30.27	0.23	0.06
BW-23	Varavoor	5.45	15.21	2.20	3.42	2.05	6.90	0.06	0.59	0.01	0.86	29.36	0.39	73.58	0.00	77.40	0.69	0.04
BW-23	Varavoor	1.62	8.51	1.56	0.79	3.91	5.44	0.09	0.16	0.08	0.32	11.88	-0.85	44.49	0.00	44.08	0.24	0.06
BW-23	Varavoor	1.19	5.80	1.08	0.37	1.89	5.38	0.14	0.16	0.03	0.32	14.24	-0.40	57.71	0.00	26.95	0.22	0.09
BW-23	Varavoor	1.70	7.02	2.47	1.56	4.66	2.84	0.11	0.24	0.09	0.39	13.22	-1.37	42.60	0.00	60.91	0.33	0.08
BW-23	Varavoor	1.91	11.63	1.21	1.59	5.09	9.58	0.08	0.23	0.09	0.38	12.27	-0.92	45.30	0.00	61.37	0.31	0.05
BW-23	Varavoor	2.35	11.30	2.05	0.96	3.08	5.51	0.07	0.23	DNA	0.43	15.38	0.12	52.62	0.00	48.85	0.31	0.05
BW-23	Varavoor	1.21	10.12	1.28	1.57	5.68	7.89	0.09	0.20	DNA	0.29	12.23	0.09	54.75	0.00	61.14	0.32	0.05
BW-23	Varavoor	0.95	6.10	0.69	1.46	6.17	8.84	0.13	0.18	0.09	0.27	11.15	-0.90	44.47	0.00	59.33	0.29	0.09
BW-24	Arthat	0.64	0.54	0.28	1.01	0.71	1.92	1.86	0.55	DNA	0.78	44.55	-0.24	99.94	0.02	50.15	0.67	0.52
BW-24	Arthat	1.17	3.62	0.56	0.51	1.32	6.46	0.22	0.25	DNA	0.39	25.41	-0.03	84.62	0.00	33.56	0.41	0.14
BW-24	Arthat	1.11	2.62	0.26	0.33	0.79	10.18	0.29	0.27	0.02	0.41	28.90	-0.01	96.27	0.00	24.95	0.42	0.18

Appendix

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
BW-24	Arthat	4.96	5.53	0.63	0.36	0.12	8.72	0.18	0.70	0.03	2.00	71.01	0.60	146.07	0.00	26.65	0.80	0.10
BW-24	Arthat	1.16	4.76	0.54	0.23	0.79	8.74	0.18	0.21	DNA	0.35	23.40	0.16	94.34	0.00	18.47	0.33	0.11
BW-24	Arthat	1.81	3.54	0.66	0.50	0.55	5.34	0.28	0.43	DNA	0.66	42.57	0.11	125.82	0.00	33.38	0.59	0.14
BW-24	Arthat	1.39	2.13	1.62	0.76	0.78	1.32	0.47	0.45	0.07	0.66	40.08	-0.10	106.47	0.01	43.27	0.60	0.21
BW-24	Arthat	2.12	4.71	0.77	0.22	0.41	6.16	0.20	0.33	0.04	0.65	33.84	0.04	95.91	0.00	18.02	0.44	0.11
BW-24	Arthat	2.53	4.13	0.84	0.51	0.41	4.89	0.24	0.51	DNA	0.91	48.50	0.20	126.36	0.00	33.73	0.64	0.12
BW-24	Arthat	1.37	2.33	0.45	0.76	0.54	5.12	0.40	0.54	0.10	0.95	47.67	0.33	121.33	0.00	43.03	0.67	0.20
BW-24	Arthat	0.97	2.74	0.69	0.75	1.30	4.00	0.36	0.32	DNA	0.39	32.24	-0.04	111.35	0.00	42.96	0.54	0.17
BW-24	Arthat	0.92	3.54	0.35	1.21	1.99	10.24	0.28	0.32	DNA	0.37	28.24	0.06	106.67	0.00	54.68	0.55	0.14

BDL: Below detectable level

DNA: data not available

Appendix

Table 6.1 Details of litholog collected from various places of Palaeo-lagoon (Kole land basin)

