Salinity Intrusion and Seasonal Water Quality Variations in the Tidal Canals of Cochin

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by

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CERTIFICATE

This is to certify that the thesis entitled "SALINITY INTRUSION AND SEASONAL WATER QUALITY VARIATIONS IN THE TIDAL CANALS OF COCHIN" is an authentic record of the research work carried out by Mr. Alex P.M. (Reg. No. 2599) under my supervision and guidance in the School of Environmental Studies, Cochin University of Science and Technology, and that no part thereof has been presented before for the award of any degree/diploma of any University or Institute.

Cochin-22
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Abstract

Salinity Intrusion and Seasonal Water Quality Variations in the Tidal Canals of Cochin

Alex P.M.

The study was carried out during the water year 2003-2004 on the major tidal canals of Greater Cochin . It had a multi-pronged approach with the following succinct objectives.

(i) To identify salinity intrusion profile of each canal over a hydrologic year.

(ii) To spell out the seasonal and possibly cyclic water quality variation of the surface waters of the canals and to find out the Water Quality Index of the fresh water segments of the canals where salinity does not cross economically meaningful levels.

(iii) To identify the hierarchical utility of the water bodies and to identify management options to upgrade their quality and economic potentials.

(iv). To carry out salinity and nutrient budget modeling on Chithrappuzha so as to have a better understanding of the fate of non-conservative components in the water body.

Water samples were collected from sixteen selected tidal canals on a monthly basis with the sampling points fixed to be around 500 m apart. The parameters monitored were pH, temperature, alkalinity, conductivity, DO, COD, BOD, chloride, total hardness, calcium hardness, dissolved phosphate, nitrate, total iron, sulphate, turbidity, Total Coliform, and SUVA at 254 nm. A standard operating procedure (SOP) was prepared for the study. The tidal canals of Greater Cochin

were found to be creeks extending to the interior, canals inter connecting parts of the estuary or canals with seasonally broken segments. Based on utility the canals could be classified as:

1. Canals heavily polluted and very saline
2. Canals polluted by urban waste but having fresh water for some part of the year
3. Canals having fresh water for most part of the year and not much polluted and
4. Fresh water bodies heavily polluted.

During the rainy months carbon fixation by plankton is nonexistent, and during the dry months Chithrappuzha becomes a sink of phosphate. The study indicated abiotic subroutes for dissolved phosphate and revealed the potential pitfalls in LOICZ modeling exercise on sewage laden tidal canals. It was also found that all canals except for the canals of West Cochin and Chittoorpuzha have fresh water for some part of the year. The water quality index in the durable fresh water stretches was found to be of below average category. Recommendations for the .amelioration of the poor quality of water are given in the concluding chapter.

PREFACE

Greater Cochin region is a fast growing urban agglomeration on the south western Coast of India. With the population and economic activities ever on the rise, infra structural development to meet the spiraling demand will demand more concerted and intelligent environmental and technological tools. Banking on the congenial geo political climate of the world, Cochin is poised to be the nodal point of business and industrial activity with a global footing. The geographical climatic and demographic vantage points not withstanding, fresh water scarcity among many other crippling turn offs, is looming over the city. Traditionally the main water hole of Greater Cochin is the Periyar. Though the people of the interior rely on private wells the industries and the city dwellers are depending on water harnessed from this greatest river of Kerala. But the Periyar has forfeited many of its original endowments because of anthropogenic intervention by way of inter basin transfer and industrial waste insult. The Chithrappuzha-Kadambrayar system has lately become the platform for numerous economic activities and it is heavily taxed as a fresh water source by the industries. It is a major tidal arm of Cochin Estuary and regular tidal intrusion moderated by run off governs over the biogeochemical processes in the system.

Availability of fresh water is one of the key elements that decide the pace of development and the standard of living. In this context Cochin draws the flak and industrial initiatives often run into rough weather. This being the state of affaires Greater Cochin Development Authority (GCDA) has had the drive and wisdom to take the initiative to explore untried avenues of water resources. Once the salinity intrusion finger print is identified and the environmental quality of the waters quantified, the prospects of availing the tidal canal waters for lesser utilities where fastidious quality requirements are not important, become clear. Hence a comprehensive study was carried out to identify the seasonal salinity profile characteristic of each canal of reckoning, and to suggest plausible management options. Water Quality Index (WQI) for the pertinent tidal stretches was found out using recommended methodology.

The study embodied here is part of the work carried out under this project. To ensure the reliability, accountability and reproducibility, recommended activities such as planning, organization, scheduling, compilation of Standard Operating Procedures (SOP), training of supporting staff and data evaluation were done. The results presented in this dissertation qualify to be reliable according to international protocols. Since we lack standard procedural norms and guidelines, US -EPA guidelines were relied on.

The major problem with urban discharge is excessive C, N, P input into the nearby water bodies. Estuaries act as a valve mechanism and also as a buffer zone between the river and the ocean. Hence estuaries bear the brunt of urban nutrient pollution. LOICZ modeling addresses this problem and identifies the magnitude and biogeochemical behavior of the nutrients in the system. This approach quantifies the net ecosystem metabolism and determines whether the system is a sink or source of dissolved plant nutrients. LOICZ modeling was carried out for a limited stretch of Chithrappuzha creek. Chemical precipitation under the influence of salinity is a major sink for phosphate in the water body. The floating mat of fresh water vegetation stands in the way of quantifying alga dominated carbon fixation activity.

The thesis was prepared following the format and arrangement given in the Thesis Manual used by Drexel University. Their format reflects the general run of thesis structure used by in the US universities.

List of Abbreviations

AIMS	Amrita Institute of Medical Sciences
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CSEPZ	Cochin Special Economic Processing Zone
CUSAT	Cochin University of Science and Technology
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DON	Dissolved Organic Nitrate
DOP	Dissolved Organic Phosphate
ETM	Estuarine Turbidity Maximum
FACT	Fertilizers and Chemicals Travancore Limited
GCDA	Greater Cochin Development Authority
KINFRA	Kerala State Infrastructural Development Corporation
KSPCB	Kerala Pollution Control Board
KSRTC	Kerala State Road Transport Corporation
LOICZ	Land Ocean Interaction in the Coastal Zone
NEM	Net Ecosystem Metabolism
NEP	Net Ecosystem Productivity
NH 47	National High way 47
PVIP	Periyar Valley Irrigation Project
ROB	Railway Over Bridge
SOP	Standard Operating Procedure
TP	Thevara -Perandoor
WQI	Water Quality Index

Chapter I

INTRODUCTION

1.1 Fresh water as a natural resource:

The earth is a suitable habitat for organic life because of its unique environment in which water plays a vital and significant role helping to feedback conditions supportive to life. The planet should in fact be called ocean since 70% of its surface is water (Newson, 1992). Each of us depends entirely on water as the solvent and reactant for all the processes we call life. The unique properties of water derive from the structure and bonding of water molecule. Water behaves differently from H_2S, H_2Te and H_2Se owing to its hydrogen bonding. The grave realization that quality as well as quantity of fresh water decides the pace of progress and the very survival of civilization is steadily sinking into the psyche of all the nations. The broad views on the role of water and other wet environments on earth have helped move hydrology, oceanography and climatology up the scientific agenda, both in research and education. The holistic environmental approach has quickly replaced the narrower traditional ones like chemistry, biology, physics and engineering, which have dominated mankind's management of water resources. This new approach has resulted from severe shortages, pollution of existing water bodies and hence a need for restoration and conservation. With industrial development and increasing population, our need for fresh water, distilled by the global heat engine, is fast spiraling to alarming levels. **Figure - 1.1** gives a schematic representation of global hydrologic cycle. Shortages and devastating droughts have

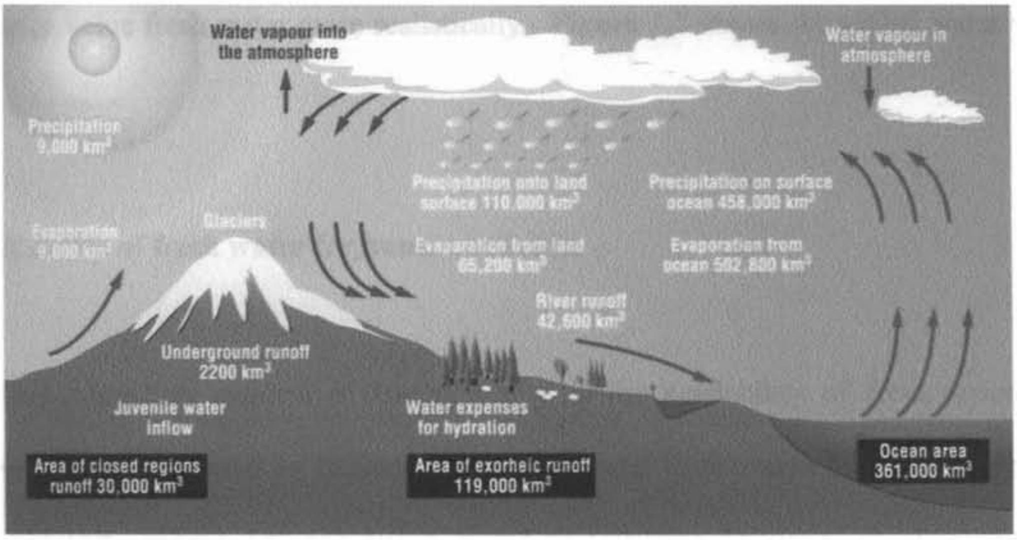

Figure1.1 Global Hydrologic Cycle

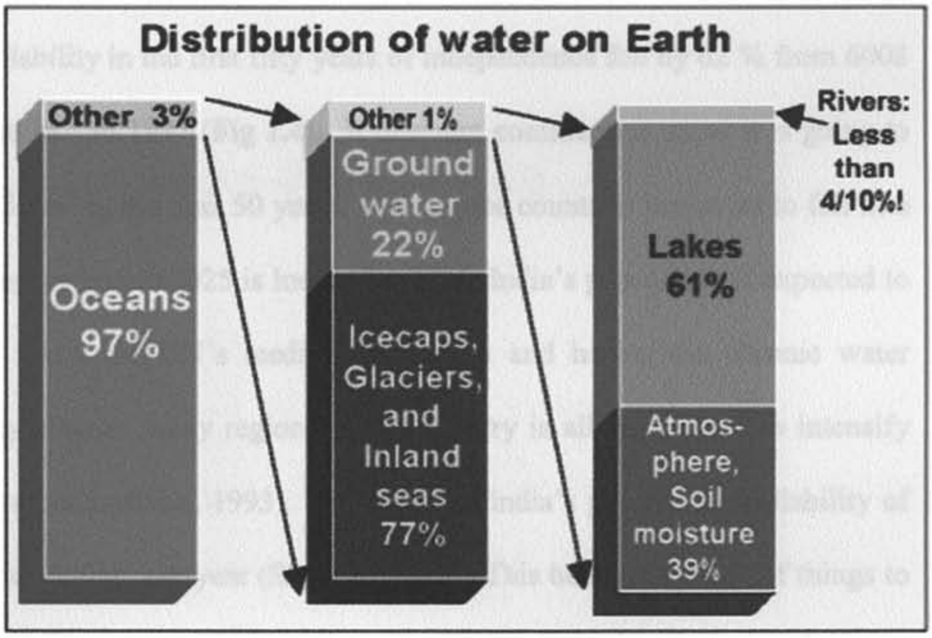

Figure 1.3 Global Distributions of Fresh Water and Salt Water

taught us to value fresh water more realistically. **Figure 1.2** shows the global water use pattern.

1.2 Availability of fresh water for human activities

The immediate concern of human beings is the availability of fresh water at terrestrial patches inhabited by humans. The fresh water distribution over our globe is uneven and quite unrelated to population spread or economic development. **Figure 1.3** depicts the distribution of water resources. Due to rapid population growth, the potential availability of water decreased from 12900 M^3 per capita per year in 1970 to 9000 M^3 in 1990 and less than 7000 M^3 in 2000. Also, it is estimated that three billion people will be in the water scarcity category of 1700 M^3 per capita per year by 2025 (UNEP, 2002). In India the water availability in the first fifty years of independence fell by 62 % from 6008 M^3 in 1947 to 2266 M^3 in 1997 (**Fig 1.4**). If business continues as usual it is going to fall from 2266 to 750 m^3 in the next 50 years. Among the countries projected to fall into the water stress category before 2025 is India. By 2025, India's population is expected to exceed 1.4 billion under the UN's medium projection and hence, the chronic water scarcity that already plagues many regions of the country is all but certain to intensify (World Water Resources Institute, 1993). By that time India's per capita availability of water will fall below 1000M^3 per year (Sharma, 2003). This being the shape of things to come it is the duty of the state and the people to preserve the physical, chemical and biological integrity of the nation's water sources. Integrity of the water body is defined as the ability of the water body's ecological system to support and maintain a balanced, integrated and adaptive community of organisms comparable to that of the natural biota of the region (Novotny,. *et al.*, 2004). Table 1.1 illustrates the global distribution of water.

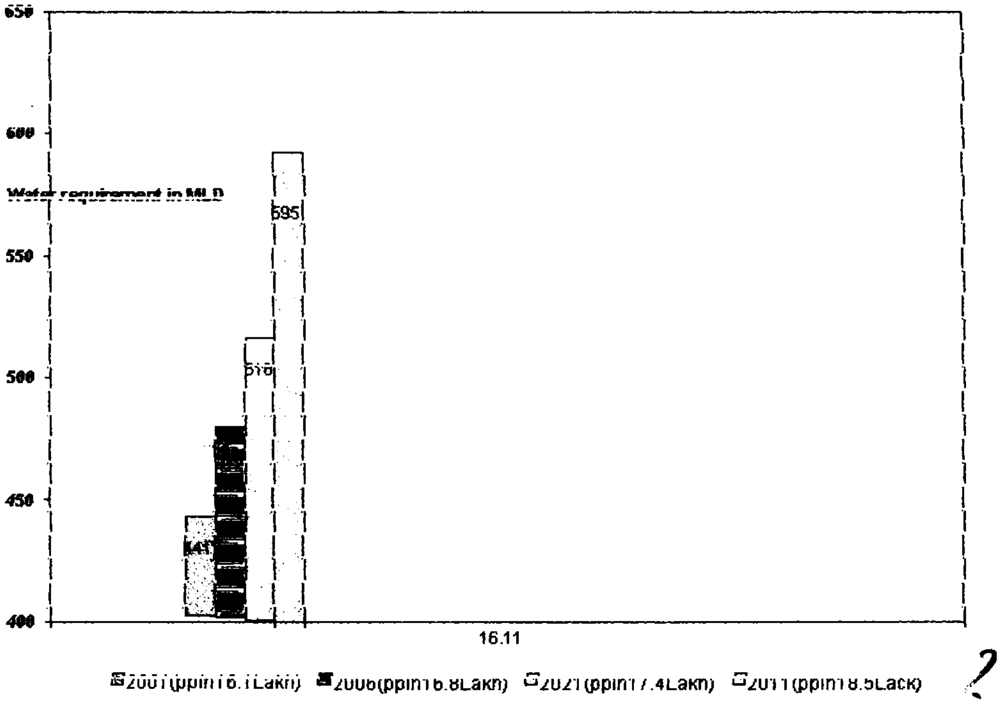

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Fig 1.9 Population and Water use pattern of Cochin

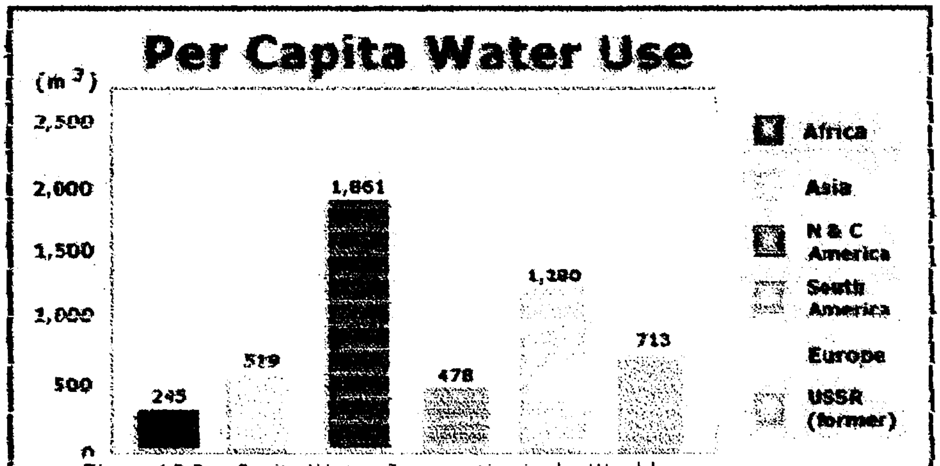

Figure 1.2 Per Capita Water Consumption in the World

Source:Belyaev V

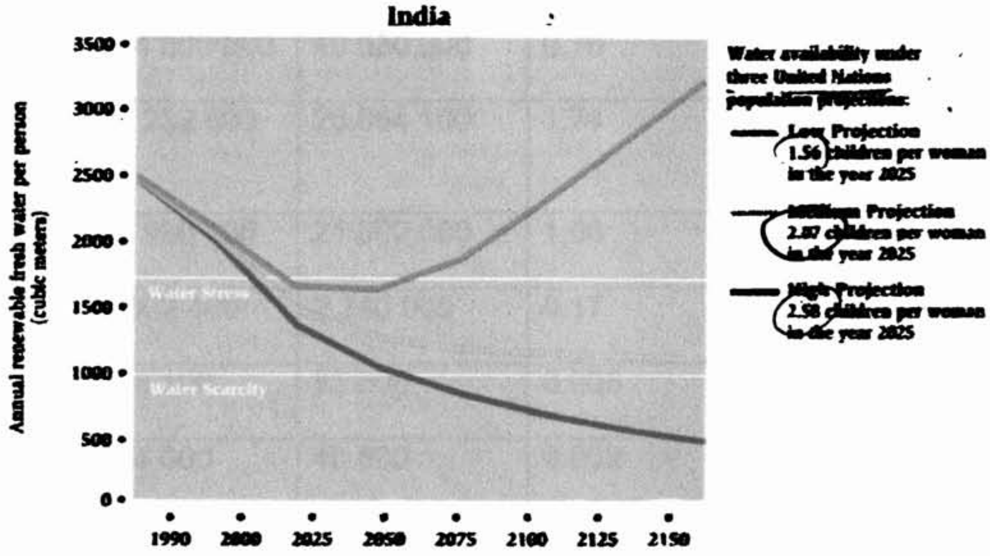

Figure 1.4 Water Availability in India under Three UN Projections

Self?

Table1.1 The Distribution of Global Water Resources

Zone of the resources	Catchment area km ^{2}	Volume of water km ^{3}	% of total resources	% of fresh water resources
Oceans	361 300 000	1 338000 000	96.5	
Land	148 800 000	47 971 710	3.5	
Ground water	134 800 000	23 400 000	1.7	
Fresh water	134 800 000	10 530 000	0.76	
Glaciers & snow	16 232 500	26 064 100	1.74	
Antarctic	13 980 000	21 600 000	1.56	
Greenland	1 802 400	2 340 000	0.17	
Arctic	226 100	83 500	0.006	
Mountains	224 000	40 600	0.003	0.12
Soil moisture	82 000 000	16 500	0.0001	0.05
Permafrost	21 000 000	300 000	0.022	0.86
Fresh water lakes	1 236 400	91 000	0.007	0.26
Salt water lakes	822 300	85 400	0.006	
Marshland	2 682 600	11 470	0.0008	0.03
Water courses	148 800 000	2 120	0.0002	0.006
Biological water	510 000 000	1 120	0.0001	0.003
Atmospheric water	510 100 000	12 900	0.001	0.04

Source: Keller (1984)

There is another 230,000,000 km^3 of water which is chemically bound to materials on the earth's mantle.(Schippers, 1991)

Table 1.2. The population and water requirement in the study area

	2001	2006	2011	2021
Population,(lakhs)	16.11 l	16.76	17.35	18.52
Water requirement(MLD)	441	478	516	595

Source: Kerala Sasthra Sahithya Parishad Project Report,2002

The hydrosphere functions as the flywheel of the global heat engine by cushioning out sharp thermal fluctuations. The fraction of fresh water actually available to terrestrial biota is precariously meager. The remarkable dissolving capacity of water makes all the aquatic ecosystems vulnerable to deleterious pollution. According to Schippers (1991), $425\text{x}10^{12}$ M^3 of water vapor enters the atmosphere per year of which $320\text{x}10^{12}$ M^3 precipitates on sea and $105\text{x}10^{12}$ M^3 precipitates on land out of which $75\text{x}10^{12}$ M^3 evaporates and $30\text{x}10^{12}$ M^3 flows back to the sea sooner or later. Hence whatever little fresh water is available gets denatured by human interventions in the form of his economic activities. Water is the medium common to all ecosystems and maintains the integrity of all the organisms that live, grow and reproduce in it. Hence, water is a crucial element of all ecosystems and its availability has governed the siting of all communities, hence the development and progress of man. Water is indispensable because:

- The existence and evolution of plant and animal ecosystems depend entirely on water
- It is an essential constituent of photosynthesis
- It establishes a means of nutrition for plants and forms the natural living condition for many living species
- It acts as a solvent of organic and inorganic materials
- It plays a role in metabolism
- It is a necessary component of body liquids

From the anthropocentric point of view, where economic matters get an upper hand, water plays a critical role. Water is the wonder chemical which finds ubiquitous application in all realms of human activity. Also, water is the main deciding factor in all his agricultural and industrial activity since:-

- It is used for irrigating agricultural sectors
- It is vital for hygienic needs and general amenity aspects
- It is used in recreational activities
- It is used for transportation of raw materials via navigational routes by ships steamers etc
- It is utilized for the production and generation of energy
- It enters the production and manufacturing of industrial products, goods and commodities
- It is used as a heat transfer medium, for cooling purposes, preparation of baths etc.,
- It is used for scrubbing of gaseous substances
- It is used in air conditioning and cooling tower operation
- It is used for the disposal of wastes.

The role played by water as a solvent, as a biological fluid and as a geological tool is enormous. The restraining factors of quantity, quality and availability decide the nature of aquatic life, terrestrial life and also the nature of man's activity. Civilizations of the distant past flourished on water and perished later because of the mismanagement of water resources. Fresh water, hitherto referred to as a free good, is fast getting too dear to be branded so. Water, in all probability, is going to be the economic pivot on which the geopolitics of the centuries to come will be centered on. In the long march of industrialization and urbanization, water often becomes the limiting factor. Enormous quantities of water will be needed to keep the cities going. Per capita water consumption is a universally accepted indicator of the degree of industrialization and living standards of the citizens of a state. Given the unique physical and chemical properties of this triatomic polar molecule, water is going to be the most important raw material that the booming industrial activities are thirsting to feed on.

There is no such thing as pure water. The distinction is more of degree. Water immediately gets polluted mainly from the following sources:

Natural sources - atmospheric and eolian dissolved materials, decay of vegetation, aquatic growths, storm run off.

Agricultural sources - increased erosion, animal wastes, fertilizers, pesticides, irrigation return flows

Waste waters - municipal sanitary sewage, industrial waste waters, municipal storm runoff, waste waters from boats and water treatment by-products

Impoundments - leaching from bottom deposits, aquatic growths

Miscellaneous sources - construction activities, mines, dumps and land fills, ground water.

The alarming projection of the shape of things to come notwithstanding, local solutions could be tried to trace out alternate and unconventional sources of water. Sustainable management of water resources envisages self reliance and local resource autonomy. The quality criterion for water is use specific. Water for uses other than drinking does not have to comply with drinking water criterion

1.2.1Rationale for choosing Greater Cochin for the study

Greater Cochin area, for one, falls in the grey area between land and ocean and the thick of the city is chronically plagued by water logging. Cochin is endowed with a fairly large estuary and an elaborate network of tidal canals. Such a complex and highly productive ecosystem is, at present, not effectively managed as a viable natural resource. At the same time ground water resources are heavily taxed to cope up with the burgeoning demand for fresh water. The municipal water supply fails miserably to meet the ever increasing demand of this fast growing city. Traditionally these canals have been used for bathing and recreation, irrigation, navigation, fishing, flushing and storm water discharge. The utility of the canals however has been impaired by the changes in land use pattern and haphazard urban growth. The present study is aimed at exploring the prospects of availing the aforesaid canals as a potential fresh water source. A typical water consumption hierarchy could be as follows

1. Domestic water supply
2. Industrial water supply

3. Commercial water supplies
4. Waste disposal
5. Irrigation

Other water uses include

1. Fishing
2. Transportation
3. Recreation and amenity

1.2.2 Fresh water scenario of core and periurban Cochin

Experts have already suggested that the Cochin Corporation should resort to dual water supply by which water of drinking quality can be supplied for the entire domestic uses and other uses like toilet flushing, gardening, washing etc water of lower quality can be supplied, (KSSP, 2002). Such a system reduces strain at the source, reduces the cost people have to pay for, and reduces investments. It has been proved that fresh water polluted with municipal waste could be of some economic use. Land disposal of waste water at some sites has been practiced in India for up to 160 years. Sewage farming as a method of waste water disposal is reported to take place at more than 200 sites (Rower, 1995). A recent survey conducted by NEERI showed that many of the environmental and public health problems at these waste water utilization sites could be attributed to over application of the untreated sewage. Hookworm, round worm, whip worm, pinworm, dwarf tape worm, *Entamoeba histolitica*, and *Giardia intestinlis* occurred from 51 to 60% more often in the farm workers than in a control group, (Rower, 1995). Experimental results show that primary treated and secondary treated waste waters are superior to untreated sewage in terms of crop yields and soil nutrient utilization efficiency and would reduce the health problems associated with utilizing raw sewage. Tentative guidelines with regard to using secondary treated and disinfected sewage indicate it is suitable for all crops with out restrictions. In arid and semi arid regions of the world waste water reuse has become a general practice. At Windhock, Namibia a full scale plant is operating where potable water is reclaimed from municipal waste water. In countries of the Middle East, Australia, USA, South Africa, Canada, Japan and Western Europe treated waste water is used for irrigation and industrial applications (Rower, 1995)

1.2.3 Urban water supply of Cochin and the burgeoning demand

The existing water supply system in Cochin encompasses an area of about 564 km^2 covering the Cochin Corporation area and the municipalities of Paravur, Aluva, Kalamassery and Thrippunithura and 27 adjoining panchayaths, serving a population of nearly 1.5 million as per 1991 census. Even though the production capacity is 240 MLD the carrying capacity of the transmission mains is only 133MLD. (KSSP, 2002)

The National Commission on Urbanization instituted in the eighties has decided that it is the benign duty of even the lowest grade municipal body to provide the following minimum facilities: 1) potable water supply 2) street lighting 3) drainage 4) surfaced roads and streets 5) sanitation conservancy and arrangements for the disposal of town wastes.(http://www.indiabusiness.nice.in/india-states/kerala/urbanp final.htm). The census of India report (2001) defines urban area as a region with more than 50,000 population, at least 75 per cent of the male working population engaged in non-agricultural pursuits and the density of population at least 400 per square kilometer.

The status report presented above depicts that the water availability is less than 90L per head per day, a value much less than that of a developed country. It may be noted that per capita demand depends on season and way of life. A realistic estimate is 360L per capita per day. According to Prof. Malin Falkenmark 100L/day (36.5 cubic meters per year) is the minimum per capita water requirement to meet one's basic domestic needs. (Falkenmark and Widestrand, 1992). In India, of the urban population 84.9% had access to clean drinking water in 1993 as compared to 69% in 1985, but rural population figure fell from 82 % in 1985 to 78.45 % in 1993 (State of India's Environment, Report No.1995EE52, 1996). When Cochin catches up with the Western industrialized democracies it will require ten times more water even if the population remains unchanged (**Figure 1.9**). This fact itself is reason enough to turn to the natural water bodies of the city. The Cochin back waters are fresh enough for at least some part of the year and the study zeros upon these water bodies. Many of the major rivers of the world finally reach the ocean through deltas, which have some of the characteristics of an estuary. In many instances the flow in these rivers is so great that the dilution of the ocean can be measured for miles out into the sea. Some plants have used the brackish waters of the tidal basins as cooling tower make up, since the water is low enough in dissolved solids to be concentrated by evaporation without severe scaling problems just as fresh waters. One example is a chemical plant on the island of Trinidad which uses water from the bay side of the island as cooling tower make up (NALCO, 1979)

1.3 Estuary and the urban situation

An estuary is a semi enclosed coastal body of water which has a free connection with the open sea and within which the sea water is measurably diluted with fresh water derived from inland drainage (Pritchard, 1967). Estuaries generally, are located between fresh water ecosystems and coastal shelf systems, are relatively shallow and are particle rich (Cloern, 1996). Many estuaries are naturally nutrient rich because of inputs from land surface and biological processes that act as filters to retain nutrients within estuaries (Kennedy, 1984). Estuaries are particle rich relative coastal systems and have physical mechanisms that tend to retain particles. These suspended particles mediate a number of activities (e.g., absorbing and scattering of light, or absorbing hydroscopic materials such as phosphate and toxic contaminants). New particles enter with the river flow and may be resuspended from the bottom by tidal currents and wind – wave activity (www.epa.gov/ost/standards/nutrients/marine/chapter.2.pdf). The zone where land and sea meet is composed of a variety of complex environments. The coastal areas of the world contain a large percentage of its population and are therefore of extreme economic importance. Industrial residential and recreational developments, as well as large urban complexes occupy much of the coastal region. Certainly future urban expansion in the developing countries will be concentrated on coastal areas. Coastal and marine environments are particularly vulnerable to over exploitation because they include areas where a diversity of incompatible activities are confined to minorities, while costs are imposed on the environment.

The concerns relating to all coastal environments can be generalized as follows:

- Declining marine and coastal water / sediment quality, particularly as a result of inappropriate catchment land use practices.
- Loss of marine and coastal habitat
- Unsustainable use of marine and coastal resources

- Lack of marine resource policy and lack of long term research and monitoring of the marine environment
- Lack of strategic integrated planning in the marine and coastal environments (Zann, 1995).

The estuary, where the flow of the river meets the flood of the tide, is a unique and important part of the aquatic environment. It forms the transition zone between the inland world of fresh water and the sea water lying off shore. It retains some characteristics of both fresh water and the marine environment but it also has unique properties of its own. As an ecosystem, the estuary performs several vital functions. Many marine organisms spend at least some part their life in an estuary, hence an estuary is often referred to as the cradle of the sea (Zann, 1995)

The estuary, where the flow of the river meets the flood of the tide, is a unique and important part of the aquatic environment. It forms the transition zone between the inland world of fresh water and the sea water lying offshore. It retains some characteristics of both fresh water and marine environment but it also has unique properties of its own. As an ecosystem, estuary performs several vital functions. Coastal areas, including estuaries and upwelling regions, account for only 10% of the ocean by area but at least 25% of the ocean's primary productivity and upwards of 95% of the world's estimated fishery yield (Walsh, 1988).

Conditions in the estuary are more variable than those in either fresh water or marine environment. The variation is primarily in the salinity of the water which varies with the degree of mixing and the river discharge. Hence estuarine characteristics suffer

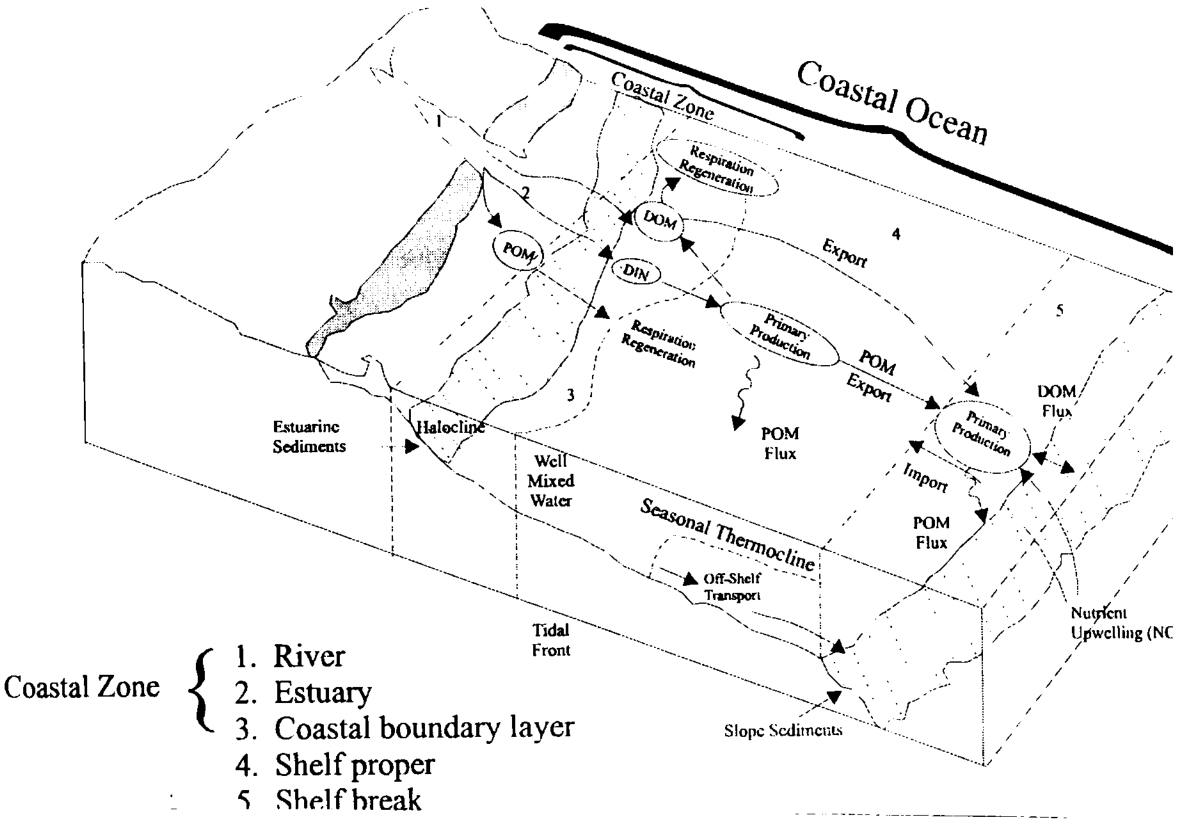

Figure 1.5 Idealized scheme defining the coastal ocean and the coastal zone, with some key biochemical fluxes linking land and sea and pelagic and benthic processes. Source: Alongi(1998)

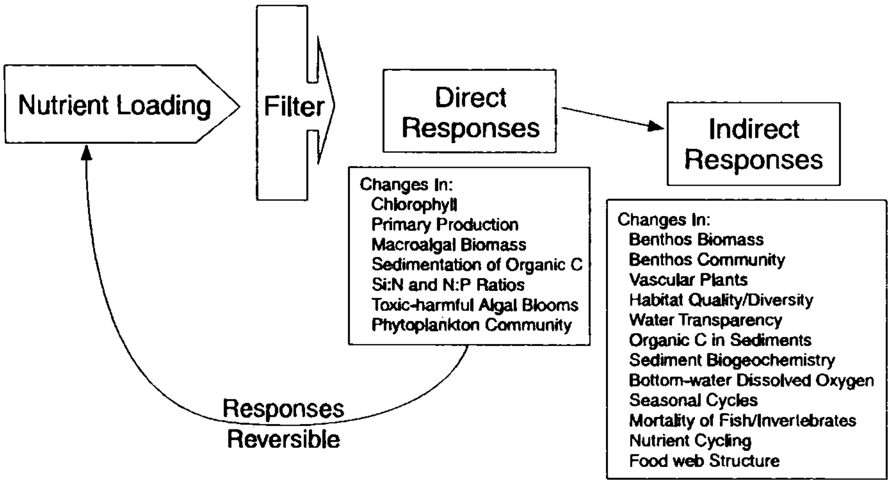

Figure 1.6 Schematic representation of the contemporary conceptual model of coastal eutrophication. Source: Cloern(2001)

temporal and lateral variation. Temporal variation includes hourly daily and seasonal changes as a result of tide wind and weather making the system a thoroughly dynamic one. If mixing is not effective stratification occurs and a vertical salinity gradient develops. Estuaries and similar marginal marine environments are the principal places where the two major types of earth –surface water meet: fresh land derived water and the saline ocean water. A schematic of estuarine processes is shown in **figure 1.5.** Suspended matter which is chemically equilibrated with fresh water is carried by rivers and, upon subjection to a series of changing salinities and pH changes within the estuary, undergoes chemical reactions. This often causes precipitation of the suspended matter by flocculation and / or aggregation. Additionally there are chemical changes between the suspended sediment and the estuarine water that change the chemistry of both. Besides the mixing of fresh and saline water in the estuaries, there are internal processes within the estuary itself that can change the chemical composition of the water (Berner, 1987). Exchange of both dissolved and particulate matter occurs between the sediments of the bottom of the estuary and overlying water. In addition, considerable biological activity occurs in the estuarine water in the surrounding tidal marshes and in the bottom sediments. Nutrients are cycled biologically within the estuary (C,N,P,Si) and as a result dissolved and particulate organic matter are both produced and consumed. Man causes changes in estuaries both in the amount and type of suspended sediment and of dissolved material reaching the estuaries through the rivers and land run off from surrounding urban and rural areas. Nutrients are particularly affected by pollution, and estuaries, because they retain water for appreciably long periods, can become eutrophic. A schematic of coastal eutrophication process is shown in **figure 1.6.** There is also concern about trapping of anthropogenic trace metals in estuaries.

Salinity intrusion is the most significant factor in the bio-chemical processes and ecological patterns in the coastal aquatic environment. The migration of salinity happens in the midst of a continuous tussle between run off and tidal push. To a lesser degree, density gradient, frontal eddies, wind surges, Coriolis force and turbulent mixing influence the conservative cycle of the migration of salinity (Zann, 1995). As long as the discharge momentum of fresh water is sufficient to keep sea water at a bay the tidal canal remains fresh. And the ubiquitous tidal bulges, instead of pushing the saline water upstream, spends itself in bulking. When precipitation grows thin and run off slackens a tongue of saline water moves upstream with the active and intermittent support of tides. Strong tidal forces push salinity upriver beneath the out flowing river water. The turbulence caused by these tidal forcing results in resuspension of sediments and other particulate material present on the river bed. Concurrently dissolved material in the river water flocculates when it comes into contact with salt wedge. The combination of these two processes results in elevated levels of suspended particulate matter- the estuarine turbidity maximum (ETM). Within the region of the ETM material in the water column and in bed of the estuary, is trapped, resuspended and advected. The strength and distance of ETM depend on tidal phase and river discharge. But the chemistry of the water column alone is not responsible for cases of algal bloom especially in the case of shallow water embayments. Diffusion, resuspension, macrophyte translocation and the regular migration between the water column and the sediments can result in significant transfer of nutrients from the sediments to the water column. The tidal dynamism imparts a time variable mixing through frictional interaction with bottom and overlying fresh water flows and a spatially asymmetric flow pattern through interaction with bottom topography, resulting in a residual circulation pattern of small magnitude but great persistence, patterns that play a significant role in the transport of pollutants. (Martin and McCutcheon, 1999)

The tide dominated estuaries are distinguished by at least three important characteristics:

1. Mixing by tidal activity obliterates vertical density stratification so that the effects of buoyancy at the river mouths are negligible
2. For at least part of the year tides account for a greater fraction of the sediment transporting energy than the river and cause a bidirectional sediment transport.
3. The range of positions of the land sea interface and the zone of marine–riverine interventions is extended both vertically and horizontally.

The dissolved constituents of estuarine water can be divided into two groups (Liss, 1976)

1. Those which are abundant in sea water than in fresh water. (e.g., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl-, and $SO4^{2-}$)
2. Those which are abundant in fresh water than in sea water. (e.g., Fe^{3+}, Al^{3+}, P, N, Si and dissolved organic matter.).

Since the elements in sea water maintain a constant concentration ratio, the dissolved constituents that have a higher concentration in river than in sea water must be removed either in the estuaries or later in the oceans (Mackenzie and Garrels, 1966). Thus, there is a reason to suspect that removal of elements such as Fe and Al might occur in the estuaries.

The elements are removed in the estuaries predominantly by biogenic or non biogenic processes. Removal of some elements such as Si, P and C may occur by both processes.

The inorganic removal of iron in estuaries is well documented and generally agreed upon. (Liss 1976; Aston 1978). Most of the iron removal occurs by the time the salinity

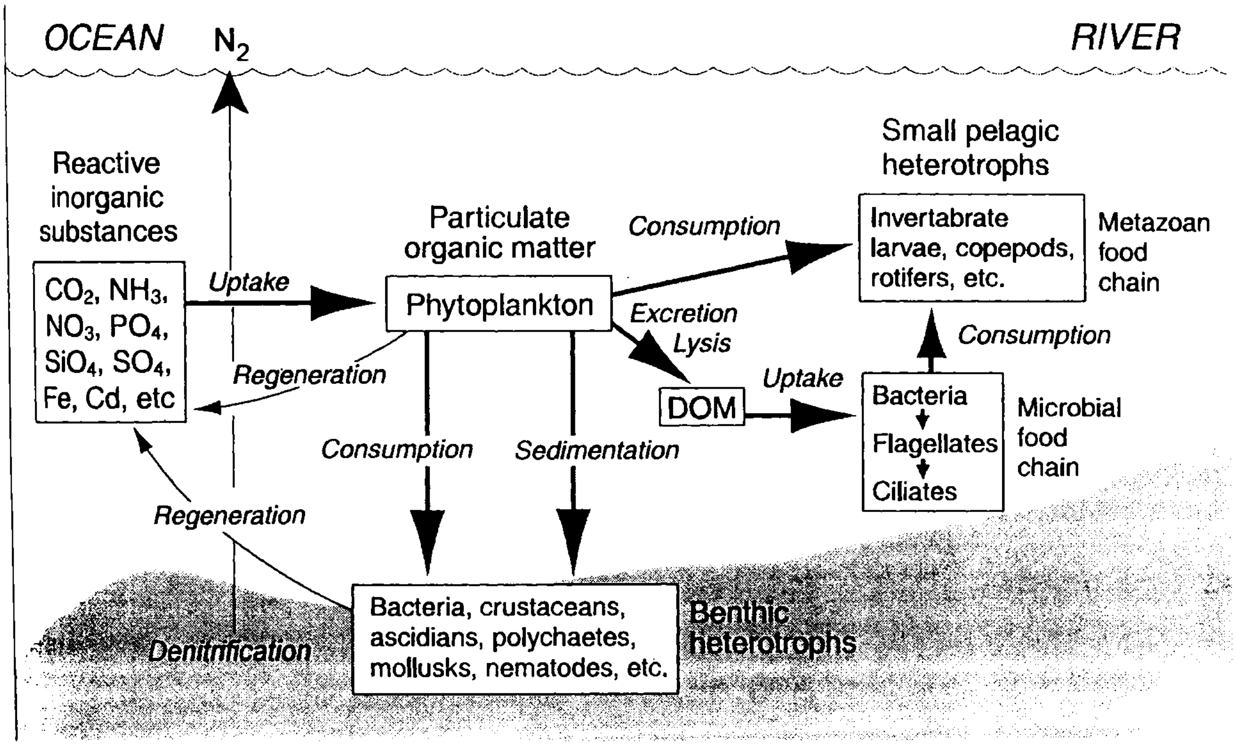

Figure 1.7 Schematic illustrating the central role of phytoplankton as agents of biogeochemical change in shallow coastal ecosystems. Source: Cloern(1996)

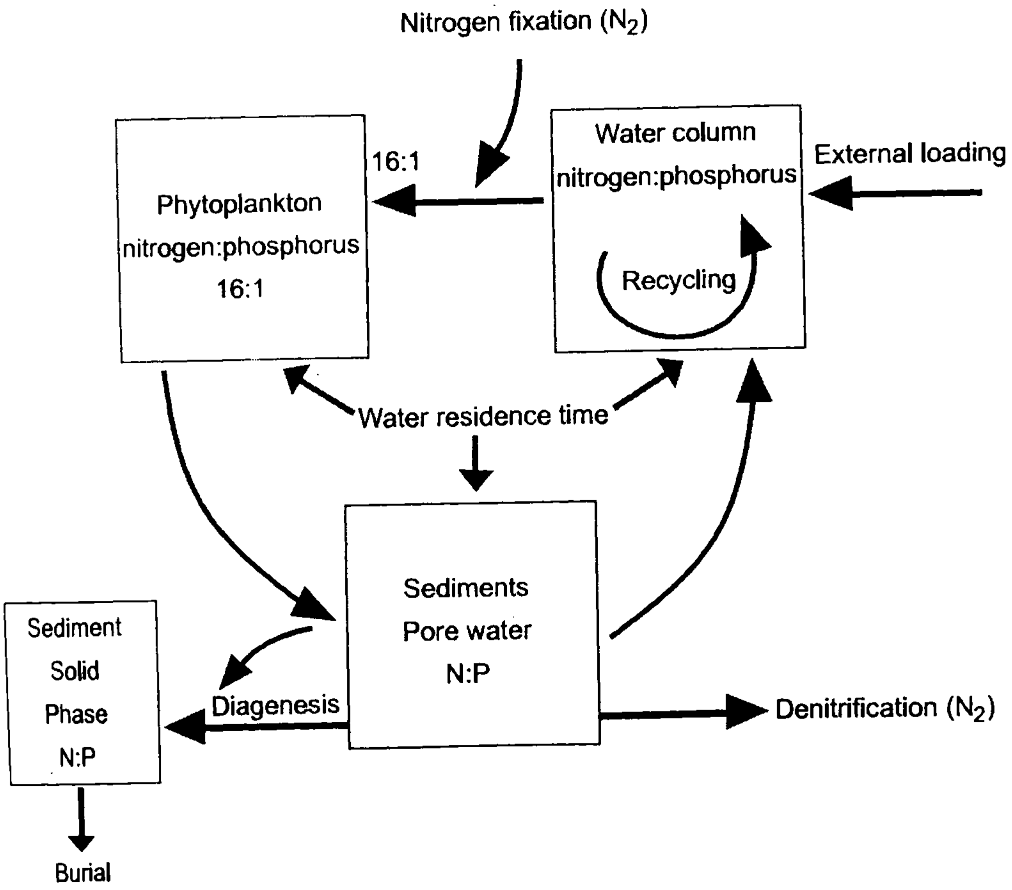

Figure 1.8 Factors that determine whether nitrogen or phosphorus is more limiting in aquatic ecosystems, where one of these macro nutrient sis limiting to net primary production. Source: NRC (2000)

reaches 15 g/kg. Work by Boyle, Edmond & Sholkovitz (1977) suggests that for iron removal the pH change is less important than the mixing of sea water electrolytes with fresh water. The marine cations Ca^{++}, Mg^{++} and Na^{+} neutralize the negative charge of river borne substances and cause flocculation and coagulation. Sholkovitz (1976) in laboratory experiments found that the solubility of the inorganic constituents in river water and their flocculation in sea water are due to their association with organic matter. The mechanism suggested is the flocculation of mixed iron oxide –organic matter colloids due to the neutralization by sea water cations of the negative colloid charges.

Several recent review papers (Downing 1997, Smith 1998, Smith *et al.* 1999, Conley 2000 & the NRC, 2000) concluded that the major nutrients causing over-enrichment problems in estuaries are N and P. A schematic of phytoplankton and nutrient circulation is shown in **figure 1.7.** P limits primary production in some tropical near shore habitats, although the study of these systems is limited (Howarth *et al.,* 1995). Often the addition of both N and P will elicit greater phytoplankton biomass stimulation than the sum of both nutrients added separately (Fisher *et al.*, 1992). There are reported cases where both N and P are required to elicit a phytoplankton bio mass production response in estuaries (Flemer *et al.*, 1998), suggesting that N and P supply rates are equally limiting **(Figure 1.8)**. Tidal fresh and brackish waters in many estuaries are more light limited than higher saline waters (Flemer, 1970, Sin *et al.* 1999). As fresh water flows seaward, processes operate to modify nutrient stoichiometry (e.g., sedimentation of P-absorbed particles, denitrification, and differential microbial decomposition). Experiments showed that P addition was not stimulatory, but N or N+P caused large increases in the net primary production (Oviatt *et al.* 1995). In a 17-year field experiment carried out in Himmerfjarden Estuary south of Stockholm, Sweden (Elmgren & Larsson, 1997). The concentration of total N tended to reflect the N input from the sewage treatment plant, and both abundances of phytoplankton and water clarity were clearly related to the total N concentration and not to total P. The fate of sewage borne nutrients is significantly modulated by complex physical processes that operate virtually at every physical scale (Giller *et al.* 1994). In estuaries bottom bathymetry and topography form the basin in which tidal currents, fresh water inflow and wind vectors act as principal drivers of estuarine coastal processes and contribute to variability in mixing and circulation of waters (Cloern, 1996). Physical processes can attenuate or exacerbate nutrient enrichment effects.

Crerar *et a*l.,(1981) as a result of their study in acidic and organic rich rivers in New Jersey found that organic matter was less important in the removal of Fe and Al. They found that Fe, Al and DOM were all removed from the estuaries but these substances were not necessarily chemically associated with one another, but rather were removed by a common physical-chemical mechanism, that is flocculation by sea water electrolytes. They felt that the removal of elements varies from estuary to estuary depending on such effects as pH and chemistry and DOM content of the water. In highly polluted estuaries (Wollast, 1981) where anoxic bottom waters exist, reactive Fe^{3+} hydroxides carried by the river were reduced to Fe^{2+}. Phosphate which had been adsorbed by the Fe^{3+} was released as PO_4^{3-}. When the estuarine water became more oxygenated further downstream the ferrous iron was re precipitated as ferric hydroxide removing dissolved PO_4^{3}. Similar effects may occur in the sediment water interface where oxygenated and anoxic conditions prevail (Krone & Berner 1981). The role of suspended matter in the estuarine removal of Fe, Al and other substances has variously been interpreted. Aston and Chester (1973) found in laboratory studies that increased suspended particle concentrations increased the rate of Fe^{3+} removal from solution. The mechanism suggested was the formation of Fe oxides and hydroxides on negatively charged suspended sediment particles that act as nuclei with further precipitation of Mn, Ni, Co and Cu. But works by Sholkovitz, (1976) Crerar *et al* (1981) have shown that flocculation in estuaries can readily occur without suspended particles. Hydes and Liss (1977) suggested that the mechanism of removal of Al is the flocculation of very fine clay particles containing adsorbed Al which are suspended in fresh water but which are irreversibly coagulated upon entering the estuary. Dion (1983) found that Al was associated with humic acids probably as organic complexes. An alternate model for the flocculation of Al was suggested by Mackin and Aller (1984). Al is removed from water borne organic complexes and adsorption sites by the increase in cation concentrations and rise in pH in estuaries. The displaced Al reacts in solution with H_4SiO_4 and cations to form aluminosilicates which precipitate out. In addition bottom sediments can act as either a source or sink of Al. The question arises as to whether the estuarine removal is permanent or is remobilized and removed from the estuary. Although Fe in river water flocculates extensively it is not found concentrated in the bottom sediments, leading to the assumption that most flocculated Fe is carried out into the shelf by currents (Coonley, Baker and Holland 1971). In addition, ferric iron that is precipitated on to the bottom sediments or originally deposited as Fe coatings on clay minerals can be remobilized as ferrous iron by reactions in reducing sediments and then released by wave action or diffusion.

Inorganic removal of P is less well documented. Boyle, Edmond and Sholkovitz (1977) found, associated with humic acid Fe removal the large scale inorganic removal of phosphate along with varying amounts of Mn and trace elements such as Cu Ni Co and

Cd. The removal of phosphate may occur by more than one mechanism. In addition to flocculation of colloidal PO_4 associated with Fe adsorption of phosphate on other colloids probably occurs (Bale and Morris 1981). The existence of a buffering mechanism by partially reversible adsorption onto suspended particles in the low salinity part of the estuaries has been suggested by Liss (1976). The removal of dissolved silica in estuaries is variable. In some estuaries silica is conservative and in others it is removed by inorganic or biological processes. In laboratory mixing experiments Sholkovitz (1976) found very little silica removal associated with Fe and humic acid removal. He suggested that this is because Si is truly dissolved and not colloidal. Liss (1976) however noted that inorganic silica removal can occur in early stages of fresh water. Faxi (1980) suggested that the mechanism of silica removal is adsorption on colloidal ferric and Al hydroxides formed during early stages of mixing.

Physical and chemical factors are involved in the flocculation of suspended sediments. Shear stress and differential velocities are the physical factors provoking precipitation. Clay minerals transported in suspension in river waters may be deposited in an estuary as a result of the change in chemical environment represented by the presence of saline waters. In the river waters clay minerals remain in a dispersed state because of surface charges that tend to repel the particles. Increasing salinity reduces these repelling charges. Einstein and Krone (1961) showed that maximum flocculation occurs at a flow velocity of 15 cm/sec. Higher flow velocities tend to break the cohesive electrostatic bonds. Meade (1972), however, has contended that suspended matter is not necessarily precipitated by saline intrusion rather such a feeling is created by dilution with saline water. Na, Mg and K salts seem to be precipitating in the estuary which means these sea water components must be removed somehow (Berner, 1987)

Nutrients are generally more abundant in river water than in sea water due partly to their removal by organisms from oceanic water and partly to the input to rivers from pollutants and land weathering. Rivers serve as nutrient sources for estuaries and here biogenic removal is often found. For phytoplankton blooms to occur in estuaries the surface water must be fairly clear so that the light necessary for photosynthesis can pass though, large amounts of suspended sediments tend to inhibit organic growth. In temperate estuaries blooms are seasonal occurring in the spring and summer when there is more light and warmer water temperatures. Another factor that influences bloom in an estuary is flushing time for fresh water. Longer flushing time favors greater growth and more biogenic nutrient removal. The flushing time for fresh, nutrient rich water is longer in a well mixed estuary than in a stratified estuary where the river water rapidly flows out in the surface layer. Krone and Berner (1981) found that there was a considerable flux from sediments to the water column of dissolved PO_4 which had been adsorbed on ferric oxyhydroxides. This P release accompanied the reduction of the iron minerals by H_2S in anoxic portions of the sediment. Thus the flux of PO_4 from the bottom sediment was due to both the microbial breakdown of organic P and the release of adsorbed inorganic P. Some planktonic organisms remove silica from solution as well as P and N. Diatoms use Si in forming their opaline–silica shells. Silica removal associated with diatom blooms has been observed in the Amazon River estuary (Milliman & Boyle 1975). However because of the redissolution of diatom shells on the bottom the net removal of dissolved river silica by deposition of biogenic silica in natural estuarine sediments is probably far less than 20% and in some well mixed estuaries at least silica is conservative. In addition to dissolved nutrients carried in fresh water river run off into estuaries, there are a number of other nutrient sources for phytoplankton in the surface water (Berner and Berner, 1987)

1. Dissolution nutrients from particulate organic and inorganic material carried by rivers
2. Regeneration of nutrients from the breakdown of internally produced biogenic debris as it passes downward through the water column.
3. Benthic nutrient regeneration
4. Fixation of atmospheric nitrogen
5. Coastal upwelling of nutrient rich oceanic bottom water
6. Lateral advection of deep offshore ocean waters

Permanent removal of nutrients from estuaries can occur by

1. Sedimentation and burial of biogenic debris in bottom sediments
2. Wash out to the sea
3. Denitrification with loss of N_2 and N_2O to the atmosphere
4. Inorganic adsorption of phosphate on particles

Physical conditions are complex in those estuaries that have vertical stratification plus a bottom salt wedge and only local or partial mixing. In such cases nutrients removed from surface water may be regenerated in the bottom layer and carried land ward in the estuarine circulation. Since nutrients must reach surface water to be used by organisms these complex physical conditions often make calculation of nutrient balances difficult.

Nitrogen is found to be the limiting factor in coastal waters, not phosphorus (Ryther & Dunstan 1971). This situation has three principal causes- i) the ratio of nitrogen to phosphorus in many rivers is lower than that of estuarine plankton so that there is excess P left over, ii) due to microbial denitrification nitrogen can be selectively lost and iii) finally upon deposition in sediments N is regenerated much more slowly than P. Krone and Berner (1981) found that there was a considerable flux from sediments to the water column of dissolved PO_4 which had been adsorbed on ferric hydroxides. This P release accompanied the reduction of iron minerals by H_2S in anoxic portions of the sediment. Thus the flux of PO_4 from the bottom sediment was due to both the microbial breakdown of organic P and the release of adsorbed inorganic P. The buffering ability of the water body depends upon its concentration of HCO_3^- which is influenced by calcium ions solubilized from calcareous background or from sea water.

1.4 Urbanization and water chemistry of estuary

Urban activities lead to increased input of plant nutrients which may provoke a runaway algal proliferation and high biological productivity. Algae in water can be a nuisance in themselves, since they cause internal production of organic matter in estuaries. This organic matter is broken down by bacterial action resulting in increased depletion of oxygen. Also the organic matter entering the system from urban waste demands oxygen to break the same down to inorganic plant nutrients. Eutrophication as such has a deleterious feed back effect on biodiversity and environmental health of the water body. At the turn of the last century nitrogen and phosphorus were prized as the fuel that fed the great engine of marine production. Today they are seen as lethal pollutants leading to toxic blooms and suffocation (Nixon, 2000).

Because of the convenience of sea transport and recreational facilities many of the major cities of the world are on the shores of estuaries. The concentration of population and industries on the banks of estuaries has inevitably led to the discharge of waste materials into the estuaries so that many are seriously polluted today. There are very few unpolluted estuaries left and most of these are comparatively small. Man introduces a variety of dissolved pollutants into the estuaries. Addition of nutrients and organic wastes leads to eutrophication. Direct organic matter enrichment occurs from the addition of large quantities of dissolved and particulate organic carbon and organic nitrogen mainly from sewage. The immediate result of this event is the depletion of dissolved oxygen. Oxygen depletion is greatest in bottom layers leading in some extreme cases to totally anoxic conditions at depth. Sewage is a particularly rich source of ammonia and P, even after secondary waste treatment. The response of phytoplankton to increased pollution derived nutrients is more complex than bacterial response to increased organic matter and varies from estuary to estuary depending on estuarine circulation and original nutrient supply and balance. Natural mechanisms, primarily denitrification, exist for removing excess nitrogen from estuarine water but that does not exist for phosphorous. The urban modification of tidal canals can potentially have adverse environmental impact which in particular circumstances may include

1. Loss of wetland habitats and other sensitive aquatic systems, including the reduction in the sustainable values of estuaries as highly productive nursery areas necessary for fisheries.
2. Inadequate hydraulic functioning which may reduce water quality through poor flushing, cause sedimentation or affect structural integrity.
3. Impact caused by storm water and urban runoff, including erosion and sedimentation away from the site.
4. Impacts associated with imported fill.
5. Problems caused by disturbing acid sulfate soils.
6. Pollution by wastes from vessels.
7. Ongoing impacts from maintenance including maintenance dredging.

8. Loss of wetland plants alters the chemistry of water. Wetland plants have the ability to release oxygen through the roots and could possibly increase the solubility of metals and arsenic (Stoltz, 2004).

Most of the estuarine banks have already been urbanized and as a result the shores and the network of tidal canals have forfeited their original morphology. The pre urban tidal canals were swales and braided rivulets in which interaction with the bottom sediment was unimpeded. The construction of bath tub canals substantially decreased the inter tidal zone in the canals and sewage waste load denatured the quality of water. This is the general pattern of all the urban tidal canals of the world. There rare significant water management issues and areas of concern related to flow control measures in drainage basins in the inter tidal zone

1. Because of the inextricable linkage between flow and transport, there could be contamination of the wetland from nutrient enriched agricultural or contaminant laden land which have the potential to alter plant life and affect biological communities.
2. What are the cause and effect relations between tides, winds and altered fresh water flows on neighboring wetlands, mangrove ecosystems and coastal water bodies?
3. What are the effects of out flows on salinity dynamics?
4. What processes control the fate of nutrients or contaminants and govern their dispersal into neighboring wetlands and adjacent ecosystems?
5. What are the consequences of various redesign alternatives on inflows to bays, sounds and other coastal water bodies?
6. How do the dynamics of out flows affect sheet flow through adjacent wet lands?

The design, according to Maxted *et al* (1997) of man made linear, dead end canals dug deeper than the estuary produces poor flushing and circulation, leading to poor water quality, poor sediment quality, and a decimated biological community. A suggested method for improvement of tidal water quality is to connect canals in a loop to natural bodies of water (Baca, 1988). Marvin *et al*, (1990) recommends that canal excavations be designed to maintain adequate oxygen levels by eliminating dead end canals and aligning canals in such a direction as to receive maximum turbulent mixing from prevailing winds and that canal depths not exceed the bordering bay, Maxted *et al.*, (1997) suggested to maintain certain channel shapes like low aspect ratio and rounded corners. Mitigation techniques for the problem of low oxygen levels focus on knowing the system (i.e. its nutrient load) use of aerators has been shown to be a short term approach to the problem while a long term measure points toward circulation as a critical design feature. Other options are a reduction of sources of contaminants and introduction of buffer strips to act as contaminant filters. It is, however, impossible to insulate the tidal canals from urban and periurban influence as humanity has a seasoned tendency to gravitate towards estuarine coastal belts.

The effect of urban discharges on the natural water bodies has lately provoked a great deal of interest and concern. The effect of market effluent from the Oja-titun market, Nigeria on the chemical quality of the Opa Reservoir was investigated between February and November; 2000. Sharp seasonal variations were recorded for most variables. Comparison of the reservoir water with international limitation standards for drinking water showed that the quality of the reservoir water was very low and that treatment was required to achieve minimum limitation standards, (Eludoyin *et al.*, 2004). Water represents a key element in the development of Ho Chi Minh City, Vietnam. The city is intersected by canals and rivers, used as a dumping ground for all the industrial and domestic waste, a dwelling place for the most destitute families, traffic routes for water way transport and market gardening areas. The question of water utilization arises because level of contamination recorded exceeds generally accepted hygiene standards, and constitutes a risk for the population's health, (Bolay *et al*, 1997). Mass balance calculations for the Delft inner city canal system, The Netherlands, show that, of the accumulated heavy metals, a major part originate from out side the inner city, viz. via open inlets with the main canal. In view of the decreasing contents in the sediment top layer, it is anticipated that, with the various pollution abatement measures being taken, a gradual improvement in the Delft canal sediment quality will take place (Kilderman *et al.*, 2000).

Rapid nucleated urban growth associated with industrialization through out the 19th century involved an exponential growth of in materials transfers and in waste flows. The current post industrial phase of Manchester has to cope with the environmental and social legacies of its industrial past and with growing per capita materials consumption and increases in the number of house holds. Changes in material flows land usage and river morphology in Greater Manchester over the past 200 years have reflected changing technologies industry economics social expectations and environmental legislation. (Douglas *et al*, 2002). The spatial relationships between land uses and river water quality measured with biological, water chemistry and habitat indicators were analyzed in the little Miami River watershed, OH, USA. Data obtained from various federal and state agencies were integrated with Geographical Information System spatial analysis functions. After statistically analyzing the spatial pattern of the water quality in receiving rivers and land uses and other point pollution sources in the water shed the results showed that the water biotic quality did not degrade significantly below waste water treatment plants. Significantly lower water quality was found in areas downstream from high human impact areas where urban land was dominated. The study exhibits the importance of integrating water quality management and land use planning (Wang, 2001). Non-point sources of pollution are difficult to identify and control, and are one of the main reasons that urban rivers fail to reach the water quality objectives set for them. Whilst sustainable drainage systems are available to help combat this diffuse pollution they are mostly installed in areas of new urban development. They must also be installed in existing built areas if diffuse loadings are to be reduced. (Mitchell, 2004). Decision making in urban water management should essentially be acceptable to the stakeholders. It should force the decision makers to make their chosen premise more visible (Starki, 2004).

Studies by the USGS National Water Quality Assessment Program found the following characteristics in urban water sheds (http://www.ai.org/1dem/water/assess br/master swqms 072000sev.pdf)

- Concentration of fecal coli form bacteria commonly exceeded recommended standards for contact recreation
- Concentrations of total phosphorus is generally high in urban streams leading to nuisance plant growth
- Insecticides such as diazion, carbaryl and Malathion occur more frequently. Their effect on aquatic life may be a matter of concern
- Herbicides are wide spread in surface water and ground water
- Pesticides in urban waters usually occur in mixtures, nearly 80% of the stream samples contained 5 or more pesticides

- Sediment in urban streams is associated with higher frequencies of occurrence of DDT, chlordane and dieldrin
- Volatile organic compounds used in plastics cleaning solvents gasoline and industrial operations occur widely in shallow ground water
- Concentration of selected trace elements such as cadmium, lead, zinc and mercury are elevated above background levels in populated urban settings
- Sediment cores indicate that zinc and PAHs are on the rise apparently due to increased motor vehicle traffic.
- Toxic compounds found in stream bed were also found in fish tissue
- Deteriorated water quality and sediment as well as habitat disturbances contribute to degraded biological communities in urban streams.

1.5 Effluent load and water quality

The import of organic matter, especially in estuaries, can lead to water quality problems. Organic matter input from sewage was historically a major source of organic carbon that drove aquatic systems toward dissolved oxygen deficiency through direct microbial heterotrophic activity (Capper *et al*, 1983). However, the input of nutrients, whether in organic form followed by recycling or inorganic form with direct nutrient intake, is what stimulates potential phytoplankton biomass production and this organic matter may contribute to symptoms of nutrient over enrichment .

Ecological responses to nutrient enrichment may be quantitatively related to nutrient load rather than complexity in physical transport and mixing. The relationship between N load and sea grass recovery in Tampa Bay, Florida, is an example of where nutrient load was predictive but concentrations of N was not (Greening *et al.*, 1997). Marginal marine ecosystems exhibit a notable degree of process asymmetry and lag in a response, which means that a stress at one location and time may show up as a response at another location and time. Furthermore, different mechanisms may result in a similar response (Malone *et al.*, 1999). This type of behaviour enhances the tendency to confound cause and affect relationships. Conceptual models for estuaries in particular are still evolving. These models suggest that systems modulate stresses so that a single stress does not necessarily result in a single response (Cloern, 2001). This fact alone contributes to ecological uncertainty in load response relationships. Conceptual models help define expectations of cause–and–effect relationships and degree of nutrient–caused impairment, and refine hypotheses. Conceptual models should be a standard tool for water quality managers

1.6 Material Balance of the city

When towns grow and graduate into cities of consequence that can harm the local water resources with diffuse urban refuse. Hence steps will have to be taken to protect rivers, streams and aquifers. Urban development most often than not leads to population growth , erosion and sedimentation, urban runoff, nitrogen and phosphate influx, sewage over flows, water borne pathogens, toxic metals, pesticides, PCBs and chlordane in fish. A city in effect is an artificial agglomeration of humanity where the flux of matter and energy is neither balanced nor natural. In the primitive villages, circulation of plant nutrients is smooth as whatever is produced is ultimately consumed there. On the other hand, in cities like Cochin consumables are steadily being imported used and discharged and they inevitably end up in the local water bodies. Hence cities are the sink of plant nutrients, particularly phosphate. Much of the rain fall in the villages is absorbed in the porous soils and is stored up as ground water. When urbanization comes much of the vegetation and top soil is replaced by impervious surfaces. And the rain water used to be absorbed into the ground will be collected in storm sewers that send the runoff into local streams. These streams are not conditioned by nature to contain urban runoff and flooding and contamination occurs. Urban areas generate both point and non point sources of contaminants. Point sources that impact surface water include industrial and municipal waste discharges and also leaky underground storage facilities as well as miscellaneous accidental organic and inorganic contaminants. Ground water contamination by organic volatile compounds is common place in urban settings due to heavy use of fuels and solvents.

The city, like any other system, feeds on matter and energy and leaves behind both matter and energy qualitatively degenerated. In a balanced system the flux of energy is unidirectional but matter undergoes circulation. In a city matter and energy are on one way traffic. The energy refuse of the city degraded as unavailable energy manifests itself in the form of urban heat domes and thermal pollution in the water bodies it relies on. Most of the ecosystems of the world are propelled by the sun and things happen in the earth-atmosphere system during the flux of solar energy from a high energy level to a low energy level and cities also join forces in this process. For every 10^{o} C rise in temperature oxidation rate is doubled and DO is decreased (Tebbut, 1998). Hence the oxygen requirement of the aquatic fauna increases with temperature and availability of oxygen sharply falls in urban environment.

For a city fast growing, as in the case of Cochin, the influent mass and energy will be more than the effluent, and when the city declines the trend reverses. The city relies mostly on a vast hinterland that it queens over, to draw its sustenance from. The anthropogenic waste load left behind in the environment is directly related to the density of population, the standard of living and the environmental vigilance of the local administration. When the chronic and vicious circle of poverty, population and pollution nags the third world countries, environment often becomes a non-issue as the people are in a frenzy to keep soul and body together, and in such a situation today is more important than an uncertain tomorrow. At present the population of Cochin is in the neighborhood of six hundred thousand. It could potentially generate solid waste equivalent to 1116000 kg N /year and 222000 kg P /year. Domestic sewage generated is equivalent to 2400,000 kg N /year and the phosphate out put from sewage and detergents is to the tune of 1200, 000kg P /year (based on the coefficients given by San Diego-McGlone *et al.,* 2000). Externality of livestock agriculture and manufacturing sectors is in addition to this. Urbanization inevitably portents the contamination of water bodies because cities develop in the proximity of perennial water sources. Urbanization is steady accumulation of mass, mostly bio degradable, collected from elsewhere. Every refuse of urban activity, finds its way to the water bodies as leachate, sewage or atmospheric wash outs. Hence it would appear that urban activity is antagonistic to itself unless a working mechanism is incorporated to spread the refuse thin into the vast hinterland. Engineering modifications without a long term perspective further obliterates the inherent potentials of the city to rejuvenate itself. As urbanization is an integral part of civilization man will have to seek the prospects of making each city self reliant insofar as most elemental natural endowments like water are concerned. In place of a culture of use and refuse a new one of use and reuse must evolve. This study streamlines the possibilities thereof.

1.7 Objectives of this study

The purpose of the study was

1. To identify salinity intrusion profile for a canal over a hydrologic year.
2. To spell out the seasonal and possibly cyclic quality variation of the surface waters of the canal
3. To identify the hierarchical utility of the water body, and to identify management options to upgrade their quality.
4. To carry out salinity and nutrient budget modeling on selected canals so as to have a better understanding of the nutrient budget and to help the streamlining of management options.

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CHAPTER 2

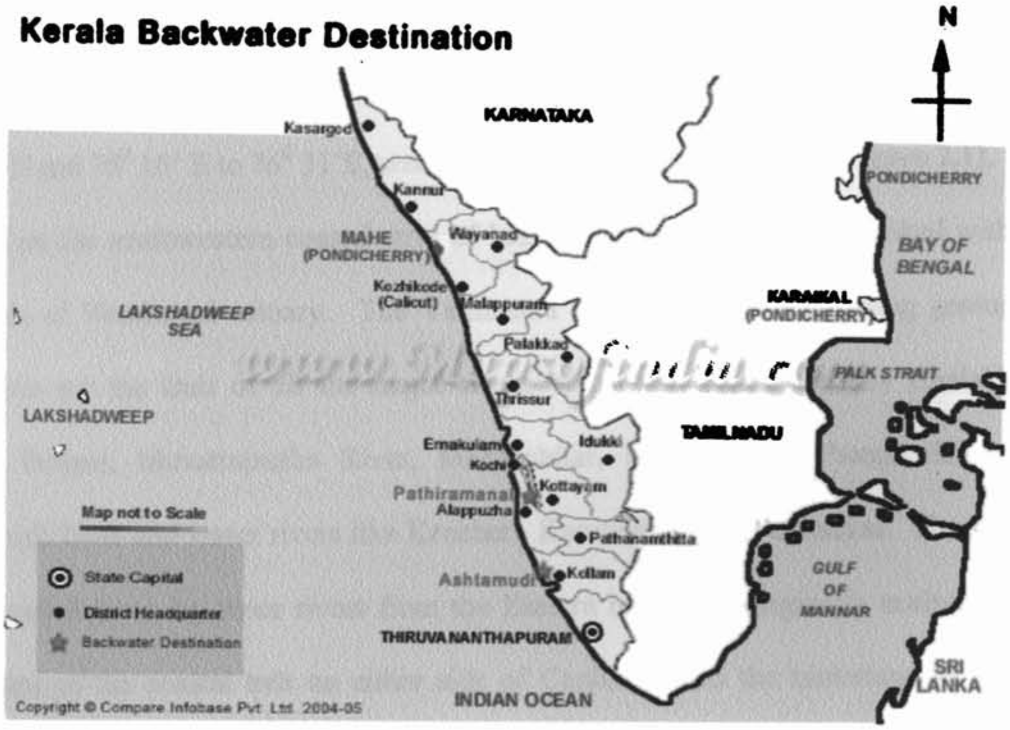


Figure 2.1 Location Map Showing the State and Location of the Study Area

Chapter 2

MATERIALS AND METHODS

2.1 The study area

The Cochin metropolitan area comprising of 275.85 km^2 and the surrounding region with varying shades of urbanization within the geographical co-ordinates 9^0 49' to 10^0 14'N and 76^0 10' E to 76^0 31'E, were targeted for the present study **(Figure 2.1).** It is located on the southwestern coastal strip of India. Cochin is inseparably linked with the wetlands of Vembanad estuary. The Vembanad Lake and the surrounding geological formation are the fruit of all the major rivers of central Kerala, namely Chalakkudy puzha, Periyar, Muvattupuzha River, Meenachilar, Manimalayar, Pampa River and Achancoil River and lesser rivers like Keecheri, Karuvannur and Puzhackal. The silt and sand washed down by these rivers from the Eastern highlands originally sculptured the landscape of the coastal belt on either side of Cochin. Also the hinterland of Cochin comprising of Ernakulam, Idukki, Kottayam and Pathanamthitta districts is watered and in a sense nurtured by these rivers. The oceanic wave action and the unimpeded discharge of sediment load before the debut of civilization resulted in the formation of a long sand bar from Arattupuzha to Kodungalloor along with a large network of deltaic islets and lowlands in between braided streams. There are reasons enough to conclude that the seashore began along the western fringe of the midlands well before the emergence of the Vembanad Lake. In Kuttanad region, thick layers of calcareous shells of extinct marine organisms are seen betraying a marine past of this region (Ampatt, 1992). Today the low lands and the catchments of the seven rivers aforesaid are economically the most important region of Kerala. And this part of the state, over the past one hundred years or so, has undergone sweeping anthropogenic modifications.

Vembanad wetland system is the largest of its kind on the west coast. Nearly half of the population of Kerala depends directly or indirectly on this wetland or its drainage basins. The wetland system with its drainage basins cover an area of about 16,200 km^2, which is about 40% of the area of Kerala (James *et al*, 1996).

A major portion of Periyar water is diverted to Tamilnad from Mullaperiyar Dam. Another major human intervention on the Periyar is the Idukki dam, which diverts water to the Muvattupuzha River after power generation. It appears that the greatest river of Kerala has been slighted and degraded by inter-basin and inter-state water transfers. The transfer of the Periyar river water to Muvattupuzha basin has unleashed a phalanx of environmental and industrial problems.

The most industrialized zone of Periyar lies between Angamaly and Cochin, with over 50 large and medium scale industries. The Edayar branch of Periyar, which caters to the needs of these industries, is estimated to have a lean season flow of 80-100 m^3/sec while the monsoon flow is around 150-250 m^3/sec (KSSP Report, 2002). The industries of Edayar-Eloor area are estimated to consume about 1, 89,340 m^3 of water per day and discharge 75 percent of this as waste water along with a variety of pollutants (KSSP, 2002). The incursion of salinity upstream during the lean months has crippled many economic activities on several occasions. Drinking water shortages became a problem in Greater Cochin region. Barrages were laid across the river to contain migration of salinity and the trapped water bodies upstream became heavily polluted with acidic industrial effluents and fish kills became regular (Pillai, 2002).

2.1.1 Cochin watershed

Cochin is a coastal settlement interspersed with backwater system and fringed on the eastern side by laterite capped low hills from which a number of streams originate and drain into the backwater system. The western part of the study area is a flat coastal zone, which forms a part of the coastal plains of Kerala, and the eastern low hills are part of the midland region (Benjamin, 1998)

According to Benjamin (1998) the western flat land comprises of 52 drainage units covering an area of 115 km^2 and islands in the backwater system with a total area of 56.4 km^2. The backwater extending to an area of 72.6 km^2 also comes within this zone. The eastern low hills, covering an area of 291 km^2, comprises of 21 stream basins or micro catchments, each with independent watershed area.(Benjamin,1998). These 21 major streams originating from the eastern low hills, run mostly west in between the low hills and drain into the tidal canals with a linkage to the back water system. The drainage basins of these streams have laterite or lateritic soil with occasional rock out crops. The tidal water canals of Chithrappuzha, Karingachirapuzha and Edappallythodu receive the waters from the east.

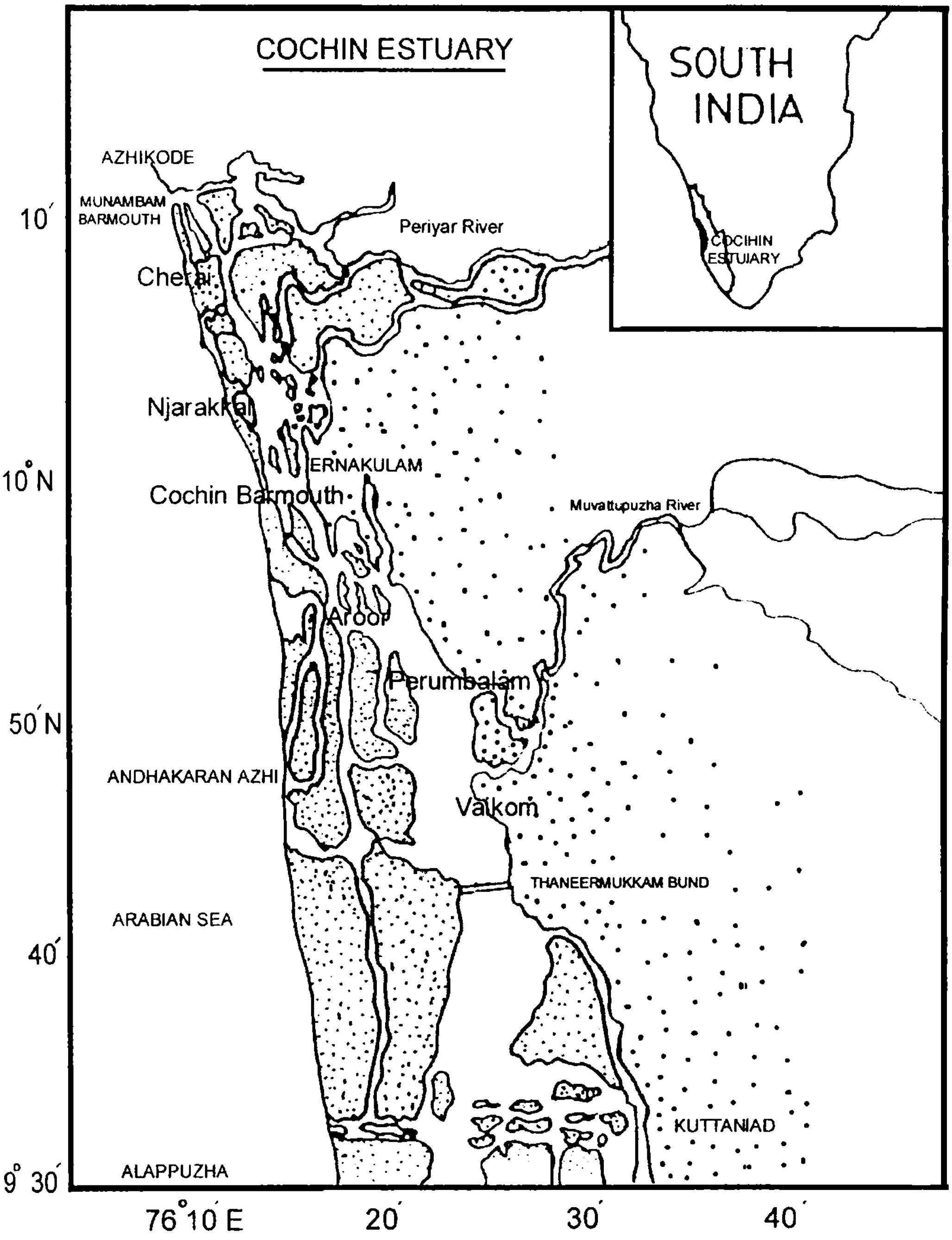


Figure.2.2 Location map of Cochin estuary

2.2 Cochin and the back water lagoon system

The estuary on the western parts of the city, stretching in the North South direction, has suffered large-scale siltation in the heydays of the Periyar **(Figure 2.2).** This has resulted in the formation of a number of mud bank islets, which are heavily populated. Overpopulation and industrial activities further north have degraded the quality of this sensitive marginal marine environment.

The destiny of Cochin is intertwined with the environmental status of the estuary and the rivers that run into it. But at present, human intervention is the most significant contributing factor in the environmental havoc wreaked upon the estuary. The Vembanad backwater receives considerable quantities of industrial effluents, agrochemicals, municipal and domestic wastes, most of these untreated. Though the water body has been resilient enough to effectively assimilate the pollution load in the past, symptoms of deterioration have already been observed (Jayapalan *et al* 1976, Quasim *et al.*, 1979 Gore *et al* 1979, Paul *et al*, 1984, Rajendran *et al.*, 1987). The major urban centers of Cochin and Alappuzha release to the Vembanad backwaters a pollution load equivalent to 1, 95,547 and 64,237 kg/day of BOD respectively (KSPCB, 1982).

2.3 Growth of Cochin as an important urban centre and its impact on the tidal canals

From the human point of view, Cochin is the focal point of Vembanad wetland system. Cochin emerged as a major port city on the west coast in 1939 through the zeal and vision of Sir Robert Bristow. But it is to be borne in mind that the coastal belt of Cochin running north up to Kodungalloor had sported ancient settlements and active trading ports for thousands of years. At present, Cochin is the chief centre of Kerala's

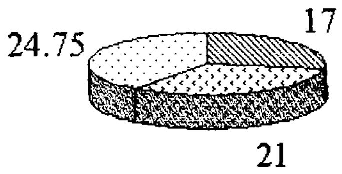


Fig.2.3.LAND USE PATTERN OF COCHIN IN 19TH CENTURY (in square miles)(Day,1863)

in Sq.
miles

▨ Farmland ☐ Waterbody ☐ Settlements

business and industry. Muziris, a place near to Paravur was the hub of commercial activity for hundreds of years. It is traditionally recorded that the cataclysmic floods of 1341 A.D. burst through the shallow bar at Cochin and so provided a larger and better natural harbor eclipsing Muziris once and for all. The discovery of Hippalos around 45 A.D. of the secret of the Monsoons gave a quantum jump to Roman trade with Cochin. The fact that Roman coins were unearthed from various parts of the region points to direct Roman connection (Bristow, 1950). Cochin finds its way into modern history with the arrival of Vasco da Gama in 1498 and the advent of European colonialism. In early 16th century, Mattanchery and Cochin regions had grown to important trading posts where merchants and sailors of various nationalities jostled. In 1501 Cabral observed that Cochin was a low sandy island with rich coconut groves and Moorish merchants (Day, 1863). During 19th century, the maritime district of Cochin comprised of 62.75 sq, miles, 17 of which were under cultivation, 21 were water bodies and the rest was villages and settlements **(Figure 2.3).** It was a region cursed by the Brahmins and was fit only for outcastes, (Day, 1863). Cochin was the second largest trading post in the Madras presidency in late 19th century (Logan, 1887). Cochin had a natural inner harbor and sufficient road connection. Logan noticed that Cochin possessed great natural facilities for trade as it was the centre of an immense area of rich country, tapped in all directions by inland backwaters and navigable creeks. He has recorded that *the Cochin River, rather the tidal opening of an immense system of backwaters in which numerous large rivers from the Ghat Mountains lose themselves, stretched north and south into Travancore and Cochin kingdoms and afforded an admirable means of conveying the produce of that immense tract to the markets of Cochin'.*

Cochin originally developed as a converging point of water transport. Cochin had water transport connections with Alappuzha, Quilon, Kottayam, Changanassery, Ambalappuzha, Neelamperoor, Pulikeezhu, Mannar, Athirampuzha, Paippad and Neerettupuaram in the south and Arattukara Canal and the Edathuruthy canal constructed in 19th century made water transport possible between Cochin and Trissur (Premananthan, 2005). Mattancherry and Fort Cochin and the rest of the region were by far rural. In 1905, Ernakulam got connected to the rest of the country by rail roads. Thereafter, the process of urbanization picked up momentum. The debut of Cochin as a major port on the west coast, triggered urbanization and industrialization in the modern lines, radically transforming the physiographic personality of this region. Road and rail traffic facilities pushed canal transport systems to a humble backseat and urbanization inched its way further east. Demography changed and traditional farming and fishing petered to near extinction. The land use pattern underwent a dramatic change. Armed with an all weather harbor, cheep electricity from Pallivasal, railroad connection to Indian mainland across the ghats and the availability of enough fresh water Cochin-Aluva belt turned all too ready to become a significant industrial nerve centre. Pressure on land increased and in the same measure utility of the canals plummeted. Canals and wetlands were a casualty when greed for dry lands increased.

The urban centre of Cochin originally developed around Fort Cochin and Mattancherry as a centre of maritime trade and commerce. And these parts are thickly populated, despite water logging and unhealthy environment. When road and rail traffic facilities improved, the centre of gravity of the city shifted to the eastern mainland. Fortunately, the city is still gravitating further east with a nose for more fresh air. More new investments are down the line to come to this region. Even then, the tidal canals, which once served the purpose of modern roads, cannot be left to decline and decay as water is growing more precious and dear in Cochin and elsewhere.

The domestic sewage from Cochin and its satellite towns ends up in the tidal canals and the estuary. Cochin City alone generates 2550 million L/day of urban sewage that directly enters the estuary. In Cochin, the sewage treatment plant covers only 1 % of the population (KSPCB, 1982). It is estimated that nearly 260 million liters of trade effluents reach the Periyar estuary from the industrial belt daily. This discharge is fraught with heavy metals, nutrients and insecticides (Venugopal, 1982). Cochin Back water system, the largest of its kind on the west coast (256 km^2), receives 260t/day of organic wastes from the16 major industries (Balachandran, 2001)

2.4 Population growth of Cochin and urbanization

In Kerala the rural-urban divide is not that sharp as far as basic amenities are concerned and hence there is not an appreciable flux of humanity into the city. In 1875, the population of Ernakulam town was 20,000. From 1875 to 1901, the demography remained more or less stalled. From the turn of 20th century an explosive growth of population was observed (**Figure 2.4**). This tendency persisted up to 1961 when the population reached 2, 50,000 (Benjamin, 1998). In 1981, the population in the corporation area was 5, 13,249 with a density of 5400/.km^2. In 1991, it reached 5, 64,000 and 5950 respectively. Census of 2001 shows that the total population of Cochin Corporation is 5, 96,473, and the population of GCDA area is around two million. A remarkable shoot up in population is expected in the years to come as the city is spreading itself thin to the east, transgressing the city limits. A floating population of around

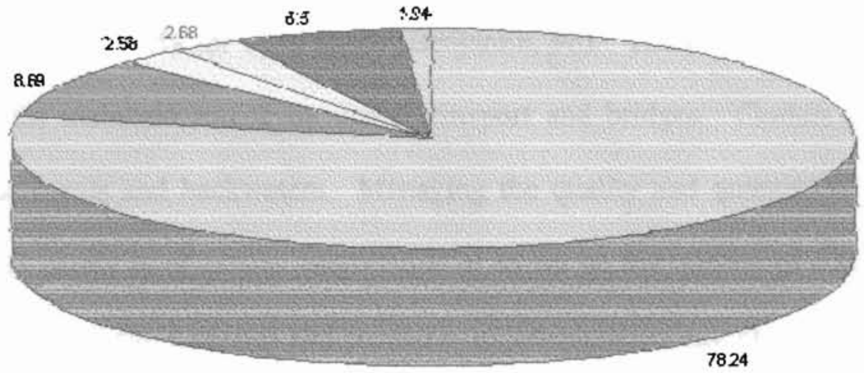
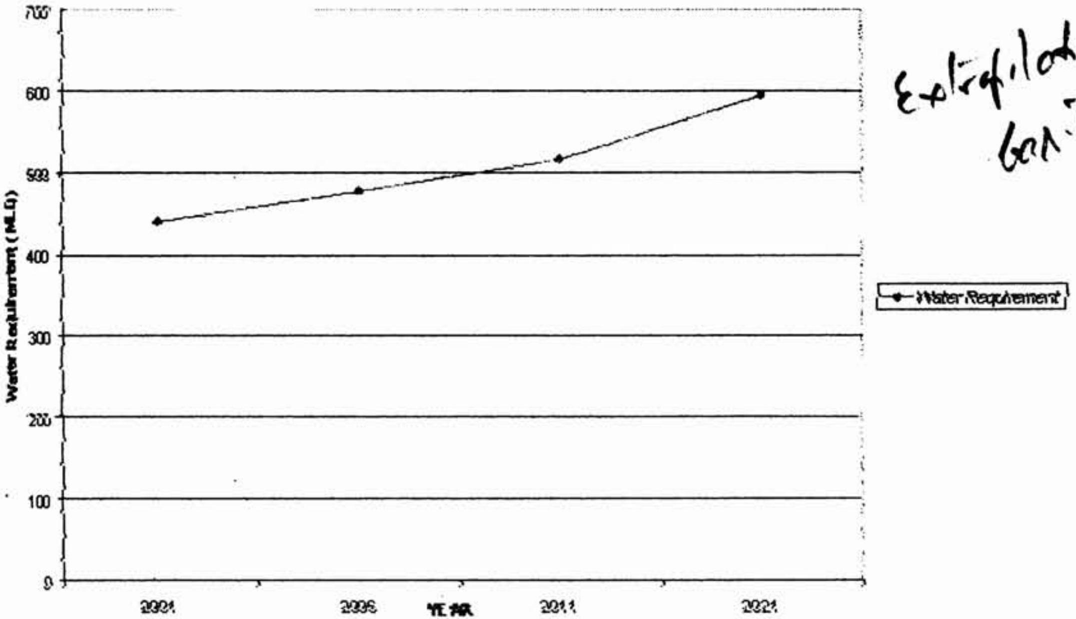


Fig.2.5 Land use pattern of Cochin in km²



Extrapolation
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Fig. 2.4 Projection of Water Requirement of Cochin

400,000 commutes to the city from the suburbs (CUSAT and Oak Ridge National Laboratory Study, 2002). According to GCDA estimates **(Figure 2.5)** 78.24 % of the land area of the city is residential, 8.69%for transport and communication, 2.58% for commercial establishments, 2.68% for industry, 6.5%for public and semi-public institutions and 1.04% for open space (Benjamin, 98). The city consists of islands and parts of the mainland linked by water transport and bridges. Cochin is dissected by numerous canals and backwaters. Managing the quality and quantity of the waters in these tidal canals is of utmost importance in so far as the quality of life is concerned. Insufficient drainage facilities and pressures of urbanization nag the city. Diffuse urban liquid and solid wastes naturally find their way to the nearest watercourses. The main threat from municipal sewage waste are anoxia and eutrophication. At present, the sanitary waste disposal system is limited to a small portion, with only one treatment plant at Elamkulam. The outlets of the septic tank and wash systems are directly connected to the public drains and, as a result, a wide spectrum of degradable and biodegradable pollutants is entering the drains and ultimately the water bodies. For most residents, the canals are the easiest option to get rid of their refuse. Urban run off is the single great source of water pollution and is an ecological problem threatening the long-term health of estuarine ecosystems and local economy.

When many of the arterial roads of the city emerged into prominence, many age-old canals and wetlands were a casualty. M.G Road, the flashy showpiece of the city, was once a fairly long wetland, so was modern Banerji road as well. The costly strip of land west of Shanmugham road was the shallow edge of the estuary. The evolution of Cochin alluvial bars followed a regular pattern. Immediately west of the rolling hills, alternate rows of swales and sand bars with a north-south orientation existed before the

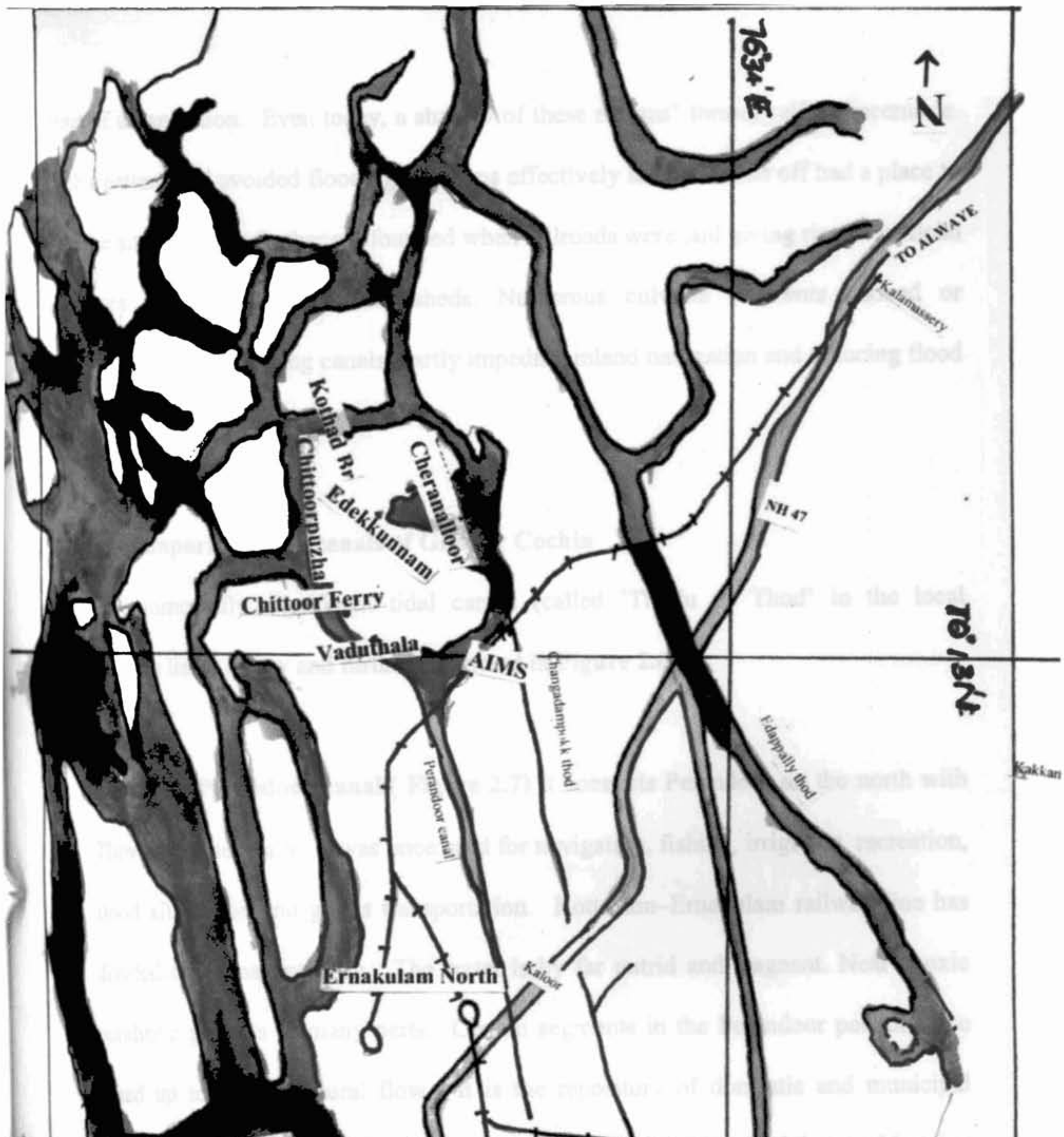

Figure 2.11 Map showing the sampling points on Chittoor puzha and neighboring canals

onset of urbanization. Even today, a shadow of these regions' former self is discernible. Such a pattern had avoided flooding problems effectively as natural run off had a place to go. The situation was further confounded when railroads were laid giving rise to artificial ridgelines dividing natural water sheds. Numerous culverts *en route* choked or bottlenecked all the existing canals, partly impeding inland navigation and reducing flood discharging capacity.

