COASTAL AND GROUND WATER POLLUTION IN KAVARATTI ISLAND, LAKSHADWEEP SEA

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By

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THIRUVANANTHAPURAM

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Dedicated to
my kind,ever loving mother

DECLARATION

I hereby declare that the thesis entitled COASTAL AND GROUND WATER POLLUTION IN KAVARATTI ISLAND, LAKSHADWEEP SEA", is an authentic record of the research work carried out by me under the supervision and guidance of Dr.P.P.Ouseph, Head, Chemical Sciences Division, Centre for Earth Science Studies, Thiruvananthapuram, in partial requirements for the Ph.D. Degree of Cochin University of Science & Technology, under the Faculty of Environmental Science and no part thereof has been presented for the award of any degree in any University.

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CERTIFICATE

This is to certify that this thesis entitled "COASTAL AND GROUND WATER POLLUTION IN KAVARATTI ISLAND, LAKSHADWEEP SEA", is an authentic record of the research work carried out by Mr. G. Madhusoodanan Pillai, under my supervision and guidance, at Chemical Sciences Division, Centre for Earth Science Studies, Thiruvananthapuram, for the award of the Ph.D. Degree of Cochin University of Science & Technology, under the Faculty of Environmental Science and no part thereof has been presented for the award of any degree in any University.

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(G. Madhusoodanan Pillai)

EXECUTIVE SUMMARY

The tiniest Union territory of India, Lakshadweep, is an archipelago, with an area of 32 Sq. km. consisting of 12 atolls, three reefs and five submerged banks, lies between 8° and 12°30'N latitudes and 71° and 74° E longitudes. It is one of the most important and critical territories of India from economic and defence point of view. Specialised environment having typical geological set up, Lakshadweep is ecologically sensitive to even slight climatic or anthropogenic interference. Pollution of coastal seas, over exploitation and contamination of the fresh water sources are thus become great concerns to the existence of the island. Typical geological set up and interference cause threat to the ecology of the fragile environment and resources of the island as well as its resources. Marine pollution and ground water contamination are concerns in this regard.

Even though attentions were made to assess the physico-chemical and bacteriological status of the marine and groundwater systems separately, an integrated approach has not been evolved. The present study with its broad objectives is attempted for an integrated assessment of microbiological, physico-chemical and biological characteristics of the surrounding seawater and microbiological and physico-chemical characteristics of the ground water in Kavaratti island. The entire study has been organised in 4 chapters.

The introductory chapter deals with a comprehensive discussion of the significance of the study, highlighting the contemporary status on marine and ground water pollution in national and global scenario. Background of the study area is given, citing the uniqueness of the specialised habitat. History, geology, people, administration, flora and fauna, and natural resource of the island are briefly described. Pertinent research works related to the study undertaken in Lakshadweep islands and elsewhere are reviewed and the significance of assessing the marine as well as ground water sources in the fragile island is appraised.

The second chapter deals with the methodology of the collection, preservation and analysis of water samples for different parameters; analytical techniques for physico-chemical parameters are described highlighting the principle behind the procedure used. The ingredients of bacteriological media and methods regarding isolation of different species are shown in this chapter.

Chapter III details the results of the analysis, which is divided into two segments; such as results and discussion of Seawater analysis and results and discussion of well water analysis. The first segment contains the microbiological, physico-chemical and biological parameters of the marine pollution monitoring over the period of 4 years. The data are summarised in tables and plotted in charts. The results are discussed, comparing with similar studies. Study highlights that the heterotrophic bacterial population due to the increased input of organic wastes into coastal waters has considerably increased over the years, which reduces the

overall primary productivity, and affect the very basic sustenance of corals. The sharp increase in the counts of faecal coliforms and faecal streptococci in the lagoon, are too high to the prescribed limits for recreational purpose. Salmonella, Shigella and Proteus, Klebsiella, and Vibrio cholera like organisms isolated from the lagoon waters of Kavaratti clearly proves the faecal contamination, which is of epidemiological significance. The overall distribution of dissolved oxygen and nutrients especially in the lagoon doesn't depict a healthy picture. The primary productivity, chlorophyll concentration and phytoplankton count reveals that the lagoon is comparatively lower productive and the enhancement of macro algal growth due to waste addition was found to be attributing to this.

The second segment comprises the results of well water studies in 30 dug wells and 2 tube wells over a period 1997-2001 (December 1997, April 1999, August 2000 and May 2001). Results of bacteriological parameters like total viable count, Coliforms, Salmonella like organisms, Faecal streptococci etc., are tabulated and elaborated with charts and significance discussed. The isolation of E.coli, enteropathogenic indicator bacteria from 50% of the wells is alarming. The causative agents of typhoid fever, cholera and diarrhoea are frequently enumerated from drinking water. Physico-chemical variables indicate overdraft and resultant seawater intrusion to the groundwater and mixing of domestic sewage with fresh water lens. Conductivity and dissolved solids, at many cases have

crossed even the permissible levels, which are prescribed for the cases without an alternative.

The fourth chapter briefs the salient conclusions derived from the exhaustive study and suggestions and recommendations for the implementation of management action plans that helps to prevent coastal as well as ground water pollution in the fragile island.

The study invites urgent management action for sewage treatment, enforcement of coastal pollution prevention laws and creation of awareness to common man.

CONTENTS

1. INTRODUCTION

1.1 Marine pollution monitoring

Oceans, the big blue, the source of life and the hallmark of Earth; Vast, tranquil, and treacherous, the oceans bear the signature of our planet. The only planet in the solar system blessed with a liquid medium for life to evolve in, we hold the oceans within us, both physically and mentally. So vast are the oceans, that they take up almost 71% of the entire surface of the globe (139 million square miles) and have an average depth of 12,230 feet (3730 m) and reach the deepest point in the Mariana Trench of the northwester Pacific Ocean, at 36,204 feet (11,038m) below sea level. The ocean basins hold at vast quantity of water, over 285 million cubic miles of water (1185 million cu. km.). This vast quantity of water arose from the Earth's interior as it cooled. The oceans are the largest repositories of organisms on the planet, with representatives from all phyla from the obvious large whales, fish, corals, to the microscopic bacteria in 100 - 1,000,000 cells per cubic centimeter. Living organisms either live in water or have specific mechanisms to conserve it within their bodies. Water surrounds all marine organisms, composes the greater bulk of their bodies, and is the medium in which various chemical reactions take place, both inside and outside of their cells. Survival also requires energy input to drive these chemical reactions and environmental conditions suitable to maximize the efficiency of these reactions.