Sl. No.	1	2	3	4	5	6	7	8	9	10
Depth BGL (m)	Kaduppassery	Mattathoor	Nellayi	Tholur	Thrikkur	Choondal	Madakkathara	Panancherry	Kolazhi	Athani
0 - 1	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
1–2	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite
2–3	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite
3–4	Laterite	Laterite	Laterite	Laterite	Clay	Laterite	Clay	Laterite	Laterite	Laterite
4–5	Laterite	Laterite	Laterite	Laterite	Clay	Laterite	Clay	Laterite	Laterite	Laterite
5–6	Laterite	Laterite	Laterite	Clay	Clay	Laterite	WR	Laterite	WR	WR
6–7	Laterite	Laterite	Laterite	Clay	Clay	WR	BG	Clay	CHNKT	BG
7–8	Laterite	Laterite	Laterite	Clay	Clay	BG	BG	Clay	CHNKT	BG
8–9	BG	Laterite	Laterite	Clay	Clay	BG	BG	Clay	CHNKT	BG
9–10	BG	WR	Clay	Clay	Clay	BG	BG	Clay	CHNKT	BG
10–11	BG	BG	Clay	Clay	Clay	BG	BG	Clay	CHNKT	BG
11–12	BG	BG	Clay	Clay	Clay	BG	BG	Clay	CHNKT	BG
12–13	BG	BG	WR	Clay	WR	BG	BG	WR	CHNKT-F	BG
13–14	BG	BG	WR	Clay	WR	BG	BG	WR	CHNKT-F	BG
14–15	BG	BG	BG	Clay	BG	BG	BG	BG	CHNKT-F	BG
15–16	BG	BG	BG	GB-Clay	BG	BG	BG	BG	CHNKT-F	BG
16–17	BG	BG	BG	GB-Clay	BG	BG	BG	BG	CHNKT-F	BG
17 - 18	BG	BG	BG	GB-Clay	BG	BG	BG	BG	CHNKT-F	BG
18 - 19	BG	BG	BG	WR	BG	BG	BG	BG	CHNKT-F	CHNKT-F
19 - 20	BG	BG	BG	WR	BG	BG	BG	BG	CHNKT-F	CHNKT-F
20 - 21	BG	BG	BG	CHNKT	BG	BG	BG	BG	CHNKT-F	CHNKT-F
21 - 22	BG	BG-F	BG	CHNKT	BG	CHNKT-F	BG-F	BG	CHNKT-F	CHNKT-F
22 - 23	BG	BG-F	BG	CHNKT	BG	CHNKT-F	BG-F	BG	CHNKT-F	CHNKT-F
23 - 24	BG	BG-F	BG	CHNKT	BG	CHNKT-F	BG-F	BG	CHNKT-F	CHNKT-F
24 - 25	BG-F	BG-F	BG	CHNKT	BG	CHNKT-F	CHNKT-F	BG	CHNKT-F	CHNKT-F
25 - 26	BG-F	BG-F	BG	CHNKT	BG	CHNKT-F	CHNKT-F	BG	CHNKT-F	CHNKT-F
26 - 27	BG-F	BG-F	BG	CHNKT	BG	CHNKT-F	CHNKT-F	BG	CHNKT-F	CHNKT-F
27 - 28	BG-F	BG-F	BGQ-F	CHNKT	BG	CHNKT-F	CHNKT-F	CHNKT-F	CHNKT-F	CHNKT-F
28 - 29	BG-F	BG-F	BGQ-F	CHNKT	BG	CHNKT-F	CHNKT-F	CHNKT-F	CHNKT-F	CHNKT-F
29 - 30	BG-F	BG-F	BGQ-F	CHNKT	BG	CHNKT-F	CHNKT-F	CHNKT-F	CHNKT-F	CHNKT-F
30 - 31	BG-F			CHNKT	BG			CHNKT		
31 - 32	BG-F			CHNKT	BG			CHNKT		
32 - 33	BG-F			CHNKT	BG			CHNKT		
33 - 34	BG-F			CHNKT	BG			CHNKT		
34 - 35	BG-F			CHNKT	BG			CHNKT		
35 - 36	BG-F			CHNKT-F	BG			CHNKT		
36 - 37	BG-F			CHNKT-F	CHNKT-F			CHNKT		
37 - 38	BG-F			CHNKT-F	CHNKT-F			CHNKT		
38 - 39	BG-F			CHNKT-F	CHNKT-F			CHNKT		
39 - 40	BG-F			CHNKT-F	CHNKT-F			CHNKT		
40 - 45	BG-F			CHNKT-F	CHNKT-F			CHNKT-F		
45 - 50					CHNKT-F			CHNKT-F		
50 - 55								CHNKT-F		

CHNKT: Charnockite, **CHNKT-W**: Charnockite weatherd, **CHNKT-F**:Charnockite fractured, **WR**: Weathered rock

CHNKT-WF: Charnockite weatherd and fractured, **BG**: Biotite gneiss, **BG-F**: Biotite gneiss fractured