2.5 List of important tidal canals of Greater Cochin

The environmentally significant tidal canals (called `Thodu or Thod' in the local parlance) are listed below and further illustrated in **Figure 2.6**

1. **Thevara - Perandoor canal:(Figure 2.7)** It connects Perandoor on the north with Thevara on the south. It was once used for navigation, fishing, irrigation, recreation, flood alleviation and goods transportation. Kottayam–Ernakulam railway line has divided this canal into two. The water is by far putrid and stagnant. Near anoxic condition prevails in many parts. Certain segments in the Perandoor portion have silted up impeding natural flow. It is the repository of domestic and municipal waste. It is no more navigable and no fish survives. Effective dredging could revive the flood alleviation potentials. This canal has significant urban relevance in the present settings. It divides the city into two halves and is the chief repository of urban liquid and solid discharges. Rejuvenation and committed maintenance of this canal could give a tremendous fillip to the aesthetic appeal of the urban environment. If the southern and northern segments of the canals are linked across the railroad and if the obstacles at Aryampadom are removed water would oscillate between the southern and northern extremities, being propelled by the gradient induced by tidal

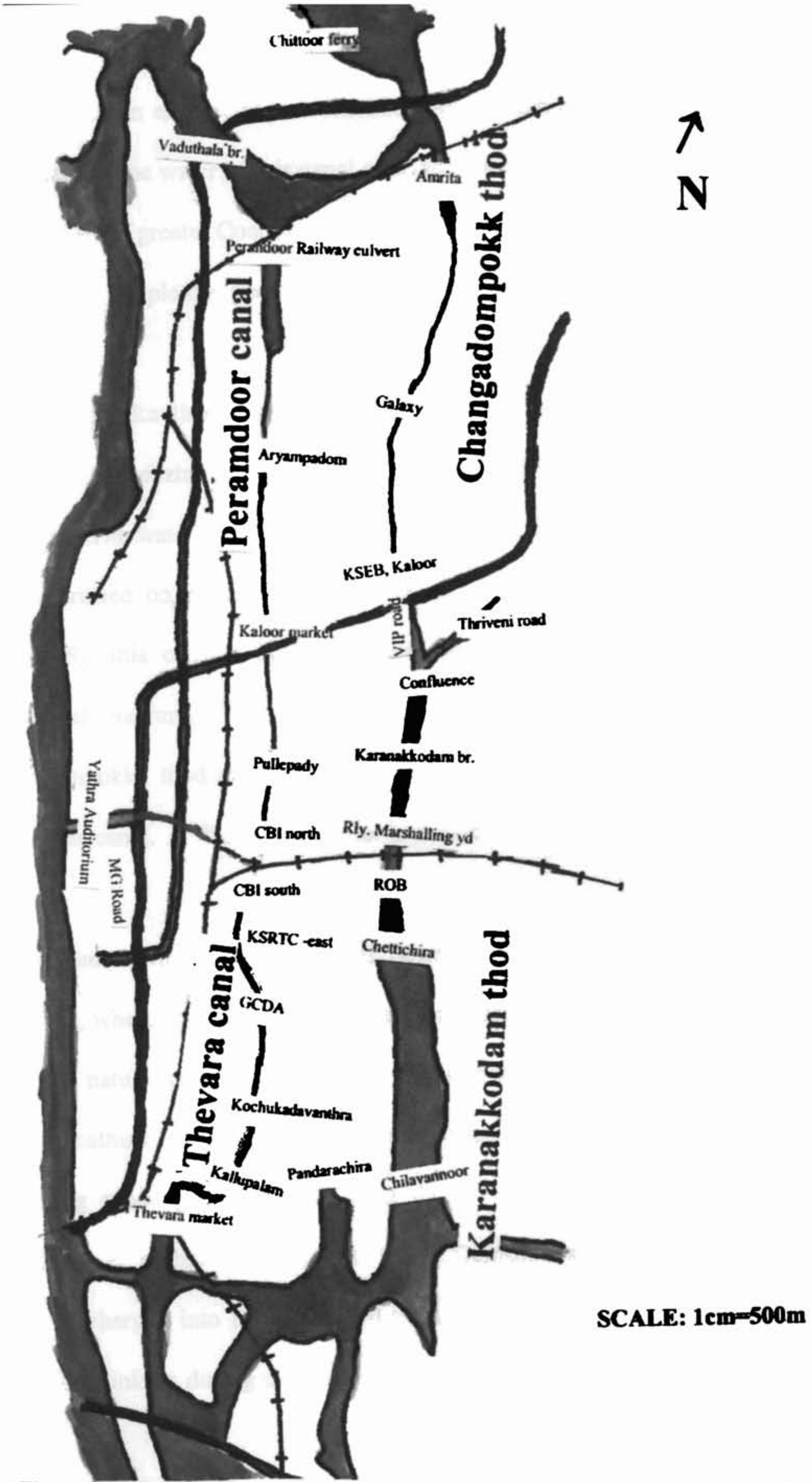

Figure 2.7 Map showing sampling sites on T-P Canal, Karanakkodam thod, and Changadampokk thod

disparity. Such an engineering modification would dramatically alter the chemical environment of the water of this canal once and for all. As it runs through the most urbanized part of greater Cochin region, its quality reflects the civic sense and social altruism of the people that people the sides of the canal.

2. **Changadampokku thod** (Barge Way Canal **Figure 2.7**). This canal links Kaloor with the Chittoorpuzha. As the name indicates this canal was developed for inland navigation. The water was used for fishing, washing, irrigation and bathing. Paddy fields flourished on either side of the canal. NH-47 has practically become a ridgeline for this canal. The canal tails out at the western boundary of the international stadium. And south flowing Karanakkodom thod begins where Changadompokku thod ends. Excessive waste load has ripped off the economic utility of the canal. At Kaloor, the water is anoxic and black.

3. **Karanakkodam thod (Figure 2.7)** It flows south from International stadium to Chettichira, where it merges with Elamkulam kayal. Railway marshalling yard has altered the natural course of the canal. Once it was used for fishing, navigation, washing, bathing and irrigation. The railroad culvert **has** crippled its flood discharging capacity. Discharges from the sewage treatment plant have led to conspicuous eutrophication at Chettichira. Domestic and Municipal wastes are directly discharged into the water body. At the beginning of the canal, water is anoxic and stinking during dry spells whereas, down south water is comparatively better.

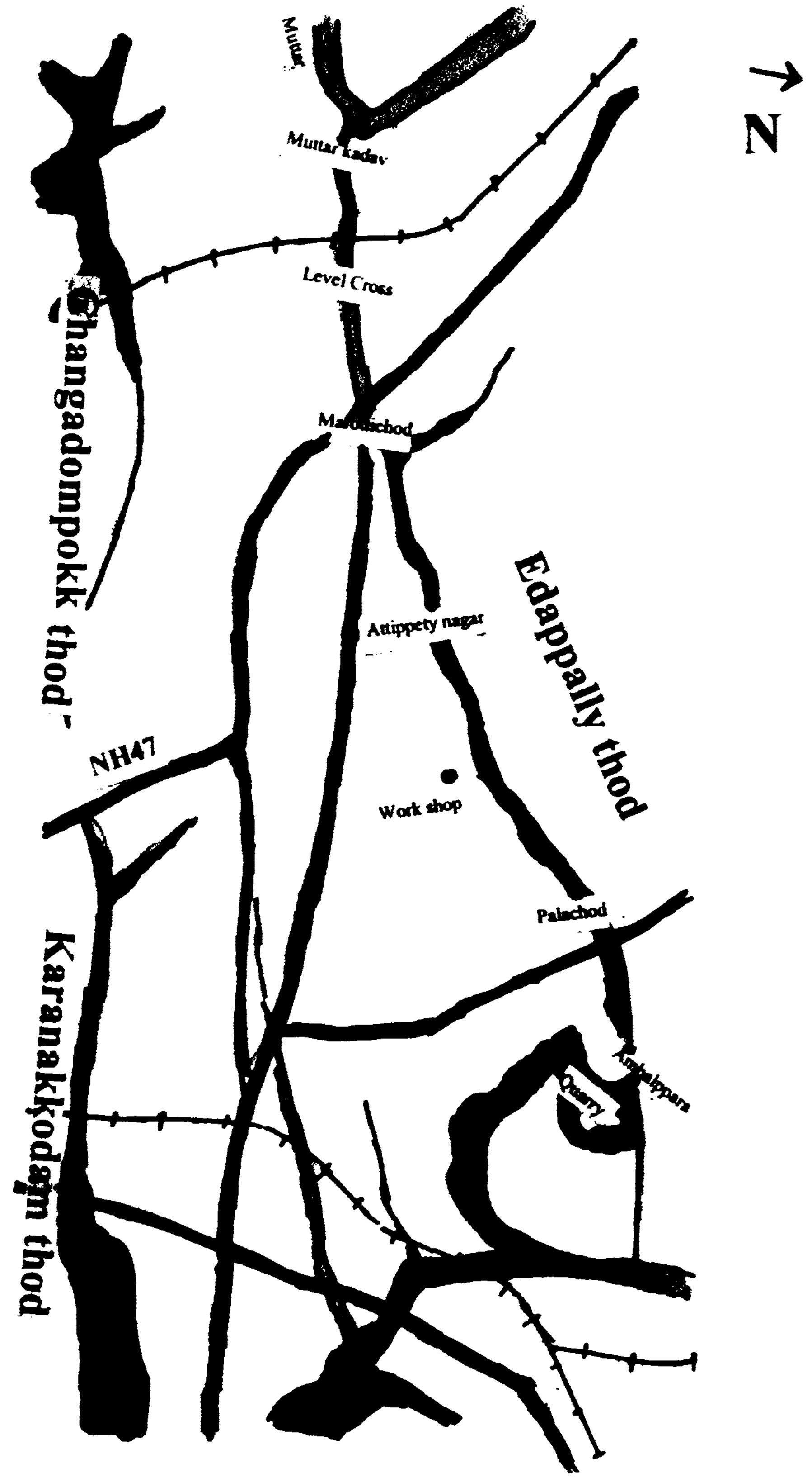

Figure 2.8 Map showing sampling points on Edappally thod

SCALE: 1cm=500m

4. **Mullassery canal**: **(Figure 2.7)** This canal begins near KSRTC Bus station and has a link with Thevara canal. Building spree has transgressed into the canal space in many parts along its length. Water is stagnant and anoxic. The canal begins at a low-lying area around Ernakulam South Railway Station and the natural gradient is not conducive to smooth flow of floodwaters. Water is turbid and colored. Concrete slabs have been built on top of the canal.

5. **Edappally thod**: **(Figure 2.8)** This major canal connects the Muttar River on the northwest with the Chithrappuzha on the southeast. Before urbanization reached the present levels, this canal was the chief commercial link of Edappally. It functioned as the boundary between erstwhile Travancore and Kochi kingdoms. The water was reportedly less turbid and was used for fishing, irrigation, recreation and navigation. At present NH-47 has cut the canal into two halves. The northern half is in a very bad shape by siltation, unwieldy outgrowth of weeds, clandestine solid waste disposal and neglect. The southern half is comparatively better off. Since agricultural activities have tapered off water is not any more used for irrigation. This canal marks the eastern geographical boundary of the metropolitan area. To the east of this canal the lateritic midland undulations become more pronounced. The alluvial bars and associated wetlands in between Edappally thod and the backwaters are being subjected to anthropogenic modifications as part of accommodating the demands of urbanization.

6. **Adimury thod**: It begins at Palarivattom and joins Karanakkodam thod behind the International stadium. Domestic biological waste, mostly faecal contamination, has turned the water unhygienic. Water is anoxic at the confluence.

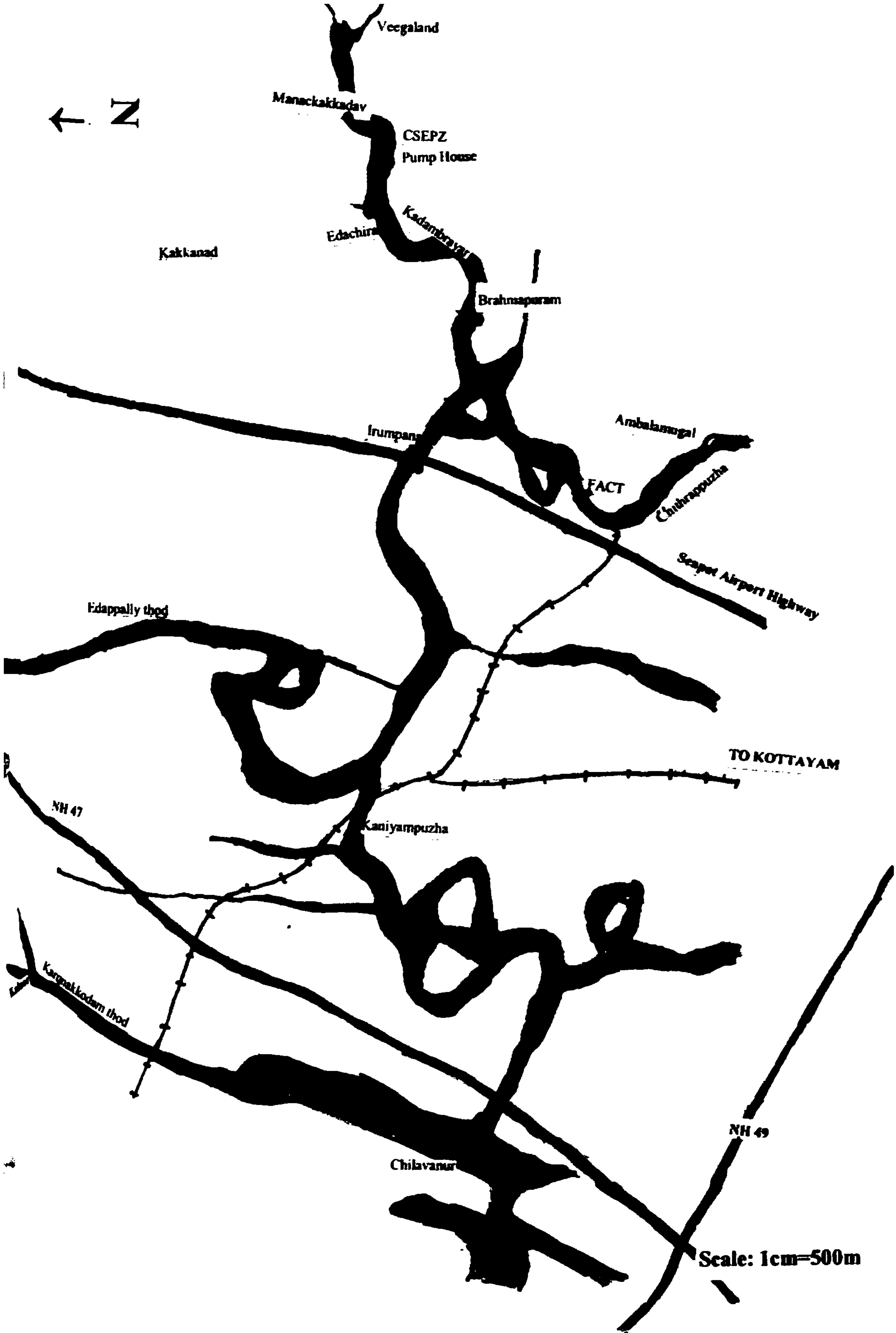

Figure 2.9 Map showing sampling points on Chithrappuzha-Kadambrayar

7. **Punchappadam thod**: This was developed as a natural drainage amidst the paddy fields (Punchappadam). The canal begins at Palarivattom and crosses NH Bypass north of Vyttila, flows south and joins Kaniyampuzha. The water was once used for irrigation, fishing and navigation.

8. **Kharee thod**: It runs parallel to Punchappadom thod and joins Kaniyampuzha. It evolved as a farmland drainage system. Once it was used for irrigation, fishing and small-scale navigation.

9. **Chithrappuzha: (Figure 2.9)** It is a rivulet having a defined catchment area and is a major source of fresh water in the agricultural regions upstream. It is navigable up to Ambalamugal. Agriculture is on the wane in the traditional agricultural regions upstream. Paddy cultivation has altogether stopped at Ambalamugal. Industrial pollution is a major insult. Currently this river is used for fresh water fishing, bathing, navigation and washing.

10. **Kadambrayar (Figure 2.9)** Kadamprayar assumes the gravity of a stream near Kizhakkambalam where a number of upland streams join together. In the nearby areas of this stream also agricultural operations are on the way out. It is a fresh water source for industries including Cochin Special Economic Processing Zone (CSEPZ) and the new industrial parks coming up. Fishing and navigation are still carried out. Fish kills are reported. Fugitive discharges from industries are suspected.

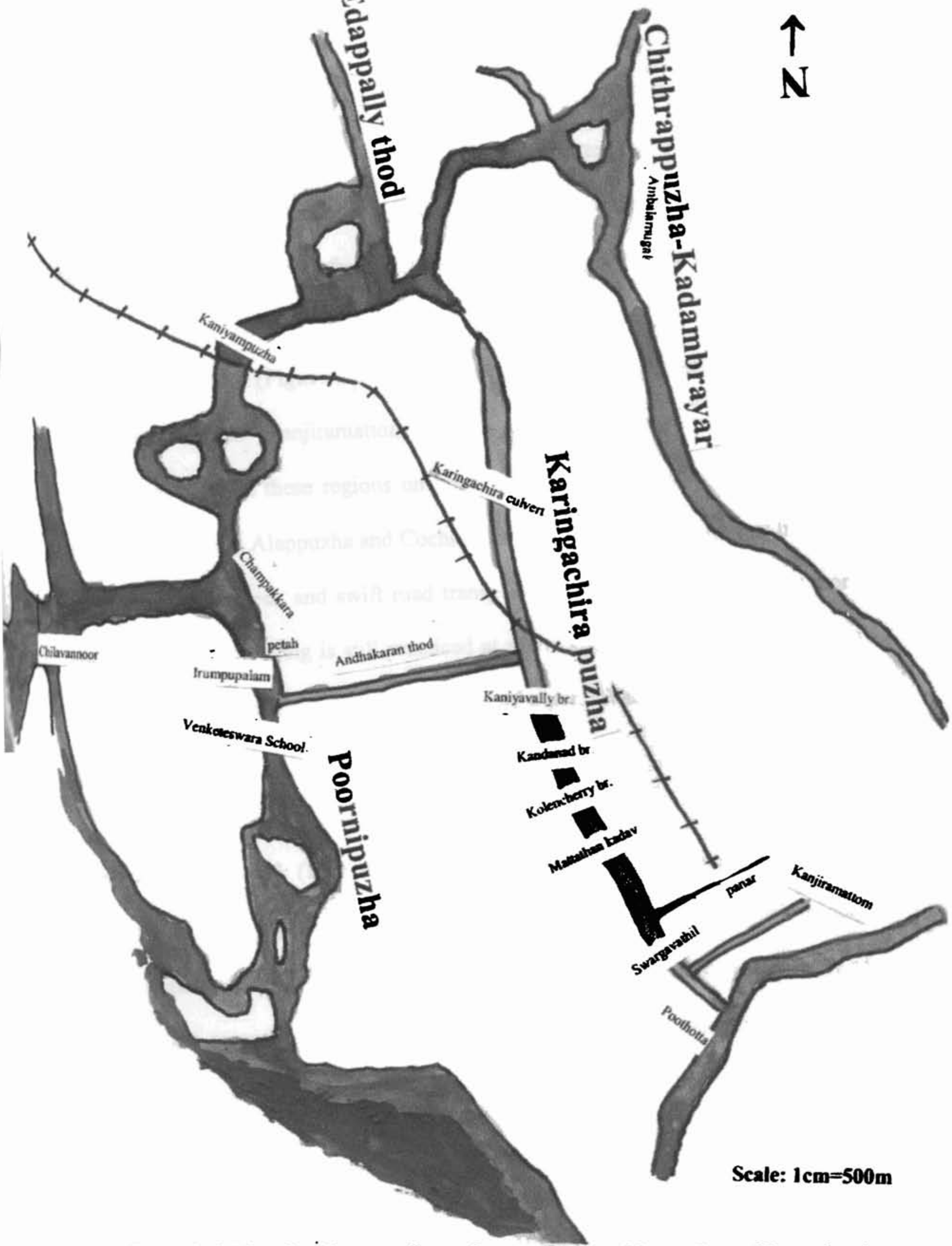

Figure 2.10 Map showing sampling points on Karingachirapuzha and Poornipuzha

11. **Poornipuzha:(Figure 2.10)** It is one of the arms of Champakkara canal stretching to Trippunithura and down south to Vembanad estuary. The canal crosses a flat wetland, where Andhakaran thod joins it. It was used extensively for navigation and fishing. Now fishing continues to a limited extent. The water is saline for most part of the year. Municipal waste from Trippunithura municipality ends up here.

12. **Karingachirapuzha (Figure 2.10)** It was the lifeline of Mulanthuruthy, Kandanad, Udayamperoor and Kanjiramattom regions for many years. Pilgrims and merchandise reached these regions on boats. Agricultural produce reached major markets of Vaikom, Alappuzha and Cochin this way. Now water transport has been out-moded by the sleek and swift road transport facilities. Water is not any more used for irrigation; fishing is still practiced at a low-key level. Industrial pollution has eaten into the aesthetic appeal and clarity of water. Water is not any more used for bathing either.

13. **Kanjiramattom canal: (Figure 2.10)**. It is a man made canal which facilitated the movement of boats right up to the midlands. At present, the canal is left in poor repair. Improved surface transport facilities have eclipsed it. Eastern extremity of the canal has recently been filled up for a taxi stand. The canal is choked by luxurious and riotous aquatic vegetation.

14. **Andhakaran thod:(Figure 2.10)** It is a canal crossing Trippunithura town and linking the Poornippuzha and the Panar. It was dug for the movement of the vessels of royalty. Now it carries the waste load of the municipal town. Water is not any more used for any domestic or social activity.

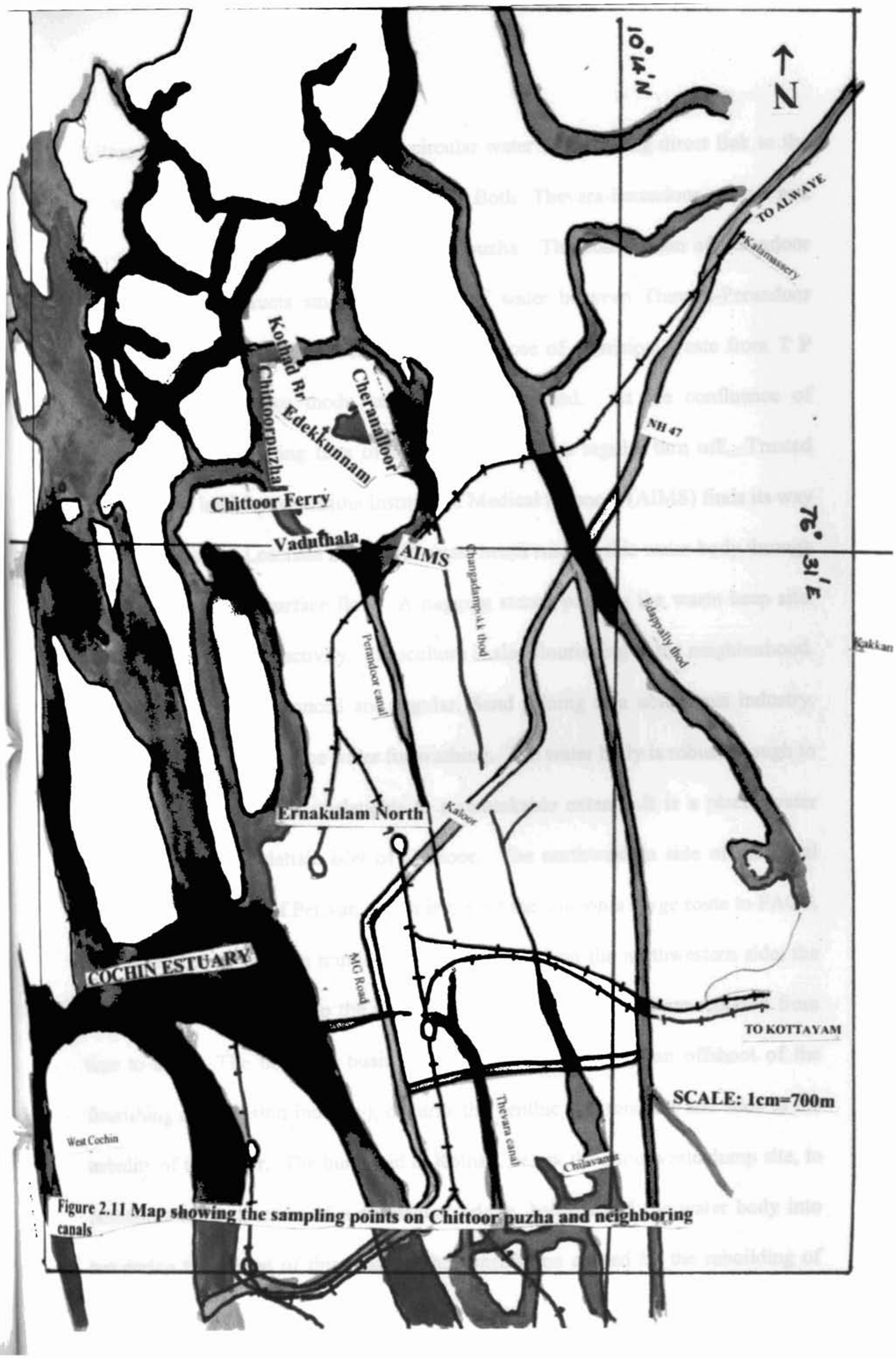

Figure 2.11 Map showing the sampling points on Chittoor puzha and neighboring canals

15. **Chittoor puzha**: **(Figure 2.11)** It is a circular water body having direct link to the Periyar estuary and the Muttar River. Both Thevara-Perandoor canal and Changadom pokku thod end up in Chittoor puzha. The constriction of Perandoor railway culvert obstructs smooth exchange of water between Thevara-Perandoor canal and Chittoor puzha. It receives a heavy dose of municipal waste from T P canal, Changadompokku thodu and Aryanpadom thod. At the confluence of Aryanpadom thod floating tarts of human excreta are a regular turn off. Treated hospital waste load from Amritha Institute of Medical Sciences (AIMS) finds its way to this water body. Leachate from solid waste heaps reaches this water body through surface flow and sub-surface flow. A nagging stench plagues the waste heap site. Still fishing is a serious activity. Pisciculture is also flourishing in the neighborhood. Tidal influence is pronounced and regular. Sand mining is a ubiquitous industry. People in the vicinity use the water for washing. The water body is robust enough to outlive the environmental onslaughts to a remarkable extent. It is a placid water body, encircling the deltaic islet of Chittoor. The northwestern side of the canal merges with a branch of Periyar, which is part of the ammonia barge route to FACT, Udyogamandal. From the municipal solid waste site on the northwestern side, the leachates find their way into the water body. Events of fish kill are reported from time to time. The booming business of illegal sand mining (an offshoot of the flourishing construction industry), disturbs the benthic environment and adds to the turbidity of the water. The bund laid at Kothad, below the solid waste dump site, to facilitate the construction of a permanent bridge, had divided the water body into two during the period of this study. The constriction caused by the rebuilding of Vaduthala Bridge is still impeding the natural flow of water from Perandoor. There

are two fresh watercourses ending up in this canal-Perandoor thod and Changadompok thod. Both are among the highly polluted canals of the city. Perandoor thod begins at CBI junction, near Pullepady and traverses the busy commercial district of Kaloor, assimilating high doses of municipal liquid waste. Siltation and outgrowth of grass and aquatic weeds have thwarted the smooth flow of water further north. Aryampadom thod, an out and out sewage outlet during the lean months, joins the flow one-kilometer above Perandoor. By the time the waters struggle their way down to the Perandoor Railroad Bridge, it appears to be remarkably clarified. Salt water intrusion does not reach serious proportions along the course. Changadompokku thod begins at KSEB Office, Kaloor and proceeds north via Ponekkara and Amritha Hospital (AIMS) to merge into Chittoor puzha. Here also municipal waste load is the chief source of pollution. The catchment area of both canals is thickly populated. Agricultural activities have lost their viability and economic sustainability because of urbanization and pressure on land. A cluster of chemical industries functions on the upper reaches of the estuary.

16. **Pashni thod**: It is a man-made canal built during the world war famine connecting Kaithappuzha kayal and Perumpadappu kayal. Water is turbid and unhealthy. Discharges from nine fish processing industries make its waters unfit for any economic activity. Fish kills are regularly reported. However, fishing is going on at the kayal opening.

17. **Pallichal thod**: It is a small canal running across Thoppumpady evening market to Kochi kayal. The water is ash-coloured anoxic slurry. It drains the market refuse and tidal action purges the canal to a certain degree.

18. **Rameswaram canal**: It represents the state of all the canals of Fort Cochin – Mattanchery region. Its present condition portents regular outbreaks of water borne epidemics. It is used as a common septic rank. Every body's property is nobody's property. Navigation is possible in limited segments at the openings.

Many of these canals were man-made when wetlands were reclaimed for paddy cultivation. Canals were developed to drain away excess water. This explains the genesis of canals like Punchappadam thod, Khari thod, Karanakkodam thod, Adimury thod etc. Edappally thod, TP Canal, Andhakaran thod, Changadompokku thod, Pashni thod etc were developed by man to facilitate navigation. .

2.6 Measurement of daily rainfall

A manually operated rain gauge was set up on the terrace of the university building and daily precipitation was measured at 9 30 AM. Along with the 24 hours' rainfall, the daily weather also was recorded in the master record. The monthly rainfall was to be computed from the data generated so. Monthly rainfall is an essential component in nutrient budget modeling.

2.7 Sampling procedure

All the sampling sites have been covered 14 times over in a space of 14 months. The data thereof have meticulously been tabulated to sift out secondary data and to distill out the salient temporal tendencies characteristic of each tidal canal. According to

Cochin Corporation records, there are altogether 65 canals in the city (Sustaining Cochin, KSSP, 2002). But a good many of them do not have any relevance in the present context. Some of them have even faded away into oblivion and many more are in the throes of extinction (due to encroachment, siltation etc.). A complete list of canals crisscrossing the landscape of the city is given as an addendum. Many of them, however, are not functional and fail to serve the purpose. Siltation and organic waste load have fragmented most of them to isolated fresh water pools quite immune to tidal and seasonal variations. Many low-lying areas are prone to serious communicable diseases including leptospirosis, typhoid, malaria, and hepatitis. Even as early as 1996, the city was armed with 267 hospitals, 5932 beds, 847 doctors, 1464 nurses and 16300 out patients per year (Cochin Corporation Report, 1996). Hospital and other allied services is already a booming business.

The canals chosen for the present study have a conspicuous tidal influence, a definite water regime, a significant catchment area and some degree of economic utility.

Standard methods lay down by APHA (20th edition, 1998) are broadly followed in the full gamut of activities including sampling and analyses. Preservation of the samples was not required since all the unstable parameters were analyzed well within 3 hours of sampling. Hence the samples collected were not split nor were they subjected to pH control chemical addition, refrigeration, filtration, freezing or bottling in amber coloured or opaque containers. All the sampling sites are well within 20 km radius from the site of analysis, except for Poothotta and Kanjiramattom. Thus elaborate modalities involved in the shipment of samples were altogether impertinent.

The "chain–of-custody" report, as is required of a systematic sample analysis, is also not relevant in the present context as samples were collected, transported and analyzed by the self-same hands. With three field trips per week, each canal singled out for the study is sampled every month. All samples were collected between 6 30 am and 8 30 am without fail, the apt time prescribed being around 8 am, when photosynthetic activity is not yet established and ambient temperature has not reached its zenith.

The tidal canals chosen for the study, the sampling sites earmarked for each canal and their respective serial numbers are given hereunder. In table 2.1

Table- 2.1. Tidal canals of Greater Cochin Development Area chosen for the study and sampling points

1. **Karingachira puzha**

    1. Karingachira (Culvert on the High Way)
    2. Andhakaran thod (the culvert on Thrippoonithura Market - Puthiyakavu Road)
    3. Kaniyavally Bridge (on Puthiykavu - Chottanikkara Road)
    4. Kandanad Bridge
    5. Kolenchery Bridge (on Vayalvaram - Mulanthuruthy Road)
    6. Mattathan Kadav(behind St. John's Hospital, Poothotta)
    7. Poothotta (the bridge on Kottayam - Ernakulam Road)
    8. Swargavathil Down (the barrage on Poothotta - Kanjiramattom Road)
    9. Swargavathil Up (reservoir side of the barrage)
    10. Kanjiramattom (in front of the fish kiosk on Poothotta - Kanjiramatom Road)
    11. Panar River (the bridge on Kanjiramattom - Amballoor Road)

2. Poorni River - Konnara thod - Pallimatom thod

1. Venkiteswara School (at the end of the foot path leading to the river)
2. Irumpu palam (the bridge)
3. Pettah Bridge (the bridge on Thrippoonithura - Ernakulam road)
4. Chambakkara Market (the foot bridge leading to Eroor)
5. Pisharady Kovil (Konnara thod) (at the culvert near the shrine)
6. Pallimattom - Kaniyampuzha (where the stream joins the river)

3. Edappally thod

1. Ambalappara (in front of the quarry)
2. Quarry (the south western corner of the quarry adjoining the cobbled road)
3. Palachuvadu Bridge (on Vennala - Palachuvadu Road)
4. Workshop (on Vennala - Palchuvadu Road)
5. Attipety nagar (culvert on Palarivattom - Kakkanad Road)
6. Marottichuvad Bridge (beneath the stone bridge)
7. Level Cross - Edappally (NH17)(the culvert on Muttar Road)
8. Muttar kadav (at the bathing ghat)
9. Muttarpuzha (south of the confluence near the HT tower)

4. Chithrapuzha – Kadambrayar

1. Veegaland (the bathing ghat in front of Veegaland)
2. Manakkekadav Palam(on Kakkanad Pallikkara road)
3. CSEPZ Pump house
4. Edachira thod (the culvert on Nilampahtinjamugal - Kakkanad Road)
5. Irumpanam Bridge (on Kakkanad - Irumpanam Road)

6. FACT – Crematorium
7. Ambalamugal (culvert on Brahmapuram Road)
8. Brahmapuram (near the HT tower in the Power house area)
9. Kaniyampuzha Bridge. (On Vytilla - Eroor Road)

5. Thevera Canal - Koithara Canal - Mullassery Canal

1. Thevera Market (at the extremity of the Canal)
2. Kallupalam (the bridge leading to Konthuruth)
3. Kochukadavanthra palam (the bridge on Konthuruth - Panampilly nagar Road)
4. GCDA (culvert on Sahodaran Ayyappan Road)
5. KSRTC - east (eastern side of the railroad)
6. CBI - south (southern side of the railroad where the canal begins)
7. KSRTC - west (western side of the railroad)
8. Yathra Auditorium (the culvert on Shanmugham Road)
9. Railway Over bridge (Panampilly nagar)
10. Emerald Quarters (culvert in front of the apartment, Panampillynagar)

6. Perandoor canal - Changadampokku thod

1. CBI-North (the southern extremity of the canal)
2. Pullepady (on Pullepady - Kaloor Road)
3. Kaloor Market (close to Manappattiparambu)
4. Aryan padam(where the drain joins the canal)
5. Perandoor Railway over bridge
6. Popular Godown (the culvert on Ayyappankavu - Ponekkara Road)
7. AIMS-South (the railway culvert south of AIMS)

8. KSEB-International Stadium (close to KSEB gate)

7. Karankkodam thod - Adimuri thod

1. VIP Road (the culvert in front of the Stadium)
2. Karanakkodam Bridge
3. Railway Marshaling Yard
4. Kathrikadav – Railway Over Bridge
5. Chettichira (the Sewage treatment plant)
6. Pandarachira (at the culvert)
7. Chilavanoor (at the bridge on "New Road)
8. Triveni road (at the beginning of the Road
9. Confluence - Behind International Stadium

8. Chittoor puzha

1. Vaduthala Bridge (on Chittoor Road)
2. Chittoor Ferry (Close to the Boat landing point)
3. Kothad Down (Kothad Bridge)
4. Kothad Up
5. Edekkunnam (Bridge on Chittoor - Cheranalloor Road)
6. Cheranalloor (at the ferry on Muttar)
7. AIMS-Behind

9. West Kochi

1. Pallichal thod (At Thoppumpady Market)
2. Pashni thod - Edacochi (the bridge on Aroor Road)

3. Pashni thod – Perumpadappu (at the extremity of the canal)
4. Pandarachal (the Bridge)
5. Rameswaram canal – Karuvelypady (the way side shop)
6. Pathaya thod (behind Govt. Hospital)
7. Kalvathy Bridge (on Market Road)
8. Rameswaram Canal – Mundamveli (on Thoppumpady Road)

10. **Puncha thod - Kharee thod**

1. East of Bypass-Vyttila (on Chakkarapparampu Road)
2. Kaniyampuzha Railway Over bridge.
3. Aysha Road (culvert near the Highway)
4. Naroth Road (culvert near St. George Church)
5. Chakkaraparambu (Culvert at the end of the Road)
6. Ponnuruny (culvert)

A complete list of tidal canals in Greater Cochin region is given in table2.2

Table. 2.2 Complete List of Canals In The City

Sl.No	Name	Length	Width
1	**Edappally zone**Karithodu	4km	1.5M
2	Adimurithodu	1	3
3	Karuvelithodu	1.8	3.3
4	Changadompokkuthodu	3	3to8
5	Karanamkoduthodu	2.5	4to 8
6	Edappallythodu	10	15
7	**Palluruthy zone**Pashnithodu	3.5	10
8	Pallichal thodu	4	10

9	Perumpadappu kayal	3	
10	Kumbalangi-Edakkochi kayal	22.5	
11	Vembanadu kayal	6	
12	Vembanttukayal **Fort cochin zone**	25	
13	Arabian sea	7.5	
14	Manthra canal	3.5	10
15	Rameswaram canal	2	10
16	Pandarachal	3.5	15
17	Athirthi thodu **Vyttila zone**	2	1.5
18	Thorothupurampokkuthode	0.8	2.5
19	Major roadside thodu	1.5	1.5
20	Near Dinny club thodu	0.5	2
21	Girinagar thodu	1	1
22	Paravilkadavu thodu	2.5	2.5
23	Kishavanathodu	1	2
24	Ravipuram K.C.Abraham thodu	0.3	1.5
25	Ponnathuchal thodu	2	8
26	Ponnath branch thodu	0.3	1.5
27	Karanamkoduthodu	0.57	7
28	Punchathodu	1.45	3.5
29	Marshalling yard thodu	0.7	5
30	Rail nagar thodu	1.7	6
31	Kuthappady thodu	1.2	4
32	Kudumbi colony thodu	0.6	2
33	STP thodu	0.8	3
34	Matha nagar thodu	0.75	2
35	Thodu near Pullepady gate	1.05	5

36	Thodu near Kaloor –Kadavanthra fly over	0.3	2
37	Karshaka road Perandoor canal thodu	0.8	2.6
38	Kathrikadavu fly over thodu	0.85	2.6
39	Perandoor bye lane thodu	1	2.5
40	Thevara Preandoor thodu	7.5	14
41	Chilavanoor puzha	4.4	28
42	Chambakkara canal		
43	Chithrappuzha	3.2	35
44	Karithodu	3.2	4
45	Bhoodanappilly htodu	0.75	2.5
46	Nedumpillichal	0.65	2.5
47	Mannarakkara thodu	0.7	2.5
48	Aarattukadavu thodu	0.75	3
49	Kathambayil thodu	1.4	3
50	Poothura thodu	0.6	2.5
51	Chettichira thodu	0.3	6
52	Kavalampilly htodu	0.45	2.5
53	Padavutham thodu	0.35	2
54	Co-operative road thodu	0.8	2.5
55	Railway to puzha	0.75	3
56	Mundampilly htodu	0.6	3
57	Father Manuel thodu	0.75	3
58	Thykkoodam thodu	0.8	3
59	**Central zone** Thevara perandoor thodu	9	5
60	Koithara canal	2.6	5.1
61	Thevara canal	1.5	16—20
62	Karankkodam thodu	1.8	8

63	Mullassery canal	1.5	1 to1.3M
64	Market canal	0.8	
65	Seena thodu	1	

White plastic cans of three litre capacity were used as sample containers. The cans were thoroughly washed with tap water and distilled water in advance and if there were persistent stains, the cans were washed with dilute HCl. They were labeled indicating the name of the sampling site and the respective serial number. BOD bottles also undergo the same preliminaries. As for bacteriological sample containers, they were washed, stoppered, hooded and autoclaved before hand.

In the field diary, the day and date of sampling sites and their respective serial numbers were entered well before the sampling trip was embarked upon. At the site, the time of sampling and the temperature of the sample taken were entered. Surface water sample was collected from the same site every month. All the water bodies covered were less than 1 M in depth and for uniformity; samples are collected from the surface. It is assumed that vertical mixing is complete and that stratification is non-existent.

The grab sampler and the containers were rinsed thrice with the sample and the DO was fixed *in situ*. Bacteriological sampling bottles were opened under water. On every field trip, the conspicuous visual features were observed and noted, especially the status of floating vegetation, colour variations, cases of fish kill, construction / destruction of temporary bunds, evolution of H_2S and presence of mosquito larvae.

Once back in the laboratory, where reagents had in advance been prepared and the instruments calibrated, the analyses were carried out immediately, except for total iron, hardness and chloride, which were done in the afternoon.

2.8 Laboratory quality control checks

The validity of any monitoring programme depends on the quality of monitoring data. To ensure the quality of data the following Quality Control aspects were ensured. To prevent any deviation in analytical procedures a document on standard operating procedure (SOP) was compiled. All the members of the team were trained in the procedures laid down in the SOP.

- Familiarity with the quality assurance plan required of all the analyses
- Pre cleaning of sample containers with material specific to the preservation of that fraction
- Use of APHA recommended sample preservatives whenever analyses got delayed
- Adherence to APHA recommended sample holding times
- Maintenance of samples in the safe custody of the crew until after the analyses
- Documentation of all reagent preparation
- Routine calibration of all analytical instruments
- Precision criteria applied to duplicate samples
- Accuracy criteria applied to spiked samples
- Monitoring of reagent blanks and slopes of standard curves
- Specified corrective action

- Supervisor review of all data generated in the laboratory

Strict quality assurance procedures for data entry were routinely followed in all sampling events. Any changes made to data on bench sheets were initialed by the analyst. Analysts reviewed the raw data for outliers and questionable entries, if any, were immediately verified. Final data were recorded on a master data book and thereafter, fed to the computer.

The full gamut of the study involved a three pronged approach - regular water quality monitoring, measurement of daily precipitation and tide gauging. Cochin is saturated with scores of canals, and all of them, *en masse*, did not qualify for the study. The canals relevant enough in the present context were earmarked after a few reconnaissance surveys during the pre-monsoonal lull of late May. The rationale for selecting a particular canal was based on its present status, its ostensible water potential, potential utility and the existence of perennial fresh water links and a tidal end. Many canals were seasonal, silted to extinction or too small to be included

The distance between two consecutive sampling sites, as a general rule, was fixed to be 500m. However, accessibility and the nature of the site were the deciding factors in the flexible rule. If another stream joins the parent stream, sampling site was fixed above the confluence. Field trips were undertaken on every Tuesday, Thursday and Friday and this rhythm remained unaltered, all through the sampling year. The parameters monitored were- pH, Alkalinity, DO, COD, BOD, Total Hardness, Calcium Hardness, dissolved Phosphate, Sulfate, Total iron, Nitrate+Nitrite, Conductivity, Chloride, SUVA at 254 nm, Turbidity and Total Coliform (MPN Method).

pH was chosen as a regular parameter to be monitored because it is indicative of the degree of the saline water intrusion, biogeochemical processes and contamination. Fresh water is generally acidic where as seawater is alkaline. Thus the pH variation around the year, covering all seasons, was expected to be revealing. Alkalinity, conductivity, chloride, hardness and sulphate are directly related to salinity intrusion. When salinity starts picking up, all the above parameters show a rising tendency, unless some other chemical sub-routes are involved. Hence the rise and fall could be in phase with the migration of salinity. This possibility was explored by monitoring the above parameters.

Nitrate and phosphate are the essential plant nutrients and their ratio is indicative of sewage contamination. Increased pH and the intrusion of marine cations could lead to the flocculation of phosphate. Nitrate is a very unstable component in an oxygen-depleted aquatic ecosystem and hence, the concentration of nitrate and DO are complimentary. In the absence of DO, nitrate is reduced by the oxygen-demanding wastes. Again DIP and DIN are the essential parameters for the budgetary modeling of the water body. Solubility of iron is directly related to pH and DO. Iron is immediately precipitated to the sediments by hydrogen sulfide in anoxic conditions. On interaction with alkaline marine water, Fe was expected to be removed from the water column. DO, COD and BOD are the most important parameters required to define the quality of a water body. Percent saturation of DO is a direct measure of the purity of water.

(The standard Operating Procedure has been documented)

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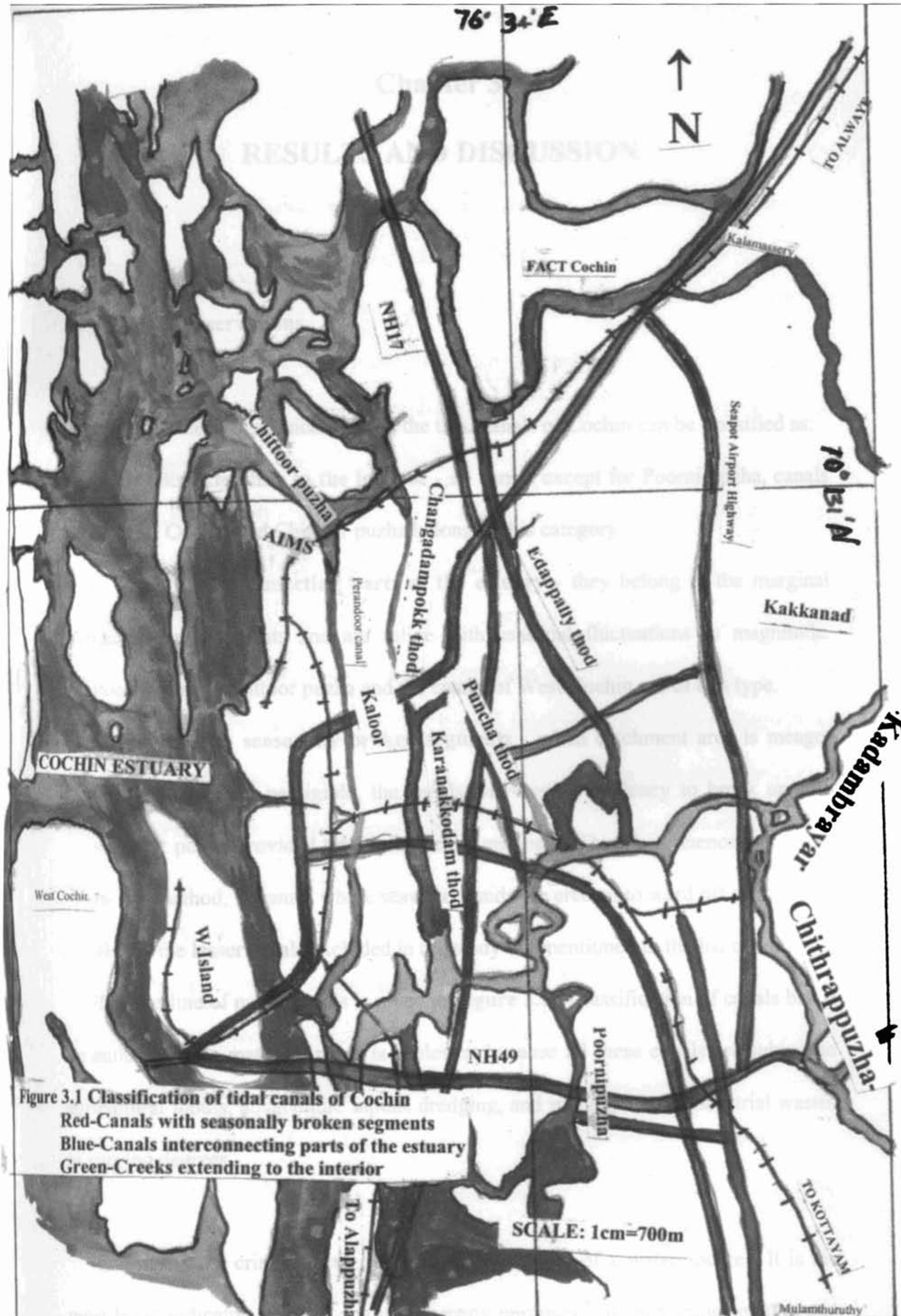

Figure 3.1 Classification of tidal canals of Cochin
Red-Canals with seasonally broken segments
Blue-Canals interconnecting parts of the estuary
Green-Creeks extending to the interior

Chapter 3

RESULTS AND DISCUSSION

3.1. General Observations

Based on the geographical setting, the tidal canals of Cochin can be classified as:

a. **Creeks extending to the interior** - all canals except for Poorni puzha, canals of West Cochin and Chittoor puzha belong to this category.

b. **Canals interconnecting parts of the estuary** - they belong to the marginal marine environments and are saline with seasonal fluctuations in magnitude. Poorni puzha, Chittoor puzha and the canals of West Cochin are of this type.

c. **Canals with seasonally broken segments** - when catchment area is meager and residual flow negligible, the canals will have a tendency to break up into stagnant pools, provided tidal influence is minimal. This phenomenon is evident in Punchathod, in canals where seasonal bunds are erected to ward off salinity and also in the lesser canals excluded in the study but mentioned in the list of canals.

The out line of major canals is given in **Figure 3.1.** Classification of canals based on anthropogenic material inputs is irrelevant because all these canals are subject to agricultural inputs, aquaculture inputs, dredging, and municipal and industrial wastes in varying degrees.

Salinity is the critical factor that decides the utility of a water source. It is the most basic indicator of water quality for many purposes. Salinity indicates the ratio of mixing of fresh water with seawater in the water body and stratification. It influences chemical process like sorption-desorption and flocculation as well as physical process like vertical mixing, stratification etc. which in turn influence the distribution and speciation of many trace elements. The level of salinity also influences the survival of fresh water microbes.

The concentration of various cations and anions being constant in sea water, the degree of dilution of sea water with fresh water in the tidal canals is reflected in the chloride concentration. Any deviation in the dilution factor in the case of non-conservative dissolved chemicals sheds some light into the physico-chemical changes that salinity intrusion becomes the platform for. Chloride in sea water is around 19000mg/L and in fresh water it is around 10-40 mg/L depending on anthropogenic inputs. Hence chloride levels, being a conservative ingredient, register the degree of dilution within reliable margins. But if chloride level is the indicator of dilution, the calcium concentration in the canals is at least two times more than the Calcium ions entering from the seas. Hence precipitation of calcium as calcium phosphate, if at all, does not rise to very high levels.

Iron in sea water is less than 20μg/L. Hence total Fe appearing in the water bodies is entirely from terrestrial wash out in which economic activities make up a major share. Soluble phosphate, though a major plant nutrient, does not go beyond 30μg/L in the surface layers of the sea water. This fact implies that sea water does not add to PO_4^{3-}levels in the tidal canals. Phosphate concentration sharply falls in the initial stages of salinity intrusion in December–January, because of dilution of sewage rich water body with sea water and a dramatic rise in photosynthetic activity. Phosphate steadily rises thereafter because of the accumulation of sewage as natural flushing is not effective during the dry months. Therefore, in the lean months, primary effect of sea water intrusion is dilution of phosphates followed by accumulation due to subdued flushing. Thus the governing process is physical than chemical. It can safely be assumed that pH and salinity levels should cross a threshold which could potentially trigger salt water induced chemical reactions bringing about a shift in the chemical environment comparable to the patterns spelt out in the introduction.

In water logged regions and in places where natural drainage is ineffective or stalled, salinity will persist, irrespective of the season of the year. In the case of tidal canals where the flux is not severely impeded, migration of salinity is essentially seasonal and is decided by runoff and tidal impact. Urbanization confounds the situation because of lightning floods and diminished residual flow. In the light of the data obtained across the water year 2003-2004, the saline pendulum characteristic of each canal of the city is spelt out in the pages to follow. Annual precipitation and its distribution being invariable within reasonable margins, the tidal fingerprint and human intervention alone are the deciding factors in the salt-water migration phenomenon. The time frame given in the data below is subject to small variations given the vagaries of monsoons. During the sampling year, for example, North East Monsoon was comparatively very weak and sporadic. Though samples were collected from the surface it has been pointed out by Mishra *et al.*, (2003) from their studies held in the coastal waters of Orissa, that phosphate and nitrate have a proclivity of concentrate at the bottom

Perhaps the most important environmental problem that the water bodies of the city are nagged by is deficiency of DO. With improved DO, the whole chemical spectrum of the water bodies will change. It will also affect the interaction between the sediment and the water column. The micro algal dynamics of the water column and the sediment have a significant say on nutrient dynamics. But DO deficiency obliterates the algal sub routes that dissolved nutrients can potentially take.

Some chemical changes brought about by anoxic conditions in natural waters (Berner & Berner, 1987) are as follows:-

Bacterial nitrate reduction: $5\ CH_2O+4NO_3 \longrightarrow 2N_2+4\ HCO_3+CO_2+3H_2O$

Bacterial sulfate reduction: $2\ CH_2O+SO_4 \longrightarrow H_2S+2\ HCO_3$

Bacterial methane formation: $2\ CH_2O \longrightarrow CO_2+CH4$

Iron reduction: $CH_2O+7CO_2+4\ Fe(OH)_3 \longrightarrow 4Fe^{++}+8\ HCO_3^-+3H_2O$

Manganese reduction: $CH_2O+3CO_2+H_2O+2\ MnO_2 \longrightarrow 2Mn^{++}+4\ HCO_3^-$

Ferrous sulfide precipitation: $Fe^{++}+H_2S \longrightarrow FeS+2H^+$

Manganese and ferrous carbonate precipitation:

$$Mn^{++}+2\ HCO_3 \longrightarrow MnCO_3+CO_2+H_2O$$

Ferrous phosphate precipitation: $8H_2O+3\ Fe^{++}+2PO_4^{---} \longrightarrow Fe_3(PO_4)_2.\ 8\ H_2O$

The tidal phase at the time of sampling influences the chemistry of water. In most cases, samples were collected during ebb tides, and thus, the salinity values will be towards the lower side. Even if the salinity status of a body of water were on the favourable side, that in itself does not qualify the body of water to be of some economic utility unless other quality parameters also fall in line. Migration of salinity is a natural phenomenon, but the deterioration of water quality is basically a problem man is squarely responsible for, and thus, fortunately, man always has the safe option of switching to the aqua-friendly ways and thus ameliorating the situation. The salinity pattern is applicable to the present pattern of urbanization and subject to the present run of hydrologic cycle. In most cases, rise and fall of salinity is sharp and abrupt, and as a result, either the water is a fresh water source or not at all, there is no grey area in between.

The carbonate–bicarbonate-carbonic acid balance operates as an excellent buffering mechanism in all the water bodies. The stability of pH and alkalinity in most of the canals is on account of the resilience offered by bicarbonates in the water bodies. Bicarbonate enters the system from terrigenous carbonate minerals and also with Ca and Mg bicarbonates from the ocean.

3.2 Canalwise details of Data

The enormous volume of data collected could not be presented due to unwieldy volumes of printed matter. Therefore the result shave been pruned for presentation as condensed tables with statistical parameters, correlation among indicator parameters and water quality index (WQI) which is a weighted scale based on selected parameters.

3.2.1 **Adimury thod, a** major tributary of Karankkodam thod, has fresh water for most part of the year. Chloride level is less than 50mg/L from the middle of April to late November. Chloride levels start rising from late November and reach a peak by the December. Thereafter, chloride levels decline and reach the monsoonal levels by the second half of April. Salinity in the canal never crosses the deleterious levels. At the eastern end of the canal, the peak value is 200 mg/L only and at the western extremity, where it merges with the Karankkodam thod, there is nominal tidal action and yet chloride rises to 300 mg/L only and then shows a declining tendency. Hence, for all practical purposes the canal is a fresh water source all through the year. For most part of the year alkalinity dominates total hardness indicating that hardness is temporary and that HCO_3 is the governing component.

3.2.2 **Chithrapuzha-Kadambrayar river system** is fresh water through out the year down to Ambalamugal. At FACT, Irumpanam and Kaniyampuzha, chloride levels pick up from the middle of October, and hit an annual peak in the first half of March, when at Kaniyampuzha chloride level nears 9000 mg/L, whereas at Irumpanam and FACT it is around 2600 mg/L. From the middle of March, chloride levels fall and reach nominal levels by the middle of May. In the tidal stretch of the river, salinity makes a minor peak in early October to the tune of 1500 mg/L at Kaniyampuzha presumably on account of the inter-monsoonal lull. The inference is that, above FACT, the river water is fresh throughout the year. From FACT to Kaniyampuzha, it is fresh from the second half of May to late September.

3.2.3. In the case of **Edappally thod**, the water course from Muttar puzha to Marottichod is fresh throughout the year, with a nominal rise in chloride from the beginning of December to the latter half of April. From Attipetty nagar downwards, the water is saline from early November to early June. But Attipetty Nagar does not ever become as saline as the points downstream. At Attippetty, the maximum value of chloride is 2700 mg/L, recorded on 9th March. The Ambalappara Quarry follows a pattern different from the main course. Here, chloride peaks on 20th May to 9000 mg/L and does not subside in tune with the other points. It remains saline until after early November, and then starts rising immediately. Hence it is saline for most part of the year. Other tidal points have fresh water from mid June to early November. Wherever salinity is pronounced bicarbonate hardness becomes negligible and alkalinity is entirely due to temporary hardness (Hounslow, 1995).

3.2.4. **Kharee thod** is fresh from early May to late November. Salinity reached the highest value in the first week of January. The salinity levels are innocuous enough throughout the rainy season. The sewage influx and the ensuing hypoxia keep the water alkaline. Total iron and phosphate keep rising through the dry months, primarily through the entrapment of sewage. In the northern parts of the canal, where tidal impact is less pronounced the nutrient rich and unruffled water body becomes a hatchery for mosquitoes. Most of the houses along the canal have their raw liquid waste outlets directly into the canal. During the dry months residual flow is nearly non-existent.

3.2.5 The tail end of **Changadompokk thod** is immune to tidal ministrations. So the southern extremity of the canal has fresh water throughout the year. In the segments downstream, chloride sharply shoots up by the first week of October and remains at the prohibitively high levels all through the summer days, up to the middle of March, in the case of AIMS culvert and up to early February in the case of Galaxy Apartments site. Thereafter, salinity thins out and water becomes fresh again, by the first week of May in the case of Galaxy and at AIMS towards the end of May. The tidal part is saline from early October to mid May. When the water is fresh alkalinity rises above total hardness and both are predominantly due to bicarbonates.

3.2.6 On **Karingachirapuzha**, tidal intrusion is potentially possible from either end, but the northern end of the canal where it joins with Kaniyampuzha is silted up preventing the exchange of water. Temporary bunds at Swargavathil and Andhakaran thod substantially obliterate the seasonal tidal influence. All segments of the canal are fresh up to early November. Salinity peaks in the first week of January and then falls a little. Towards the end of March, salinity reaches the maximum, measuring around 12000 mg/L at Andhakaran thod. At the sampling points of Andhakaran, Kanjiramattom, Swargavathil down, and Poothotta, salinity crosses 5000 mg/L from November to mid March. But salinity hovers around 2000 mg/L during the lean months at the sites of Karingachira, Kaniyavally, Kandanad, Kolenchery, Mattathankadav and Swargavathil Up. Panar, a stream coming from the east, is fresh throughout the year. Alkalinity is entirely due to temporary hardness through out the year except for Karingachira site during the advanced stages of salinity intrusion.

3.2.7 **The tidal canals of West Cochin** *in toto* are saline for most part of the year. The utility of these canals as a fresh water source is apparently doubtful. From early December to late April, chloride level is very close to or even equal to that of the sea water. By mid-May, salinity stoops to brackish water level and yet it undergoes swift transformation in tune with local weather. In any case, water is very saline from December to late April. The effect of tides on polluted fresh water is more pronounced in West Cochin in winter. Here the canal waters are severely denatured by huge doses of municipal waste and fish processing wastes. Even if the waste loads are brought down to an innocuous minimum, the water will not be of any economic significance because of the sharp fluctuations in salinity in response to rains and close proximity to sea water. Hardness is mostly from marine cations. And temporary hardness from bicarbonates is much less than permanent hardness

3.2.8 From late May to mid October, the **Poorni puzha** and the associated lesser canals are endowed with fresh water. From late October salinity begins to build up and crosses 6000 mg/L level by mid January and reaches a maximum in late April. Water is again fresh by late May. Highest chloride-level was recorded at Venkiteswara School site and Iron Bridge site. Temporary hardness does not alter significantly whereas total hardness does as it closely follows chloride.

3.2.9 The tidal impact fails to reach out to the northern extremity of **Karanakkodam thod**. The tail end of the canal on VIP Road flanking the International Stadium is free of salinity throughout the water year. But from the confluence of Adimury thod, the canal is progressively saline by late September and remains so until after early March. So from mid April to mid September, the canal is having fresh water. Maximum salinity occurs from late December to late March. At VIP Road total hardness remains nearly constant across time whereas alkalinity (temporary hardness falls with the fall in residual flow. Widening of Changadompokk thod and linking it with Karankkodam thod across the national high way at Kaloor would apparently facilitate better flushing in the canals.

3.2.10 The two arms of **Thevara Canal**, in its northern extremity, at KSRTC and CBI office in the central lowlands of the city, are well beyond the reach of tidal incursions and have fresh water at all times of the year. Floating fresh water weeds find their wintering haven along these stretches. Linking Thevara canal with Perandoor canal would permanently undo most of the environmental problems that the central lowlands of the city are chronically notorious for. In the section down south, water is very saline from late August to late April. All parts of the canal have fresh water from early May to late August. But during up tides, Thevara Market site becomes saline to the tune of 1000 mg/L.

3.2.11 **Mullassery Canal** has fresh water from late May to late October. At Yathra Auditorium, salinity reaches a peak in early January and thereafter slides down to a mid term low in late January. Salinity again peaks in mid March. At KSRTC site, salinity fluctuates, but the source of salinity may not be the sea, as it has no direct connection with the estuary. Here the canal flows eastward to join the fresh water stretch of Thevara Canal. The hydrologic bottleneck in the lowlands around the KSRTC Bus station is exacerbated by the latest engineering modifications introduced on Mullassery canal. The water from the inner half of the canal flows east to the natural depression at KSRTC resulting in regular flood events. Short fuse floods could be eased out by modifying the gradient of Mullassery canal in such a way that if drains the water from Thevara canal also instead of adding to the water load of Thevara canal as it does at present.

3.2.12 **Chittoor puzha**. It is a circular water body around the islet of Chittoor. Water from the major tidal canals of Perandoor and Changadompokk thod ends up in this water body. The water is saline for most part of the year. Water from Edayar enters this canal.

3.2.13 **Perandoor Canal:** In effect it operates as the main drainage of the business area of Kaloor. Naturally municipal waste influx is high. It begins at Pullepady at the railway line and flows north to Chittoor puzha. The southern extremity of the canal is fresh through out the year and the thick mat of floating vegetation thwarts smooth diffusion of atmospheric oxygen. This tells on the quality of water and demotes its economic potentials.

Table 3.1 List of Canals Surveyed and the Pertinent Inferences

#	Name of canal	Present status	Remarks
1	Karingachirapu-zha	Except for the northern half of the canal, the water is by far clear and clean. Excessive weed growth is choking the northern half of the	The local administration has done a serious job of de-weeding a major part of the canal, remarkably promoting

		canal. On Karingachirapuzha, there is tidal intrusion from both ends. Seasonal bunds at Swargawathil and on Andhakaran thod substantially obliterate annual migration of salinity.	its aesthetic value and navigability. As the work is left incomplete, eichornia will be back with a bang when the time is ripe. Bunds built at Swargavathil and Andhakaran thod have *ipso facto* turned it into a trapped water body. So the natural cycle of the migration of salinity is obliterated, whereas Kanjiramattom *thod* is left to the whims of nature and its water has taken a turn for the good. Karingachirapuzha had a natural link to Chithrappuzha. If this link is rejuvenated, this river could function as an effective buffer zone cushioning out the fluctuations in salinity in Chithrappuzha.
2	Poorni puzha	Water is neither stagnant nor anoxic; it bears the brunt of	Poorni puzha is an arm of Kaniyampuzha offering an

		ThripoonithuraMunicipality's waste dumping. From late May to mid October Poornipuzha and associated lesser canals are endowed with fresh water. From late October, salinity starts to build up and crosses 6000 mg/L level by mid January and reaches a maximum in late April. By late May water is again fresh. Total hardness closely follows chloride on Poorni puzha.	easy vent to the backwaters down south. If left to its own devices, a healthy circulation of water takes place between the kayals Poorni puzha and Kaniyampuzha. If the ebb flow from Chithrappuzha is diverted to Panar and Poorni puzha they could function as a viable fresh water flywheel.
3	Edappally thod	The western half of the canal is anoxic and is smothered by riotous and aggressive profusion of bushy floating vegetation. Refuse from slaughter houses is dumped outright into it. Muttar puzha, where it ends up, is also choked by a thick mat of floating weeds. The western half of the canal is more or less immune to quality modifications through chloride fluctuation whereas, the eastern parts are very much under the spell of tides except for Marottichod. At Attippetty Nagar	The canal has long ago forfeited its traditional utilities. It is basking in the glory of its former self. The canal is, in the first place, cut into two, eclipsing its commercial pertinence. The segment from Attippetty nagar to Edappally is plagued by copious outgrowth of weeds. They are moving upstream to escape salinity inching its way up. Water further downstream has been

		salinity slightly rises in the high pitch of summer. Wherever tidal effect is nominal the sinuous fluctuation of salinity flattens out to insignificance. This fact is evident in the case of Marottichod, Level Cross and Muttar. From December to late May, water is saline from Attippetty Nagar to Ambalappara. Water is slightly acidic because sewage input is fast diluted and salinity impact is not strong enough to push the water to the alkaline side. DO is very low throughout the lean months.	clarified by migrating salinity. Decaying vegetation and sulphates from seawater being subjected to reduction have resulted in the evolution of H_2S and even elemental sulfur deposits. Sulfate rich salt water, on entering the sewage rich and hence anoxic fresh water, results in the evolution of H_2S. If the pH range is within 6-7, the H_2S on reaching the oxygen-rich top layers gets oxidized to elemental sulfur, as is observed at Ambalappara Quarry in December. If the pH is between 7-9 sulfides, sulfates and thiosulfates are formed. H_2S is extremely toxic to aerobic organisms because it inactivates the enzyme *cytochrome oxydase*, interfering with energy metabolism at the cellular level

4	Chithrappuzha-Kadambrayar	Water doled out from Periyar Valley Irrigation Project keeps the river going. In Chithrappuzha – Kadambrayar system, tidal influence progressively diminishes when one proceeds upstream. Even in the heydays of summer, chloride levels do not reach a critical stage at the upstream sites. Only at FACT, Irumpanam and Kaniyampuzha, salinity peaks to deleterious levels in March –April. The two prongs of the river above FACT display fresh water characteristics all around the year. As for the lower reaches of the river, plant nutrients, hardness, iron and chloride peak in March –April. Sulfate fluctuates at Kaniyampuzha in tune with the tidal pendulum. The first wash out due to pre-monsoonal rains increases iron content and nutrient levels in the water bodies. In the initial stages of salinity intrusion calcium apparently precipitates PO_4 as	It is the lifeline of many a key industry. Discharges from chemical industries have turned the waters acidic and phosphate-rich. But, Gypsum, turns the water murky further upstream. KINFRA Industrial Park and Water theme park have joined forces with the traditional delinquents polluting Kadambrayar. Fury of the locals is seething and reeking that the discharges from the water theme park are marring the utility of the river. The river is recouping from anoxic conditions of the past few months as Periyar Valley Irrigation Project has given it a new lease of life..

		phosphate and calcium hardness seem to fall simultaneously. Fe lies low during the dry season and sharply rises with the first rains. pH is mostly to the acidic side throughout because municipal waste load is less, and residual flow is substantial. Alkalinity never crosses the threshold.	
5	Thevara Canal	Heavily polluted and bedeviled by excessive weed growth. Thevara canal is subject to regular tidal influence but for its northern finger tips at KSRTC and CBI Office. At these points, sulfates and chloride remain constant right across the year. Iron keeps rising and tips over the peak in late February. Sulfate level fluctuates and reaches a maximum in mid March in the southern parts. The tidal stretch of the canal is saline from late December to mid April. At KSRTC, sewage load is exceedingly high in all seasons and this region as a	A canal being slighted by the refuse of down town Cochin. The region around KSRTC Bus station is a natural depression. The canals radiating away from KSRTC do not and cannot serve their purpose. They offer ideal nurseries for mosquitoes and a safe haven for weeds. At Panampallynagar also the stench of hydrogen sulfide persists

		whole is flood prone. The canal is more or less anoxic throughout and like Mullassery canal, pollution load is very high. The water is coloured black. pH sharply fluctuates but water is clearly on the alkaline side due to heavy sewage load. COD & BOD simultaneously peak in January and April with maxima in salinity.	
6	Mullassery Canal	The most polluted canal in the city, its self-purification capacity is long lost. It is a tidal stream substantially humbled in the course of urban evolution. At the eastern tail end of the canal, water flows to the east only to accumulate at KSRTC Bus station. Here also parallel to the pattern followed by the sister canals; nitrate sharply shoots up in late May in response to the first overland wash out. BOD, COD, sulfate, chloride, as usual, marking the beginning and the end of the	There is no other canal in the study area as anoxic and heavily polluted from the beginning to the end all through the year like this canal. It is a canal subjected to the highest degree of indignities. Building spree has eaten into its morphology and it flows east at KSRTC.

		desiccating dry spell, make two peaks. Iron keeps rising to mid March and then starts falling. Whereas phosphate stumblingly rises to a peak in March and starts declining with the first rains. Water remains anoxic for most part of the year. The canal is saline from early November to the first week of May. Heavy sewage input keeps the canal alkaline. Iron keeps rising until the first rains of the year. At KSRTC, the source of salinity may not be the ocean, as it has no connection with the estuary. Here the canal flows eastward to join the fresh water stretch of Thevara canal.	
7	Perandoor Canal	Siltation impedes continuous flow and natural flushing. Insulated from tidal action. Perandoor canal, the northern counterpart of Thevara canal, is tidal for most part. But the tidal effect is damped by siltation and uneven morphology. Kaloor, the commercial hub of the city, has	It is the northern extension of Thevara canal. Perandoor canal flows through the very thick of the city and it deserves special care and maintenance. Waste from residential areas and markets ends up in this canal. The

		a deleterious effect on the quality of the canal. Nitrate reaches a maximum in late June. BOD, COD, hardness and sulfate have two maxima in summer. Phosphate steadily rises to the end of the dry spell but Pullepady site shows a freak maximum in early December. Conductivity reaches a pinnacle in March. The water is not hard except at Perandoor during the dry period. Nor is the water saline but for Perandoor from early November to early May.	northern extremity of the canal is remarkably clean and healthy. Saline water could purge the filth of KSRTC if both these canals are widened and linked across the rail road and Perandoor canal is subjected to regular dredging. Weed growth is phenomenal at the tail end of the canal. Water is saturated with mosquito larvae at CBI junction.
8	Changadompok thod	Water is thick and nauseous slurry at Kaloor whereas at the delivering end it is by far clean. Of the three sampling points on this canal, AIMS culvert and Galaxy sites are very much under the influence of tidal action whereas KSEB site at Kaloor remains insulated from tidal influence all through the year. This fundamental difference is evident in the graph. Plant nutrients sharply	This canal virtually tapers out at Kaloor. Its flood relief potentials are apparently crippled. Changadompok Thod is in fact the northern extension of Karanakkodam thod. Both are to be widened and linked at Kaloor across NH 47 for natural purging and purification. At present the stench is noticeable and is

		rise at the onset of the rainy season and then decline with an equal haste because nutrient content of overland flow thins out when rainy season gets established. Chloride hardness and conductivity rise and fall in tune with the seasons. In this case the first two sampling sites behave exactly as a tidal canal. At Kaloor, the controlling factor is the input of organic waste alone. By early January, sulfate level reaches its zenith and then plummets, apparently indicating early saline intrusion and ensuing temporary hypoxia resulting from decaying vegetation. Phosphate sharply falls at the first stage of salinity intrusion. At Kaloor, BOD and COD remain very high indicating extreme levels of pollution. In the later stages of salinity intrusion, phosphate actually rises with chloride.	a safe nursery for mosquitoes.
9	Karanakkodam	The northern half of the canal from	Adimury thod, a branch of

	- Adimury	the railroad to Kaloor is in a very bad shape. The temporary bund at Karanakkodam bridge further confounds the case. Karankkodam thod is a tidal canal of extremes. At its northern extremity, on the western flank of the International Stadium, bordering VIP Road, tidal influence is next to nil and is denatured by heavy influx of organic waste. When rainy season gives in, total iron picks up and reaches a summit in early March. The other side of the picture is seen in the southern parts where the tidal action is pronounced and mixing is vigorous. Eutrophication and high diurnal DO alkalinity and pH are experienced at Chettichira when fresh water biota is established in July-August. Whereas at Pandarachira, eutrophication coupled with high diurnal DO alkalinity and pH are experienced when mesohaline organisms are established in	Karankkodam thod, is fresh. But its potentials as a fresh water source are damaged by sewage influx. Same is the case with the tail end of Karankkodam thod.

		February–March. Nitrate following the regular run of the canals elsewhere, peaks with the first rains. Except for the northern end, the water is saline from mid November to mid April. Hardness keeps rising until the rainy season steps in. Sewage load keeps the water alkaline throughout.	
10	Chittoor puzha	Quasi-estuarine characteristics. Chittoor puzha cannot be availed as a freshwater source as chloride level crosses 500 mg/L for most part of the year. Salinity fluctuates remarkably across the months in response to tidal intrusion and events of rainfall. Being under the direct and unimpeded influence of tides, the river experiences daily fluctuations in water quality. Here, contrary to the regular pattern, nitrate peaks in early February. The water is hard and saline for most part of the year. Sulfate reaches its lowest in early February and in	It is the intermediate repository of the municipal waste of northern half of the city. Tidal action, thorough mixing and pH shock keep the waters clean. The temporary bund at Kothad and the solid waste heap upstream do apparently weigh on its self-purification capacity. Salinity levels were steadily on the rise until after April. Sharp fluctuations in pH levels are presumably due to fugitive discharges. Fish kills are reported from time to

		June. Phosphate increases until early June and then decreases. Total iron falteringly rises over the summer. Water is never alkaline and is often very acidic which is not expected of a tidal embayment. This implies that factors other than sewage pollution and tidal dynamics are overtly or covertly operating in the system. Acidic discharges from the chemical industries upstream could be surmised. The violent fluctuation of alkalinity provokes precipitation and solubilization of iron alternately. .	time
11	Canals of West Cochin	Fast becoming coloured after the temporary post-monsoonal clarification. West Cochin is confronted with extreme cases of municipal pollution. Pathayathod, just behind the Government Hospital, is the most polluted. Pandarachal is plagued by eutrophication in the summer	The canals of West Cochin present a different temporal pattern. These canals begin at a certain part of the estuary and end up in yet another part of the estuary. During the rainy season, fresh water confounded by municipal waste accumulated in the

		months and has high diurnal DO and alkalinity. But at the onset of Monsoon, water turns anoxic and fishes come to the surface gasping for oxygen, only to fall prey to the lurking fishermen. Towards the end of February, salinity reaches its zenith. Pallichal, Karuvelippady, Perumpadap and Edakochi showed the highest levels of salinity in late February. From mid September to mid April, all the canals are very saline and hard. As a fresh water source, these canals have no relevance because the waters are prohibitively saline all through the year. From early December to late April, chloride level is very close to or even equal to that of sea water. By mid May, chloride level stoops to brackish water level and yet it undergoes swift alteration in tune with the local weather. The water is alkaline because of sewage and marine influence. . Right now, as	canals effectively warding off seawater intrusion. As a result, all the canals turn anoxic and heavily polluted. In many parts, water becomes thick and nauseous slurry haunted by an uneasy stench. The waste is trapped in the canals and flushing does not take place. Once the rainy season is run out picture takes a turn for the good. When the fresh water pressure is slackened, estuarine water barges in from one side and flushes out the wastes accumulated over the months. Spatial asynchronism in the tidal pendulum does the trick. As the tidal paroxysm sweeps past, no two parts separated by a few kilometers, are having the same water level and this phenomenon gives rise to a water gradient. So

		the analyses indicate, the canal's water quality is far better than the well water of this region, except for salt content. According to a study conducted in this region, sulfate in ground water samples ranges from 59 mg/L to BDL But the canals register sulfate levels many times more than the background. Similarly, total hardness of the ground-water samples ranged from 123 to 300 mg/L, whereas in the canals, hardness crosses 1500 mg/L in the lean months. (Thankachan Anitha, 2001). This fact proves that direct salinity intrusion is the predominant factor in the chemistry of the canals of West Cochin.	water flows to and fro in the canals in phase with tidal pendulum. By January the water in all the canals of this region becomes surprisingly clear. Biological activity is stalled and no aquatic life is visible during this period. But in a few days time, the canals assume estuarine characteristics
12	Punchathod-Kharee thod	Mosquitoes breed and multiply. Kari thod is a shallow tidal canal with dense residential areas on either side. Nitrate reaches a maximum and suddenly falls in May. From late November to the first week of May, the water is	Punchathod west of NH-47 By pass has dried out lately. Both canals are marred by enormous influx of domestic waste. Punchathod has the same environmental setting as that

		saline. The southern part of the canal has hard water all through the summer months. But the northern part is hard immediately after the rainy season is over. Phosphate peaks in mid April and then climbs down. The reason is that even slight rains can flush this shallow canal. This canal is flushed very fast by a moderate rain and with equal rapidity it turns anoxic, coloured and stinking when rains shy away for a day or two. The reason is that the residents on either side of the canal vent the sewage and solid waste generated by them straight into the canal and go Scot free. .	of Kari thod. The segment west of NH Bypass suffers no tidal influence. Hence chloride level remains stable irrespective of climatic stages. When summer days progress, fresh water segment dries out in many parts. The water east of the Bypass is saline from early February to early May. Here domestic waste-water occupies a significant volume of the water. Nitrate suddenly peaks in May and total iron keeps rising in the early stages of the rainy season

3.3 Salient Characteristics

The qualitative changes brought about by the salinity intrusion are not in conformity with the expected patterns discussed in the first chapter. Phosphate level sharply falls in the initial stages of salinity intrusion, as it is precipitated by cations of oceanic origin. But Phosphate level recovers from the initial slump and rises in line with chloride and peaks along with chloride, and then curiously enough, falls in phase with chloride. Phosphate level rises because the sewage input is not flushed out as residual flow becomes too weak to take care of the nutrient load. Anoxic or near anoxic conditions prevailing during the dry months corroborate this fact. But P should fall when Cl rises. It does not happen so because the expected rise in alkalinity and pH does not happen and also because of the accumulation of sewage. Thus phosphate remains in suspension all along the dry months. The reason why alkalinity does not rise with the intrusion of cations is to be explained in terms of carbonate-bicarbonate balance.

The governing equation is $CO_2 + H_2O \quad H_2CO_3 \quad H^+ + HCO_3$

When H^+ ions are added to the system bicarbonates and protons are consumed to keep the proton concentration constant producing H_2CO_3. When OH^- ions are added to the system, H^+ ions are consumed forming water more H^+ ions are produced by the dissociation of carbonic acid to form protons and bicarbonate. Insoluble calcium carbonate molecules play a crucial role in this reversible buffering reaction.

But it is to be assumed that intrusion of marine cations does not reach significant levels to initiate a perceptible change in the local aquatic chemistry. It is interesting that total hardness and sulfate ephemerally fall sharply in February after the initial rise, which coincides with the fall in phosphate; and alkalinity temporarily rises at this stage. The plant nutrients NO_3-N and PO_4 -P are never above the dangerous levels in the water bodies. Total iron, for one, is in most cases above the recommended levels. But iron is not a grave aquatic pollutant; it is more of an aesthetic deterrent. But the phosphate levels found are often more than sufficient to promote eutrophication.

The statistics of the quality parameters of each sampling point is shown in the tables 3.2 to 3.83

ADIMURITHODU

Table 3.2 Confluence

Parameters	SD	Mean	Range
pH	0.5	7.2	1.6
Alk(mg CaCO3/L)	91.2	206.2	286.7
DO(mg/L)	1	1.5	3.9
BOD(mg/L)	0.4	0.4	1.3
COD(mg/L)	63.6	70.9	214.7
Fe(microgram/L	295.8	425.6	966.7
SO4(mg/L)	12.6	16.3	37.5
PO4(microgram/L)	445.5	750.7	1420.9
CaH(mg CaCO3/L)	30.5	88.4	110
TH(mg CaCO3/L)	37.9	123.5	138
Cond(millimho/cm)	0.2	0.2	0.6
Cl(mg/L)	74.6	79.4	264.6
NO3(mg/L)	0.4	0.4	1.3

TAble.3.3 Thriveni Road

Parameters	SD	Mean	Range
pH	0.5	7.3	1.8
Alk(mg CaCO3/L)	415.7	227	390.5
DO(mg/L)	0.8	2.2	2.5
BOD(mg/L)	1	0.7	2.6
COD(mg/L)	65.9	69.5	260.3
Fe(microgram/L	366.5	462.9	1137.2
SO4(mg/L)	11.4	16.8	38.5
PO4(microgram/L)	453.9	729.8	1946.8
CaH(mg CaCO3/L)	41.7	100.9	158
TH(mg CaCO3/L)	44.8	128.2	164
Cond millimho/cm ()	0.2	0.3	0.5
Cl(mg/L)	65.4	66.1	181.1
NO3(mg/L)	1	0.7	2.6

CHITRAPUZHA

Table 3.4 Manakkodam Palam

Parameters	SD	Mean	Range
pH	3.8	6.4	0.8
Alk(mg CaCO3/L)	40.7	38.3	55.1
DO(mg/L)	72.7	1.8	5
BOD(mg/L)	36.9	11.8	15.6
COD(mg/L)	125.8	40	179.9
Fe(microgram/L	108.9	436.5	1369.7
SO4(mg/L)	119.3	7.8	32.7
PO4(microgram/L)	183.4	33.7	190.7
CaH(mg CaCO3/L)	41.3	14.4	22.6
TH(mg CaCO3/L)	42.8	18.4	31.6
Cond(millimhocm)	93.9	0.2	0.5
Cl(mg/L)	237	47.9	432.2
NO3(mg/L)	237	0.7	5

Table 3.5 Veegaland

Parameters	SD	Mean	Range
pH	3.8	6.4	0.8
Alk(mg CaCO3/L)	43	42.1	71.4
DO(mg/L)	137	1.7	8.1
BOD(mg/L)	55.8	9.5	19.4
COD(mg/L)	116.3	37.9	159.9
Fe(microgram/L	97.9	430.4	1131.4
SO4(mg/L)	115.8	5.6	25
PO4(microgram/L)	211	55.6	40.5
CaH(mg CaCO3/L)	37.1	13.2	18.6
TH(mg CaCO3/L)	37.2	18.9	21.6
Cond(millimho/cm)	85.9	0.2	0.5
Cl(mg/L)	205.1	30.4	238
NO3(mg/L)	205	0.1	8.1

Table 3.6 CSEZ Pumphouse

Parameters	SD	Mean	Range
pH	5.1	6.5	1.2
Alk(mg CaCO3/L)	48.7	37.2	63.2
DO(mg/L)	50.3	3.5	6.7
BOD(mg/L)	61.9	9.2	17.4
COD(mg/L)	115.7	39.7	152.1
Fe(microgram/L	109.2	235.5	873.1
SO4(mg/L)	124.3	13.9	49.1
PO4(microgram/L)	132	26.9	118.2
CaH(mg CaCO3/L)	76.8	18.3	40.7
TH(mg CaCO3/L)	82	25.8	73.7
Cond(millimhocm)	94.1	0.2	0.6
Cl(mg/L)	255.1	59.8	578.9
NO3(mg/L)	10358.6	0.1	0.3

Table 3.7 Edachira Thodu

Parameters	SD	Mean	Range
pH	5.3	6.4	1.1
Alk(mg CaCO3/L)	37.6	36.9	47
DO(mg/L)	51.2	1.6	2.7
BOD(mg/L)	61.9	9.2	17.4
COD(mg/L)	22.2	127.8	920.6
Fe(microgram/L	110.4	447.6	1717.9
SO4(mg/L)	97.7	6.1	23.5
PO4(microgram/L)	89.5	35.8	88.8
CaH(mg CaCO3/L)	41.5	17.3	26.7
TH(mg CaCO3/L)	115.7	32.5	152.6
Cond(millimho/cm)	97.6	0.2	0.6
Cl(mg/L)	287.9	155.4	1701.2
NO3(mg/L)	13405.8	0.1	0.3

CHITHRAPUZHA

Table 3.8 Irumpanam Palam

Parameters	SD	Mean	Range
pH	4.8	6.4	1.3
Alk(mg CaCO3/L)	44.4	40.9	54.7
DO(mg/L)	44.8	2.3	4.4
BOD(mg/L)	7.4	17.5	43.3
COD(mg/L)	152.5	90.5	486.6
Fe(microgram/L	173	279	1729.3
SO4(mg/L)	112.3	54.9	185.6
PO4(microgram/L)	77.7	1392	3429.1
CaH(mg CaCO3/L)	135	186.9	885
TH(mg CaCO3/L)	120.2	272.9	1069.7
Cond(millimhocm)	146.9	0.8	3.9
Cl(mg/L)	120.2	948.2	326.5
NO3(mg/L)	5131.1	0.5	1.1

Table 3.9 Crematorium

Parameters	SD	Mean	Range
pH	6.9	6.3	1.6
Alk(mg CaCO3/L)	45.6	39.1	60
DO(mg/L)	68.6	2.75	7.7
BOD(mg/L)	62.5	13	27.7
COD(mg/L)	195.6	123.6	786.4
Fe(microgram/L	133.3	246.2	946.2
SO4(mg/L)	120.4	56.2	230.8
PO4(microgram/L)	105.5	1660	6562
CaH(mg CaCO3/L)	194.7	109.4	791.3
TH(mg CaCO3/L)	161.6	164.9	981.5
Cond(millimho/cm)	150.4	0.5	3.1
Cl(mg/L)	167.8	428.3	2636.9
NO3(mg/L)	3047.3	0.6	1.7

Table 3.10 Ambalamugal

Parameters	SD	Mean	Range
pH	5.4	6.5	1.3
Alk(mg CaCO3/L)	42.4	35.7	54.7
DO(mg/L)	59	2.1	4.6
BOD(mg/L)	45.1	9.9	12.5
COD(mg/L)	126.7	36.3	167.9
Fe(microgram/L	106.3	311.1	908.3
SO4(mg/L)	98.7	6.4	21
PO4(microgram/L)	99.6	71.8	218.9
CaH(mg CaCO3/L)	40.9	1.2	14
TH(mg CaCO3/L)	52.6	165	36
Cond(millimho/cm)	92	0.2	0.7
Cl(mg/L)	184	45.8	318.5
NO3(mg/L)	4450.2	0.3	0.6

Table 3.11 Brahmapuram

Parameters	SD	Mean	Range
pH	5.4	6.5	1.3
Alk(mg CaCO3/L)	33.1	33.5	56.3
DO(mg/L)	52.6	2.4	4.6
BOD(mg/L)	47.7	9.15	15.1
COD(mg/L)	100.4	41	156
Fe(microgram/L	130.5	369.3	1623.9
SO4(mg/L)	103.8	11.5	43.7
PO4(microgram/L)	162.3	321.5	1494.5
CaH(mg CaCO3/L)	46.9	17.3	30.6
TH(mg CaCO3/L)	55.8	267	56
Cond(millimho/cm)	95	0.2	0.6
Cl(mg/L)	165.2	88.6	448.2
NO3(mg/L)	8861.1	0.2	0.4

Table 3.12 Kaniyampuzha

Parameters	SD	Mean	Range
pH	4.7	6.7	1.2
Alk(mg CaCO3/L)	41.2	56.3	73.6
DO(mg/L)	41	2.9	4.2
BOD(mg/L)	80.2	12	35.4
COD(mg/L)	162.6	290.5	1580.8
Fe(microgram/L	201.5	390.6	2852.3
SO4(mg/L)	194.2	170.2	1244.2
PO4(microgram/L)	81.7	1012.7	2894.8
CaH(mg CaCO3/L)	117.2	656.1	2479.8
TH(mg CaCO3/L)	112.8	967.5	3287.9
Cond(millimho/cm)	141.3	2	9.3
Cl(mg/L)	109.5	3119.4	8688.5
NO3(mg/L)	109.5	0.6	4.2

EDAPPALLY THOD

Table 3.13 Ambalappara

Parameters	SD	Mean	Range
pH	4.2	6.9	0.8
Alk(mg CaCO3/L)	27.3	101.5	93.6
DO(mg/L)	87.4	1.9	5
BOD(mg/L)	204.5	45.6	346.6

Table 3.14 Quarry

Parameters	SD	Mean	Range
pH	9.4	7.3	1.9
Alk(mg CaCO3/L)	64.3	129.4	168.2
DO(mg/L)	89.4	4.5	11.5
BOD(mg/L)	74.7	35.6	72.5

COD(mg/L)	73.4	103.3	243.1
Fe(microgram/L	117.3	205.9	486.4
SO4(mg/L)	117.1	105.2	327.8
PO4(microgram/L)	116.6	987.3	3220.5
CaH(mg CaCO3/L)	134.4	447.9	1664
TH(mg CaCO3/L)	121.5	708.2	2234
Cond(millimho/cm)	151.5	1.5	7.6
Cl(mg/L)	129.4	2232.5	6512
NO3(mg/L)	142.7	0.3	1.7

COD(mg/L)	61.9	129	308
Fe(microgram/L	87.2	179.9	363.5
SO4(mg/L)	82.9	111.7	261.7
PO4(microgram/L)	95.8	1185.7	3142
CaH(mg CaCO3/L)	124.5	421.8	1378
TH(mg CaCO3/L)	102	675.2	1786
Cond(millimhocm)	132.6	1.4	6.3
Cl(mg/L)	109.2	2270.8	6011.9
NO3(mg/L)	174.2	0.5	2.7

Table 3.15 Palachuvadu

Parameters	SD	Mean	Range
pH	4.3	6.9	0.8
Alk(mg CaCO3/L)	39.3	124.7	185
DO(mg/L)	55.4	1.3	2.2
BOD(mg/L)	68.1	20.1	39
COD(mg/L)	137.9	87.4	470.8
Fe(microgram/L	103.4	288.2	636.5
SO4(mg/L)	117.5	103.4	341.5
PO4(microgram/L)	123	930.4	2916.3
CaH(mg CaCO3/L)	131.6	476.9	1560
TH(mg CaCO3/L)	123.1	659.3	2144
Cond(millimho/cm)	148.4	1.4	6.8
Cl(mg/L)	132.3	2042.5	6512
NO3(mg/L)	151.9	0.5	2.4

Table 3.16 Workshop

Parameters	SD	Mean	Range
pH	5.4	6.9	1.2
Alk(mg CaCO3/L)	36.3	113.1	134.2
DO(mg/L)	123.7	1.36	3
BOD(mg/L)	93.5	26.6	70.7
COD(mg/L)	63	118.8	258.8
Fe(microgram/L	113.3	405.2	1580.8
SO4(mg/L)	106.4	107.3	316.7
PO4(microgram/L)	99.4	1080.7	3026.4
CaH(mg CaCO3/L)	131.1	456.7	1476
TH(mg CaCO3/L)	106.4	705.5	1816
Cond(millimho/cm)	148.6	1.5	8
Cl(mg/L)	116.1	2042.6	6676.8
NO3(mg/L)	4097	0.3	1

Table 3.17 Attipetinagar

Parameters	SD	Mean	Range
pH	3.4	6.9	0.8
Alk(mg CaCO3/L)	43.2	155.9	203.5
DO(mg/L)	93.5	0.8	1.6
BOD(mg/L)	80.2	20.3	55.9
COD(mg/L)	70.4	55.5	159.2
Fe(microgram/L	89.1	366.8	703.8
SO4(mg/L)	110.7	58.9	164.9
PO4(microgram/L)	119.2	654.5	2042.5
CaH(mg CaCO3/L)	131.5	187.2	870
TH(mg CaCO3/L)	117.2	280.9	1044
Cond(millimho/cm)	159.5	0.6	3.4
Cl(mg/L)	150.3	617.5	2779.5
NO3(mg/L)	158.5	0.8	3.3

Table 3.18 Marottichuvadu

Parameters	SD	Mean	Range
pH	3.7	6.8	0.7
Alk(mg CaCO3/L)	59.2	133.9	220
DO(mg/L)	99.4	0.8	2.2
BOD(mg/L)	93.6	25.4	69.2
COD(mg/L)	67.1	47.1	116.4
Fe(microgram/L	88.6	721.7	2187.1
SO4(mg/L)	70.3	26.6	56.2
PO4(microgram/L)	218.9	1205.6	10240
CaH(mg CaCO3/L)	26.2	67.9	72
TH(mg CaCO3/L)	23.5	82.5	76
Cond(millimho/cm)	66.1	0.2	0.4
Cl(mg/L)	124.1	82.2	328
NO3(mg/L)	159.6	0.6	3.3

Table 3.19 Level Cross

Parameters	SD	Mean	Range
pH	5.4	6.6	1.1
Alk(mg CaCO3/L)	56.5	96.9	168
DO(mg/L)	55.7	0.9	1.4
BOD(mg/L)	70	22.1	58.9
COD(mg/L)	51.6	39.9	84
Fe(microgram/L	65.8	432.5	734.3
SO4(mg/L)	62.4	19.1	39.6
PO4(microgram/L)	53.1	306.7	590.5
CaH(mg CaCO3/L)	34.8	50.5	60
TH(mg CaCO3/L)	35.3	64.3	66
Cond(millimho/cm)	64.6	0.2	0.3
Cl(mg/L)	142.8	112.2	527.5
NO3(mg/L)	82.4	0.3	0.8

Table 3.20 Muttar Kadav

Parameters	SD	Mean	Range
pH	5.7	6.5	1.2
Alk(mg CaCO3/L)	53.3	67.1	112.1
DO(mg/L)	85.9	1	2.63
BOD(mg/L)	68.5	16.8	37.1
COD(mg/L)	68.1	43.2	91.2
Fe(microgram/L	61.6	338.4	666.5
SO4(mg/L)	90.9	23.6	69.4
PO4(microgram/L)	79.8	295.5	914.6
CaH(mg CaCO3/L)	51.4	41.7	68
TH(mg CaCO3/L)	55.3	59.6	120
Cond(millimho/cm)	75.5	0.2	0.5
Cl(mg/L)	130.9	130.5	438.6
NO3(mg/L)	192.9	0.4	2.7

Table 3.21 Muttarpuzha

Parameters	SD	Mean	Range
pH	7.3	6.3	1.2
Alk(mg CaCO3/L)	33.5	48.2	63

DO(mg/L)	90.2	1.7	4.4
BOD(mg/L)	66.6	14.2	32.2
COD(mg/L)	97.8	31.5	106.4
Fe(microgram/L	114.7	448.7	1951.9
SO4(mg/L)	90.2	16.5	44.7
PO4(microgram/L)	60.2	463.9	836.9
CaH(mg CaCO3/L)	58.3	28.6	53
TH(mg CaCO3/L)	64.9	40.2	786
Cond(millimho/cm)	70.6	0.2	0.4
Cl(mg/L)	155.5	95.9	485.2
NO3(mg/L)	157.6	0.3	1.8

KHAREE THOD

Table 3.22 Ponnurunni

Parameters	SD	Mean	Range
pH	0.9	7.3	3.5
Alk(mg CaCO3/L)	86.4	197.1	279
DO(mg/L)	0.9	0.9	2.6
BOD(mg/L)	12.9	20.9	33.8
COD(mg/L)	54.9	100.8	200.7
Fe(microgram/L	482.3	484.2	1445.7
SO4(mg/L)	97.9	79.3	369.1
PO4(microgram/L)	714.9	1107.4	2423.8
CaH(mg CaCO3/L)	307.8	279.4	970
TH(mg CaCO3/L)	445.5	453.7	1112
Cond(millimho/cm)	1.2	0.9	4.2
Cl(mg/L)	1881.2	1407.2	5056.1
NO3(mg/L)	0.7	0.4	2.5