Pollution causes unfavourable alteration of environment that poses threat ultimately to the survival. Pollutants can be natural or anthropogenic, but even when it is natural, its adverse effect may be primarily due to human contributions and exposure in populated areas. Water pollutants can be classified into categories such as sewage and other oxygen demanding wastes and non-point source pollutants (NPS). Oxygen-demanding wastes lead to oxygen depletion, which affects aquatic life and produce annoying taste, odour and colour and impair water quality. The indiscriminate discharge of domestic and municipal wastes into the natural ecosystem makes the natural ability of self-purification ineffective. Every year millions of fish are reported killed as the result of municipal and industrial wastes that find their way to the ocean/water bodies (Subramanian, 1999).

One of the most worrisome aspects of the increase in pollution is that human have now become a factor in several of the great biogeochemical cycles and may be causing irreversible change without realizing it. The marine and coastal areas harbour a variety

of specialized ecosystems like mangroves, coral reefs, islands, salt lakes, sand/ mud flats, which provide unique habitats for a myriad of flora and fauna. Due to manifold usages of Seas and Oceans for harvesting resources, shipping and dumping of wastes, the areas constantly face various environmental stresses and threats. The thickly populated urban centres and industrial areas face pollution by untreated sewage and industrial wastes. While microbial pollution is largely confined to nearshore waters, released/dumped chemicals are found even in the offshore waters. Due to the rapid increase in global population and industrialization, the major source of marine pollution is from municipal and urban runoff and among them, industrialization altogether contributes for 56 % of the pollution load (Subramanian, 1999).

India has a coastline of 7515 km with an exclusive economic zone (EEZ) of 2.04 million sq. km. Out of the 100 million population, 25% live in coastal areas. The domestic sewage waste disposal into the Indian coast has been estimated approximately 18,240 MLD. Domestic wastes are mostly untreated due to the lack of treatment facilities in most of the cities and towns. It has been reported that only primary treatment facilities are available in cities and towns where the population is more than 1,00,000, though the capacity is highly inadequate. This partial treatment allow the wastewater retain its original features causing damage to the water quality. The industrial waste discharge is estimated to be 0.79×10^9 cu. m as of 1994 (Subramanian, 1999).

Human can have a significant impact of the biology of the ocean, where we alter its chemical composition by ways of human activities, including sewage and trash, storm drain and river run-off, and oil spills that influence ocean chemistry. Sewage and trash all over the world are dumped into the sea. This ranges from raw, untreated sewage, to partially treated sewage. Chemically, sewage acts like fertilizer and can be responsible for toxic plankton blooms, detoxification and introduce diseases. The introduction of unhealthy chemicals like heavy metals and carcinogens into coastal waters is equally dangerous. Although the ocean is good at ridding itself of pollutants by chemical processes and dilution, as coastal population grow, so do the human impacts on the marine environment. Apart from this, storm drain and river run-off as non-point source pollution input large quantities of suspended solids, fertilizers, soap and organic wastes, that reduces oxygen dissolution the same way sewage does. Debris like trash can entangle or be eaten by birds, fish and mammals, which can be very harmful. Oil floats

on the surface of seawater and when spills occur, it tends to end up on the shore where it hurts wildlife by matting down bird feathers, sticking to fish gills, disrupting breathing, and by poisoning animals and plants.

Concentration of the gases dissolved in seawater is modified further by biological activity particularly by plants and certain bacteria. Oxygen is vital for all living things and hence dissolved oxygen in seawater plays a very important role with respect to marine life. The amount of dissolved oxygen present in seawater is comparatively lower than that in fresh water or that present in the atmosphere. In the lower layers of the atmosphere, oxygen constitutes about 200 ml /L whereas in seawater it is only between 0-8.5 ml /L (Nair and Thampi, 1980) and the capacity of water to contain oxygen in solution increases with decrease in temperature and salinity. Cold waters can contain more oxygen than warm waters. Temperature is a very important physical parameter in the marine environment. It limits the distribution and ranges of ocean life by affecting the density, salinity, and concentration of dissolved gasses in the oceans, as well as influencing the metabolic rates and reproductive cycles of marine organisms. When the physico-chemical composition of the seawater is affected by pollutants, the sensitive ecosystems are very much affected. One among them is a coral reef, which are self-prepared biogenic structures. In India coral reef ecosystem extends over approximately 2300 sq. km area as against a total 6 million sq. km area in all seas together. The reefs are of fringing type in Andaman and Nicobar Islands, and in Gulf of Mannar. There is a 320 km long luxuriant barrier reef on the west coast of Andaman extending between 10°26'' North to 13.41 north and a depth of 80 km. Atoll reefs are found in Lakshadweep. Reef formation is governed by some physicochemical parameters such as temperature depth of the sea, light, salinity and wave action. Reefs are well developed in areas where the annual mean temperatures are approximately around 23° to 25°C with an optimum range of 29 °C and salinity range between 27 % and 40 %. A total of 200 species of corals from 71 genera are known from Indian seas, of which 155 species from 50 genera are hermatypic.

The percentage coverage of both dead and live corals in sample plots in Kavaratti in both lagoon and reef varied from 10 to 60 percent of the area, of which an average 50% of the corals are dead. This indicates that more than 50% of corals of Kavaratti are represented by dead and disintegrating corals (James *et al.*, 1989).