BGQ: Biotite gneiss with quarts vein, **GB clay**: Greenish black clay

Table 6.1 Details of litholog collected from various places of Palaeo-lagoon (Kole land basin)

Sl. No.	11	12	13	14	15	16	17	18	19	20
Depth BGL (m)	Chengaloor	Mupliyam	Mudikode	Velapaya	Kaiparambu	Peechi	Chittilppilly	Nelluvayi	Kandanissery	Aloor
0 - 1	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
1--2	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite
2--3	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite
3--4	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite-H	Clay	Clay	Laterite	Laterite
4--5	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite-H	Clay	Clay	Laterite	Laterite
5--6	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite-H	Clay	WR	Laterite	Laterite
6--7	Clay	Clay	Laterite	Clay	Laterite	WR	Clay	WR	Laterite	Laterite
7--8	Clay	Clay	Laterite	Clay	Laterite	BG	WR	CHNKT	Laterite	Laterite
8--9	Clay	Clay	Laterite	Clay	Laterite	BG	WR	CHNKT	Laterite	Laterite
9--10	WR	WR	Laterite	WR	Laterite-H	BG	CHNKT	CHNKT	Laterite	Laterite
10--11	WR	BG	Laterite	WR	Laterite-H	BG	CHNKT	CHNKT	Laterite	Clay
11--12	BG	BG	Laterite	BG	Laterite-H	BG	CHNKT	CHNKT	Laterite	WR
12--13	BG-F	BG	Clay	BG	Laterite-H	BG	CHNKT	CHNKT	Clay	BG
13--14	BG-F	BG	Clay	BG	Laterite-H	BG	CHNKT	CHNKT	Clay	BG
14--15	BG-F	BG	Clay	BG	Laterite-H	BG	CHNKT	CHNKT	Clay	BG
15--16	BG-F	CHNKT	WR	BG	Laterite-H	BG	BG-F	CHNKT	WR	BG
16--17	BG-F	CHNKT	BG-F	BG	Laterite-H	BG	BG-F	CHNKT	CHNKT	BG
17 - 18	BG-F	CHNKT	BG-F	BG	Laterite-H	BG	BG-F	CHNKT	CHNKT	BG
18 - 19	BG-F	CHNKT	BG-F	BG	WR	BG	BG-F	CHNKT	CHNKT	BG
19 - 20	BG-F	CHNKT	BG-F	BG	WR	BG	BG-F	CHNKT	CHNKT	BG
20 - 21	BG-F	CHNKT	BG-F	BG	WR	BG	BG-F	BG-F	CHNKT	BG
21 - 22	BG-F	BG	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	CHNKT	BG
22 - 23	BG-F	BG	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	CHNKT	BG
23 - 24	BG-F	BG	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	CHNKT	BG
24 - 25	BG-F	BG	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	BG	BG
25 - 26	BG-F	BG	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	BG	BG
26 - 27	BG-F	BG	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	BG	BG
27 - 28	BG-F	BG-F	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	CHNKT-F	BG
28 - 29	BG-F	BG-F	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	CHNKT-F	BG
29 - 30	BG-F	BG-F	BG-F	BG	CHNKT	CHNKT-F	BG-F	BG-F	CHNKT-F	BG
30 - 31		BG-F		CHNKT-F	CHNKT-F	CHNKT-F		CHNKT-F	CHNKT-F	BG
31 - 32		BG-F		CHNKT-F	CHNKT-F	CHNKT-F		CHNKT-F	CHNKT-F	BG
32 - 33		BG-F		CHNKT-F	CHNKT-F			CHNKT-F	CHNKT-F	BG
33 - 34		BG-F		CHNKT-F	CHNKT-F			CHNKT-F	CHNKT-F	BG
34 - 35				CHNKT	CHNKT-F			CHNKT-F	CHNKT-F	BG
35 - 36				CHNKT	CHNKT-F			CHNKT-F	CHNKT-F	BG
36 - 37				CHNKT	CHNKT-F			CHNKT-F	CHNKT-F	BG
37 - 38				CHNKT	CHNKT-F			CHNKT-F	CHNKT-F	BG
38 - 39				CHNKT	CHNKT-F			CHNKT-F	CHNKT-F	BG
39 - 40				CHNKT	CHNKT-F			CHNKT-F	CHNKT-F	BG
40 - 45				CHNKT					CHNKT-F	BG
45 - 50										BG
50 - 55										BG
55 - 60										BG
60 - 65										BG

CHNKT: Charnockite, **CHNKT-W**: Charnockite weatherd, **CHNKT-F**:Charnockite fractured, **WR**: Weathered rock
CHNKT-WF: Charnockite weatherd and fractured, **BG**: Biotite gneiss, **BG-F**: Biotite gneiss fractured