Table 3.23 Chakaraparamb

Parameters	SD	Mean	Range
pH	0.5	7.4	1.6
Alk(mg CaCO3/L)	83.2	249.8	294
DO(mg/L)	0.7	0.8	1.9
BOD(mg/L)	17.3	29.6	67.4
COD(mg/L)	53.9	80.7	208.3
Fe(microgram/L	588.9	566.6	1788.9
SO4(mg/L)	28.3	32.3	115.2
PO4(microgram/L)	775.5	1138.3	2244.4
CaH(mg CaCO3/L)	277.4	198.5	1120
TH(mg CaCO3/L)	450.9	287.4	1720
Cond(millimho/cm)	6.3	2	23.9
Cl(mg/L)	1458.7	568.1	5545.8
NO3(mg/L)	0.2	0.2	0.8

MULLASSERI CANAL

Table3.24 Yathra Auditorium

Parameters	SD	Mean	Range
pH	0.5	7.1	1.5
Alk(mg CaCO3/L)	105.7	235.3	351
DO(mg/L)	0.5	0.4	1.4
BOD(mg/L)			
COD(mg/L)			
Fe(microgram/L	327.4	403.9	937
SO4(mg/L)	143.7	121.3	447.5
PO4(microgram/L)	750.2	927.6	2999.4
CaH(mg CaCO3/L)	593.4	619.6	1530
TH(mg CaCO3/L)	1182.6	1150.6	3454
Cond(millimho/cm)	1.8	1.5	5.5
Cl(mg/L)	4049.3	3172.9	10841.2
NO3(mg/L)	1.2	0.6	4.4

Table 3.25 KSRTC West

Parameters	SD	Mean	Range
pH	0.4	7.1	1.5
Alk(mg CaCO3/L)	117.9	310.3	349
DO(mg/L)	0.7	0.7	1.9
BOD(mg/L)			
COD(mg/L)			
Fe(microgram/L	404.6	572.1	1195.6
SO4(mg/L)	35.9	43.3	128.3
PO4(microgram/L)	866.9	1498.1	2990.5
CaH(mg CaCO3/L)	293.9	219.6	1141.2
TH(mg CaCO3/L)	432.4	352.1	1581
Cond(millimho/cm)	0.5	0.4	1.9
Cl(mg/L)	174	191.7	558.1
NO3(mg/L)	1.4	0.7	0.7

PERANDOOR CANAL

Table 3.26 CBI North

Parameters	SD	Mean	Range
pH	6.2	7	1.3
Alk(mg CaCO3/L)	48.2	198.5	322.7
DO(mg/L)	106.4	0.7	2.8
BOD(mg/L)	76.5	37.7	75.7
COD(mg/L)	132.9	109.9	528.2
Fe(microgram/L	70.5	515.8	1106.8
SO4(mg/L)	144.4	50.3	278.4
PO4(microgram/L)	63.6	550.5	1314
CaH(mg CaCO3/L)	63.2	144.1	331.7

Table 3.27 Pullepady

Parameters	SD	Mean	Range
pH	5.2	7	1.3
Alk(mg CaCO3/L)	43.1	228.3	370.2
DO(mg/L)	178.4	0.5	3
BOD(mg/L)	67.6	40.5	73.7
COD(mg/L)	112.5	165.1	553.8
Fe(microgram/L	75.3	646.9	1765
SO4(mg/L)	118.2	40.5	174.1
PO4(microgram/L)	62.1	1056.3	2067.8
CaH(mg CaCO3/L)	103.4	111.2	456.3

TH(mg CaCO3/L)	64.7	186.4	443
Cond(millimho/cm)	69.8	0.3	0.6
Cl(mg/L)	71.5	106.9	277.3
NO3(mg/L)	115	0.3	1.2

TH(mg CaCO3/L)	67.1	160.2	439
Cond(millimho/cm)	60.2	0.3	0.7
Cl(mg/L)	68.7	81.2	178.8
NO3(mg/L)	127.1	0.3	1.2

Table 3.28 Kaloor Market

Parameters	SD	Mean	Range
pH	5.2	7	1.2
Alk(mg CaCO3/L)	40.9	284.1	383.7
DO(mg/L)	171.9	0.4	2.7
BOD(mg/L)	49.7	44.8	67.2
COD(mg/L)	79.4	146.3	399
Fe(microgram/L	91.6	584.6	1601.9
SO4(mg/L)	85.8	44.1	142.4
PO4(microgram/L)	46.4	1478.2	2029.4
CaH(mg CaCO3/L)	39.9	128.4	195.3
TH(mg CaCO3/L)	60.3	184.6	435
Cond(millimho/cm)	54.7	0.3	0.5
Cl(mg/L)	93.6	211.2	710.2
NO3(mg/L)	155.7	0.4	2.4

Table 3.29 Aryampadam

Parameters	SD	Mean	Range
pH	5.4	7.2	1.2
Alk(mg CaCO3/L)	35.8	214.9	259
DO(mg/L)	100	1.2	3.7
BOD(mg/L)	58.7	31.8	66
COD(mg/L)	85.5	75.6	205.2
Fe(microgram/L	86.7	339.5	163.2
SO4(mg/L)	54.5	23.5	42
PO4(microgram/L)	46	979.5	1133.7
CaH(mg CaCO3/L)	63.4	107.1	204
TH(mg CaCO3/L)	64.8	135.9	350
Cond(millimho/cm)	73.2	0.3	0.8
Cl(mg/L)	75.3	105.3	234.8
NO3(mg/L)	19.7	0.6	4.5

Table 3.30 Perandoor Railwaybridge

Parameters	SD	Mean	Range
pH	5.5	6.9	1.3
Alk(mg CaCO3/L)	44.1	109.6	189.9
DO(mg/L)	65.3	1.7	3.1
BOD(mg/L)	85.3	24.9	75.5
COD(mg/L)	90.9	134.9	438.3
Fe(microgram/L	125.6	209.8	869.4
SO4(mg/L)	118.1	106	384.8
PO4(microgram/L)	70.5	493.8	1168.1
CaH(mg CaCO3/L)	108	510.8	1590
TH(mg CaCO3/L)	16.4	839.3	2548
Cond(millimho/cm)	103.7	1.4	4.8
Cl(mg/L)	117	2448.1	6913.8
NO3(mg/L)	140	0.5	2.5

PUNCHATHOD

Table 3.31 East of Bypass

Parameters	SD	Mean	Range
pH	6.7	7.2	1.7
Alk(mg CaCO3/L)	37.6	228.3	331
DO(mg/L)	96.2	0.9	2.7
BOD(mg/L)	73.3	28.6	64.9
COD(mg/L)	80.5	111.5	308.3
Fe(microgram/L	103.3	748	2106.1
SO4(mg/L)	129.9	40.5	163.6
PO4(microgram/L)	76.1	744.7	1755.8
CaH(mg CaCO3/L)	122.2	191	122.2
TH(mg CaCO3/L)	114.4	253.8	1028
Cond(millimho/cm)	125	0.5	1.9
Cl(mg/L)	229.7	452.8	3637
NO3(mg/L)	104.1	0.2	0.8

Table 3.32 Railway bridge Kaniyampuzha

Parameters	SD	Mean	Range
pH	6	7.2	1.4
Alk(mg CaCO3/L)	39.3	185.4	230.1
DO(mg/L)	85.1	1.2	3.6
BOD(mg/L)	53	21.5	38.6
COD(mg/L)	70	85.6	200
Fe(microgram/L	129.7	586.5	2167.2
SO4(mg/L)	110.7	64.5	247.4
PO4(microgram/L)	77.1	850.9	2122.5
CaH(mg CaCO3/L)	126.3	333.5	1260
TH(mg CaCO3/L)	132.9	519	1980
Cond(millimho/cm)	187.1	1.1	7.8
Cl(mg/L)	166.2	1455.4	7000.1
NO3(mg/L)	173.1	0.4	2.2

Table 3.33 Narothu Road

Parameters	SD	Mean	Range
pH	5.4	7.2	1.3
Alk(mg CaCO3/L)	28.3	182	172.7
DO(mg/L)	56.1	0.9	2
BOD(mg/L)	54	15.1	28.1
COD(mg/L)	82.7	61.2	188
Fe(microgram/L	102.6	710.5	2249.2

Table. 3.34 Aisha Road

Parameters	SD	Mean	Range
pH	7.6	7.1	1.7
Alk(mg CaCO3/L)	29.7	191.9	214
DO(mg/L)	71.3	0.8	2
BOD(mg/L)	67.5	17.3	34.6
COD(mg/L)	152.4	98	512
Fe(microgram/L	114.2	680.4	2026.2

SO4(mg/L)	74.7	15.8	33.2	SO4(mg/L)	85	17.5	36.1
PO4(microgram/L)	66.8	630.5	1227.7	PO4(microgram/L)	62.4	536.8	938.1
CaH(mg CaCO3/L)	34.7	84.8	100	CaH(mg CaCO3/L)	38.5	90.5	100
TH(mg CaCO3/L)	31.4	119.9	140	TH(mg CaCO3/L)	33.7	129.1	148
Cond(millimho/cm)	57.1	0.3	0.5	Cond(millimho/cm)	64.1	0.3	0.5
Cl(mg/L)	100.1	69.7	232.6	Cl(mg/L)	51.5	43.7	83
NO3(mg/L)	108.5	0.3	1	NO3(mg/L)	157.8	0.2	1.2

WEST KOCHI

Table 3.35 Pallichal Thodu

Parameters	SD	Mean	Range
pH	4.6	7.2	1.2
Alk(mg CaCO3/L)	40.8	310.4	492.9
DO(mg/L)	269.6	0.3	3
BOD(mg/L)	55.5	37.4	75.9
COD(mg/L)	74.5	301.9	365.4
Fe(microgram/L	111.2	253.1	780
SO4(mg/L)	90.3	143.1	389.2
PO4(microgram/L)	66.7	1532.5	3592.2
CaH(mg CaCO3/L)	92.9	1063.6	2439
TH(mg CaCO3/L)	85.3	1754.8	4084.8
Cond(millimho/cm)	128.4	2.4	11.4
Cl(mg/L)	110.7	5188.5	16684.6
NO3(mg/L)	110.7	0.3	1.3

Table 3.36 Pashnithodu

Parameters	SD	Mean	Range
pH	3.1	7.3	0.9
Alk(mg CaCO3/L)	37.9	94.8	106
DO(mg/L)	25.5	2.8	2.5
BOD(mg/L)	79.8	15.8	37.2
COD(mg/L)	81.4	438.7	1055.2
Fe(microgram/L	96.5	282.9	608
SO4(mg/L)	110.8	278.1	1181
PO4(microgram/L)	65.4	273.3	595.9
CaH(mg CaCO3/L)	89.1	1112.9	2531.6
TH(mg CaCO3/L)	88.2	2539.3	6884.8
Cond(millimho/cm)	98.9	3	10.4
Cl(mg/L)	88.9	7983.4	17805.9
NO3(mg/L)	45.7	0.3	0.4

Table 3.37 Pashnithodu near Perumpadappu

Parameters	SD	Mean	Range
pH	3.7	7.3	1
Alk(mg CaCO3/L)	41.1	95.2	116
DO(mg/L)	25.4	3.4	2.5
BOD(mg/L)	74.9	16.7	41
COD(mg/L)	82.9	382.2	853.4
Fe(microgram/L	114.3	132	404.9
SO4(mg/L)	64.9	213.8	366
PO4(microgram/L)	188.2	455.2	3378.6
CaH(mg CaCO3/L)	98.3	1165.5	3342.4
TH(mg CaCO3/L)	85.8	2424.9	5695.6
Cond(millimho/cm)	100.5	3	10.4
Cl(mg/L)	78.8	7647.9	14354.3
NO3(mg/L)	61.4	0.2	0.4

Table 3.38 Pandarachal

Parameters	SD	Mean	Range
pH	3.9	7.5	1.2
Alk(mg CaCO3/L)	54.5	183	391.2
DO(mg/L)	64	2.5	6.1
BOD(mg/L)	57	23.1	39.8
COD(mg/L)	80.7	374.6	990.4
Fe(microgram/L	111.6	101.1	320
SO4(mg/L)	114.4	263.9	1181.7
PO4(microgram/L)	74	664.7	1462.8
CaH(mg CaCO3/L)	76.9	1254.9	2516.4
TH(mg CaCO3/L)	77.9	2283.2	4570.4
Cond(millimho/cm)	101.4	2.9	10
Cl(mg/L)	88.2	7491.5	18272.7
NO3(mg/L)	74.9	0.2	0.6

Table 3.39 Mundamveli

Parameters	SD	Mean	Range
pH	3.9	7.4	1.1
Alk(mg CaCO3/L)	35.7	383.9	477.8
DO(mg/L)	274.4	0.2	1.8
BOD(mg/L)	46.1	44.3	61.9
COD(mg/L)	113.6	318.1	1223.4
Fe(microgram/L	165.8	417.6	2720
SO4(mg/L)	66.5	137.8	244.7
PO4(microgram/L)	59.6	1760.6	3347.6
CaH(mg CaCO3/L)	91.4	971.5	2550
TH(mg CaCO3/L)	93	1458.2	4486.6
Cond(millimho/cm)	104.8	1.8	6.5
Cl(mg/L)	108.3	4245.7	13328.3
NO3(mg/L)	72.6	0.3	0.5

Table 3.40 Pathaya Thod

Parameters	SD	Mean	Range
pH	5.2	7.4	1.3
Alk(mg CaCO3/L)	43.2	340.5	485.9
DO(mg/L)	163.8	0.6	3.2
BOD(mg/L)	91.2	51.9	188.3
COD(mg/L)	112.7	440.2	1281.7
Fe(microgram/L	138.2	365.5	1838.2
SO4(mg/L)	179.4	393.6	2748.6
PO4(microgram/L)	67.6	1406.2	3506.2
CaH(mg CaCO3/L)	88.5	1015.9	2919
TH(mg CaCO3/L)	81.1	2019.2	4361.4
Cond(millimho/cm)	112.4	2.5	9.5
Cl(mg/L)	88.4	7060.8	15512.5
NO3(mg/L)	56.2	0.2	0.3

CHITTOORPUZHA

Table 3.46 Vaduthala Bridge

Parameters	SD	Mean	Range
pH	2.7	6.8	0.6
Alk(mg CaCO3/L)	37.4	57.9	67.8
DO(mg/L)	45.6	2.1	2.7
BOD(mg/L)	64.3	11.7	20.5
COD(mg/L)	130.5	159.9	671.5
Fe(microgram/L	105.3	160.8	442.6
SO4(mg/L)	96.7	152	397.8
PO4(microgram/L)	101.2	276.2	683.7
CaH(mg CaCO3/L)	94.5	684.1	1770
TH(mg CaCO3/L)	87.7	1249.2	2740
Cond(millimho/cm)	99.6	1.9	6.3
Cl(mg/L)	92.7	4110.1	9536
NO3(mg/L)	87.9	0.4	1.3

Table 3.47 Chittoor Ferry

Parameters	SD	Mean	Range
pH	2.9	6.8	0.6
Alk(mg CaCO3/L)	51	53.8	91.2
DO(mg/L)	22.9	4.6	3.5
BOD(mg/L)	72.7	13.3	28.8
COD(mg/L)	127.8	154.1	644.6
Fe(microgram/L	98.2	250	592.7
SO4(mg/L)	95.8	200.8	543.2
PO4(microgram/L)	106.6	181	604.1
CaH(mg CaCO3/L)	92.9	836.1	1882
TH(mg CaCO3/L)	88.5	1480	3270
Cond(millimho/cm)	93.9	2.2	6.9
Cl(mg/L)	82.3	4794.1	10456.3
NO3(mg/L)	80.5	0.4	1.1

Table 3.48 Kothadu

Parameters	SD	Mean	Range
pH	4.9	6.5	1.1
Alk(mg CaCO3/L)	51.5	50.2	72.4
DO(mg/L)	18.2	3.9	2
BOD(mg/L)	59.6	11.6	19.3
COD(mg/L)	119.4	210	780.7
Fe(microgram/L	155.4	181.2	672
SO4(mg/L)	85.6	168.7	335.4
PO4(microgram/L)	124.7	116.1	464.8
CaH(mg CaCO3/L)	79.3	1015.1	1990
TH(mg CaCO3/L)	72.1	1499	2780
Cond(millimho/cm)	75.3	2.2	5.3
Cl(mg/L)	47.5	5720.4	7347.4
NO3(mg/L)	60.6	0.4	0.8

Table 3.49 Edekkunnam

Parameters	SD	Mean	Range
pH	8.9	6.3	2
Alk(mg CaCO3/L)	35.5	29.8	32.4
DO(mg/L)	20.2	5.3	3.7
BOD(mg/L)	71.9	16.6	38.2
COD(mg/L)	76.2	60.9	140.3
Fe(microgram/L	99.9	210.9	659.3
SO4(mg/L)	100.3	152.3	421.6
PO4(microgram/L)	137.2	132.4	605.4
CaH(mg CaCO3/L)	103.8	386.2	1095
TH(mg CaCO3/L)	93.7	569.6	1470
Cond(millimho/cm)	81.9	0.9	2.2
Cl(mg/L)	103.3	1545.6	4870.4
NO3(mg/L)	63.2	0.3	0.8

Table 3.50 Cheranalloor

Parameters	SD	Mean	Range
pH	5.9	6.3	1.5
Alk(mg CaCO3/L)	48.1	38.9	62.4
DO(mg/L)	38.6	3.4	3.7
BOD(mg/L)	57.8	11.1	22.5
COD(mg/L)	75.7	58.7	116.4
Fe(microgram/L	121.2	250.9	975.7
SO4(mg/L)	100.6	137.8	353.3
PO4(microgram/L)	124	139.8	505
CaH(mg CaCO3/L)	105.3	423.2	1390
TH(mg CaCO3/L)	96.3	613.3	1580
Cond(millimho/cm)	76.2	1.1	2.3
Cl(mg/L)	98.6	1964	5459.9
NO3(mg/L)	63.7	0.3	0.8

Table 3.51 AIMS

Parameters	SD	Mean	Range
pH	10.6	6.2	2.1
Alk(mg CaCO3/L)	46.9	31.6	43.8
DO(mg/L)	49.5	2.6	3.8
BOD(mg/L)	60.7	9	18.2
COD(mg/L)	93.3	66.1	231.5
Fe(microgram/L	124.3	253.4	1152.3
SO4(mg/L)	135.9	95.8	360.3
PO4(microgram/L)	111.4	270.5	812.4
CaH(mg CaCO3/L)	119.7	251.3	895
TH(mg CaCO3/L)	117.6	386.7	1470
Cond(millimho/cm)	82.2	0.6	1.5
Cl(mg/L)	120.3	1136.9	3390.4
NO3(mg/L)	91.9	0.3	1.1

KARANAKODAM THODU

Table 3.52 Chettichira

Parameters	SD	Mean	Range
pH	10.7	7.3	3.1
Alk(mg CaCO3/L)	50.3	162.8	338
DO(mg/L)	116.9	2.3	9.3
BOD(mg/L)	43.8	16.4	22.1
COD(mg/L)	140.3	201.1	968.4
Fe(microgram/L	118.3	272.5	974.8
SO4(mg/L)	125.4	143.4	473.3
PO4(microgram/L)	56.9	896.3	1602
CaH(mg CaCO3/L)	125	689.8	2690

TAble 3.53 Katrikadavu ROB

Parameters	SD	Mean	Range
pH	10.7	7.4	3.1
Alk(mg CaCO3/L)	52.4	248.9	422
DO(mg/L)	160.6	1.4	8.4
BOD(mg/L)	56.2	21.1	32.6
COD(mg/L)	111.2	149.6	624
Fe(microgram/L	86.8	315.7	778.1
SO4(mg/L)	133.8	88.7	359.7
PO4(microgram/L)	74.2	1017.7	2237.8
CaH(mg CaCO3/L)	120.9	483.5	1975

TH(mg CaCO3/L)	114.6	1334.3	3480
Cond(millimho/cm	114.2	2	7.3
Cl(mg/L)	113.3	4347.7	11165
NO3(mg/L)	76	0.3	0.8

TH(mg CaCO3/L)	119.5	814.1	2610
Cond(millimho/cm)	112.1	1.3	4.6
Cl(mg/L)	139	2328.9	8365.8
NO3(mg/L)	90.7	0.4	1.2

Table3.54 Karanakodam

Parameters	SD	Mean	Range
pH	6	7.1	1.5
Alk(mg CaCO3/L)	58.8	247.6	396
DO(mg/L)	117.6	0.6	2.1
BOD(mg/L)	63.8	22.5	47.9
COD(mg/L)	140.7	203.5	915.4
Fe(microgram/L	83.2	405.4	991.7
SO4(mg/L)	135	77.8	291.4
PO4(microgram/L)	77.7	1091	2635
CaH(mg CaCO3/L)	134	369.8	1630
TH(mg CaCO3/L)	121.9	589.8	2090
Cond(millmho/cm)	119.3	1.1	4
Cl(mg/L)	145.8	1648.8	7236.2
NO3(mg/L)	97.4	0.3	0.9

Table 3.55 Railway Yard

Parameters	SD	Mean	Range
pH	6.1	7.1	1.4
Alk(mg CaCO3/L)	57.4	253.7	480.5
DO(mg/L)	125	0.6	2.3
BOD(mg/L)	49.4	25.3	47.3
COD(mg/L)	136.9	14.9.2	748.2
Fe(microgram/L	77.9	379.2	957.8
SO4(mg/L)	137.5	81	296.5
PO4(microgram/L)	28.5	1117.3	2891
CaH(mg CaCO3/L)	115.6	485.9	1730
TH(mg CaCO3/L)	118.4	695.3	2300
Cond(millimho/cm)	122.7	1.1	4.6
Cl(mg/L)	138.8	1815.8	6947.5
NO3(mg/L)	153	0.5	2.6

Table 3.56 VIP Road

Parameters	SD	Mean	Range
pH	6.1	7.1	1.2
Alk(mg CaCO3/L)	44.8	282.4	380.6
DO(mg/L)	93.2	0.9	2.9
BOD(mg/L)	53.6	27.5	52.1
COD(mg/L)	67.6	102.8	286.4
Fe(microgram/L	75.6	761.6	1629.7
SO4(mg/L)	35.7	25	33.7
PO4(microgram/L)	59.9	1130.5	1964.5
CaH(mg CaCO3/L)	31.7	118.5	155
TH(mg CaCO3/L)	25.1	154.6	140
Cond(millimho/cm)	59.2	0.2	0.5
Cl(mg/L)	101.7	116.1	397.8
NO3(mg/L)	128	0.6	2.5

Table 3.57 Pandarachira

Parameters	SD	Mean	Range
pH	8.8	7.3	2
Alk(mg CaCO3/L)	44.5	114.7	168.5
DO(mg/L)	69	3.3	8.1
BOD(mg/L)	74.9	15.2	35.6
COD(mg/L)	133.1	348	1468.2
Fe(microgram/L	86	152.6	423.3
SO4(mg/L)	112.4	135	410.9
PO4(microgram/L)	61.5	898.8	1941
CaH(mg CaCO3/L)	127.8	677.4	2385.9
TH(mg CaCO3/L)	114	1464.5	3841.4
Cond(millimho/cm)	120.7	2	7.9
Cl(mg/L)	111.4	5297.1	15127.7
NO3(mg/L)	114.3	0.5	1.8

Table. 3.58 Chilavanoor

Parameters	SD	Mean	Range
pH	6.5	7.1	1.5
Alk(mg CaCO3/L)	23.4	103.4	79.6
DO(mg/L)	49.2	3.4	5.7
BOD(mg/L)	45.6	9.7	16.4
COD(mg/L)	116.1	457.7	16.88
Fe(microgram/L	104.4	111.2	347.8
SO4(mg/L)	118.1	139.2	421
PO4(microgram/L)	46	720	1328.7
CaH(mg CaCO3/L)	129.1	690.9	2567.7
TH(mg CaCO3/L)	115.3	1488.1	3739.4
Cond(millimho/cm)	117	2.2	8.4
Cl(mg/L)	108.5	5071.2	12215.9
NO3(mg/L)	96.9	0.5	1.5

POORNIPUZHA

Table 3.59 Venkateswara School

Parameters	SD	Mean	Range
pH	8.2	6.8	2
Alk(mg CaCO3/L)	33.4	70.5	75.3
DO(mg/L)	48.2	3.1	5
BOD(mg/L)	80.9	9.6	25.5
COD(mg/L)	131.2	244.9	956
Fe(microgram/L	116.8	150.1	473.9
SO4(mg/L)	101.5	151.4	436.5
PO4(microgram/L)	66.8	591.4	1291
CaH(mg CaCO3/L)	116.2	901.1	2680
TH(mg CaCO3/L)	118	1453.9	49.78
Cond(millimho/cm)	93	2	5
Cl(mg/L)	109.9	4751.6	14079.8
NO3(mg/L)	226.6	0.7	5.5

Table. 3.60 Irumpupalam

Parameters	SD	Mean	Range
pH	5.5	7	1.3
Alk(mg CaCO3/L)	44	63.2	106
DO(mg/L)	34.9	4.2	4.3
BOD(mg/L)	80.6	9.8	27
COD(mg/L)	131.2	199.6	976
Fe(microgram/L	110	104.2	339.6
SO4(mg/L)	104.9	145.3	392.7
PO4(microgram/L)	59.3	592.4	1099.4
CaH(mg CaCO3/L)	113.2	878.2	21.77
TH(mg CaCO3/L)	123.4	57.76	1459.6
Cond(millimho/cm)	95.2	1.9	4.9
Cl(mg/L)	111.1	4752.6	14217.8
NO3(mg/L)	131.6	0.4	1.7

Table.3.61 Petta Bridge

Parameters	SD	Mean	Range
pH	4.9	6.8	1.3
Alk(mg CaCO3/L)	34.9	69.3	74.8
DO(mg/L)	42	3.1	3.6
BOD(mg/L)	71.9	9.8	25.4
COD(mg/L)	202.4	185.6	1404.9
Fe(microgram/L	129.2	111.7	459.3
SO4(mg/L)	105.4	148.8	417.1
PO4(microgram/L)	64.4	720	1493.6
CaH(mg CaCO3/L)	112.9	896.1	2290
TH(mg CaCO3/L)	118.5	1366.1	4386
Cond(millimho/cm)	93.2	1.9	4.6
Cl(mg/L)	111.5	4666.6	12644.5
NO3(mg/L)	184.7	0.5	3.2

Table 3.62Chambakara Market

Parameters	SD	Mean	Range
pH	4.4	6.9	0.9
Alk(mg CaCO3/L)	37.5	66	73.6
DO(mg/L)	30.8	3.1	3.3
BOD(mg/L)	87.1	8.8	24
COD(mg/L)	107.3	230	811.1
Fe(microgram/L	145.3	260.3	1398.3
SO4(mg/L)	112.2	147.7	456.4
PO4(microgram/L)	66.2	767.9	1792.3
CaH(mg CaCO3/L)	115.5	861.7	2582
TH(mg CaCO3/L)	117.9	1311.2	39.82
Cond(millimho/cm)	92.1	1.9	4.3
Cl(mg/L)	108.8	4503.4	11880.2
NO3(mg/L)	142.6	0.7	3.4

Table 3.63 Konnarathodu

Parameters	SD	Mean	Range
pH	4.1	6.9	0.8
Alk(mg CaCO3/L)	45.5	124.5	166.3
DO(mg/L)	47.8	2.1	3.3
BOD(mg/L)	77.5	12.3	34.2
COD(mg/L)	93.2	163.2	449
Fe(microgram/L	94.9	281.7	953.1
SO4(mg/L)	123.8	115.2	367.8
PO4(microgram/L)	102	830.2	2548.5
CaH(mg CaCO3/L)	109.1	697.1	1974
TH(mg CaCO3/L)	118.8	1074.3	33.62
Cond(millimho/cm)	98.9	1.4	3.7
Cl(mg/L)	124.9	3165.6	10477.6
NO3(mg/L)	165.6	0.7	3.6

Table 3.64 Pallimattom Thodu

Parameters	SD	Mean	Range
pH	4.1	6.7	0.9
Alk(mg CaCO3/L)	33.8	83.3	105
DO(mg/L)	81	1	2.2
BOD(mg/L)	81.2	11.4	32.2
COD(mg/L)	84.2	146	384.1
Fe(microgram/L	113.7	151.8	575.5
SO4(mg/L)	112.2	115.3	350.3
PO4(microgram/L)	68.4	1336.3	2528.1
CaH(mg CaCO3/L)	117.4	6079.1	2376
TH(mg CaCO3/L)	117	924.2	2862
Cond(millimho/cm)	98	1.3	3.4
Cl(mg/L)	120.4	2842.4	8892.9
NO3(mg/L)	186.8	0.5	3

THEVARA CANAL

Table. 3.65 Thevara Market

Parameters	SD	Mean	Range
pH	4.1	7.2	0.9
Alk(mg CaCO3/L)	28.3	121.5	123.2
DO(mg/L)	69.5	2.3	4.7
BOD(mg/L)	74.4	19.6	45.8
COD(mg/L)	129	461.2	1680
Fe(microgram/L	105.9	221.5	695.3
SO4(mg/L)	92.5	176.6	439.4
PO4(microgram/L)	76.7	481	1129.1
CaH(mg CaCO3/L)	126.5	947.8	3455

Table 3.66 Kallupalam

Parameters	SD	Mean	Range
pH	4.5	7.3	1.1
Alk(mg CaCO3/L)	43.2	116.4	154
DO(mg/L)	44.6	2.8	4.4
BOD(mg/L)	60.1	15.2	29.7
COD(mg/L)	128.3	330.1	1396.2
Fe(microgram/L	112	329.7	1302
SO4(mg/L)	147	290.8	1230.8
PO4(microgram/L)	69.9	590.5	1321
CaH(mg CaCO3/L)	121.3	782.6	2950

TH(mg CaCO3/L)	118.8	2489.4	9800
Cond(millimho/cm)	121.7	2.6	10
Cl(mg/L)	105.4	6453.8	15782.4
NO3(mg/L)	141.7	0.5	2.7

TH(mg CaCO3/L)	105.8	1995.1	4700
Cond(millimho/cm)	10	2.7	9.8
Cl(mg/L)	105	6203.7	15061.6
NO3(mg/L)	159.6	0.5	2.8

Table 3.67 Kochukadavanthara

Parameters	SD	Mean	Range
pH	3.9	7	0.8
Alk(mg CaCO3/L)	37.2	177.3	226.1
DO(mg/L)	113.1	0.9	4
BOD(mg/L)	49.8	28.7	52.2
COD(mg/L)	103.4	288.1	1073
Fe(microgram/L	101.5	298.5	815.4
SO4(mg/L)	94.5	145.2	353.7
PO4(microgram/L)	68.8	769.8	1644
CaH(mg CaCO3/L)	101.2	678.6	1830
TH(mg CaCO3/L)	97.1	1304.9	3536
Cond(millimho/cm)	110.8	1.8	6.4
Cl(mg/L)	108.1	4317.5	13676.8
NO3(mg/L)	182	0.4	2.4

Table 3.68 GCDA

Parameters	SD	Mean	Range
pH	3.8	7.1	0.8
Alk(mg CaCO3/L)	43.4	254.2	375.1
DO(mg/L)	129	0.3	0.9
BOD(mg/L)	29.9	31.5	40.1
COD(mg/L)	98.1	100.7	304.4
Fe(microgram/L	90.1	430.1	1047.5
SO4(mg/L)	102.7	99.4	299.4
PO4(microgram/L)	59.9	1260.1	2448.6
CaH(mg CaCO3/L)	96	426.8	1138
TH(mg CaCO3/L)	88.7	611	1598
Cond(millimho/cm)	99	0.9	3
Cl(mg/L)	120.3	1748.6	6370.1
NO3(mg/L)	152.9	0.4	2.1

Table 3.69 KSRTC East

Parameters	SD	Mean	Range
pH	3.9	7.1	0.9
Alk(mg CaCO3/L)	46.3	269.1	391
DO(mg/L)	161.9	0.8	4.8
BOD(mg/L)	54.1	37.4	66.1
COD(mg/L)	78.2	131	316.2
Fe(microgram/L	87.8	646.7	2087.6
SO4(mg/L)	69.1	35.7	95.1
PO4(microgram/L)	63.6	1561.7	1316.7
CaH(mg CaCO3/L)	120.9	216.2	953.8
TH(mg CaCO3/L)	109.1	341.2	311.8
Cond(millimho/cm)	42	0.3	0.4
Cl(mg/L)	67	181.5	359.6
NO3(mg/L)	174.8	0.7	4.3

Tables 3.70 CBI South

Parameters	SD	Mean	Range
pH	5.1	6.9	1.2
Alk(mg CaCO3/L)	54.2	159.6	263.3
DO(mg/L)	59.9	0.9	1.9
BOD(mg/L)	104.3	24.2	92.2
COD(mg/L)	96.8	71.3	216.6
Fe(microgram/L	92.7	580.4	1707.8
SO4(mg/L)	74.5	23.5	56.4
PO4(microgram/L)	83.2	515.7	1499.8
CaH(mg CaCO3/L)	62.4	85.7	172.7
TH(mg CaCO3/L)	78.3	126.9	370.6
Cond(millimho/cm)	67.3	0.2	0.6
Cl(mg/L)	76.5	102	322.4
NO3(mg/L)	88.6	0.3	1.1

KOITHARA CANAL

Table. 3.71 ROB

Parameters	SD	Mean	Range
pH		7.3	0.9
Alk		239.7	405.8
DO		1.2	3.9
BOD		30.3	80.3
COD		111.6	437
Fe		416.1	1031.5
SO4		73	193.1
PO4		982.7	3278.2
CaH		275.9	731.3
TH		471	1600
Cond		0.7	2.5
Cl		1408	6370.1
NO3		0.6	1.7

Table. 3.72 Emerald

Parameters	SD	Mean	Range
pH		7.2	1.1
Alk		241.1	344
DO		0.6	2
BOD		25.7	50.6
COD		127.3	423.4
Fe		313.6	675.6
SO4		85.8	253
PO4		1088.5	1389.6
CaH		465.1	1432
TH		782.3	2860
Cond		1.1	4
Cl		1744.6	5100
NO3		0.4	1.8

KARINGACHIRAPUZHA

Table 3.73 Karingachira Palam

Parameters	SD	Mean	Range
pH	5.5	6.7	1.3
Alk	61.6	109.5	270.2
DO	117.1	0.3	0.8
BOD	44.4	16.8	29.7
COD	82.6	65.5	196.1
Fe	113	1257.9	4462.2
SO4	46.2	15.9	26.4
PO4	80.8	143.9	379.3

Table 3.74 Anthakaran Thodu

Parameters	SD	Mean	Range
pH	6.8	5.3	1.4
Alk	30.9	115	98.4
DO	79.3	1.3	3.6
BOD	64	17.4	35.2
COD	128.1	205.9	952.2
Fe	117.7	465.6	1550.5
SO4	101.2	102.2	304.9
PO4	92.4	380.5	966.1

CaH	109.1	128.7	472
TH	113	275.7	962
Cond	114.4	0.3	1.3
Cl	143.8	367.4	1495.6
NO3	58.9	0.2	0.3

CaH	129	618.6	2264
TH	117	1027	35.3
Cond	133.3	1.8	7.2
Cl	124.5	3321.9	11399.3
NO3	127.5	0.4	2

Fig 3.75 Kaniyavally Palam

Parameters	SD	Mean	Range
pH	5.3	6.7	1.3
Alk	54.7	105.8	157.5
DO	62.3	0.5	1.2
BOD	46.4	12	17.9
COD	43.9	58.5	84.4
Fe	100.8	75.7	2323
SO4	104.7	18.1	68.3
PO4	71.4	103.5	302.6
CaH	94.9	119.7	278
TH	93.7	216	563
Cond	105.6	0.4	1.4
Cl	103.3	516	1394.7
NO3	72.7	0.2	0.4

Fig 3.76 Kandanad

Parameters	SD	Mean	Range
pH	6.6	6.9	1.4
Alk	44.6	82	109.6
DO	87	1.6	3.6
BOD	65	11.2	28.1
COD	74	67	200
Fe	133.1	332.7	1464.8
SO4	98.2	68.3	167.5
PO4	73.9	33.7	81.6
CaH	102	225.3	584
TH	97.2	308.8	768
Cond	126.2	0.7	2.9
Cl	112.5	958.1	2666.7
NO3	53.9	0.1	0.2

KARINGACHIRAPUZHA

Table 3.77 Kolenchery Palam

Parameters	SD	Mean	Range
pH	7.4	6.8	1.8
Alk	51.8	74.2	126
DO	56.9	2	3.5
BOD	46.7	12.5	21
COD	50.8	62.2	116.1
Fe	142	417.2	2079.3
SO4	104.4	78.9	207.4
PO4	75.9	44.1	118.7
CaH	111	210.9	588
TH	103.9	289.5	870
Cond	127.5	0.6	2.7
Cl	113.9	856.6	2399.6
NO3	61.5	0.1	0.3

Table3.78 Mattathan Kadavu

Parameters	SD	Mean	Range
pH	6.8	6.7	1.6
Alk	43.4	56.4	93.6
DO	50.6	3.1	5.8
BOD	37.4	11.4	14.7
COD	200.8	117.5	864
Fe	137	321.2	1394.8
SO4	115.2	66.2	235.1
PO4	54.7	35.7	69.7
CaH	125.8	148.5	594
TH	108.4	203.6	674
Cond	125.8	0.5	2.5
Cl	118.9	693	2168.5
NO3	50	0.1	0.2

Table 3.79 Poothotta Bridge

Parameters	SD	Mean	Range
pH	4	6.8	1
Alk	33.3	46.5	53.6
DO	32.4	4.4	6.2
BOD	53.7	10.1	20.8
COD	140	97.1	464.8
Fe	111.2	171.1	568.4
SO4	112.6	142.2	408.9
PO4	75.6	45.1	104.5
CaH	126.3	520.7	1996
TH	119.3	843.2	2495
Cond	140.3	1.6	7.2
Cl	121.8	2585.1	8470.5
NO3	40.2	0.2	0.2

Table 3.80 Swargavathil Up

Parameters	SD	Mean	Range
pH	6.4	7.1	1.2
Alk	29.9	81.5	66
DO	14.9	3.6	1.5
BOD	47.2	15.5	18.2
COD	67.7	50.5	80.3
Fe	184.3	99.8	484.7
SO4	54.5	143	233.9
PO4	76.2	29.4	59.7
CaH	69.8	300.8	470
TH	68.9	445	630
Cond	66.9	1.3	2.6
Cl	46.3	1817.7	2189.7
NO3	36.5	0.2	0.1

Table 3.81 Swargavathil Down

Parameters	SD	Mean	Range
pH	5.3	6.8	1
Alk	30	51.4	54.4
DO	32.1	3.8	3.9
BOD	46.8	10.5	15.4
COD	153.8	198	1004

Table 3.82 Kanjiramattom

Parameters	SD	Mean	Range
pH	5	6.8	1.2
Alk	37.9	57.7	75.6
DO	41	4.2	4.8
BOD	137.2	15.5	82.1
COD	116.9	145.2	624.2

Fe	144.1	249.8	1241.7	Fe	108.2	196.4	730.3
SO4	111.4	136.3	384	SO4	107.9	124.4	330
PO4	76	30.9	80.1	PO4	129.7	34.4	165.5
CaH	125	503.1	1590	CaH	119.1	518.8	1696
TH	116.4	805.6	2272	TH	114.4	753.1	2190
Cond	136.1	1.5	6.8	Cond	142.5	1.6	7.5
Cl	121.2	2529.9	7592.9	Cl	114.6	2469.6	6743
NO3	193.7	0.4	2.6	NO3	55.9	0.2	0.3

KARINGACHIRAPUZHA

Table. 3.83 Panar Bridge

Parameters	SD	Mean	Range
pH	6.4	6.4	1
Alk	44.4	32.8	53
DO	40.3	4.2	5.6
BOD	58.9	10.1	22
COD	118	33.2	140
Fe	117.2	259	896
SO4	70	11.2	20.8
PO4	94.1	43.3	134
CaH	156.8	158	96
TH	93.8	19.4	75
Cond	75	0.2	0.4
Cl	123.2	74.2	243.6
NO3	62.9	0.2	0.6

3.4 Water Quality Index of the Tidal Canals During Their Fresh Water Phases

Many water quality-monitoring agencies across the world have introduced water quality indices to indicate the overall quality of the water body imparting appropriate weightage to specific water quality parameters. Many such calculations are based on the frequency of temporal quality infringement events.

US Department of Education and Technology Innovation (Pathfinder Science) (1988) (Ref: http://pathfinderscience.net/stream/cproto4.cfm) has prescribed methodology to subject the water bodies to water quality ranking reflecting the utility of the same. This method was originally developed by National Science Foundation (NSF), USA. Based on the same procedure the water quality index of the tidal canals during the fresh water phases is tabulated.

The worksheet for the calculation of WQI is provided in http://pathfinder science/stream/forms/WQI_worksheet.pdf. The Water Quality Index uses a scale from 0 to 100 to rate the quality of the water, with 100 being the highest possible score. Once the overall WQI score is known, it can be compared against the following scale to determine how healthy the water is on a given day.

Table.3.84 The scheme for calculating water quality index

Test Parameter	Test results	Q-value(from graphs)	Weighing factor	Total
BOD	mg/L		0.11	
DO	% Saturation		0.17	
Nitrates	mg/L		0.10	
FecalColi form	Colonies/100ml		0.16	
PH			0.11	
Temperature			0.10	
TDS	mg/L		0.07	
Total Phosphate	MgL		0.10	
Turbidity	NTU		0.08s	

Water supplies with ratings falling in the good or excellent range would be able to support a high diversity of aquatic life. In addition, the water would also be suitable for all forms of recreation, including those involving direct contact with the water. Water supplies achieving only an average rating generally have less diversity of aquatic organisms and frequently have increased alga growth.

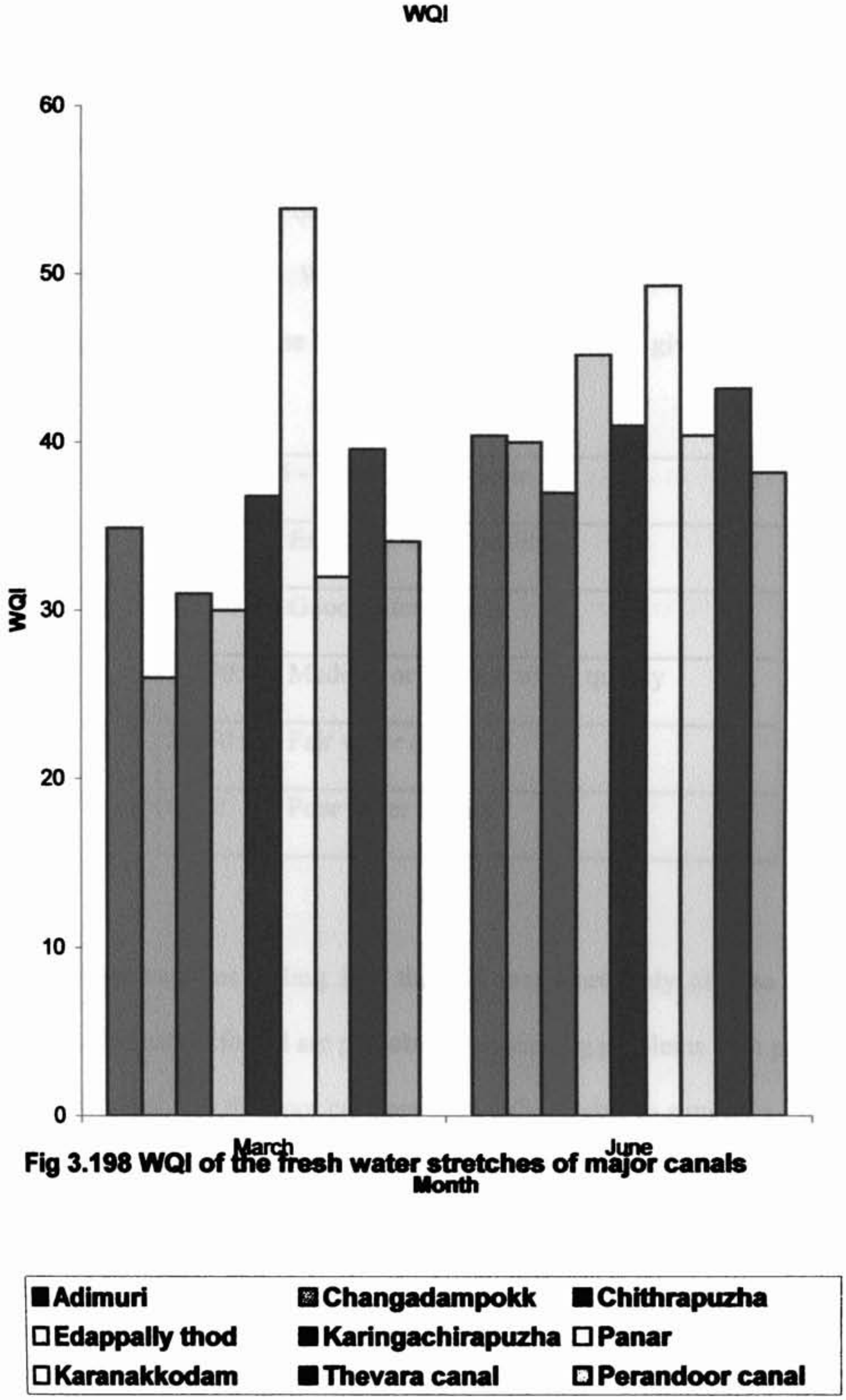

Fig 3.198 WQI of the fresh water stretches of major canals

The worksheet for the calculation of WQI is provided in http://pathfinder science/stream/forms/WQI_worksheet.pdf. The Water Quality Index uses a scale from 0 to 100 to rate the quality of the water, with 100 being the highest possible score. Once the overall WQI score is known, it can be compared against the following scale to determine how healthy the water is on a given day.

Table 3.85 - WQI Quality Scale	
91-100:	Excellent water quality
71-90:	Good water quality
51-70:	Medium or average water quality
26-50:	Fair water quality
0-25:	Poor water quality

Water supplies falling into the fair range are only able to support a low diversity of aquatic life and are probably experiencing problems with pollution. Water supplies that fall into the poor category may only be able to support a limited number of aquatic life forms, and it is expected that these waters have abundant quality problems. A water supply with a poor quality rating would not normally be considered acceptable for activities involving direct contact with the water, such as swimming.

From the WQI Table (Table3.86) it is evident that nearly all the fresh water stretches belong to fair (below average) water quality category. This implies that water from these sources can be made useful after adequate managerial interventions.

As **Figure 3.198** depicts water quality declines when dry days become established. In June the WQI reaches its possible best thanks to the dynamism imparted by runoff. Panar was found to have quality characteristics a little better than other potential fresh water sources because it receives little or no urban discharges.

Table 3.86 Water quality index of the fresh water canals in March and June 2004

Name of the freshwater stretch	WQI in March 2004	WQI in June 2004
Adimury thod	34.90	40.4
Changadompokk thod(KSEB Kaloor)	26	40
Chithrapuzha (above FACT)	31	37
Edappally thod (north of Attipeti nagar)	30	45.2
Karingachira puzha	36.8	41
Panar	53.9	49.3
Karanakkodam thod (VIP road)	32	40.4
Thevara canal (northern end)	39.6	43.2
Perandoor canal (south end)	34.1	38.2

3.5 Observed Characteristics of Water Chemistry in the Canals

Table 3.89 uses phosphate concentration as a key to decide the nutrient pollution in a static water body. All the canals monitored in the study, at this rate are at various stages of eutrophication.

Nitrogen is mostly found in organic form such as proteins, peptides and humic and fulvic acids and in the dissolved inorganic state it is quite unstable especially in waters deficient of DO, whereas phosphate is mostly found in inorganic forms. The precipitation of phosphate by Aluminium has not been explored. But precipitation of PO_4 by chemically bonding with Fe does occur. Across time, the concentrations of Fe and PO_4 are in phase. Even if Fe PO_4 and ferric hydroxyl phosphates are formed, they may remain in suspension as precipitation can be very slow. Concomitant rises and falls in calcium hardness indicate that calcium also plays a role in tandem with Fe in the PO_4-P regime. Variations in sulfate levels provoke some curiosity. Sulfate hits a minimum simultaneously with Fe and PO_4 or a few weeks before the later hits the minimum. All sulfates except for the sulfates of barium, lead, silver, calcium and mercury are soluble. If sulfate is precipitated, it can mostly be through calcium, as other metals are unlikely to be present in concentrations significant enough to be reckoned with. Sulfate is, especially in polluted waters, lost through microbiological reduction. This reduction should suppress the pH and cause immediate precipitation of Fe as FeS. It is not yet clear whether this anoxic precipitation of Fe triggers the precipitation of phosphate also. As all phosphates except that of Na, K and NH_4 are insoluble, phosphates not precipitated are largely to be found in suspended form. Another fact to be borne in mind is that orthophosphate, which alone was monitored during the sampling year, is dominant only in the pH range of 7-6. Whenever pH crosses this range PO_4 value obtained may be misleading.

Table.3.87 Classification of water bodies based on nutrient level

Nature of the water body	Phosphate concentration
Oligotrophic lake	<0.01 mg/L
Eutrophic lake	>0.1 mg/L
Polluted river	0.6 mg/L
Domestic Waste water	0.6 mg/L

Ref: Hand book of Water Quality Management and Planning. Ed. Pavoni(1977)

Pyrophosphates can constitute more than 50% of phosphate in sediments of some coastal ecosystems. Soil microorganisms readily use pyrophosphates, implying that it is biologically available. More over its accumulation in the coastal zones is directly related to human activities such as industrial use and agricultural runoff. (Sundareswaran *et al,*. 2001)

pH never crosses 5.5-8.5 range in the concerned water bodies, except for temporary diurnal rises at Ambalppara Quarry, Chettichaira, Pandarachira and Pandarachal in connection with eutrophication. The water bodies are alkaline or acidic depending primarily on the concentration of sewage, and tidal influence is not a significant contributor in this regard. The more the sewage load, the higher the pH and alkalinity. NO_3 -N and PO_4-P never infringe the tolerable range of 45mg/L and 15mg/L respectively but their concentrations are sufficient for eutrophication (Table. 3.88). As for other vital water quality parameters, there is accountable fluctuation across the year. In all seasons of the year and at all sites faecal coliform count was found to be a maximum as all tubes after 48 hour incubation were registered positive. Hence disinfection is an essential requirement for the water to be of any economic utility, given the urban hygiene scenario remains as it is. The interconnected quality parameters DO, COD and BOD nearly never reach the desirable levels in the major canals.

There does exist a buffering mechanism to keep the pH from varying appreciably in the course of time. Only exception is cases of algal bloom resulting in high diurnal DO, alkalinity and pH. This phenomenon was observed at four different sites separated in time and space. Fresh water algal bloom was observed at Ambalappara Quarry in August and at Chettichira Sewage Treatment discharge site in late September. And salt-water algal bloom happens at Pandarachira, adjoining Chilavannoor Kayal, and also at Pandarachal when the dry spell is established. The pH–alkalinity flywheel is set to motion probably by CO_3--/HCO_3- coupling as pH in no case falls below 5.5.

Canals of West Cochin, Thevara Canal, Mullassery Canal, Koithara thod, Karankkodam thod and Perandoor canal are more to the alkaline side for most part of the year. But pH never crosses over to the run away deleterious levels. It oscillates between 7 and 8. Chittoor puzha and Chithrapuzha are having pH values less than 7 and remain so throughout the year, except for the thoroughly estuarine western extremity of Chithrappuzha. The most significant factor governing pH is apparently industrial discharges. Temporary drops in pH to very acidic levels lead to colour variation and fish kills in Chittoorpuzha. In any case there is not a perceptible shift or tilt to the alkaline pH on the onset of dry summer. In both water bodies sewage is not a significant component compared to other canals inside the city.

The only tidal body where the seasonal tidal modification follows the theoretical predictions discussed in chapter 1 are the canals of West Cochin because here chloride level crosses 14,000 mg/L on many an occasion. There also PO_4 -P does not fall when chloride rises instead it rises. It is because sewage input is much more than the marine factor could deal with. But in late December there is spectacular clarification and pH steadily rises, BOD and COD temporarily fall.

In most of the canals running deep into the city, plant nutrients and organic waste get entrapped during the dry months. As a result, DO reaches an all time low. Such a serious nutrient accumulation does not occur in Chithrappuzha and Chittoor puzha thanks to substantial residual flow. In spite of nutrient accumulation, the canals do not become breeding grounds of mosquitoes as long as salinity intrusion is not arrested by siltation, choking lumps of debris and temporary bunds. Wherever saline migration is thwarted, aquatic weeds aggressively proliferate and mosquitoes breed.

The behaviour of total iron in the tidal canals modified by urbanization makes curious observation. Solubility of iron is pH-dependent and is altered by the degree of DO saturation. Hydrogen sulfide should sweep away dissolved iron to the sediment. But, in reality it does not happen so. Total iron closely follows conductivity. It is a freak correlation because Fe ions increase due to cultural discharges being trapped in the canals and conductivity rises due to salinity intrusion. But total iron is not mainly of oceanic origin, it is the externality of urbanization as sea water contains less than 20 mg/L of Fe). In most cases, pH and DO do not influence much to make an impact on the iron regime. Phosphate and the cations of Fe and Ca do not suppress each other in practice. It seems that there is a mechanism to annihilate the intruding OH^- ions of oceanic origin in the tidal canals, there by minimizing alkalinity fluctuation. As pH never falls below 5.5, CO_3 –HCO_3 balance is effectively buffering the system

One important observation made during the study was that a single copious rainfall to the tune of 3 cm or so is enough to purge out the salinity gradually established during the lean months. The convective vernal rains of April and early May proved this fact. This implies that desalination in the tidal stretch of the canals is remarkably fast.

Another matter worth mentioning is that pre-monsoonal rains provoke a remarkable rise in nutrient levels in the water bodies. When rains slacken, water rapidly turns anoxic and putrid. And with the next salvo of rains, nutrient levels suddenly plummet, hypoxia and increased O_2 demand as the incoming waters are not as rich as their predecessors. Critical conditions of chloride occur when the environment is at its warmest, the stream flow the slowest and the man-made pollution the greatest such as.

There are two distinct stages of annual purging-when the pre-monsoonal torrential rains flush out the meso haline organisms and when monsoons taper out and salinity is fairly established. But monsoonal cleansing is often short-lived. As soon as the rains slacken or peter out, organic waste accumulates in the water body leading to colour, odour and gas formation. Once torrential rains have had their say, many canals sport crystal clear and flowing water for a day or two. But occasional floods turn the water muddy and murky. Floating vegetation loiters in as single spies and violently multiplies wherever the current is not inclement. Eichornia and other fresh water floating plants mask the actual pattern of dissolved nutrients and dissolved oxygen. When they grow up explosively, phosphate and nitrate content of water will diminish to misguiding levels. When they wilt and wither, DO is used up leading to hypoxia, nitrate is reduced to ammonia and as a result phosphate outdistances nitrate.

Sometimes the profiles show a marked deviation from the predicted and expected patterns because the effect of the tide-generating forces, the phase and magnitude to the tides, rainfall, temperature, influx of pollutants and degree of mixing cannot always be the same. The chemistry of the water sample is dependent on these physical factors. BOD, COD, phosphate, total hardness, sulphate and chloride peak twice every year in the portions where tidal action is effective. The first peak is in late December or early January and the second is in late April as a general rule. After the initial jump, the dissolved solids subside to a plateau during the course of the dry season and again peaks when the first rains enter the scene. In most of the tidal canals, contrary to the expectation that alkalinity would rise by oceanic influence; it actually shows a declining tendency across the lean months.

BOD and COD have, more or less, the same profile. And the revealing pattern is that at the onset of the dry season, when the pioneering quanta of salinity appear, COD as well as BOD take a slump because of the shift in biota, especially micro organisms and large-scale precipitation. Throughout the dry spell, both BOD and COD are on the high, as sewage influx is not effectively flushed out. With the first serious rains of the year, COD and BOD reach a low and salinity levels collapse. By and by, fresh water organisms get established. Here also the canals of West Cochin show a marked deviation from the general run. Hence BOD is abnormally low all through the dry season, the heavy organic waste load notwithstanding. Whereas COD is as high as the state of the canals indicates COD also falls to an all-time low in January owing to general clarification. Thereafter, both BOD and COD keep rising to a maximum in April. But BOD never ever catches up with COD. Presence of bacteriostats or toxic substances is to be surmised in the waters of this region. The rains flush out both COD and BOD in the vernal rains of late April.

Nitrate, the essential plant nutrient, is not a serious contributor to the present urban aquatic pollution scenario. Nitrogenous pollutants do enter the system in fairly large quantities. But the anoxic or near-anoxic conditions in the water bodies, immediately biologically reduce whatever nitrates entering the system. Hence nitrogenous pollutants would appear deceptively low. In all the canals, nitrate abruptly and suddenly maximizes in a certain part of the hydrologic year. For most canals, where tidal impact is neither thorough nor pronounced, nitrate peaks with the first major rains, in early May or late April. But in Chittoor puzha, Chithrappuzha and Karingachirapuzha, this happens in late January when the reducing bacteria are at an all-time low because of saline shock. On Edappally thod, nitrate peaks twice in late January, and again in mid May. Here both tidal impact and pre-monsoonal wash out are equally important.

Phosphate and iron concentrations do not decrease; rather increase in the later stages of salinity intrusion due to the accumulation of sewage. Hem (1992) reports that ferrous ion concentrations rise to 50mg/L if the bicarbonate concentration is less than 61mg/L. Falls in alkalinity correspond to rise in ferrous ion. Ferric iron is insoluble except in very acidic waters.

3.6 The manifest repercussions of the invasion of salinity in the humid tropical urban milieu of Cochin can be summed up as follows.

1. Alkalinity remains more or less steady or exhibits a falling tendency with salinity and a direct correlation is not possible.

2. Sulfate and hardness closely follow salinity, but anoxic conditions suppress sulfate levels significantly.
3. Chittoor puzha is having pH values less than 7 (Range: 2, mean = 6.2 and standard deviation = 0.57) all through the year with sharp fluctuations in the magnitude of acidity, which is echoed in the quality and quantity of aquatic life.

4. The upper portion of Chithrappuzha is slightly to the acidic side with the pH hovering around 6, becoming of a fresh water body. The industrial discharges also may be contributing to low pH levels.

5. The canals of West Cochin undergo physico-chemical alterations when chloride level crosses a threshold and follows the pattern discussed in chapter I, but iron increases with chloride, apparently due to the accumulation urban discharges in this thickly populated region of the city.

6. Iron and calcium do not appreciably precipitate phosphate in the later stages of salinity intrusion.

7. A mechanism of CO_3-HCO_3 balance is existing to resist pH and alkalinity variations and the chloride levels do not cross a critical value that triggers salinity-induced changes.

8. Approximately in January and in March, two peaks are found for chloride hardness, calcium hardness, sulfate, COD and BOD.

9. It could possibly be construed that chloride and associated parameters actually fall after a winter maximum to peak again in late March or early April because fresh water consumption rises in the hot and sultry summer months. In major canals like Chittoor and Chithrapuzha, such a double peak is not observed, whereas in the lesser canals draining the city, this pattern is evident. This fact reinforces the above conclusion.
10. In most canals, phosphate reaches a minimum level in early January when chloride maximizes for the first time and thence phosphate steadily rises with chloride and both hit their vernal peak somewhere in late March or early April. This would suggest that phosphate is diluted when sea water barges in for the first time and thereafter dissolved phosphate is not anymore bothered by s*ali*nity invasion. Marine cations precipitate phosphate in appreciable amounts when the rainy season peters out, when the dry season advances sewage influx apparently out weighs the marine cation intrusion and the rare afternoon rains wash out accumulated terrestrial phosphate. But Poorni puzha

is an exception as phosphate follows chloride on close heels irrespective of the season. This is because of the influx of sewage from Thrippoonithura Municipality.

11. BOD and COD closely follow chloride, as chloride level decides the nature of the oxidizing microorganisms. Rise in chloride indicates a fall in run off. When the flow slackens there will be accumulation of urban liquid waste.

12. Fresh water in the natural water bodies of Cochin is not hard. But during the summer months the tidal canals have hard waters with thousands of mg/L of CaCO3, which is not proportionate to the degree of saline water dilution. It is to be concluded that Ca and Mg salts enter the system from urban waste particularly sewage (Pure sea water contains 410mg/L of Ca).

13. Salinity induced chemical changes do not exactly follow the patterns discussed in the introduction. In a series of experiments held as part of the present study, it was found out that salinity as such does not bring about a perceptible change in the chemical environment of water, pH, on the other hand, does. When sodium hydroxide was added to sewage rich samples raising the pH above 10 there was prompt and spectacular clarification, and when the pH was neutralized with HCl the sample once again became coloured and turbid. In most of the tidal canals no such dramatic rise in pH was observed in tandem with the invasion of saline waters. The proportion of salt water intruded was not apparently sufficient to overcome the strong buffering actuated by carbonate –bicarbonate balance.

14. For fresh water, hardness is chiefly due to bicarbonate and thus temporary, whereas in saline waters permanent hardness of marine origin predominates and bicarbonate component of hardness slightly falls with chloride.

15. In sea water chloride and sulfate are at a constant molar ratio of 19.06 (Hounslow, 1995). But in all the tidal canals where sea water had substantially penetrated, it was found that the ratio does not hold good. The ratio was at least 4 times higher in most cases. Depletion of DO leads to the biological reduction of sulfate. whereas chlorides do not have any significant biogeochemical sub routes. But in segments where salinity is not pronounced the ratio narrows down remarkably. Sources of sulfates in natural waters are pyrite gypsum and organic compounds.

16. The micro algal dynamics of the water column and the sediment have a significant say on the nutrient dynamics. But DO deficiency obliterates the algal routes dissolved nutrients can potentially take.

3.7.Tidal Action in Cochin Estuary

Even though tides are universal and affect both land and ocean, they have conspicuous regional and temporal variations. Apart from the astronomical factors of the variable pulls of the sun and the moon, the tide is subject to other accelerating and decelerating influences of hydraulic, hydrodynamic hydrographic and topographic origin and are modified by meteorological conditions. The crests and troughs of tides sweep the earth following the sun and the moon. When they move into shallow waters, landmasses, channels etc., height variation takes place. The differences in internal viscosity affect the propagation of tides. The velocity of the wave is dependent on depth of the water column. Presence of landmasses arrests the progress of tides and the topography of the ocean floor and the estuarine geometry modify them. In confined bodies of water resonance effects between the free period of oscillation of traveling tidal wave and the confining basin may cause tilting and cresting.

The tide at Cochin is usually semi diurnal with considerable differences between the two high waters or the low waters; on some days the tide may be purely diurnal. The maximum tidal range is about 1m. There is considerable monthly variation in the water levels; however the annual pattern is more or less stable. The highest high water reaches its maximum in the dry season (Kuttanad Water Balance study, Vol 2, 1988).

Cochin is interspersed with tidal canals generally with an east-west strike, except for TP canal and Karankkodam thod. In all these canals, water budget is modified by tidal influence whose magnitude is decided by channel geometry and distance from the estuary and nutrient levels are decided by urban runoff and sewage input.

Figures 3.199 to 3.206 show the tidal characteristics (amplitude and flow rates) of Chithrapuzha and Chittoorpuzha and the corresponding chloride variations. On 19th of December, tide levels were monitored simultaneously at two sites nearly 5 km apart. As the time Vs amplitude graph indicates, there does exist a phase difference in the tidal oscillation between the two points. Yet the tide follows the same pattern. The tide observed was mixed semi diurnal with a 24 hrs 50'tidal day. Mixed tide was observed - (amplitudinal disparity between two consecutive cycles) - because of the Moon's wandering from the equator (lunar declination). Atmospheric pressure is not an important variable in controlling water level variations (Srinivas & Dineshkumar, 2002). According to Srinivas *et al.*, (2003) tidal currents were stronger in the interior than at the mouth. Spring phase of the current was dominated by semi diurnal and neap phase by diurnal tidal currents.

The velocity of the tide wave is proportional to the square root of depth. Hence velocity dampens out upstream. The irregular geometry of the canals has a destructive effect on the tidal waves. Chloride level is more or less constant across the tidal day at the upstream site, whereas it sharply fluctuates at the downstream site because mixing with the brackish water is more intense down stream.

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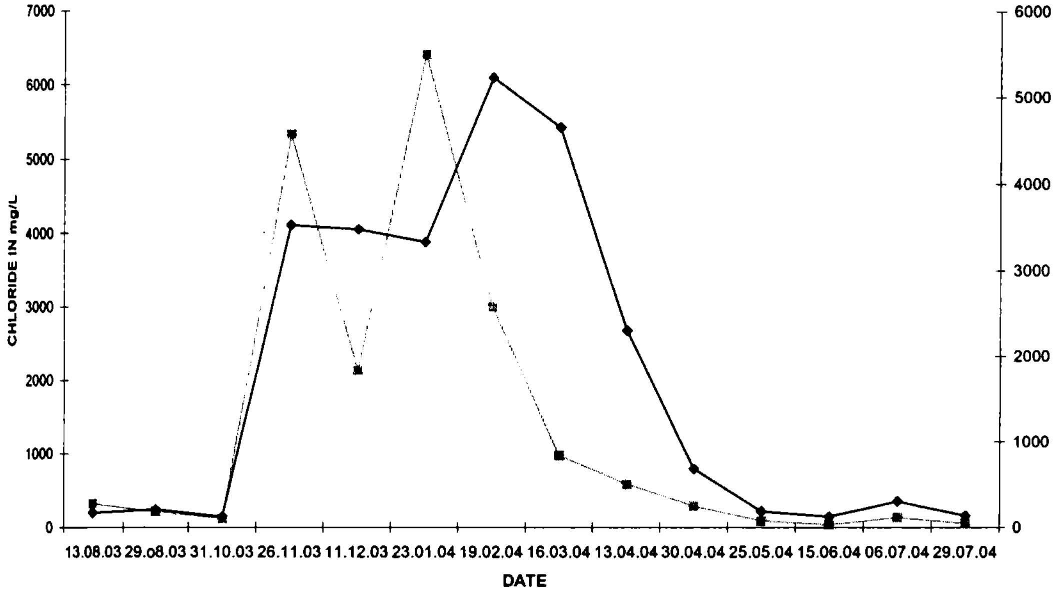


FIG.3.148 TEMPORAL VARIATION OF CHLORIDE CONCENTRATION AT VARIOUS SAMPLING POINT SON KOITHARA CANAL

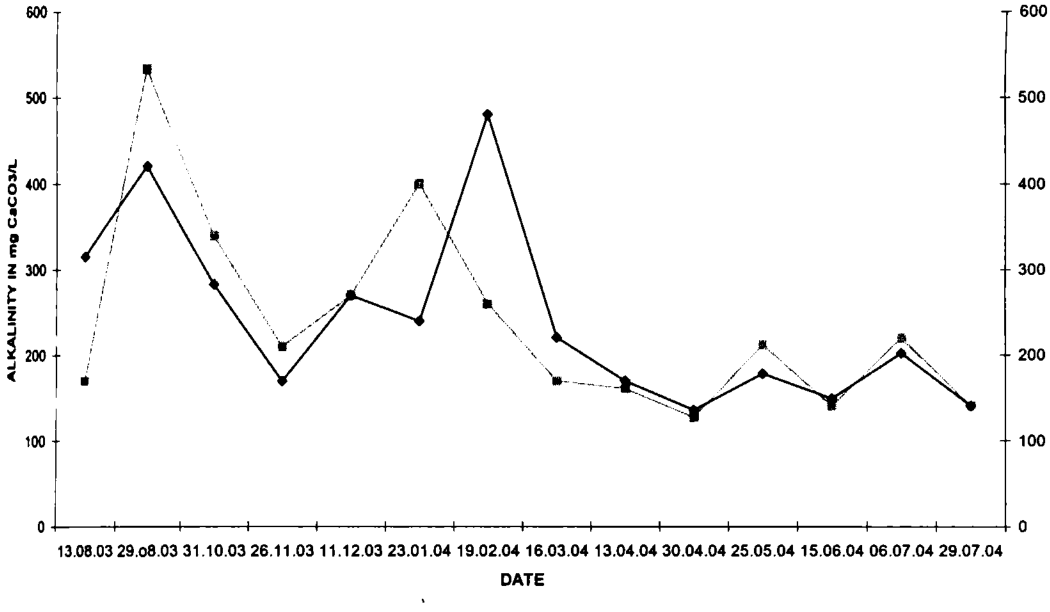


FIG.3.149 TEMPORAL VARIATION OF ALKALINITY CONCENTRATION AT VARIOIUS SAMPLING POINTS ON KOITHARA CANAL

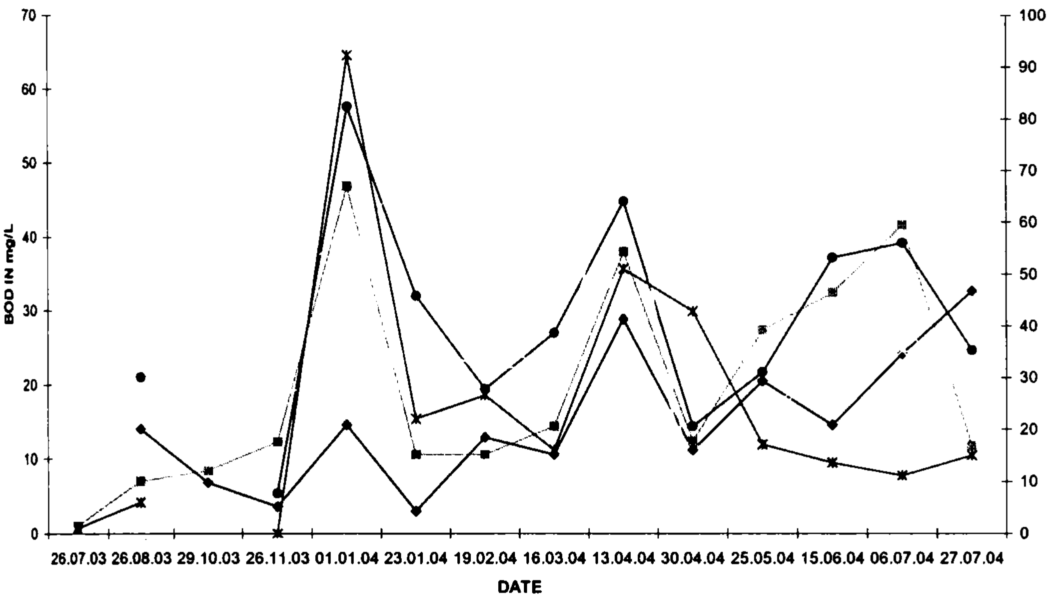


FIG.3.196 TEMPORAL VARIATION OF BOD CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

—■— Thevara market —◆— Kallupalam —●— Kochukadavanthra GCDA KSRTC-E —✱— CBI-S

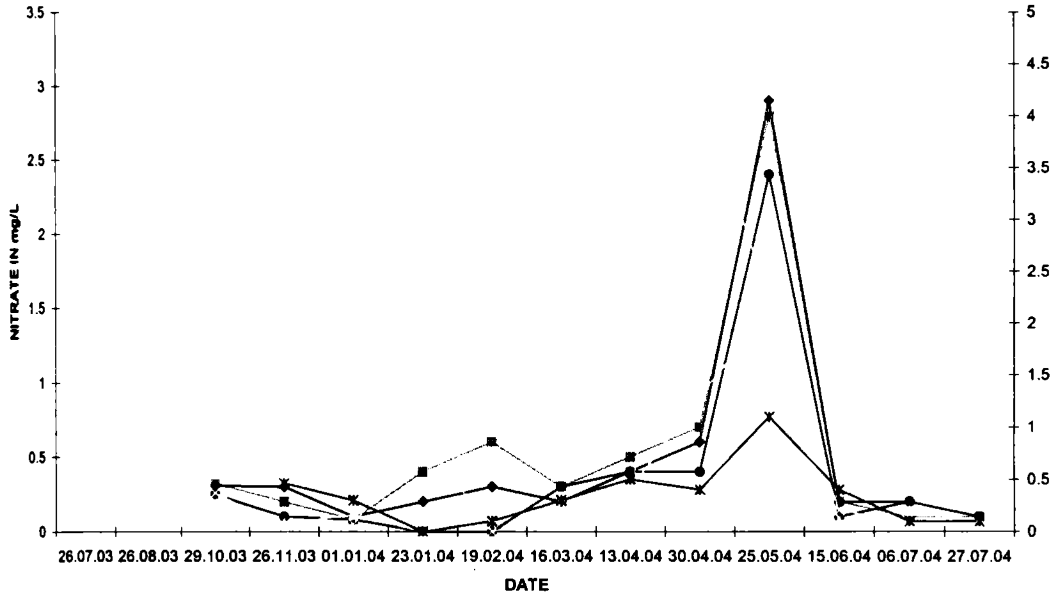


FIG.3.197 TEMPORAL VARIATION OF NITRATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

—■— Thevara market —◆— Kallupalam —●— Kochukadavanthra GCDA KSRTC-E —✱— CBI-S

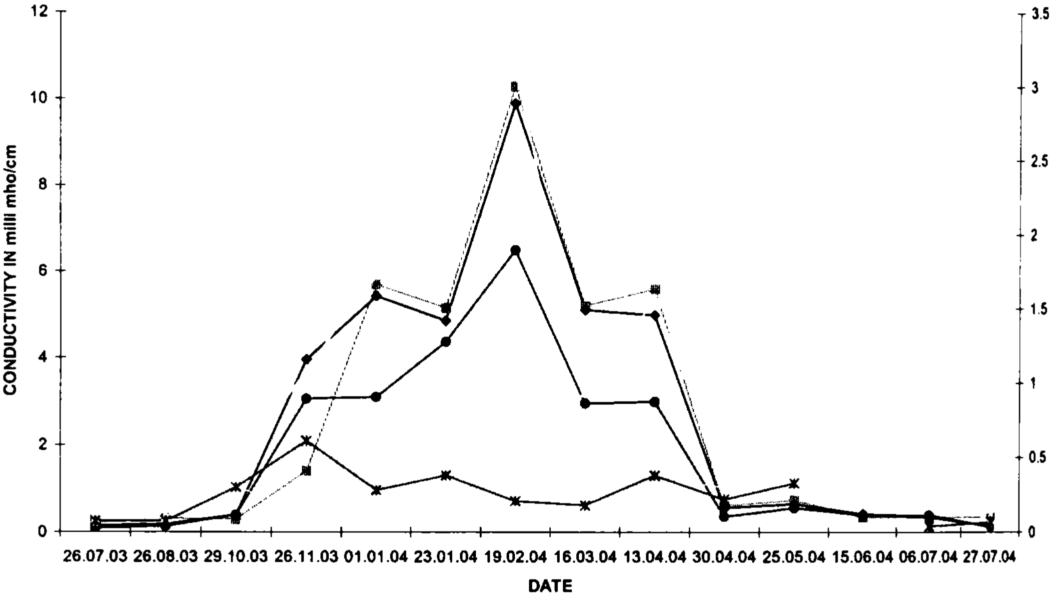


FIG.3.194 TEMPORAL VARIATION OF CONDUCTIVITY AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

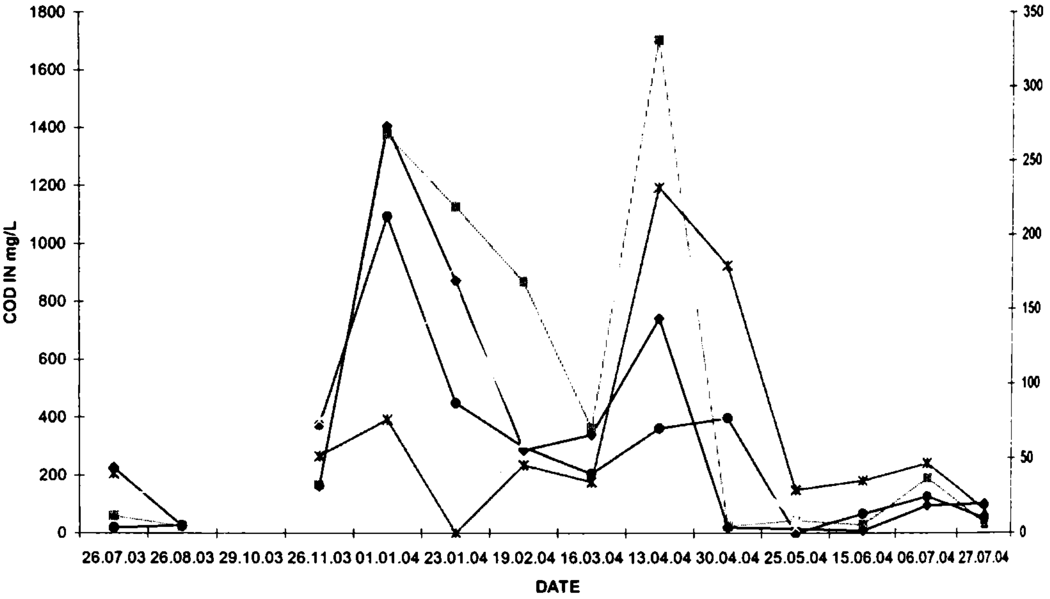


FIG.3.195 TEMPORAL VARIATION OF COD COCENTRAION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

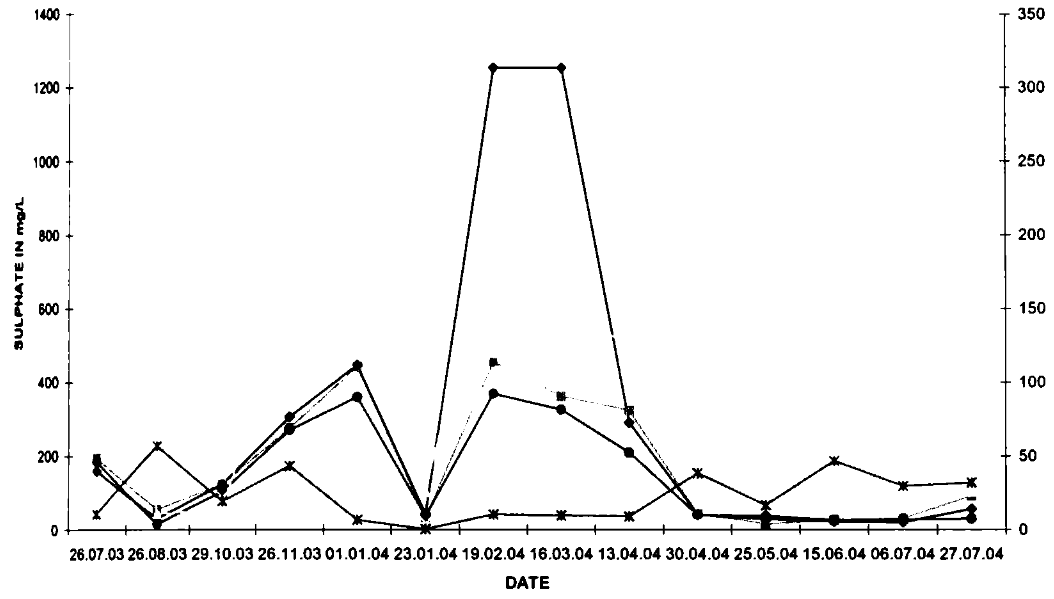


FIG.3.192 TEMPORAL VARIATION OF SULPHATE CONCENTRATION AT VARIOUS SAMPLING POITS ON THEVARA CANAL

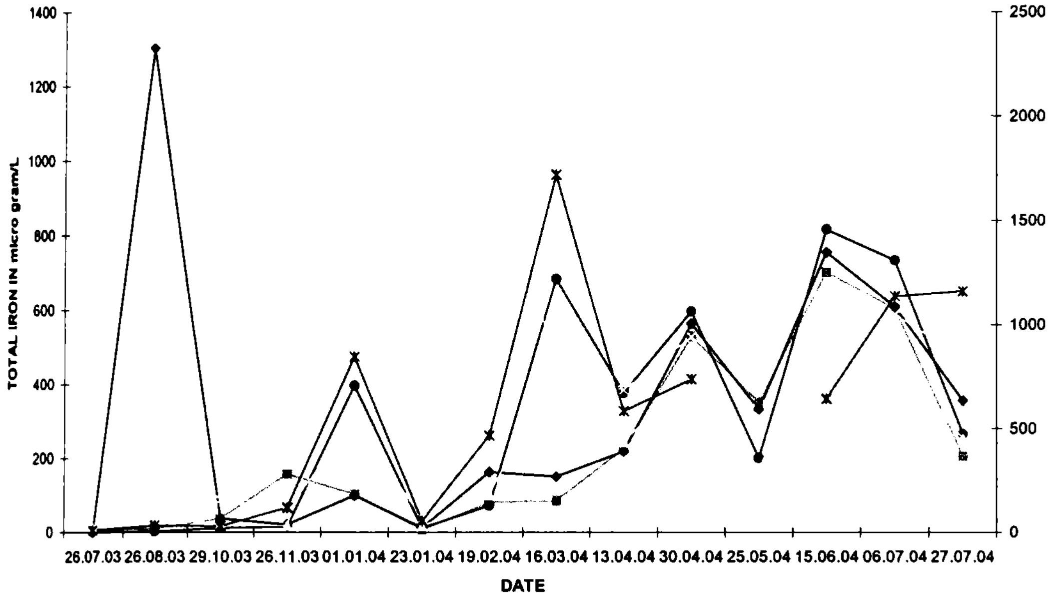


FIG.3.193 TEMPORAL VARIATION OF TOTAL IRON CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

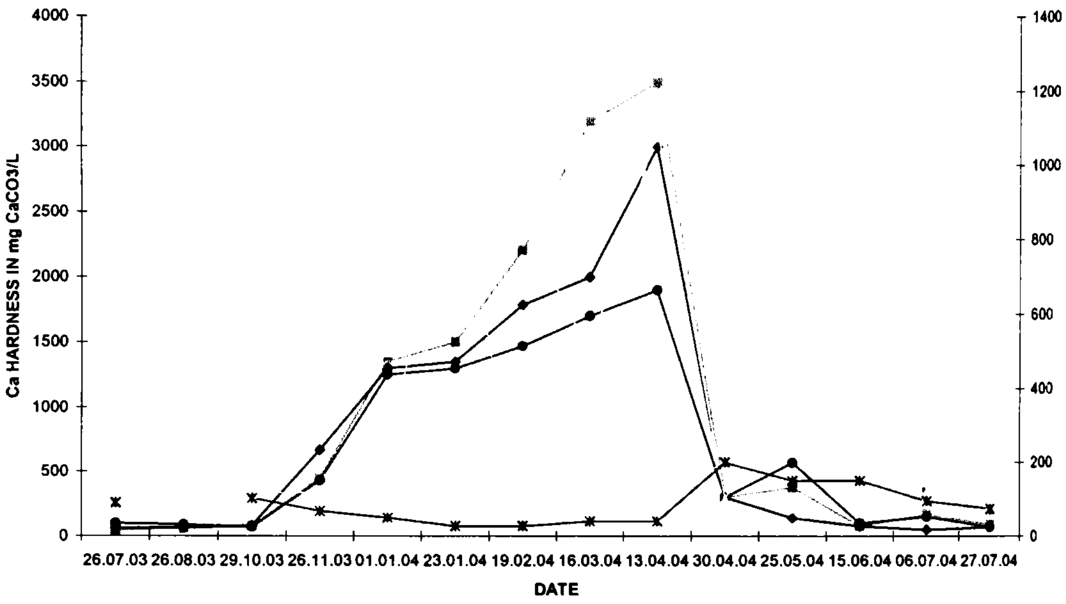


FIG.3.190 TEMPORAL VARIATION OF Ca HARDNESS CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

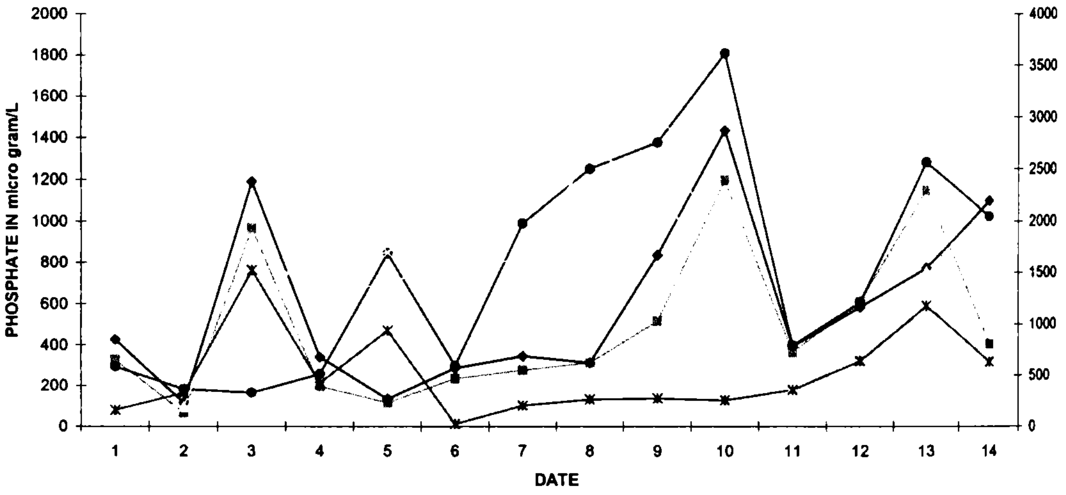


FIG.3.191 TEMPORAL VARIATION OF PHOSPHATE COCENTRATION AT VARIOIUIS SAMPLING POINTS ON THEVARA CANAL

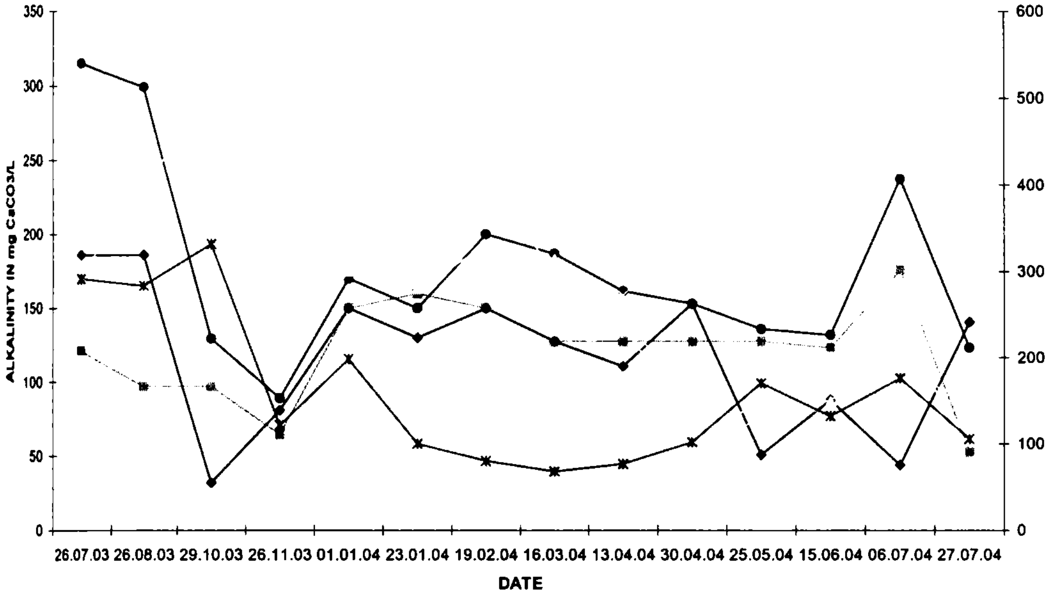


FIG.3.188 TEMPORAL VARIATION OF ALKALINITY CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

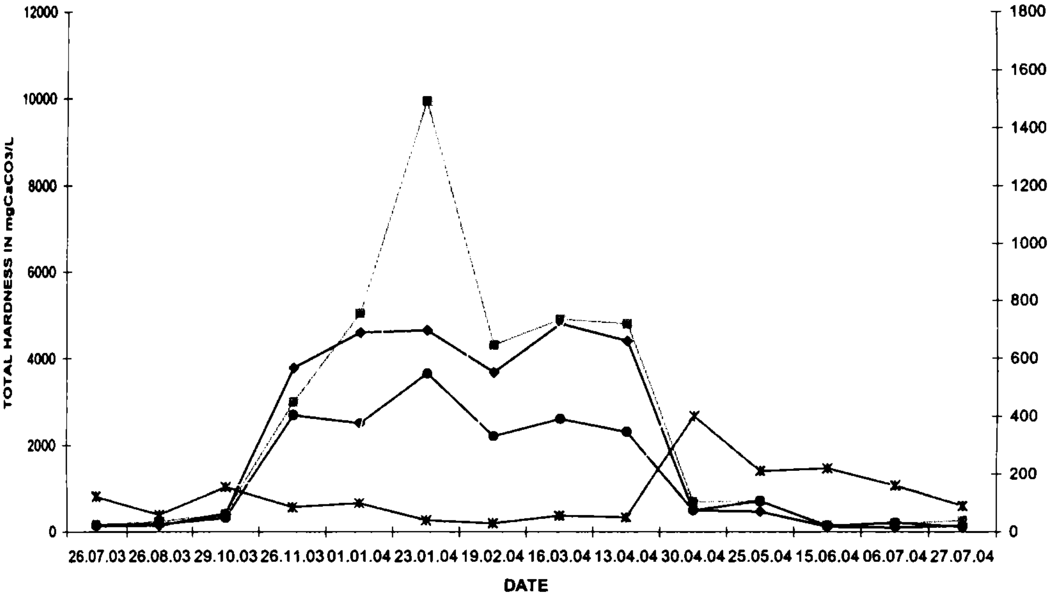


FIG.3.189TEMPORAL VARIATION OF TOTAL HARDNESS CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

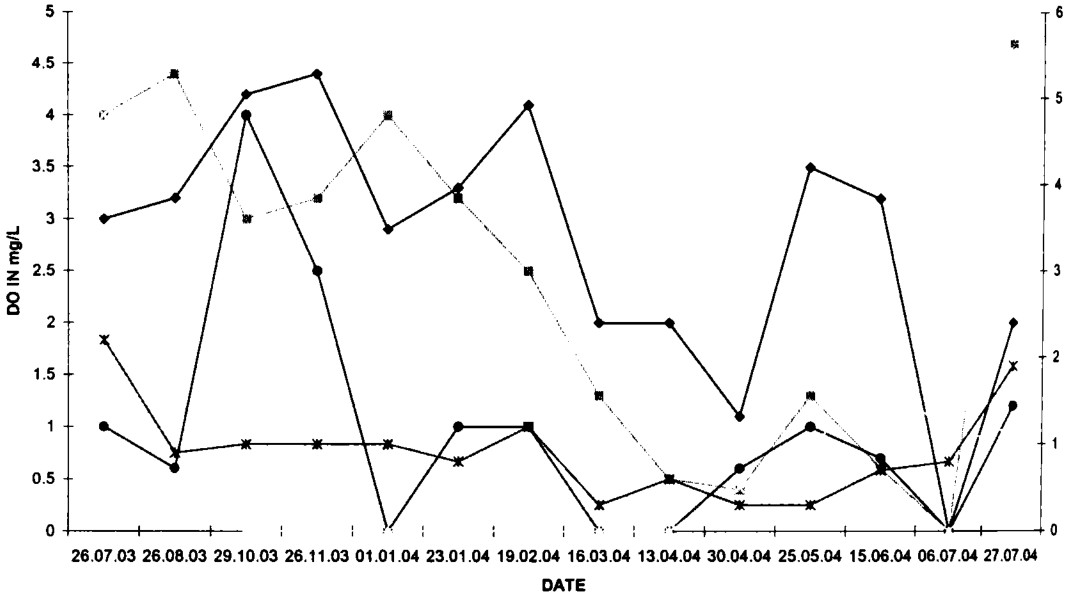


FIG.3.186 TEMPORAL VARIATION OF DO CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

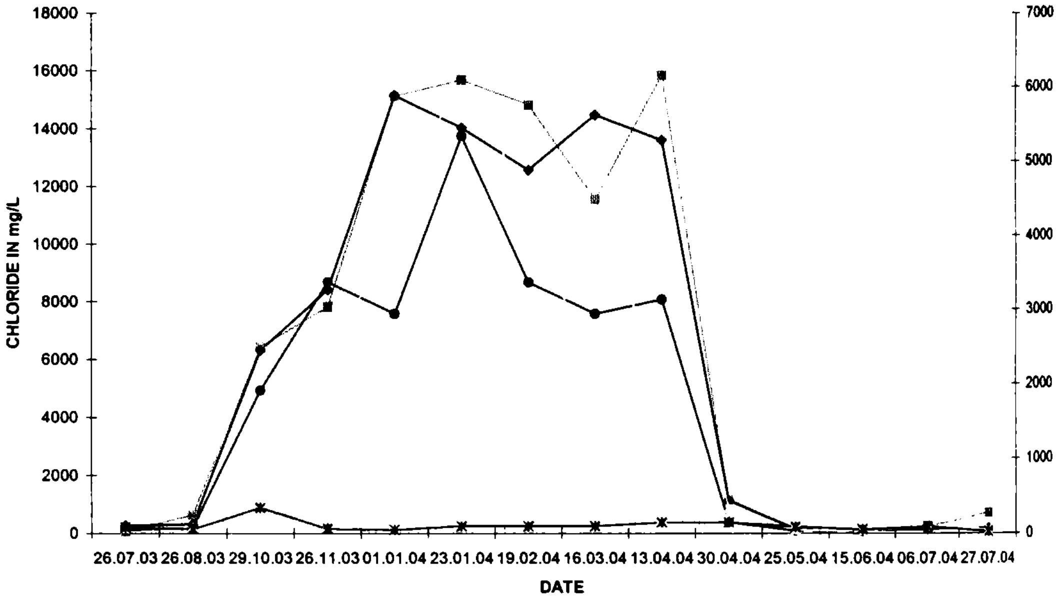


FIG.3.187 TEMPORAL VARIATION OF CHLORIDE CONCENTRATION AT VARIOUS SAMPLING POINTS ON THEVARA CANAL

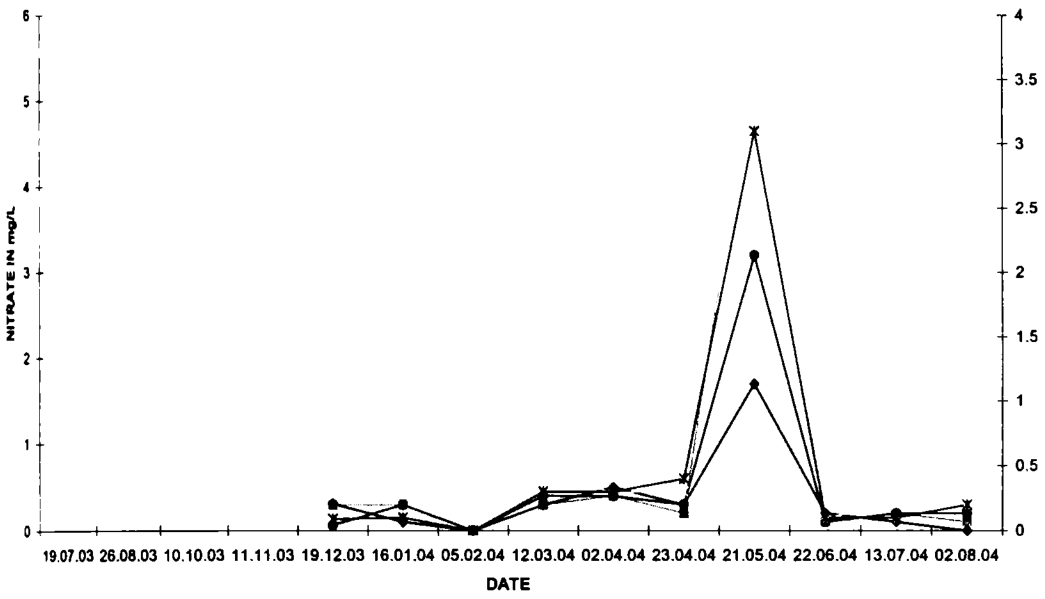


FIG.3.184 TEMPORAL VARATION OF NITRATE CONCENTRATION AT VARIOUS SAMPLING SITES ON POORNIPUZHA

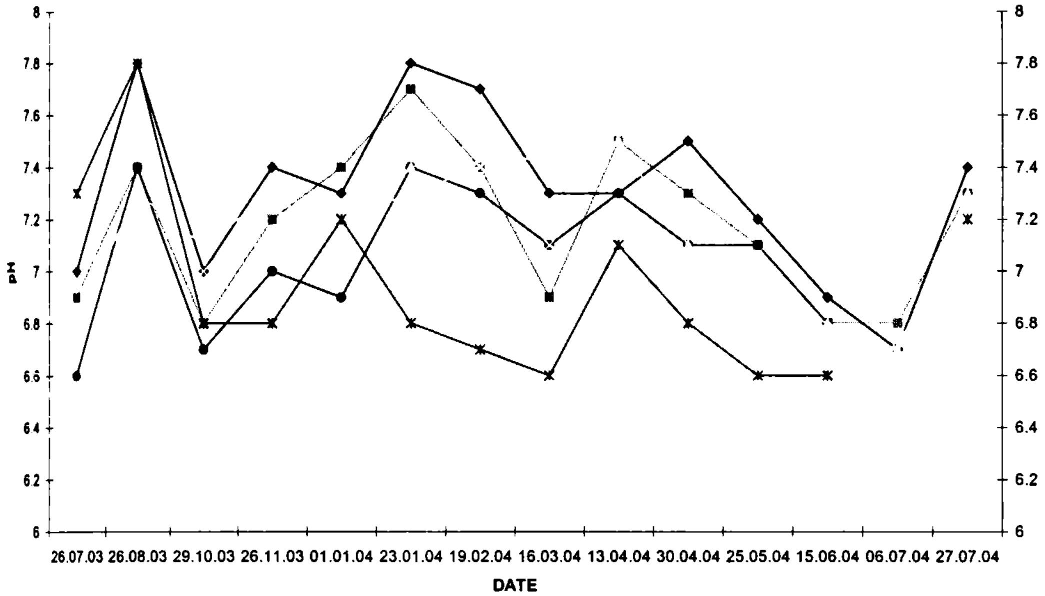


FIG.3.185 TEMPORAL VARIATION OF pH AT VARIOUS SAMPLING SITES ON THEVARA CANAL

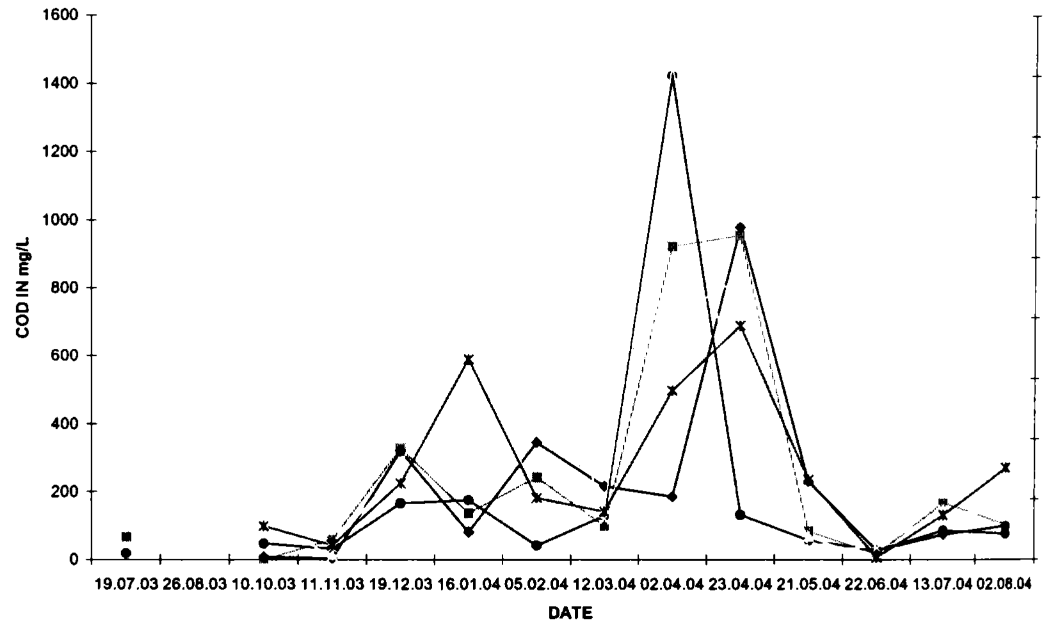


FIG.3.182 TEMPORAL VARIATION OF COD CONCENTRATION AT VARIOUS SAMPLING SITES ON POORNIPUZHA

--■-- Venkateswara school —◆— Iron bdg —●— Petta bdg Champakkara market Pisharadi kovil —✱— Pallimattom