Nutrients are inevitable parameters of a productive environment in the ocean. There is reclamation of nutrients in the form of nutrient cycles. A certain amount of nutrients utilized by phytoplankton is however regenerated by bacterial activity within the euphotic zone itself. But a good amount is lost from the euphotic zone as a result of the sinking of phytoplankton as well as through consumption by zooplankton inhabiting deeper levels during daytime. The nutrients that accumulate in the deeper levels are mostly returned to the surface waters by vertical mixing processes such as upwelling, eddy diffusion, vertical convection and wind mixing. In addition to this, land drainage and river influx also contributes to the replenishment of nutrients of the surface water at least of the coastal areas. The seasonal changes in environmental conditions drive the large-scale or global ocean-wide features while short-term variations are largely due to inherent instabilities. Such phenomena are obvious in shallow and it will be difficult to predict long-term trends and this is one of the hardships of oceanographic studies.

Biological process exerts important influence in the composition of seawater through effects on the chemical forms that are present. At the same time, chemical characteristics have an important influence on biological activity, exemplified by the contrast in productivity between oligotrophic and eutrophic waters and life processes between oxic and anoxic waters. Those features of the present day composition of sea-water which show marked temporal and spatial variations are of particular interest from the marine biological standpoint, since they are often closely related to the cycles of organic production and decomposition and have immediate relevance in relation to productivity. In the marine environment, there is no community of organisms that is totally independent and many of these are intimately related. Thus, in order to understand the processes in the sea, the sea has to be dealt with as an interrelated system, rather than as discrete units.

During the past few decades, marine microbiology, like other disciplines of the biological sciences, has witnessed a rapid growth due to multidisciplinary approach and contribution of information based on ecology, physiology and biochemistry, which caused a marked change in this field of study. Recently, however, it has been appreciated that bacteria themselves have a very high demand for phosphates and nitrates, indeed, as high as the phytoplankton because bacterial tissues contain as many or more phosphorous and nitrogen atoms for every carbon atom as do those of the photosynthetic algae. Bacteria may be a sink for nutrients along with zooplankton. The

potentialities of an aquatic ecosystem such as nutrient dynamics, productivity, standing stock and energy transfer are vast and for the assessment of it, the study of physico-chemical characteristics incognizance with biological processes is inevitable. These parameters are interdependent and vary with seasons.

1.2 Perception of monitoring potable water

Man's biological need for water is modest; only a few litres/day are needed to support life. Furthermore, since much of this is usually supplied by food, often a litre or two of drinking water is adequate. Man's desire for water, however, vastly exceeds his need. In most of the developing countries, water- carriage, sanitation is a luxury few can afford and 75% of the population lacks adequate sanitary facilities. Pathogens such as bacteria, viruses and parasites are dangerous environmental pollutant. Four out of every five common diseases in developing countries are linked to either infection from dirty water or lack of sanitation. Water-borne diseases cause an average of about 25,000 deaths a day (UNEP, 1987). Scarcity of water supply and heavy pollution have led to situation in which at least of one-fifth of city dwellers and three-quarters of rural people in developing countries lack access to reasonably safe supplies of water.

Human beings are probably most concerned about direct effects of pollutants on their own health. Infectious agents like bacteria are a hazardous constituent of wastewater from municipalities or sewage. Many of the diseases whose epidemics recurrently decimate human population are transmitted through water. Cholera and typhoid are important examples. From the epidemiological point of view, it is important to formulate base line information and identify the potential pathogenic hazards in a potable water resource. This information is vital in terms of designing proper management action plans.

Dependence on dug wells as drinking water sources, therefore, will continue indefinitely. One serious aspect of the density of houses with dug wells and septic tanks/leach pits in small plots is that the possibility of bacterial contamination of drinking water increases. A variety of water borne disease outbreaks are attributed to consumption of contaminated water from poorly protected wells.

1.2.1 Water borne diseases

Waterborne Disease	Causative organisms	Source of organism in water	Symptom
Gastroenteritis	Rota virus	Human feces	Acute diarrhea or vomiting
Diarrhea	*Salmonella* (bacterium)	Animal or human feces	Acute diarrhea or vomiting
Diarrhea	Enteropathogenic *E. coli* (bacterium)	Human feces	Acute diarrhea or vomiting
Typhoid	*Salmonella typhosa* (bacterium)	Human feces	Inflamed intestine, enlarged spleen, High temperature; sometimes fatal
Dysentry	*Shigella* (bacterium)	Human feces	Diarrhea – rarely fatal
Cholera	*Vibrio cholera* (bacterium)	Human feces	Vomiting severe diarrhea, rapid dehydration mineral loss; high mortality
Infectious hepatitis	Hepatitis A (virus)	Human feces, Shell fish grown in polluted waters	Yellowed skin, enlarged liver, abdominal pain; low mortality; lasts up to 4 months
Amoebic dysentery	*Entamoeba histolytica* (protozoan)	Animal or human feces	Mild diarrhea chronic dysentery
Giardiasis	*Giardia lamblia* (protozoan)	Animal or human feces	Diarrhea, cramps, nausea and general weakness; not fatal; lasts 1 week to 30 weeks
Cryptosporidiosis	*Cryptosporidium* (Protozoan)	Animal or human feces	Diarrhea, stomach pain; lasts an average of 5 days

(Source: GEMS/Global database, WHO 1989).

Historically, some of the most severe public health effects from contaminated drinking water were from diseases such as cholera and typhoid. A variety of water borne disease outbreaks have been attributed to contaminated aquifers or poorly protected well sites containing pathogenic bacteria, virus or eucaryotic organisms (ITRC, 1989,Chaudhuri, 1985). Specific bacterial pathogens that have been isolated from well waters include entero-pathogenic *E.coli, Vibrio cholera, Shigella flexneri, S.sonnei, Salmonella typhimurium* (Centre for Disease Control, 1973,1974, 1980). Contaminated, untreated ground water was the source of 35.3 % of water borne disease outbreaks in the USA

over a 30 year period (Lippy & Waltrip, 1984). Another study shows that 83% of well samples analysed contain thermotolerant coliform count > 10 organisms per 100 ml. Microbial contamination continues to be a national concern because contaminated drinking water systems can rapidly spread diseases (WHO & UNEP, 1987). Even though 80% of water borne diseases and out-breaks are due to bacteriological contamination of water, most of the workers involved in water quality management are concerned more about the removal of chemical contaminants from water (Forsund, 1986). Regular surveillance of water sources for quality and efforts to control bacteriological contamination is, therefore essential.