Table 6.1 Details of litholog collected from various places of Palaeo-lagoon

Sl. No.	21	22	23	24	25	26	27	28	29	30
Depth BGL (m)	Vellangalloor	Varavoor	Arthat	Wadakkancherry	Pudukkad	Vellanikkara(KAU Veg.garden)	Chiranellur	Alur	Vellanikkara(KAU Main gate)	Vellanikkara(KAU Pepper.garden)
0 - 1	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
1–2	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite
2–3	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite
3–4	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite
4–5	Laterite	Laterite	Laterite	Laterite	Laterite	Laterite	Clay	Laterite	Laterite	Laterite
5–6	Laterite	Clay	Laterite	Laterite	Laterite	Laterite	Clay	CHNKT-WF	Laterite	Laterite
6–7	Laterite	WR	Laterite	Laterite	Laterite	Laterite	Clay	CHNKT-WF	WR	Laterite
7–8	Laterite	BG-F	Laterite	WR	Laterite	CHNKT-WF	CHNKT-WF	CHNKT-WF	CHNKT-W	Laterite
8–9	Laterite	BG-F	Laterite	WR	Laterite	CHNKT-WF	CHNKT-WF	CHNKT-WF	CHNKT-W	Laterite
9–10	Laterite	BG-F	Laterite	WR	Laterite	CHNKT-WF	CHNKT-WF	CHNKT-WF	CHNKT-W	Laterite
10–11	Clay	BG-F	Clay	WR	Laterite	CHNKT-WF	CHNKT-WF	CHNKT-WF	CHNKT-W	Laterite
11–12	Clay	BG-F	Clay	WR	Laterite	CHNKT-WF	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
12–13	Clay	BG-F	Clay	BG	Laterite	CHNKT-WF	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
13–14	Clay	BG-F	Clay	BG	Laterite	CHNKT-WF	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
14–15	CHNKT	BG-F	WR	BG	Laterite	BG-F	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
15–16	CHNKT-F	BG-F	BG-F	BG	Laterite	BG-F	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
16–17	CHNKT-F	BG-F	BG-F	BG	Clay	BG-F	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
17 - 18	CHNKT-F	BG-F	BG-F	BG	Clay	BG-F	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
18 - 19	CHNKT-F	BG-F	BG-F	BG	Clay	BG-F	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
19 - 20	CHNKT-F	BG-F	BG-F	BG	Clay	BG-F	CHNKT-WF	CHNKT-WF	CHNKT-W	CHNKT-W
20 - 21	CHNKT-F	BG-F	BG-F	BG	Clay	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
21 - 22	CHNKT-F	BG-F	BG-F	BG	WR	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
22 - 23	CHNKT-F	BG-F	BG-F	BG	WR	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
23 - 24	CHNKT-F	BG-F	BG-F	BG	CHNKT	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
24 - 25	CHNKT-F	BG-F	BG-F	BG	CHNKT	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
25 - 26	CHNKT-F	BG-F	BG-F	BG	CHNKT	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
26 - 27	CHNKT-F	BG-F	BG-F	BG	CHNKT	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
27 - 28	CHNKT-F	BG-F	BG-F	BG	CHNKT	BG-F	CHNKT-WF	CHNKT	CHNKT-W	CHNKT-F
28 - 29	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNKT-WF	CHNKT	CHNKT	CHNKT-F
29 - 30	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNKT-WF	CHNKT	CHNKT	CHNKT-F
30 - 31	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
31 - 32	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
32 - 33	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
33 - 34	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
34 - 35	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
35 - 36	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
36 - 37	CHNKT-F	BG	BG-F	BG-F	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
37 - 38	CHNKT-F	BG	BG-F	BG-F	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
38 - 39	CHNKT-F	BG	BG-F	BG-F	CHNKT	BG-F	CHNK	CHNKT	CHNKT-F	CHNKT-F
39 - 40	CHNKT-F	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT-F	CHNKT-F