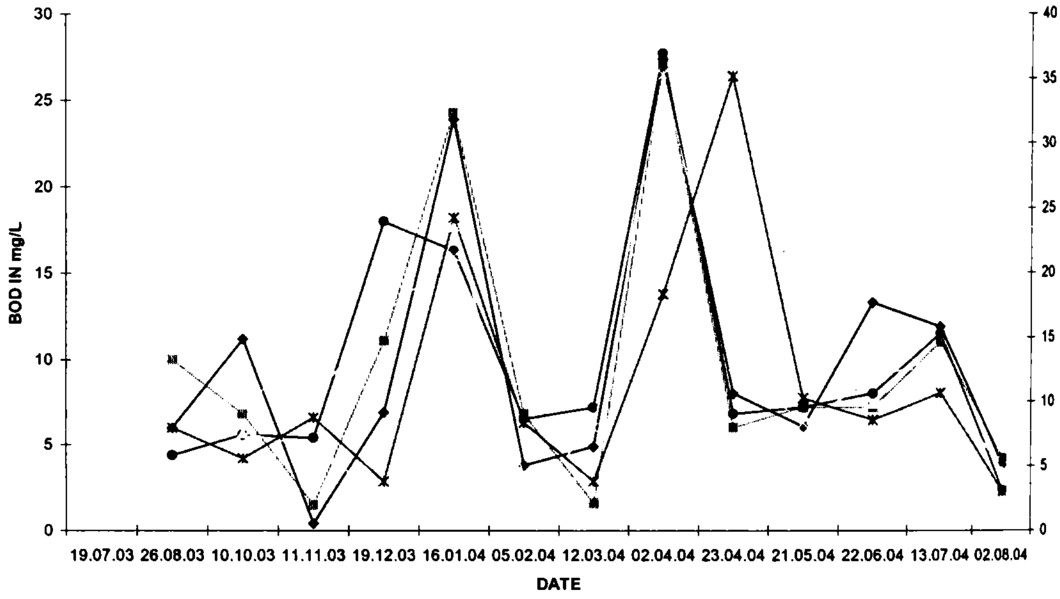


FIG.3.183 TEMPORAL VARIATION OF BOD CONCENTRATION AT VARIOUS SAMPLING SITES ON POORNIPUZHA

--■-- Venkateswara school —◆— Iron bdg —●— Petta bdg Champakkara market Pisharadi kovil —✱— Pallimattom

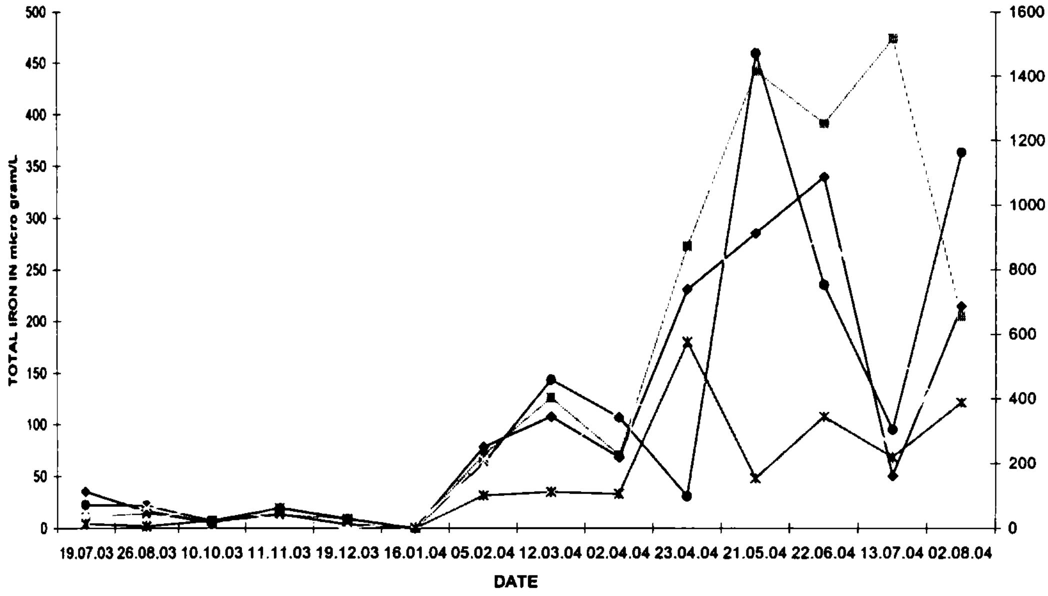


FIG.3.180TEOPRAL VARIATION OF TOTAL IRON CONCENTRAION AT VARIOUS SAMPLING POINTS ON POORNIPUZHA

—■— Venkateswara school —◆— Ironbdg —●— Petta bdg Champakkara market Pisharadi kovil —✱— Pallimattom

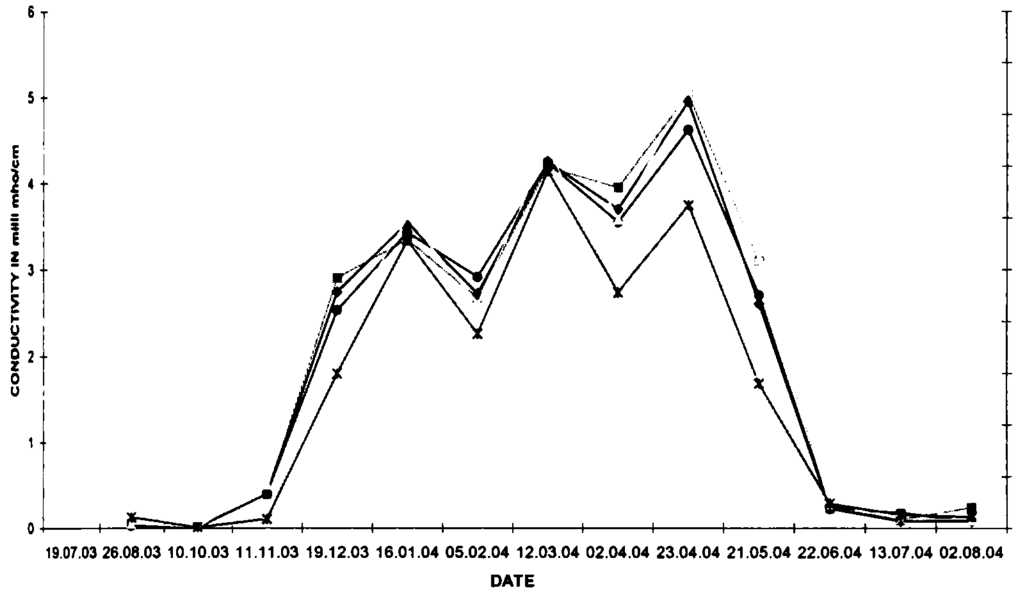


FIG.3.181TEMPORAL VARIATION OF CONDUCTIVITY AT VARIOUS SAMPLIG POINT SON POORNIPUZHA

—■— Venkateswara school —◆— Iron bdg —●— Petta bdg Champakkara market Pisharadi kovil —✱— Pallimattom

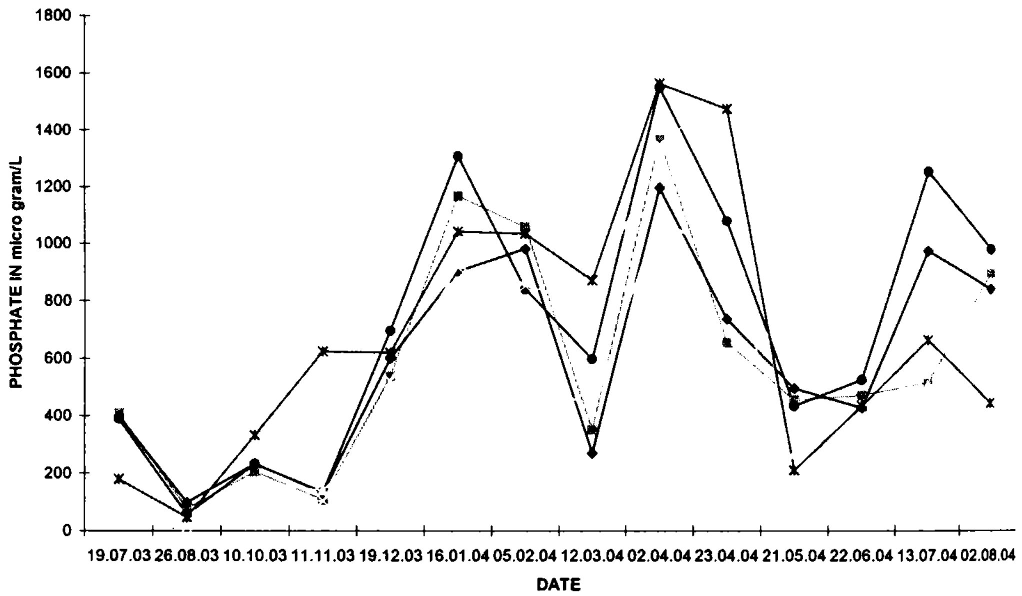


FIG.3.178 TEMPORAL VARIATION OF PHOSPHATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON POORNIPUZHA

■ Venkateswara school ◆ Iron bdg ● Petta bdg Champakkara market Pisharadi kovil ✱ Pallimattom

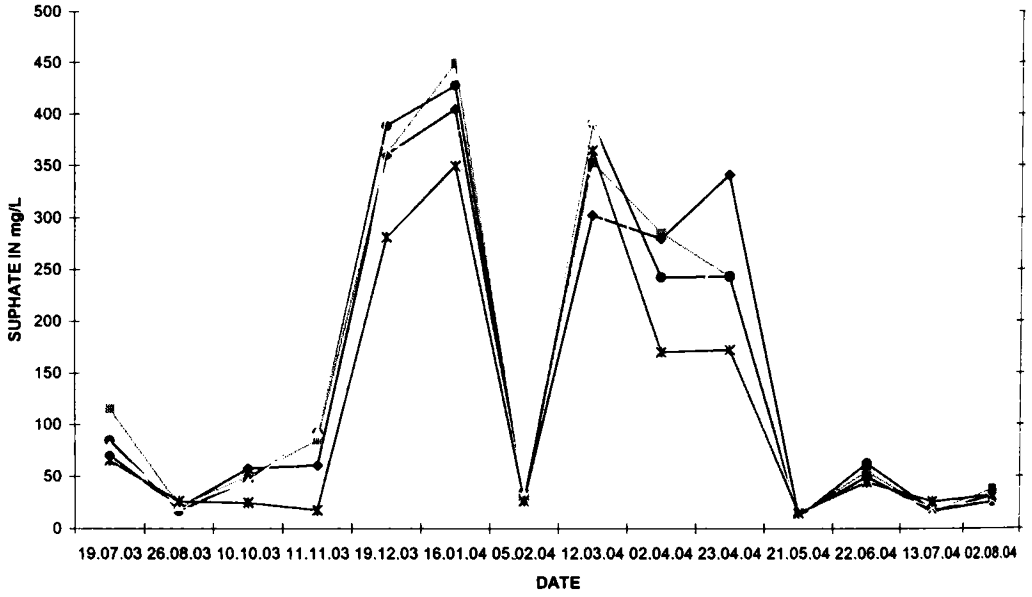


FIG.3.179 TEMPORAL VAIATION OF SULPHATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON POORNIPUZHA

■ Venkateswara sschool ◆ Iron bdg ● Petta bdg Champakkara market Pisharadi kovil ✱ Pallimattom

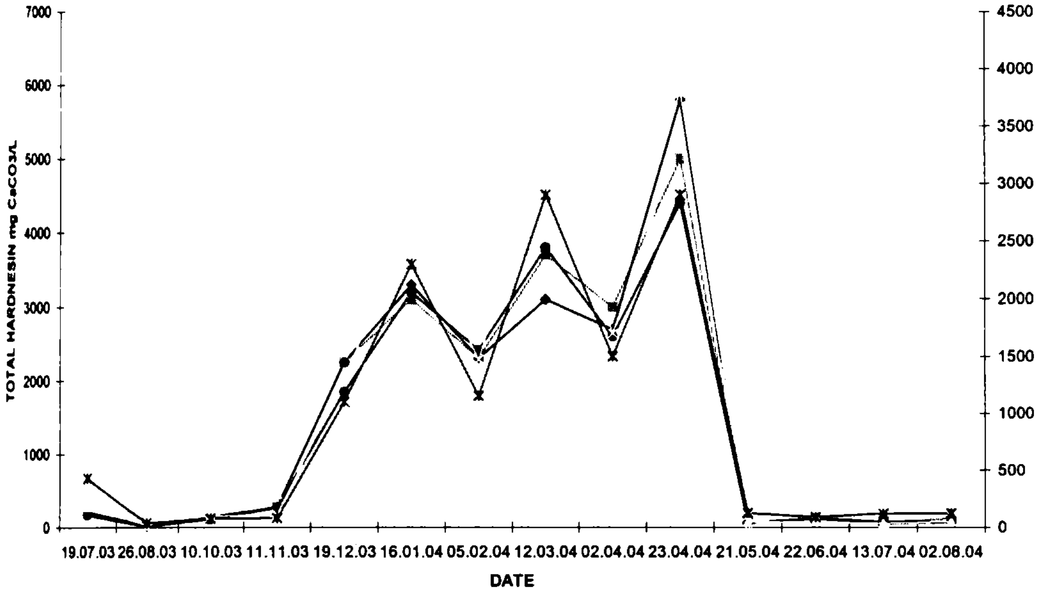


FIG.3.176 TEMPORAL VARIATION OF TOTAL HARDNESS CONCENTRATION AT VARIOUS SAMPLING POINTS ON POORNIPUZHA

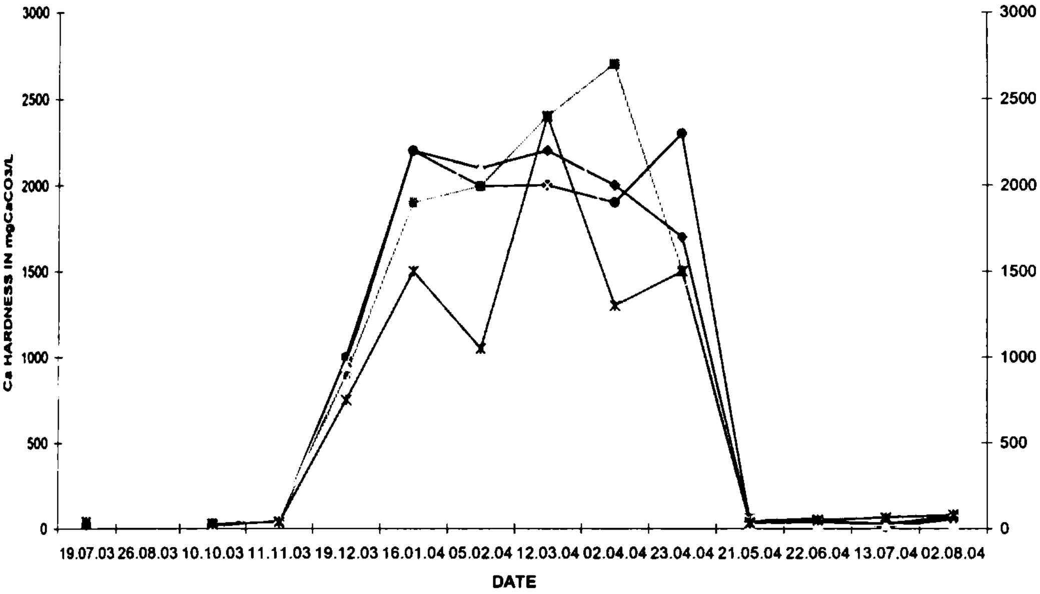


FIG.3.177 TEMPORAL VARIATION OF Ca HARDNESS CONCENTRATION AT VARIOUS SAMPLING SITES ON POORNIPUZHA

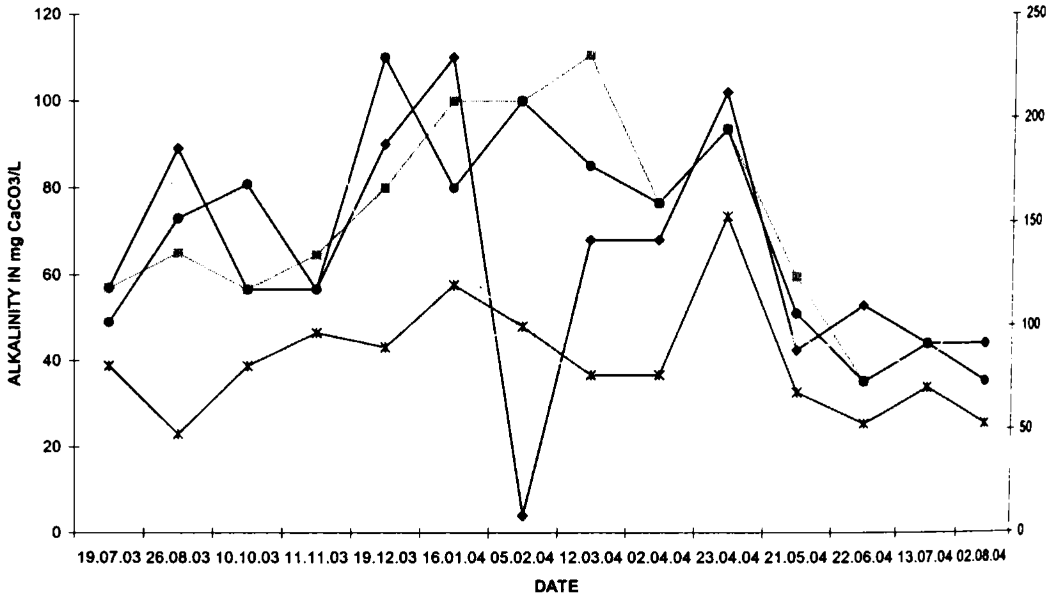


FIG.3.175 TEMPORAL VARIATION OF ALKALINITY CONCENTRATION AT VARIOUS SAMPLING POINTS ON POORNIPUZHA

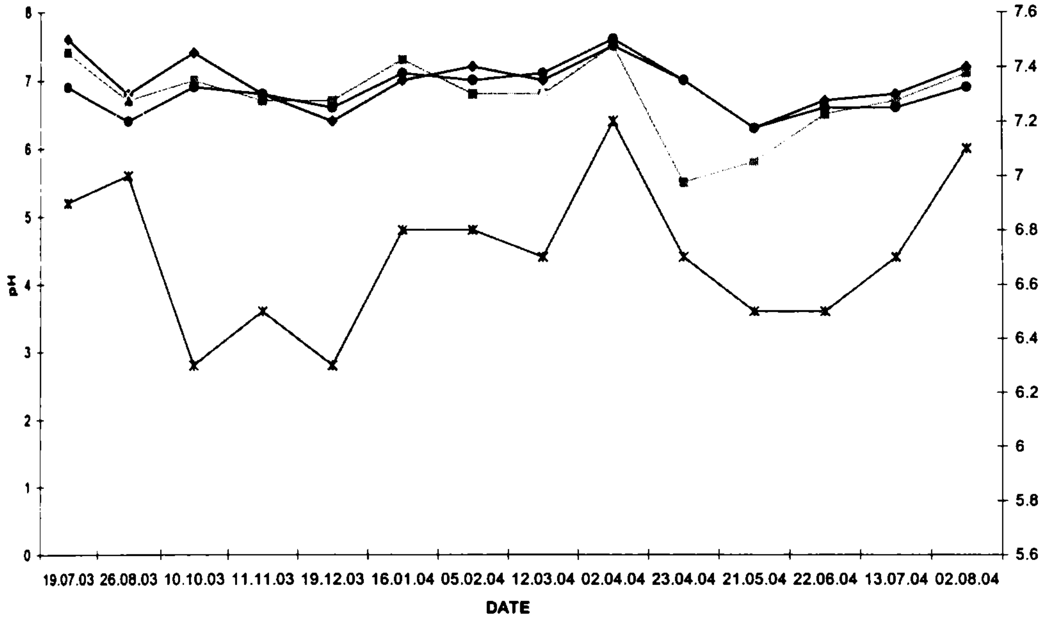


FIG.3.172 TEMPORAL VARIATION OF pH AT VARIOUS SAMPLING POINTS ON POORNIPUZHA

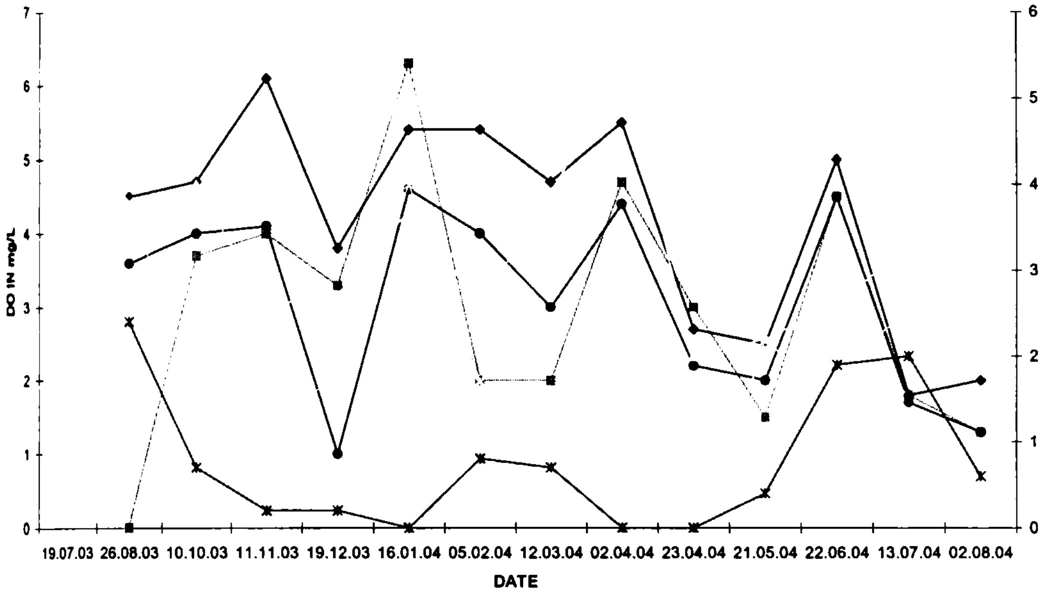


FIG.3.173 TEMPORAL VARIATION OF DO CONCENTRATION AT VARIOUS SAMPLING POINTS ON POORNIPUZHA

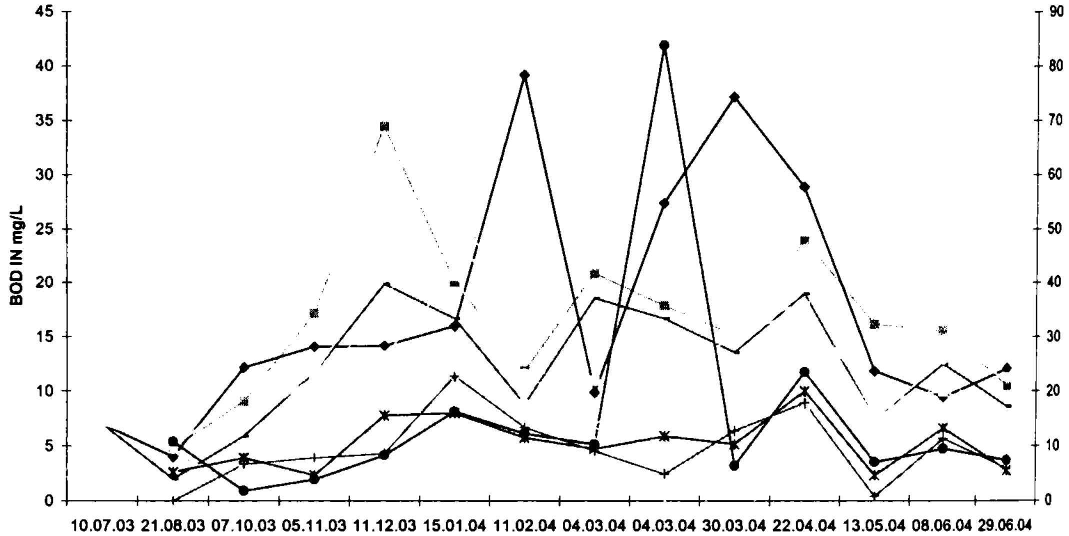


FIG.3.170 TEMPORAL VARIATION OF BOD CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

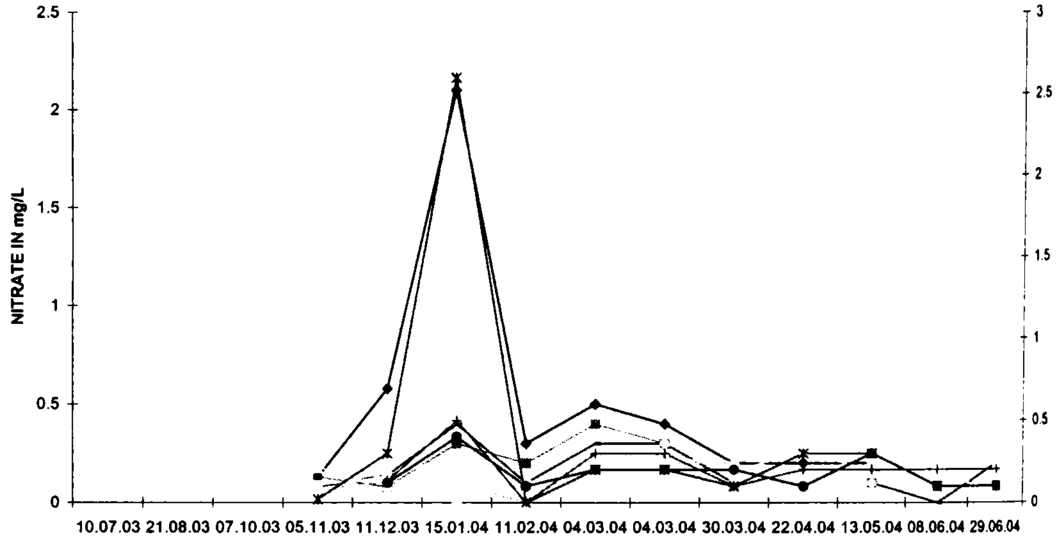


FIG.3.171 TEMPORAL VARIATION OF NITRATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

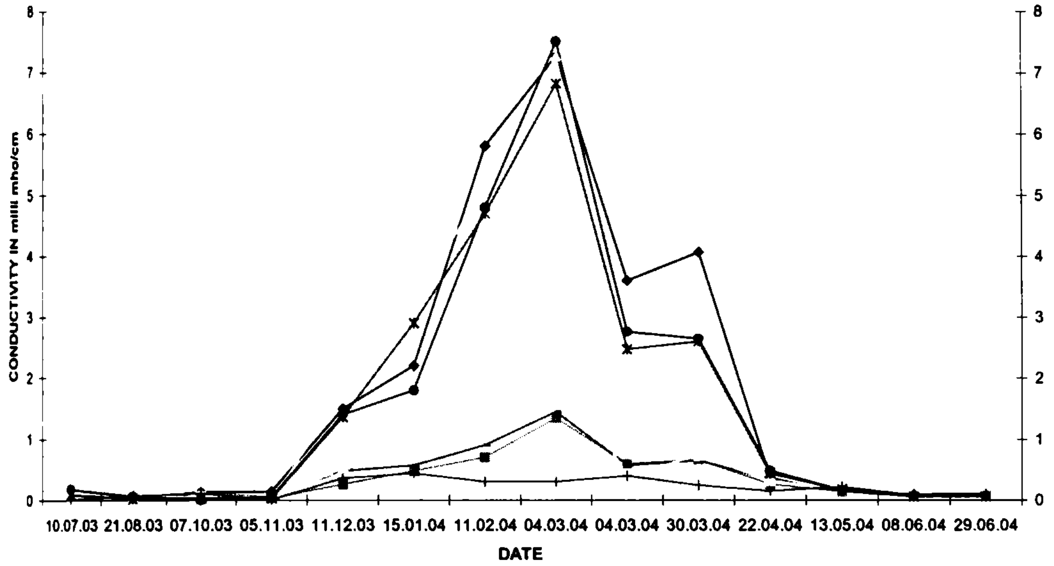


FIG.3.168 TEMPORAL VARIATION OF CONDUCTIVITY AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

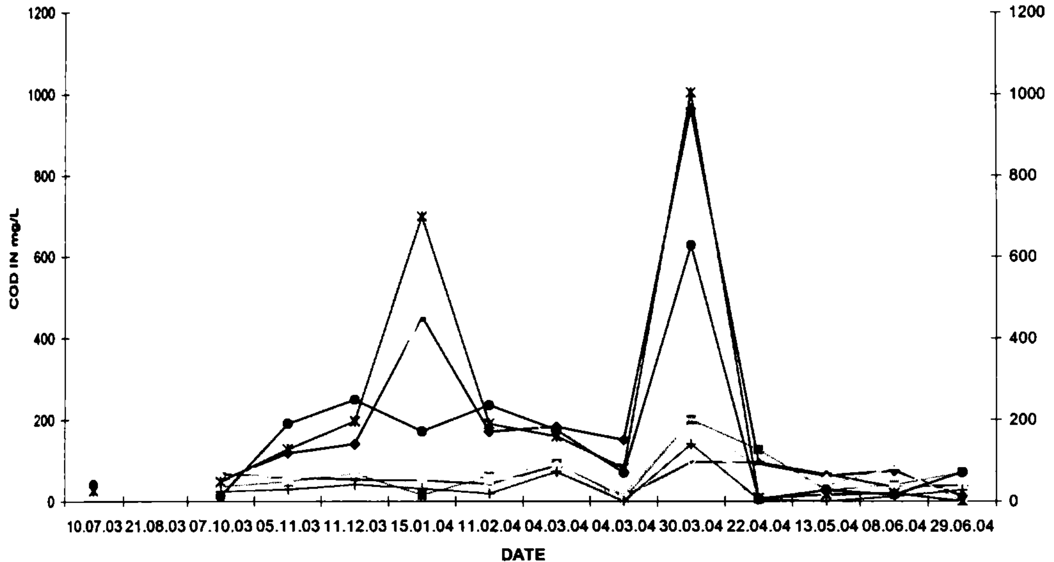


FIG.3.169 TEMPORAL VARIATION OF COD CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

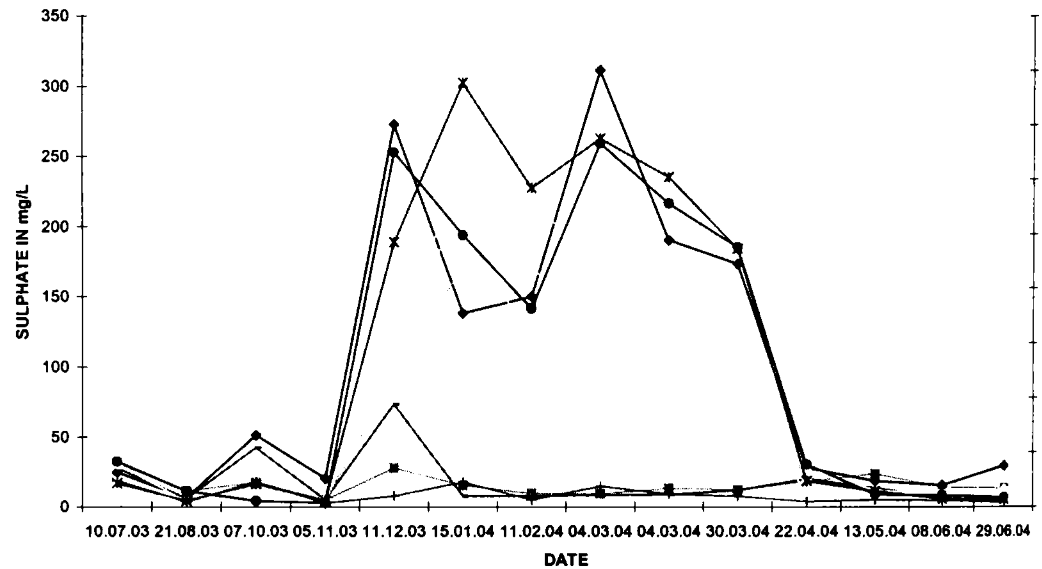


FIG.3.166 TEMPORAL VARIATION OF SULPHATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

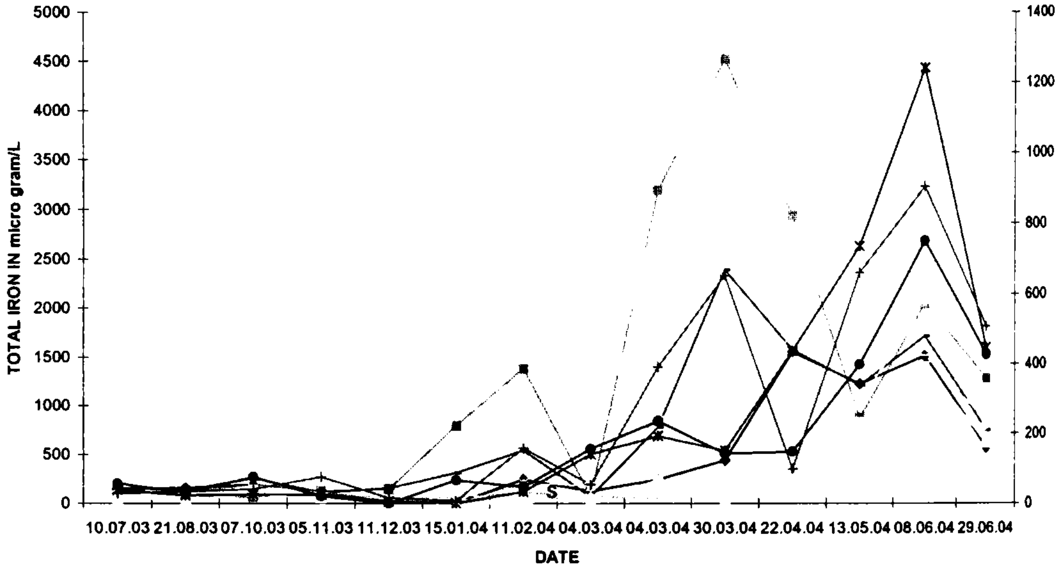


FIG.3.167 TEMPORAL VARIATION OF TOTAL IRON CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

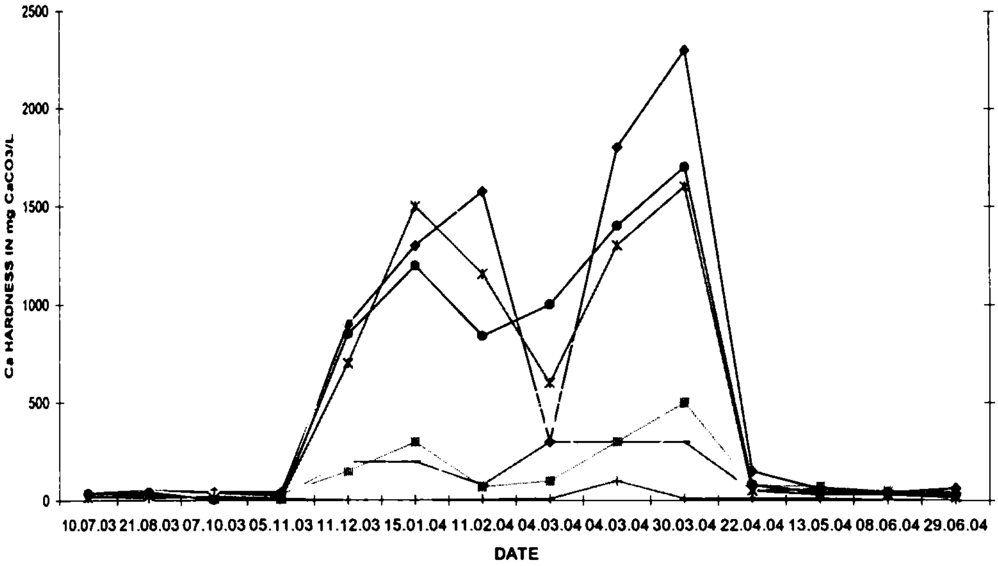


FIG.3.164 TEMPORAL VARIATION OF Ca HARDNESS CONCENTRATION AT VARIOUS SAMPLIG SITES ON KARINGACHIRAPUZHA

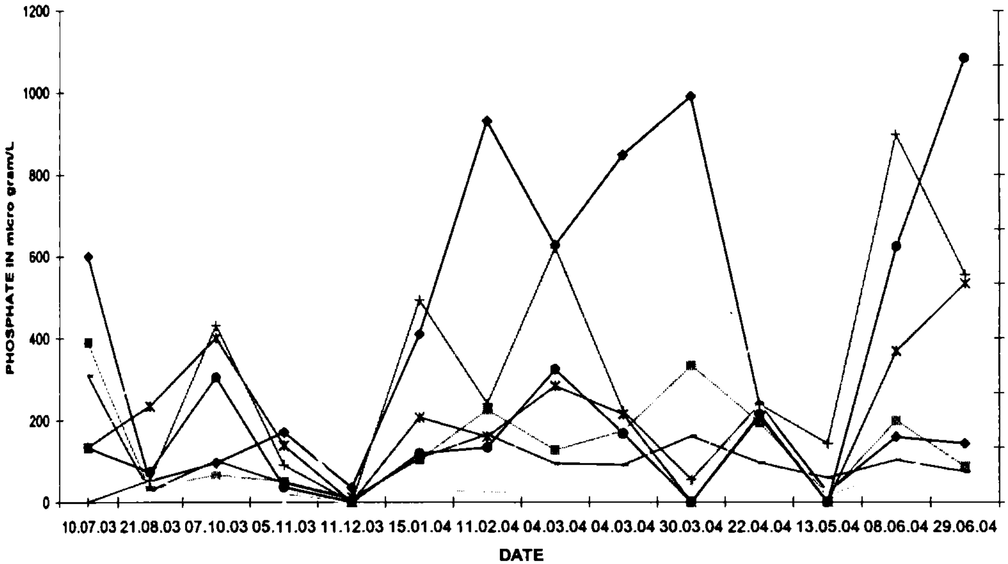


FIG.3.165 TEMPORAL VARIATION OF PHOSPHATE CONCENTRATION AT VARIOUSSAMPLING POINTS ON KARINGACHIRAPUZHA

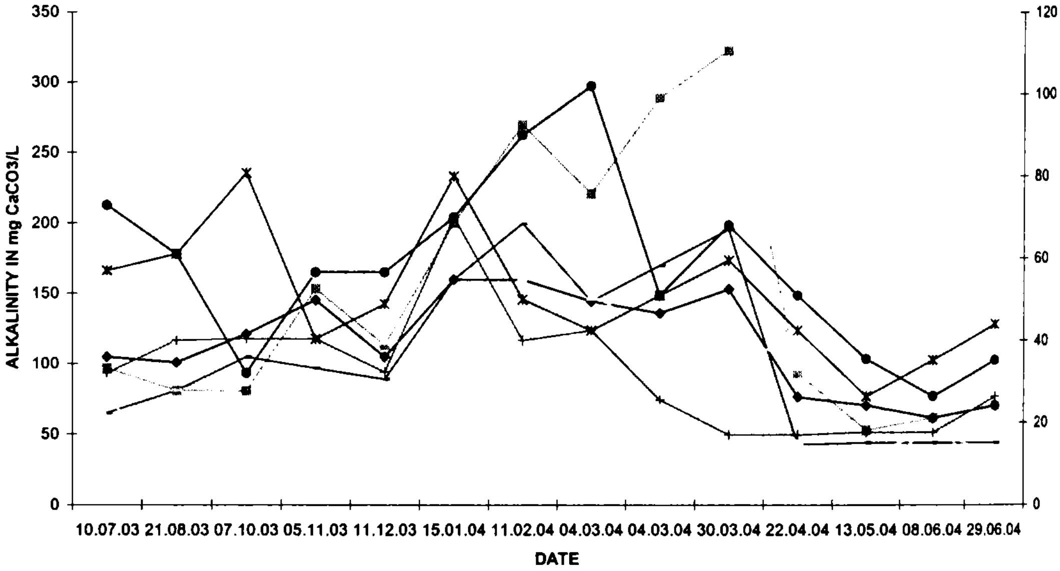


FIG.3.162 TEMPORAL VARIATION OF ALKALINITY CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

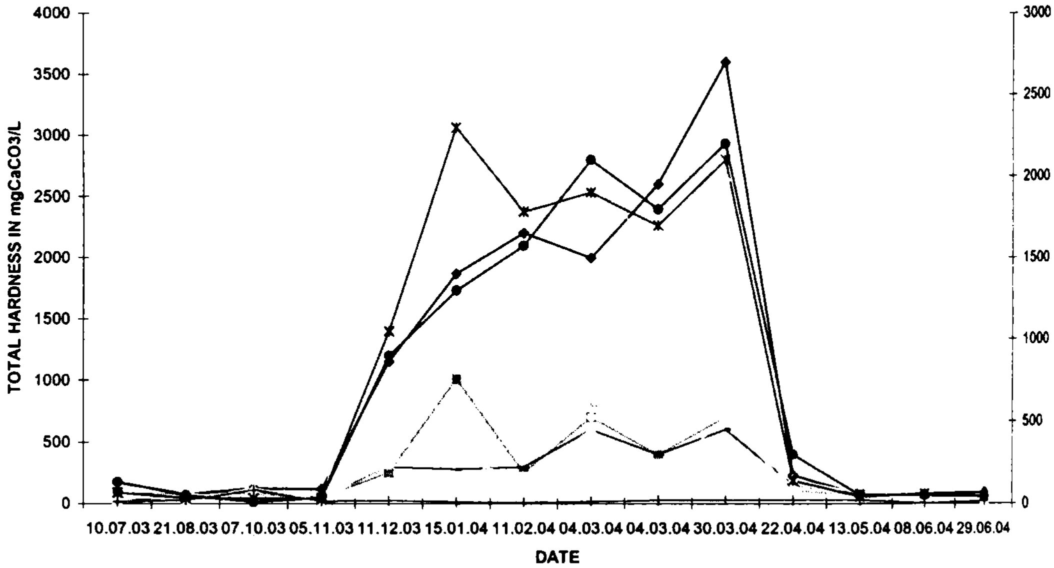


FIG.3.163 TEMPORAL VARIATION OF TOTAL HARDNESS CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPPUZHA

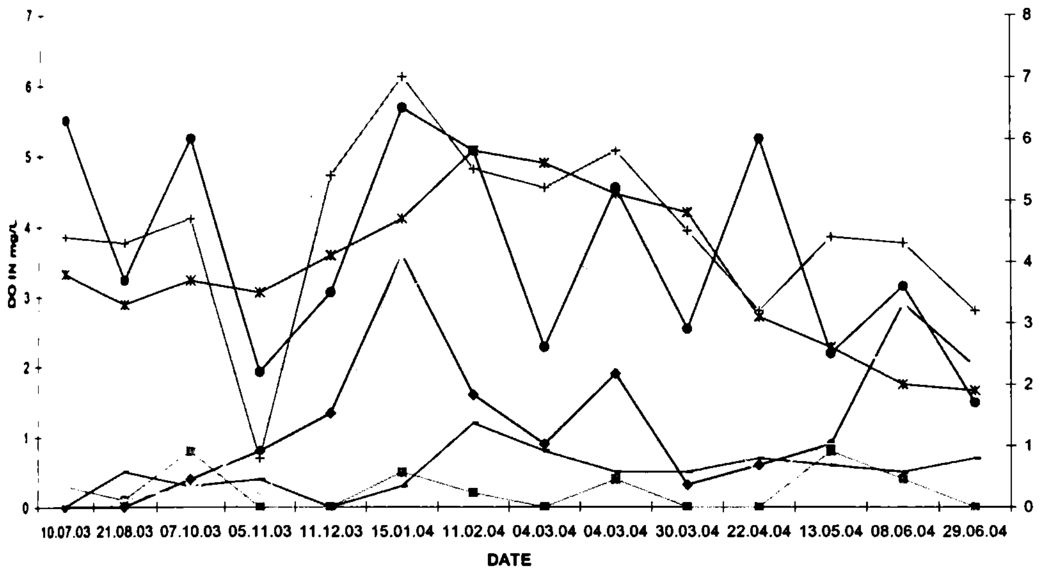


FIG.3.160 TEMPORAL VARIATION OF DO CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

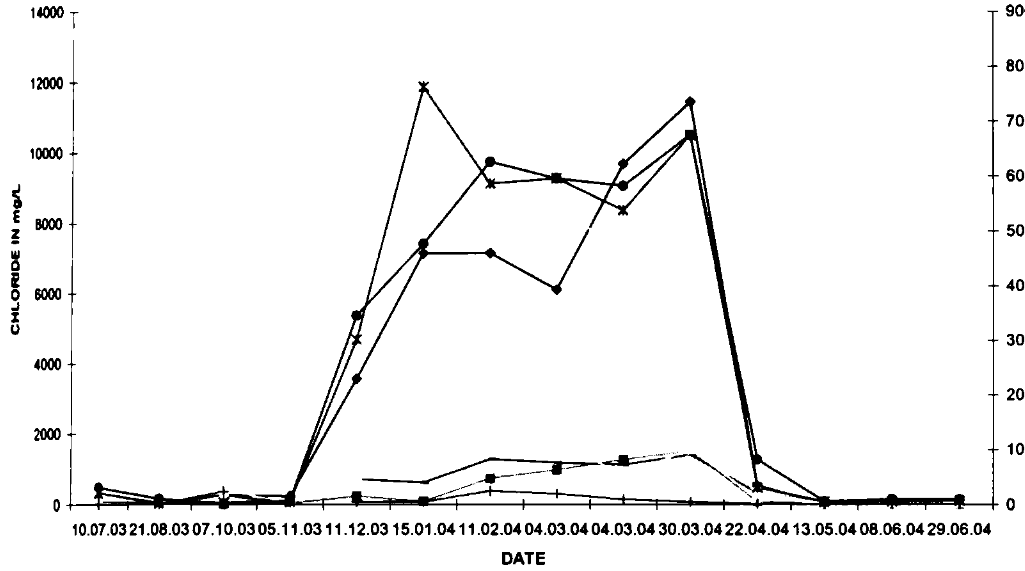


FIG.3.161 TEMPORAL VARIATION OF CHLORIDE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

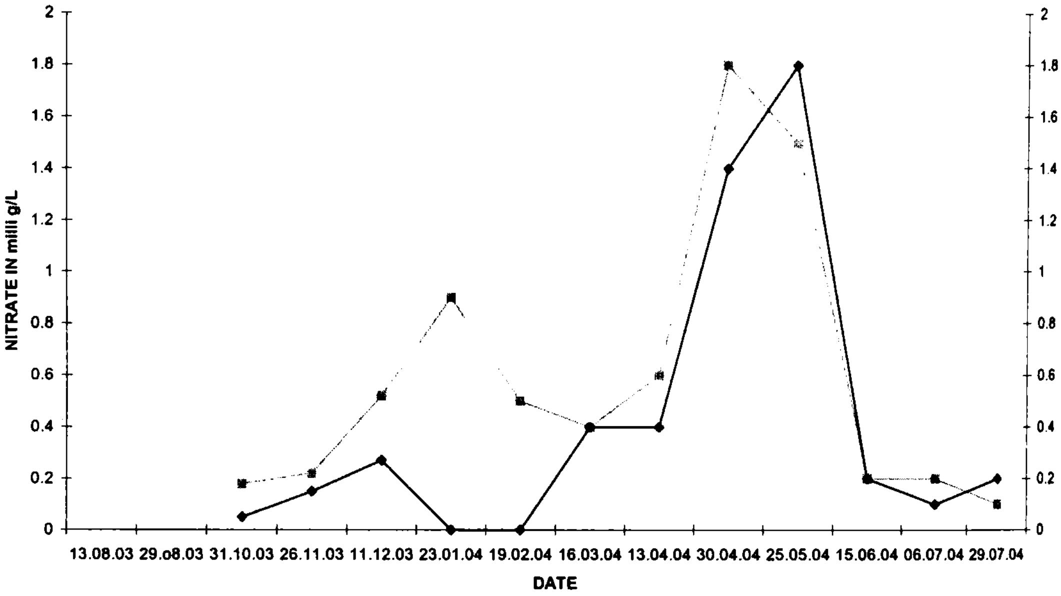


FIG.3.158 TEMPORAL VARIATION OF NITRATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KOITHARA CANAL

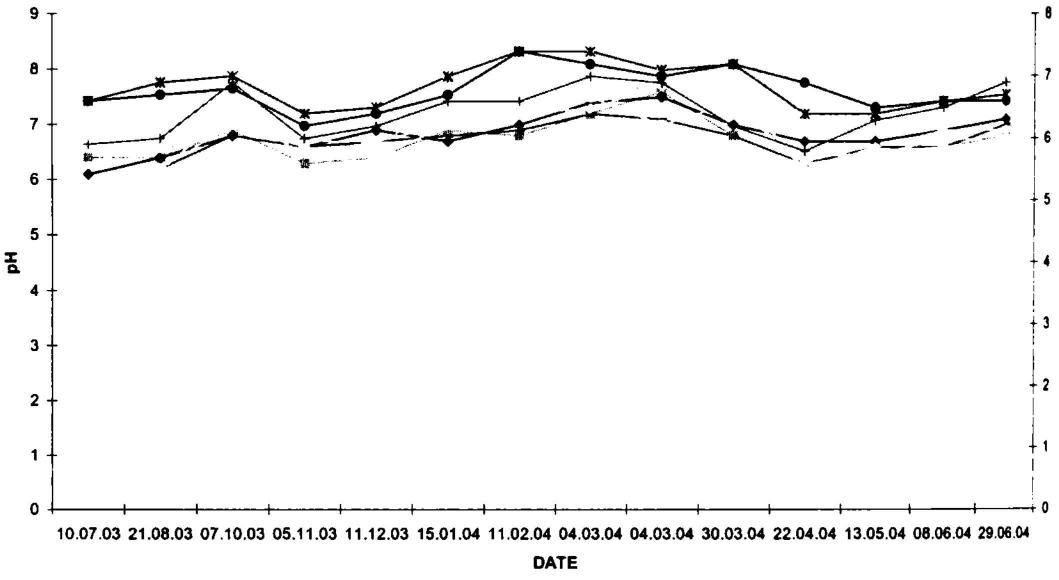


FIG.3.159 TEMPORAL VARIATION OF pH AT VARIOUS SAMPLING POINTS ON KARINGACHIRAPUZHA

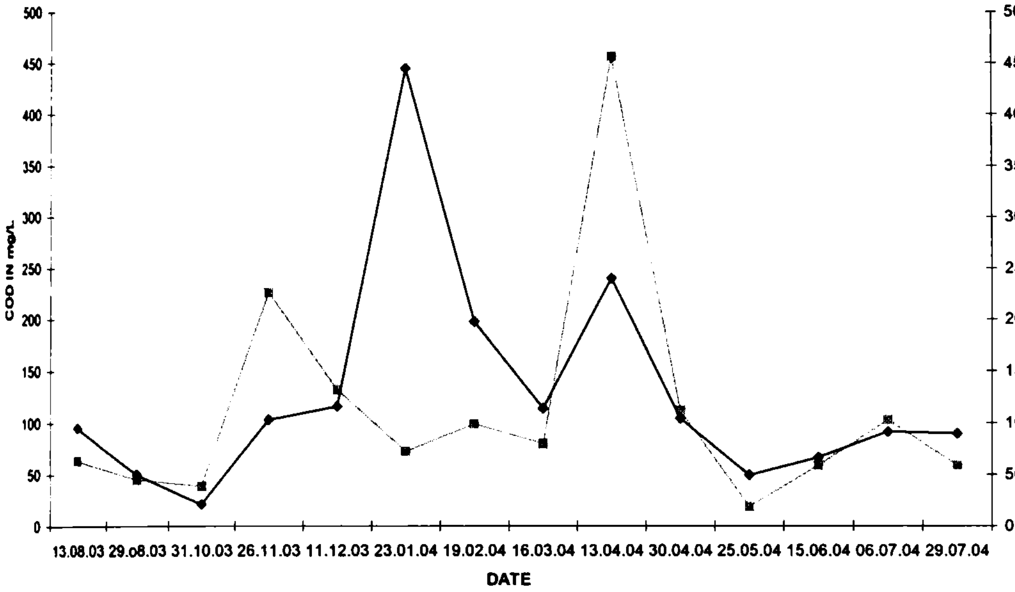


FIG.3.156 TEMPORAL VARIATION OF COD CONCENTRATION AT VARIOUS SAMPLING POINT SON KOITHARA CANAL

—■— ROB —◆— Emarald

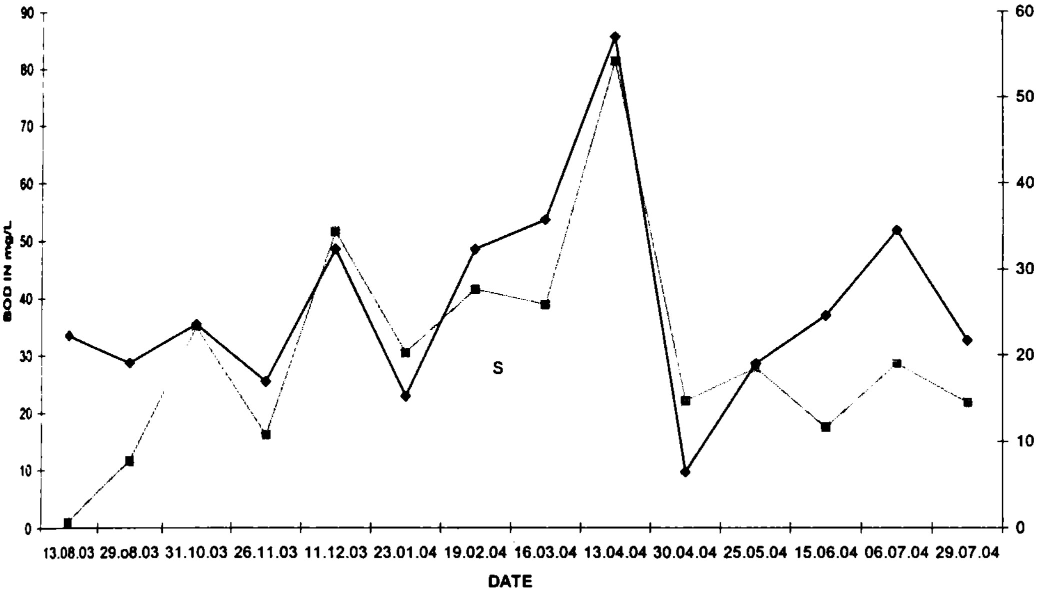


FIG.3.157 TEMPORAL VARIATION OF BOD CONCENTRATION AT VARIOUS SAMPLING POINTS ON KOITHARA CANAL

—■— ROB —◆— Emarald

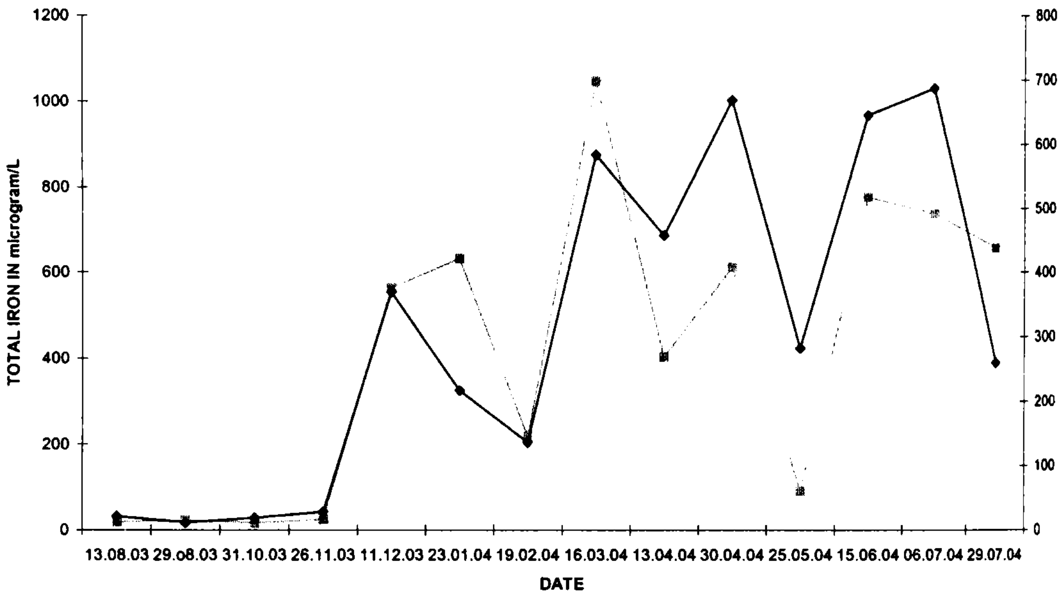


FIG.3.154TEMPORAL VARIATION OF TOTAL IRON CONCENTRATION AT VARIOUS SAMPILING SITES ON KOIHTARA CANAL

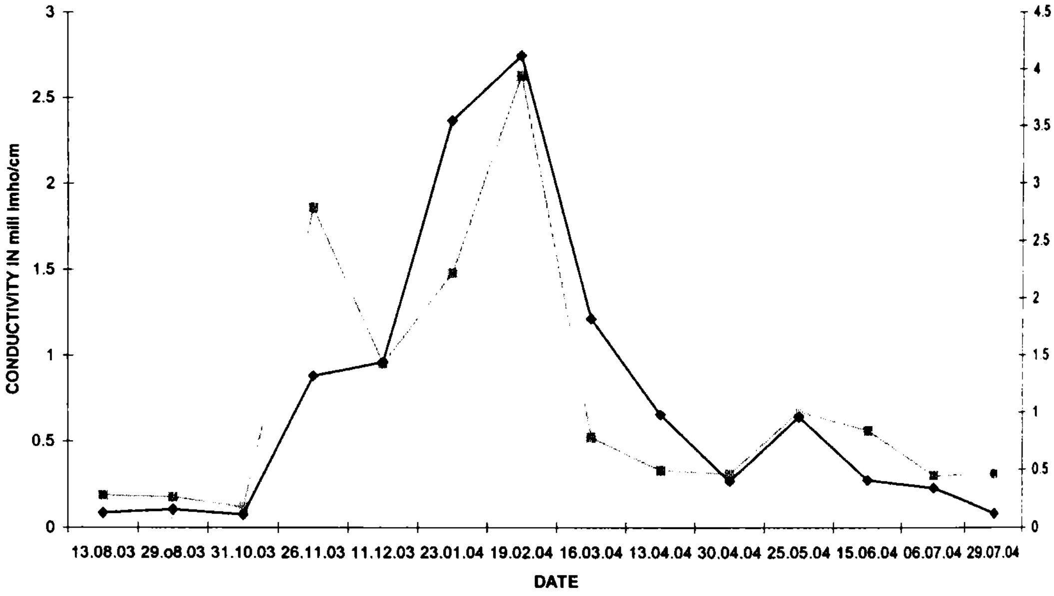


FIG.3.155 TEMPORAL VARIATION OF CONDUCTIVITY AT VARIOUS SAMPLING POINTS ON KOITHARA CANAL

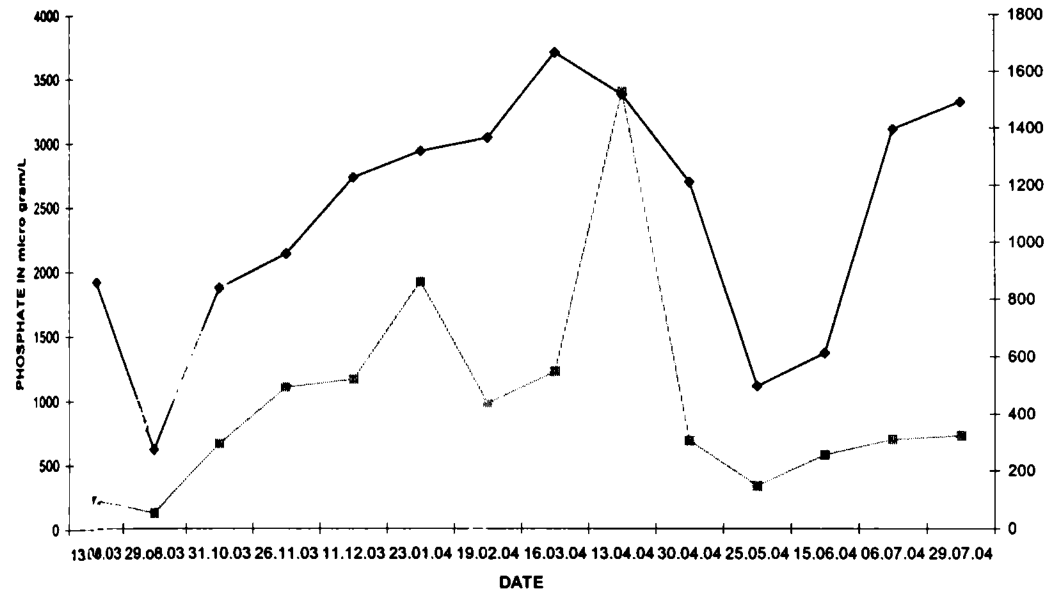


FIG.3.152 TEMPORAL VARIATION OF PHOSPHATE CONCENTRATION AT VRIOUS SAMPLING POINTS ON KOITHARA CANAL

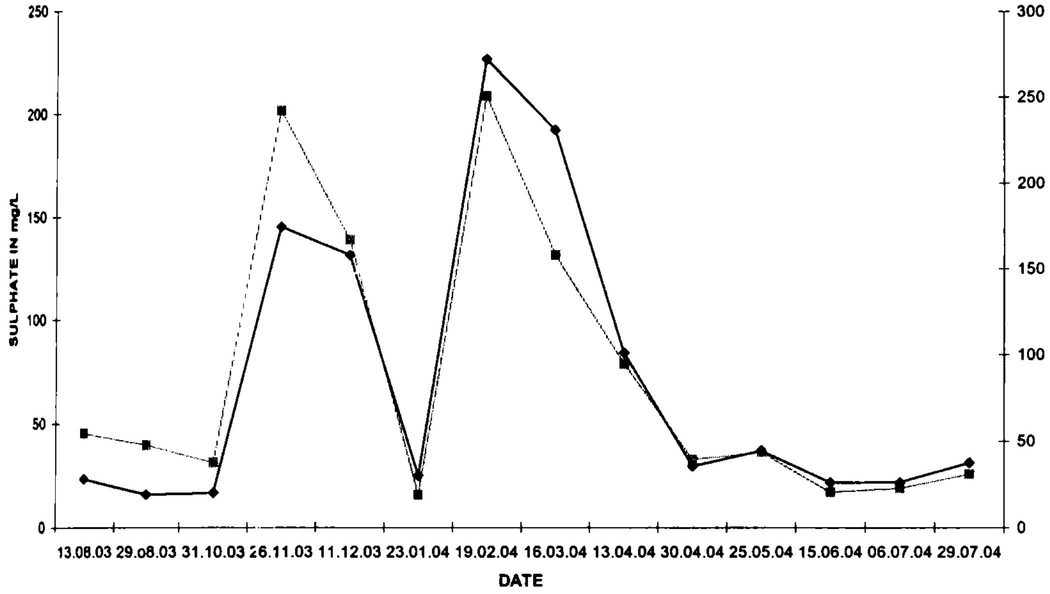


FIG.3.153 TEMPORAL VARIATION OF SULPHATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KOITHARA CANAL

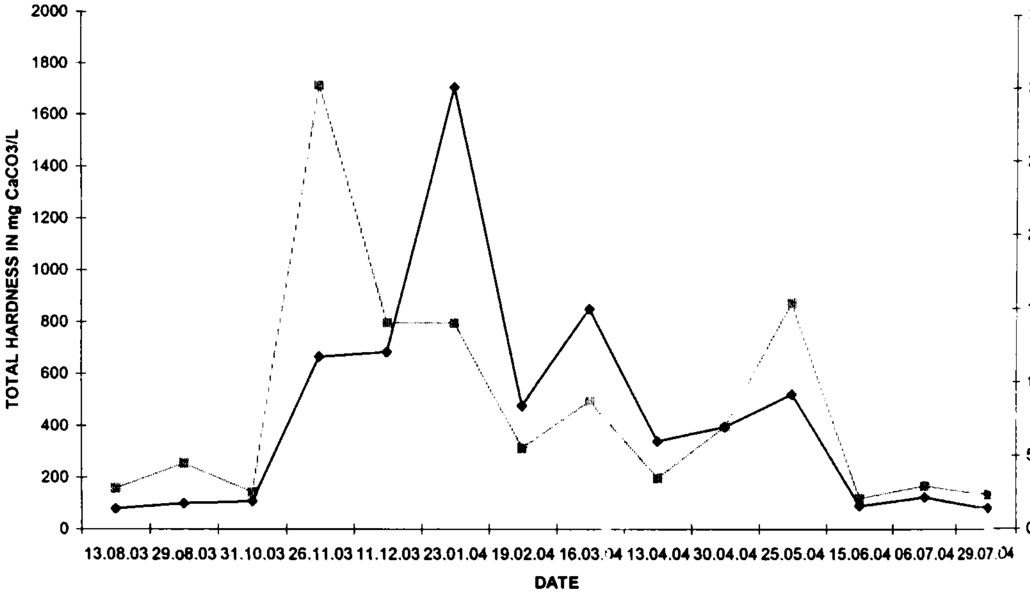


FIG.3.150 TEMPORAL VARIATION OF TAOTAL HARDNESS CONCENTRATION AT VARIOIUS SAMPLING POINT SON KOIHTARA CANAL

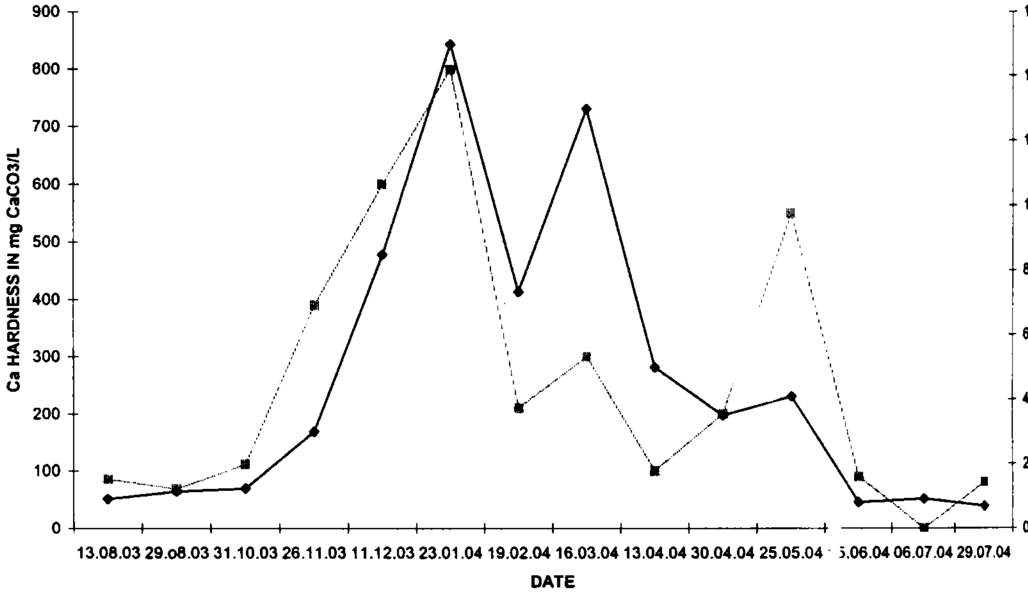


FIG.3.151 TEMPORAL VARIATION OF Ca HARDNESS CONCENTRATION AT VARIOUS SAMPLING POINTS ON KOITHARA CANAL

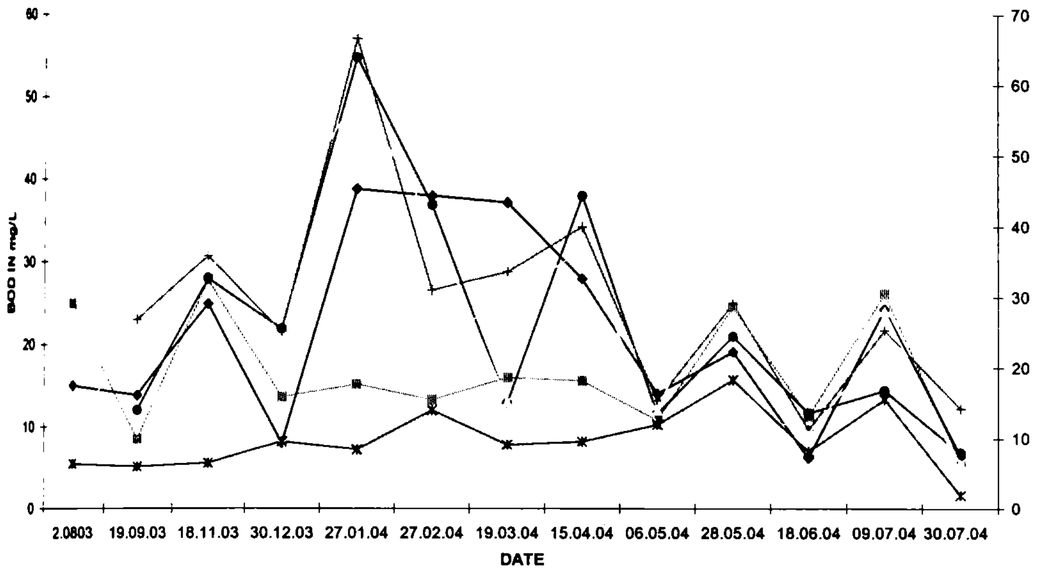


FIG.3.144 TEMPORAL VARIATION OF BOD CONCENTRATION AT VARIOUS SAMPLIN GPOINTS ON KARANAKKODAM THOD

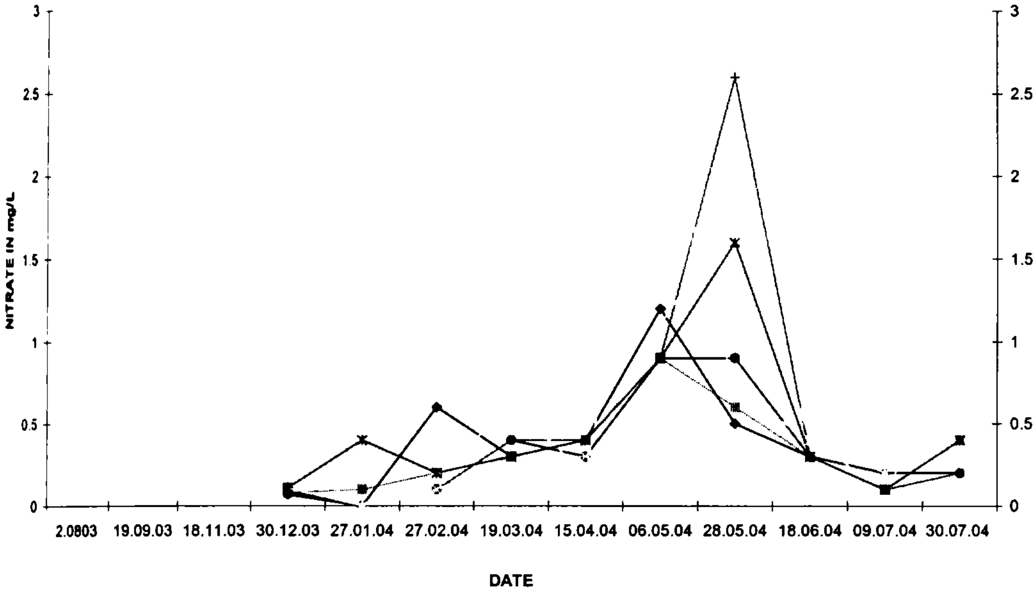


FIG.3.145 TEMPORAL VARIATION OF NITRATE CONCENTRATION AT VARIOUS SAMPLIN GPOINTS ON KARANAKKODAM THOD

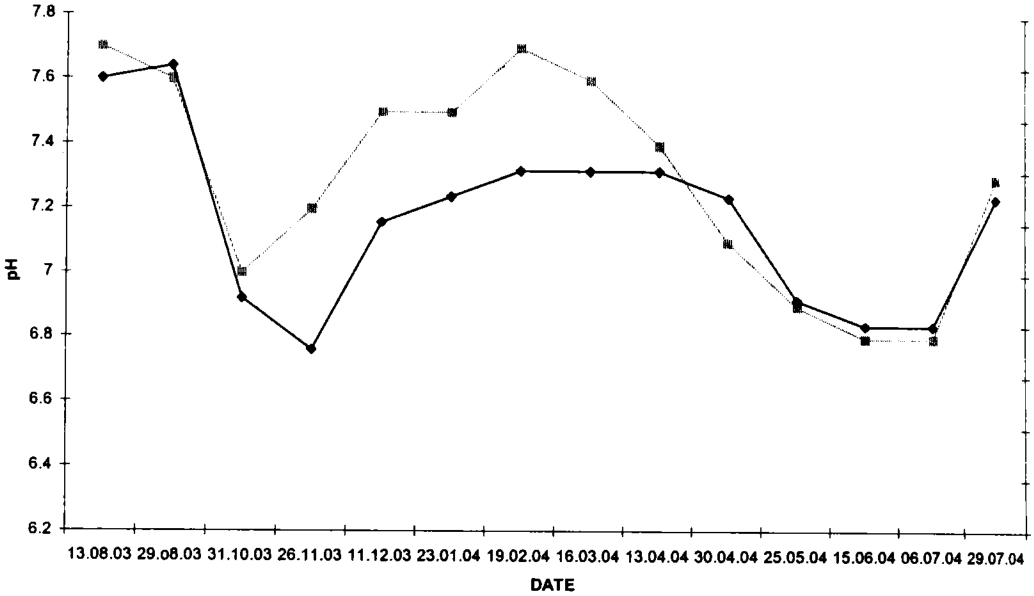


fIG.3.146 TEMPORAL VARIATION OF pH AT VARIOUS SAMPLING POINTS ON KOITHARA CANAL

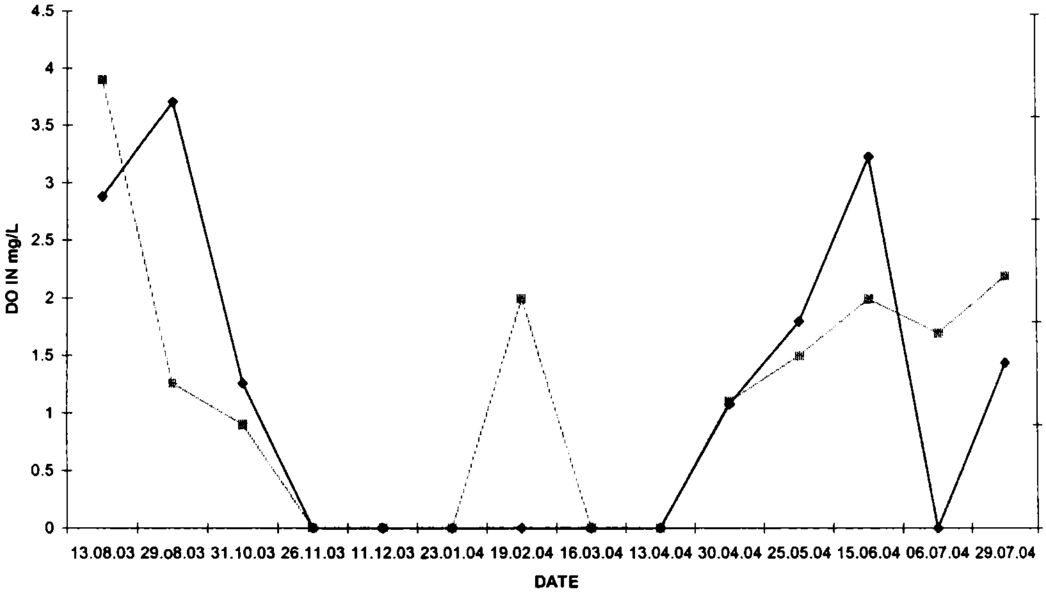


FIG.3.147TEPORAL VARIATION OF DO CONCENTRATION AT VARIOUS SAMPLING POINTS ON KOIHTARA CANAL

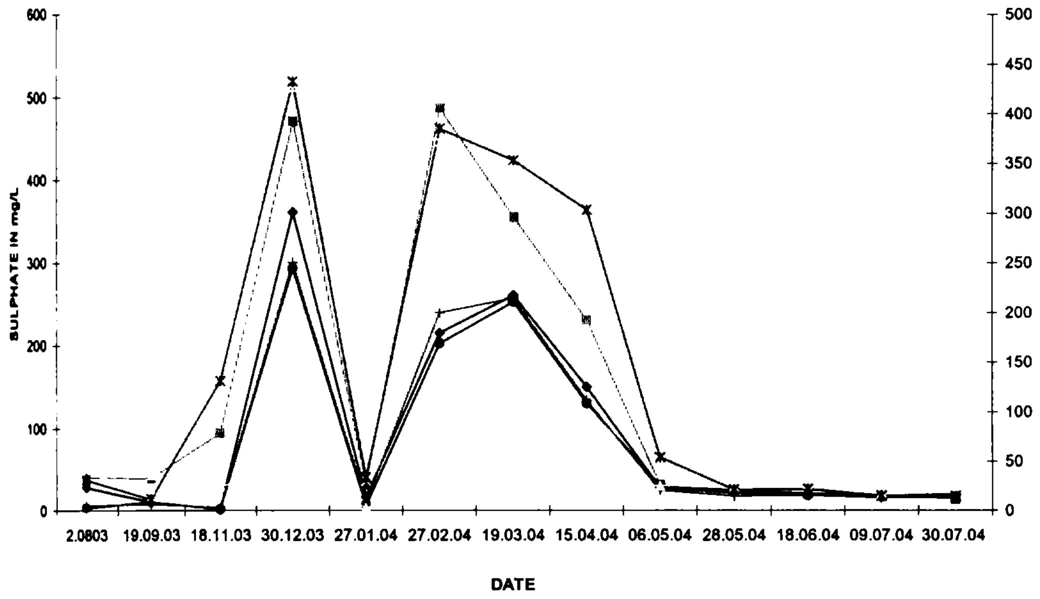


FIG.140 TEMPORAL VARIATION OF SULPHATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

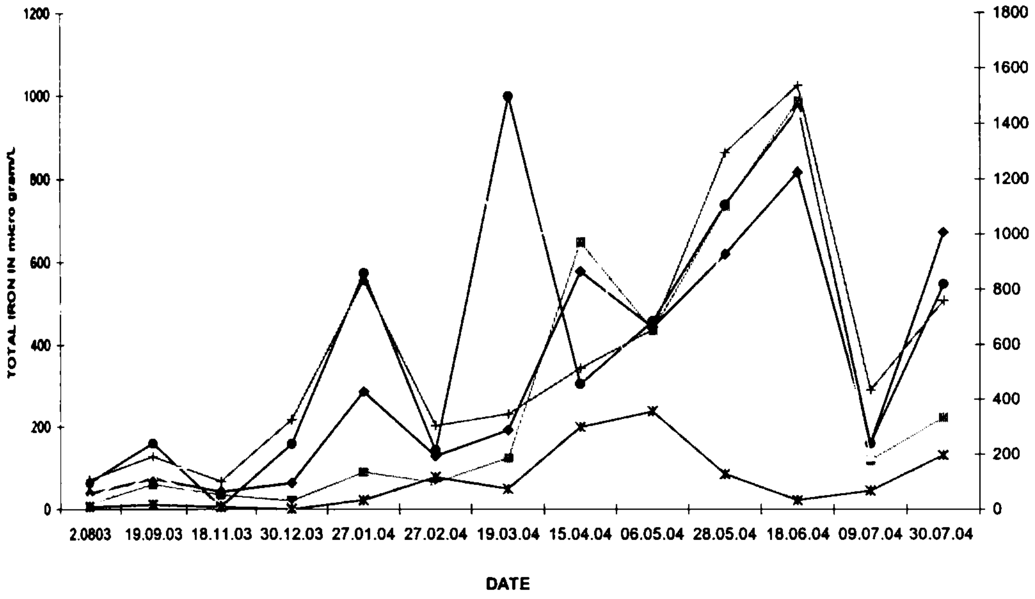


FIG.3.141 TEMPORAL VARIATION OF TOTAL IRON CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

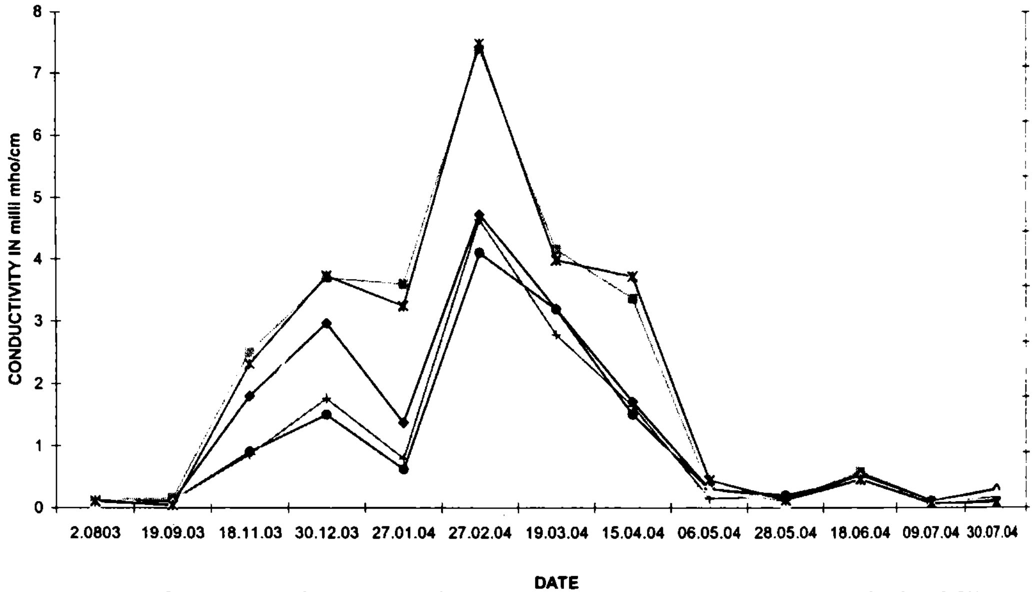


fIG 3.142. TEMPORAL VARIATION OF CONDUCTIVITY AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

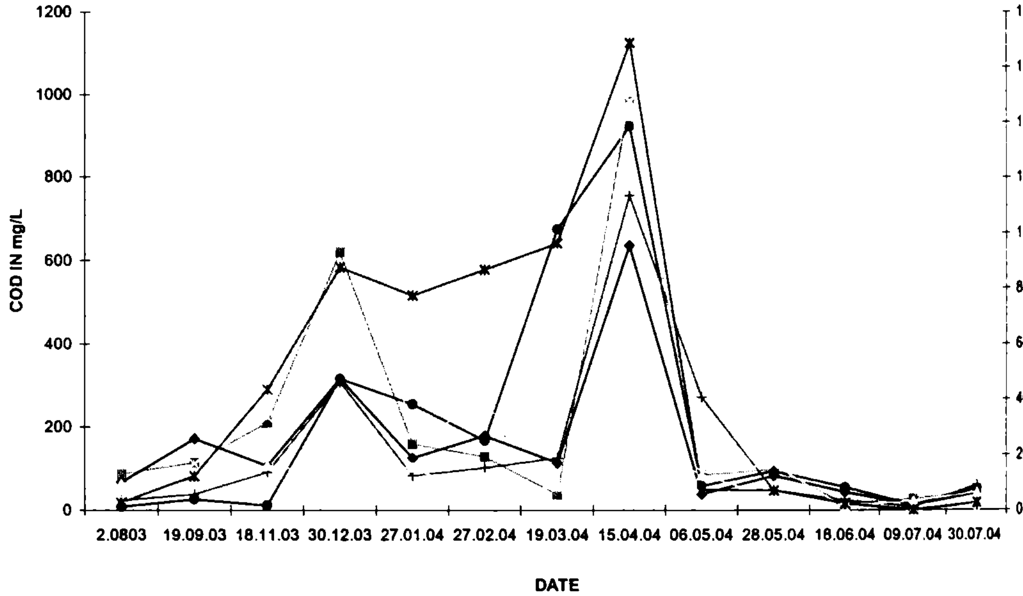


FIG.3.143 TEMPORAL VARIATION OF COD CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

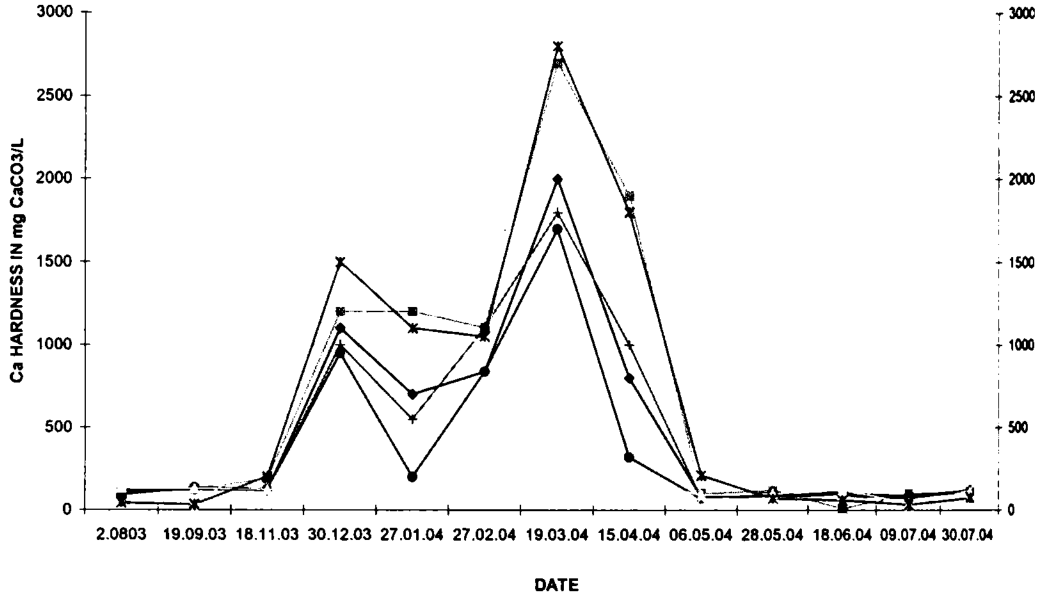


FIG.3.138 TEMPORAL VARIATION OF Ca HARDNESS CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

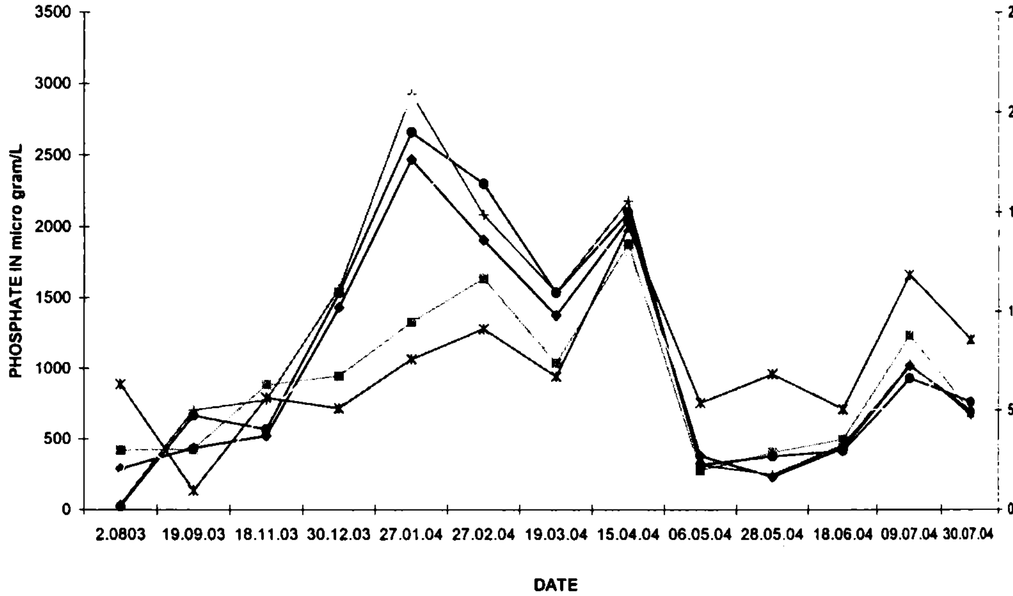


fIG.3.139 TEMPORAL VARIATION OF PHOSPHATE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

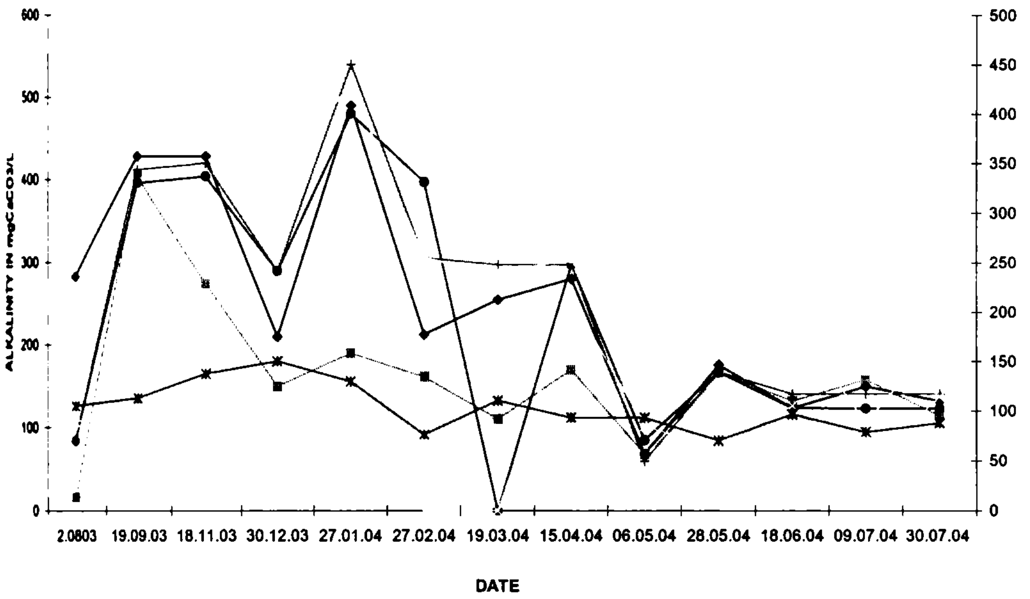


FIG.3.136 TEMPORAL VARIATION OF ALKALINITY CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

■ Chettichira ◆ ROB ● Karanakkodam + Marshaling yard VIP road PANDARACHIRA ✱ Chilavanoor

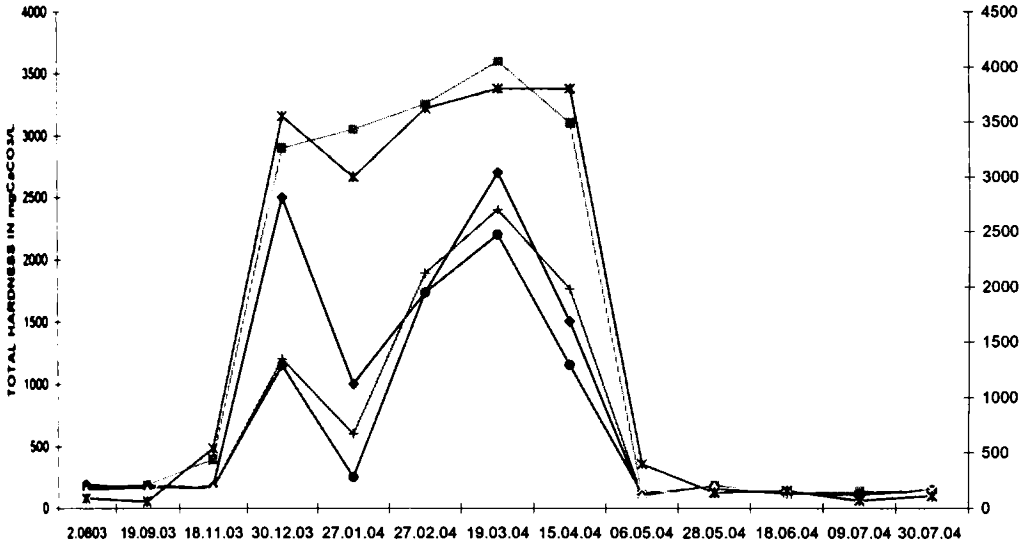


FIG 3.137 TEMPORAL VARIATION OF TOTAL HARDNESS CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKODAM THOD

■ Chettichira ◆ ROB ● Karanakkodam + Marshaling yard VIP road PANDARACHIRA ✱ Chilavanoor