Any program of public health cannot be a success without the participation of local community. General public should be educated and public awareness created to prevent, reduce and eliminate ground water pollution through integrated and co-ordinate regulatory actions. In absolute numbers, most human sufferings and deaths in developing countries are due to water-associated diseases. Inadequate water supply, unsanitary excreta disposal and vector-infested water courses are held responsible for approximately half of the present child (< 5 years of age) diarrheal mortality of 4 millions per year in the third world (M.Merson, Diarrhoeal diseases control programme, WHO, Geneva). Besides creating awareness, disinfectants can be applied as the final treatment process to inactivate any residual pathogenic organisms and indicator bacteria (Wimpenny *et al.,* 1972; WHO & UNEP, 1987). Interpretations of the findings of the disinfection studies will provide an opportunity to verify water use areas of greatest potential risk to public health and the need for adequate protective barriers. In the long run, water resource management must focus in prevention from point sources of waste discharge and diffuse penetration of storm water run off (Bartram and Balance, 1996). Thus with respect to water borne diseases, only the improvement of the microbiological quality of drinking water, together with supporting measures in hygiene education, sanitation and food safety will cut by half the morbidity and mortality of water-related diseases (Hughes, 1993).

Also, water as it passes through the geohydrobiological cycle naturally picks up a variety of chemicals from the earth's crust. Some of these chemicals can be beneficial as dietary intake while others are of organoleptic concern: but few above a certain concentration impairs serious health effects. In terms of health impact assessment, water may be classified in three typical categories (Galal-Gorchev, 1986) as substances

exerting acute and/or chronic toxicity (eg., metals, nitrates, cyanide etc.), genotoxic substances causing carcinogenicity, mutagenicity and birth defects (synthetic organics, chlorinated microorganisms, arsenic and some pesticides) and essential elements which are mandatory as dietary constituent (fluoride, iodine, selenium). Although industry uses much less water than agriculture, it causes more pollution. More than 80% of it is returned immediately to the natural water cycle, often polluted with by-products. Thus, pollution of water resources has been a priority for several decades. New threats and contaminants have emerged today with such diverse water quality problems.

Despite its scientific and economic importance, many people poorly understand water quality. Too often the natural variations in natural water chemistry are assumed to be random or even enigmatical. Many of the gross characteristics of water quality, however, have been understood in recent years. Advances in general biogeochemistry as well as analytical techniques, more over, have stimulated research in hydro geochemistry so that it is one of the most rapidly expanding fields in the earth sciences. The recent realization that the mobility and chemical activity of water in the atmosphere, and in terrestrial branches of the hydrological cycle, have contributed to the long-range transport of pollutants was perhaps surprising. Anthropogenic activities in one place are the cause of water quality deterioration and ecological disturbances elsewhere (Falkenmark, 1986).

Assessment of water quality today in global terms implies the need for a reference point against which results of monitoring can be measured and weighed. Aquatic ecosystems as part of the natural environment are balanced both within themselves and with other environmental compartments, and this equilibrium is subject to natural variations and evolutions as well as variations caused by human intervention. The present assessment is to identify, and possibly quantify, anthropogenic influences over time against a "natural" baseline situation. Water pollution problems have only recently been taken seriously in retrospect. Once damage occurred it became measurable, and control action was initiated. Long-term effects, however, such as salinization of ground waters of rising nitrate levels have been neglected for decades and the message has only recently started to pass from the hands of scientists to policy makers.

The general occurrence and the natural variations of the constituents in ground water and their relation to the water use are of utmost significance in water quality management. Monitoring and assessment over a period of time are required to conduct the rational management. The monitoring should cover standard measurements of water quality variables of chemical and biological components. To ensure safe recreational water and a continuous supply of potable water, frequent monitoring of both raw water sources and finished products for the presence of pathogens is very important. This procedure will establish baseline data against which microbiological quality can be compared during water bone epidemics or other unusual circumstances. Also, periodic examination will help to establish a system or protocol that can be activated, with our significant delay, in emergency situations, including sudden disease outbreaks. More importantly, the detection of any organisms not previously observed or a marked increase in the number of specific pathogens in the source water may provide an early indication of possible health risks. The detection of any enteric bacteria, even of low pathogenicity, in the aquatic environment may serve as a warning of unsafe recreational water or a breach in the integrity of disinfection or distribution system for potable water. Thus the presence of pathogens is expected to be detected more often than before. Moreover, it is desirable to adopt relatively easy, sensitive, and highly specific methods for detecting every pathogen that could potentially be present in water sources.

The enteric diseases caused by the coliforms, bacteria are transmitted almost exhaustively by the fecal contamination of water and food materials. Transmission through contaminated water supplies is by far the most serious source of infection and was responsible for the massive epidemics of the more serious enteric disease particularly cholera and typhoid fever. The faecal coliforms bacteria, predominantly *Escherichia coli*, are not usually long term occupants of aquatic ecosystems. Thus their presence in water serves as a useful indicator of recent faecal contamination. The bacteria that have principally served as indices of such contamination are the faecal streptococci and *E.coli*. Organisms like *Escherichia*, *Salmonella*, *Shigella*, *Proteus*, *Vibrio cholerae* and *V parahaemolyticus* belong to enteric group of organisms. *Salmonella* cause typhoid fever and Shigella cause bacterial dysentery whereas *V cholera* and *V parahaemolyticus* cause cholera and food poisoning. Some members of genera such as *Klebsiella* that have an extra intestinal prevalence and can cause disease

by gaining entry into water from environmental sources and there fore should also be monitored.

Although microbial pathogens in water will be the main pollution problem for most developing countries for some time, chemical pollution has emerged as an equally serious threat in all countries, which have industrialization and chemically supported agriculture. The most immediate stress on human health from water pollution is through ingestion of contaminated water. Nitrates, for example, not only contribute to algal blooms in lakes and reservoirs but, when present in drinking water at high levels, can result in methaemoglobaenemia. The rapid increase in population density has generated human wastes, which have reached surface waters or percolated into the ground with both immediate contamination and long-term deterioration of the aquatic environment. The limits of the waste assimilative capacity of the aquatic environment have been rapidly approached in the high-density agglomerations.