Appendix

S No	21	22	23	24	25	26	27	28	29	30
40 - 45	BG	BG	BG-F	BG	CHNKT	BG-F	CHNK	CHNKT	CHNKT	CHNKT-F
45 - 50	BG	BG	BG-F	BG	CHNKT	CHNK	CHNK	CHNKT	CHNKT	CHNKT-F
50 - 55	BG	BG	BG-F	BG	CHNKT-F	CHNK	CHNK	CHNKT	CHNKT	CHNKT-F
55 - 60	BG	BG-F	BG-F	BG	CHNKT-F	CHNK-F	PGMT	CHNKT	CHNKT-F	CHNKT-F
60 - 65	BG	BG-F	BG-F		CHNKT-F	CHNK-F	PGMT	CHNKT	CHNKT-F	CHNKT-F
65 - 70	BG	BG	BG-F		CHNKT-F	CHNK-F	PGMT	CHNKT	CHNKT-F	CHNKT-F
70 - 75	CHNKT-F				CHNKT-F	CHNK	PGMT	CHNKT	CHNKT-F	CHNKT-F
75 - 80					CHNKT-F	CHNK	PGMT	CHNKT	CHNKT-F	CHNKT-F
80 -85					CHNKT-F	CHNK-F	PGMT	CHNKT	CHNKT-F	CHNKT-F
85 - 90					CHNKT-F	CHNK-F	CHNKT	CHNKT	CHNKT-F	CHNKT-F
95 - 100					CHNKT-F	CHNK-F	PGMT	CHNKT	CHNKT-F	CHNKT-F
100-125					CHNKT-F	CHNK-F	CHNKT-F	CHNKT	CHNKT-F	CHNKT-F
125-150					CHNKT-F		CHNKT-F	CHNKT	CHNKT-F	CHNKT-F
150-175					CHNKT-F		CHNKT-F	CHNKT-F	CHNKT-F	
175-200					CHNKT-F		CHNKT-F	CHNKT-F	CHNKT-F	
200-225								CHNKT-F	CHNKT-F	
225-250								CHNKT	CHNKT-F	
250-275								CHNKT	CHNKT-F	
275-300								CHNKT	CHNKT-F	

CHNKT: Charnockite, **CHNKT-W**: Charnockite weatherd, **CHNKT-F**:Charnockite fractured, **WR**: Weathered rock

CHNKT-WF: Charnockite weatherd and fractured, **BG**: Biotite gneiss, **BG-F**: Biotite gneiss fractured