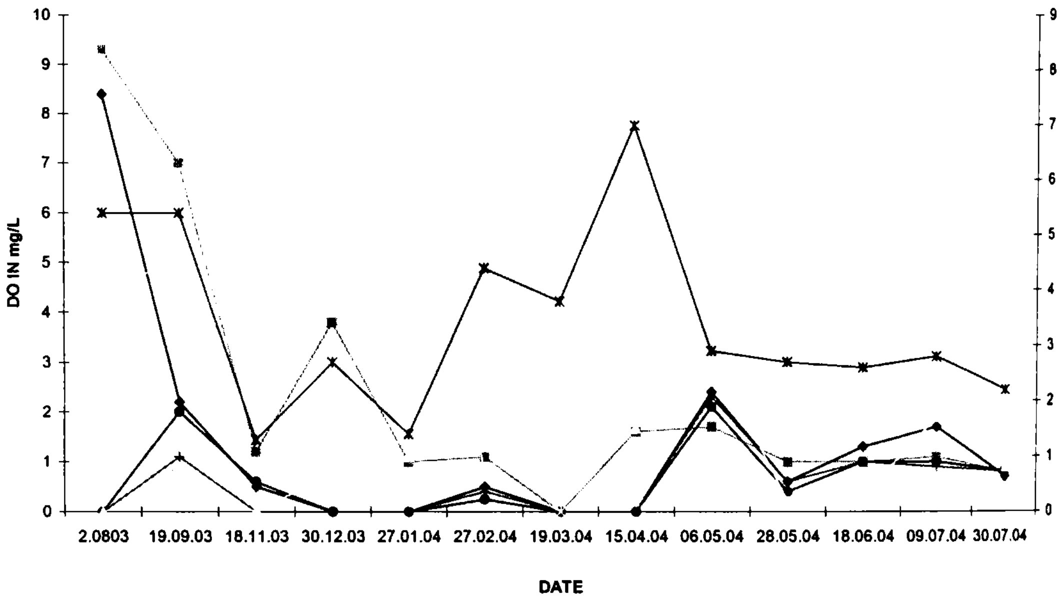


fIG.3.134 tEMPORAL VARAITION OF DO CONCENTRATION AT VARIOUIS SAMPLING SITES ON KARANKKODAM THOD

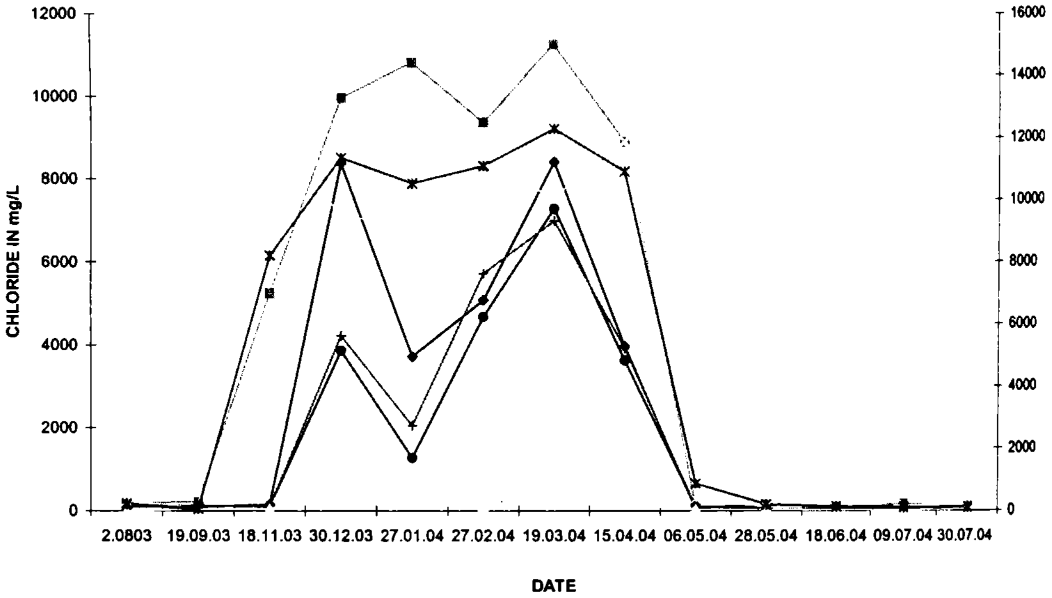


fIG.3.135tEMPORAL VARIATION OF CHLORIDE CONCENTRATION AT VARIOUS SAMPLING POINTS ON KARANAKKODAM THOD

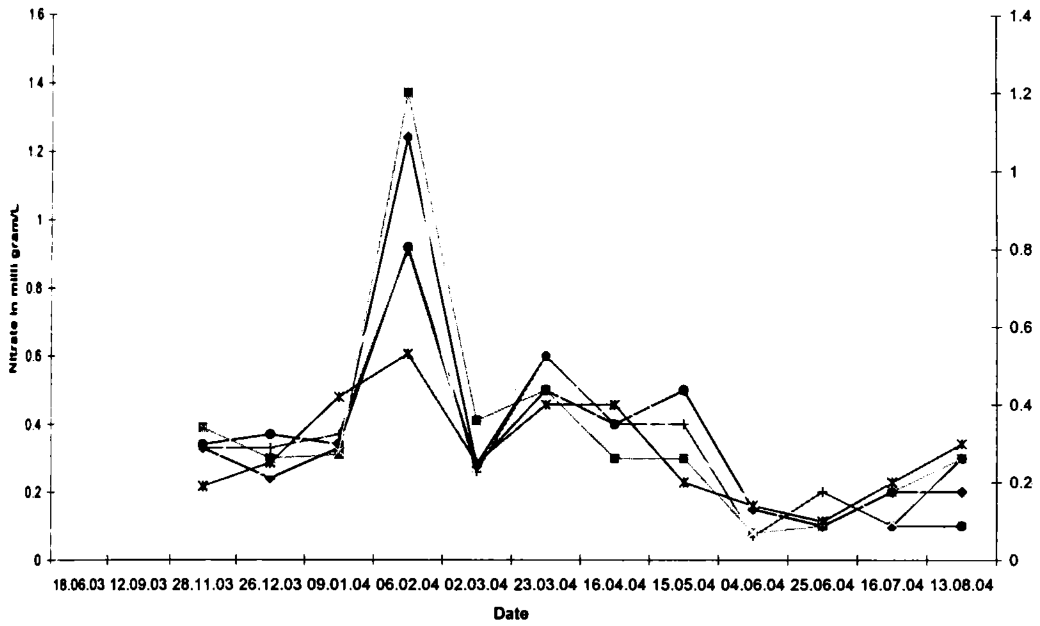


Fig.3.132 Temporal vriation of nitrate concentration at various sampling point son Chittoor puzha

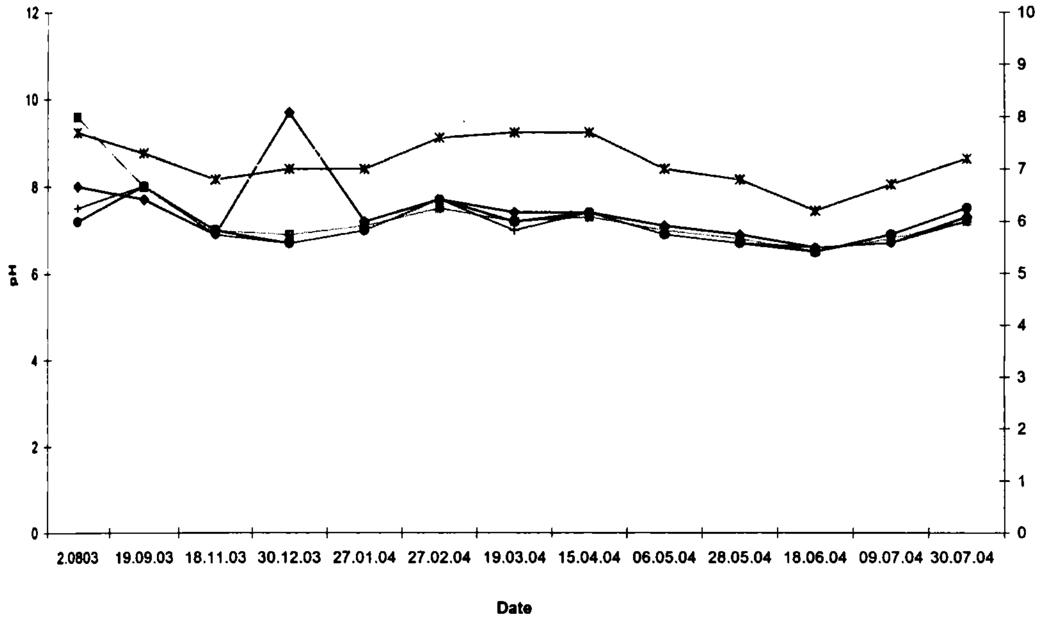


Fig.133 Temporal variation of pH at variouis sampling points on Karanakkodam thod

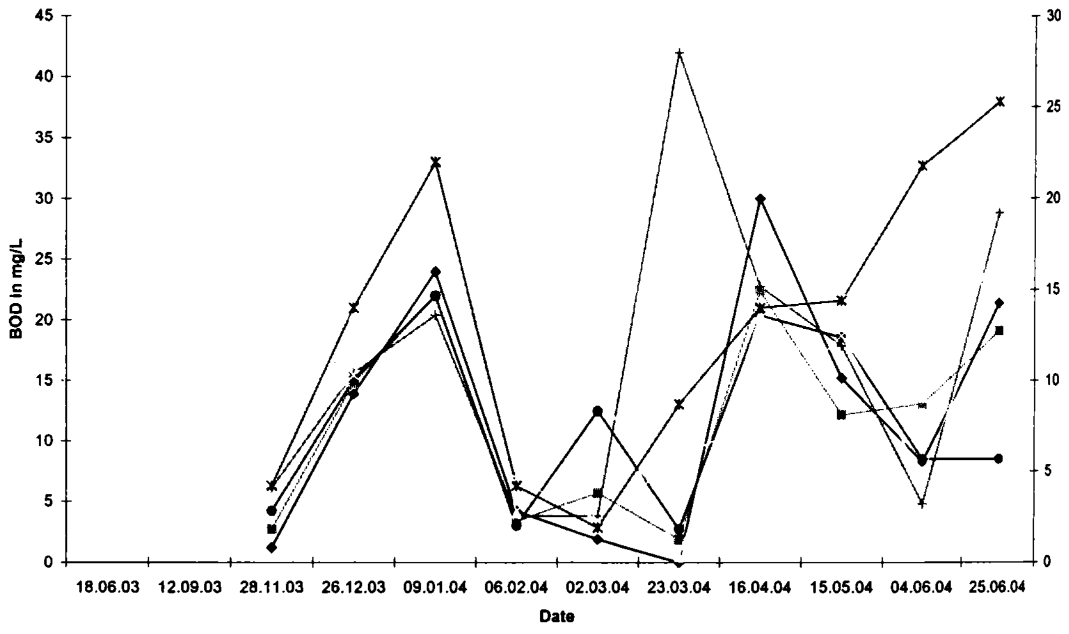


Fig.3.130 Temporal variation of BOD concentration at vrioius sampling points on Chittoor puzha

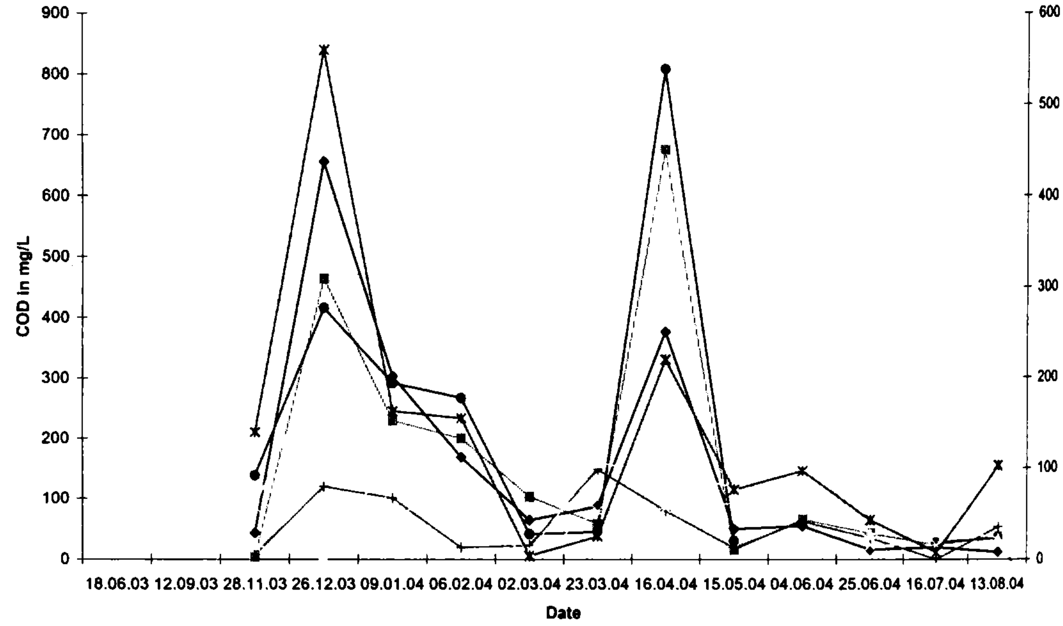


Fig.3.131 Temporal vraition of COD concentration at various sampling sites on Chittoor puzha

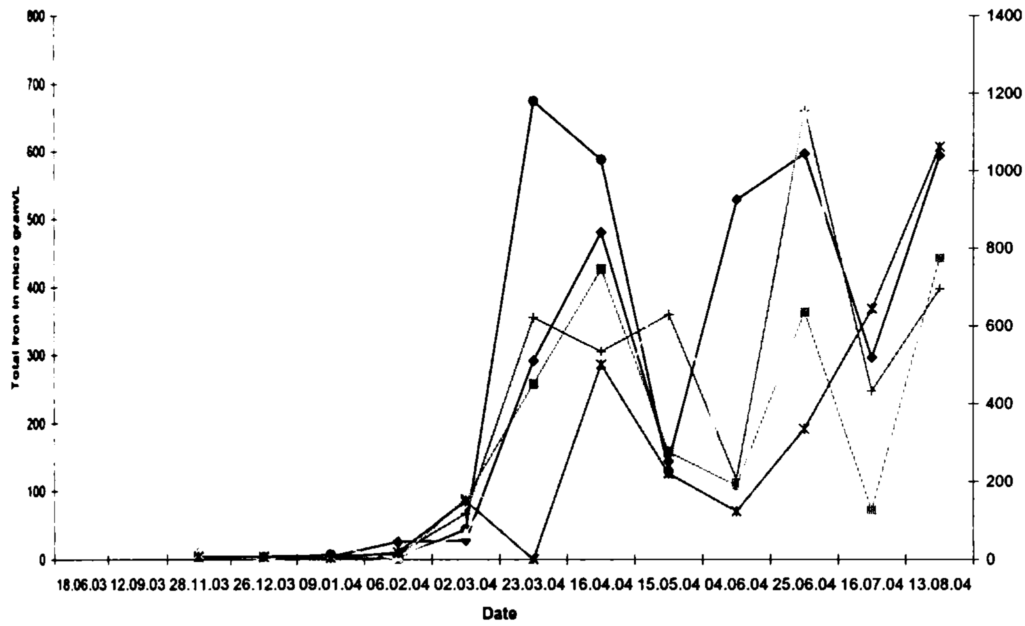


Fig.3.128 Temporal variation of total iron concentration at various sampling points on Chittoor puzha

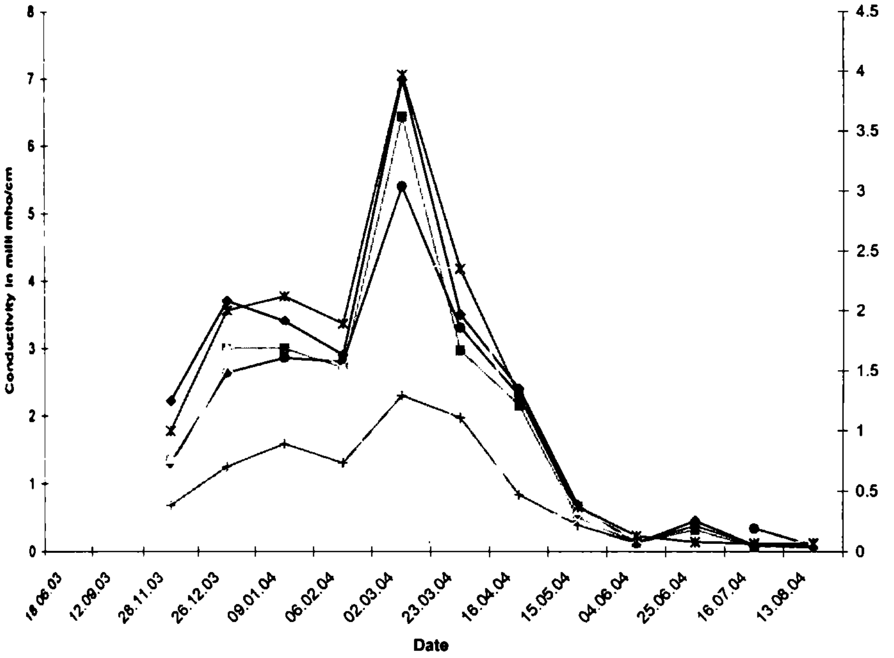


Fig.3.129 Temporal variation of Conductivity at various sampling sites on Chittoor puzha

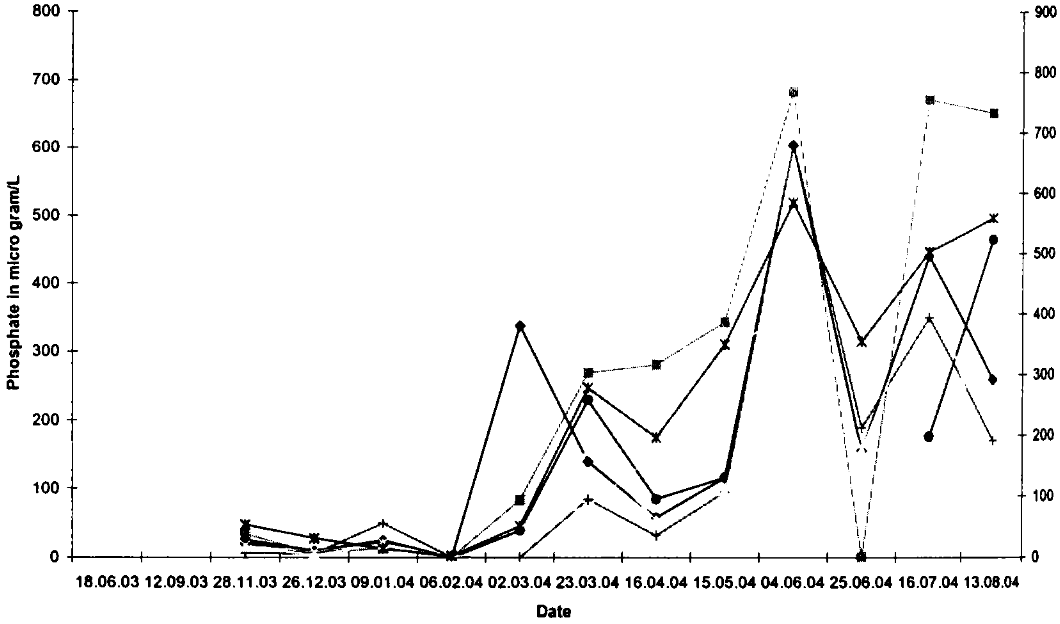


Fig.3.126 Temporal variation of Phosphate concentration at various sampling points on Chittoor puzha

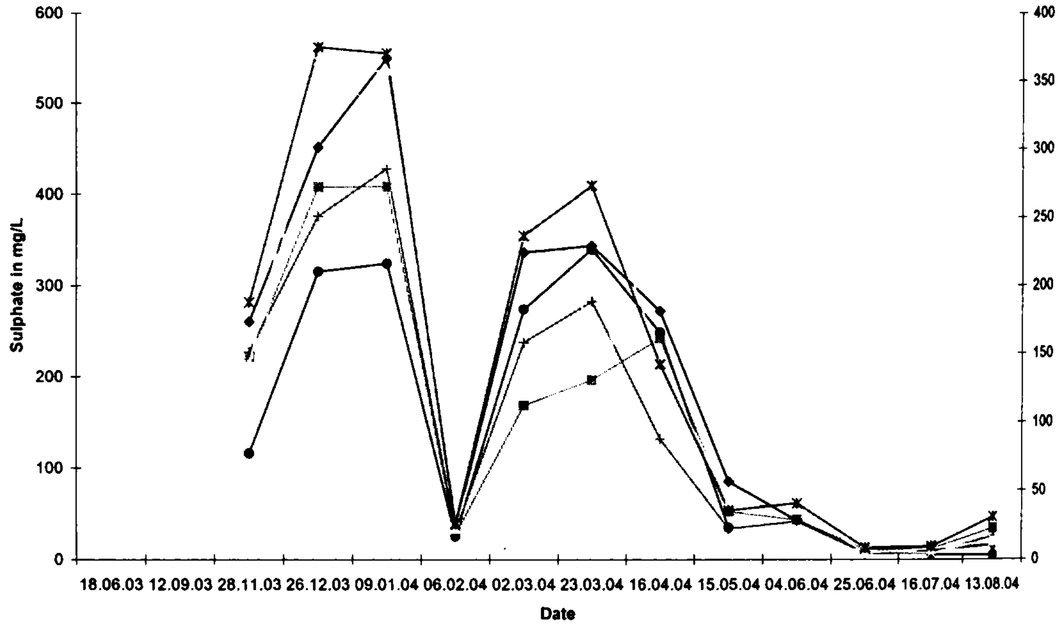


Fig.3.127 Temporal variation of sulphate concentration at various sampling points on Chittoor puzha

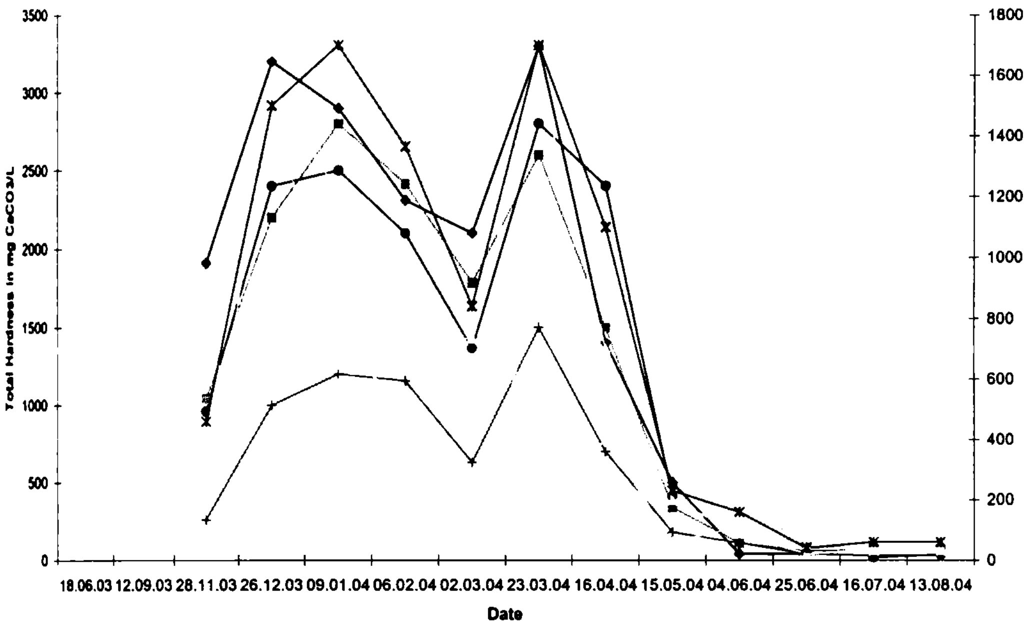


Fig.3.124 Temporal variation of total Hardness concentration at various sampling points on Chittoor puzha

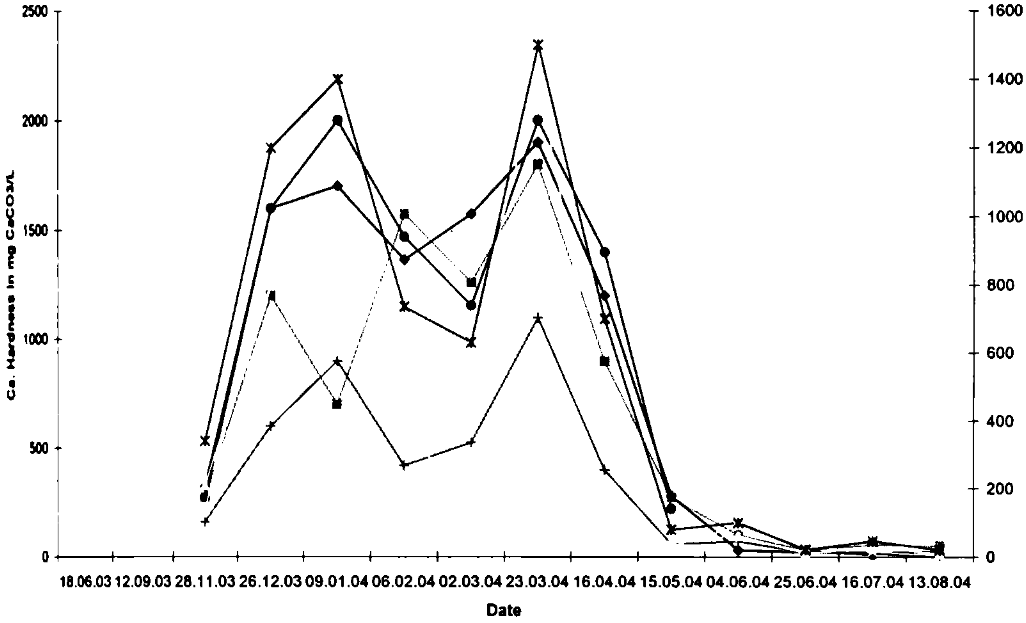


Fig.3.125 Temporal variation of Ca Hardness concentration at various sampling point son Chittooe puzha

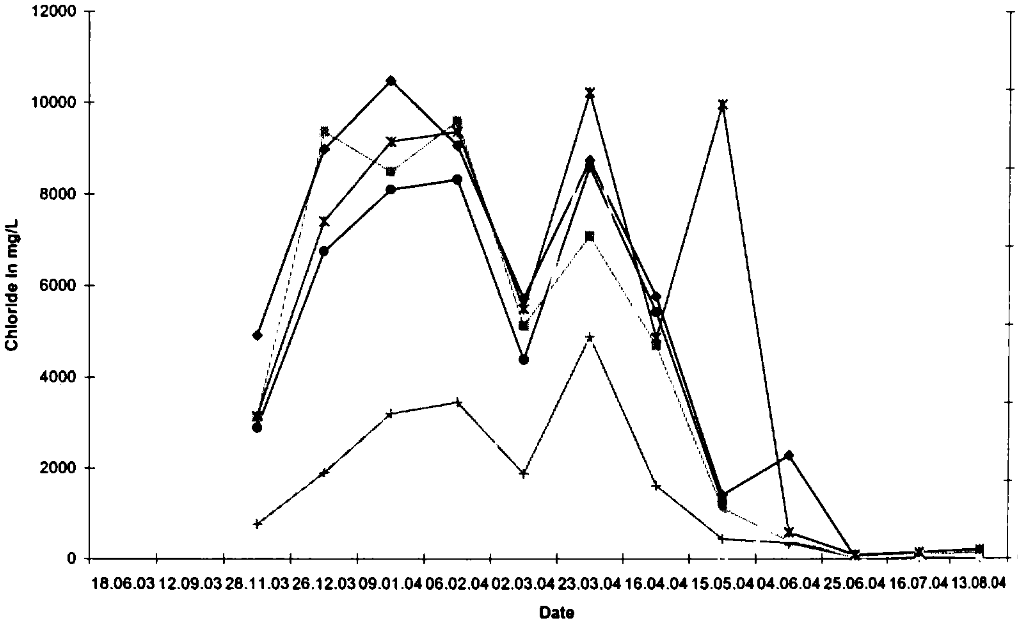


Fig.3.122 Temporal variation of Chloride concentration at various sampling points on Chittoor puzha

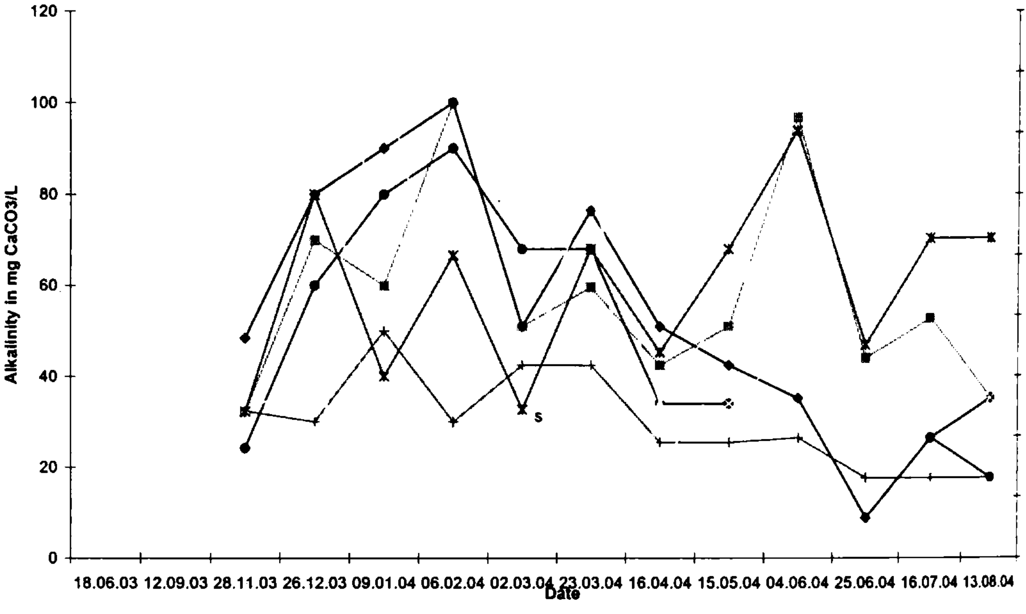


Fig.3.123 Temporal variation of Alkalinity concentration at various sampling points on Chiottoor Puzha

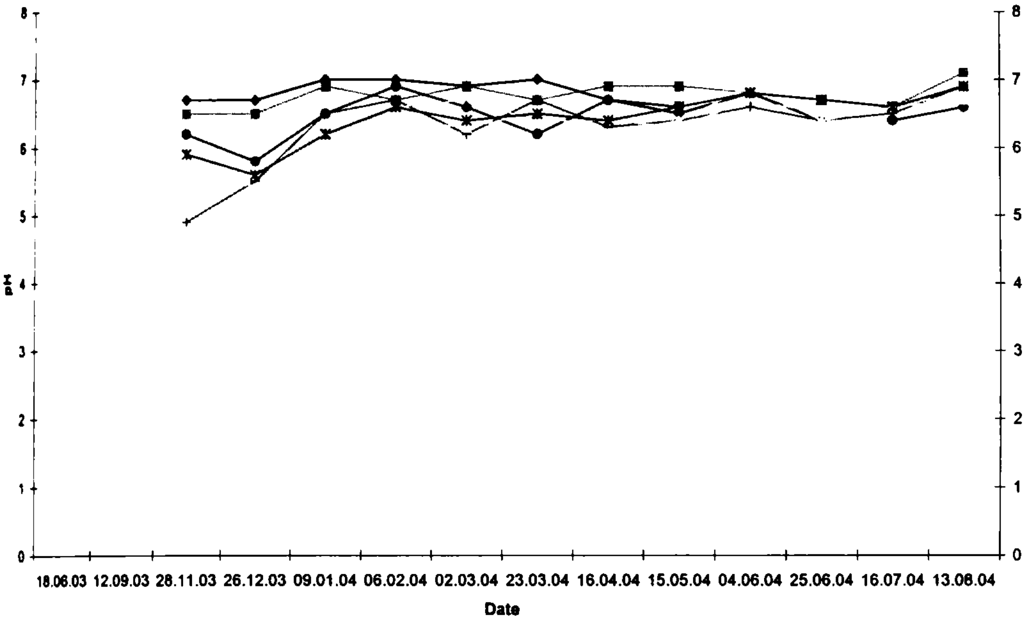


Fig.3.120 Temporal variation of pH at various sampling points on Chittoor puzha

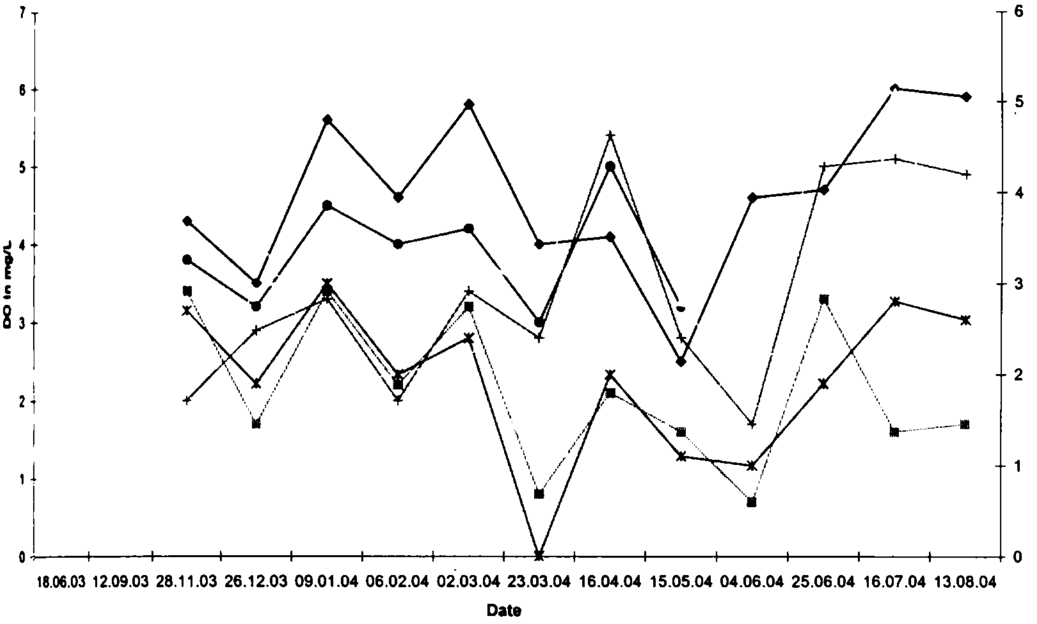


Fig.3.121Temporal variation of DO concentration at various sampling points on Chittoor puzha

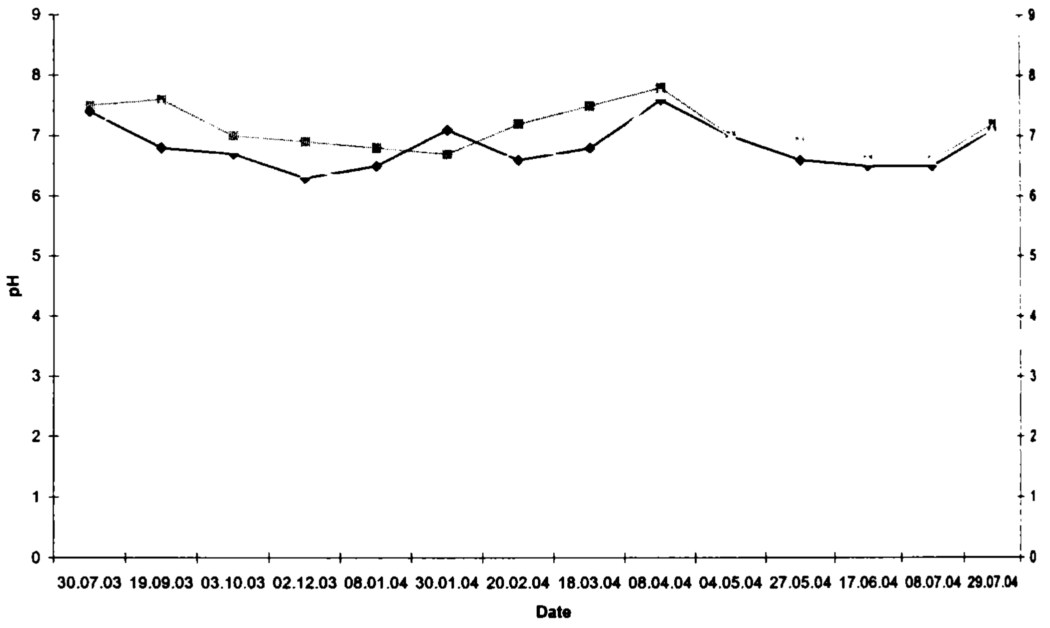


Fig.3.118 Temporal variation of pH at various smpling points on Changadompokk thod

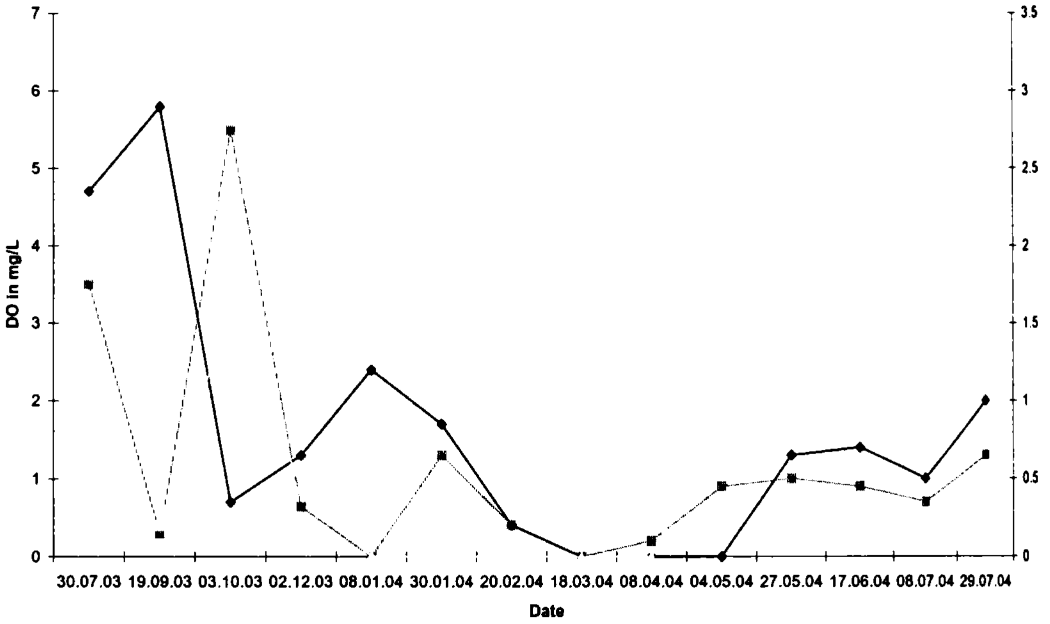


Fig.3.119 Temporal variation of DO concentration at various sampling points on

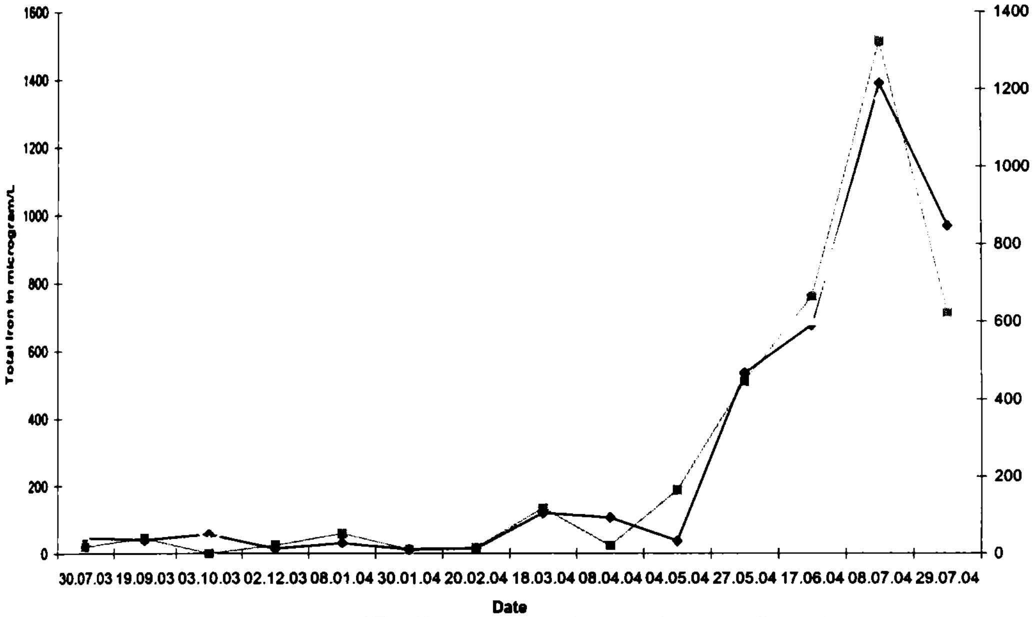


Fig.3.116 Temporal variation of Total Iron concentration at various sampling points on Changadompokk thod

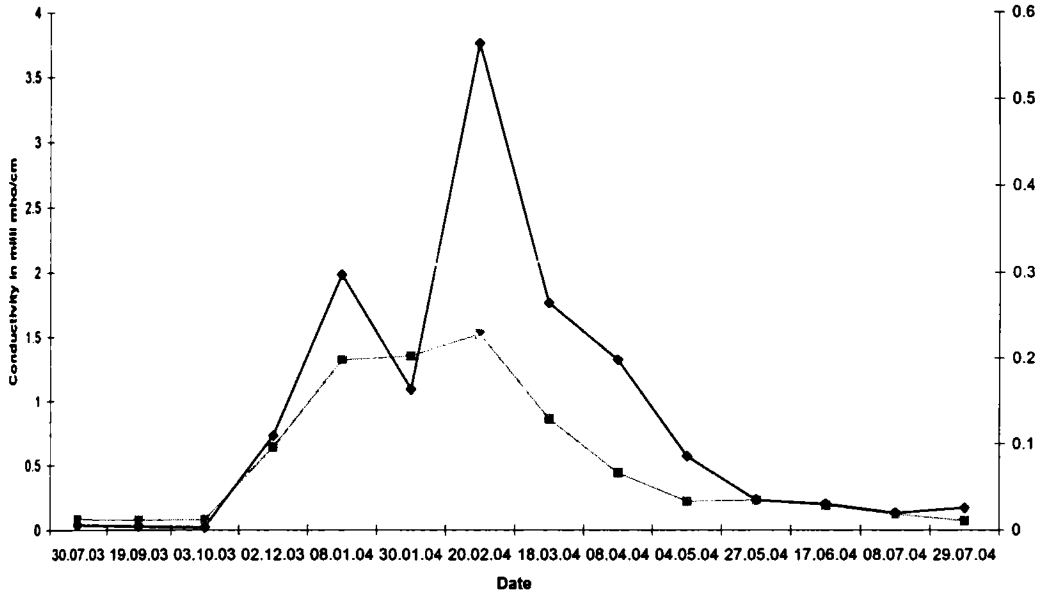


Fig.3.117Temporal variation of Conductivity at various sampling points on Changadompokk thod

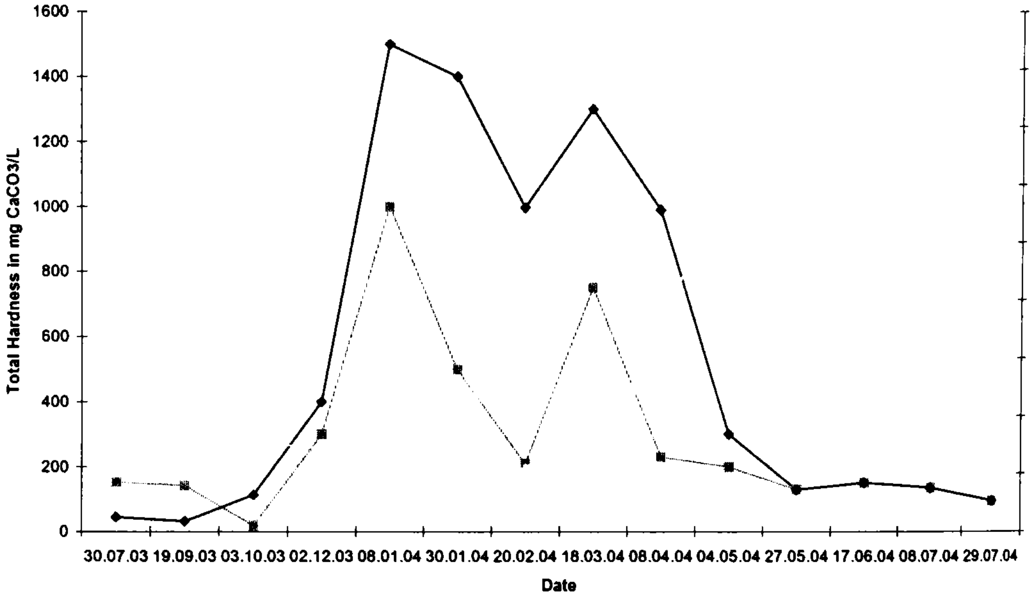


Fig.3.114 Temporal variation of Total Hardness concentration at various sampling points on Changadompokk thod

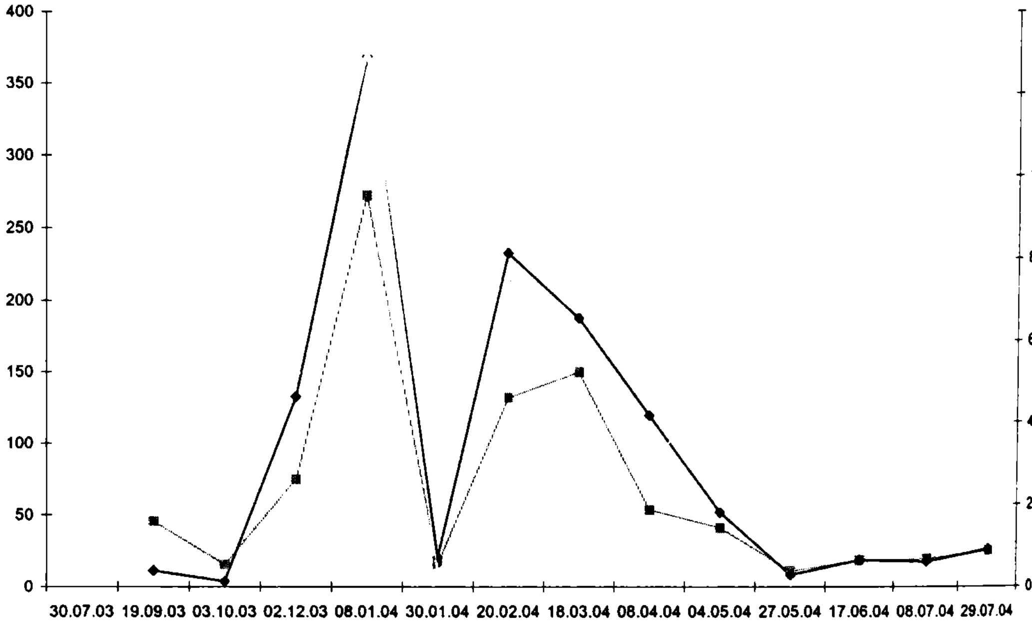


Fig.3.115Temporal variation of Sulphate concentration at various sampling points on Changadompokk thod

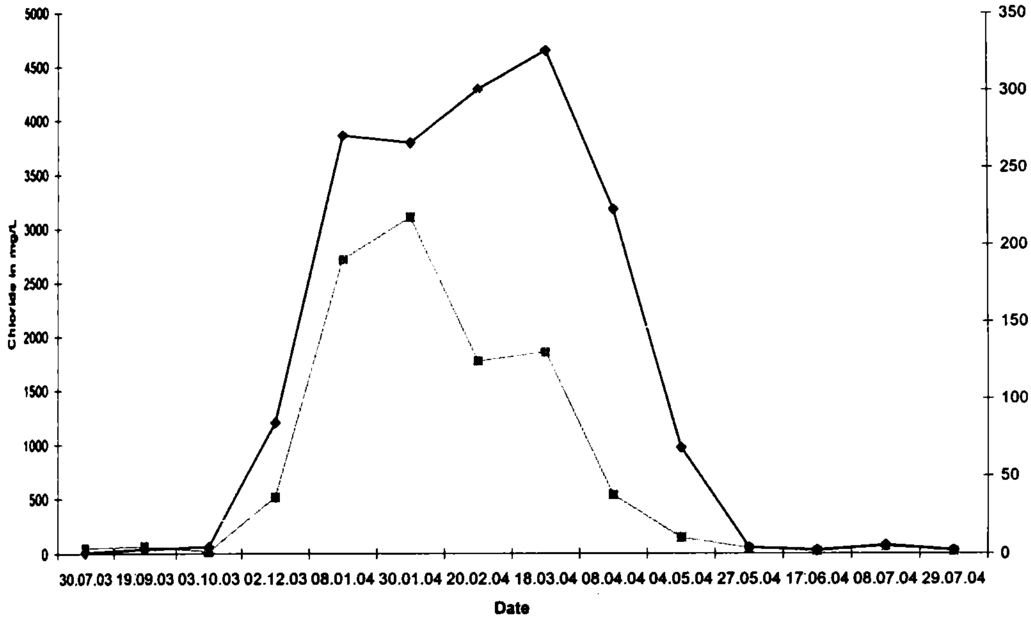


Fig.3.112Temporal variation of Chloride concentration at various sampling points on Changadompokk thod

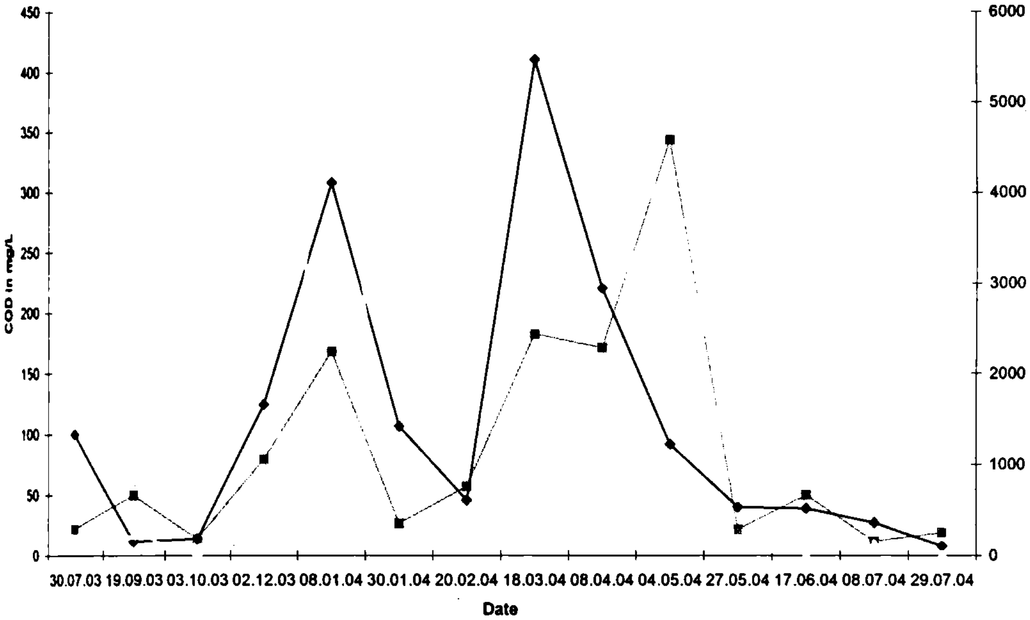


Fig.3.113Temporal variation of COD concentration at various sampling points on Changadompokk thod

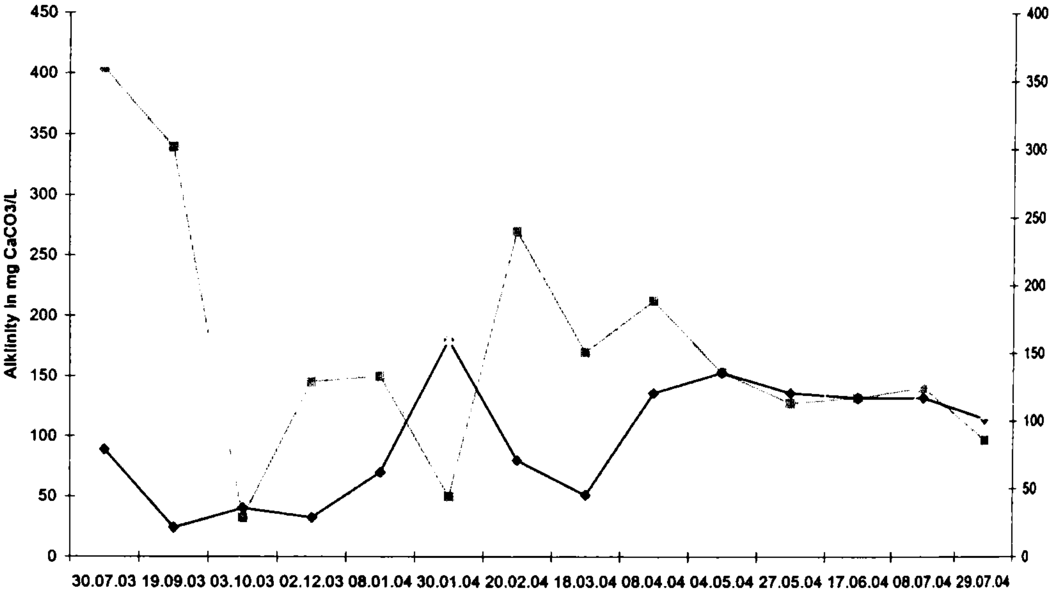


Fig.3.110 Temporal variation of Alklinity concentration at various sampling points on Changadompokk thod

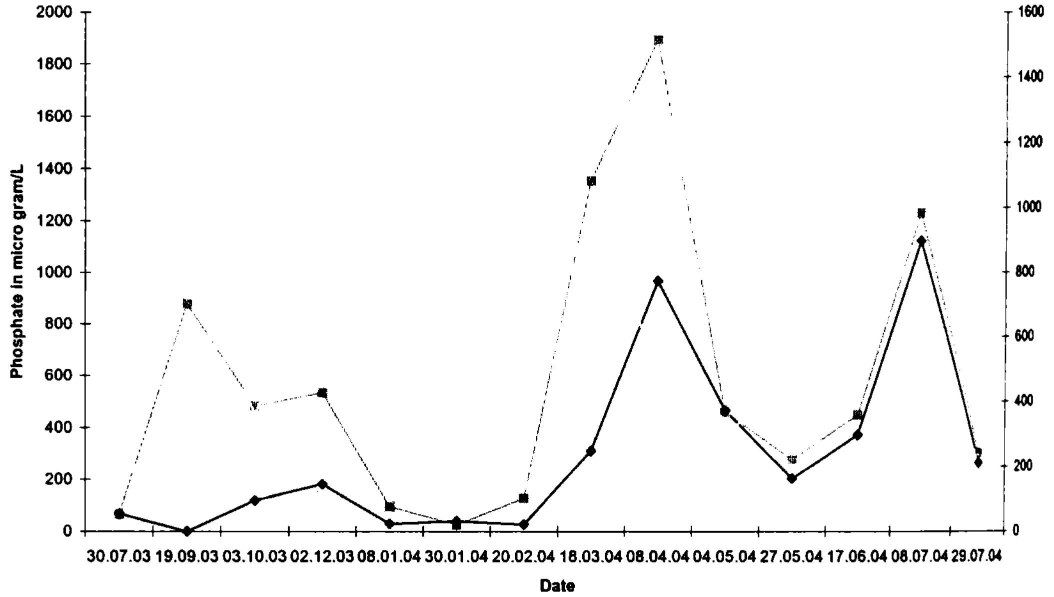


Fig.3.111 Temporal variation of phosphate concentration at various sampling points on Changadompokk thod

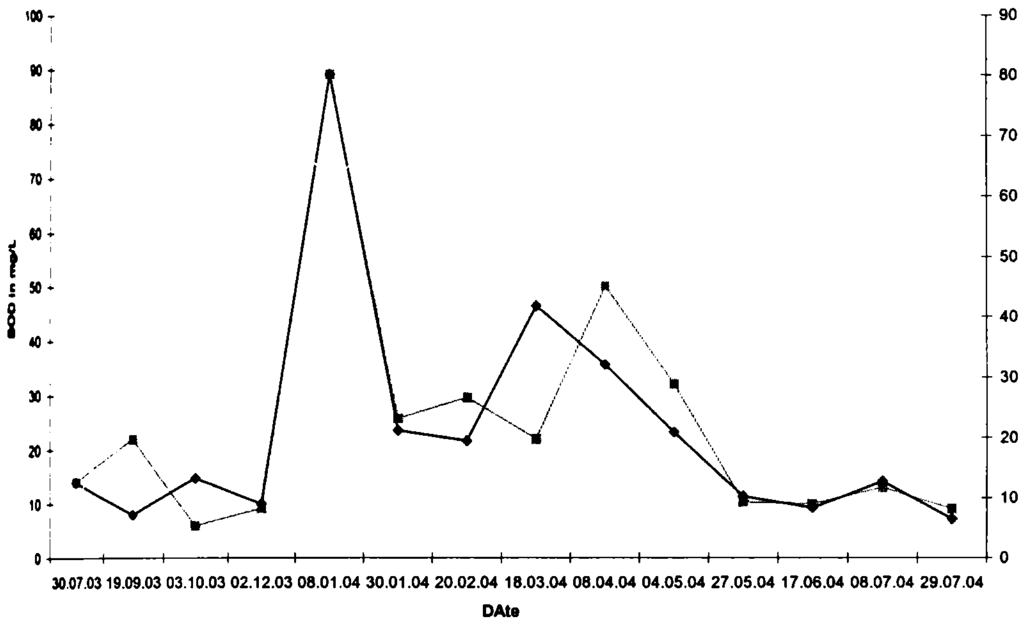


Fig.3.108Temporal variation of BOD concentration at various sampling points on Char

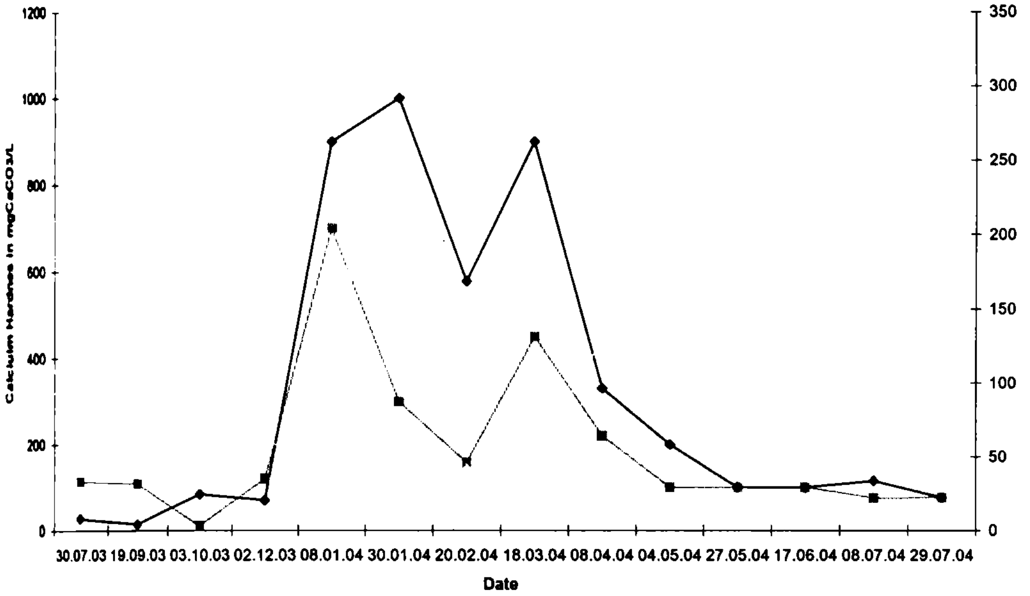


Fig.3.109Temporal variation of Calcilum Hardness concentration at various sampling points on Changadompokk thod

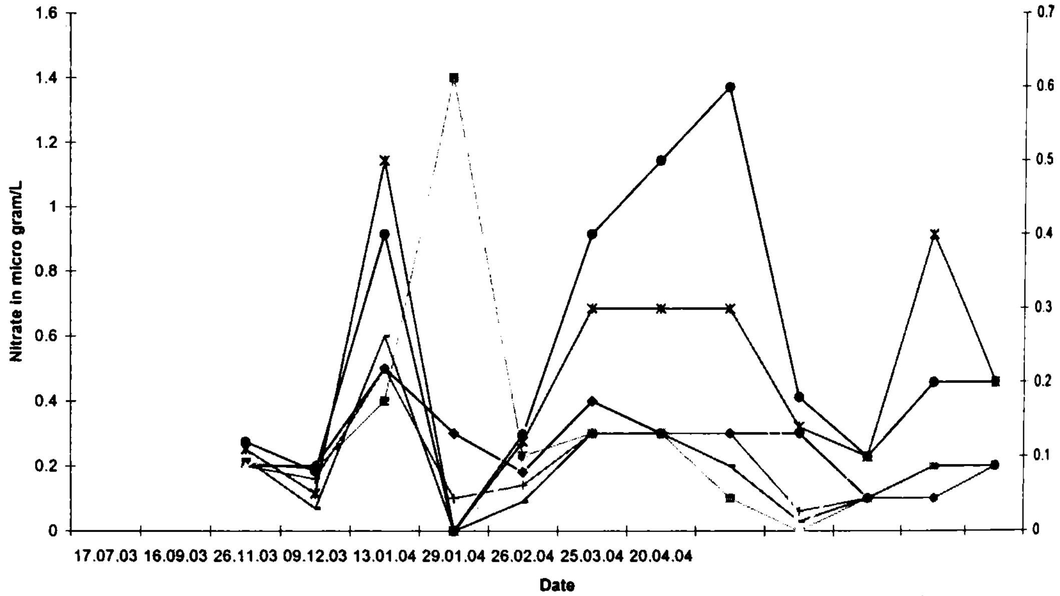


Fig. 3.106Temporal variation of Nitrate concentration at various sampling points on the canals of West Cochin

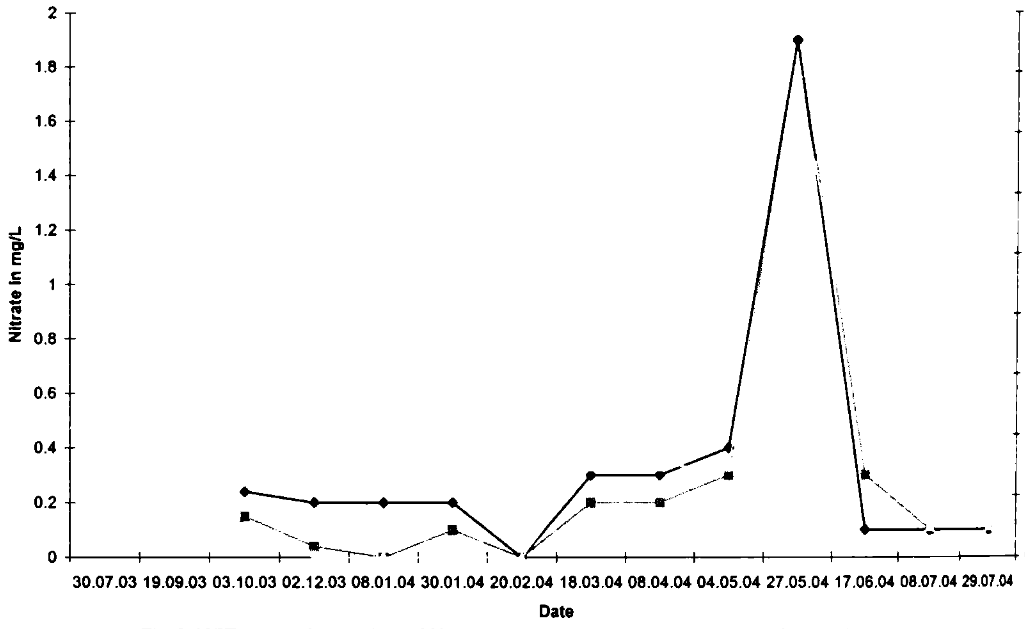


Fig.3.107Temporal variation of Nitrate concentration ar various sampling points on Changadopokk thod

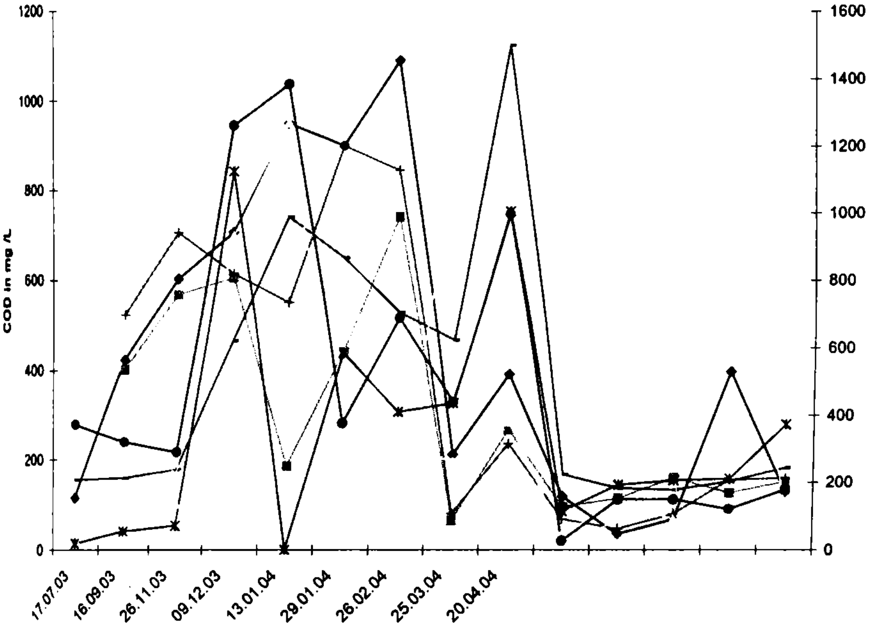


Fig.3.104Temporal variation ofCOD concentration at various sampling points on the canals of West Cochin

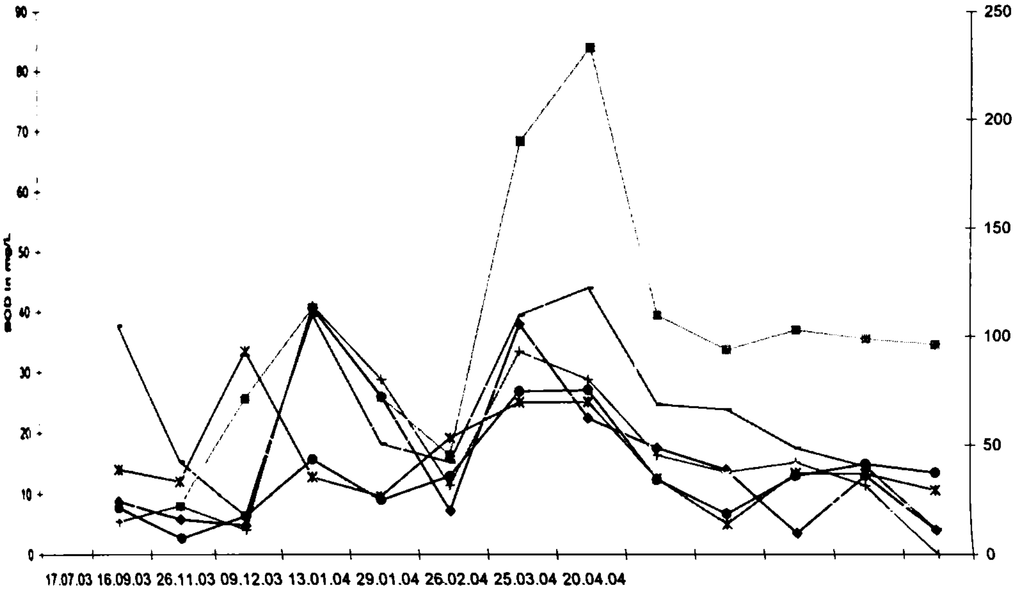


Fig 3.105Temporal variation of BOD concentration at variou ssampling point son the canals of WestCochin

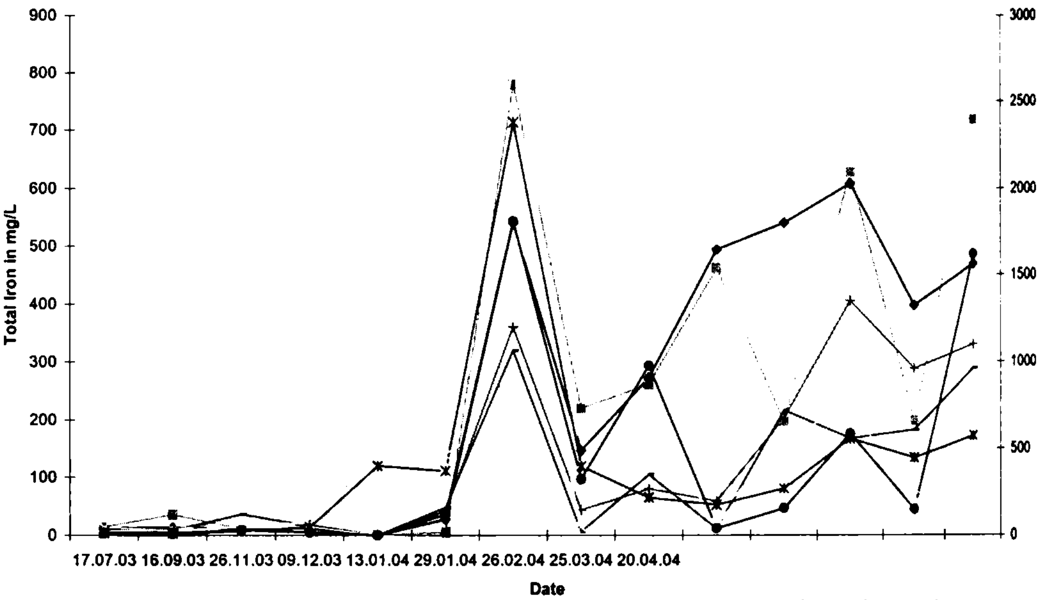


Fig.3.102 Temporal variation of Total Iron concentration at various sampling points on the canals of West Cochin

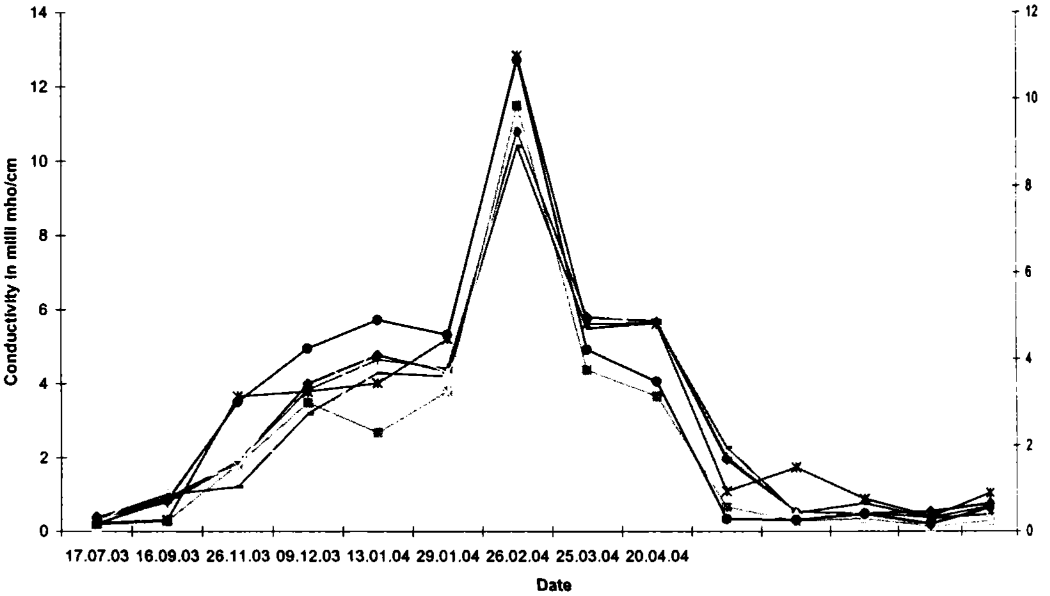


Fig.3.103Temporary variation of Conductivity concentration at various sampling points on the canals of West Cochin

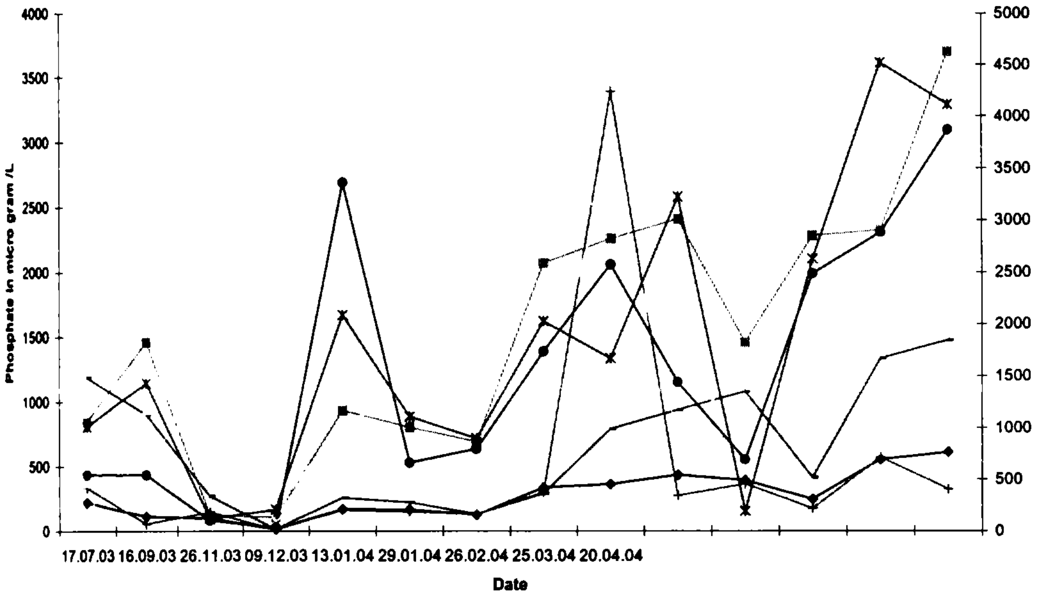


Fig.3.100 Temporal variation of phosphate concentration at variolus sampling points on the canals of West Cochin

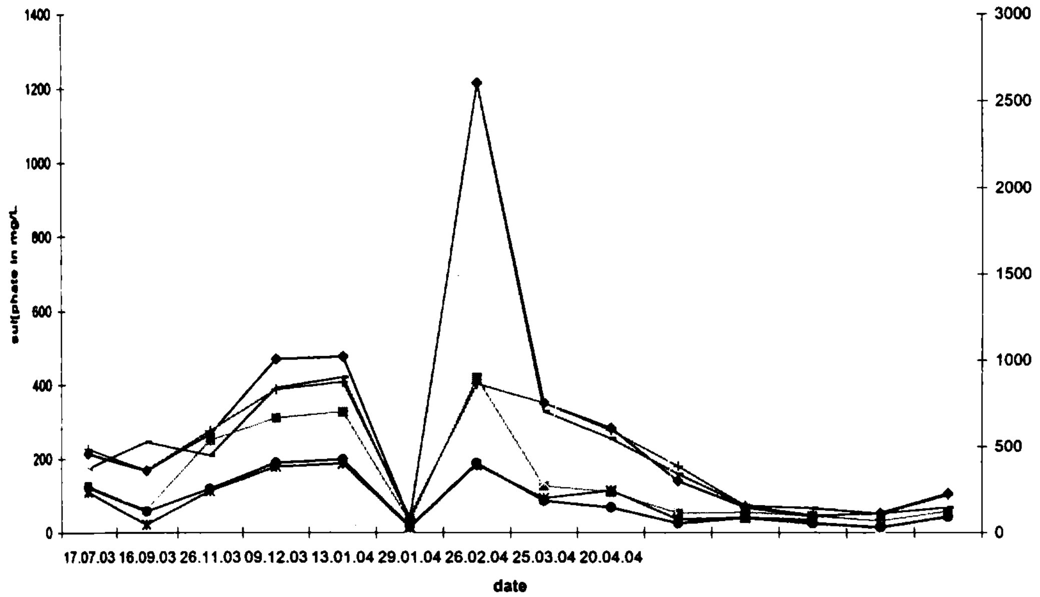


Fig.3.101 Temporal variation of sulphate concentration at various sampling points on the canals of West Cochin

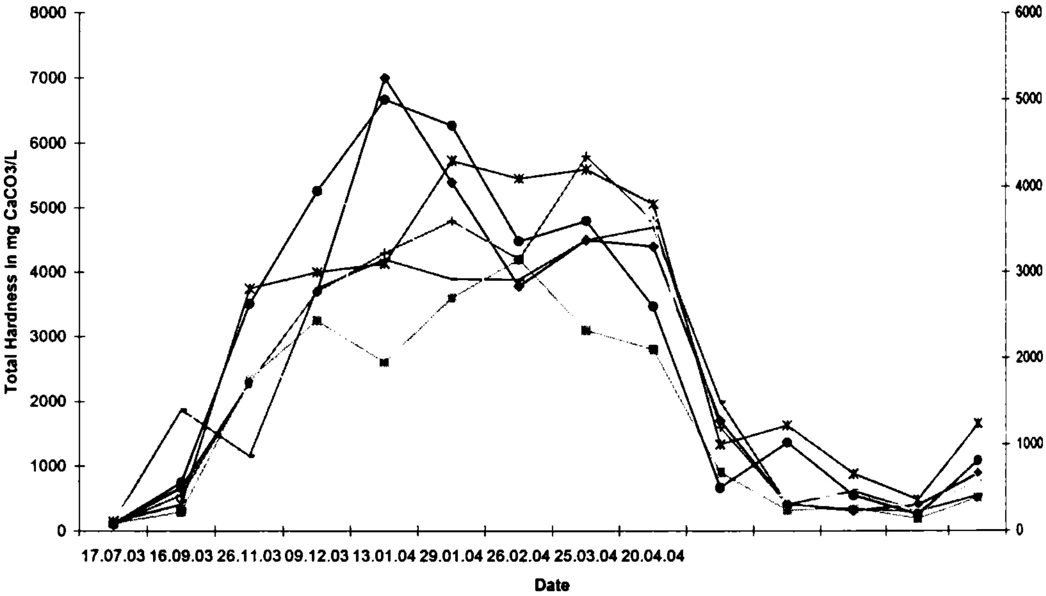


Fig.3.98 Temporal variation of Total Hardness concentration at various sampling points on the Canals of West Cochin

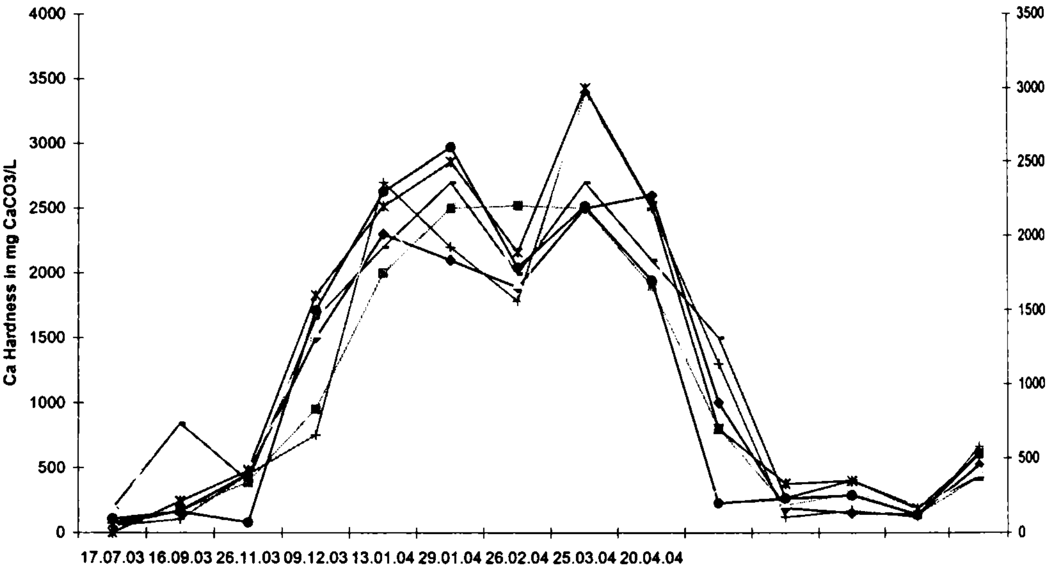


Fig.3.99Temporal variation of Ca Hardness concentration at various sampling points on the canals of West Cochin

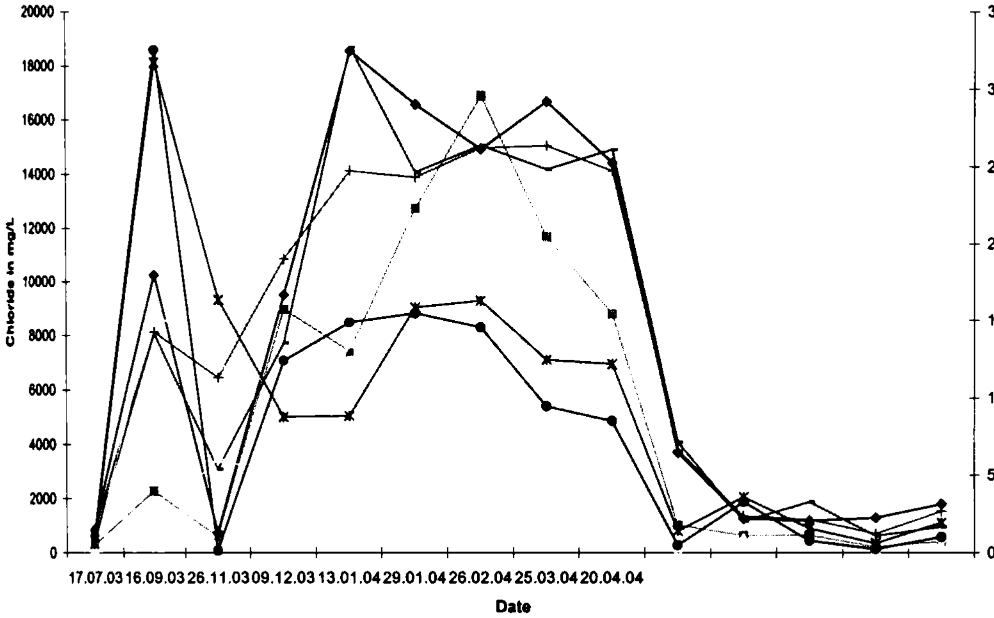


Fig.3.96 Temporal variation of chloride concentration at various sampling sites on thecanals of West Cochin

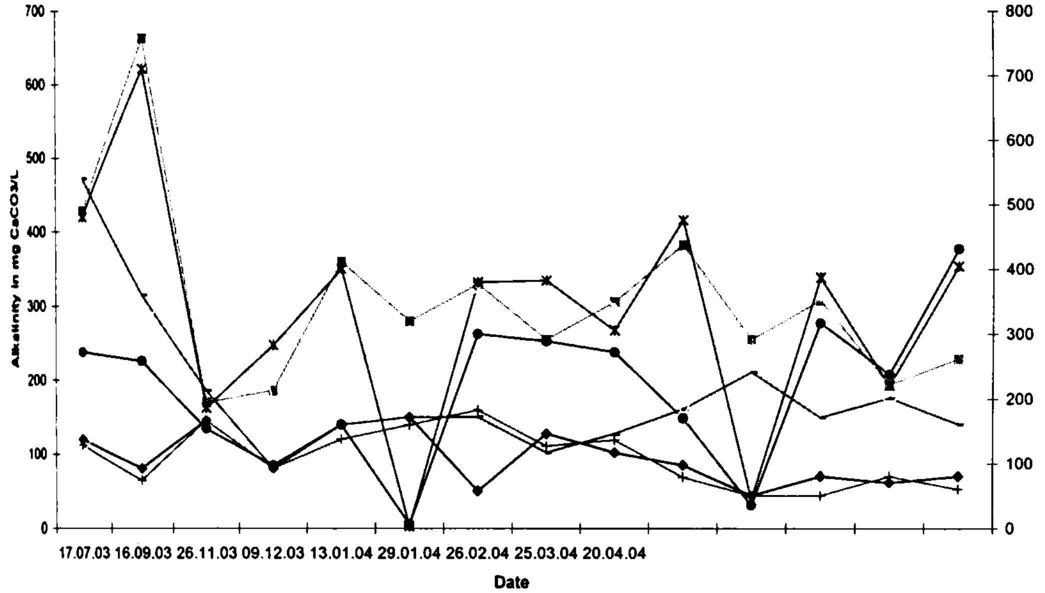


Fig.3.97Temporal variation of Alkalinity concentration at various sampling sites on the canals of west Cochin

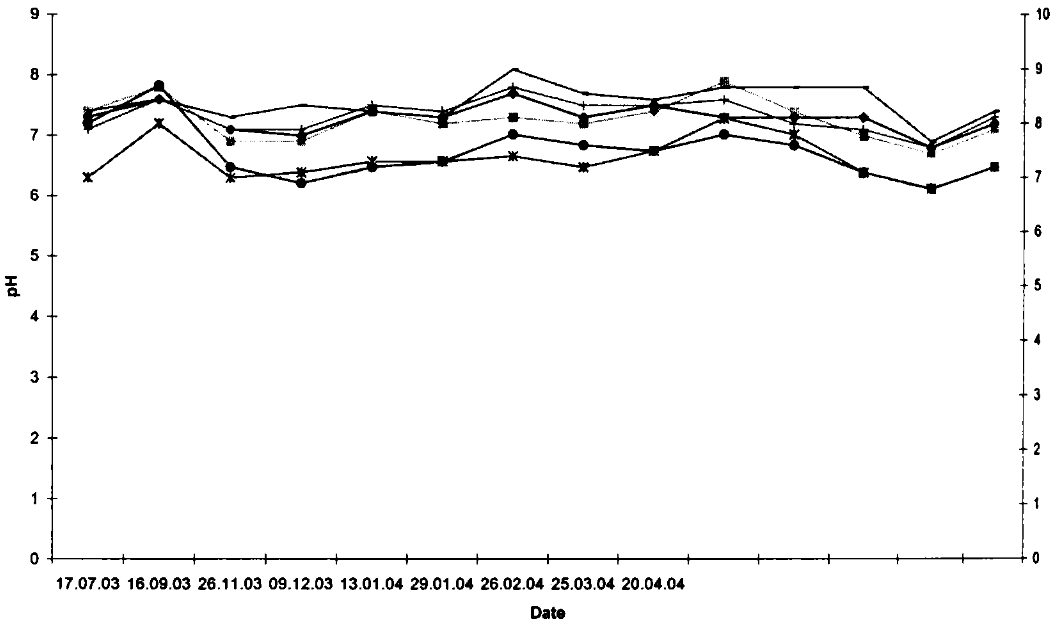


Fig.3.94 Temporary variation of pH at various sampling points on the canals of West Cochin

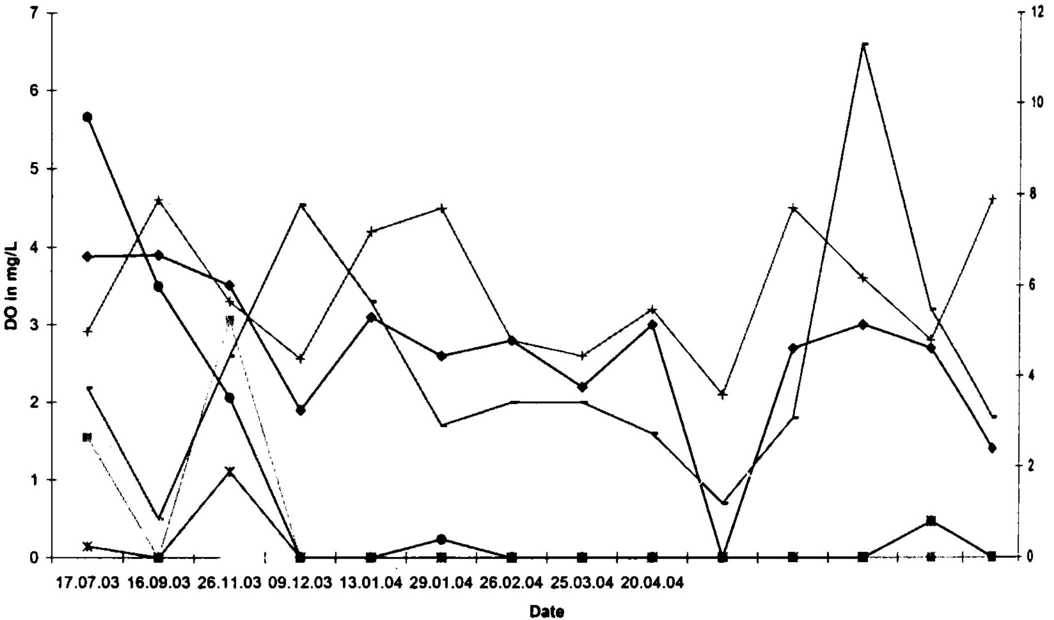


Fig.3.95Temporal variation of DO concentration at various sampling points on the canals of West Cochin

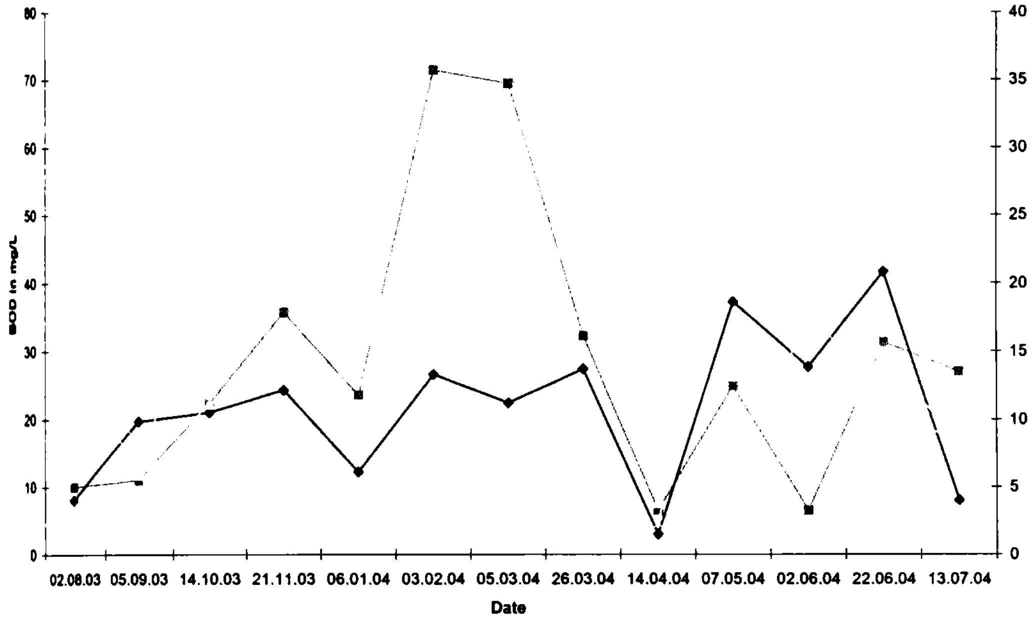


Fig.3.92 Temporal variation of BOD concentration at various sampling points on Puncha thod

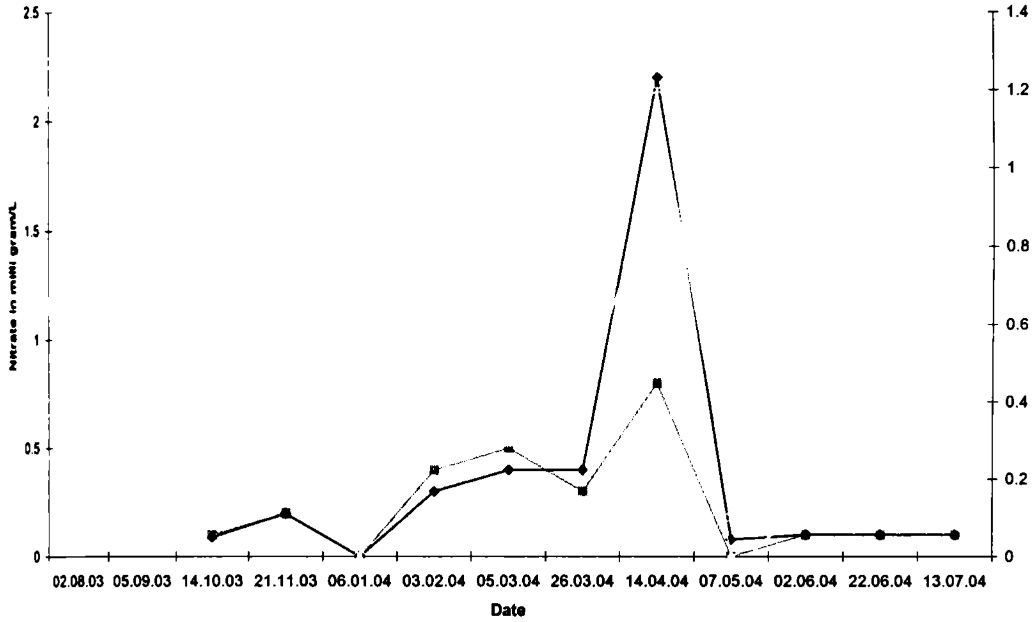


Fig.3.93 Temporal variation of Nitrate concentration at various sampling points on Puncha thod

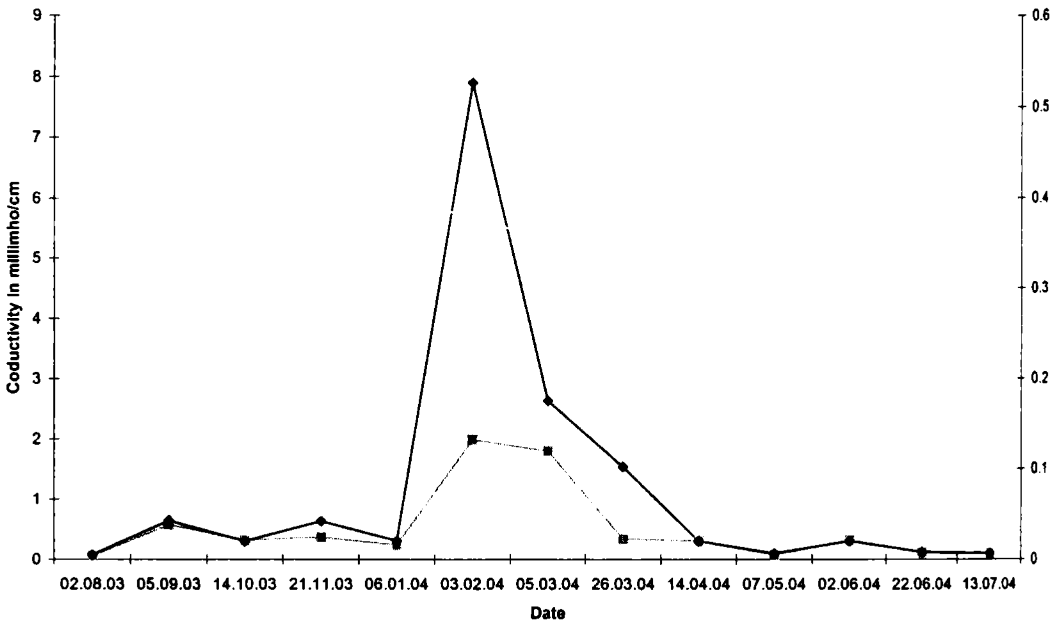


Fig.3.90 Temporal variation of conductivity at various sampling points on Puncha thod