A great deal of valuable information concerning the sanitary quality of water is undoubtedly obtained by chemical analysis, and many sources of pollution are detected by this method. Also, it is generally true that, under natural conditions, water, which on chemical analysis shows evidence of recent pollution, is at the time bacteriologcally impure. Organic matter, admittedly, is food supply for bacteria and favours their multiplication, but large numbers of bacteria may be found in water of the highest standard of organic purity. As compared with chemical methods of analysis, bacteriology affords far greater delicacy and gives more exact information of the presence in water of excremental matter. Chemical analysis affords valuable information of past or remote pollution. Bacteriological examinations give less information of the remote history of the water but, is far more important, they disclose the immediate or near antecedents with reasonable ease, and with greater reliability. It is desirable that the chemical and bacteriological examinations always be correlated.

Water quality does not constitute a value by itself, but it has to be seen in relation to ecological systems and the different uses made of the water. Hydrological as well as natural water quality considerations provide the reference points against which anthropogenic impacts become measurable. As a function of control measures being enacted, scenarios for different world regions illustrate the crucial importance of integrated control strategies being adopted in a timely fashion.

1.3 Study area

History

Early history of Lakshadweep is unwritten. Local traditions attribute the first settlement on these islands to the period of Cheraman Perumal, the last king of Kerala. The advent of Islam dates back to the 7^{th} century around the year 41 Hijra. Even after the conversion of the entire islands to Islam, sovereignty remained in the hands of the Hindu Rajah of Chirakkal for some years. From the hands of the Chirakkal Raja the administration of the island passed on to the Muslim house of Arakkal of Cannanore around the middle of 16^{th} century. Then the island's sovereignty came to be divided as five and fall under the rule of Tippu Sultan while a part continued under the Arakkal house. After the battle of Seringapattom in 1799, the islands were annexed to the British East India Company. The British later brought the Lakshadweep Regulation 1912, which confers restriction to outsiders. Nine Primary Schools and a few dispensaries were started during the colonial rule in the islands. The Union Territory was formed in 1956 and it was named Lakshadweep in 1973.

Location, Area and Population

The tiniest Union territory of India, Lakshadweep is an archipelago consisting of 12 atolls, three reefs and five submerged banks. It lies between 8^0 and 12^0 30 N latitudes and 71^0 and 74^0E longitudes. It is a uni-district Union Territory with an area of 32 Sq.Kms. and is composed of ten inhabited islands, 17 uninhabited islands attached islets, four newly formed islets and 5 submerged reefs. The inhabited islands are Kavaratti, Agatti, Amini, Kadamat, Kiltan, Chetlat, Bitra,Andrott, Kalpeni and Minicoy. They lie about 220 to 440 Km from the coastal city of Kochi by ship, Helicopter and NEPC service. Considering its lagoon area of about 4 lakh Sq.Kms. of economic zone, Lakshadweep is large territory. The atolls of the island rest on an underwater platform of about 100 fathom deep. The islands have formed as a result of many thousand years of reef building activity.

According to 2001 Census, Lakshadweep has a population of 60595 persons. More than 93.4% of the population, who are indigenous, are Muslims and the majority of them belong to *Shafi* School of the *Sunni Sect*. The islands, ranging in area from 1 ha to nearly 440 ha., are little specks in the Indian Ocean. They are beautiful, idyllic and strategically located from the point of view of economic and defence considerations of

India. Being oceanic islands, the continental shelf around them is limited to about 4336 sq. km, but considering the lagoon area of about 4200 sq. km., 20,000 sq. km of territorial waters and about 400000 sq. km of oceanic zone, Lakshdweep is one of the largest territories of our nation.

Administration

Prior to the formation of this Union Territory on 1st November 1956, these Islands formed part of the erstwhile Madras state and were considered as one District and divided into four Tahsils and each put in charge of a Tahsildar, except Minicoy where the post of Tahsildar was abolished and a Deputy Collector appointed in August 1978. The Headquarters of the Administration was shifted from Calicut (Kerala State) to Kavaratti Island in March 1964 and new offices were created in 1972. The Administrator appointed under Article 239 of the Constitution of India is the head of this U.T. Panchayati Raj system came to existence under 73rd amendment of 1992. Ten inhabited Islands have the 10 Dweep Panchayats. The district Panchayat has its Headquarters at Kavaratti. There is 22 seats in the District Panchayats and of these 20 seats are reserved for Scheduled Tribes including 7 seats reserved for women belonging to STs.

Climate

The climate, more or less comparable to that of the coastal areas of Kerala, is warm and humid but bearable. The average rainfall is about 1640 mm for Minicoy and 1504 mm for Amini. The rainiest months are June to September with June receiving the maximum. Maximum temperature may range from 35^0C to 38^0C and minimum from 17^0C to 18^0C. Occasionally cyclonic storms occur, the oldest and the most serious recorded being the one that struck Kalpeni and Androth on April 15, 1847 (Mannadiar, 1977).

Geology

There are no conclusive theories about the formation of these coral atolls. The English evolutionist Charles Darwin gives the most accepted theory in 1842 that the subsidence of a volcanic island resulted in the formation of a fringing reef and the continual subsidence allowed this to grow upwards. When the volcanic island became completely submerged, the atolls were formed encircling the lagoon where, with the action of the wind, waves, reef tom, currents and temperature, the coral islands were formed. The

fringing reefs are quickly built, repaired and strengthened by a microorganism called *Polypous*. They are the architects of these atolls. The corals are hard calcareous skeleton of this *Polypous*.