Appendix

Table 6.1 Details of litholog in various places of Palaeo-lagoon (Koleland basin)										
Sl. No.	31	32	33	34	35	36	37	38	39	40
Depth BGL (m)	Nattika	Edakazhiyoor	Maruthiyoor	Vattekkad	Anjangadi-Kadappuram	Kaipamangalam	Guruvayur	Mathilakam (Emmad)	Vatanapilli east	Vatanapilli west
0-0.5	L-sand	L-sand	Loam	L-sand	L-sand	L-sand	Loam	L-sand	L-sand	L-sand
0.5-1	L-sand	L-sand	L-sand	L-sand	Sand-F	L-sand	L-sand	L-sand	L-sand	L-sand
1-1.5	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	L-sand	Sand-F
1.5-2	Sand-M	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-M
2-2.5	Sand-M	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-M
2.5-3	Sand-M	Sand-F	Sand-F	Sand-F	Sand-M	Sand-F	Sand-F	Sand-F	SC	Sand-M
3-3.5	Sand-M	Sand-M	Sand-M	Sand-M	Sand-M	Sand-MS	Sand-M	Sand-MS	SC	Sand-M
3.5-4	Sand-M	Sand-M	Sand-M	Sand-M	Sand-M	Sand-MS	Sand-M	Sand-MS	SC	Sand-M
4-4.5	Sand-M	Sand-M	Sand-M	Sand-M	Sand-C	Sand-MS	Sand-M	Sand-MS	GB clay-s	Sand-M
4.5-5	Sand-F	Sand-C	Sand-C	Sand-C	Sand-C	Sand-FS	Sand-C	Sand-FS	GB clay-s	Sand-F
5-5.5	Sand-FS	Sand-C	Sand-C	Sand-C	Sand-FS	Sand-FS	Sand-C	Sand-FS	GB clay	Sand-FS
5.5-6	Sand-FS	Sand-F	Sand-FS	Sand-F	Sand-F	Sand-F	Sand-FS	Sand-F	GB clay	Sand-FS
6-6.5	Sand-FS	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	Sand-F	GB clay	Sand-FS
6.5-7	Sand-FS	Sand-MS	Sand-F	Sand-MS	Sand-F	Sand-FS	Sand-F	Sand-FS	GB clay	Sand-FS
7-7.5	Sand-C	Sand-F	Sand-F	GB clay-S	Sand-F	Sand-FS	Sand-F	Sand-FS	GB clay	Sand-C
7.5-8	SC-S	Sand-F	CS	GB clay-S	Sand-F	SC	Sand-F	SC	GB clay	SC-S
8-8.5	SC-L	Sand-CS	GB clay-S	GB clay-S	Sand-F	GB clay	GB clay-S	GB clay	GB clay-P	GB clay
8.5-9	Sand-C	Sand-CS	GB clay-S	GB clay-S	Sand-F	GB clay	GB clay-S	GB clay	GB clay-P	GB clay
9-9.5	Sand-C	Sand-CS	GB clay-S	GB clay-S	Sand-F	GB clay	GB clay-S	GB clay	GB clay	GB clay
9.5-10	Sand-C	Sand-CS	GB clay-S	GB clay-S	Sand-F	GB clay	GB clay-S	GB clay	GB clay	GB clay
10-10.5	Sand-C	Sand-CS	GB clay-S	GB clay-S	Sand-F	GB clay	GB clay-S	GB clay	GB clay	GB clay
10.5-11.	Sand-C	Sand-CL	GB clay-S	GB clay-S	Sand-F	GB clay	GB clay-S	GB clay	GB clay-P	GB clay
11-11.5	SC	Sand-CL	GB clay-S	GB clay-S	SC	GB clay	GB clay-S	GB clay	GB clay	GB clay
11.5-12	SC	Sand-CL	GB clay-S	GB clay-S	SC	GB clay	GB clay-S	GB clay	GB clay	GB clay
12-12.5	SC	Sand-CL	GB clay-S	GB clay-S	SC	GB clay	GB clay-S	GB clay	GB clay-P	GB clay
12.5-13	SC	Sand-CL	GB clay-S	GB clay-S	SC	Laterite-H	GB clay-S	Laterite-H	GB clay-P	GB clay
13-13.5	SC	Sand-C	GB clay-S	GB clay-S	SC	Clay-LM	GB clay-S	Clay-LM	GB clay-P	GB clay
13.5-14	SC	Sand-C	GB clay-S	GB clay-S	SC	Clay-LM	GB clay-S	Clay-LM	GB clay-P	GB clay
14-14.5	SC	Sand-C	GB clay-S	GB clay-S	SC	Clay-LM	GB clay-S	Clay-LM	GB clay	GB clay
14.5-15	SC	Sand-C	GB clay-S	GB clay-S	SC	Clay-LM	GB clay-S	Clay-LM	GB clay	GB clay
15-15.5	SC	Sand-C	GB clay	GB clay-S	SC	Peat	GB clay	Peat	GB clay	GB clay
15.5-16	SC	Sand-C	GB clay	GB clay-S	SC	Peat	GB clay	Peat		
16-16.5	SC	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Clay-B		
16.5-17	SC	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Clay-B		
17-17.5	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Peat		
17.5-18	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Peat		
18-18.5	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Sand-C		
18.5-19	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Sand-C		
19-19.5	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Sand-C		
19.5-20	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Sand-C		
20-20.5	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Sand-C		
20.5-21	Sand-C	Sand-C	GB clay	GB clay-P	SC	Sand-C	GB clay	Sand-C		
21-21.5	GB clay	Sand-C	GB clay	GB clay-P	Gravel	Sand-C	GB clay	Sand-C		
21.5-22	GB clay	Sand-C	GB clay	GB clay-P	Gravel	Sand-C	GB clay	Sand-C		
22-22.5	GB clay	Sand-C	GB clay	GB clay-P	Gravel	Sand-C	GB clay	Sand-C		
22.5-23	GB clay	Sand-C	GB clay	GB clay-P	Gravel	Sand-C	GB clay	Sand-C		
23-23.5	GB clay	Sand-C	GB clay-SL	GB clay-P	Gravel	Sand-C	GB clay-SL	Sand-C		
23.5-24	GB clay	Sand-C	GB clay-SL	GB clay-P	Gravel	Sand-C	GB clay-SL	Sand-C		
24-24.5	GB clay	Sand-C	GB clay	GB clay-P	Gravel	Sand-C	GB clay	Sand-C		
24.5-25	GB clay	Sand-C	GB clay	GB clay-P	Gravel	Sand-C	GB clay	Sand-C		
25-25.5	GB clay	GB clay	GB clay	GB clay-P	Gravel	Sand-C	GB clay	Sand-C		
25.5-26	GB clay	GB clay	GB clay	GB clay-S	Gravel	Sand-C	GB clay	Sand-C		