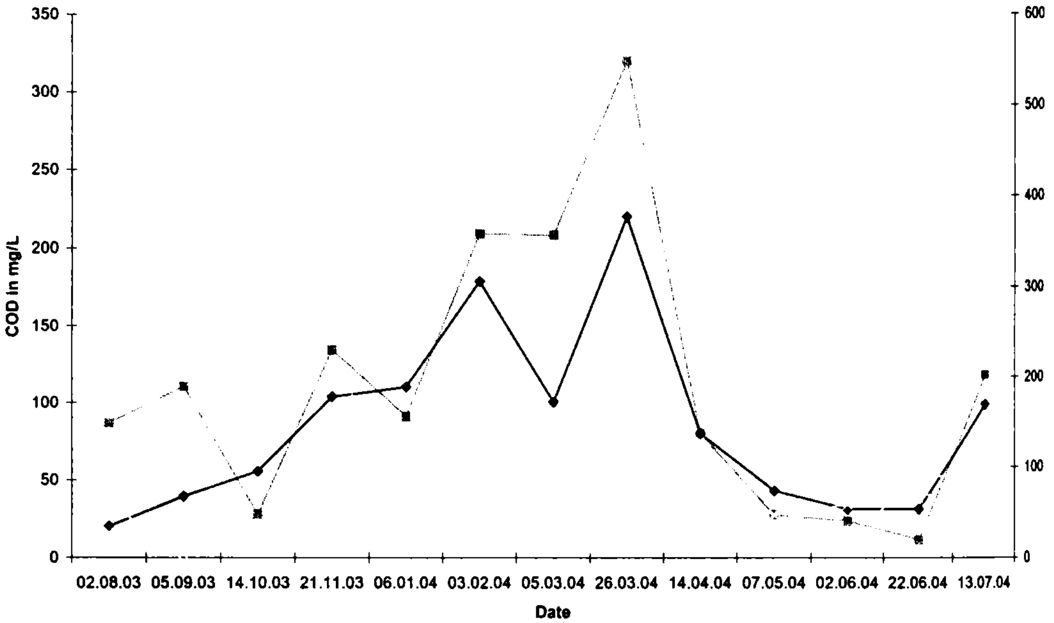


Fig 3.91 Temporal variation of COD concentration at various sampling points on Puncha thod

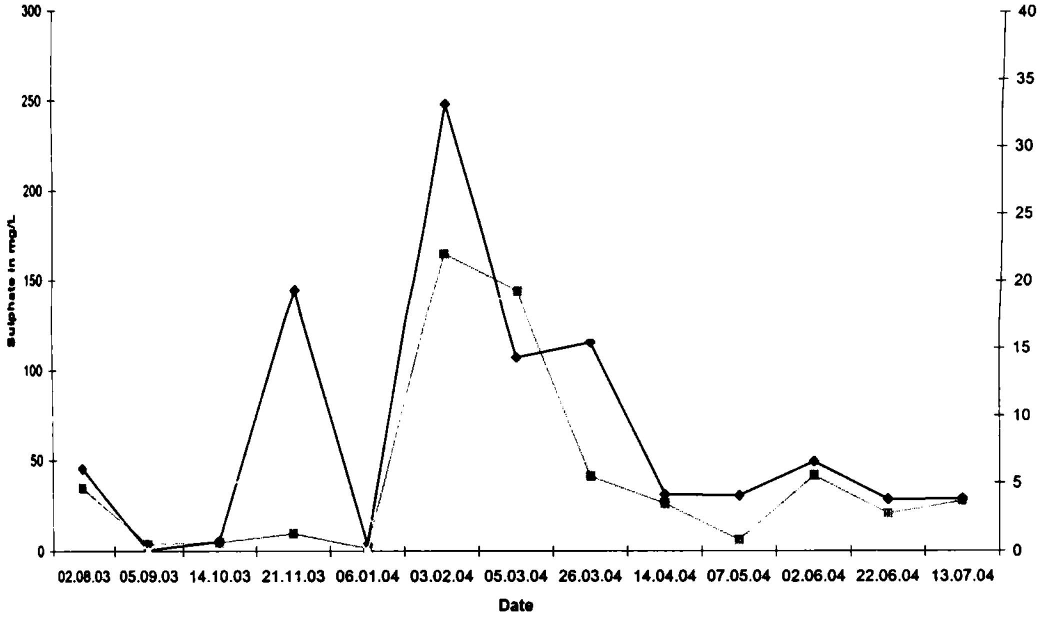


Fig.3.88. Temporal variation of sulphate concentration at various sampling points on Puncha

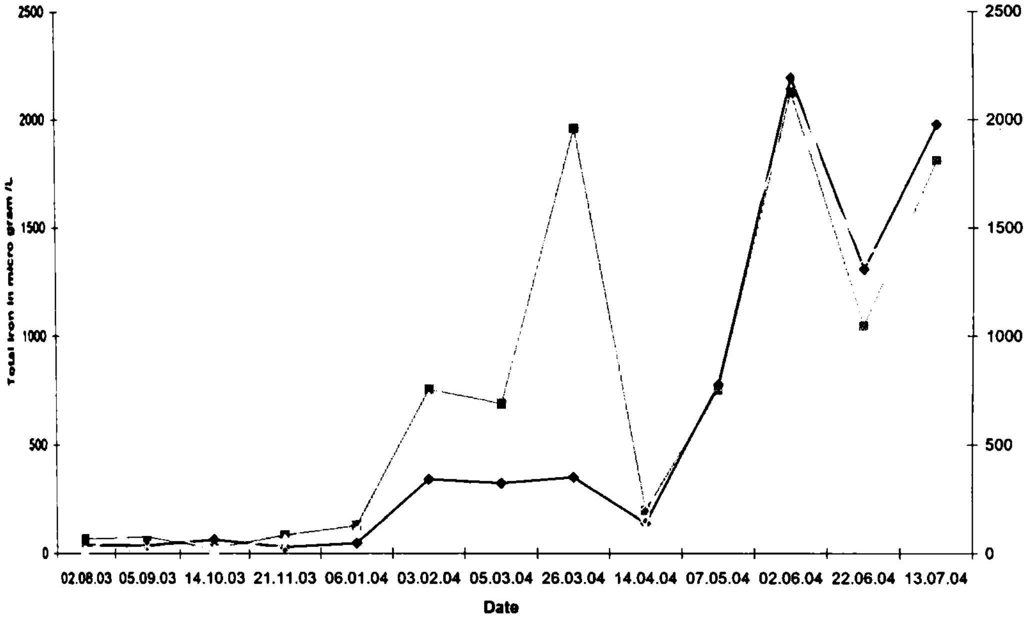


Fig.3.89 Temporal varaition of Total Iron concentration at various sampling points on Puncha thod

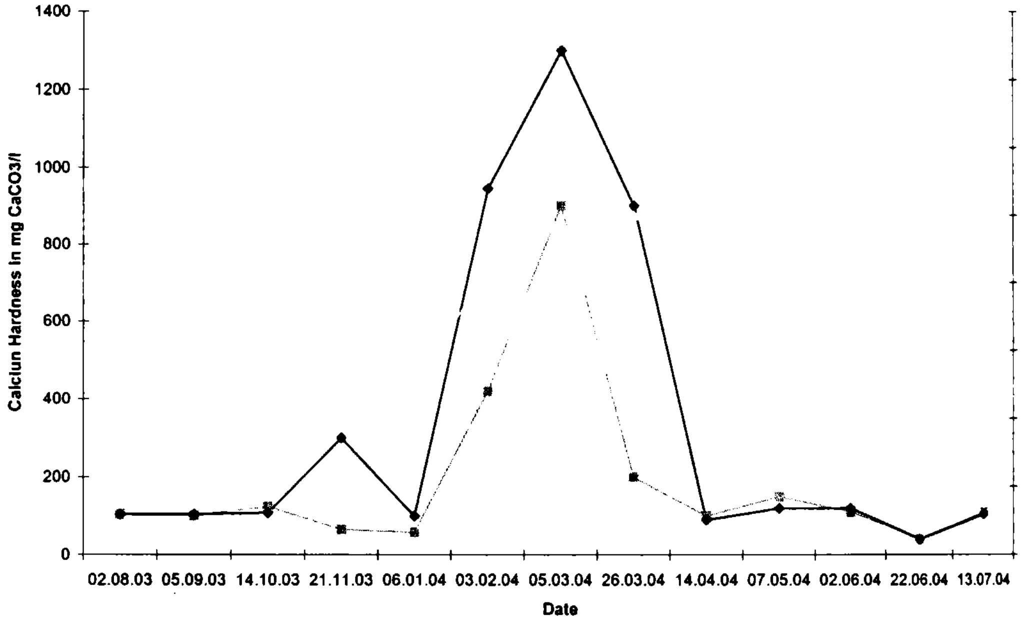


Fig.3.86 Temporal variation of Ca Hardness concentration at various sampling point son Puncha thod

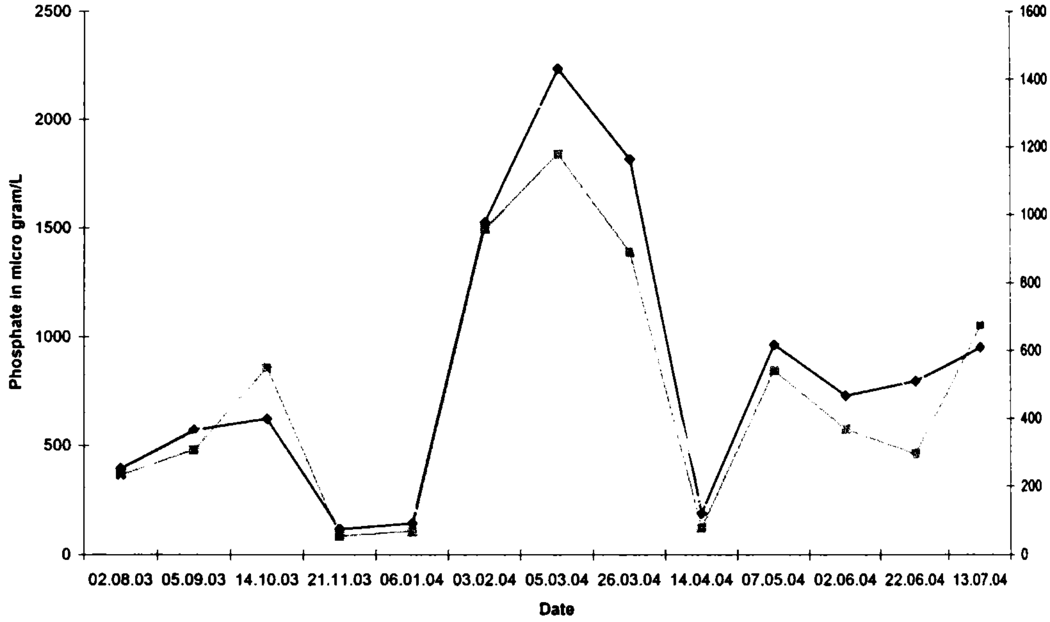


Fig.3.87 Temporal variation of phosphate concentration at various sampling points on Puncha thod

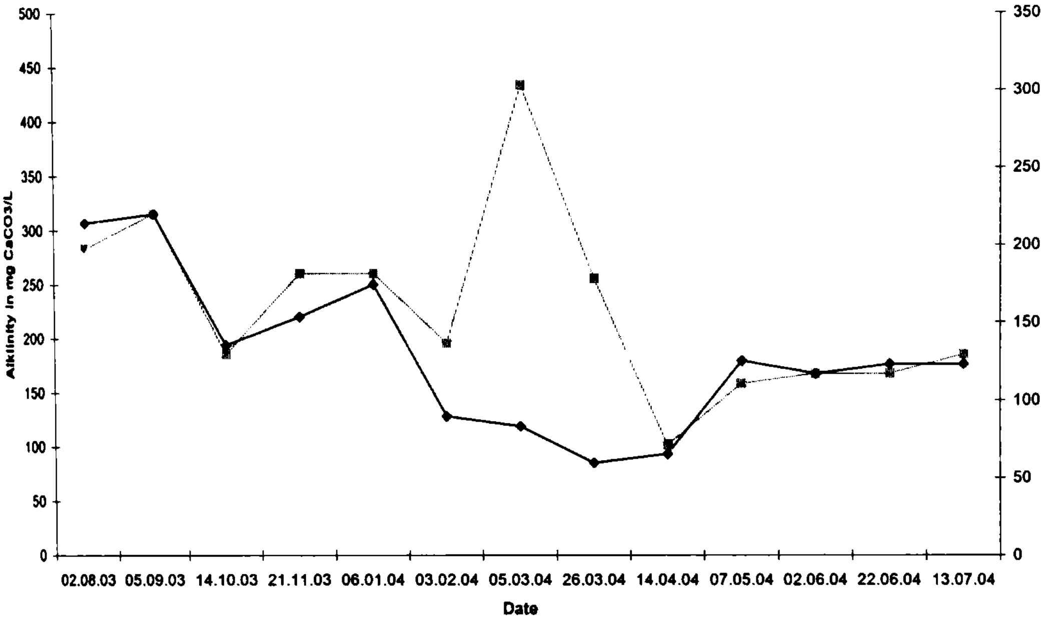


Fig.3.84 Temporal variation of Alkalinity concentration at various sampling points on Puncha thod

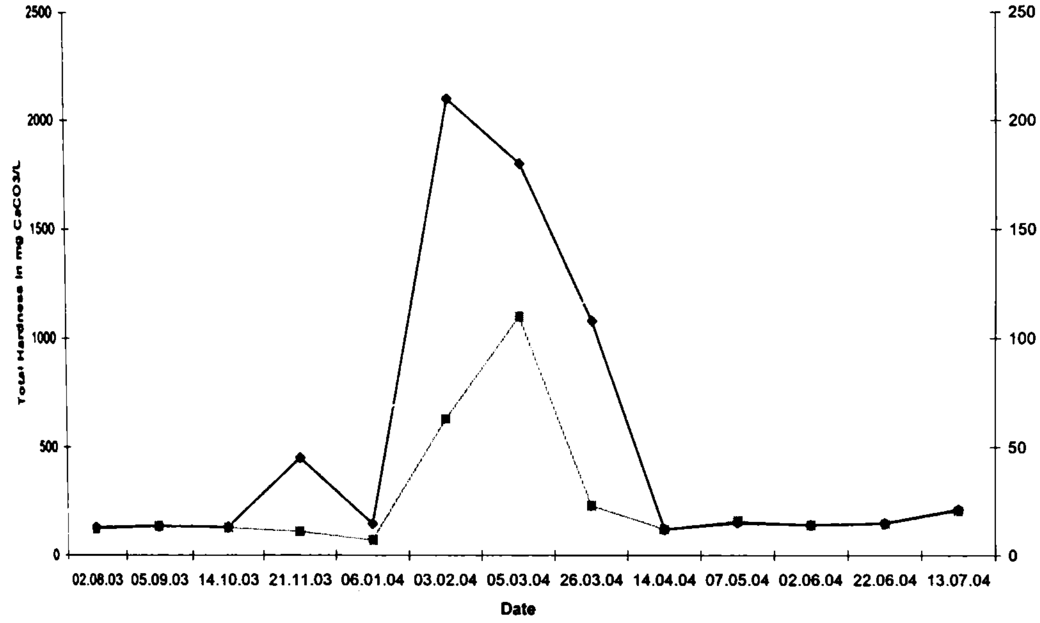


Fig.3.85Temporal variation of Total Hardness concentration at various samplin gpoints on Puncha thod

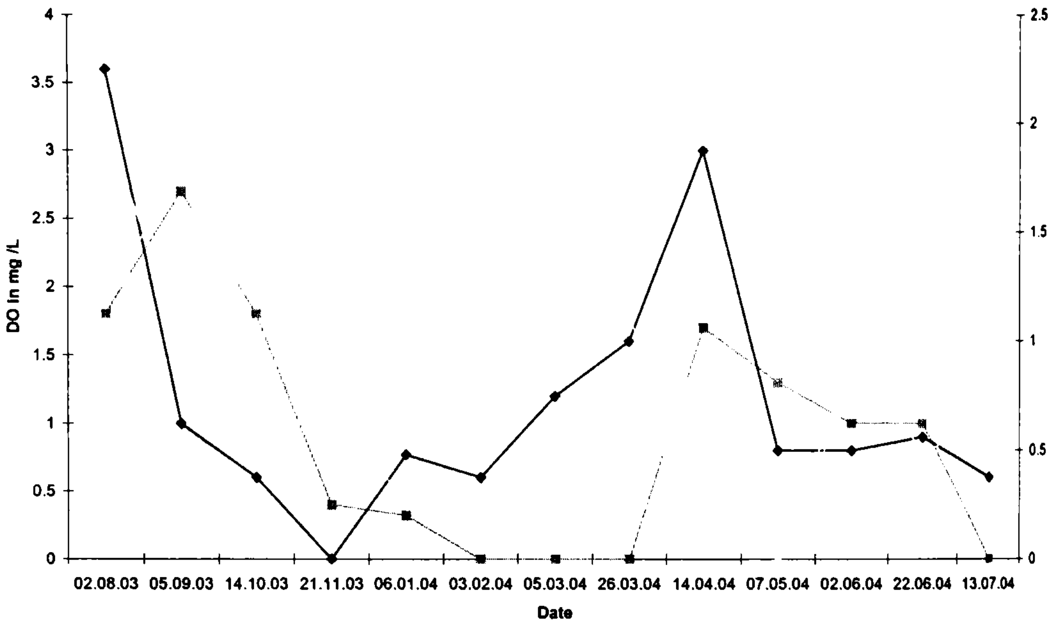


Fig.3.82 Temporal variation of DO concentration at various sampling points on Punch thod

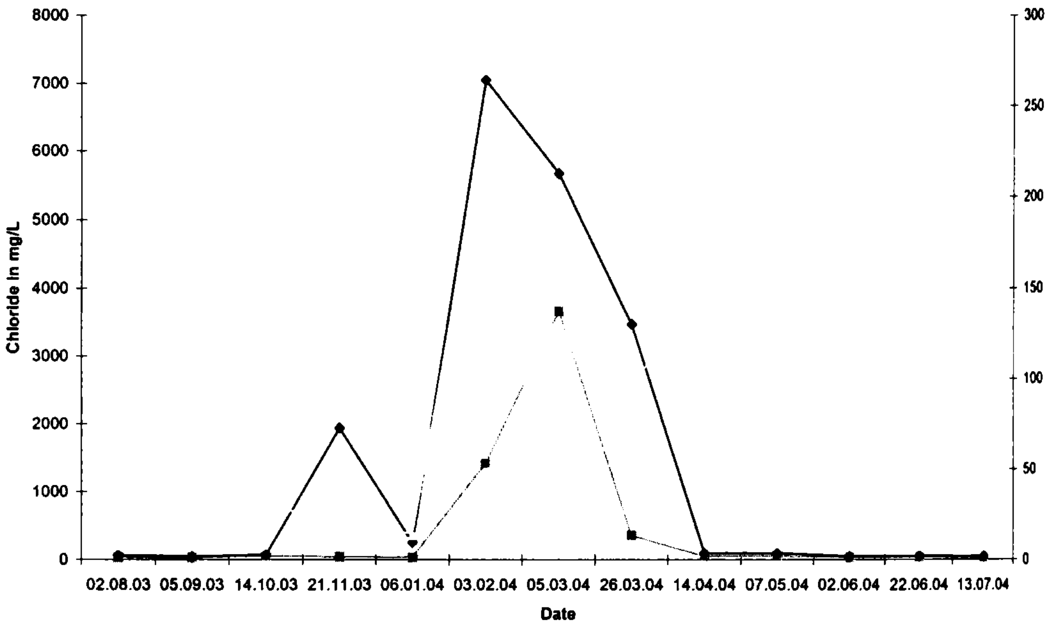


Fig.3.83 Temporal variation of chloride concentration at various sampling points on Punch thod

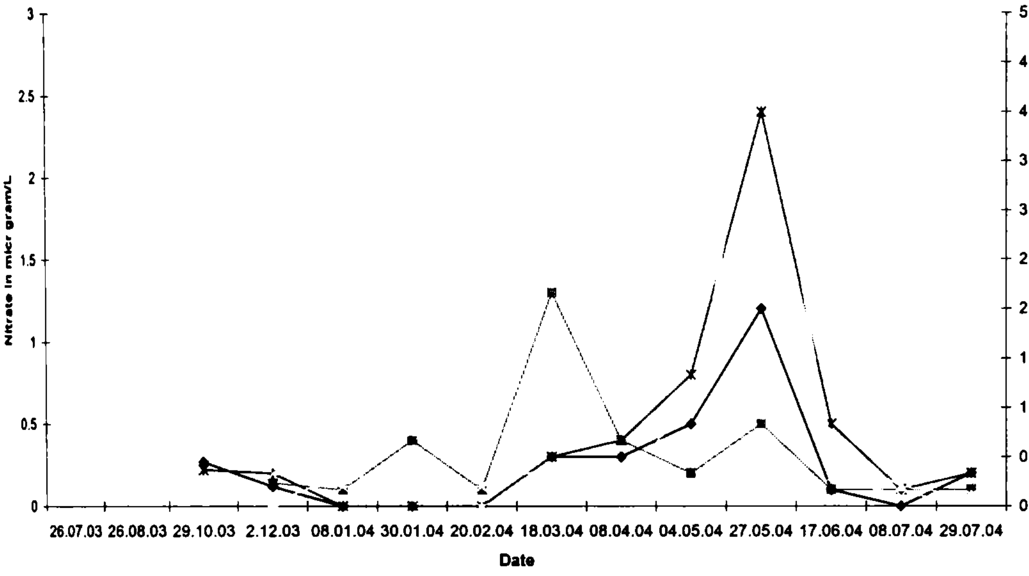


Fig.3.80 Temporal variation of nitrate concentration at various sampling points on Perandoor canal

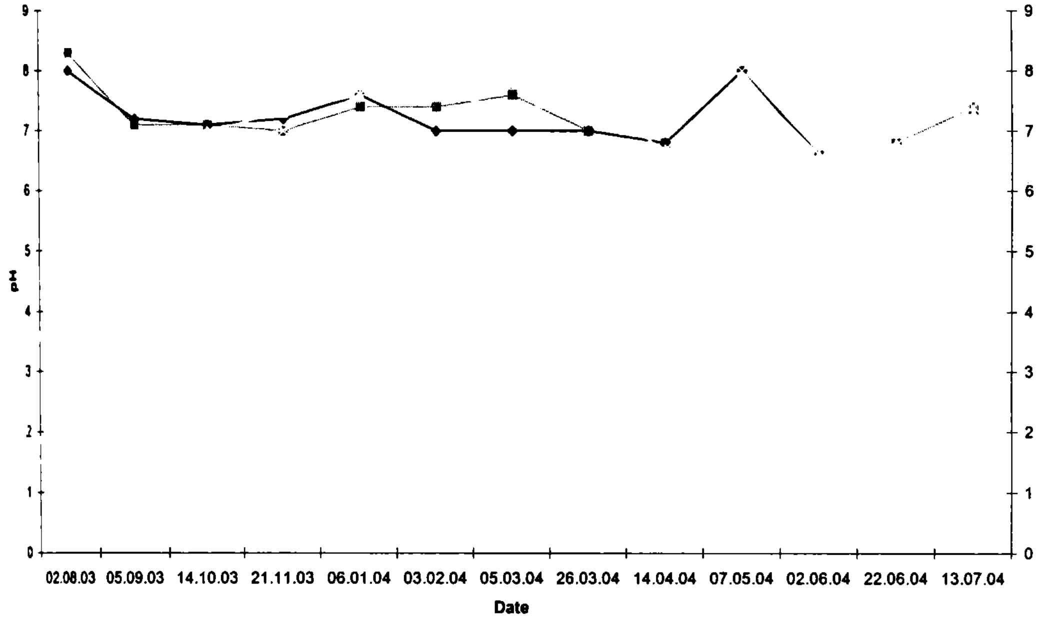


Fig.3.81 Temporal variation of pH at various sampling points on Punch thod

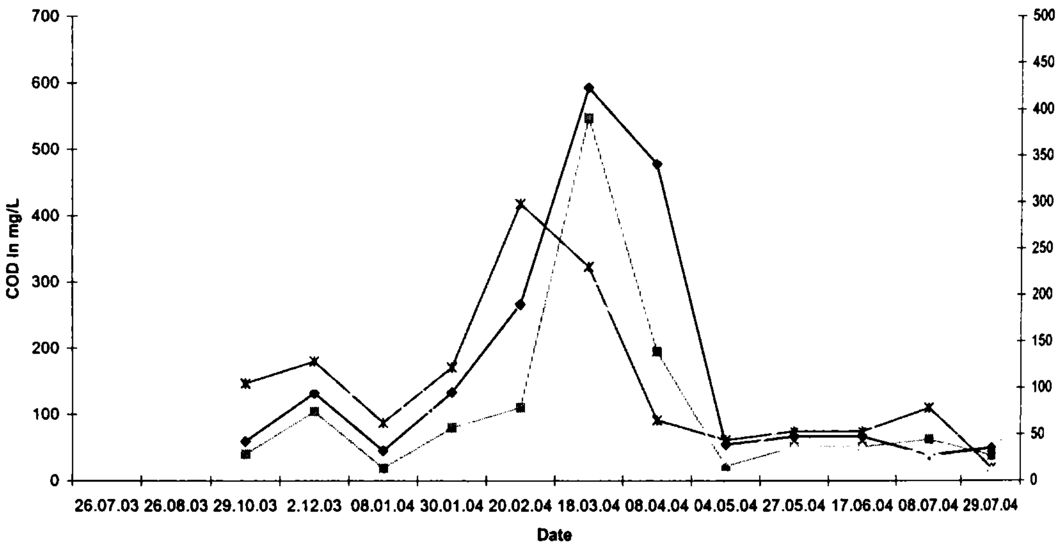


Fig.3.78 Temporal vriation of COD concentration at various sampling points on Perandoor canal

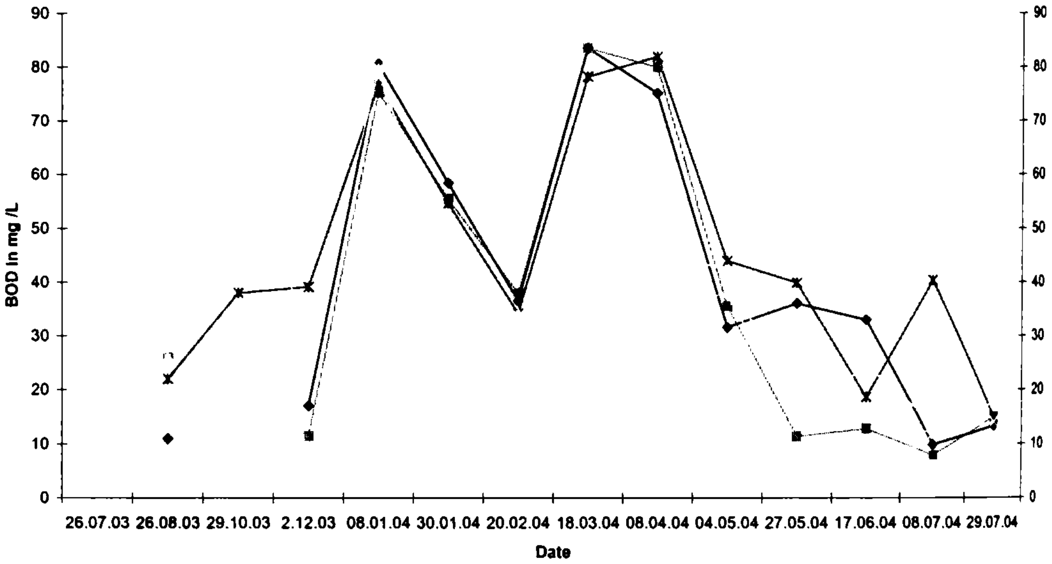


Fig.3.79.Temporal variation of BOD concentration at various sampling points on Perandoor canal

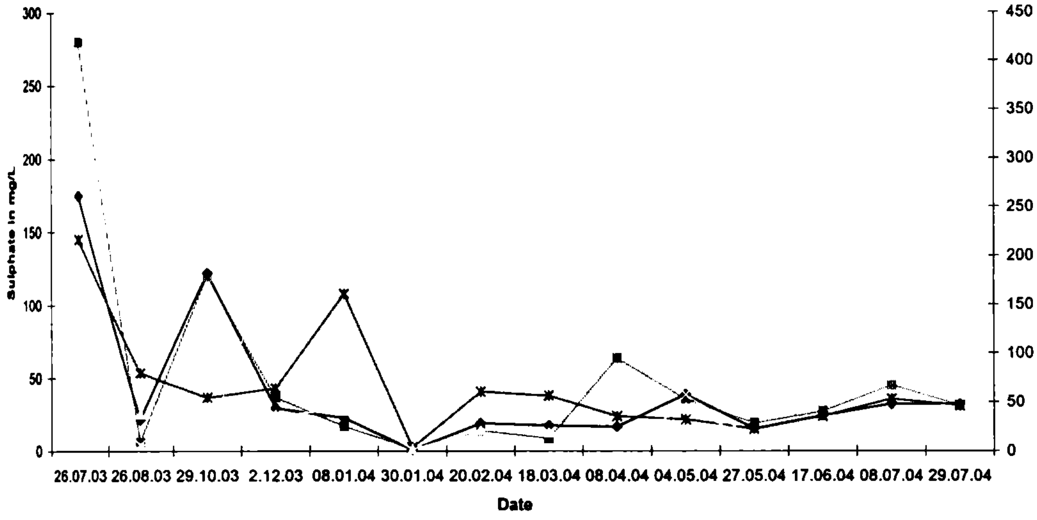


Fig. 3.76 Temporal variation of sulphate concentration at various sampling points on Perandoor canal

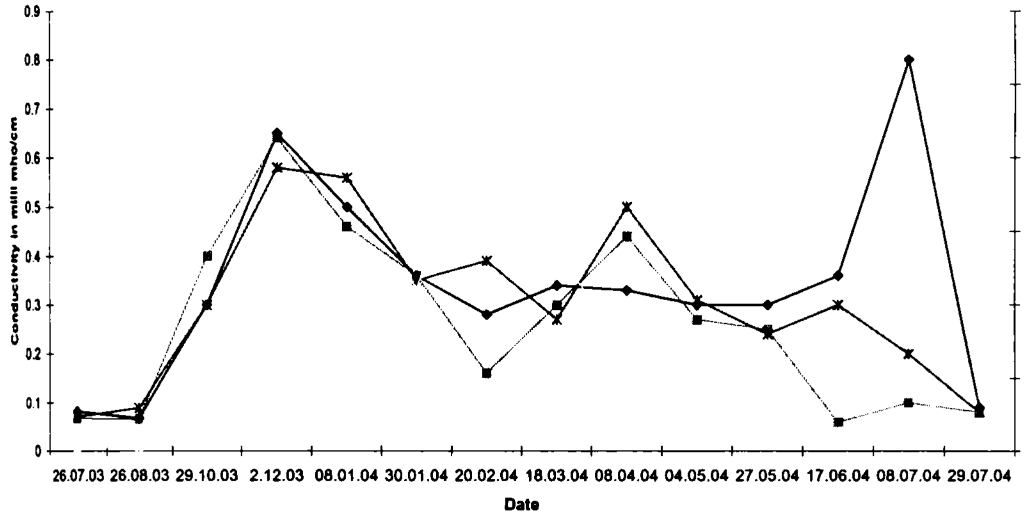
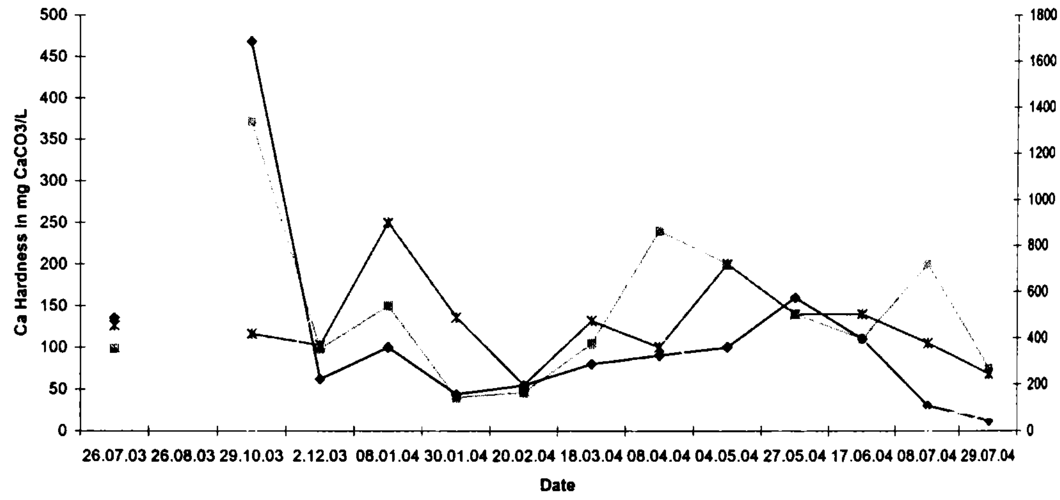


Fig.3.77 Temporal variation of Conductivity concentration at variou ssampling points on Perndoor canal



Fif. 3.74 Temporal variation of Calcium Hardness concentration at various sampling points on Perandoor canal

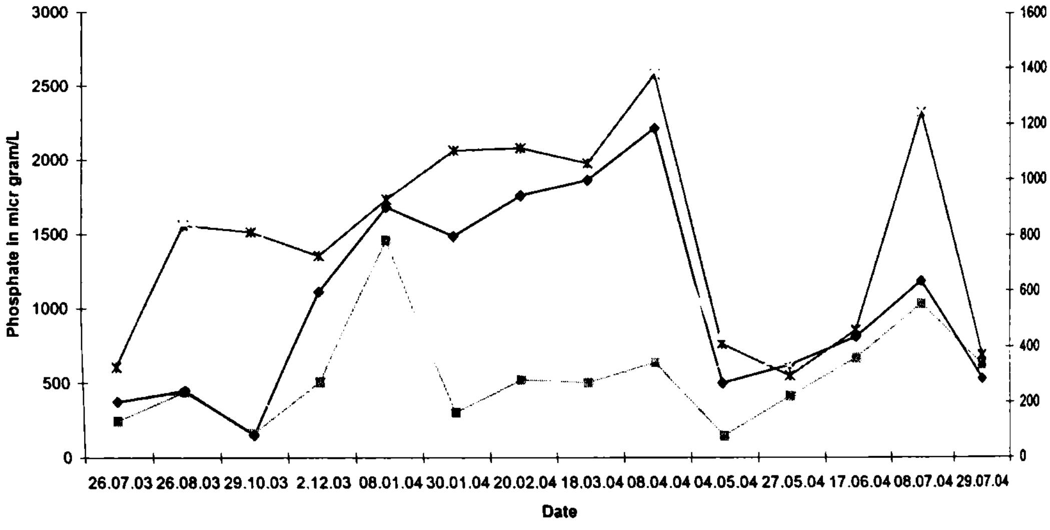


Fig.3.75 Temporal variation of Phosphate concentration at various sampling points on Perandoor canal

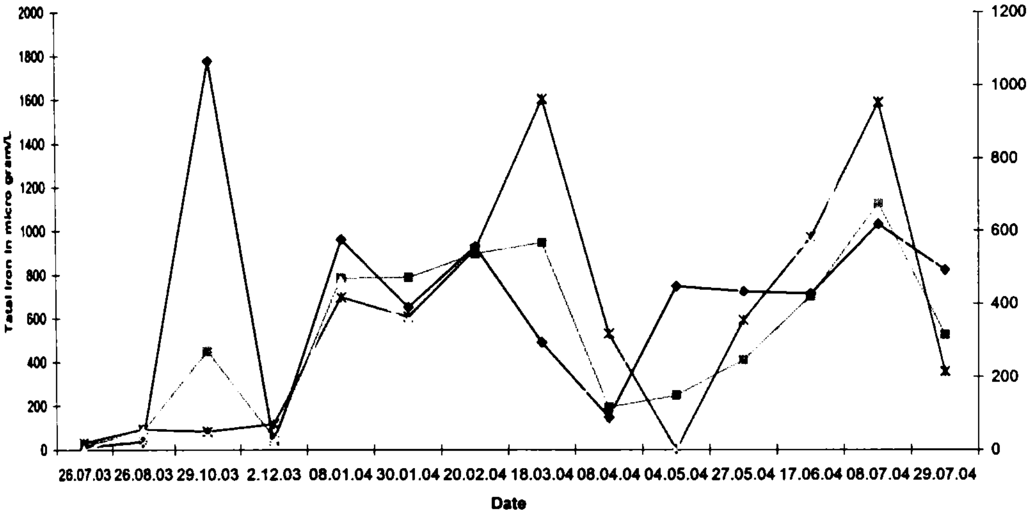


Fig.3.72 Temporal variation of total iron concentration at various sampling points on Perandoor canal

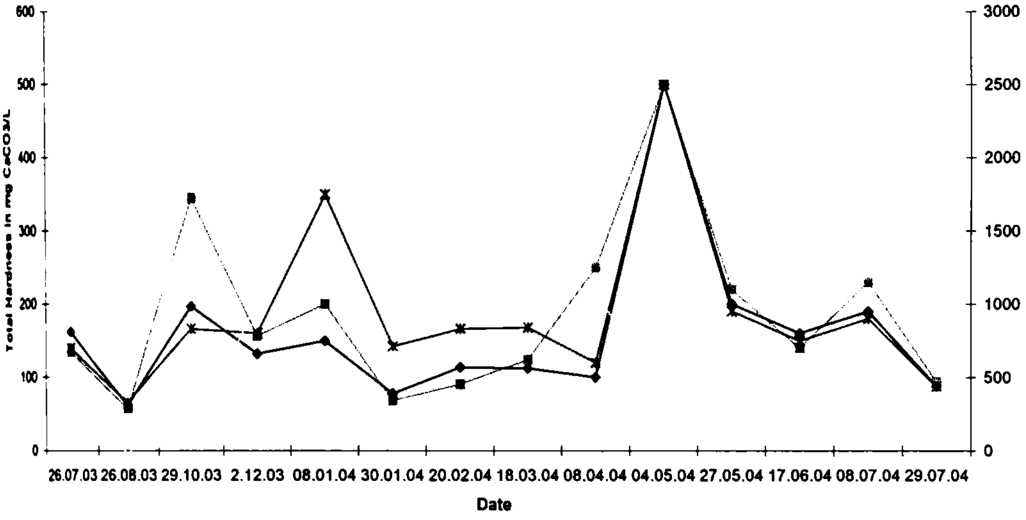


Fig.3.73Temporal variationof Total Hardness concentration at various sampling points on Perandoor canal

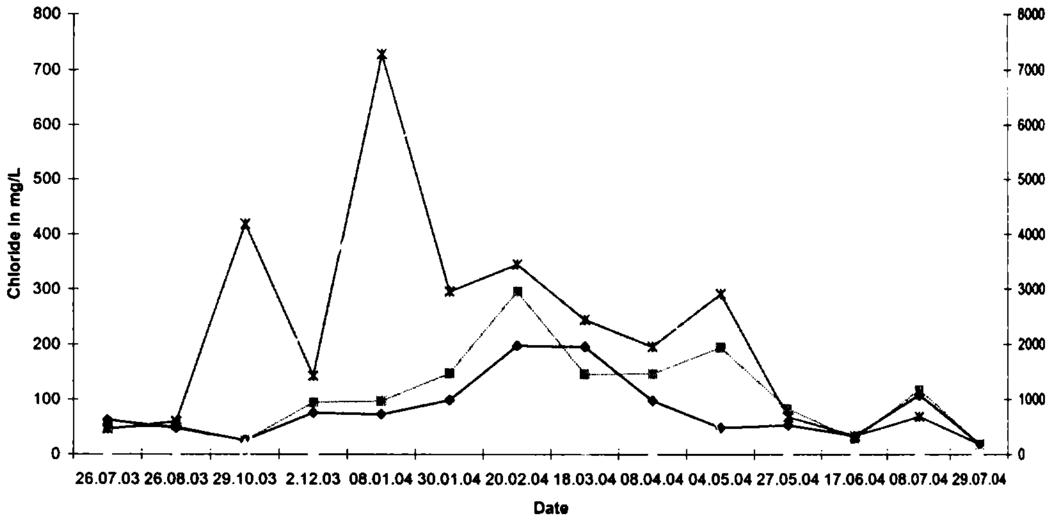


Fig.3.70Temporal variation of chloride concentration at various sampling points on Peerandoor canal

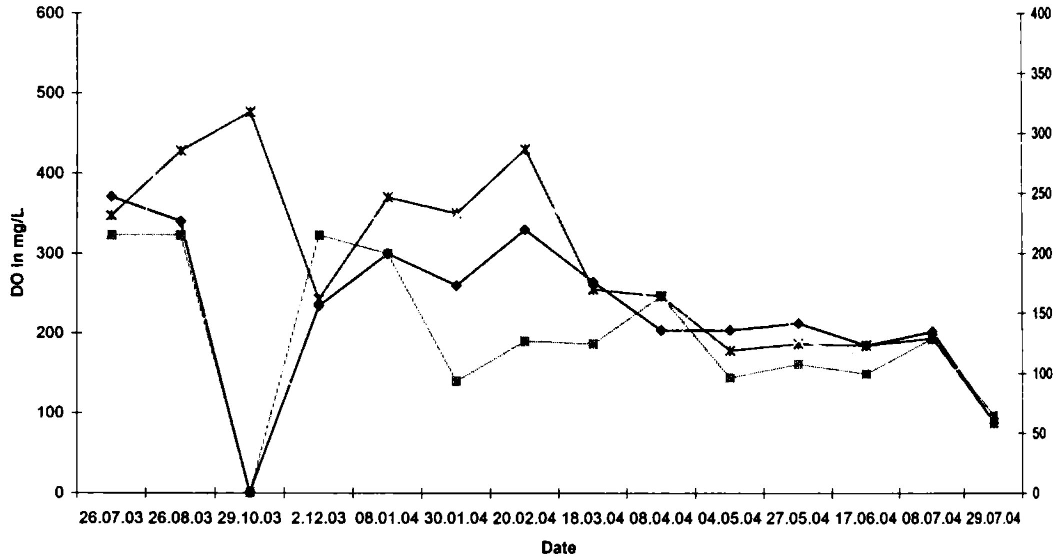


Fig.3.71 Temporal variation of alkalinity concentration at various sampling points on Perandoor canal

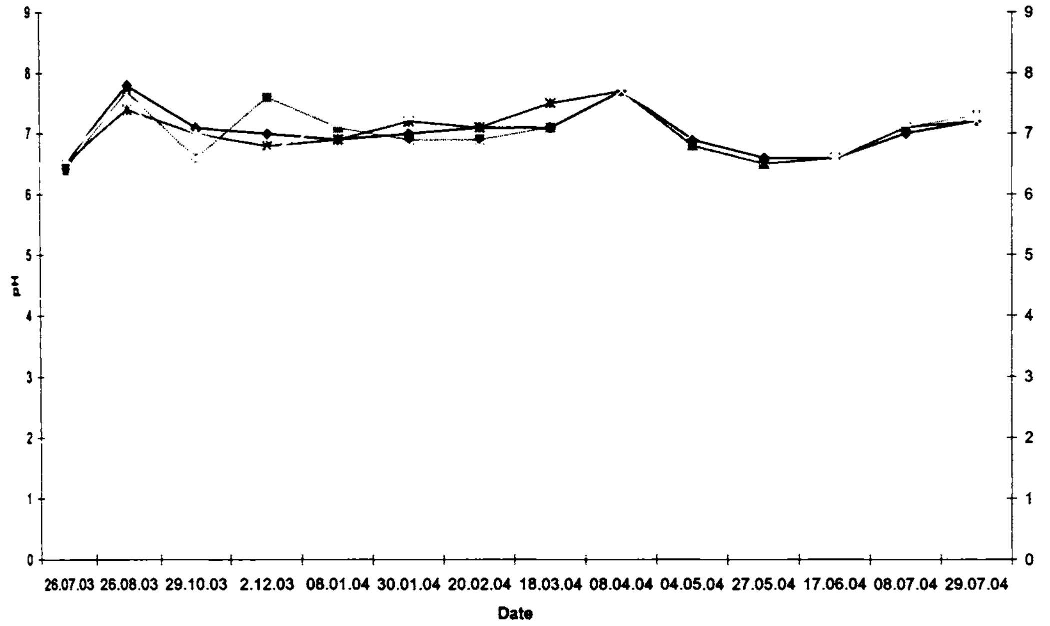


Fig.3.68Temporal variation of pH at various sampling points on Perandoor canal

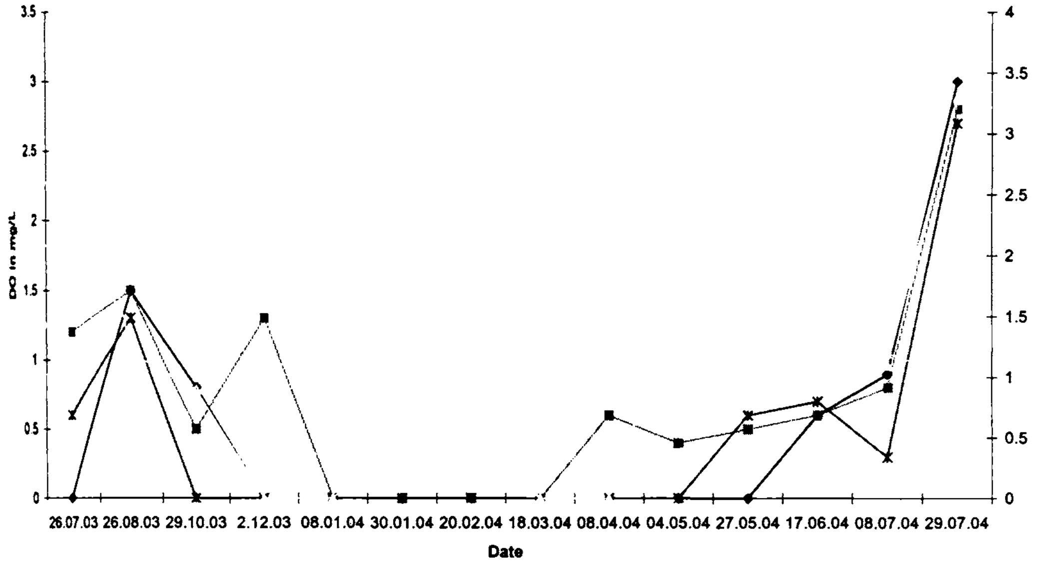


Fig.3.69 Temporal variation ofDO concentration at various sampling points on Perandoor canal

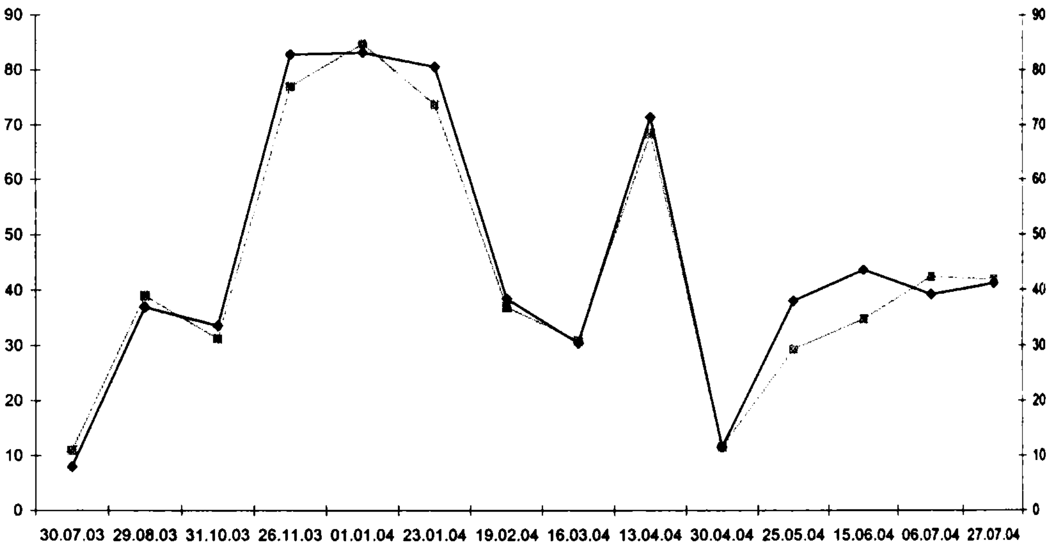


Fig.3,66 Temporal variation of BOD concentration at various sampling points on Mullassery canal

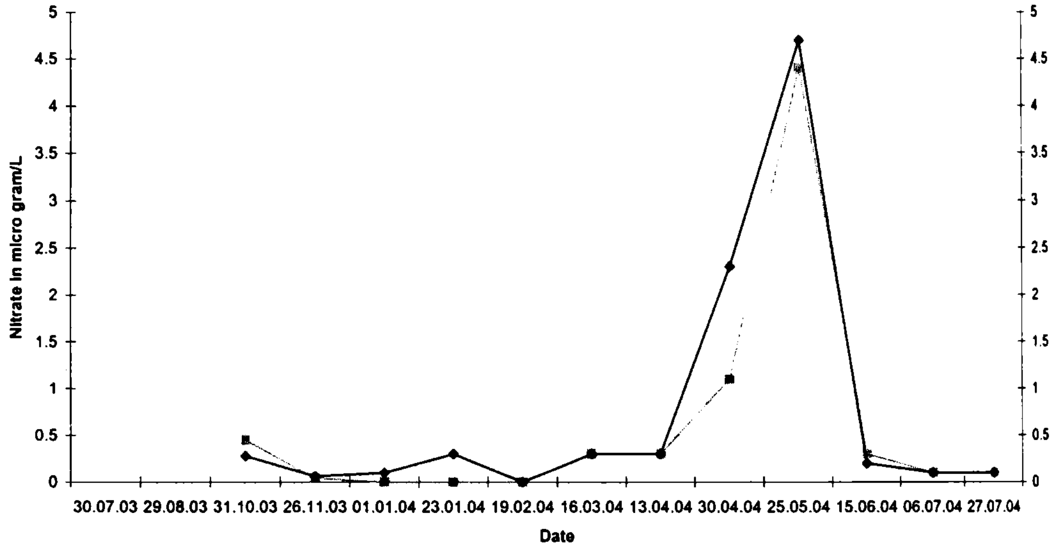


Fig.3.67 Temporal variation of nitrate concentration at various sampling points on

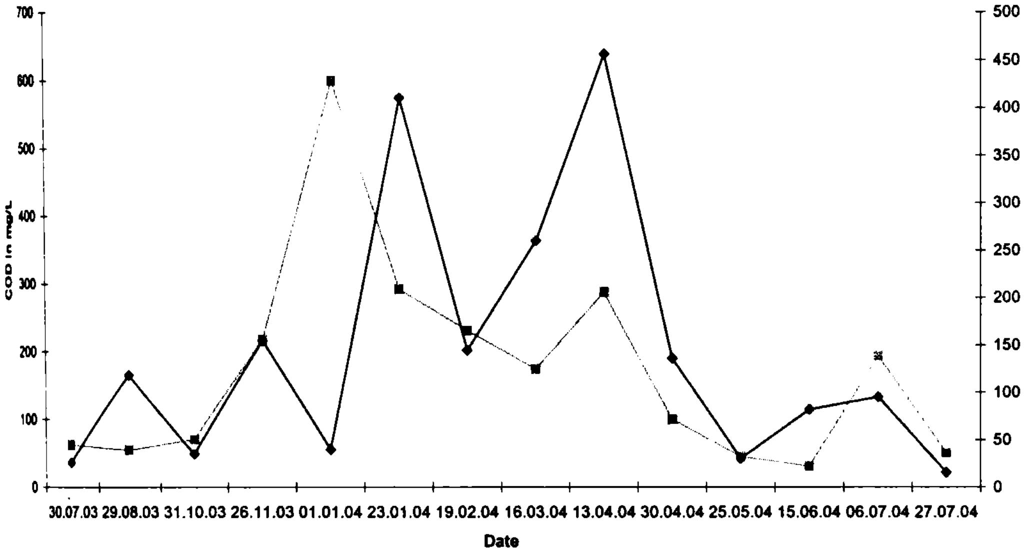


Fig.3.65Temporal variation of COD concentration at various sampling points on Mullassery canal

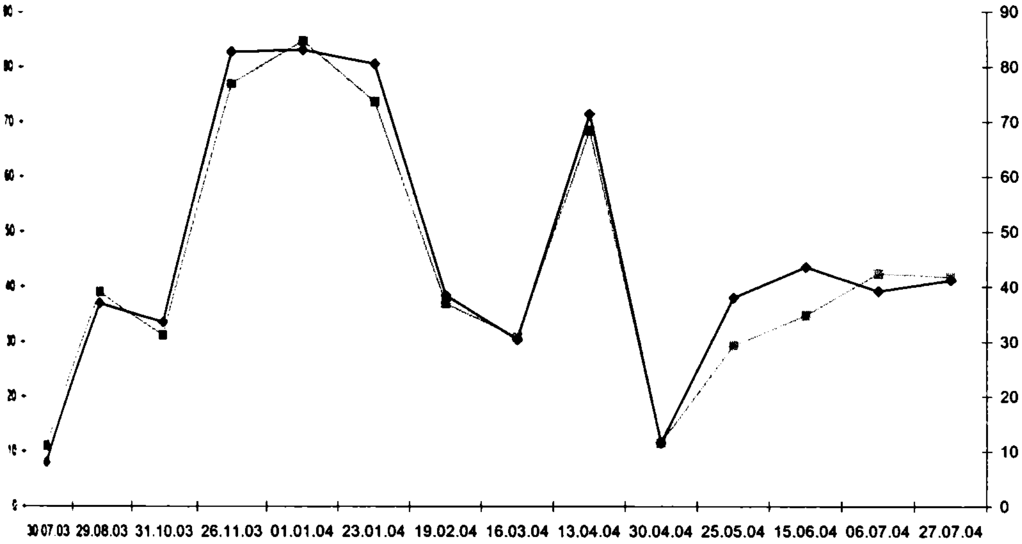


Fig.3,66 Temporal variation of BOD concentration at various sampling points on Mullassery canal

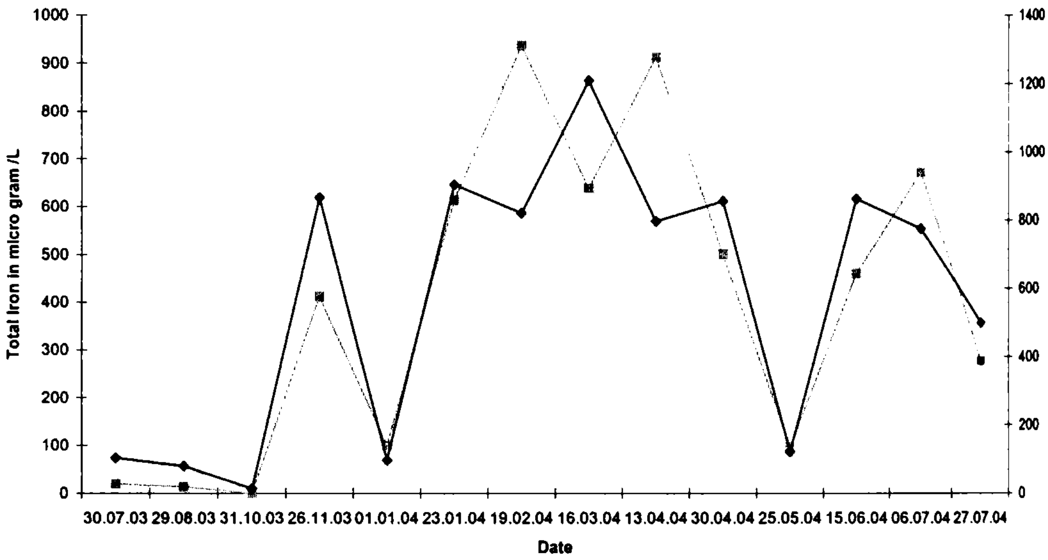


Fig.3.63 Temporal variation of Total iron concentration at various sampling points on Mullassery canal

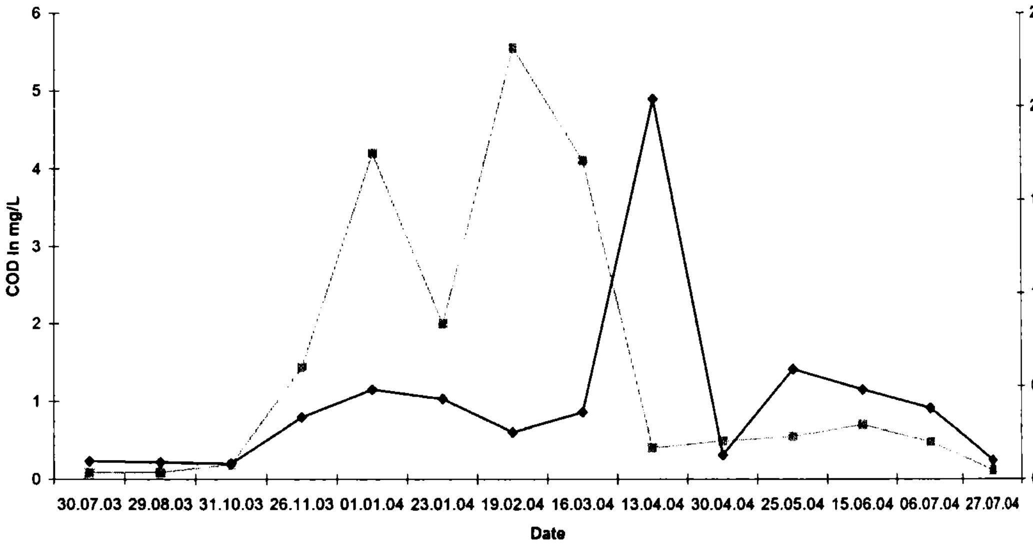


Fig 3.64.. Temporal variation of COD concentration at various sampling points on Mullassery canal

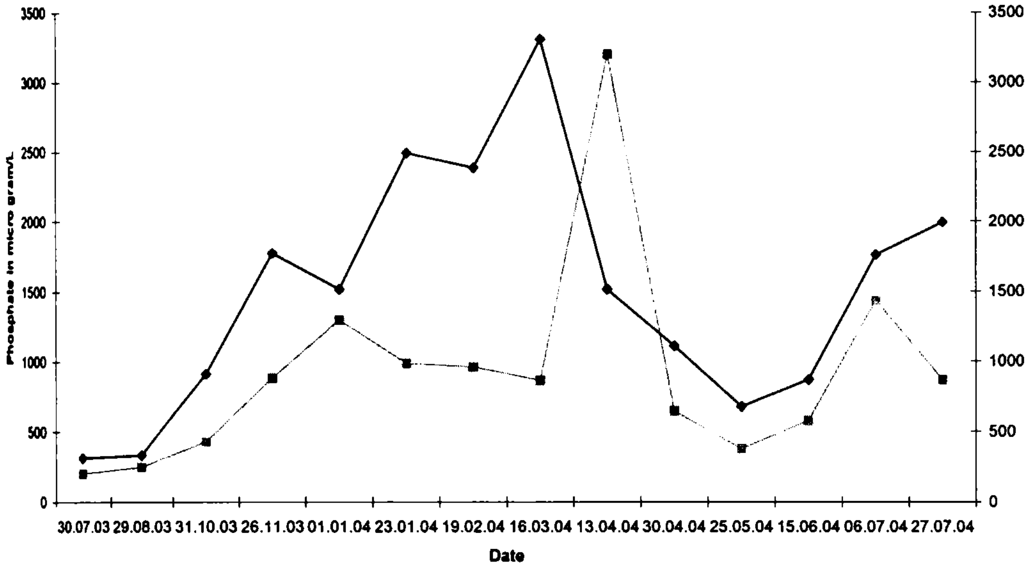


Fig.3.61 Temporal variation of phosphate concentration at various sampling points on

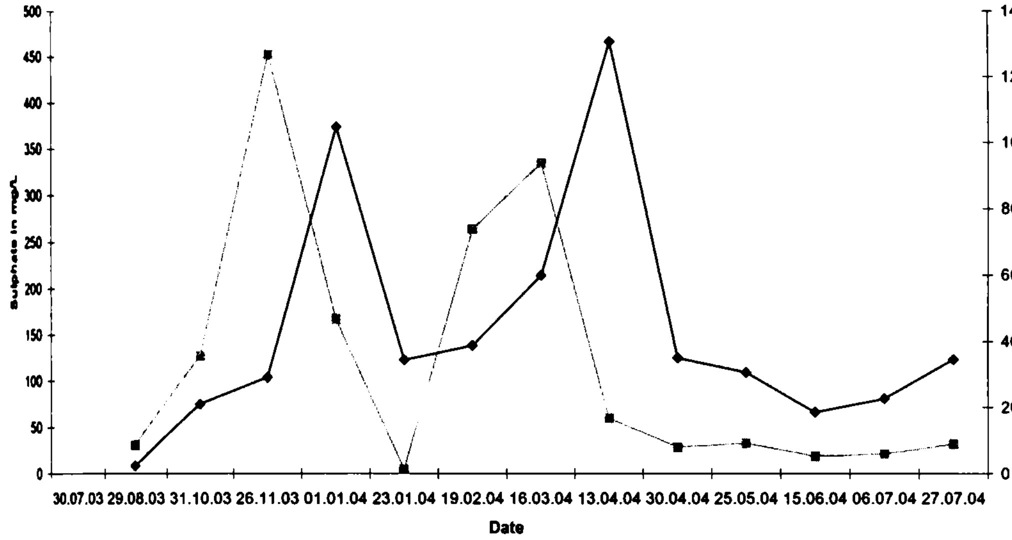


Fig.3.62 Temporal variation of sulphate concentration at various sampling points on

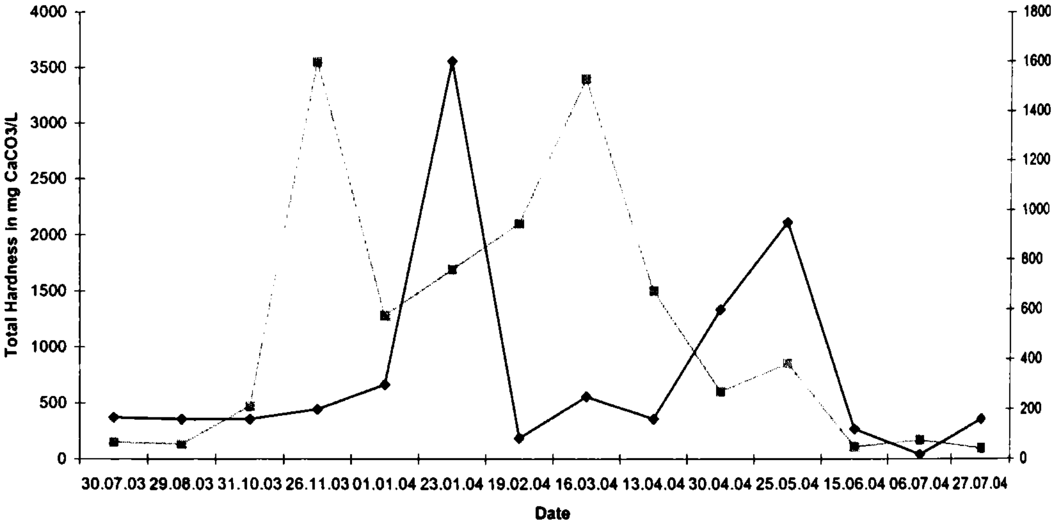


Fig3.59.Temporal variation of Total Hardness concentration at various sampling points on Mullassery canal

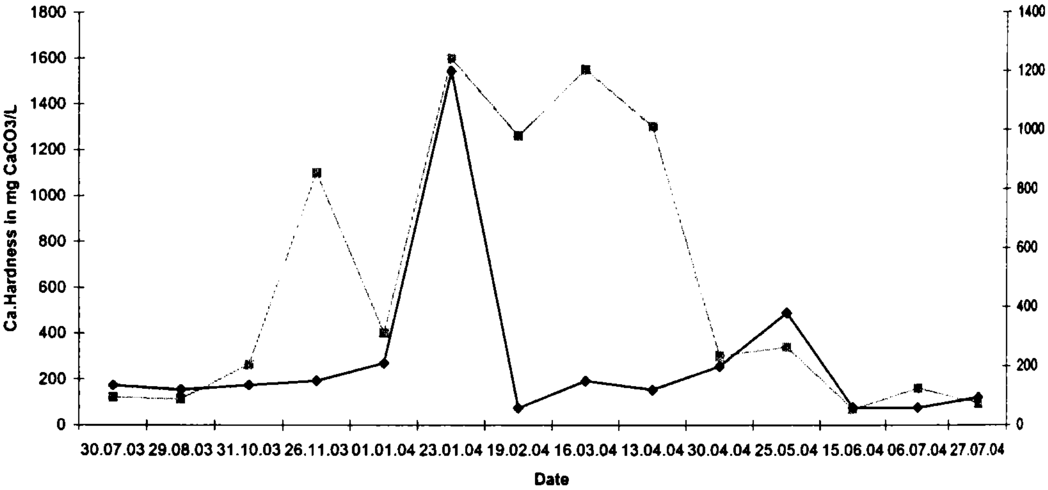


Fig.3.60 Temporal variation of calcium hardness concentration at various sampling points on Mullassery canal

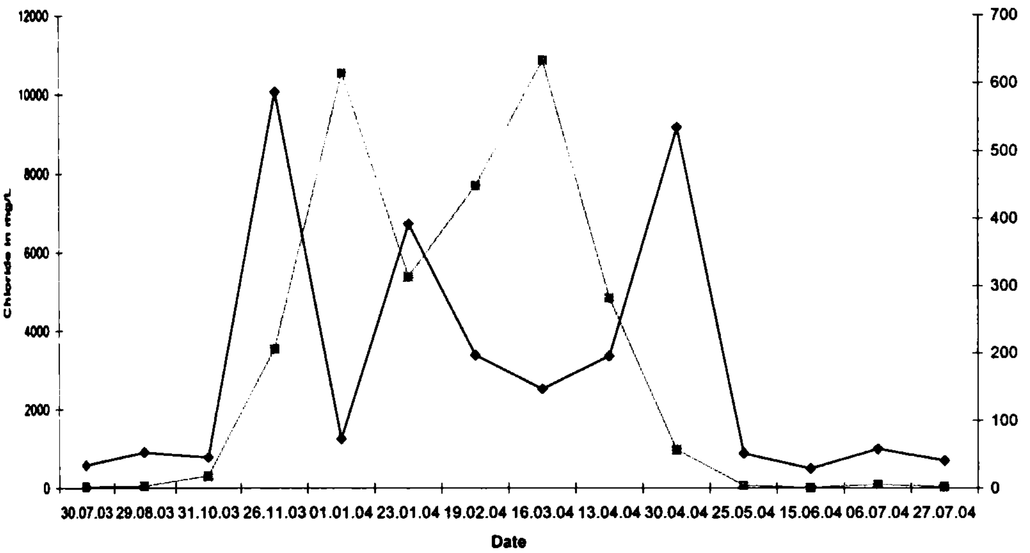


Fig.3.57 Temporal variation of Chloride concentration at various sampling points on Mullassery canal

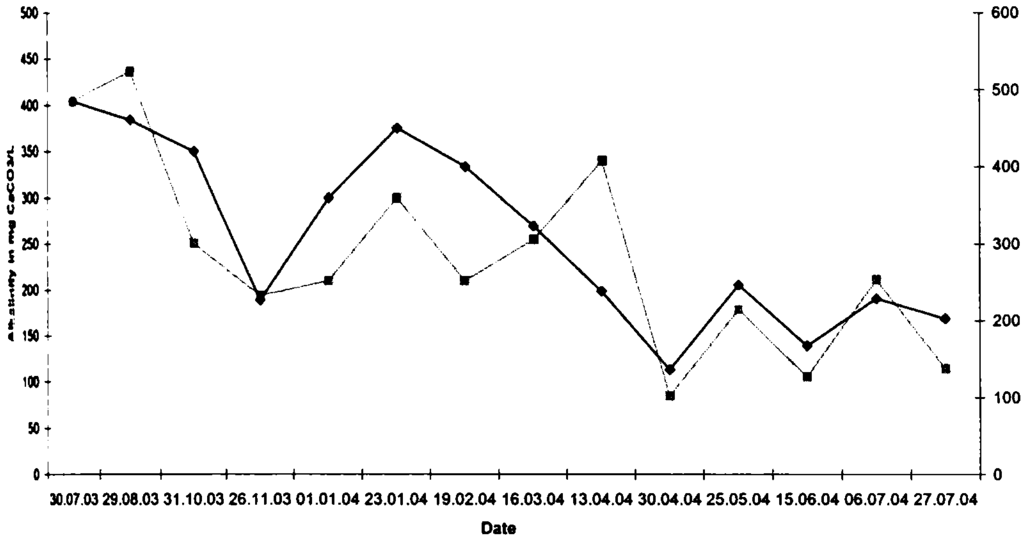


Fig.3.58Temporal variation of Alkalinity concentration at various sampling points on Mullassery canal

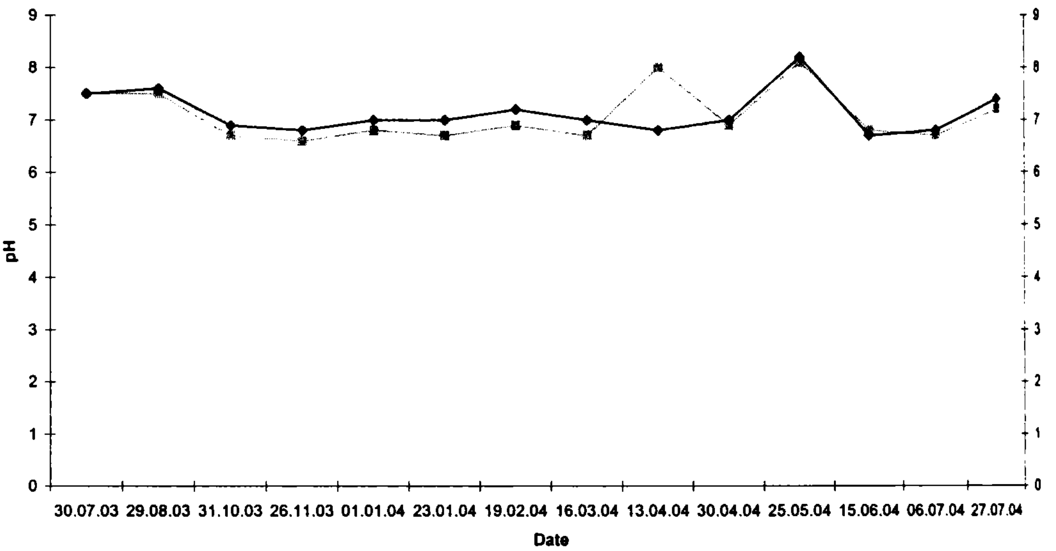


Fig.3.55Temporal variation of pH at various sampling points on Mullassery canal

Yathra KSRTC w

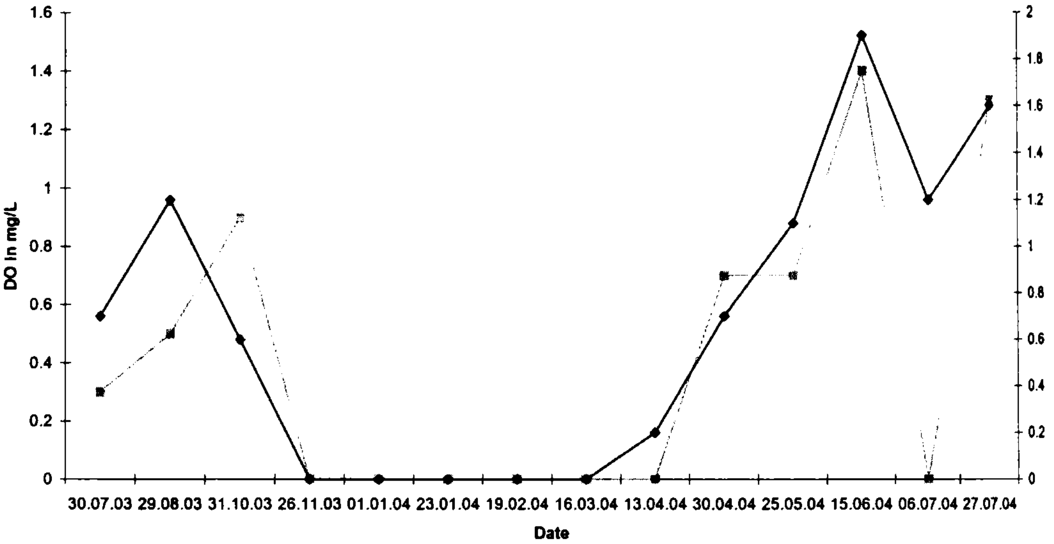


Fig.3.56Temporal variation of DO concentration at various sampling points on Mullassery

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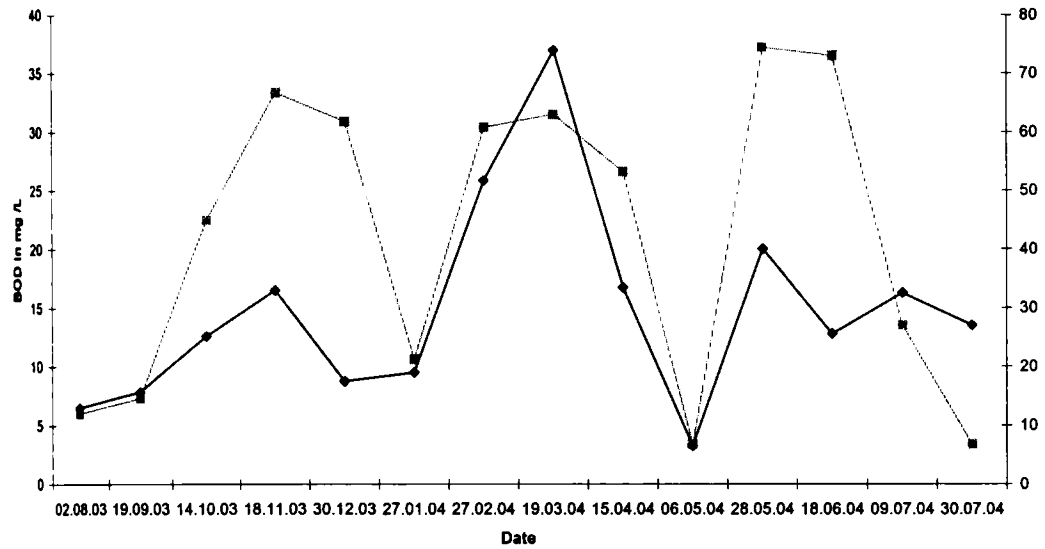


Fig.3.53 Temporal variation of BOD concentration at varioius sampling points on Kharee thod

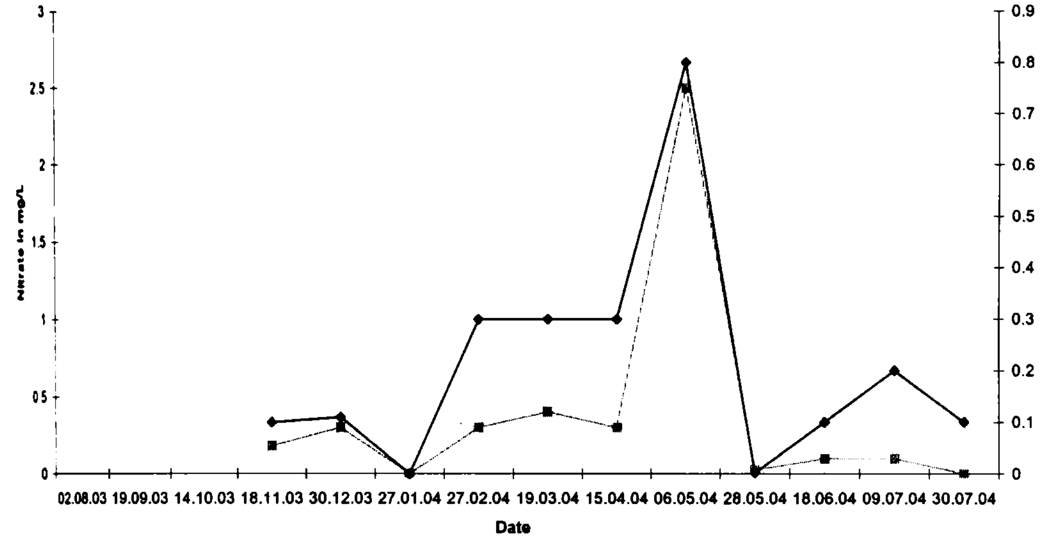


Fig.3.54Temporal variation of nitrate concentration at various sampling points on Kharee

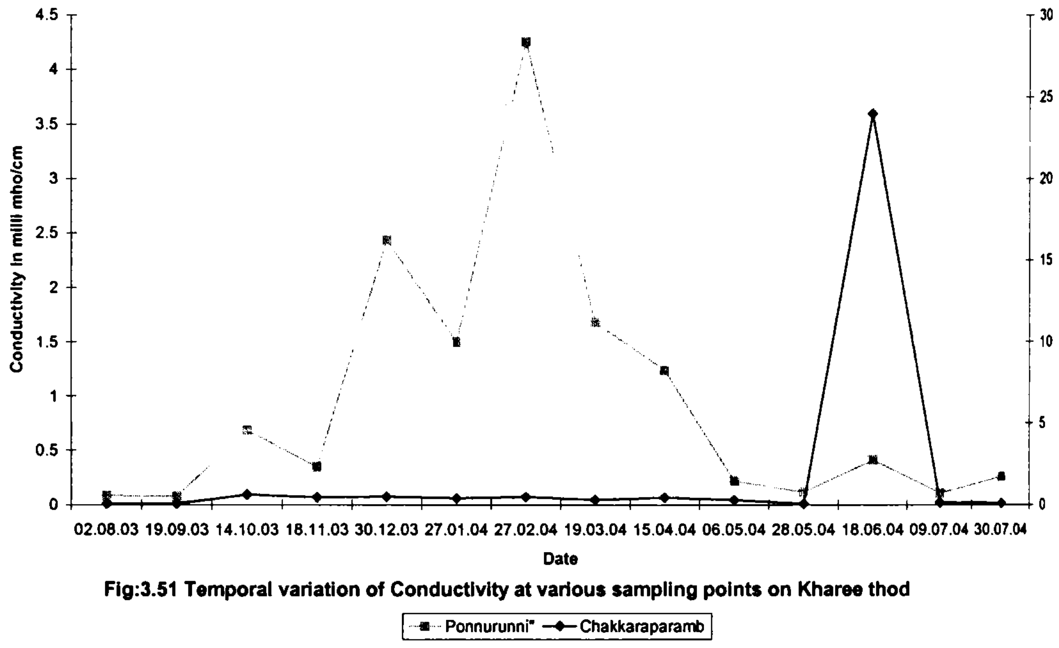


Fig:3.51 Temporal variation of Conductivity at various sampling points on Kharee thod

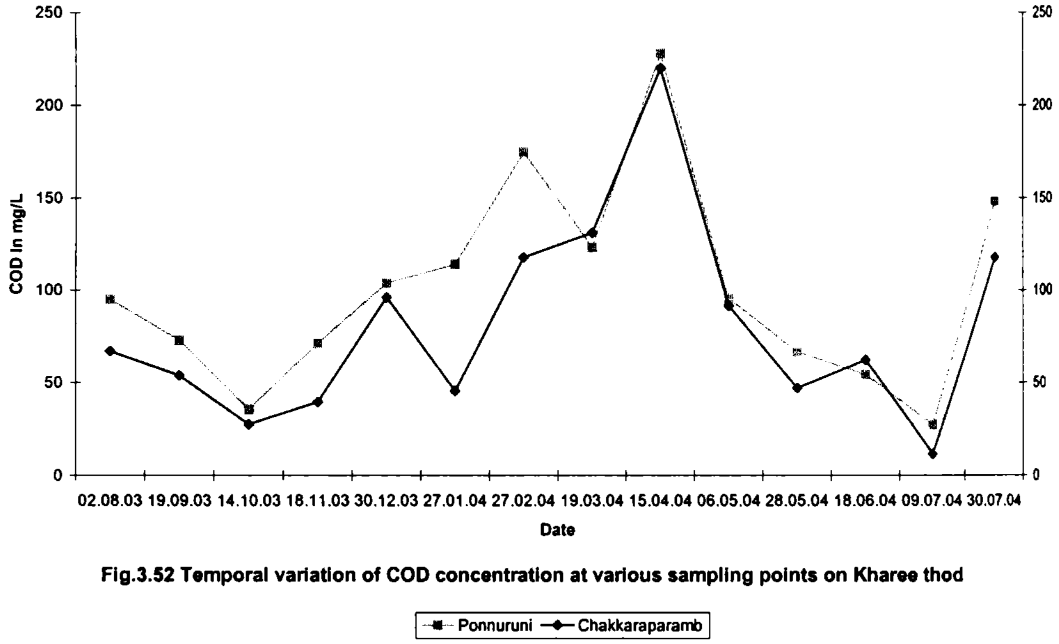


Fig.3.52 Temporal variation of COD concentration at various sampling points on Kharee thod

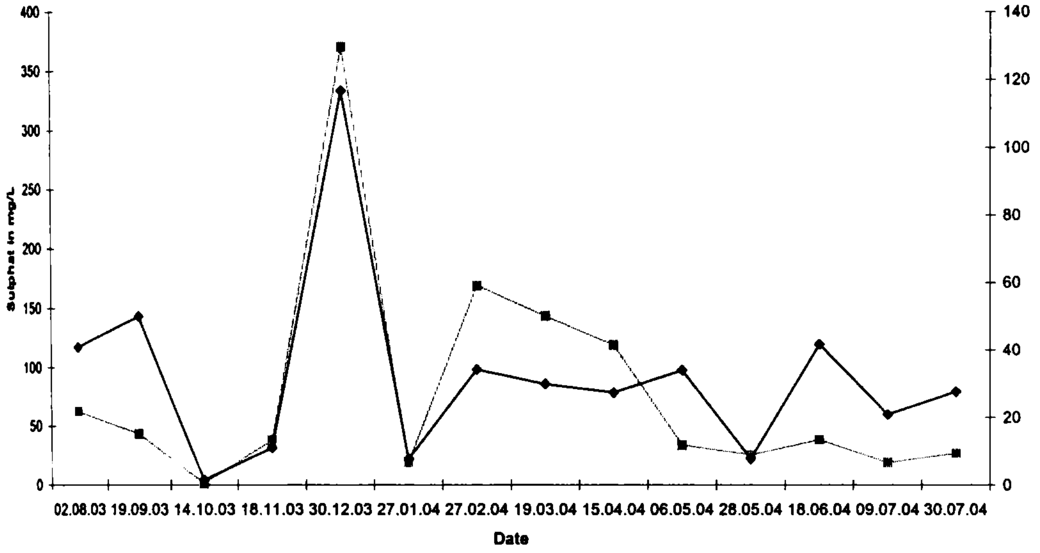


Fig:3.49Temporal variation of sulphate concentration at various sampling points on Kharee thod

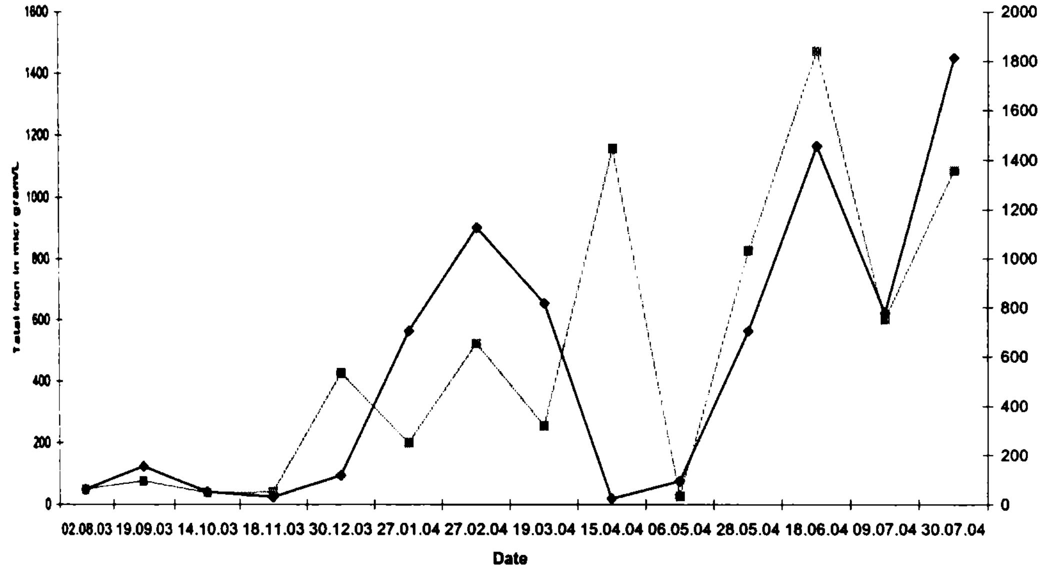


Fig.3.50 Temporal variation of total iron concentration at various sampling points on Kharee

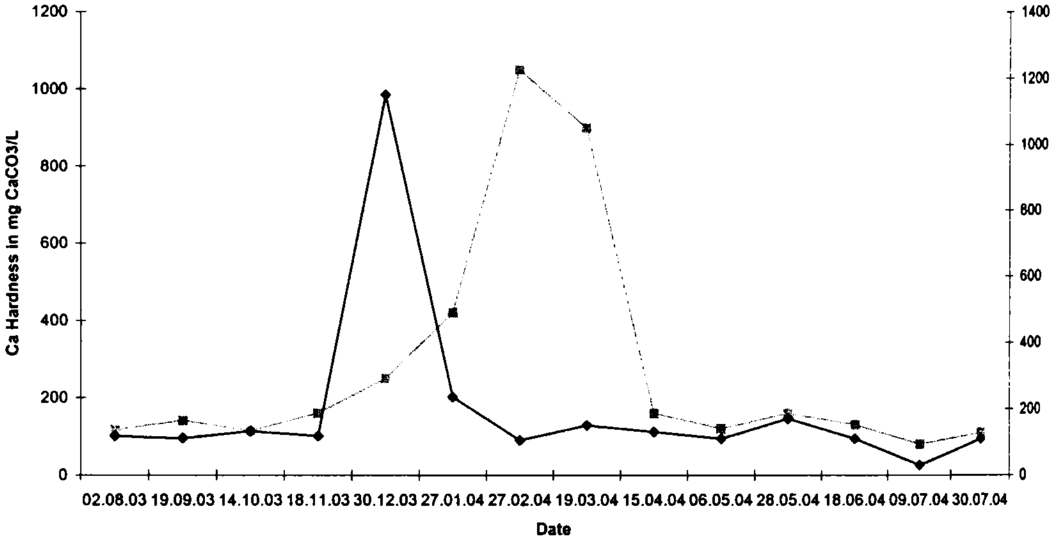


Fig.3.47 Temporal variation of Ca hardness concentration at various sampling points on

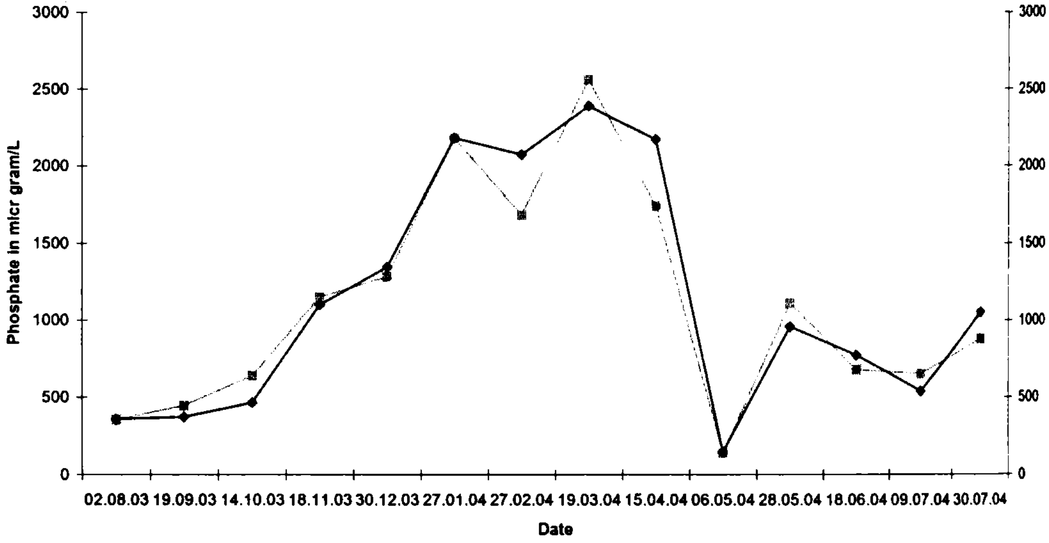


Fig:3.48 Temporal variation of phosphate concentration at various sampling points on Kharee thod

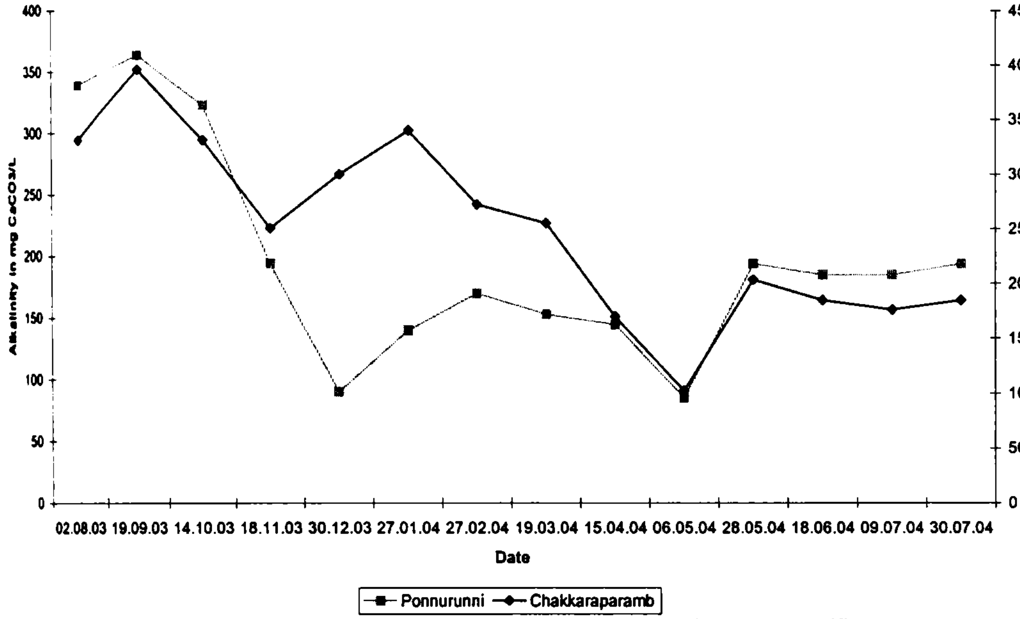
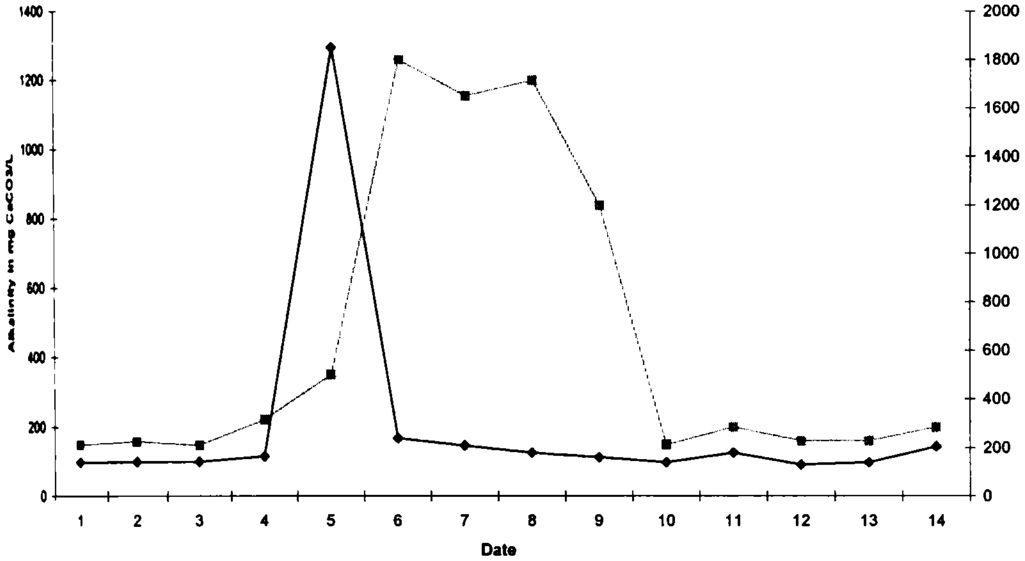


Fig.3.45 Temporal variation of Alklinity concentration at various sampling points on Kharee thod



3.46 Temporal variation of Total Hardness concentration at various sampling points on Kharee thod

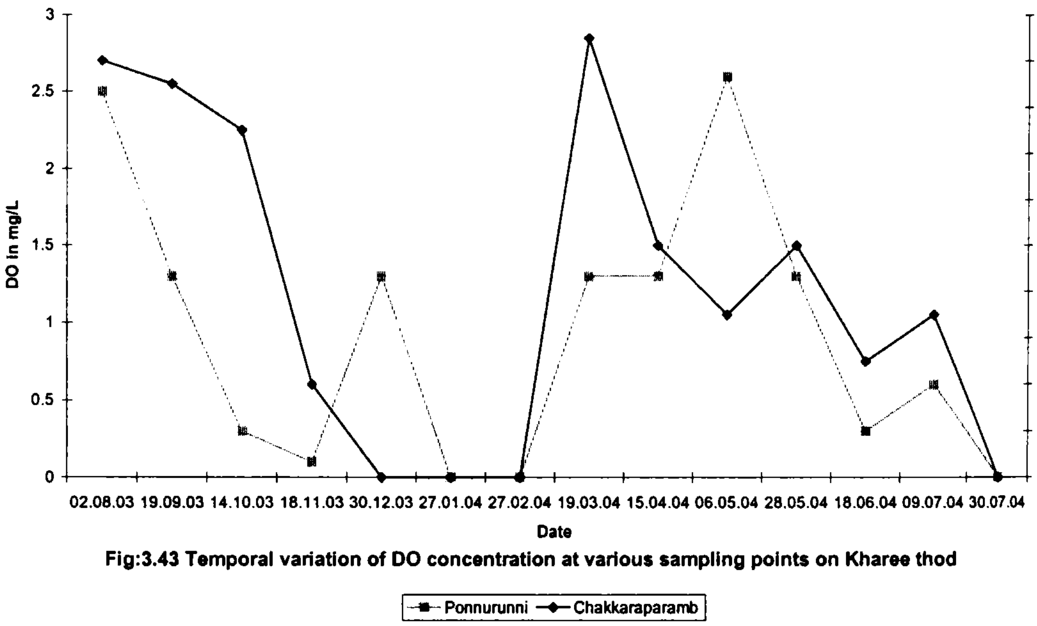


Fig:3.43 Temporal variation of DO concentration at various sampling points on Kharee thod

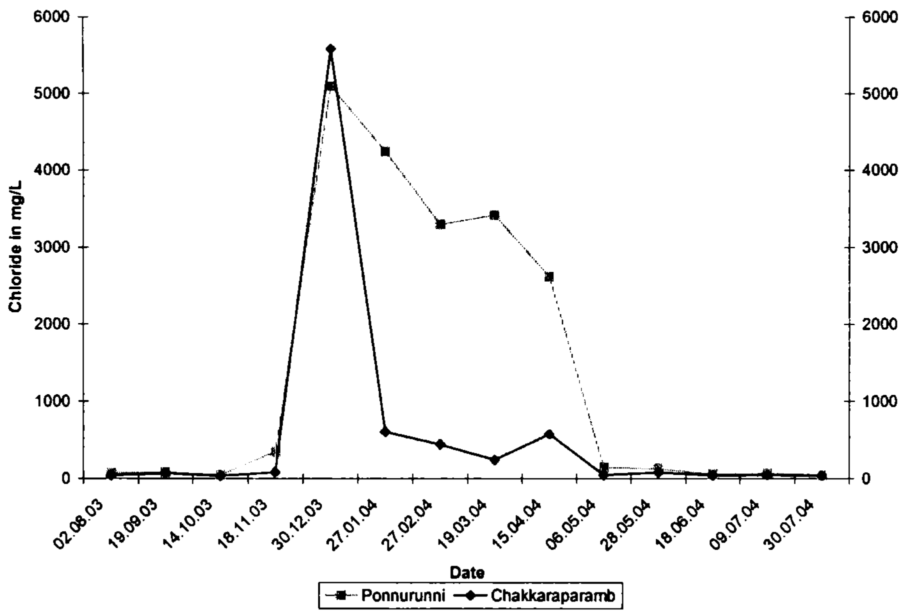


Fig.3.44Temporal variation of in Chloride concentration at various sampling points on Kharee thod