Natural Resources

The most important flora and fauna of the islands are coconut trees and fishes, which form the mainstay of the economy of the islands. No cereal of any significant importance is grown in the islands. The flora of the islands consists mainly Vazha (*Musa paradisiaca*), Chembu (*Colocasia antiquorum*), drumstick (*Moringa oleifera*), 'Chakka' (*Artocarpus incisa*) and wild almond (*Terminalia catappa*). Tapioca, Yam, fourds, legumes etc are also cultivated. A variety of wild herbs and shrubs grow and new plants occasionally introduced from the mainland. Two different varieties of sea grass are seen adjacent to the beaches, which prevent sea erosion and movement of the beach sediments. They are known as *Thalassia hemprichin* and *Cymodocea isoetifolia*. Oceanic birds generally found are Tharathasi (*Sterna fuscata*) and Karifetu (*Anous solidus*) seen in one of the uninhabited islands, Pitti, which has been declared as a bird sanctuary. Molluscan forms, also important from the economic point of view of the islands are money cowrie (*Cypraea monita*), cypraca talpa and cyprea maculiffera. Among crabs, the hermit crab is the most common. Colourful coral fish such as parrot-fish (*Callyedon sordidus*), Butterfly fish (*Chaetodon auringa*), Surgeon fish (*Ancanthurus lineotus*) are also found in plenty. The Butterfly fish (*Chaaetodon auriga*) locally known as **Fakkikadia** is the animal, Sooty tern (*Anusolidus piletus*) locally known as **Karifettu,** the bird and bread-fruit (*Artocarpus Incise*) locally known as **Chakka** as the tree are the state symbols of Lakshadweep.

1.4 Review of literature

A good amount of work has already been carried out to monitor the pollution status of the Arabian Sea. The studies included the analysis of water and sediment quality in terms of physico-chemical and biological variables. Many studies were also conducted on the fresh water quality elsewhere.

The general features and considerations with respect to the fish information service of Lakshadweep islands were dealt with the following workers. When the general features of the Islands were described by Jones (1959) for the first time, Jayaraman *et al.*, (1960) studied the hydrography of the Laccadive offshore waters. Jones (1968 & 1969)

surveyed the fishery resources of the Laccadive Archipelago and also made a catalogue of fishes from the Laccadive Archipelago in the reference collections of the CMFRI and studied the fresh water bacteria association with algae and alkaline phosphate activity. Jones and Kumaran made a new record of the fishes from the seas around India-part 7 (1970) and also a record on the fishes of the Laccadive Archipelago (1980). Bhattathiri *et al.*, (1971) carried out the initial assessment of the biological characteristics of the Laccadive Sea. Qasim and Bhattathiri (1971) specifically studied the primary productivity of sea grass bed on Kavaratti Atoll. Nair and Pillai (1972) investigated the primary productivity of some coral reefs in Indian seas. Comparative studies were made by Madhupratap *et al.*, (1977) on the abundance of zooplankton in the surrounding seas and lagoon in the Lakshadweep. Alderslade *et al.*, (1991) discovered a new species of soft corals (*Coelenterata octocorallia*) from the Laccadive Archipelago. Anand and Pillai (1995) conducted studies on some aspects of biology and ecology of coral reef fishes of Lakshadweep with observations on other coral reef ecosystems of India. Anon (1991) described the fauna of Lakshadweep. Bhattathiri and Devassy (1971) conducted studies on the biological characteristics of the Laccadive sea. Bhattathiri (1984) studied the primary production and physico-chemical parameters of Laccadive and Andaman Sea. Rao and Jayaraman (1966) studied the up welling in the Minicoy region of the Arabian Sea when Rao *et al.*, (1970) conducted a general survey of Lakshadweep for establishing a marine park.

Gardiner (1903 & 1906) was among the pioneers who studied the fauna and geography of the Maldive and Laccadive Archipelago. George *et al.*, (1986) also studied the ancillary living marine resources of Lakshadweep. Goes and Devassy (1986) studied the primary productivity and carbon assimilation patterns in tropical marine phytoplankton in the Lakshadweep sea. Jayaraman (1972) studied on the occurrence of blooms of blue-green algae and the associated oceanographic conditions in the Northern Indian Ocean. Goswamy (1973 & 1979) made observations on some planktonic groups of Kavaratti atoll (Laccadives) and also studied the zooplankton abundance in the Laccadive Sea (Lakshadweep) and found out that copepods contributed the dominant constituent. He studied (1979, 1990) the diel variations of zooplankton at Kavaratti atoll and Minicoy lagoon. He made observations (1983) on the production and community structure of zooplankton in Kavaratti lagoon. Goswamy *et al.*, (1992) studied the zooplankton standing stock assessment and fishery resources in the Indian seas.

Madhupratap *et al.*, (1991) made estimates of high absolute densities and emergence rates of demersal zooplankton from the Agatti Atoll, Laccadives. Rao, K.K *et al.*, (1992) studied the distribution of planktonic foraminifera in waters of the submarine coral banks in southeast Arabian Sea during winter. Jones (1968, 1969) conducted surveys on the fishery resources of the Laccadive Asrchipelaho and catalogued the fishes in the references of the CMFRI. He made (1972) studies on fresh water bacteria association with algae and alkaline phosphate activity. Jones and Kumaran (1980) made new records of fisheries from the seas around India-part-7 and wrote about fishes of Laccadive Archipelago. Madhupratap *et al.*, (1991) found out the estimates of high absolute densities and emergence rates of demersal of zooplankton from the Agatti Atoll, Laccadives. Diel patterns and emergence of zooplankton of the lagoons of Laccadives were also investigated by them. Mathew and Gopakumar (1986) made observations on certain environmental parameters in relation to surface tuna fishery at Minicoy Island, Lakshadweep. Mathew (1986) also edited a special issue on Lakshadweep which includes a series of articles to briefly review the marine fisheries research conducted in Lakshadweep Archipelago. Matondkar *et al.*, (1992) conducted studies on the role of the bacterial sized phytoplankton in the Indian Ocean regions.