Appendix

S.No	31	32	33	34	35	36	37	38
26-26.5	GB clay	GB clay	GB clay	GB clay-S	Gravel	Sand-C	GB clay	Sand-C
26.5-27	GB clay	GB clay	GB clay	GB clay-S	Gravel	Sand-C	GB clay	Sand-C
27-27.5	GB clay	GB clay	GB clay	GB clay-S	Clay-G	Sand-C	GB clay	Sand-C
27.5-28	GB clay	GB clay	GB clay	GB clay-S	Clay-G	Sand-C	GB clay	Sand-C
28-28.5	GB clay	GB clay	GB clay	GB clay-S	Clay-G	Sand-C	GB clay	Sand-C
28.5-29	GB clay	GB clay	GB clay	GB clay-S	Clay-G	Sand-C	GB clay	Sand-C
29-29.5	Gravel	SC	GB clay	GB clay-S	Clay-G	Sand-C	GB clay	Sand-C
29.5-30	Gravel	SC	GB clay	GB clay-S	Clay-G	Sand-C	GB clay	Sand-C
30-31	Gravel	SC	Gravel	GB clay-S	Clay-G	Sand-C	Gravel	GB clay
31-32	Gravel	SC	WR	GB clay-S	Clay-G	Sand-C	WR	GB clay
32-33	Gravel	GB clay	BG	GB clay-S	Clay-G	Sand-C	BG	GB clay
33-34	Gravel	GB clay		GB clay-S	Clay-G	Sand-C		GB clay
34-35	Gravel	GB clay		GB clay-S	Clay-G	Sand-C		GB clay
35-37	Gravel	GB clay		Gravel	Clay-G	GB clay		GB clay
37-39	Gravel	GB clay		WR	Clay-G	GB clay		GB clay
39-41	Gravel	GB clay		BG	Clay-G	GB clay		GB clay
41-43	Gravel	GB clay		BG	Gravel	GB clay		GB clay
43-45	Gravel	Gravel			Gravel	GB clay		GB clay
45-47	Gravel	Gravel			Gravel	GB clay		GB clay
47-49	Gravel	Gravel			Gravel	Gravel		Gravel
49-51	Gravel	Gravel			Gravel	Gravel		Gravel
51-53	Gravel	Gravel			Gravel	Gravel		Gravel
53-55	Gravel	Gravel			Gravel	Gravel		Gravel
55-57	Gravel	Gravel			Gravel	Gravel		Gravel
57-59	Gravel	Gravel			Gravel	Gravel		Gravel
59-61	Gravel	Gravel			Gravel	Gravel		Gravel
61-63	Gravel	Gravel			Clay-G	GB clay		SC
63-65	Gravel	Gravel			Clay-G	GB clay		SC
65-67	GB clay	Gravel			Clay-G	GB clay		SC
67-69	GB clay	GB clay			Clay-G	GB clay		SC
69-71	GB clay	WR			Gravel	WR		SC
71-73	WR	BG			Gravel	BG		SC
73-75	BG	BG			Gravel	BG		SC
75-77	BG				Gravel			WR
77-79					Gravel			BG
79-81					Gravel			
81-83					WR/BG			

Appendix

Table 6.1 Details of litholog collected from various places of Palaeo- lagoon (Kole land basin)										
Sl. No.	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
Depth BGL (m)	Kanjani	Vatanapalli	Irimbranellur	Venkitangu	Kandasamkadavu	Manaloor	Pokulangara	Engadiyoor	Chavakkad	Pulavaya
0-0.5	L-Sand	L-Sand	Clay-B	L-Sand	L-sand	L-Sand	L-Sand	CS	L-sand	L-Sand
0.5-1	Clay	CS	Clay-B	L-sand	Sand-F	L-Sand	sand-F	Sand-F	L-sand	Sand-F
1-1.5	Clay	Sand-F	Clay-B	L-sand	SC-L	SC	sand-F	Sand-F	Sand-F	Clay-B
1.5-2	Clay	Sand-M	Clay-B	SC	SC	SC	sand-F	Sand-F	Sand-F	Clay-B
2-2.5	Clay	Sand-M	Clay-G	SC-L	SC	SC-L	sand-F	Sand-F	CS	Clay-B
2.5-3	Clay	CS	Clay-G	Sand-C	SC	SC	sand-F	Sand-M	CS	Clay-B
3-3.5	CS	CS	Clay-G	SC	SC	SC	sand-F	Sand-M	Sand-M	Clay-B
3.5-4	CS	Sand-F		SC	SC	SC	sand-F	Sand-M	Sand-M	Clay-B
4-4.5	Sand-M	Sand-F		GB clay	Clay	GB clay-S	sand-F	Sand-C	Sand-M	Clay-P
4.5-5	Sand-M	Sand-F		GB clay	CS	GB clay-S	sand-F	Sand-C	Sand-C	Sand-FS
5-5.5	Sand-F	Sand-F		GB clay	Sand-F	GB clay-S	sand-F	Sand-FS	Sand-C	GB clay
5.5-6	Gravel-L	Sand-F		GB clay	Sand-F	GB clay-S	CS	Sand-F	Sand-F	GB clay
6-6.5	Gravel-P	Clay		GB clay	GB clay-S	GB clay-S	GB clay	Sand-F	Sand-F	
6.5-7	SC	Sand-F		GB clay	GB clay	GB clay-S	GB clay	CS	Sand-MS	
7-7.5	GB clay-s	Sand-F		GB clay	GB clay	GB clay-S	GB clay	CS	Sand-F	
7.5-8	GB clay-s	Sand-F		GB clay		GB clay-S	GB clay	CS	Sand-F	
8-8.5	GB clay	CS-S		GB clay		GB clay-S	GB clay	GB clay	Sand-CS	
8.5-9	GB clay	GB clay		GB clay		GB clay-S		GB clay	Sand-CS	
9-9.5	GB clay	GB clay		GB clay		GB clay-S				
9.5-10	GB clay	GB clay		GB clay		GB clay-S				
10-10.5	GB clay	GB clay		GB clay		GB clay-S				
10.5-11.	GB clay	GB clay		GB clay		SC				
11-11.5	GB clay-P	GB clay		GB clay		Laterite-H				
11.5-12	GB clay-P	GB clay		GB clay						
12-12.5	GB clay			GB clay						
12.5-13	GB clay			GB clay						
13-13.5	GB clay			GB clay						
13.5-14	GB clay-P			GB clay						
14-14.5	GB clay			GB clay-S						
14.5-15	GB clay			GB clay-S						
15-15.5	GB clay-P			GB clay						
15.5-16	GB clay-P			GB clay						
16-16.5	GB clay-P			GB clay						
16.5-17	GB clay-P			GB clay						
17-17.5	GB clay			Laterite-H						
17.5-18	GB clay			Laterite-H						
18-18.5	GB clay									