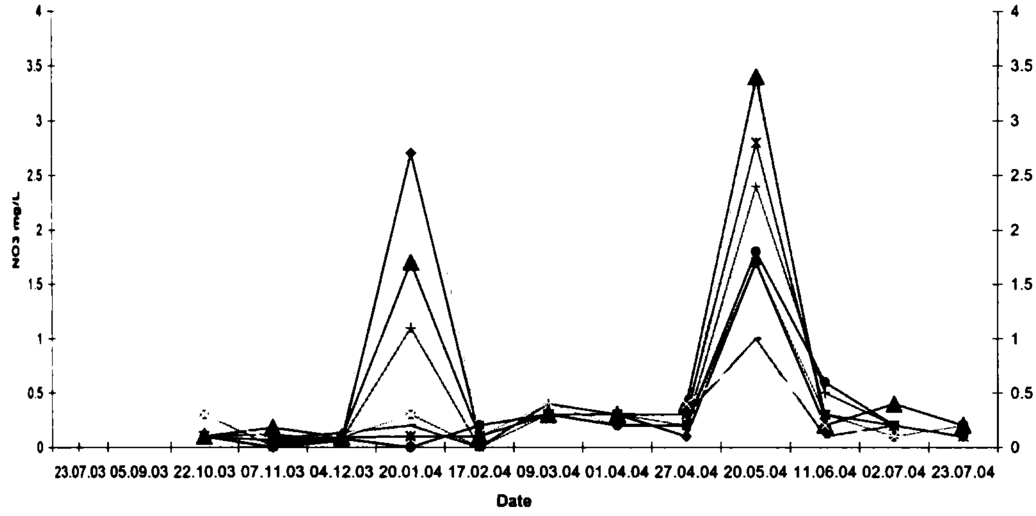


Fig 3.41 Temporal variation of Nitrate concentration at various sampling points on Edappally thod

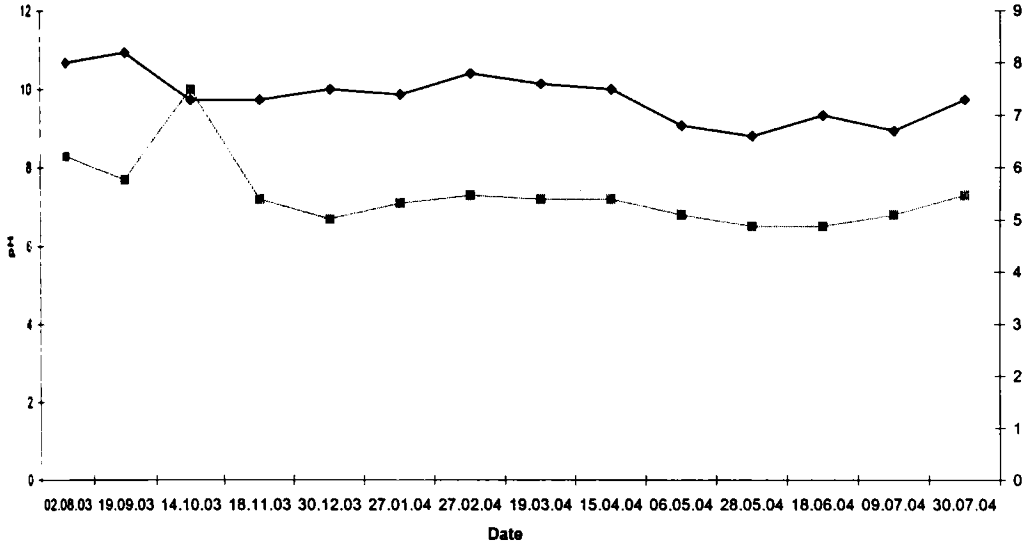


Fig:3.42Temporal variation of pH at variuous sampling points on Kharee thod

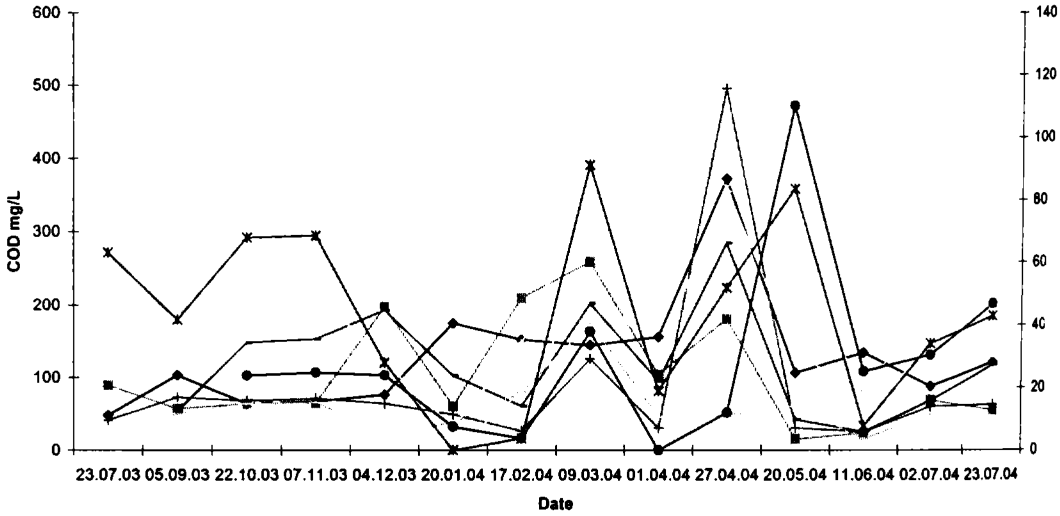


Fig 3.39. Temporal variation of COD concentration at various sampling points on Edappally thod

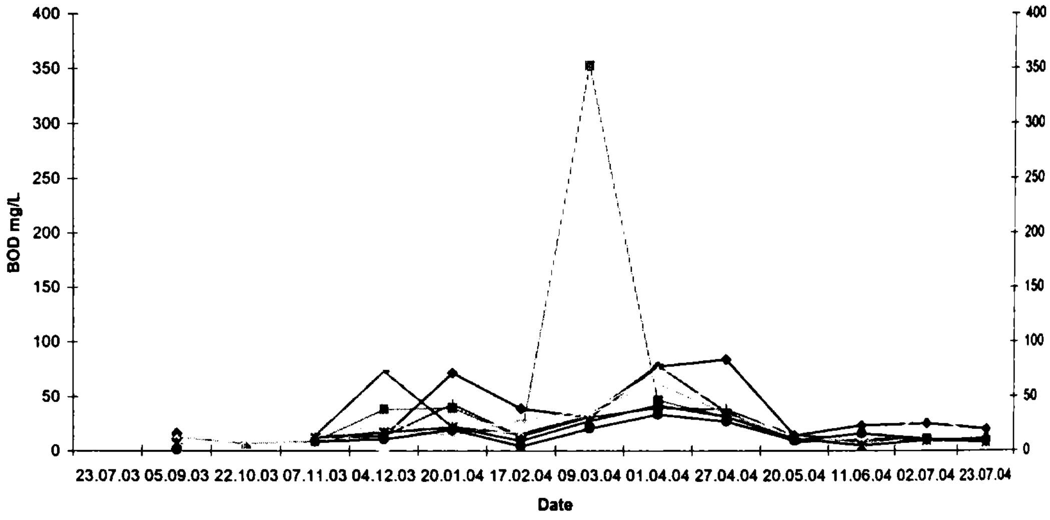


Fig 3.40 Temporal variation of BOD concentration at various sampling points on Edappally thod

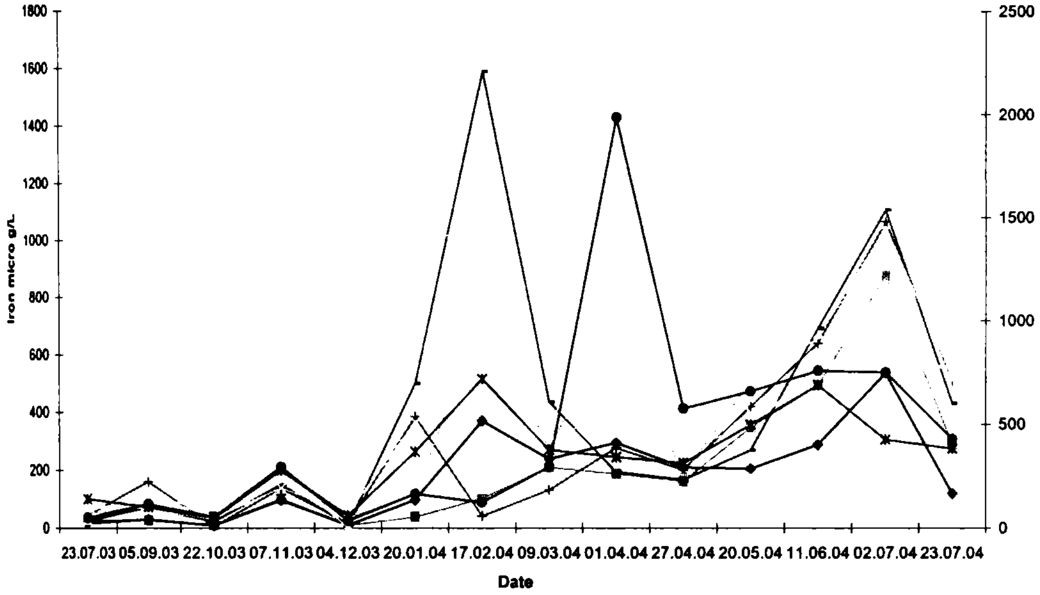


Fig 3.37 Temporal variation of Total Iron concentration at various sampling points on Edappally thod

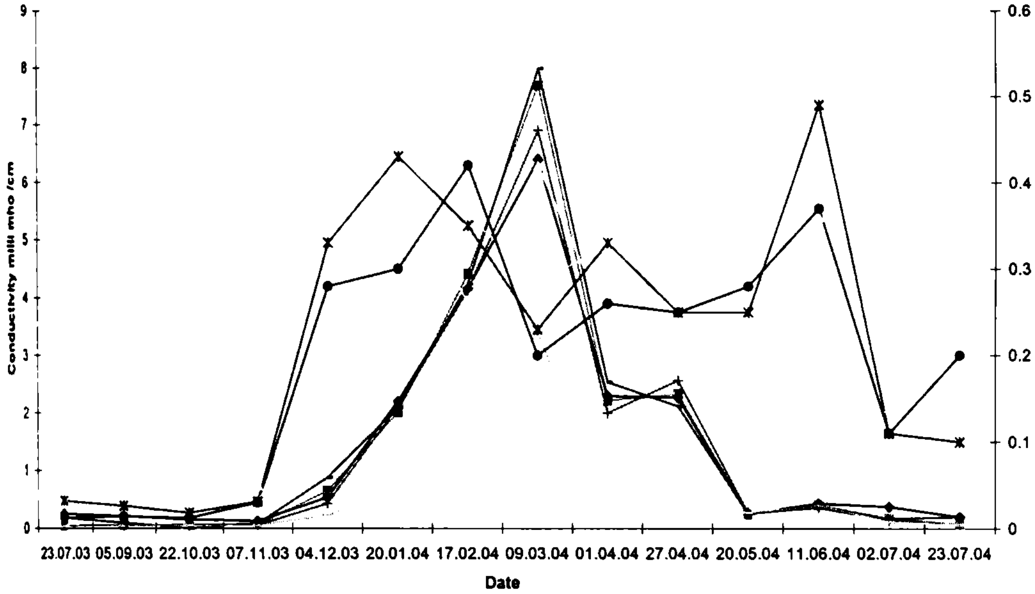


Fig 3.38 Temporal variation of Conducivity at various sampling points on Edappally thod

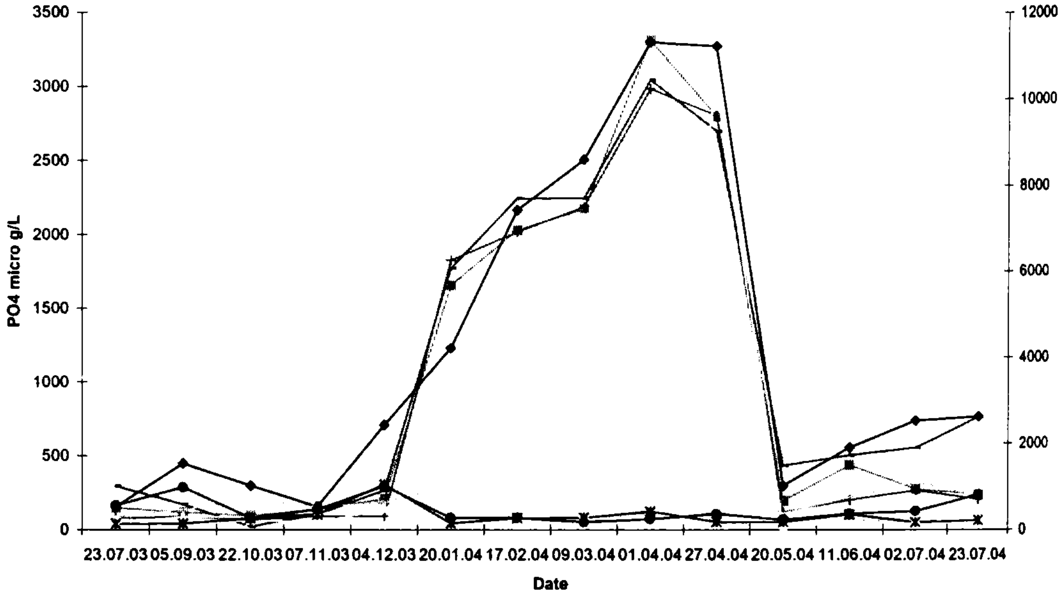


Fig 3.35 Temporal variation of Phosphate concentration at various sampling points on Edappally thod

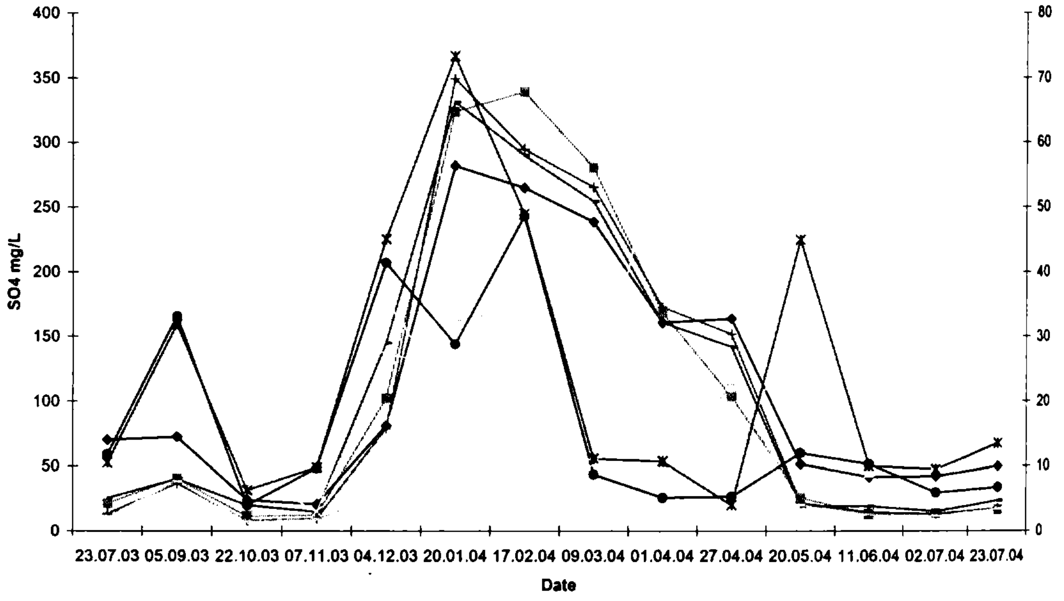


Fig 3.36 Temporal variation of Sulphate concentration at various Sampling points on Edappally thod

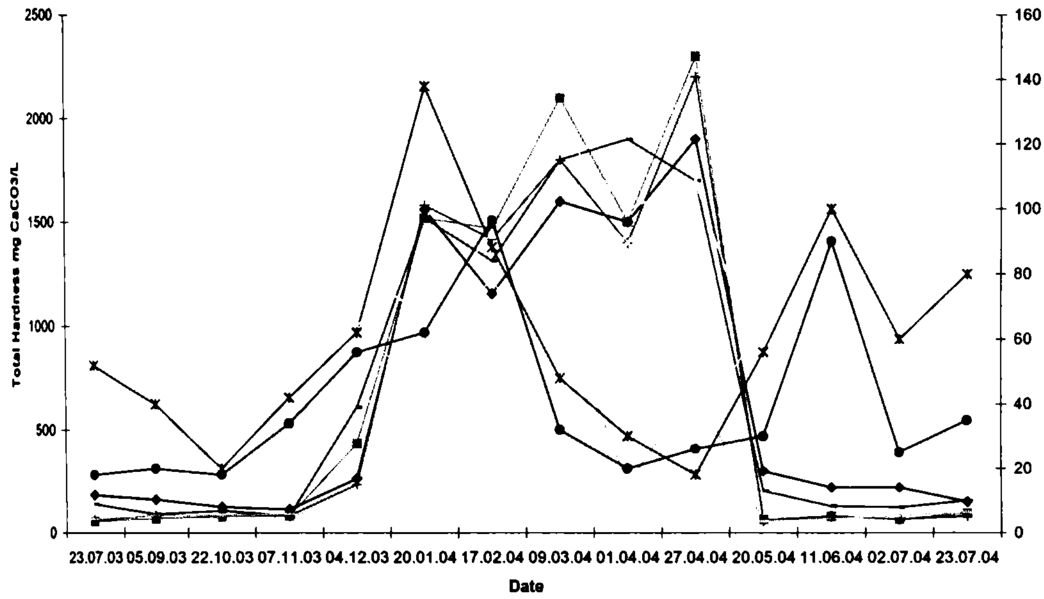


Fig 3.33Temporal variation of Total Hardness concentration at various sampling points on Edappally thod

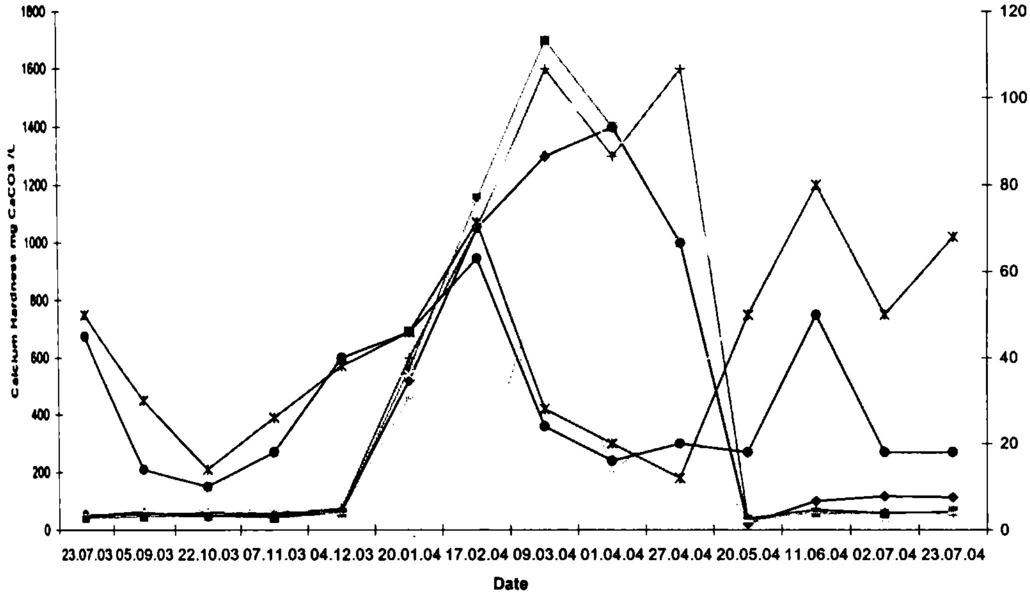


Fig 3.34 Temporal variation of Calcium Hardness concentration at various sampling points onEdappally thod

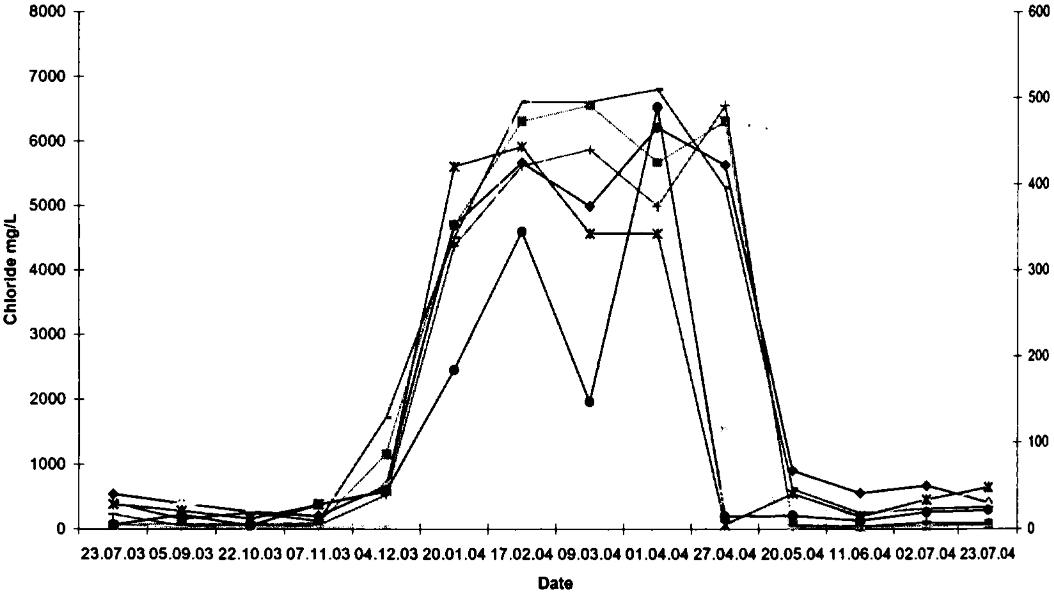


Fig 3.31 Temporal variation of Chloride concentration at various smpling points on Edappally thod

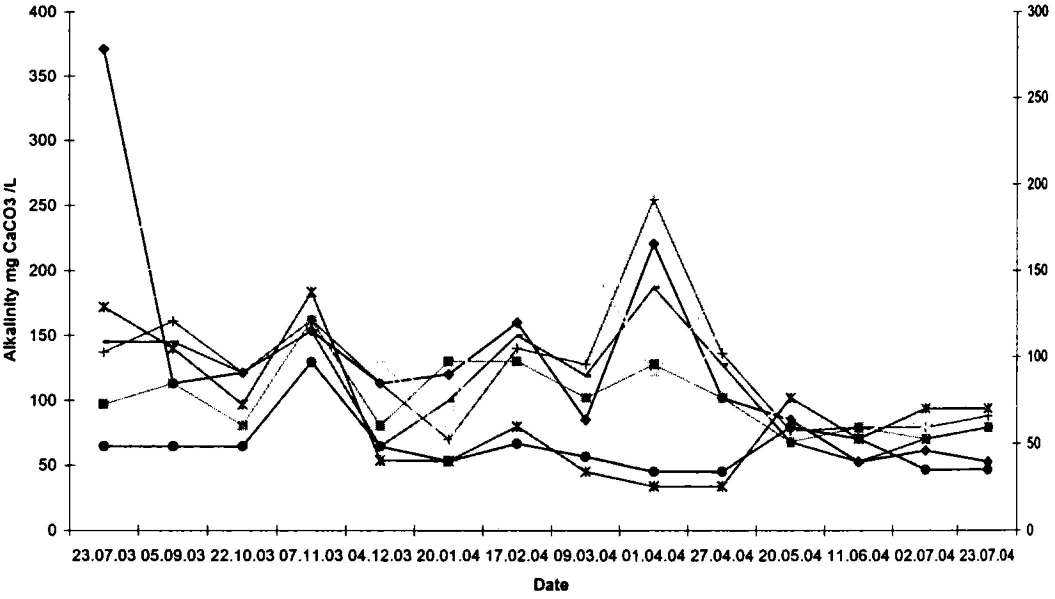


Fig 3.32 Temporal variation of Alkalinity concentration at various sampling points on Edappally thod

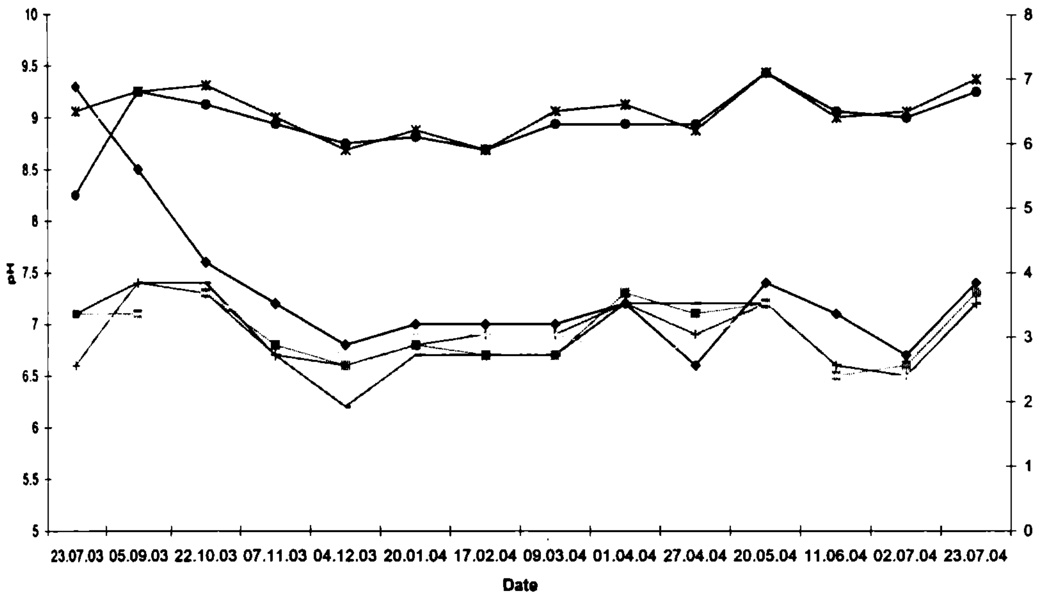


Fig 3.29 Temporal variation of pH at various sampling points on Edappally thod

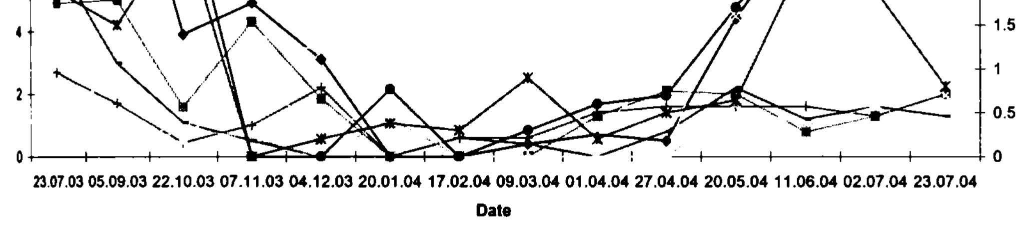


Fig.3.30 temporal variation of DO concentration at various sampling points on Edappaly thod

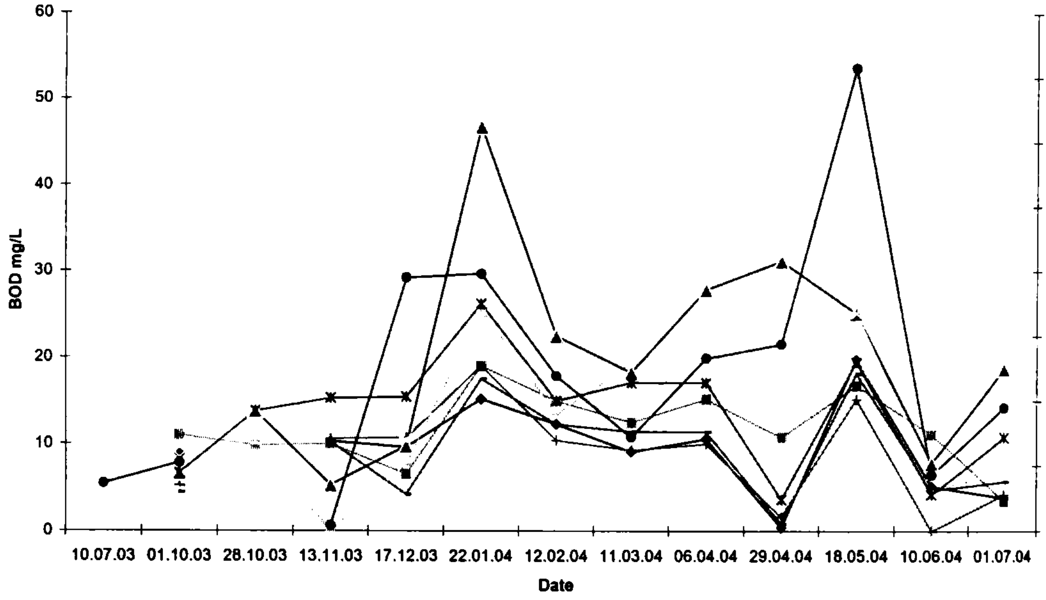


Fig 3.27 Temporal variation of BOD at various sampling points on Chothrapuzha

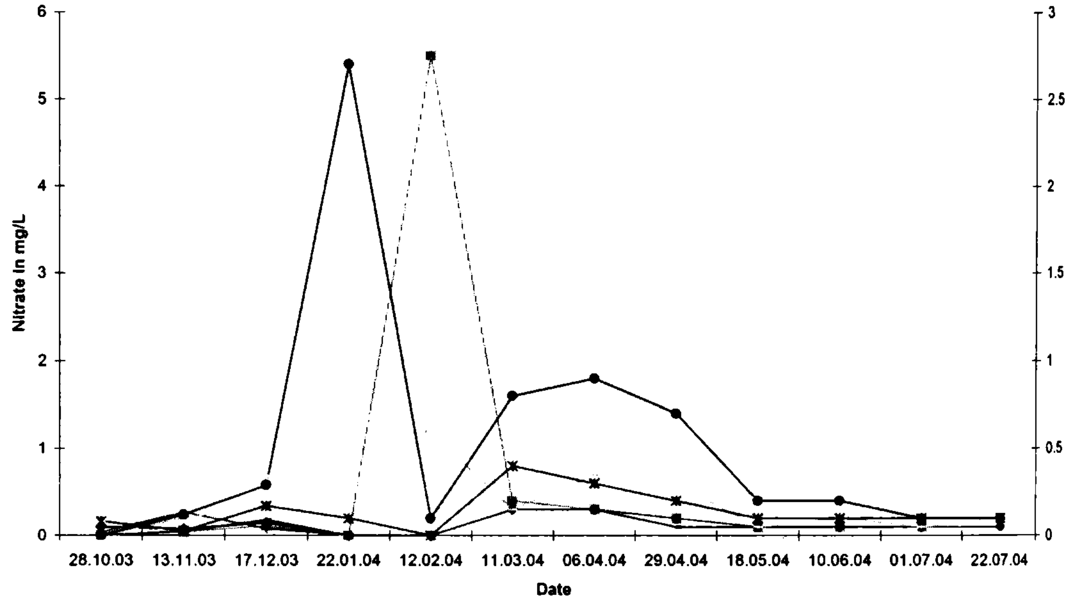


Fig No. 3.28 Temporal variation of nitrate concentration atvarious sampling points on Chitrapuzha

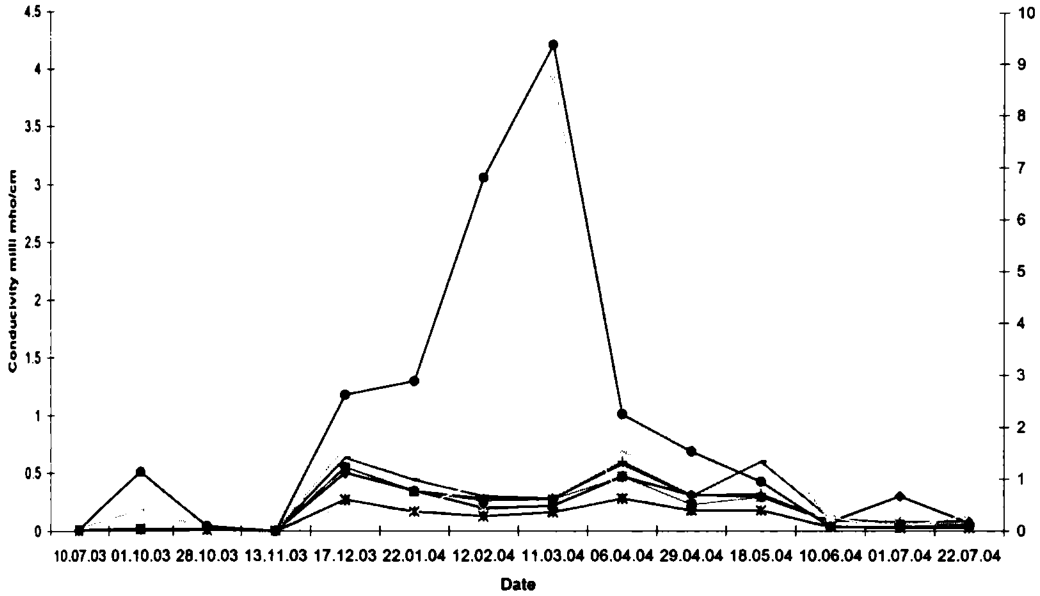


Fig 3.25Temporal variation of Conductivity at various sampling points on Chithrapuzha

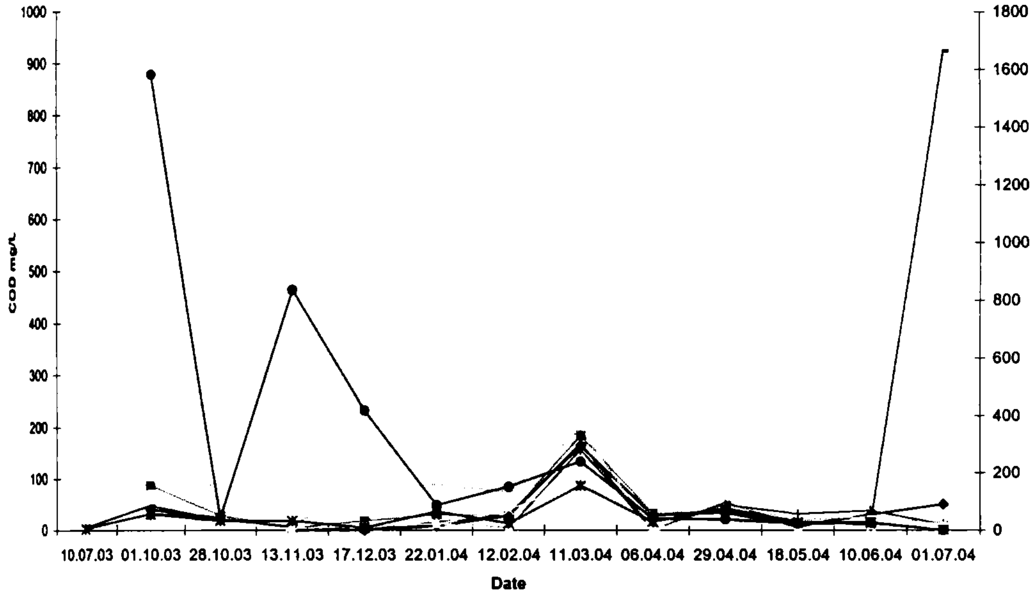


Fig 3.26 Temporal variation of COD at various sampling points on Chithrapuzha

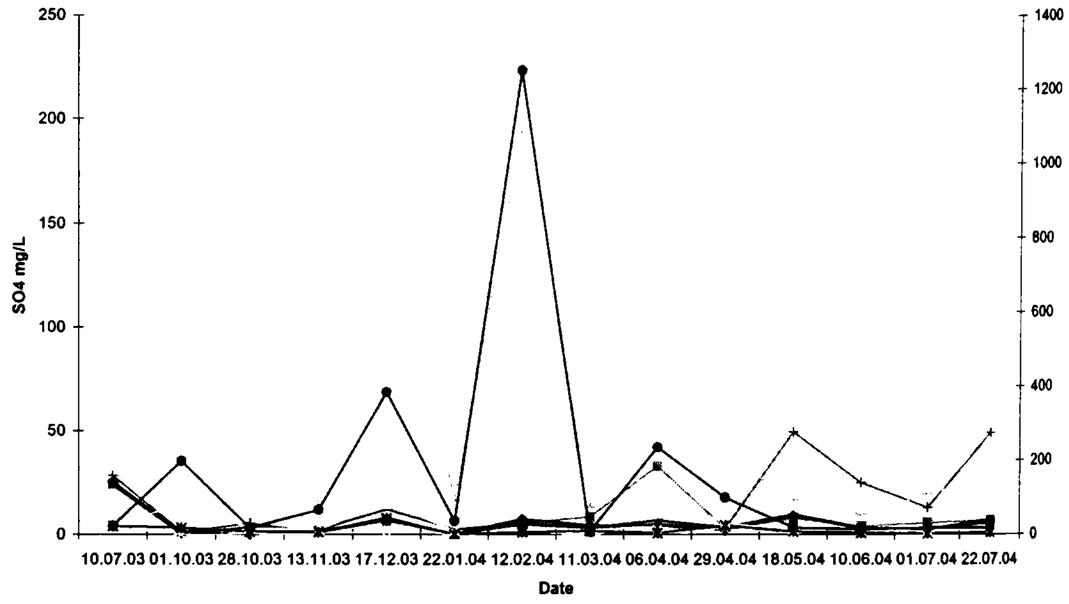


Fig 3.23 mporal variation of Sulphate at various sampling points on Chithrapuzha

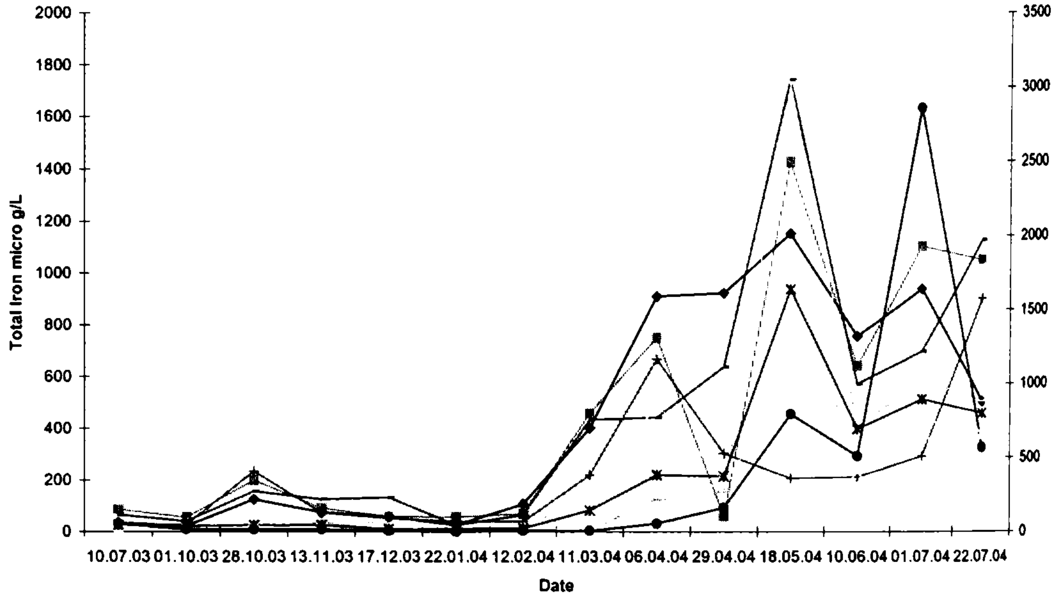


Fig 3.24 Temporal variation of Total Iron at various sampling points on Chithrapuzha

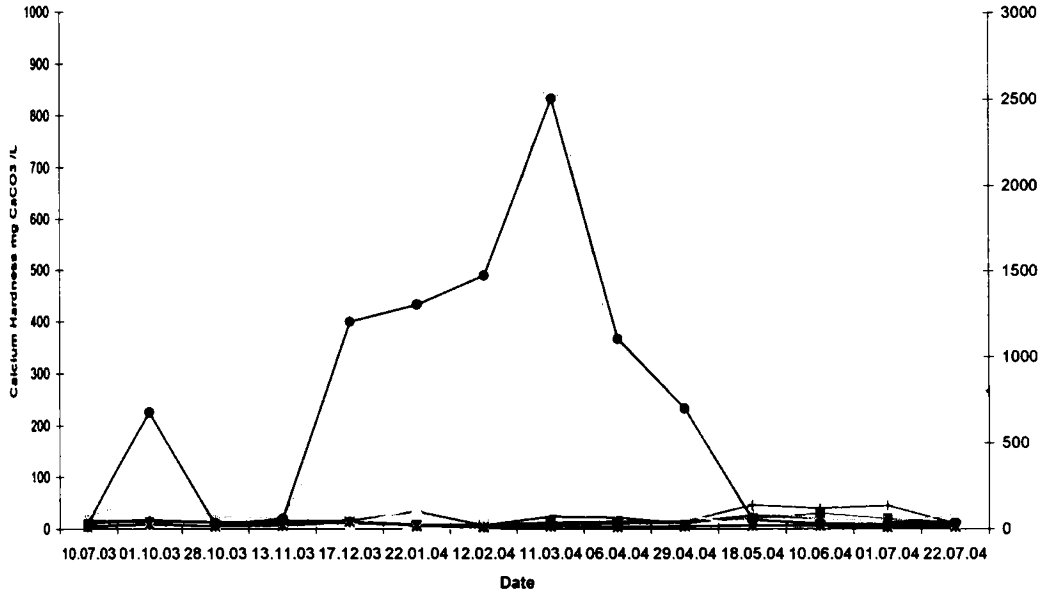


Fig 3.21 Temporal variation of Calcium Hardness at various sampling points on Chithrapuzha

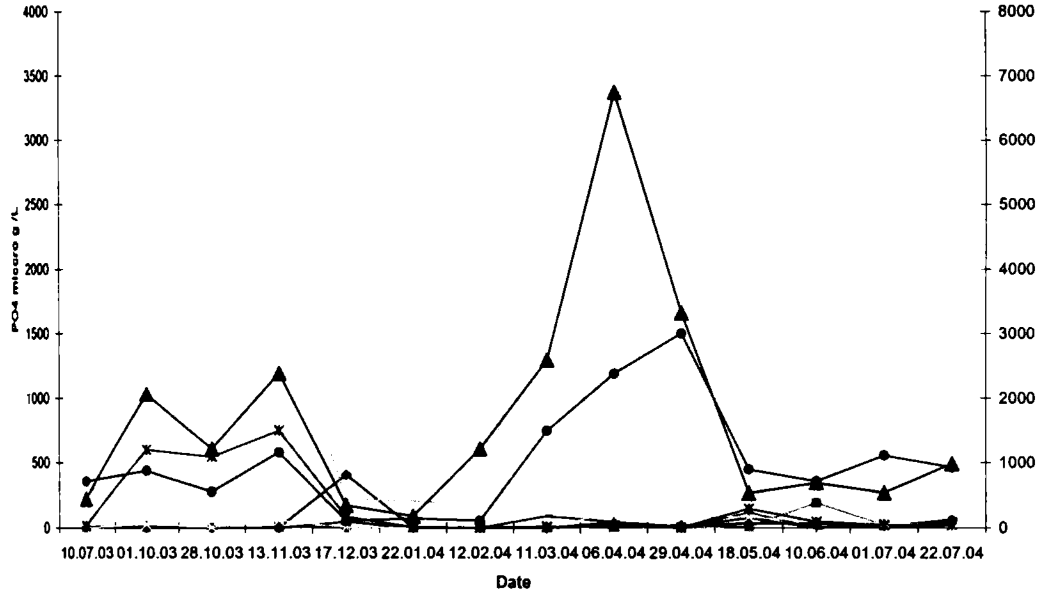


Fig 3.22 Temporal variation of Phosphate at various sampling points on Chithrapuzha

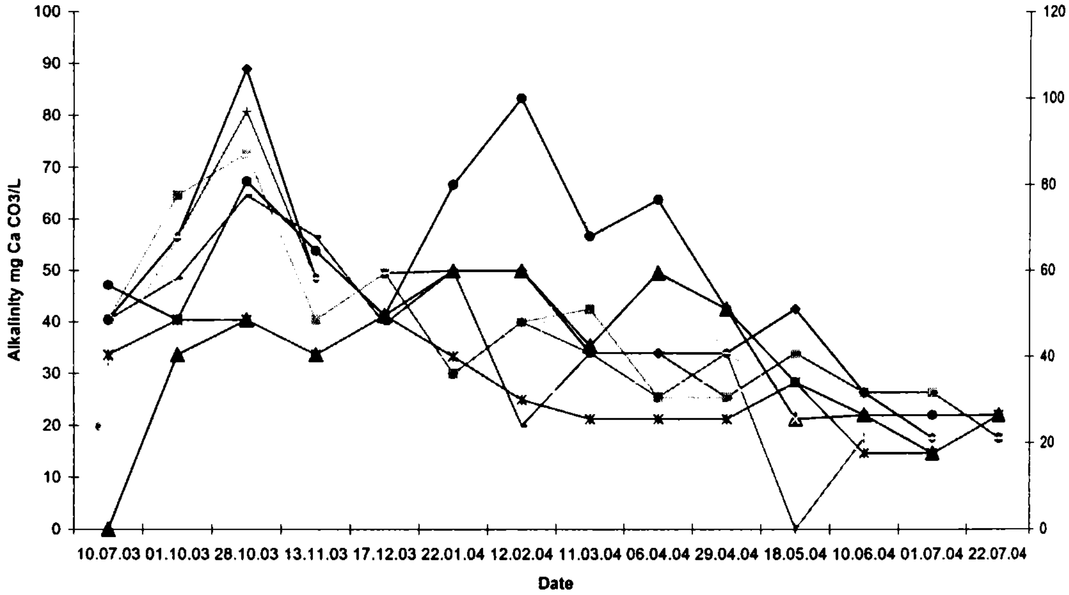


Fig 3.19 Temporal variation of Alkalinity at various sampling points on Chithrapuzha

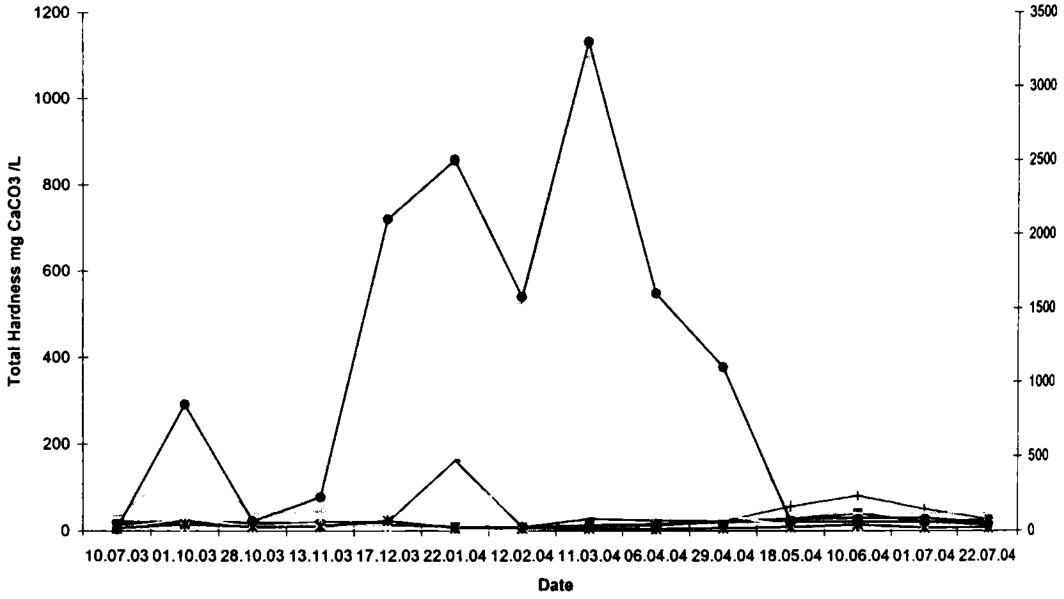


Fig 3.20 Tempiral variation of Total Hardness at various sampling points on Chithrapuzha

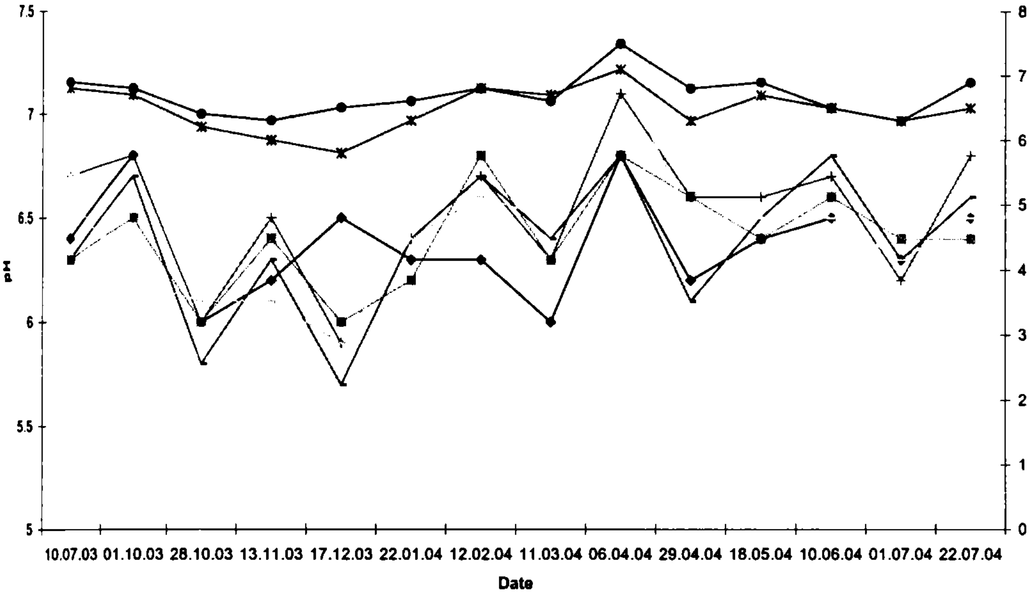


Fig 3.17 Temporal variation of pH at various sampling points on Chithrapuzha

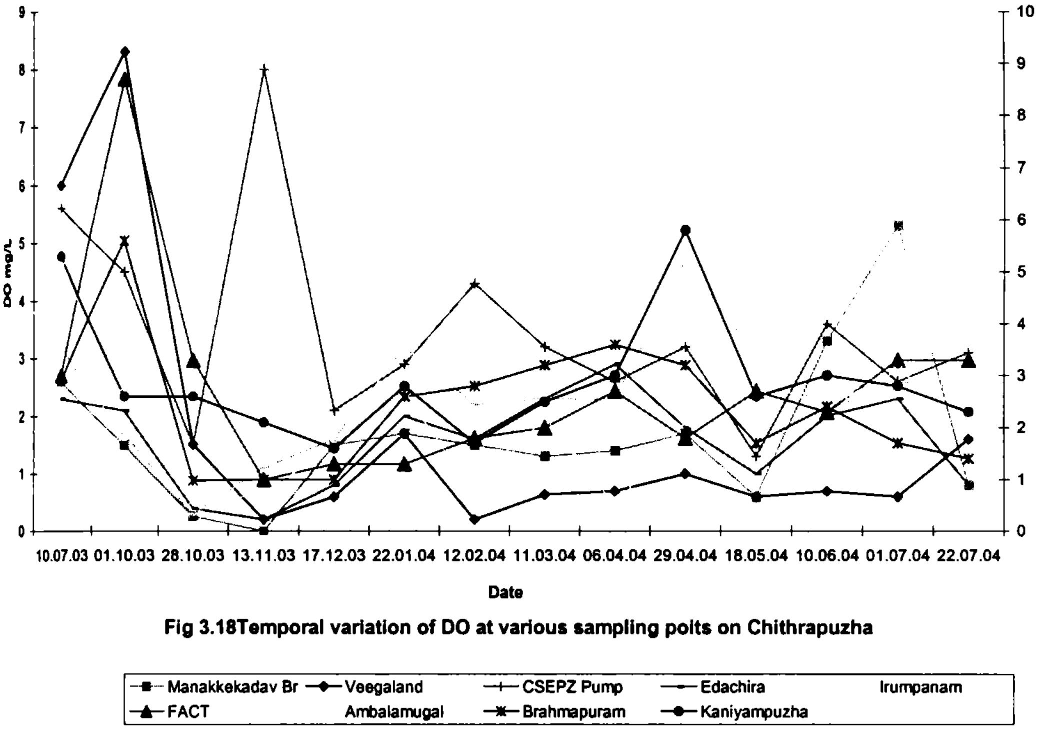


Fig 3.18Temporal variation of DO at various sampling polts on Chithrapuzha

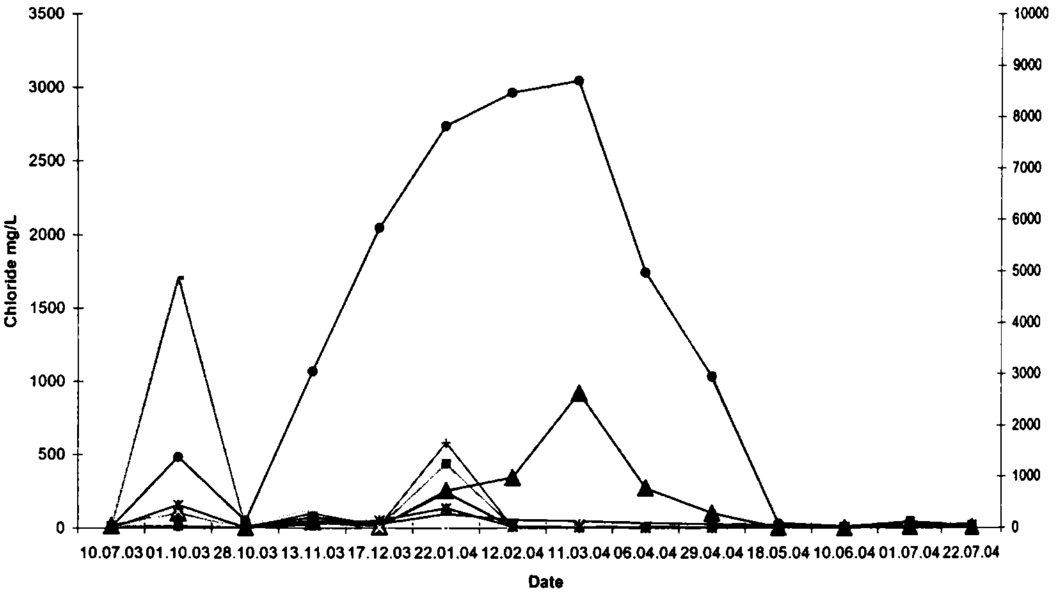


Fig 3.16 Temporal variation of CHloride concentration at various sampling points on Chithrapuzha

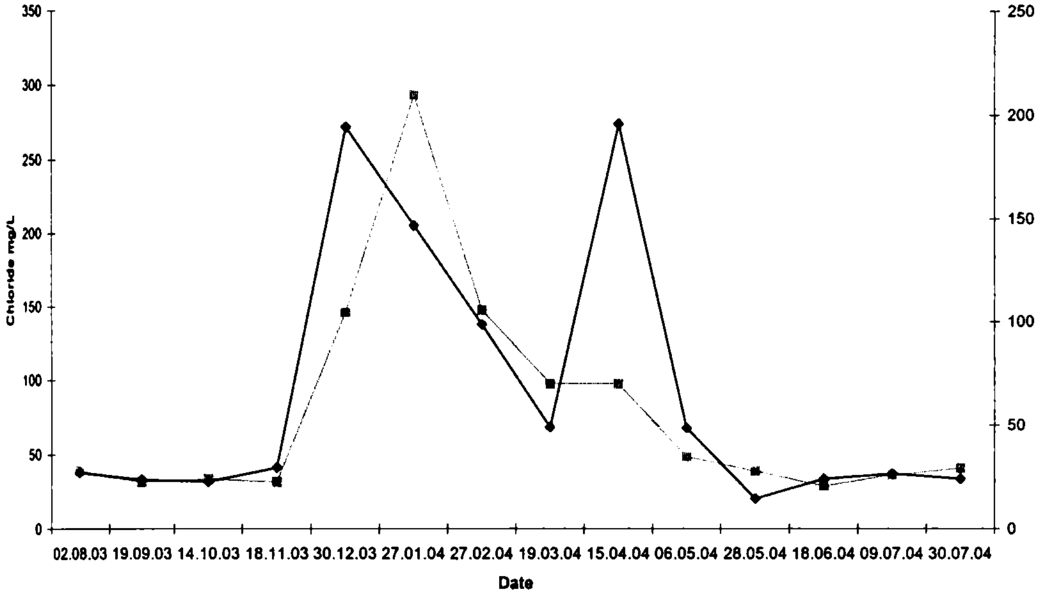


Fig 3.1 3Temporal variation of Chloride concentration at various sampling points on Adimuri thod

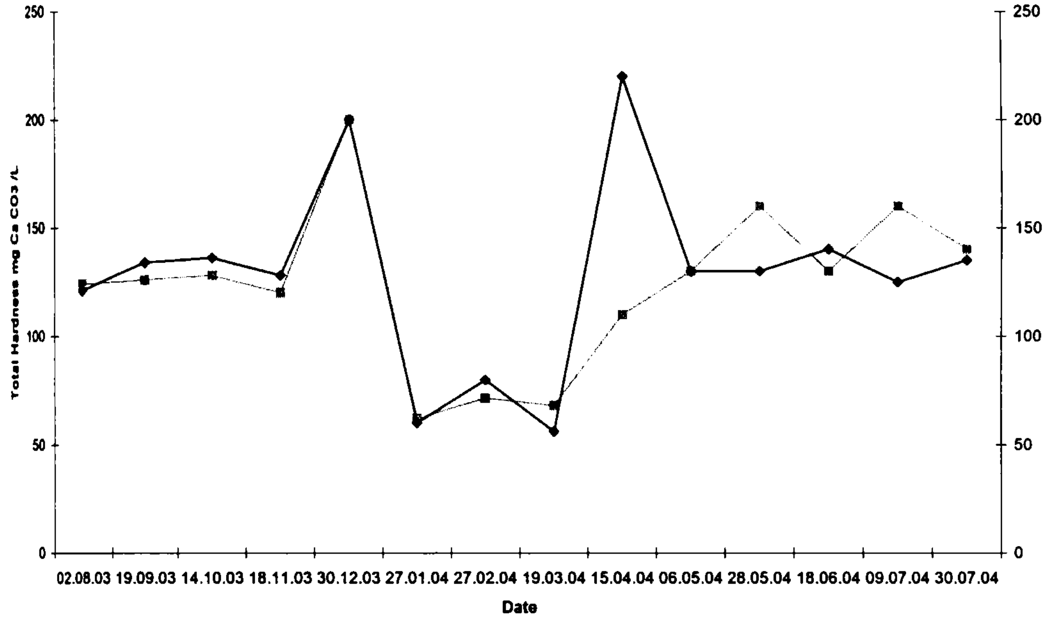


Fig 3.14 Temporal variation of Total Hardness concentration at variousm sampling points on Adimuri thod

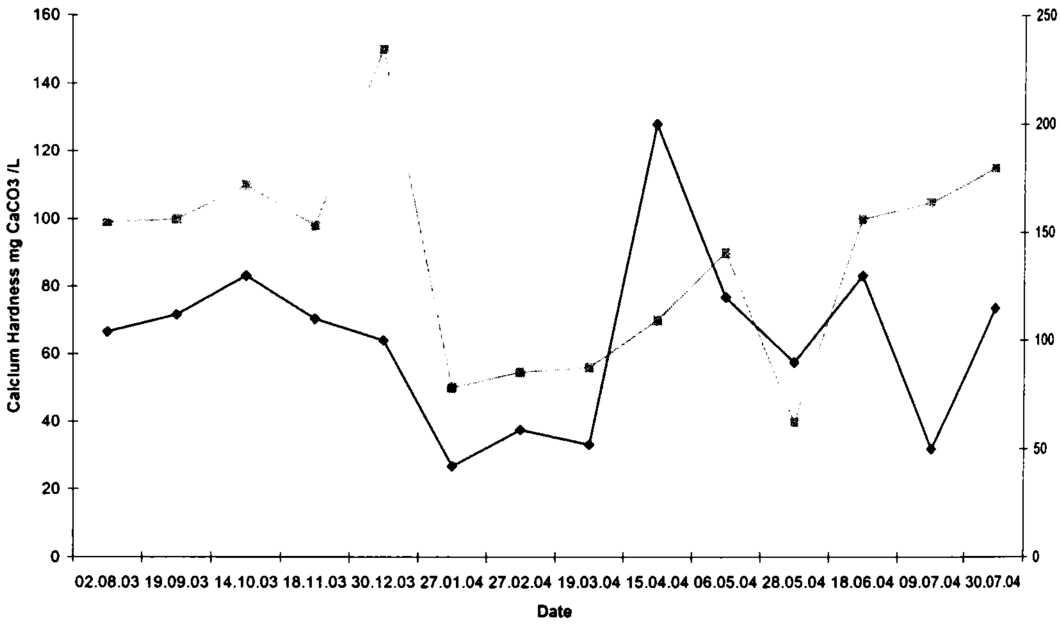


Fig 3.11 Temporal variation of Calcium Hardness concentration at various sampling points on Adimuri thod

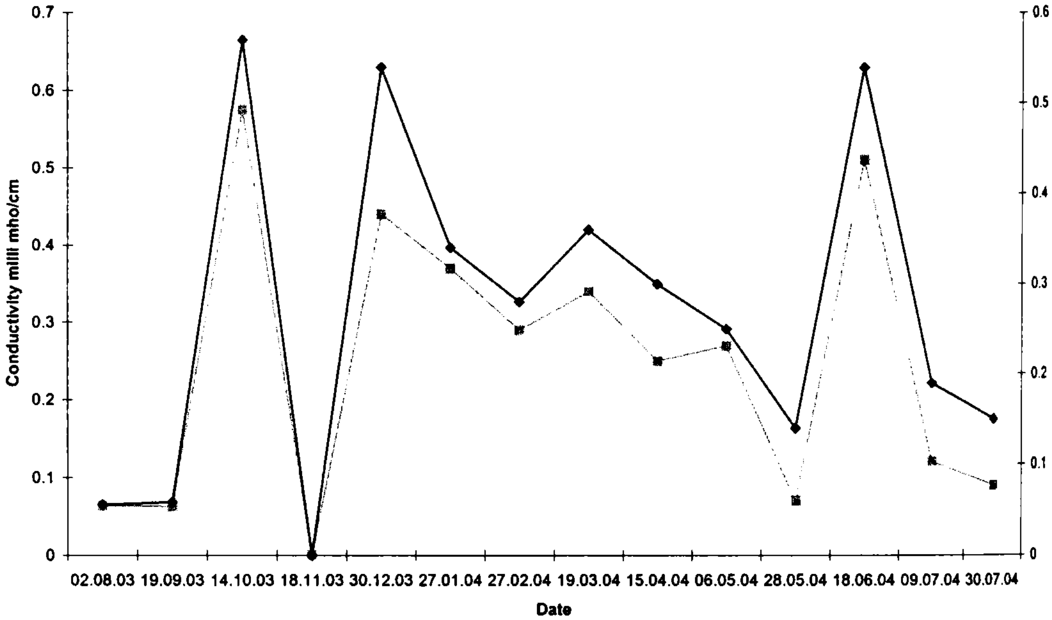


Fig 3.12 Temporal variation of Conductivity concentration at various sampling points on Adimuri thod

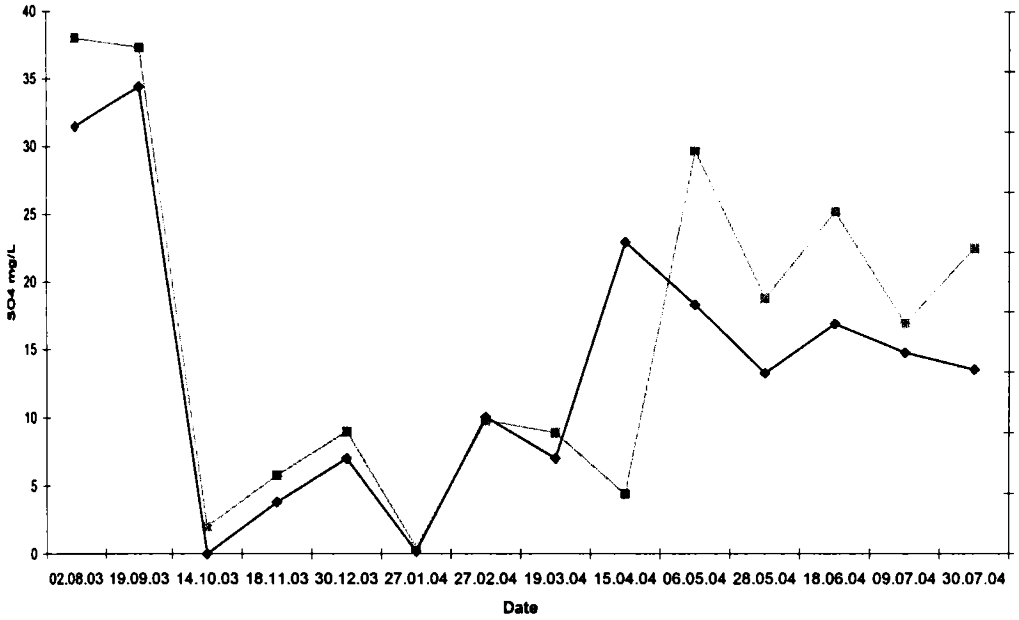


Fig 3.9 Temporal variation of Sulphate concentration at various sampling points on Adimuri thod

—■— Confluence —◆— Triveni road

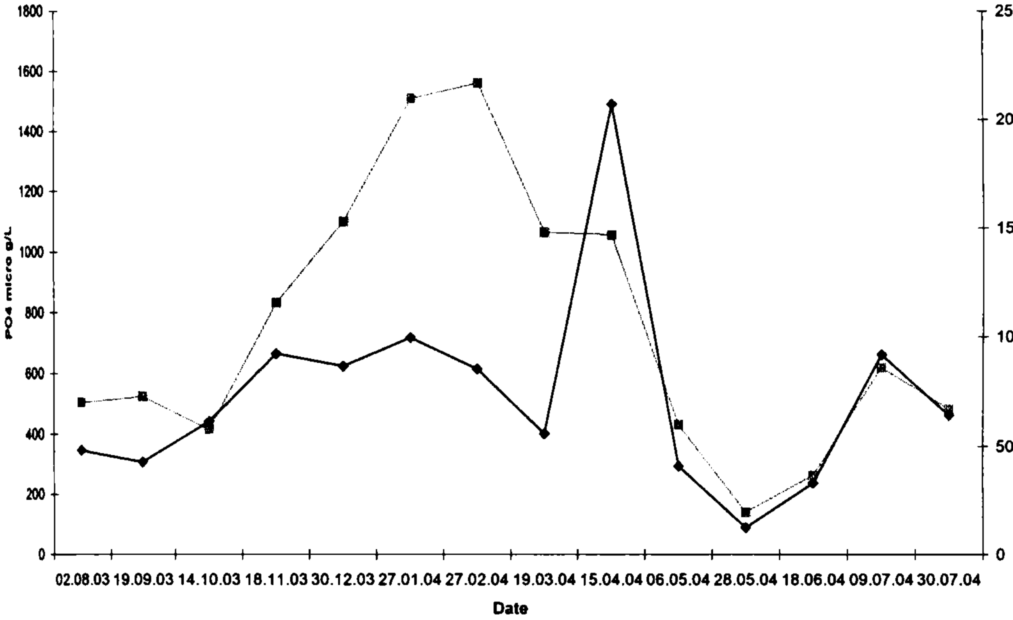


Fig 3.10 Temporal variation of Phosphate concentration at various sampling points on Adimuri thod

—■— Confluence —◆— Triveni road

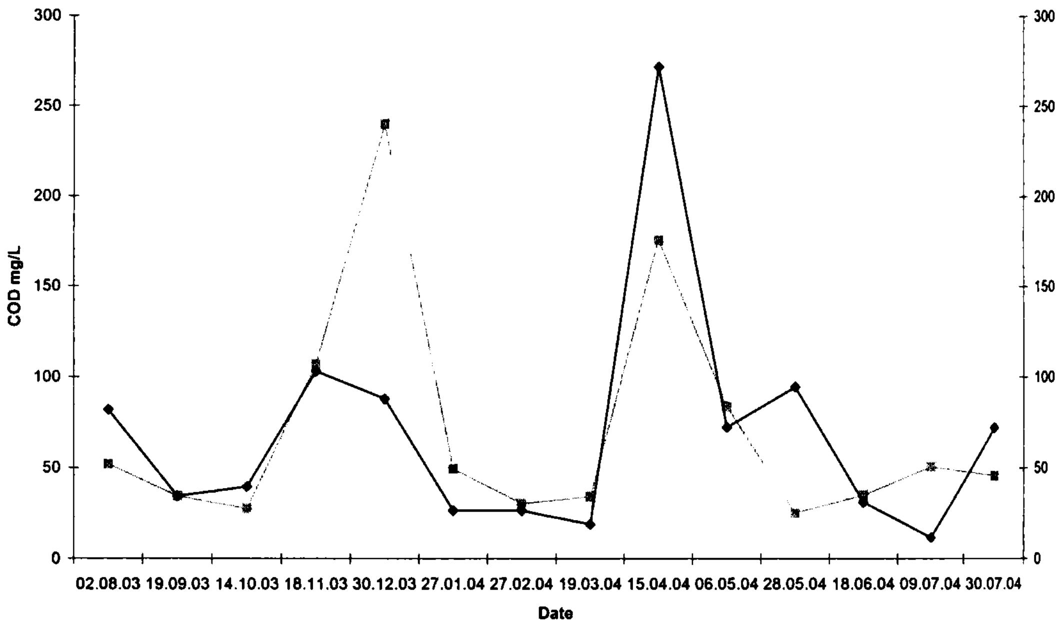


Fig 3.7 Temporal variation of COD concentration at various sampling points on Adimuri thod

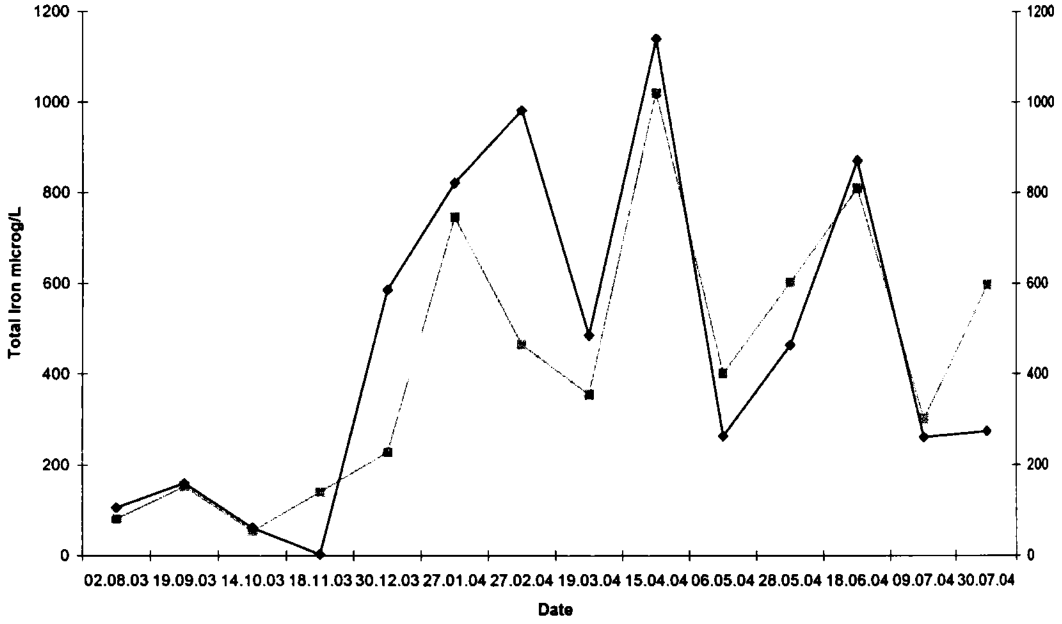


Fig 3.8 Temporal variation of Total Iron concentration at various sampling points on Adimuri thod

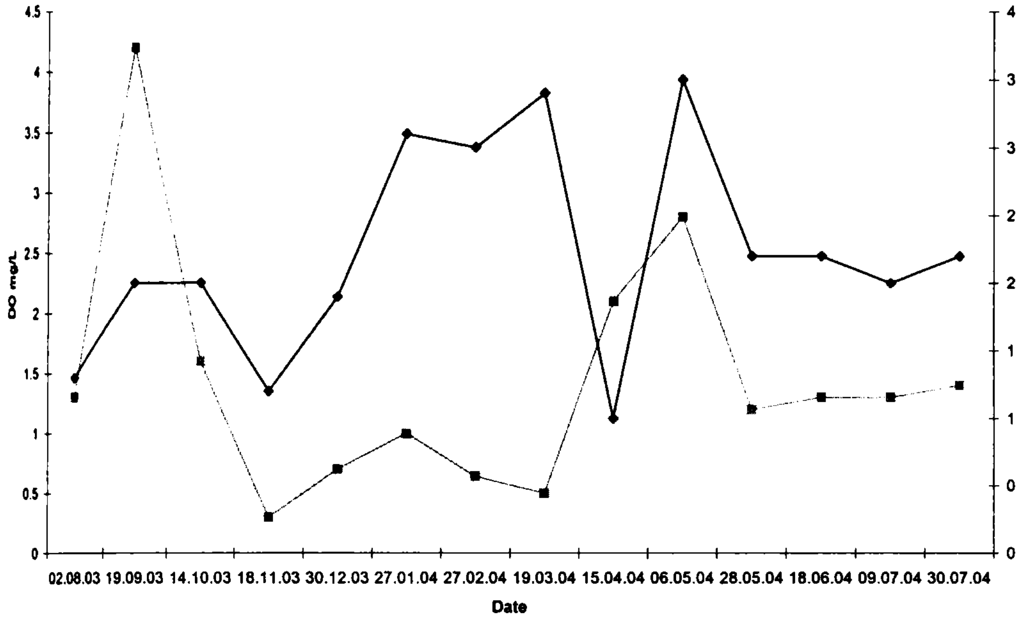


Fig 3.5 Temporal variation of DO concentration at various sampling points on Adimuri thod

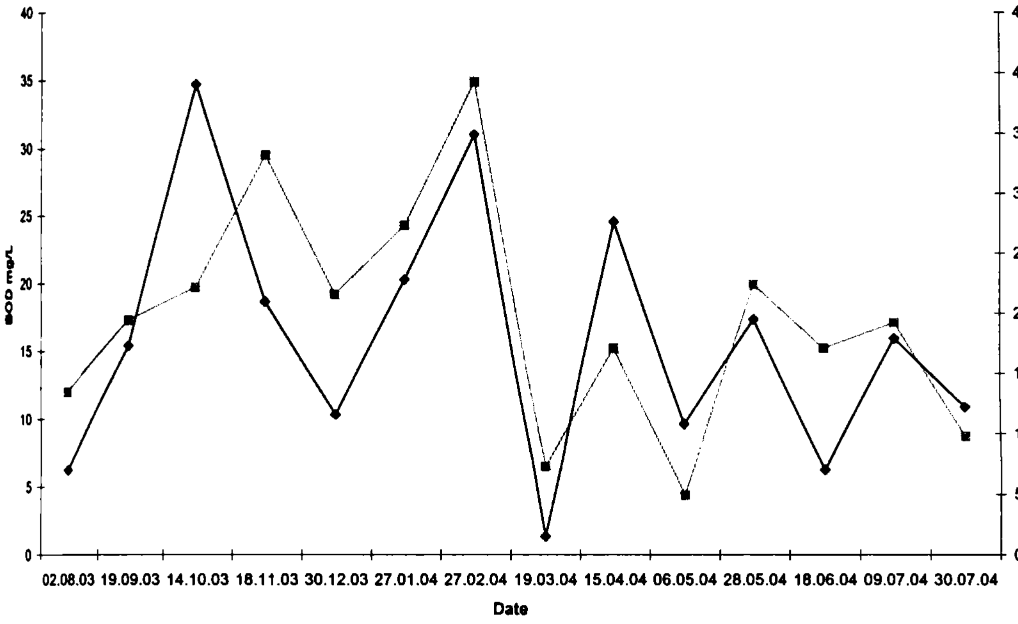


Fig 3.6 Temporal variation of BOD concentration at various sampling points on Adimuri thod

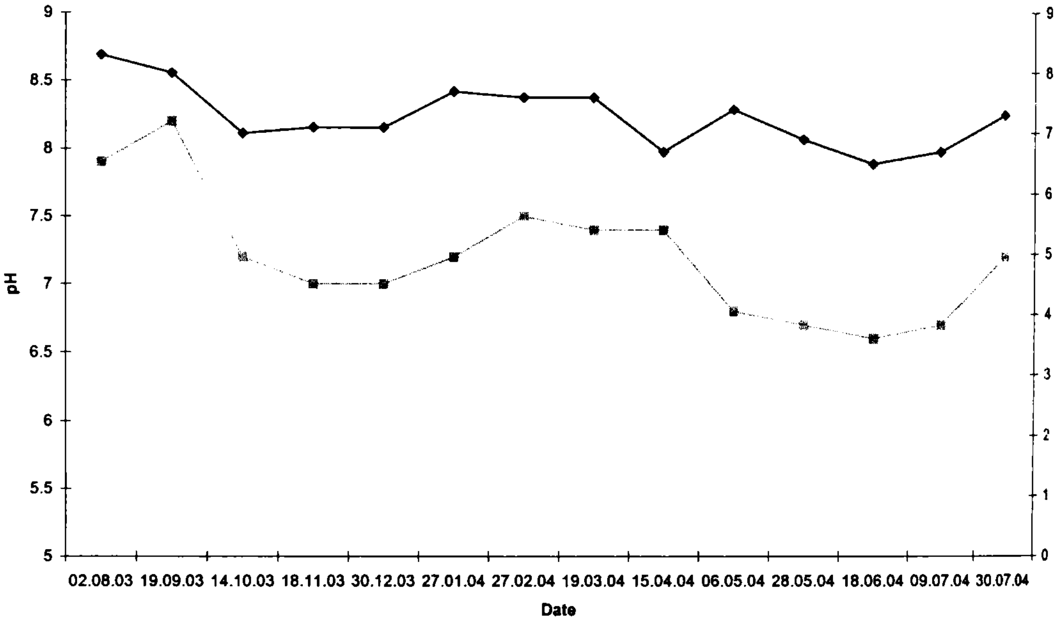


Fig 3.3 Temporal variation of pH at various sampling points on Adimuri thod

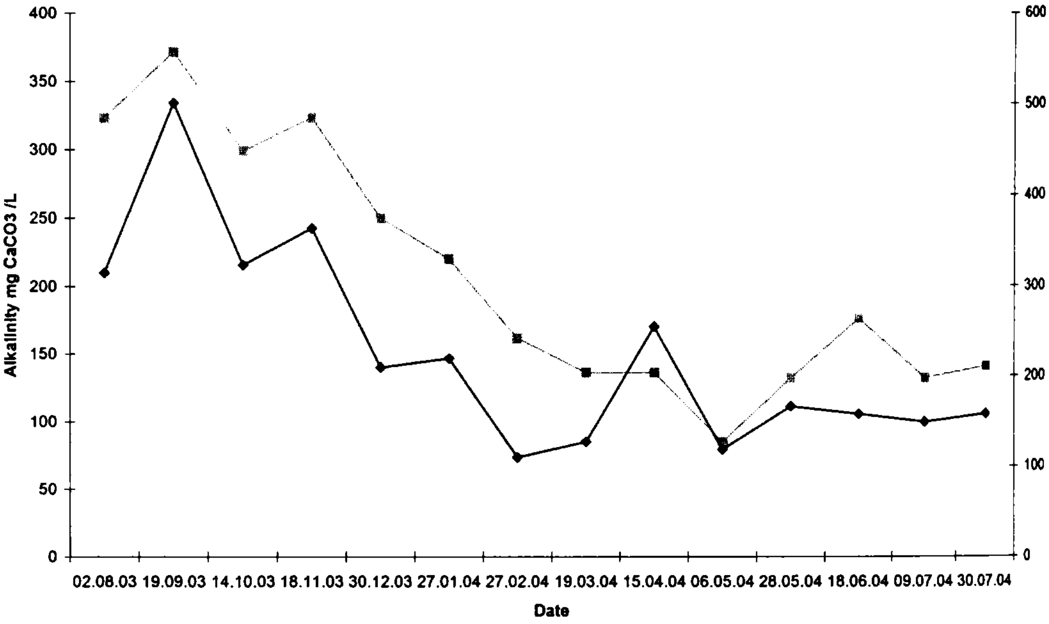


Fig 3.4 Temporal variation of Alkalinity concentration at various sampling points on Adimuri thod

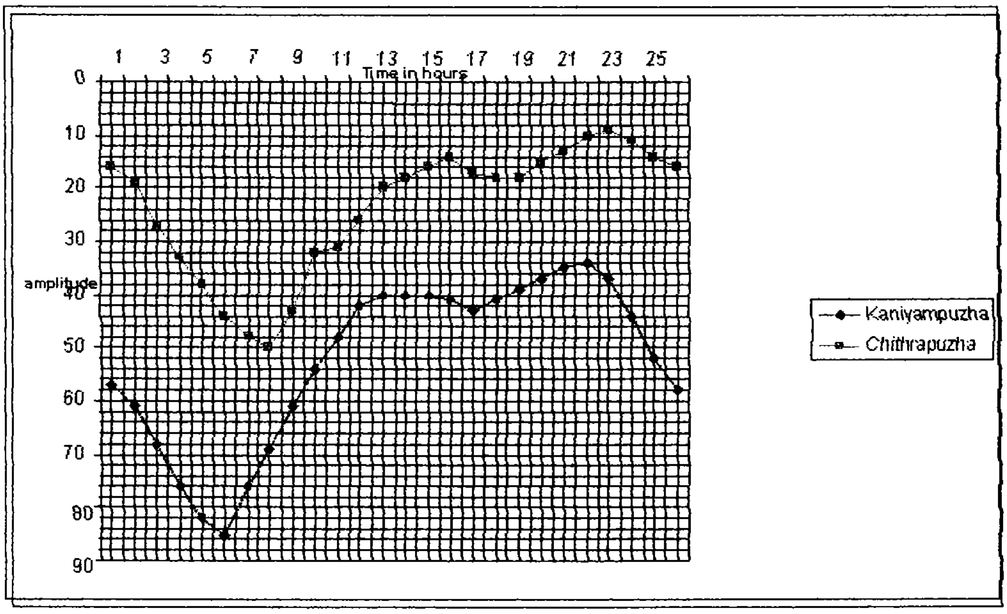


Figure 3.199 Amplitude variation across a tidal day at two sampling points on Chithrapuzha

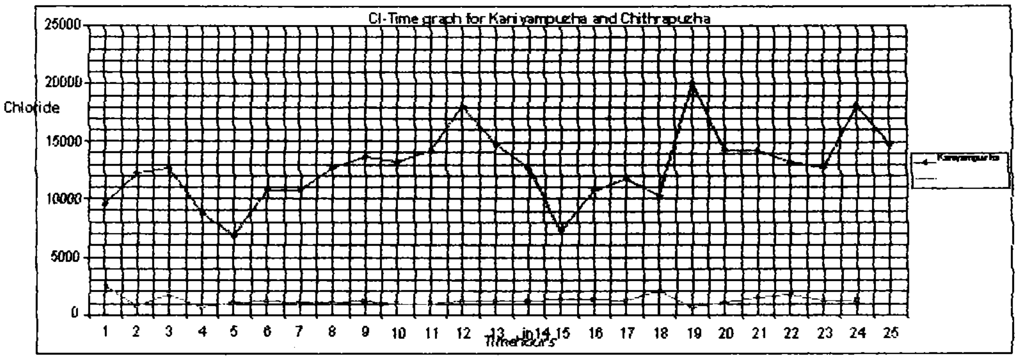


Fig.3.200 Amplitude Vs time graph of tidal variation at Perandoor

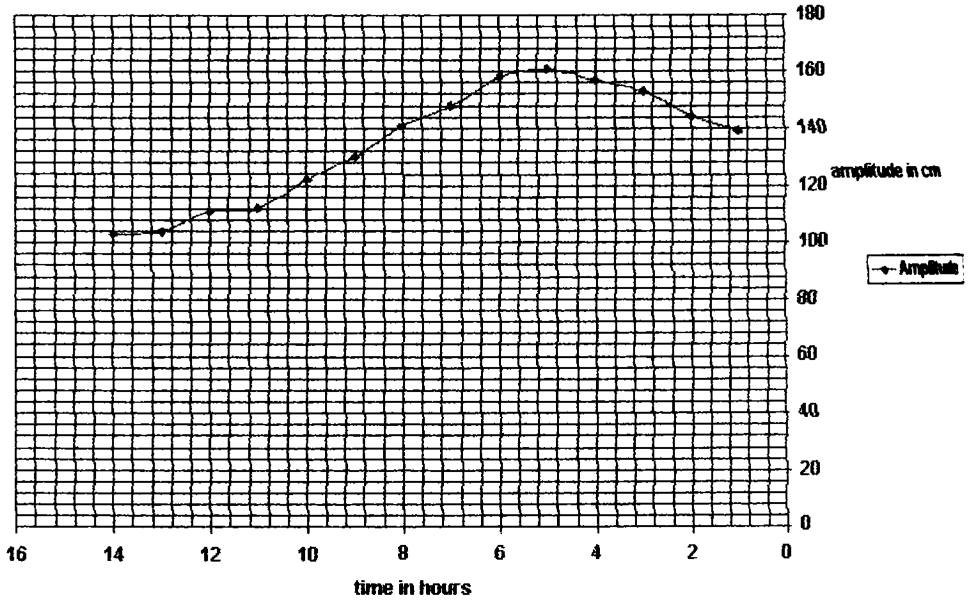


Fig 3.201 Amplitude Vs time graph of tidal variation at Perandoor

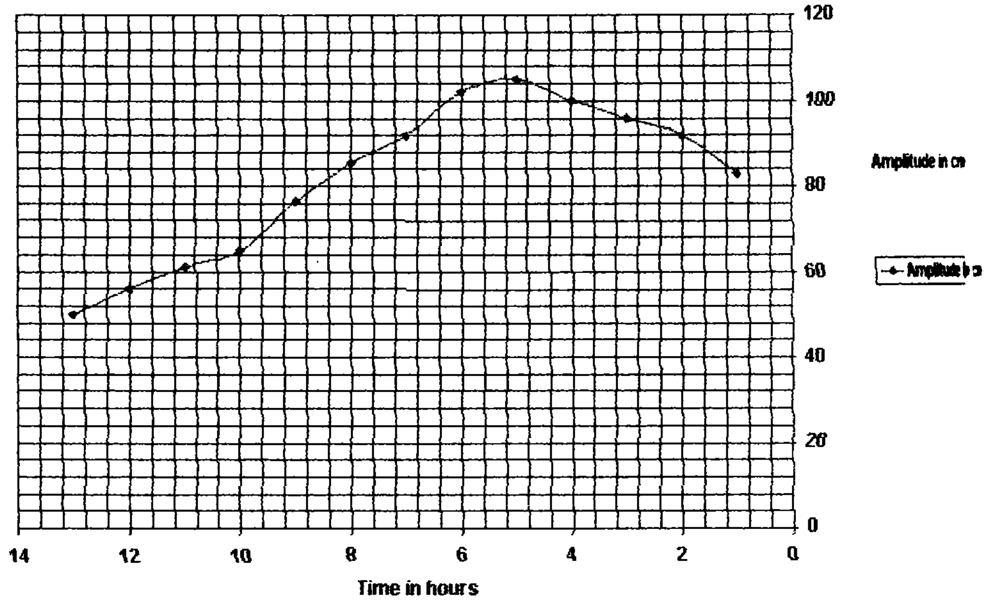


Fig.3.202 Amplitude-time graph (Chittoor)-Half day

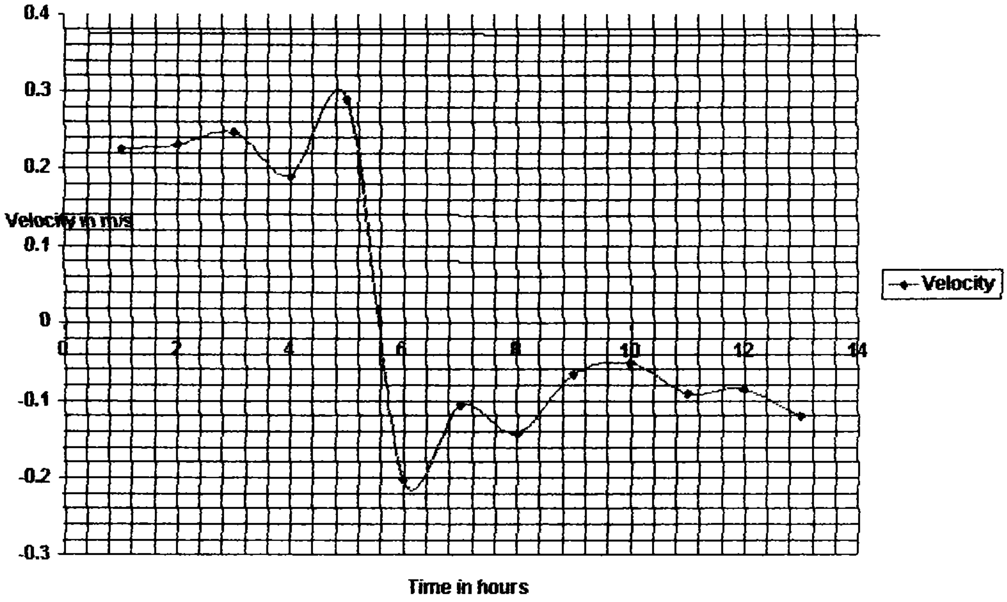


Fig.3.203 Velocity-Time Graph (Chittoor) Half day

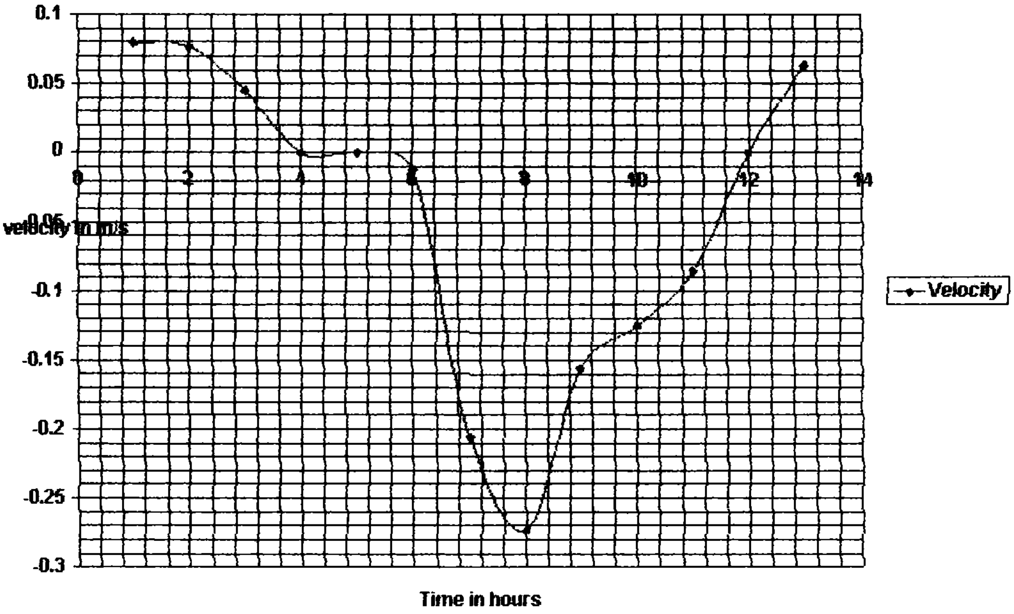


Fig.3.204 Velocity-time graph (Perandoor) Half day

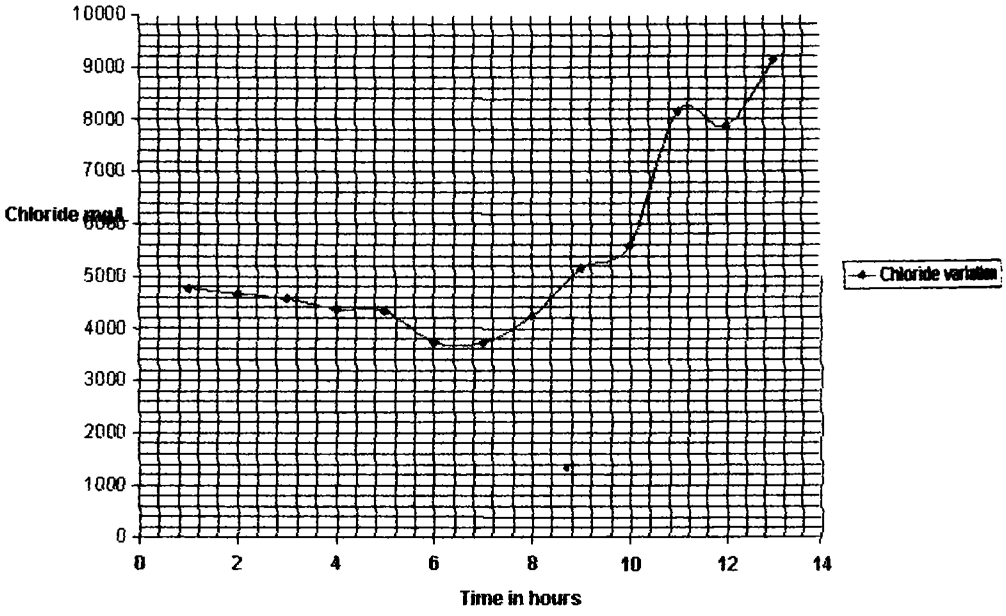


Fig.3.205 Chloride-Time Chittoor (Half day)

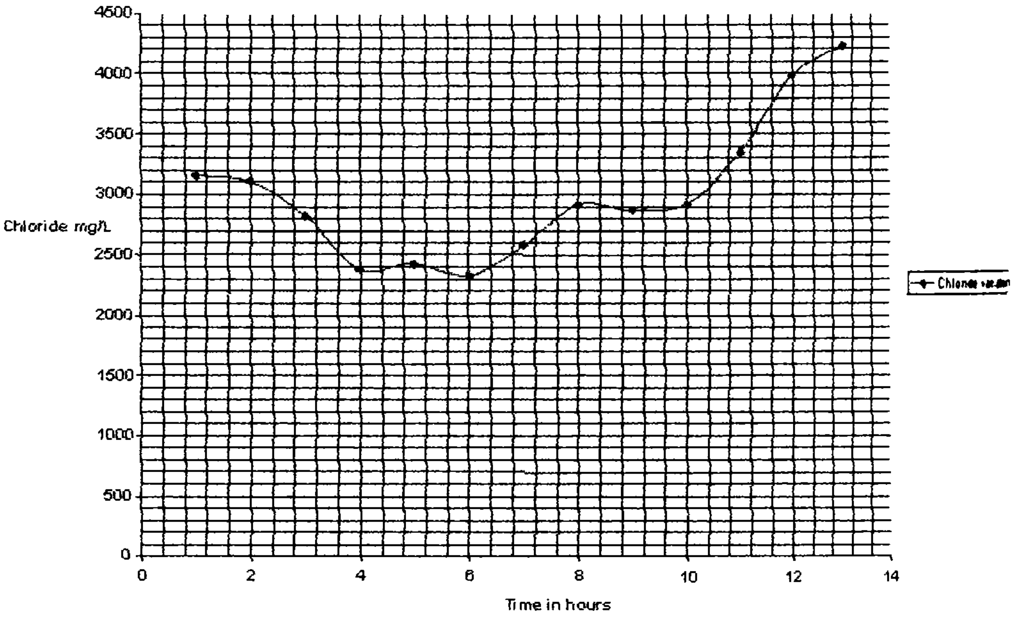


Fig.206. Chloride variation on Perandoor

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Chapter 4

SALT AND NUTRIENT BUDGET MODELLING OF CHITHRAPPUZHA

4.1 Introduction

Modeling is a powerful and important tool in science. Through salt budget modeling one can predict the degree and extend of mixing in the transition region. Thus the problem could be precisely defined before it occurs. One of the basic tenets of ecology is that matter entering a system has to find a place somewhere in the system, or should be ejected from that. This is true of the material inputs reaching an urban agglomeration. The material may undergo dispersion, concentration, elimination or transformation. Estuarine budget covers both organic matter and water balance from salinity intrusion, precipitation input and anthropogenic input. While studying the variation in the quality of water in the tidal canals this was kept in mind.