Environmental features in the Seas around Lakshadweep were investigated by Nair *et al.*, (1986). Nair *et al.*, (1978) also studied the distribution of zooplankton in the Lakshadweep Sea during the post monsoon period. Extracellular production and turn over rates of phytoplankton in the Laccadive Sea (Lakshadweep) was studied by Pant (1979). The status of coral reefs in Lakshadweep was investigated by Pillai (1986). Pillai and Mohan (1986) studied the ecological stress in Minicoy lagoon and its impact on tuna baits. Qasim *et al.*, (1972) studied the primary productivity of an atoll in the Lakshadweep. Qasim (1973) studied the productivity of specialized environments that include the atolls of Lakshadweep. Qasim *et al.*, (1979) investigated the energy pathways in the Laccadive Sea. Productivity of the Arabian Sea along the Southwest coast of India was investigated by Rajagopalan *et al.*, (1992). Seasonal primary production in different sectors of the EEZ (Exclusive Economic Zone of India was calculated by Sarupriya and Bhargava (1993). Shah (1967) studied the diurnal changes in certain oceanographic features in the Laccadive Sea off Cochin in the month of September 1966. He (1975) also studied the primary standing crop and a few related oceanographic features in the Laccadive Sea off Cochin one annual cycle. Stephen *et*

al., (1979) conducted biochemical studies on zooplankton from the Laccadive Sea (Lakshadweep). Suresh and Mathew (1993) studied the coral reefs of Lakshadweep. They (1995) also studied the growth of Staghorn coral-*Acropora aspera* (Dana) in relation to environmental factors at Kavaratti Atoll. Tranter and George (1972) studied the zooplankton abundance at Kavaratti and Kalpeni Atolls in the Laccadive Sea. Untan Wale (1983) studied the mangroves, coral reefs and Island ecosystems along the Indian coast. Wafar (1977) investigated the phytoplankton production of two atolls of the Indian Ocean. Wafar *et al.*, (1985) conducted studies on the nitrogenous nutrients and primary production in a tropical oceanic environment (Lakshadweep waters). They (1990) also studied the nitrification in reef corals. Adiga (1989) studied the geomorphic configuration of the lagoonal shore of Kavaratti Island, Lakshadweep. Bhattathiri (1987) studied the environmental Characteristics of Lakshadweep Sea. Rao *et al.*, (1987) studied the distribution of foraminifera in the lagoons of Agatti, Kavaratti, Sulehi and Minicoy atolls of Lakshadweep archipelago, Arabian Sea Sanzgiri and Moraes (1979) studied the trace metals in the Laccadive Sea. Sanzgiri *et al.*, (1979) also studied the total mercury concentration of Lakshadweep Sea. Sastry and D' Souza (1972) studied the upwelling and upward mixing in the Arabian Sea. Chemical oceanography of the Arabian Sea was investigated by Sengupta *et al.*, (1979).

Sankaranarayanan (1970 & 1973) worked on the production of particulate organic matter by the reef of Kavaratti Atoll, Laccadives and studied the chemical characteristics of waters around the Atoll (1973). The hydrobiology of lagoons was investigated by Girijavallabhan *et al.*, (1987) when the chemical oceanography of the Laccadive Sea was deliberated by Sengupta *et al.*, (1979). James *et al.*, (1989) portrayed the overall picture of the marine living resources of the union territory of Lakshadweep. Qasim and Sankaranarayanan (1973) conducted studies on the production of particulate organic matter by the reef on Kavaratti Atoll. Silas (1972) investigated the deep-sea long layers in the Laccadive Sea. Wafar *et al.*, (1985) carried out works on nitrogenous nutrients and primary production in a tropical ocean environment. Ouseph (1989) conducted studies on dissolved particulate and sedimentary mercury in the Cochin estuary. He carried out studies on dissolved particulate and sedimentary mercury in the Cochin estuary. Ouseph (1987) presented a status report on marine pollution along Kerala coast. He also conducted studies (1992) on the dissolved and particulate trace metals in the Cochin estuary. Water quality parameters including nutrient concentration

in lagoon waters of Minicoy were studied by Ouseph *et al.*, (1998). Hem (1970) studied and interpreted the chemical characteristics of natural water. Many reports are available regarding the hydrochemistry of Kerala coast (Jacks, 1987) conducted studies on short-term variation in water quality in a spring in Kentucky. Viswanathan (1975) studied the chemistry of estuarine environment and Madhukumar and Anirudhan (1996) investigated the adsorption thermodynamics of phosphate on sediments of tropical back water system. Sengupta *et al.*, 1975, 1981, studied the chemical oceanography of the Arabian sea, its hydrochemical and hydrographical features of the variability of demtrification in estuarine sediments. Sabastian (1989) studied the nutrient salt sources and water quality of northwest Arabian Gulf. The geochemistry of natural waters was described by Drever (1982). Dakin *et al.*, (1983) studied the orgin of dissolved solids in ground of Mayne island British Columbia, Canada. Eriksson (1985) gave details on principles and applications of hydrochemistry.

The following workers investigated the geophysical potential and fresh water availability related to the tiny islands. Varma *et al.*, (1988) conducted exclusive studies on geophysical and hydrogeological aspects for the assessment of ground water potential in the Lakshadweep Islands. Eriksson (1986) studied the geophysics of Coastal Kerala ground water. Geo-chemistry and genesis of fluoride containing ground water was studied by Handa (1981). Karanth *et al.*, (1987) reported the ground water assessment, development and management. Seepage and ground water flow was aimed by Rushton and Redshaw (1978). Martin and Joe (1996) studied the short-term variation to water quality at a Kurst spring in Kantucky. When Verruijit (1982) gave a ground water flow; William Waton (1984) wrote about the analytical ground water models. Handa (1993) studied the potable water quality standards and consumers response. Balwan Singh and Janeshwar Dass (1993) investigated the occurrence of high fluoride in ground water of Hariyana, India. The quality of ground water in Gandheswari sub-basin, Bankura district, West Bengal was studied by Saha *et al.*, (1995). Varma *et al.*, (1995) carried out studies on the assessment of groundwater recharge in Kavaratti Island, Lakshadweep. They (1995) also investigated on the groundwater resource potential in the Union Territory. Varma (1997) studied the groundwater resource potential and management of the coral Atolls of Lakshadweep. The hydrogeology of Vamanapuram, Ittikara and Kallada basins of Kerala was investigated by Najeeb (1988). Chaudhuri (1985) described the Indian experience in water quality monitoring. Forsund (1986) also described the prospects of ground water quality monitoring today

and tomorrow. WHO (1984), gave guidelines for drinking water quality while WHO/EURO (1985) summarised report of working group on health hazards for nitrates in drinking water. WHO (1987a & 1987b) also laid down guidelines for drinking water quality, its health criteria and other supporting information.