GB clay: Greenish black clay, **GB clay-P**: Greenish black clay with peat, **GB clay-S**: Greenish black clay with shells
Laterite-H: laterite hard, **L- sand**: Loamy sand, **Sand-F**:Fine sand, **Sand-M**: Medium sand, **Sand-C**: Coarse sand
Sand-CS:Coarse sand with shells, **Sand-FS**: fine sand with shells, **CS**: Clayey sand, **SC**: Sandy clay, **Clay-B**:Black clay
Clay-G: Clay grey coloured, **Gravel-L**:Gravel with laterite pebbles, **Gravel-P**: Gravel with peat.

Table 6.1 Details of litholog collected from various places of Palaeo-lagoon

Sl. No.	51	52	53	54	55	56	57
Depth BGL (m)	Edathiruthi	Edamuttom west	Kattoor	Alappad	Eravu	Cheloor	Thottippal
0-0.5	L-sand	L-sand	Clay	Clay	Clay-B	L-sand	Clay
0.5-1	Sand-F	Sand-F	Clay	Clay	Clay-P	Clay	Clay
1-1.5	CS	Sand-F	Clay-S	Clay-S	SC	Clay	Clay
1.5-2	SC	Sand-F	Clay-S	Clay-S	Laterite-H	Clay	Clay-S
2-2.5	SC	Sand-F	Clay	Clay		Clay	Clay-S
2.5-3	SC	Sand-F	Clay	Clay		Clay	Clay
3-3.5	SC	Sand-F	Sand-M	Sand-M		Clay	Sand-M
3.5-4	CS	Sand-F	Sand-M	Sand-M		Clay	Sand-M
4-4.5	Sand-C	Sand-F	Sand-M	Sand-M		GB clay	Sand-M
4.5-5	Sand-C	Sand-F	GB clay	Clay-P		GB clay	Clay-P
5-5.5	Sand-M	Sand-F	GB clay	Clay-P		GB clay	Clay-P
5.5-6	Sand-C	Sand-F	GB clay	Clay-P		GB clay	Clay-P
6-6.5	Sand-C	SC-S	GB clay	Clay-P		GB clay	Clay-P
6.5-7	Sand-M	Sand-FS	GB clay	Clay-P		GB clay	Clay-P
7-7.5	Sand-M	Sand-FS	GB clay	Laterite-H		GB clay-S	Clay-P
7.5-8	Sand-M	Sand-F	GB clay-S	Laterite-H		GB clay-S	Clay-P
8-8.5			GB clay-S			GB clay	
8.5-9			GB clay			GB clay	
9-9.5			GB clay			GB clay	
9.5-10			GB clay			GB clay	
10-10.5			GB clay			GB clay	
10.5-11.			GB clay			GB clay	
11-11.5			SC			GB clay	
11.5-12			Laterite-H			GB clay	
12-12.5			Laterite-H			Laterite-H	
12.5-13						Laterite-H	