Many of the major estuarine water bodies on the coastal regions of the world have already been subjected to budget modeling in the lines laid down by ***Land Ocean Interaction in the Coastal Zone (LOICZ)*** (http://data.ecology.su.se/MNODE/). But a tidal canal (creek) at the stretch where it loses itself into the estuary has seldom been subjected to such an exercise. An essay to carry out LOICZ modeling on an urban tidal canal involves certain risks. Such canals, by nature, are shallow compared to full-fledged estuaries, coastal long-shore currents and upwelling of nutrients do not play any significant role in the exchange of water masses and nutrients, and they are particle-rich and often have a strong benthic - pelagic coupling because of their shallow nature. When the run off is strong nutrient budget modeling becomes less meaningful because of the unstable nature of the canals. But then, an essay to model Vembanad estuary *in toto* involves numerous challenges regarding quantification. For instance it is difficult to define the boundaries of an estuary in a complex wetland system. Its catchment area covers nearly 40% of the landmass of Kerala and half of the population (James, 1996). Nutrient inputs from this thickly-populated middle cross section of Kerala is not amenable to reliable quantification because of the sharp variations in topography, standards of living of the population, economic activities and land use pattern. On the other hand, a well-defined portion of a canal favours such an operation, its geometry being less complex and the morphology, activities and land use pattern of its catchment area being more uniform, defined and accountable.

4.2. LOICZ Modeling

Water and salt budgets are used to estimate water-exchange in coastal systems. Nutrient budgets are also developed, and departure of the nutrient budgets from conservative behaviour is a measure of net system biochemical fluxes (Smith, 2000). Non-conservative flux of dissolved inorganic phosphorus (DIP) scaled by an estimate of carbon-to-phosphorus ratio of the reacting material is used to estimate primary production minus respiration (p-r). The discrepancy between the observed non-conservative flux of dissolved nitrogen (DIN), scaled by the N: P ratio of the reacting organic matter, is used as an estimate of nitrogen fixation minus denitrification ($_{nfix}$ - $_{denit}$). While this is clearly a great simplification of the details of processes and reaction pathways in ecosystems, it provides some insight into possible net reactions accounting for nutrient uptake and release. This approach is preferred

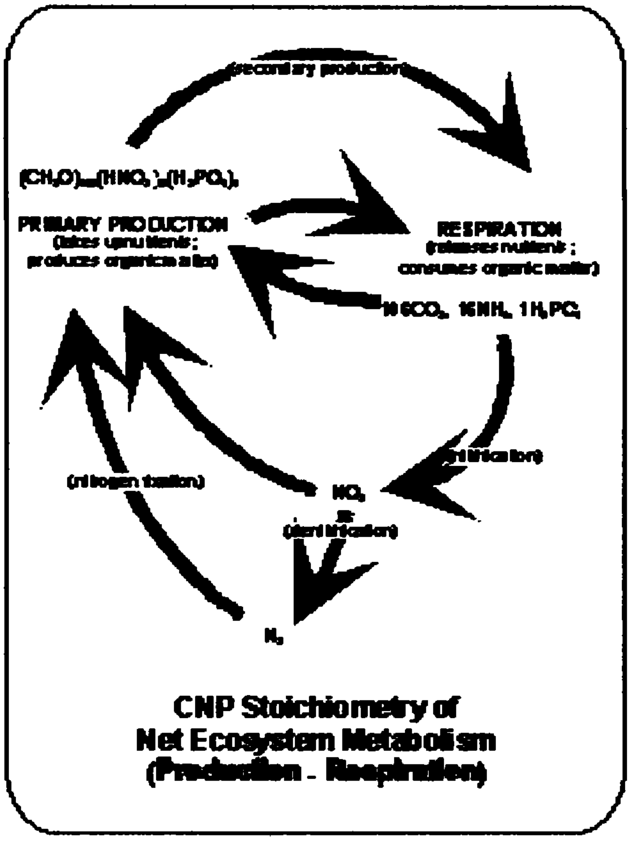


Figure 4.1 CNP Stoichiometry Of Net Ecosystem Metabolism

on estimates based on carbon flux because carbon data are available for relatively few systems. Similarly, direct estimates of production, respiration, nitrogen fixation and denitrification are difficult to obtain at system scales. **Figure 4.1** gives a schematic representation of CNP biogeochemical fluxes.

4.2.1 Definitions of key terms in LOICZ water budget modeling

4.2.1.1. Water fluxes

The water flux definitions provide the underpinning for the LOICZ budgetary analyses. These definitions are reported in Table (4.1). The justifications and derivations for these definitions of water fluxes, as well as the material fluxes that follow are given in Gordon *et al.* (1996) and on the LOICZ modeling web page (http://data.ecology.su.se/MNODE/).

4.2.1.2 Composition of various water reservoirs

S_{syst}, S_{surf}, S_{deep}, S_{ocn}, S_R (salinity of other water sources, although these are the only ones that are usually important). Units are usually reported as psu (practical salinity units), which are approximately equivalent to the older notation of parts per thousand.

Y_{syst}, Y_{surf}, Y_{deep}, Y_{ocn}, Y_R (Y composition of other water sources, as required, where "Y" is any budgeted material,. e.g. DIP). Units are most conveniently reported as mmol/m^3.

The subscripts "syst," "surf," and "deep" refer to average (1-box, 1-layer) system composition, and surface and deep (1-box, 2-layer) system composition. "ocn" refers to oceanic composition near the mouth of the system; if the ocean is locally stratified, this would be indicated by subscript. "R" is the system-ocean average composition, representing the composition at the mouth of the system. Other subscripts, including subscripts for multiple boxes, are assigned as needed and generally would follow the subscripts of the variables as reported in Table 4.1.

In general, the salinity of water sources other than those specified can be ignored in the water and salt budgets. By contrast, the composition of other Y's (notably the nutrients) are likely to be important should not be ignored in the budgets for these materials.

4.2.1.3 Material hydrographic fluxes

These are obtained as the product of the water fluxes (as given in Table 1) and the various compositions as summarized above. It is important to recognize that both flow and composition may vary in time and may be correlated. In the case of multiple discharges (e.g., multiple runoff terms into the same box), the compositions may vary significantly with the source. For these reasons, the concentration used should be flow-rate averaged. The convention that is followed is that positive flux is into the box or layer of interest and negative flux is from that box. Fluxes are reported as the product of flow rate and composition (e.g., river discharge of Y = V_QY_Q), or reported as a direct mass discharge (for example waste loading of Y as calculated from per capita waste production).

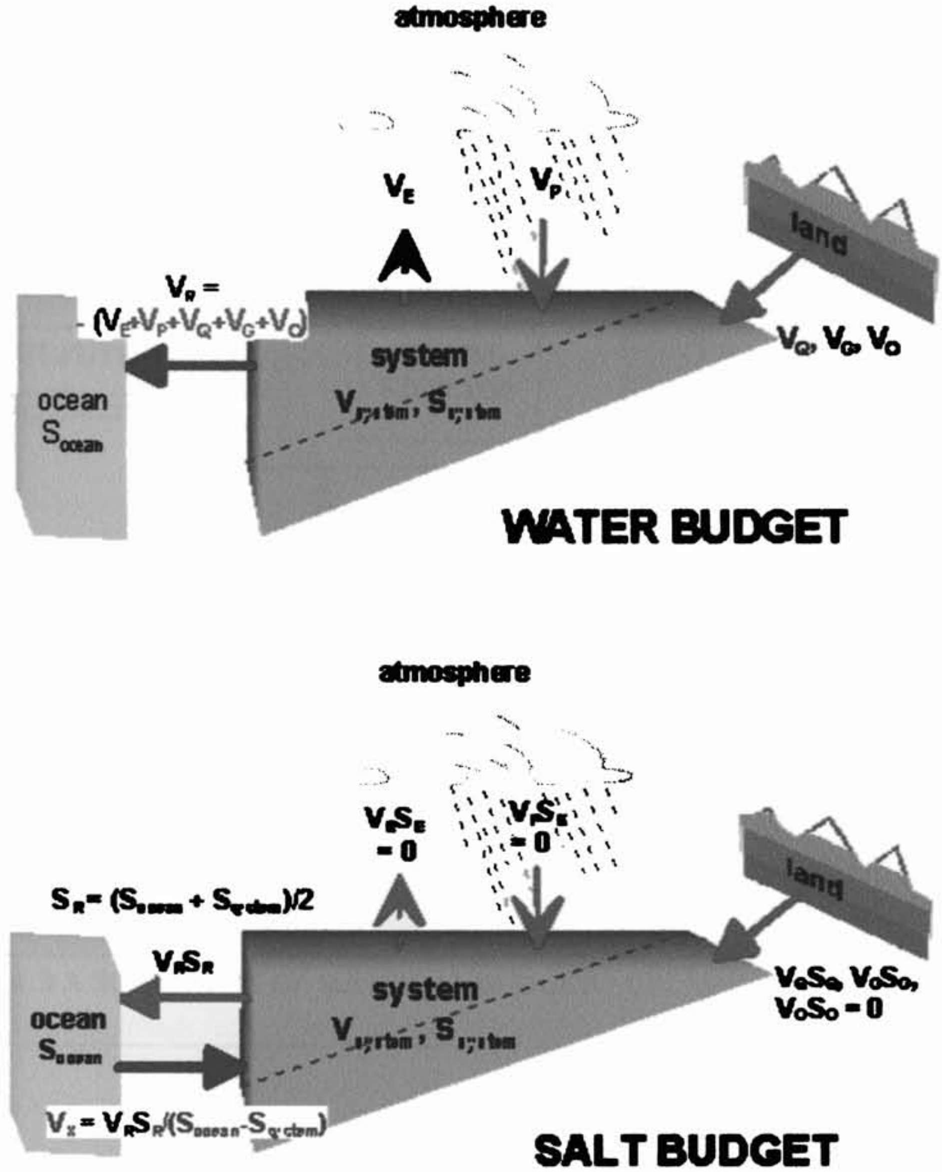


Fig.4.2 Water and Salt Budget According to LOICZ Scheme

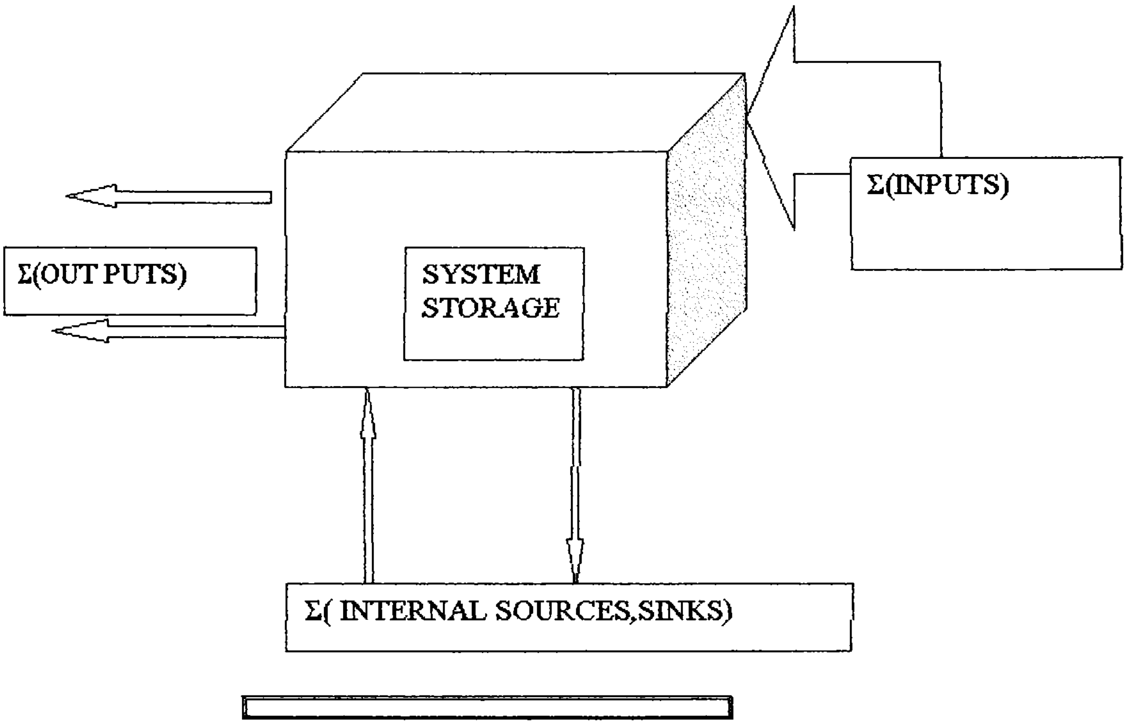


FIG: 4. 3 A SCHEMATIC OF MATERIAL BUDGET

In general, the salinity of water sources other than those specified is ignored in the water and salt budgets. By contrast, the composition of other Y's (notably the nutrients) is likely to be important and cannot be ignored in the budgets for these materials. Conservative fluxes of salt and water are shown in **figure 4.2**

The units of flux are most conveniently reported as g/L (for salinity) or moles/time for nutrients.

4.2.1.4 Material non-conservative fluxes

In the steady-state case, these are obtained as the difference between 0 and the hydrographic fluxes as described above. (**Figure4.3**) The notation Y is used for the nonconservative flux, where Y represents any material of interest. Within the context of most LOICZ calculations, the Y's most frequently examined are dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN = NO_3 + NH_4). If available, dissolved organic P and N (DOP, DON) are also examined.

While ignoring the salinity of water sources other than as-specified above is unlikely to cause significant errors in the water and salt budgets, this is not true for the nutrient budgets. Failure to account for significant fluxes of nutrients via runoff, waste load, etc. is likely to introduce spurious results for the nonconservative fluxes. The initial units follow from the hydrographic fluxes and are therefore most conveniently reported as moles/time. Because the data are used for comparisons among systems, it is usually useful to divide the initial units by system area, yielding mol length^{-2} time^{-1}.

4.2.1.5 Stoichiometric derivations from nonconservative fluxes

In order to gain insight into processes, two variables are derived from *DIP* and *DIN*.

The first of these is primary production minus respiration *(p-r)*, sometimes also designated as net ecosystem metabolism *(NEM)*: This is derived as –(C: P) $_{\text{part}}$ x *DIP*, where (C: P) $_{\text{part}}$ is the molar composition ratio of locally reacting organic matter. The assumption behind this calculation is that net system production or oxidation of organic matter is the primary nonconservative uptake (flux from the system, so -) or release (+) pathway for DIP within the system.

The second such derived variable is the difference between nitrogen fixation and denitrification *(nfix-denit)* and is calculated as DIN_{obs} - DIN_{exp}. DIN_{obs} is the observed nonconservative flux of DIN, and DIN_{exp} is the flux that would be expected if the only flux pathway were the production or consumption of organic matter with an N:P ratio represented by $(N:P)_{part}$. Thus: *(nfix-denit)* = DIN_{obs} - *DIP* x (N: P) $_{\text{part}}$. In general, the C: N: P ratio of plankton (C: N: P = 106:16:1) is used for both of the above calculations, although this ratio may be modified for systems for which more appropriate ratios are known. The assumptions behind these calculations are discussed at length in Gordon et al. (1996).

The initial units follow from the hydrographic fluxes and are therefore most conveniently reported as moles/time. Because the data are used for comparisons among systems, it is usually useful to divide the initial units by system area, yielding mol length^{-2} time^{-1}.

Table 4.1 gives the volume flux variables. The comments describe normal onditions. The comments may require modification to describe complex or unusual systems dequately. By the convention adopted here, positive flux represents flow into the system, ox, or layer of interest. In algebraic analysis of systems with multiple layers or boxes, this ign convention applies to the box for which the calculation is being made.

Variable	**Definition (units)**	**Comments**
V_Q	Runoff flow volume (length^3 time^{-1})	Sum of gauged or estimated stream flow into budgeted portion of system. Always a positive or 0 value; usually the dominant source of fresh water. Usually can be ignored in salt budget. May or may not be important in the material budgets, but should be considered.
V_G	Groundwater flow volume (length^3 time^{-1})	Sum of measured or estimated groundwater flow into budgeted portion of system. Always a positive or 0 value; usually a secondary source of fresh water and usually can be ignored in the water budget; may be important in the other material budgets.
V_O	Other flow volume (length^3 time^{-1})	Sum of other water discharges (particularly waste discharge) into budgeted portion of system. Always a positive or 0 value; usually a secondary

		source of fresh water and usually can be ignored in the water and salt budgets. If there is any inflow of V_O, it should not be ignored in the other material budgets.
V_P	Precipitation volume (length^3 time^{-1})	Obtained as precipitation (length time^{-1}) multiplied by surface area of system (length^2). Always a positive or 0 value. Can often be ignored in budgets, for both water and other materials.
V_E	Evaporation volume (length^3 time^{-1})	Obtained as evaporation (length time^{-1}) multiplied by surface area of system (length^2). Always a negative or 0 value. Can often be ignored in budgets, for both water and other materials.
V_Q	Net freshwater inflow volume (length^3 time^{-1})	An often useful generic term that includes the sum of V_Q, V_G, V_O, V_P, V_E. Will be positive, 0, or negative (in the case where V_E numerically dominates over the other terms).
V_R	Residual flow volume (length^3 time^{-1})	In single-box systems, this has a value that is equal in value and negative in sign to V_Q*. In multiple-box systems, it is important to keep track of the sign of V_R; flow **from** one box will be negative and represent positive flow **to** the next box.
V_X	Horizontal exchange volume (length^3 time^{-1})	In single-layer systems, this represents horizontal mixing between the budgeted system or box and the adjacent ocean, or between two adjacent

		boxes. V_X is always 0 or positive; any calculation generating a negative value contains some underlying error that must be addressed (e.g., bad algebra, violation of steady-state assumption, incorrect numerical values for salinity or other conservative tracer, incorrect values for contributors to V_{Q^*}).
V_s	Surface flow volume (length^3 time^{-1})	In two-layer systems assumed to have "estuarine circulation," this is the outflow from the surface layer to the ocean or adjacent box. It is the sum of V_R and V_d (defined below) in a two-layer, single-box system. It will have a negative or 0 value.
V_d	Deep flow volume (length^3 time^{-1})	In two-layer systems assumed to have "estuarine circulation," this is the inflow from the ocean or adjacent box to the box of interest. It is the difference between V_d and V_R in a two-box, single-layer system. It will have a positive or 0 value. In effect, V_d in a two-layer system is equivalent to V_X in a single layer system.
V_{en}	Vertical entrainment flow volume (length^3 time^{-1})	In two-layer systems assumed to have "estuarine circulation," this is the flow of water from the deep to the surface layer. It is equal to V_d in a two-box, single-layer system. It is negative with respect to the deep layer and positive with respect to the surface layer.

V_Z	Vertical exchange volume (length^3 time^{-1})	In two-layer systems, this represents vertical mixing between the surface and deep boxes. Like V_X, V_Z is always 0 or positive; any calculation generating a negative value contains some underlying error that must be addressed.
	Exchange time (time)	System volume divided by the sum of V_X plus the absolute value of V_R (in a single layer, single box system); or system volume divided by the absolute value of V_s in a single-box, two-layer system. For exact derivations in multiple-box systems, see Gordon et al (1996).
h ydraul	Hydraulic residence time or fill time (time)	System volume divided by the absolute value of V_Q*

4.2.2. Stoichiometric Analysis of CNP Budgets

In chemistry, "stoichiometry" is the study of the combination of elements in chemical reactions. Therefore the term "stoichiometric analysis" is used to describe this approach to budgetary analysis. The following sections outline the use of stoichiometric analysis to make rough estimates of biogeochemical processes from the comparison among fluxes of carbon, nitrogen, and phosphorus.

4.2.3. Organic metabolism and "net ecosystem metabolism"

Figure 4.1 illustrates generalized pathways of carbon, nitrogen and phosphorus cycling in response to organic metabolism. In general, pathways of organic production are shown in green, while respiratory pathways are shown in red. It is assumed, for this figure, that organic matter with the "Redfield CNP ratio" of 106:16:1 is involved in the reaction. This is probably an adequate description for plankton-based systems, but systems dominated by benthic organisms such as seagrasses, benthic algae, or mangroves may not be well-described by this ratio.

Important points to note on this diagram are as follows: First, organic matter production takes up these nutrients, while respiration liberates nutrients. LOICZ budgeting is largely designed to describe the role of ecosystem-level metabolism as a source or sink of P, N, and especially C, so the interest is largely in the *difference* between primary production and respiration. This difference is often called either "net ecosystem production" (NEP) or "net ecosystem metabolism" (NEM); the terms are equivalent.

Accepting the Redfield ratio as a representation of organic metabolism, the following general reaction is useful to describe the simplest aspects of organic metabolism. For simplicity in writing this equation, nitrate is taken as the dominant form of nitrogen being supplied to support primary production, and it is assumed that all nitrogen released during respiration is immediately converted from ammonium to nitrate. For the moment, the processes of denitrification and nitrogen fixation are ignored.

$$106CO_2 + 16H^+ + 16NO_3^- + H_3PO_4 + 122H_2O = \\ (CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 138O_2 \qquad \text{..............................}(1)$$

In its simplest form, this reaction proceeds from left to right during organic production (*p)* and from right to left during respiration (*r*). The difference between these two (*p-r*) is a measure of NEM. If organic matter of a composition other than the Redfield CNP ratio of 106:16:1 is being produced or consumed, the algebra of the reaction is adjusted to maintain a charge balance.

A second point is that even in the simple representation of metabolism illustrated by Figure 4.1, the nitrogen cycle is more complicated than the phosphorus and carbon cycles because of the side reactions of "denitrification" and "nitrogen fixation." these reactions are discussed in more detail below, but even this simple consideration of organic metabolism really needs to include these pathways. Denitrification converts nitrate (which is routinely measured) to nitrogen gas (which, in practice, is never measured), while nitrogen fixation converts nitrogen gas to organic nitrogen. Thus, these side reactions produce or consume the measured forms of nitrogen (sometimes called "fixed nitrogen") without altering the carbon and phosphorus. In some coastal ecosystems, these side reactions are quantitatively important (sometimes dominating) processes altering nonconservative nitrogen flux. Note that the additional process of "nitrification" is a side reaction which converts nitrogen from one form of inorganic nitrogen (ammonium, which is measured) to another (nitrate; also measured). This part of the N cycle is included for completeness.

Thus, the nitrogen cycle is very much more complicated than simple uptake of nitrogen into organic matter or liberation from organic matter. We can take advantage of this complexity by stoichiometric analysis. By contrast and with respect to the above cycle for organic metabolism, carbon and phosphorus simply move back and forth between dissolved inorganic forms and organic matter.

4.2.4. Nonconservative phosphorus flux and net ecosystem metabolism

One implication of the nutrient cycling as illustrated in Figure 4.2 is that phosphorus and carbon tend to "track one another" through the metabolic cycle, whereas nitrogen does not follow this track. It is assumed that the nonconservative flux of dissolved inorganic phosphorus (*DIP*) has been calculated from a budget. Phosphorus is essential for life, and in many marine systems, it can be assumed that net ecosystem metabolism (that is, the difference between primary production and respiration [*p-r*]) accounts for *DIP*. In detail, it is well understood that this is a great simplification of the phosphorus cycle, and the phosphorus is involved in inorganic reactions involving sorption—desorption and precipitation—dissolution. Nevertheless, these side reactions for phosphorus seem to be generally less quantitatively important for phosphorus than for either nitrogen or carbon in terms of net nonconservative fluxes of these three elements in coastal marine ecosystems. It was therefore decided that, in general, *DIP* was likely to be a useful general proxy for net ecosystem metabolism.

From equation (1)

If the system is a net producer of organic matter ([*p-r*] > 0), then DIP is taken up (DIP < 0)

If the system is a net consumer of organic matter, ([p-r} <0), then *DIP* > 0. It is seen that primary production (*p*) and respiration (*r*) taken individually will each be much larger than the quantity [*p-r*]. From a LOICZ perspective, though, [*p-r*] (or net ecosystem metabolism, NEM) measures the net role of organic metabolism in the system as a source or sink for C. If we know *DIP* and we can make an assumption as to the C: P ratio of the organic matter being produced or consumed, then we can make a rough, system-level estimate of [*p-r*]:

$$[p-r] = -\Delta DIP \times \left(\frac{C}{P}\right)_{part} \text{..(2)}$$

Where $(C/P)_{part}$ is the C:P ratio of the reacting particulate material. In general, the Redfield C: P ratio (106:1) is probably an adequate representation of $(C/P)_{part}$. In systems where a more specific estimate of this ratio is available (e.g., seagrass-dominated systems, where the ratio is likely to be ~300:1, or higher), a system-specific ratio can be used.

Only DIP is used in the calculation of [*p-r*]. Dissolved organic phosphorus (DOP) is also present in the aquatic environment and may be produced or consumed. However, the production or consumption of DOP is one of the possible sinks or sources accounting for DIP.

One might argue that more direct measures of [*p-r*] would be *DIC* or O_2. A problem with such a use of *DIC* is that this variable includes several processes other than organic C metabolism. In the case of O_2, there may be significant intermediate oxygen sources (i.e., alternative oxidation pathways) such as sulfate reduction which are not reflected in an O_2 budget. For both CO_2 and O_2 gas exchange may be sufficiently large budgetary terms to compromise "direct" budgeting to derive organic C metabolism. As a result of these considerations, the recommendation of the LOICZ Modeling Guidelines is to use *DIP* and equation (1) where possible as a proxy for net ecosystem metabolism. This analysis is important within the context of LOICZ, because a major question for LOICZ and all other parts of IGBP is the evaluation of the various components of the Earth system in the global carbon cycle.

4.2.5 Nitrogen metabolism and net nitrogen fixation minus de-nitrification

. It is assumed that a budget is available to define the non conservative flux of nitrogen—and preferably that this flux is available for NO_3 + NO_2, NH_4 (these grouped together here as dissolved inorganic N, DIN), and dissolved organic N (DON). These components of N may be referred to as "dissolved fixed N," to distinguish them from dissolved gaseous N. Dissolved gaseous N, dominated by N_2, is almost never measured in water, because the concentrations are both large and almost entirely controlled by the solubility of atmospheric N_2 in water. We may refer to this N of dissolved fixed N as the observed value, that is, N_{obs}. Net organic metabolism, as discussed above, is an important pathway for non-conservative fluxes of dissolved nitrogen. Note that DON is organic matter, so the production and consumption of DON is related to NEM.

An equation similar to equation (2) can be written to describe the expected amount of nitrogen (N_{exp}) taken up and released with the dissolved phosphorus flux:

$$\Delta N_{exp} \equiv (\Delta DIN + \Delta DON)_{exp} = (\Delta DIP + \Delta DOP) \times \left(\frac{N}{P}\right)_{part} \text{..........................(3)}$$

In this equation DON and DOP are considered along with DIN and DIP in order to allow for possible conversions between organic and inorganic forms of these materials. It is preferred to have data on DON and DOP, but usually these data are not available. In such cases, it can only be assumed that the non-conservative fluxes of these dissolved organic materials are small.

More importantly, there is often a large difference between N_{obs} and N_{exp}, and this difference is an indicator of processes other than organic metabolism which alter fixed N. Nitrogen fixation and de-nitrification are likely to be important pathways for non-conservative nitrogen flux in many marine systems, so this difference is taken as a measure of net nitrogen fixation minus de-nitrification ([*nfix-denit*]):

$$[nfix - denit] = \Delta N_{obs} - \Delta N_{exp} \text{(4)}$$

In the LOICZ context, this estimate is important. Coastal sediments can be important sites of de-nitrification, and some coastal environments are important sites of nitrogen fixation. It thus appears that the coastal environment may be important in the global nitrogen cycle, yet relatively few sites have been studied adequately to characterize this role. This

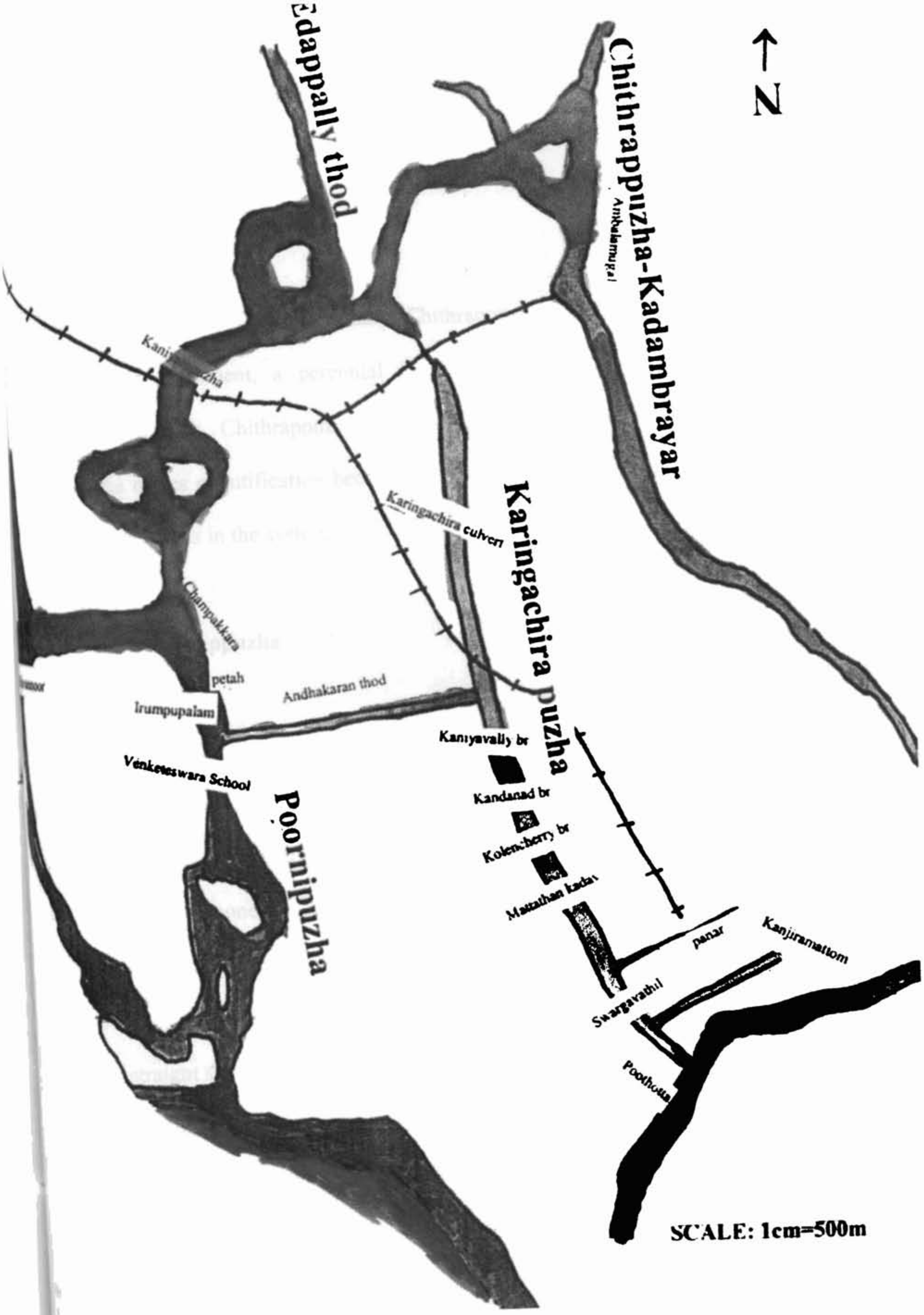


Figure 4.4 **BUDGETED STRETCH OF CHITHRAPPUZHA**

budgetary analysis will help build our understanding of the role of the coastal zone as a source or sink for fixed nitrogen.

4.3. The study area

Two tidal arms of Cochin estuary, Chithrappuzha and Chittoorpuzha are endowed with a definite catchment, a perennial fresh water flow and are subject to serious anthropogenic impacts. Chithrappuzha is treated separately hereunder. The water regime of Chittoorpuzha defies quantification because of the influx of fresh water from Periyar when the base flow slackens in the system.

4.3.1 Chithrappuzha

This rivulet lies on the eastern part of the city and rises in the largely agricultural regions of Puthencruz-Kolencherry villages (**figure 4.4).** Kadambrayar, another stream rising in the northeastern undulations joins Chithrappuzha at Brahmapuram. Agricultural runoff is a major component in both the streams. From a chain of major industries on this stretch, including petroleum, fertilizers and insecticides, Chithrappuzha receives to the order of 33, 600 m^3 per day (KSSP Report, 2002). The stream merges with Poornipuzha, a tidal arm running straight south, at Champakkara. There is inter-basin transfer of water during the dry summer months, as water from Bhoothathankettu is diverted to the stream to ward off the invading salinity. Water is pumped from Muvattupuza river at the rate of 100,000 m^3 per month to cater to the needs of the chemical industries of Ambalamugal–Karimugal belt. This water also reaches the canal. Huge investments are down the line in the Kadambrayar basin as CEPZ, KINFRA and Techno Park are setting up various industrial activities. The geometry of the tidal portion of the stream is not the way nature would have had it. Vertical bunds have been built on either side of the stream to contain water and to facilitate constructions on the river bank, and most part of the tidal stretch has rectangular cross section. The channel spends itself into Champakkara canal and proceeds to the estuary. There is regular barge service on this canal to take industrial chemicals to FACT. Low-key fishing takes place in the upper reaches and the catch is not promising enough to sustain this as a serious industry.

The climatic conditions of the study area can be divided into two; the wet season from late May to early December and the dry season from late December to early May. But such watertight division is not practical as there are freak dry and wet spells in between. The tidal range varies from 0.30 to 1m at the Champakkara end of the canal and gradually diminishes upstream. The tidal body demarcated for the salt and nutrient budget modeling is the stretch between Chlilavannoor kayal, Petta Bridge, the tidal arm of Edappally thod up to Attippetty Nagar and Brahmapuram confluence. The whole length of the canal sums up to 25.1 km and the drainage basin that this stretch receives runoff from spreads to the east, north and south to an area of 216 km^2, the volume of the system is 2938950 m^3 and its surface area is 1206460 $m^{2.}$

The hinterland is predominantly an agricultural region, the staple crops being rubber, paddy and coconut. Alternate rolling hills and wet valleys make up the landscape. There are no appreciable urban agglomerations in the dendritic drainage basin. The predominantly rural agricultural hinterlands have high standard of living and remarkably high literacy levels (Census Report, 2001), quite unusual in the Indian context. But the entire state depicts a picture of urban-rural continuum and the urban-rural divide in many respects is not sharp and conspicuous. The villages are not connected to any sewage system and depend largely on individual septic tanks; hence the sole source of pollution from the drainage basin is agricultural runoff, with a contribution from on-site sewage disposal proportional to population. Whereas in the city, the raw sewage is discharged straight into the canal. In many of the thickly populated housing colonies, anticipating the planned large-scale sewerage system, cistern type of sewage disposal was resorted to as an interim arrangement. These cistern pits often overflow, particularly in the rainy season, with the ensuing health hazards. In other areas conservancy system or septic tank system is followed which was essentially evolved to suit rural areas (Benjamin, 1998).

The sewage effluent contains phosphate concentration averaging 1.8 mg/L and nitrate concentration of 0.2mg/L. The budgeted section however, is in a remarkably urbanized and industrialized region. The average depth of the water body is maintained constant for regular barge service, except for segments where sidewalls have not been built. Salinity intrusion begins in early December but never crosses the threshold needed to wipe out the pestering fresh water vegetation beyond the Irumpanam stretch. The nutrient loadings are primarily from industrial discharges and urban runoff. The estuary is maintained navigable all through the year up to FACT jetty and is part of the National Water Way. The mount of phospho-gypsum waste heaped up by Fertilizers and Chemicals Travancore Ltd (FACT) is partly washed out into the canal and imparts a white turbidity to the water from time to time. .

Data on salinity and nutrients (DIP, DIN) were collected from eighteen stations along the course, on a monthly basis, six along the fresh water stretch, nine along the budgeted portion and three at the estuarine end of the canal. Surface samples alone where collected from all sampling sites, since the water body is too shallow for deep water samples in the fresh water stretch, and in the budgeted course, the mixing is very effective owing to continuous barge service.. Monthly budgets were calculated from the data so generated. The rainfall in this area is seasonal and 90% of the rainfall occurs between June and November.

4.4. Procedure for LOICZ budgeting and results

The part of the water body targeted for budgeting has modified bottom geometry due to engineering modifications. A major part of the canal has concrete embankments and the space in between is maintained at 44.5 m. The central core of the canal with a width of 17.5 m is scoured regularly so that a more or less constant depth of 4.2 m is maintained throughout to facilitate the movement of barges carting industrial commodities to Ambalamugal. The dredging and the turbulence induced by the movement of barges bring about regular mixing in the water column and hence natural tendencies of stratification promoted by the increased depth, is obliterated effectively. The core of the canal has a trench-like feature and the 17.5-m wide trench is flanked by shallow shoulders slopping gently from 60 cm along the embankment to 3 m along the brink of the trench. The trench-like middle groove turns rotund and gently tapering in between the dredging bouts, which happen once in two years or so. This information was obtained by regular observation during the monitoring trips and measurement of the bottom geometry. The violent mixing and the scouring at the bottom alter the sediment characteristics, which would otherwise have reflected in the chemistry of the water column.

The quantification of the water regime becomes complex because of the inter-basin transfer of water for industrial purposes and the periodic diversion of water from Periyar Valley Irrigation Project (PVIP) to the canal to ward off migrating salinity. Water is pumped from Muvattupuzha River at the pumping station at Ramamangalam at the rate of 100,000 cubic meters per month. It could be assumed that this water in a denatured state ultimately ends up in the creek.

Table 4.2 Measured variables of the study area during 2003-2004

Month	Precipitation (mm)	River runoff(m^3)	Average AirTemp.° C	Computed monthlysurface runoff (m^3/month)	Monthly Evaporation rate(mm)Ref.IMD Pune 1971
June	580	83230000	26	16646000	98
July	461	58488500	26.1	11697700	99
August	455	58488500	26.1	11697700	104
September	158	7837135	27	1567427	107
October	447	58488500	27.3	11697700	108
November	56	169690	27.5	33938	107
December	40	169690	27.5	33938	125
January	35	169690	27.5	33938	133
February	11	BDL	27.7	BDL	132
March	13	BDL	28.8	BDL	157
April	155	7837135	28.6	1567427	156
May	985	166993935	28.8	33398787	124

Run off was computed using the relation $Vq= 1000Ar[\exp(-e_0/r)]$

Where $e_0= 1.0*10^9\exp(-4.62*10^3/T)$

Vq= monthly run off in m^3

A= area of the water shed in km^2

T= Temperature on degree Kelvin

R=Precipitation in mm/month

(http://data.ecology.su.se./MNODE/methods/runoff.htm)

Trippoonithura Municipal town is located on a sand bar flanked by a swale on the east, which links to Chithrapuzha and Poornipuzha on the west. It could safely be assumed that one half of the sewage from Thrippoonithura Municipality is discharged to Karingachirapuzha. The other half reaches Poornipuzha whose flow oscillates in tune with the hydraulic gradient between the northern and southern extremities. Thus half of the sewage load reaching Poornipuzha ends up at Champakkara. Hence one quarter of the sewage output is assumed to end up in the canal being studied. Nearly all the families in the urban area depend on individual closed septic tanks and hence faecal waste directly entering the water body is very less. A good share of the urban liquid waste enters Andhakaran thod before proceeding to Karingachirapuzha and Poornipuzha. Because of unfavourable gradient, water remains trapped in Andhakaran thod and gradually diffuses into the rivers with decreased BOD and DO due to the curing it undergoes in Andhakaran thod. As agricultural activity is no more a serious business, agricultural run off is assumed negligible

The contribution of precipitation and evaporation in salt and nutrient budgets is negligible. No salt enters the water body through precipitation and no salt is lost through evaporation. It is assumed that rain water contains no phosphate. Studies held elsewhere corroborate this assumption (de Sousa, 1977). Nitrate input through precipitation is neglected, but studies held in Goa indicate that rain water contains nitrate in the range of 0.3 to 3.8 micro moles and practically no phosphate (de Sousa, 1977).

Water, salt and nutrient budgets have been computed following the LOICZ Biogeochemical Modeling Guidelines (Gordon *et al.* 1995). The surface runoff was calculated based on the monthly temperature and rainfall data for Cochin using the relationship given at (http;//data.ecology.su.se/ MNODE/Methods.runoff.htm) which is an empirical formula developed by Schreiber, (1904).

Table 4.3 spatially averaged measured variables for above the budgeted stretch

The river above the budgeted stretch				**Along the budgeted stretch**			**Estuary below the budgeted stretch**		
Month	Salinity g/L	DIP mol/m^3	DIN mol/m^3	Salinity g/L	DIP mol/m^3	DIN mol/m^3	Salinity g/L	DIP mol/m^3	DIN mol/m^3
June	0.01	2.5	9.2	0.06	20.2	17	2.4	11.3	7.1
July	0.01	0.4	9.2	0.1	18.8	14	1.4	5.4	7.1
August	0.04	1.5	7.1	0.16	23.4	14	2.7	17.8	14
Septem.	0.22	9.5	NA	0.98	23.8	32	14.7	10.0	NA
October	0.01	8.5	5	0.25	20.8	16	13.9	1.7	NA
Novem.	0.13	11.8	7.1	4.9	29.6	21	11.6	4.5	14
Decem.	0.08	4.6	9.2	6.5	10.9	56	19.6	0.3	11
January	0.74	0.2	7.1	10.6	27.1	40	25.5	5.0	35

February	0.02	0.01	392	11.7	31.5	37	27.1	4.6	10
March	0.02	0.1	25	12.8	50.6	42	27.3	4	21
April	0.01	0.84	21	6.9	84.7	36	25.5	9.3	21
May	0.02	3.6	7.1	0.4	16.9	85	6.8	8.6	21

The nutrient input from anthropogenic activities has remarkably altered the natural regime of non- conservative components. The DIP load of each month from urban activities is in the range of 509468 moles P per month irrespective of the season, which is comparable to the natural inputs. Overwhelming predominance of anthropogenic waste load eclipses the influence of natural contribution. Anthropogenic nutrient input was calculated from the relationship prescribed by San Diego–Mc Glone *et al.*, (1999) based on the studies by Sogreah (1974) Padilla (1997), World Bank (1993), WHO (1993) and Valiela (1997)

. The nutrient input from urbanization shifted the center of gravity of the nutrient budget exclusively to urban contribution. Had it not been for the anthropogenic nutrient input the system would have become a consuming one all through the yea. The net ecosystem productivity obtained was remarkably high. High productivity is plausible given the riotous outgrowth of benthic vegetation and floating weeds, but the values obtained during the productive dry months are impossibly high. In plankton-based systems, primary productivity is typically 8 to 80 mol C /square meter/year. Usually Net Ecosystem Metabolism (NEM) which is p-r is equal to 0.1p. In systems which receive extreme loads, either inorganic sewage nutrients or labile organic matter p-r can be 0.25 p (LOICZ Rules of Thump, 2000). In the budgeted stretch, net ecosystem productivity was found to be well beyond this range during the initial dry months. But in systems dominated by benthic organisms primary production rates are 2-3 times the upper limit for plankton. In LOICZ nutrient budget modeling carried out at other sites in India, the estimation of waste load based on specific economic activities was not considered.

The popular detergent brands are being switched over to phosphate-free technology using zeolites in lieu of sodium phosphates as builders. Phosphates from detergents are on the decline worldwide. At its peak, phosphates from detergents in the USA contributed around two thirds of phosphorus in sewage, but it is now less than 50% (Toy and Walsh, 1987). In Europe, it is only 10%, and human and animal wastes are more significant (Imperial College, 1994). Hence theoretical contribution of phosphate from detergents incorporated in the model has tilted productivity to a hyperbole. The contribution of groundwater on salt and nutrient budgets was not included because of the difficulties involved in quantifying the same in low-lying flat terrain. In any case, its influence is marginal compared to cultural discharges.

Cultural pollution has altered the whole attributes of nutrient regime. The water body is not productive at all for most part of the year. At this rate, the canal is a source of P all around the year but from December to March through January and February. Does this P concentration get reflected in the sediment chemistry? Large-scale deposition of P is very likely because pH is above 7 along the tidal stretch during the dry months. Biological removal of P should be treated with some caution because the persistent mat of floating vegetation often thwarts algal assimilation of P. And Redfield Equation, which was relied on to quantify net ecosystem productivity rate and net nitrogen fixation rate, on the assumption that in algae the ratio between C, N and P is 106: 16:1, does not apply to tropical aquatic weeds. DIP and DIN levels of the sediments have been analyzed and the results thereof are discussed below. DIN is not easily lost to the sediments because of high solubility. In the arger Cochin estuary downstream, a recent estimate shows that in spite of receiving 42.4x 10^3mole/day of inorganic phosphates and 37.6x 10^3mole/day of inorganic nitrate from the Periyar side of the estuary alone, the export to the coastal waters is only 28.2x10^3mole/day of inorganic phosphate and 24x10^3mole/day of inorganic nitrate (Hema Naik, 2000). Thus the larger estuary is a sink of nutrients through out the year. The fate of the accumulated nutrients in Cochin estuary is subject to intelligent speculations. A study held at National Institute of Oceanography, Cochin sheds some light into it. South coastal waters of India have special importance due to the formation of mud banks during southwest monsoon months. It is indicated that there exists a subterranean flow from Cochin estuary that supplies primary nutrients to the adjacent coastal waters and pre condition it for rich primary production.

4.5 Conclusions

The tidal canals unlike the estuaries are less resilient and are sensitive enough to respond promptly to environmental changes. During the rainy season the water body is not stable enough to fix the nutrients as the water fleets past. The larger estuary, on the other hand, is more stable and functions as an environmental flywheel. In large estuaries water has retention times stretching into weeks and months and thus they facilitate carbon fixation as algae can get established. During the dry months the tidal canals function more or less as stable mesohaline tidal arms and primary production could become a prominent environmental activity. After March afternoon vernal showers flush out the apparently hyper productive tranquil phase.

As the tables make out the stoichiometric interpretation of the water body shows that it is a productive one with an incredibly high rate of C fixation during the dry months and also during the inter monsoonal lull of August and September. The NEM ranged between 23.2 and 40 mole C/m^2. In contrast the primary productivity in the Mandovi estuary, Goa, during pre-monsoon, monsoon and post-monsoon seasons were found to be 1.42, 0.66 and 2.7 mole C/m^2/month (Quasim 1990).

Table.4.4 Results of the Budgeting exercise: Monthly variation of Net Ecosystem Productivity and Nitrogen Fixation on Chithrappuzha

Month	*DIP. (mole/month)*	NEP(moles of C / m^2/month)	$DIN_{observed}$ (moles of N / meter^2 / month)	DIN expected (moles of N / meter^2/mont)	$DIN_{observed}$ $\mathrm{DIN}_{expected}$(moles of N / meter^2 / month)	Retention Time (Days/Hours)
June	1429469	-125.6	-1.8	+18.6	-20.4	13.7hrs
July	681323	-59.9	+2.8	+9	-6.2	18.7hrs
August	110230	-97.5	-2.7	+14.7	-17.4	19hrs
September	-399592	+35	NA	-5.3	NA	5.4dys
October	474799	-41.7	NA	+6.3	NA	19.4hrs
November	-458917	+40.3	-3.1	-6	+2.9	36dys
December	-494690	+43.4	-3.1	-6.5	+3.4	42.5dys
January	-465921	+40.9	-3.1	-6.1	+3	39dys
February	-468673	+41.2	-3.1	-6.2	+3.1	49.2dys
March	-439899	+38.6	-3.1	-5.8	+2.7	48.2dys
April	657646	-57.7	-2.9	+8.7	-11.6	4.5dys
May	2319713	-203.8	+10.8	+30.7	-19.9	6.7hrs

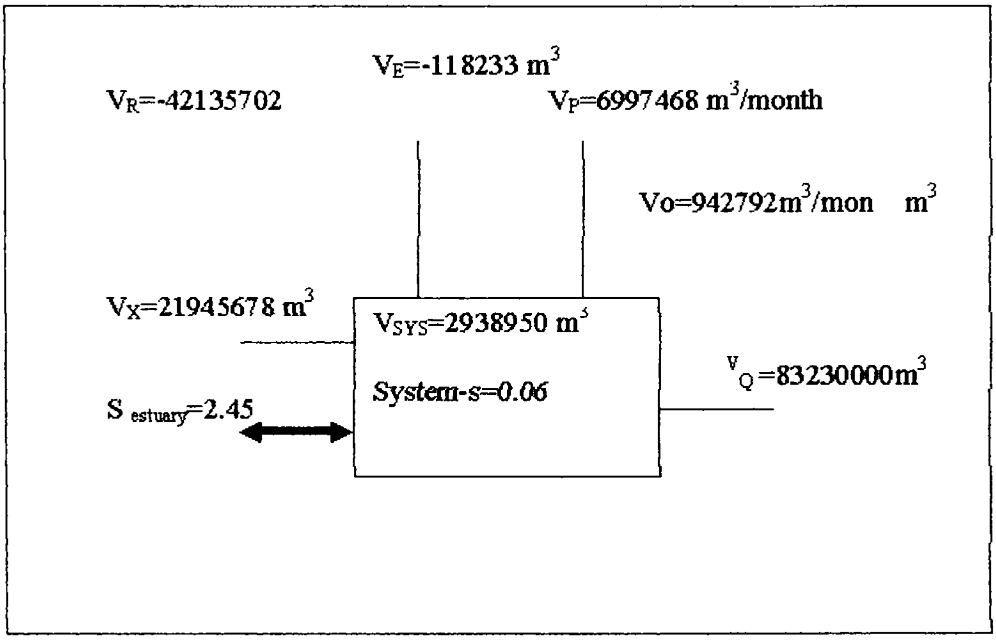
The corresponding values for Bay of Bengal at the mouth of the Ganga is 0.76 mole C/m^2/month and Arabian Sea at the mouth of the Indus is 1.4 mole C/m^2/month (Walsh, 1988). The net ecosystem productivity for the target area appears remarkably low and even negative for most part of the year in spite of the influence of anthropogenic nutrients.

NEM obtained during the dry months when sewage and marine salts steadily rise in the system are well beyond the theoretical limits. For a plankton dominated marginal marine environment this value is unacceptably on the higher side. Rules of Thump in Coastal Nutrient Budgets(http://data.ecology.su.se/MNODE/Methods/rot/thump.htm) states that primary production never crosses 8-80 mole C/m^2/year as indicated by DIP consumption. Systems dominated by benthic organisms may have primary production rates 2-3 times the upper rates for plankton. And (p-r) is never out side the range of 0.25p. But the values obtained in the present study for the months of sluggish river run off, cross this limit. Guidelines for the estimation of waste load given by San Diego-Mc Glone (1999) argue that 25% of the effluent from economic activities reaches the water bodies. But in the local circumstances where the impervious surface is very less and drainage systems are scanty and even non-existent, much less portion apparently ends up in the water bodies The impossible values obtained indicate that DIP has sub routes other than biological. The DO levels recorded during the deceptively productive phase do not support augmented photosynthetic activity. It is to be surmised that a major part of P accumulated is lost to the sediments when pH is above 7 and calcium-magnesium concentrations are on the rise.

Interpretation of nutrient ratios was initially applied in the open ocean by Redfield 1934) and further elaborated on by Redfield *et al.* (1963). Boynton *et al.* (1982) suggested hat when inorganic N:P ratios for a variety of estuarine systems are interpreted, atomic ratios ess than 10 indicated N limitation and ratios greater than 20 indicated P limitation. In the

Fig 4.5

Salt and Water budget in the month of June, 2003. Fluxes in m^3/month, salinity in g/L



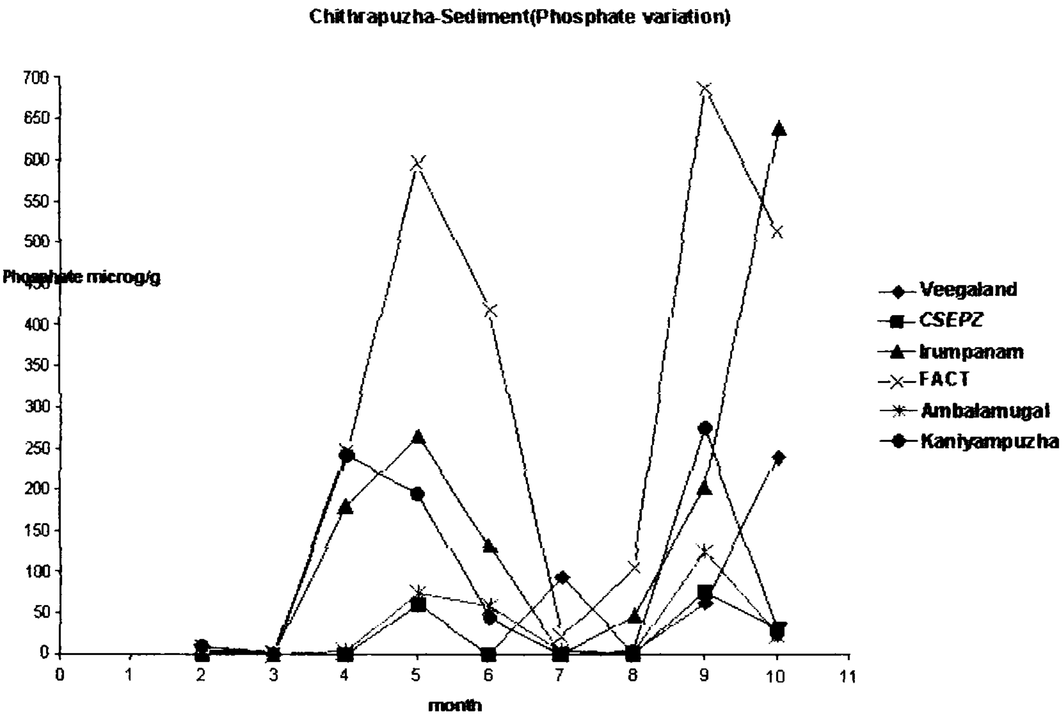


Fig 4.9 Temporal Variation of Phosphate concentrations at various sampling gpoints on Chithrappuzha

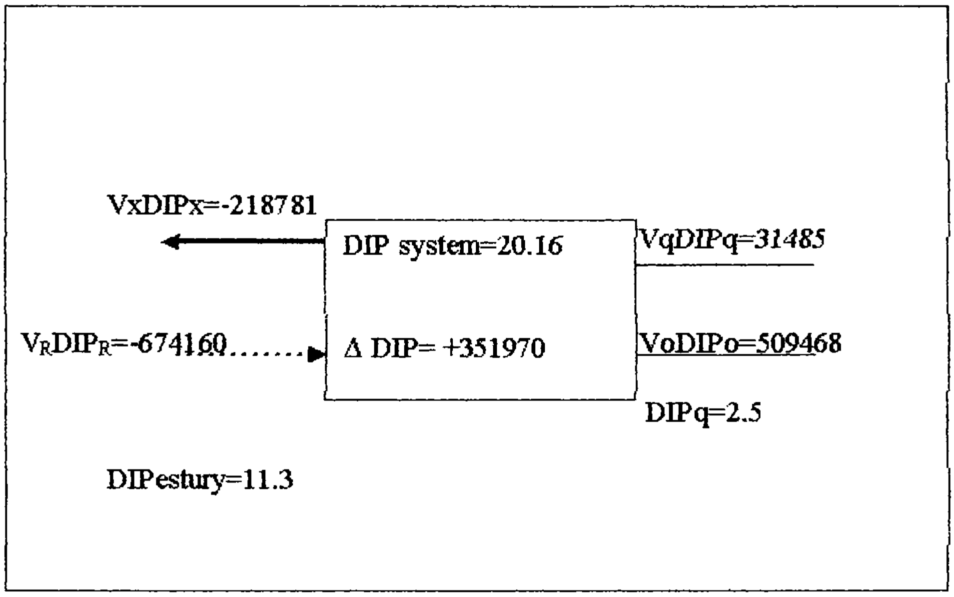


Fig. 4.6. Dissolved inorganic phosphate budget in the month of June. Fluxes in mole /month and concentrations in mole /cubic meter. Delta DIP in mole /month VoDIPo= 509468 is constant in all months.

above study conducted in 28 different estuaries across the globe the N: P ratios ranged between 1 and 240. But in the budgeted tidal arm of Cochin estuary, the ratio was always less than 5. Hence in Cochin tidal arms, P is not a limiting factor as far as algal growth is concerned and N holds the key to algal biomass variations, when other environmental parameters remain the same.

The system is a source of nitrate during the productive summer months. The nitrate budget is overwhelmingly influenced by the anthropogenic discharges from sewages and industrial wastes. Industrial and urban wastes have dwarfed other sources of nitrate. The exchange rate is rather fast from May to October excepting September and water is renewed in less than a day. During the dry months, flushing rate is naturally less and the flow becomes languid in February with a detention time of 49.2 days. Long detention time implies that the system becomes conducive to photosynthetic activity as floating primary producers can get established. This fact is substantiated in the results. It is evident that in unstable tidal canals productivity is dependent upon residence times; there is no carbon fixation when residence time is less than 5 days. But the computed NEM is far off the realistic values because of the substantial abiotic sub routes. Hence in small and unstable tidal canals LOICZ modeling does not appear to be a reliable tool. The fact that DO does not get a fillip during the dry months proves that photosynthesis is not as pronounced as it is revealed by the computation. When the flow becomes sluggish, DO stoops to the lowest levels but the water body does not become truly anoxic. Long detention time results in the accumulation of sewage in the canals and it is reflected in the chemistry of the water samples.

Figures 4.5 to 4.7 illustrate the salt-water DIP and DIN budgets for the month of June on the budgeted portion of the canal. Figures 4.8 and 4.9 show the temporal sediment variation pattern at various sampling points on Chithrappuzha.

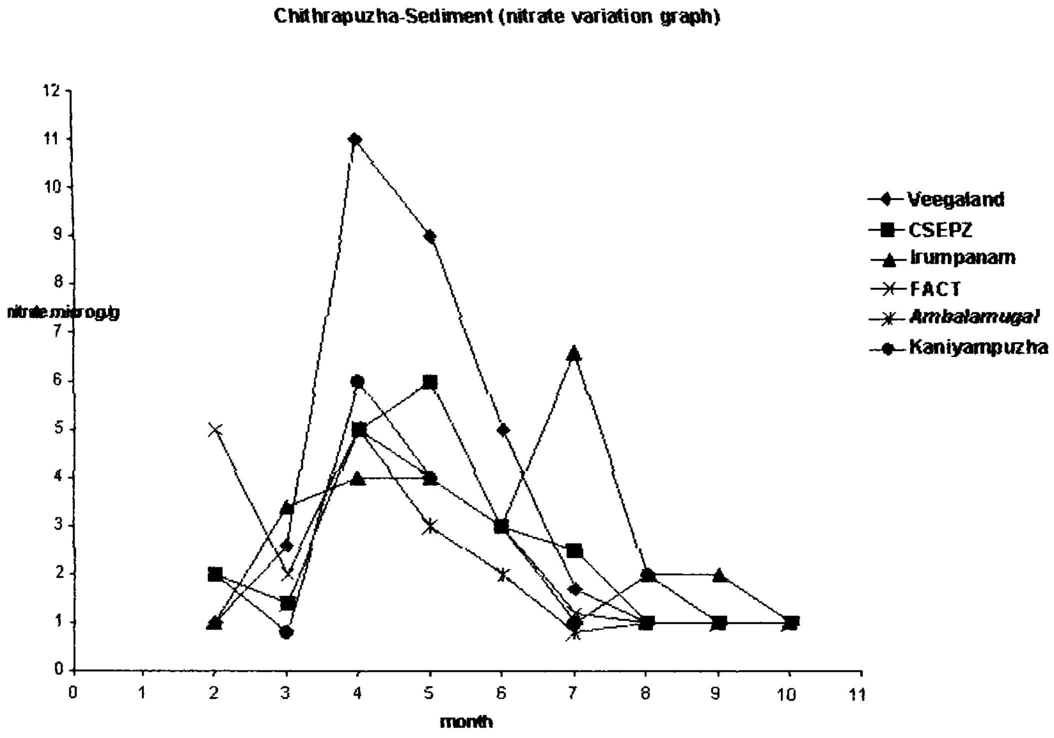


Fig 4.8 Temporal variation of nitrate at various sampling points on Chithrappuzha

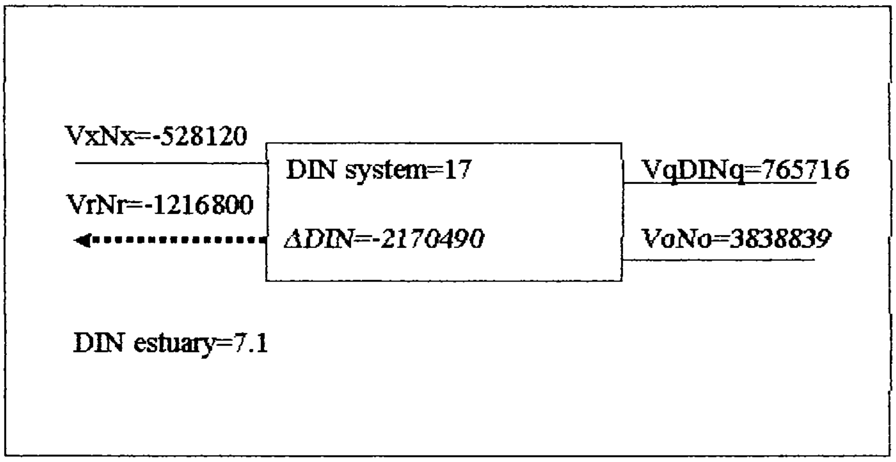


Fig.4.7.
Dissolved inorganic nitrogen budget in the month of June. Fluxes in mole /month and concentrations in micro mole /cubic meter. *Delta DIN in moles /month. VoDINo =3838839* moles' is constant for all months.

CHAPTER 5

Chapter: 5

WATER USE IN THE TIDAL CANALS- MANAGEMENT OPTIONS

5.1. Introduction

If the concentration of salinity alone were the deciding factor in judging the utility of a tidal canal as a fresh water source, the magnitude and duration of salinity along various stretches of the tidal bodies would have to be spelt out. Because of psychological reasons, the chances of relying on these sewage-laden canals to be availed as a drinking water source are too far-fetched, and drinking water qualities these canals do not either comply with. According to the standards laid down by KSPCB (1997), waters with conventional treatment can have chloride levels up to 600mg/L. There are times when several stretches of canals fall within this category but the current environmental status demotes them in the context of a drinking water source. Other lesser utilities include irrigation, construction activities, flushing, washing, recreation (contact and non-contact), industrial cooling, fishing etc.

Salinity intrusion, as such, is not an economic disaster to be averted at any cost. It is nature's way of helping to do away with the accumulated pathogens, pollutants and weeds. The practice of placing temporary bunds prevents effective tidal exchange and movement of pollutants into the estuary. Instead of annual catharsis, the trapped pollutants further deteriorate the water source. The increased pollution load undermines whatever utility the water body has as a fresh water source. Albeit the poor quality of water in the major tidal canals, it could still be availed for flushing the lesser canals of the interior during the dry months.

Want of sufficient DO is the most crippling constraint in all of the tidal canals. At present, there is not any strategy whatsoever to check the discharge of oxygen demanding wastes into the water bodies of consequence. Industrial effluents play a very minor role in this connection. Urban liquid and solid wastes are primarily responsible for oxygen depletion in the canals. Again many of the canals have lost their dynamism that would otherwise have facilitated the re-aeration of the stagnant stretches. All the canals are at sea level and natural flow is sluggish or non- existent in non-rainy days. Tidal oscillation alone infuses some life into the system. But intervention by bunds, loss of depth by siltation and bottlenecks created in the channel by civil structures and dumping of solid waste isolate the canals into stagnant wet patches.

5.2. Suggestions

5.2.1 Oxygen demanding waste treatment and regeneration

If the biodegradable waste discharged into the canals is brought down to a bearable minimum, by means of proper treatment and re–aeration possibilities are tried, like mechanical removal of obstacles arresting the flow and agitating the water with windmills; dissolved oxygen deficiency could probably be taken care of. Once DO reaches a satisfactory degree of saturation level, the water bodies can become utilizable for higher-level uses. Concerted and committed actions by the industries, locals and local administration only can bring about the desired qualitative change in the concerned water bodies.

5.2.2 Canal maintenance and silt management.

Most of the canals are subjected to annual pre-monsoonal dredging. The sludge and slime scooped up is heaped up along the brink of the canals and it naturally feels the way down to the canal well before the wet season is gotten over with. This sediment after proper curing, could be used for conditioning the soil in the agricultural belt in the east. This way, the essential plant nutrients eternally lost to the humanity could be redeemed into the terrestrial ecosystem simultaneously undoing the constrictions in the water course.

5.2.3 Restriction on waste dumping

All tidal canals exempting the canals of west Cochin are potential fresh water sources, at least for a certain part of the year. But clandestine dumping of the waste from slaughterhouses, especially in Edappally thod and Karingachirapuzha makes the water unhealthy and nauseating. A system to collect and compost slaughterhouse and fish market waste can alleviate the problem once and for all.

West Coast Canal from Kollam to Kottappuram in Kerala along with Champakkara Canal and Udyogamandal Canal was declared as National Water Way No.3 in 1993. But the prospects of availing the tidal canals inside the city as a cheap alternative to road traffic are not yet explored. But though economic, the sluggish nature of water transport makes its viability doubtful..

5.2.4 Management of aquatic weeds

Water hyacinth is a nuisance obstructing flow and navigation. A close knit mat of these weeds stops light penetration and re-aeration in the water column. The smothering aquatic vegetation could be harvested and carted east for soil conditioning and also it could be used as fodder in piggeries. When the aesthetic value of the canals has been restored, fishing in the canals can become a serious industry, which will bring back some amount of the lost nutrients. Table 5.1 lists the edible fauna found in Cochin estuary (Thomson, 2003)

Table 5.1 List of edible fauna found in the estuarine waters of Cochin

	Species		Species
1	***Acanthurus Bleokeri***	45	***Lutianus Argentimaculatus***
2	***Acanthurus Crassipinum***	44	***Lobotis Surinamensis***
3	***Ambasis Comersoni***	46	***Lutianus Fulviflamma***
4	***Amblypharygodon Mola***	47	***Lutianus jhoni***
5	***Anabus Testudeneus***	48	***Lutianus Quinquelineatus***
6	***Anadontostoma Chacunda***	49	***Macrognathus Guntheri***

7	*Arius "Plastistomus*	50	*Megalopus Cyprinoides*
8	*Caranx Nigripinnius*	51	*Mugil Cephalus*
9	*Caranx Sexfasiatus*	52	*Mystus Malabaricus*
10	*Chaca Chaca*	53	*Ompok Pabda*
11	*Chanda Commersoni*	54	*Ompok Malabaricus*
12	*Chanos Chanos*	55	*Mystuuscembalus Armatus*
13	*Chelonodon Tauvina*	56	*Ophychthys Attipinnis*
15	*Congresox Talabonides*	58	*Otolithus Argentius*
14	*Cynoglossus Cynoglossus*	57	*Oreochromis Mossambica*
16	*Cynoglossus Punticeps*	59	*Oxyeurichthys Tentacularis*
17	*Daysiana Albida*	60	*Pseudorhombus javanicus*
18	*Drapane Penetatus*	61	*Puntius Dorsais*
19	*Dussumieria Hasselti*	62	*Pristipoma Furcatum*
28	*Eliotris Carviforms*	71	*Thryssa Malabarica*
20	*Eliotris Fusca*	63	*Puntius Filamentosus*
21	*Epinephalus Malabaricus*	64	*Puntius Melanostigma*
22	*Esculosa Thoracata*	65	*Seatophagus Argus*
23	*Etroplus Maculatus*	66	*Silaho Sihama*
24	*Etroplus Suratensis*	67	*Spyraenajello*
25	*Euryglossa Orientalis*	68	*Stolephorus Indicus*
26	*Garra Maccalandi*	69	*Tetradon Leopardus*
27	*Gerrus Filamentosus*	70	*Therpon Iarbua*
29	*Gerrus Oyena*	72	*Tricanthus Brevirostris*
30	*Glosigobius Guirius*	73	*Tylosurus Crocodilus*
31	*Gobius Microlepis*	74	*Valamughil Seheli*
33	*Hemiramphus Caritori*	76	*Penaeus Monodon*
32	*Hemiramphus Far*	75	*Wallago Attu*
34	*Horabagrus Brachysoma*	77	*Paenaeus Indicus*
35	*Hyporamphus Limbatus*	78	*Penaeus Merguiensis*
36	*Labeao Dussmieri*	79	*Metapenaeus Monocerus*
37	*Latus CAlcarifer*	80	*Metapenaeus Dorsoni*
39	*Leoganthus Equulus*	82	*Metapenaeus Affinis*

38	***Leognathus Brevisostris***	81	***Metapenaeus Dobsoni***
40	***Leognathus Splendens***	83	***Macrobrachium Rosenbergil***
41	***Liza Macrolepsis***	84	***Macrobrachium Idella***
43	***Liza Parsia***	86	***V. Cyprinoides***
42	***Liza Tada***	85	***Crab (Scylla Serrata)***

5.2.5 Rain water and run off management

Lightning floods during rains and scanty residual flow during the dry months are symptomatic of an urban environment because of the impervious floors impeding rain water penetration. Water retaining capacity of the urbanscape can be substantially augmented by storing rainwater in overhead tanks in the case of multi-storied buildings and ground level tanks for single storied buildings. This practice can substantially boost the residual flow and moderate the lightning floods characteristic of urban environments.

With sufficient DO and tolerable salinity, the water from the tidal canals can be used extensively for gardening, irrigation, toilet flushing and washing. There is a sustainable and reliable source of unpolluted fresh water hitherto left unexplored - water from Moolamattom powerhouse. This water would have reached the Periyar estuary any way, had it not been for the Idikki reservoir. This water discharged at the rate of 50 cubic meters per second can be channeled down to the city without any pumping or prompting. This source can effectively cater to the potable water requirements of the city.

5.3. Classification of Canals based on implied utility

Canal monitoring and canal-assessment are the pre-requisites for canal restoration. Because of the paucity of funds and space, urban development and environmental quality, most often than not, fail to go hand in hand. Environmental quality is a pre-requisite in the long-term survival of urban agglomerations.

Based on quality and nature of salinity the tidal canals of Cochin can broadly be classified as follows:

5.3.1 Canals heavily polluted and very saline

The canals of West Cochin belong to this category. These canals are ruled out as a potential fresh water source. Here, salinity intrusion and sewage pollution are pronounced throughout the year. The aesthetic appeal of the canals can be improved by proper pre-treatment of oxygen demanding wastes.

5.3.2 Canals heavily polluted by urban waste but having fresh water for some part of the year-

Mullassery canal, Thevara canal, Perandoor canal, Karanakkodam thod, Koithara thod, Edappally thod, Poorni puzha, Changadampok thod, Kharee thod and Punchathod belong to this group. The canals of the second category call for special mention. They have many factors in common and the root cause of the sad state of affaires boils down to one point - the man. All these canals have

1. The catchment area exclusively inside the city
2. Bear the brunt of untreated sewage onslaught
3. Suffered conspicuous morphological modification in the process of Asiatic mode of urbanization, characterized by urbanization preceding planning and infrastructural development. Households have access to municipal water supply and hence water from the Periyar in a denatured form ends up in the canals.
4. Diminished water holding capacity by the pressures of land development.
5. Edible fish, for all practical purposes, been wiped out by prolonged bouts of hypoxia
6. Near vertical lateral bunds limiting soil-water interaction
7. A permanent fresh water segment along the upper half of the water course.
8. The fresh water part is the most severely polluted part due to indiscriminate raw sewage discharge; they are the chief mosquito nurseries of the city.

5.3.3 Canals having fresh water for most part of the year and not much polluted.

Kadambrayar, Chithrappuzha, Karingachirapuzha and Panar belong to this group. Canals of this category are already used as a fresh water source by industries, local water supply schemes (e.g., Mulamthuruthy) and farm lands. Annual bund building on these water courses arrests the possibility of salinity intrusion. But canals have a sizable and predominantly agricultural basin, resulting in substantial residual flow. These canals are already playing a significant role in the local economy in the capacity as a fresh water source and by facilitating large-scale navigation. As far as Chithrapuzha-Kadambrayar basins are concerned, industrial discharges cause a serious threat to the quality of water. The organic fertilizer industry on the Kadambrayar takes a serious toll on DO and apparently adds to COD and BOD. The water theme park is also allegedly influencing negatively on the quality of water. The huge Gypsum mount accumulated over the years close to Chithrapuzha deteriorates the clarity of water after every washout following a serious rain. The municipal discharge into Andhakaran thod ultimately influences the quality of Karingachira puzha. Fugitive dumping of organic wastes from the bridges has seriously affected the quality of water at Kaniyavally, Kandanad and Kolenchery. If some more managerial energy is put into the maintenance of these canals, they would function as excellent sources of fresh water

5.3.4 Fresh water bodies heavily polluted

There are only two canals under this head -Adimury thod and western half of Edappally thod. Water from these canals was once extensively used for irrigation. If the domestic sanitary discharges are subjected to treatment before discharging into Adimury thod, it can still be reclaimed as a year-round fresh water source, suitable for irrigation, washing and flushing. Good maintenance of this natural stream is of vital importance as the low-lying chunk of land behind the international stadium is flood-prone. Fortunately, the western half of Edappally thod is not in a thoroughly urbanized region. Hence sewage insult is not much beyond its self purification capacity. But the slaughterhouses in this area find it expedient to get rid of the daily waste into this canal. If the canal is

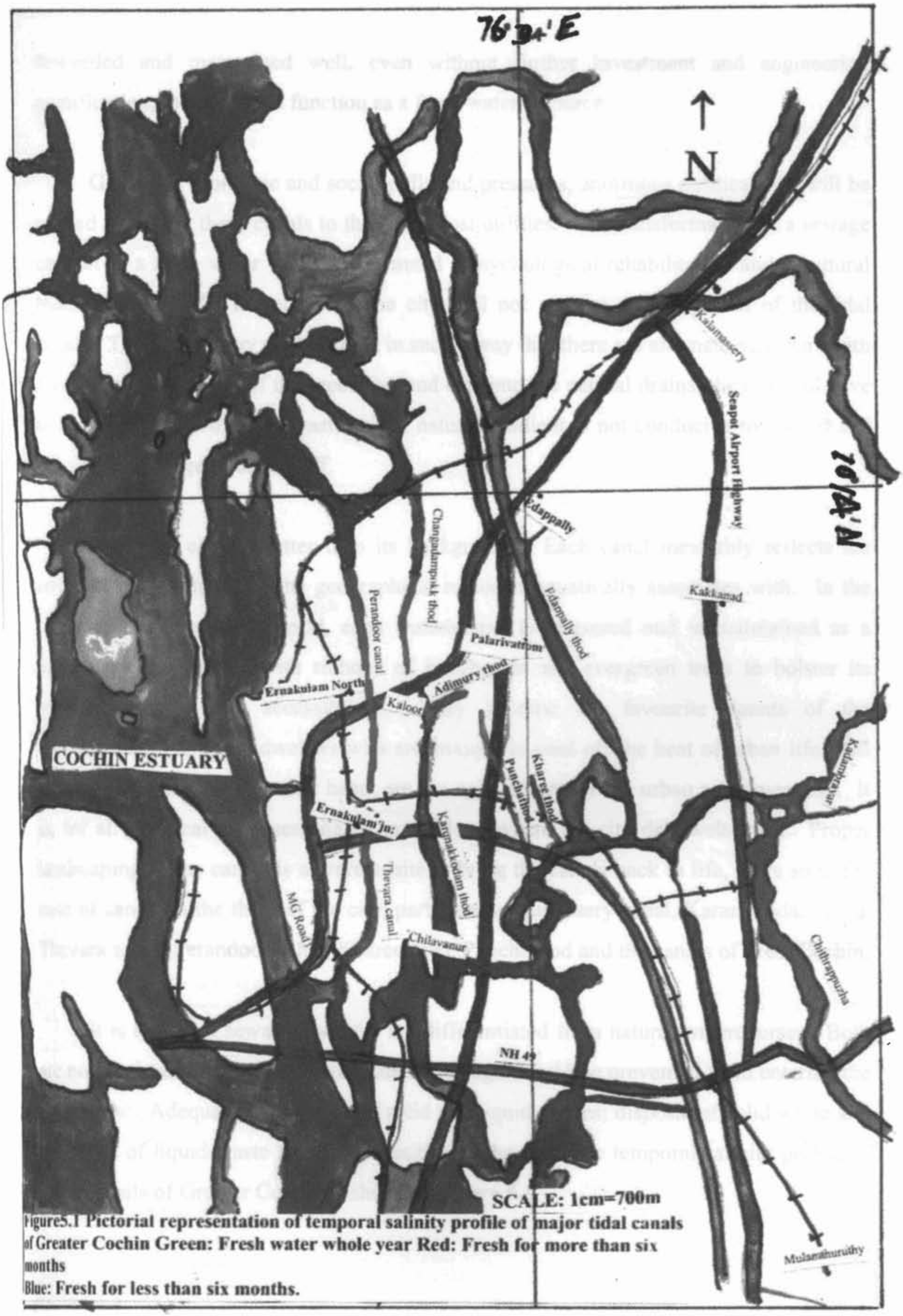


Figure5.1 Pictorial representation of temporal salinity profile of major tidal canals of Greater Cochin Green: Fresh water whole year Red: Fresh for more than six months
Blue: Fresh for less than six months.

deweeded and maintained well, even without further investment and engineering modification, the canal can function as a fresh water resource

Given the economic and social pulls and pressures, enormous political will will be needed to restore these canals to their long-lost utilities. The transformation of a sewage conduit to a fresh water canal will demand a psychological rehabilitation and a cultural mobilization amidst the people. The city will not survive the extinction of the tidal canals. The topography of the city is in such a way that there are alternate sand bars with a swale in the middle. If the greed for land eats into the natural drains, the city will have to drown in its own liquid wastes since natural gradient is not conducive to a swift and efficient discharge of the runoff.

No canal can be better than its background. Each canal inevitably reflects the environmental quality of the geographical region it aquatically associates with. In the cities of the developed world, each watercourse is treasured and is maintained as a picturesque showpiece with ribbons of boulevards and evergreen trees to bolster its aesthetic appeal and accessibility. They become the favourite haunts of the holidaymakers and city dwellers who are anxious to cool off the heat of urban life. All canals of Cochin, on the other hand, are the ugliest parts of the urban agglomeration. It is, for all practical purposes, the no man's land where the city debowels itself. Proper landscaping of the canals is a prerequisite to bring the canals back to life, more so in the case of canals in the thick of the city, particularly Mullassery canal, Karankkodam thod, Thevara canal, Perandoor canal, Kharee thod, Punchathod and the canals of West Cochin.

It is time that sewage conduits are differentiated from natural watercourses. Both are not, and cannot be, one and the same. Sewage should be prevented from entering the canals raw. Adequate segregation of solid and liquid wastes; disposal of solid waste and treatment of liquid waste are the necessities of the day. The temporal salinity profile of major canals of Greater Cochin is shown in **figure 5.1**

Table. 5.2. Slab wise temporal distribution of chloride.

Name of Canal	Cl<250mg/L	Cl<600 mg/L	Cl<1000 mg/L	Cl>1000 mg/L
Adimurythod Above Thriveni	Whole year	Whole year		
Above confluence	27 Jan to 30 Dec	Whole year		
Changadampokku thod KSEB	Whole year	Whole year		
Galaxy	27 May to 03 Oct	08 April to 02 Dec		18 March to 30 Dec
AIMS	27 May to 03 Oct			04 May to 02 Dec
Kadambrayar – Chithrapuzha Manakkekadav, Veegaland, Edachira, CSEPZ, Brahmapuram, Ambalamugal	Whole year	Whole year		
Irumpanam, FACT, Kaniyampuzha	18 May to 28 Oct			
FACT		29 April to 22 Jan	06 April to 12 Feb	12 Feb to 06 April
Irumpanam		18 May to 17 Dec	06 April to 17 Dec	17 Dec to 06 April
Kaniyampuzha			10 May to 07 Nov	07 Nov to 10 May
Edappally thod Western Half of Edappally thod	02 July to 7 Nov			
Marottichod and Western half of Eddappally thod from NH 47		Whole year		
Attipeti Nagar	18 May to 17 Dec		10 May to 22 Jan	22 Jan to 10 June
Above Ambalappara			18 May to 17 Dec	17 Dec to 18 May
Karingachirapuzha Panar	Whole year			
Karingachira	13 May to 15 Jan		13 May to 04 March	04 March to 13 May
All points but Andhakaran	13 May to 05 Nov			
Andhakaran	08 June to 05 Nov			

All points but Panar and Karingachira				
Andhakaran, Poothotta, Swargavathil Down, Kanjiramattom				05 Nov to 13 May
Swargavathil Up, Kaniyavally, Mattathan kadav				17 Dec to 29 April
West Cochin				Whole year
Poornipuzha - All stretch	21 May to 26 Aug			17 Oct to 21 May
Pisharadi and Pallimattom	21 May to 17 Oct			
Karanakkodam thod VIP Road whole stretch	Whole year			
Chettichira, Pandarachira and Chilavannoor	15 April to 19 September			19 Sept to15 April
Karanakkodam, Marshaling yard and Kathrukadav	19 March to 18 Nov			18 Nov to 19 March
Thevara canal CBI South	26 Nov to 26 Aug	Whole year		
KSRTC East	19 Feb to29 Aug	Whole year		
Whole stretch	25 May to 26 July			
All points but CBI, KSRTC				26 July to 25 May
Mullassery Canal	25 May to 31 Aug	Whole year		
Yathra				31 Aug to 25 May
Koithara Canal		25 May to 31 Oct		31 Oct to 25 May
Rob			16 March to 31 Oct	
Emerald			30 March to 31 Oct	
Perandoor Canal All points but Kaloor and Perandoor	Whole year			
Kaloor	18 March to 26 Aug			
Whole stretch but Perandoor		Whole year		
Perandoor	27 May to 29 Oct			29 Oct to 04 May
Chittoor puzha Whole stretch	25 June to 12 Sept			28 Nov to 04 June

Kharee thod	07 May to 21 Nov			
Chakkaraparamb		03 Feb to 21 Nov		21 Nov to 03 Feb
Ponnurunni				21 Nov to 07 May
Pucha thod Aysha road and Naroth road	Whole year			
ROB, Ponnurunni	14 April to 14 Oct			06 Jan to 14 April
Chalikkavattom (Bypass)	14 April to 06 Jan			06 Jan to 14 April

Table 5.3. Slab wise temporal distribution of hardness.

Name of canal/Points	$CaCO_3$< 300 mg /L	$CaCO_3$ <600 mg/L	$CaCO_3$> 600 mg/L
Adimuri thod	Whole year		
Changadampokk thod KSEB, Kaloor	April 08 to 31 Oct	Whole year	
AIMS ,Galaxy		01 Nov to 08 April	
Galaxy	08.04 to 02.12	30.01 to 02.12	02.12 to 30.01
AIMS	04.05 to 31.10		04.05 to 02.12
Chithrapuzha All points but FACT, Irumpanam, Kaniyampuzha	Whole year		
FACT	29.04 to 12.02	06.04 to 12.02	12.02 to 06.04
Irumpanam	29.04 to 17.12	06.04 to 12.02	12.02 to 06.04
Kaniyampuzha	18.05 to 28.10		28.10 to 18.05
Edappally thod Western Half of Edappally thod	Whole year		
Eastern half up to Attipetti	20.05 to 7.11	20.05 to 04.12	04.12 to 20.05
Karingachira puzha Panar	Whole year		
All points but Panar	13.05 to 5.11		
Kandanad, Karingachira, Swargavathil Up, Kaniyavalli, Mattathan	05.11 to 13.05		
Kanjiramattom, Andhakaran, Swargavathil Down, Poothotta			05.11 to13.05

West Cochin Whole stretch			Whole year
Poornipuzha Whole stretch	21.05 to 11.11		11.11 to 21.05
Karanakkodam thod VIP Road whole stretch	Whole year		
All points but VIP Road	19.03 to 18.11		18.11 to 19.03
Thevara canal CBI S whole stretch	Whole year		
KSRTC E	20.02 to 08.01		08.01 to 20.02
All points but CBI ,KSRTC	15.06 to 26.11		26.11 to 30.04
Whole stretch		30.04 to 26.11	
Mullassery Canal KSRTC W	15.06 to 01.01 and 19.02 to 13.04		30.04 to 15.06 and 01.01 to 19.02
Yathra	15.06 to 31.10		31.10 to 15.06
Koithra canal	15.06 to 31.10		31.10 to 15.06
Perandoor canal All points but Perandoor		Whole year	
Perandoor		04.05 to 29.10	29.10 to 04.05
Whole stretch	27.05 to 29.10		
Chittoor puzha Whole stretch	15.05 to 12.09		12.09 to 15.05
Kharee thod Ponnurunni	07.05 to 21.11	21.11 to 06.01	06.01 to 07.05
Chakkaraparamb	03.02 to 21.11		21.11 to 03.02
Puncha thod Aysha road, Naroth road	Whole year		
Bypass – Chalilkkavattom	26.03 to06.01		06.01 to 26.03
Rob Ponnurunni	14.04 to 06.01		06.01 to 14.04

Table 5.4. Slab wise temporal distribution of alkalinity

Name of canal / points	$CaCO_3<250$ mg/L	$CaCO_3>250$ mg/L
Adimury thod	30.12 to 30.07	30.07 to 30.12
Changadampokku thod		
AIMS	Whole year	
Galaxy ,KSEB	31.10 to 29.07	29.07 to 31.10
Chithrapuzha Whole stretch	Whole year	

Edappally thod Whole stretch	Whole year	
Karingachira puzha All points but Kaniyavally, Andhakaran, Karingachira	Whole year	
Kaniyavally, Andhakaran, Karingachira	30.03 to 15.01	15.01 to 30.03
West Cochin Pandarachal, Edacochin, Perumpadapp	Whole year	
All points but Pandarachal, Edacochin, Perumpadapp		Whole year
Poornipuzha whole stretch	Whole year	
Karanakkodam thod Chilavannoor and Pandarachira	Whole year	
Points except Chilavannoor, Pandarachira	30.12 to 30.07	30.07 to 30.12
Thevara canal Thevara market and Kallupalam	Whole year	
CBI S	26.11 to 27.07	27.07 to 26.11
Kochukadavanthra, GCDA, KSRTC E	30.04 to 27.07	27.07 to 30.04
Mullassery canal Yathra	31.10 to 27.07	27.07 to 31.10
KSRTC West	13.04 to 27.07	27.07 to 13.04
Koithara canal - Rob and Emerald	16.03 to 27.07	27.07 to 16.03
Perandoor canal	08.04 to 29.07	
Chittoor puzha - whole stretch	Whole year	
Kharee thod – Chakkaraparamb	26.03 to 02.08	02.08 to 26.03
Ponnurunni	21.11 to26.03 and 07.05 to 02.08	05.03 to 07.05
Puncha thod – Naroth road, Aysha road and ROB	14.10 to 02.08	02.08 to 14.10
Bypass	14.10 to 03.02 and 14.04 to 02.08	03.02 to 14.04

Table .5.5. Slab wise temporal distribution of sulphate

Name of canal/points	Sulfate<250 mg/L	Sulfate >250 mg/L
Adimuri thod - whole stretch	Whole year	
Changadampokk - KSEB whole stretch	Whole year	
Galaxy,	Whole year	
AIMS	Rest of the year	08.01
Chithrapuzha – all points but Kaniyampuzha	Whole year	
Kaniyampuzha	11.03 to 13.11	13.11 to11.03

Edappally thod - whole stretch above Attipetti nagar	Whole year	
Below Attipetti nagar	09.03 to 20.01	20.01 to 09.03
Karingachirapuzha - All points but Swargavathil Down and Kanjiramattom	Whole year	
Swargavathil Down and Kanjiramattom	22.04 to 11.12	11.12 to 22.04
West Cochin	14.05 to 03.08	
Poornipuzha	21.05 to 11.11and on 05.02 and 02.04	
Karanakkodam thod – VIP road	Whole year	
Whole stretch	19.03 to 18.11 and on 27.01	
Thevara canal - GCDA, KSRTC E, CBI S	Whole year	
Thevara, Kallupalam, Kochukadavanthra	04.05 to 3.12 and on 30.01	Remaining part of the year
Mullassery canal – KSRTC-West	Whole year	
Yathra	13.04 to 31.10 and on 23.01	Rest of the year
Koithra canal - whole stretch	Whole year	
Perandoor canal - All points except Perandoor	Whole year	
Perandoor	18.03 to 02.12 and 30.01	Rest of the year
Chitoor puzha	16.04 to 28.11 and on 06.02	Rest of the year
Kharee thod – Chakkaraparamb	Whole year	
Ponnurunni	03.02 to 21.11	21.11 to 03.02
Puncha thod – whole stretch	Whole year	

Table.5.6.Slab wise temporal variation of BOD

Name of the canal/points	BOD< 5 mg/L	BOD< 20 mg/L	BOD< 50 mg/L
Adimuri thod Triveni road	On 27.02		
Whole stretch			Whole year
Changadampokk thod Galaxy, AIMS		27.05 to 2.10	30.01 to 02.12
KSEB			04.05 to 31.10
Chithrapuzha Whole points but Kaniyampuzha, FACT, Irumpanam		Whole year	
Kaniyampuzha, FACT, Irumpanam		10.06 to 17.12	
Whole stretch			Whole year
Edappally thod			20.05 to 04.12

Whole stretch			
Karingachirapuzha -whole stretch except, Kanjiramattom			Whole year
Kanjiramattom-			22.04 to 04.03
Whole stretch		08.06 to 05.11	
All points but Andhakaran and Kanjiramattom		12.02 to 06.04	
West Cochin - whole stretch			14.05 to 20.11

Table 5.7. Proposed standards for irrigation for tropical conditions

TDS	400 mg/L	Poor drainage Saline soil Inadequate water supply
TDS	1000 mg/L	Good drainage Proper irrigation management
TDS	2000 mg/L	Salt resistant crop Good drainage

(Source: Schippers, 1991)

BOD, Coliform bacteria count and COD levels are well beyond the prescribed limits and total iron in spite of anoxic conditions and alkaline pH exceeds the tolerable levels and most of the canals are deficient of DO. Even then, these canals could be recognized as precious gifts of nature because all the qualitative problems are of human origin and hence can be rectified. Sulfate, alkalinity, hardness and chloride are on the favourable side at least for a certain part of the year. pH and plant nutrients are tolerably less for all waters at all times. The promising side of the temporal variation pattern is that chloride maximizes in January, a time when scarcity of fresh water does not ominously loom large on the city. Water scarcity assumes serious proportions in March and April. The sporadic afternoon thunder showers of these months only exacerbate the situation. But the fact that at this stage, salinity in canals exhibits a receding tendency could have been taken advantage of. But the drop in salinity does not reach down to the economically meaningful levels. It is ironic that the waters forfeit their utility at a time when they are needed most. During the wet season fresh water generally does not become a constraint to economic activities. Even if the water could not be put to the highest use it is fit for flushing and irrigation.

At present, the water is not fit for fish culture, out-door bathing and drinking with or without conventional treatment, because BOD, COD and DO are far from the prescribed levels. But the water qualifies for industrial cooling and irrigation for a major part of the year. Sulfate and pH are on the favourable side throughout; chloride and electrical conductivity are within the prescribed levels for some part of the year as shown in the tables above. Systematic watershed management, reduction of toxic pollutants, reduction of sewage pollution, habitat protection and restoration and long-time monitoring are part of the working strategy to bring about an improvement in water quality of the water bodies. Though it is true that canals like Changadompokk thod, Karanakkodam thod, Thevara canal and Puncha thod are fresh in the upper extremities, it does not have any significance for the moment as the water is raw sewage with no DO. Karingachirapuzha and Kadambrayar are fresh because of anthropogenic intervention in the form of seasonal bunds and inter -basin water transfer, and these rivers are already a fresh water source.

5.4. Recommendations and Prospects for future study

Urban runoff is the greatest source of water pollution in the developed areas. This non-point source of pollution is an ecological problem threatening the long-term health of aquatic ecosystems and local economies. With increasing urbanization, urban runoff becomes a lethal cocktail of pollutants damaging estuaries, wetlands, lakes and rivers. Instead of hardscaping the land it has to be softscaped (urbanization results in increased impervious floors impeding natural recharging of ground water), maximizing permeability and acknowledging it as an integral part of the hydrologic cycle. The urban runoff problem which would appear unwieldy and problematic can be mitigated by good housekeeping measures, best managerial practices and education thereby bringing about a critical shift in the philosophy and management of water resources. Since space and fund constraints stand in the way of urban storm water management, innovative techniques will have to be incorporated to mitigate the first flush environmental shock (the run off provoked by the first serious rains after the dry season is rich with plant nutrients and organic matter). For example, sand filtration systems and underground sand filters consisting of multiple chambers could be employed to remove urban wash outs. The main reason why urban storm water remains such an important contributor to water pollution is the fact that storm water receives no treatment before entering the water bodies. And in India the width of natural channels decreases with increasing urbanization.

The geographical setting of certain canals is conducive to thorough self purging if other impeding interventions, anthropogenic or otherwise, are adequately dealt with. Suitable looping of the canals to different arms of the estuary is a possibility worth a try. Thevara canal begins at the railway line close to the CBI office and debouches into Thevara water front at Thevara market. On the other side of the rail road Perandoor canal begins and it spends itself into Chittoor puzha a few kilometers north. If these two canals are connected across the rail road, the two different arms spatially separated by anthropogenic intervention would fuse into one to bring about a differential tidal bulge at the extremities and that alone could actuate an effective flushing through regular tidal gradient alone. If the tidal bulges on either end do not have a potential difference to propel a cleansing flux along the canal a mechanism can be introduced to facilitate a unidirectional flow.

The same mechanism is viable in the case of Edappally thod also provided the vital link across the high way at Edappally is restored and its original geometry is maintained. Such a move has substantial socio economic ramifications too. In the first place it opens an easy short cut between Muttar and Chithrappuzha, in effect between Udyogamandal and Ambalamugal.-a hydraulic link between south eastern suburb and north western suburb bypassing the rush and din of the city.

If Changadompokk thod is connected to Karanakkodam thod across the high way at Kaloor and widened to accommodate the water pressure the resulting canal will link Chilavannoor kayal and Muttar, and another canal running parallel to the north south strike of the city will be realized. Here also natural tidal flushing will do the needful to keep the canal in good stead. If the tidal action does not graduate beyond the oscillation of trapped canal water unidirectional flow can be introduced by means of flow regulators.

Mullassery canal is not at present endowed with the necessary attributes to carry out the environmental functions expected of it. Through bold engineering intervention and rehabilitation of the shop owners perched on top of the canal denying the sun and effective aeration to the putrid water under the slabs, this canal can effectively diffuse the short fuse floods the central low lands of the city are chronically plagued by. Further more it opens a bypass to the water load on Thevara-Perandoor canal if the canal is linked to Mullasssery canal by widening the railroad culvert near KSRTC Bus station.

The most effective control measures to address urban non-point source pollution include

1. Public education on solid waste and sewage disposal
2. Use of vegetated swales and wetlands to filter runoff before it enters the receiving streams (Wet land parks).
3. sediment traps in urban storm water systems
4. Storm water retention by way of rain water harvesting or ponds.
5. proper maintenance of septic systems
6. Removal of organic matter and nutrients from sewage by appropriate treatment.
7. Opening up of broken canals for sea water movement.
8. Aeration of canals using wind energy.
9. Removal from time to time of sediments having high sediment oxygen demand, accumulated in the sediment traps. The sediments can be used for land fill and soil conditioning.

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