Mukherjee *et al.*, (1986) studied the rainwater chemistry over Indian seas during monsoon season. Nair *et al.*, (1960) conducted studies on the Laccadive hydrography of the Laccadive offshore waters. Naqvi (1990) studied the geochemistry of some corals from Lakshadweep Islands. Naqvi and Reddy (1979) studied the variation of Calcium content of the waters of Laccadive (Arabian Sea). Nasnolkar *et al.*, (1997) studied the content boron, calcium and magnesium in lagoonal waters of Kavaratti, Lakshadweep. Navas and Mathew (1995) studied the present status of coral erosion in Lakshadweep with special reference to Minicoy. Patil and Ramamirtham (1963) studied the hydrography of Laccadives offshore waters during winter conditions. Sing *et al.*, (1990) conducted studies on the vertical distribution of phosphate, nitrate and nitrite of Lakshadweep waters in the Arabian Sea. Sundaramam *et al.*, (1959) investigated on the vertical distribution of dissolved oxygen in the deeper waters of the Arabian Sea in the neighborhood of the Laccadives during summer of 1959. Varkey *et al.*, (1979) studied the physical characteristics of the Laccadive Sea (Lakshadweep). Venkatesh (1974) conducted studies on the movement of sediments in the Kavaratti lagoon, Lakshadweep. Wafar (1992) investigated on the management and conservation options for Indian coral reefs. George (1988) also studied the distribution of labile and non-labile forms of Cd, Pb and Cu in Lakshadweep waters. Trace metal analysis of Lakshadweep Sea waters was carried out by Sanzgiri *et al.*, (1979) and Sanzgiri and Moraes (1979).

The field of marine microbiology has been recently dealt with many workers. Santha Nair (1979) was the first to ascertain the microbial characteristics of Laccadive Sea. Wright *et al.*, (1983) studied the planktonic bacteria in estuaries and coastal waters of northern Massachusetts: spatial and temporal distribution. Chandramohan and Ramaiah (1987) conducted studies on the heterotrophic activity and bacterial biomass in coral atolls of Lakshadweep Archipelago. Chandrika (1996) studied the distribution of the heterotrophic bacteria around Laccadive Islands. Lokabharathi *et al.*, (1986) described the occurrence and distribution of *Vibrio parahaemolyticus* related organisms in the Laccadive Sea. Ramaiah (1994) studied some aspects of the microbiological

characteristics in the nearshore waters of Bombay. Ramaiah *et al.*, (1995) investigated the autotrophic and heterotrophic characteristics in a polluted tropical estuarine complex. Davies *et al.*, (1995) studied the survival of faecal microorganism in marine and fresh water sediments when Park *et al.*, (1995) developed spectroflurometric assay method for rapid detection of total and faecal coliforms from surface water. Cibin *et al.*, (1995) made a comparative evaluation of modified MFC and M-TEC media for membrane filter enumeration of *E. coli* in water. Faechem et al., (1977), a statistical comparision of faecal coliforms and faecal streptococci. Brenner *et al.*, (1996) compared the efficiency of recoveries of *E. coli* and total coliforms from drinking water by MI Agar method and the US Environmental protection Agency approved membrane filter method. Ramaiah *et al.*, (1996) conducted studies on bacterial abundance and production in the central and eastern Arabian Sea when Chandramohan (1997) evaluated the recent advances in marine microbiology. Chandramohan and Lokabharathi (1998) also carried out studies on evaluation of monitoring and control methods of sulphate-reducing bacteria. Yayanor and Aristides (1995) conducted studies on deep-sea microbiology. Nemecek-Marshall (1995) experimented on the volatile organic compound produced by Marine *Vibrio* sp. Occurrence of faecal indicator bacteria in surface waters and subsurface waters and subsurface aquifer in Key Largo was investigated by Paul *et al.*, (1995). Palal *et al.*, (1995) conducted viral traces studies on surface contamination of marine waters. Cabelli *et al.*, (1983) described marine recreational water quality criterion consistent with indicator concepts and risk analysis. Dufour (1984) studied the bacterial indicators of recreational water quality. Elgamal (1987) described the relation between water and health-types, sources and control of water pollution. Bezdeck and Carlucci (1972) studied the surface concentration of marine bacteria while Braccewell *et al.*, (1980) investigated the contribution of wastewater discharges to ocean surface particulates. Delille (1992) carried out studies on marine bacterioplankton at the Weddel Sea ice edge and distribution of psychrophilic and psychrotrophic populations.

Cabelli *et al.*, (1982) studied swimming associated gastro enteritis and water quality. Austin (1983) described the bacterial microflora associated with a coastal, marine fresh rearing unit. Sarthre Alex *et al.*, (2001) studied pathogenic microbes along the Kerala coast and reported that the potential pathogens like *Salmonella*, *Shigella* and *Vibrio cholera* were present in the nearshore waters of Kerala coast throughout the year. Ghadi

et al., (1997) screened the agarolytic bacteria and developed a novel method for *insitu* detection of agarose. Lokabharati and Chandramohan (1990) studied Sulfate reducing bacteria from the Arabian Sea- Their distribution in relation to thiosulphate oxidizing and heterotrophic bacteria. Ramaiah and Chandramohan (1992) studied the cellulases, alginate and pectin lyases of luminous and other heterotrophic bacteria associated with marine algae.

Rosenfield and Bower (1979) gave management strategies for mitigating adverse health impacts of water resources development projects. Kubo (1983) gave a picture on water pollution control technology in Japan. Disease in the tropics in the context of water engineers and development was also dealt by MC Junkin (1975) for the US agency for International Development. Carmichael and Strzerper (1987) investigated on the industrial water use and treatment practices. Lippy and Waltrips (1984) studied the water borne disease outbreaks with a thirty-five year perspective from 1964 to 1980. When White (1986), edited a handbook on chlorination, the inactivation of microbial agents by chemical disinfectants was described by Hoff (1986).

Daniel Delille and Suzanne Razouls (1994) studied Community structures of heterotrophic bacteria of copepod faecal pellets. Hobbie and Crawford (1969) studied the respiration corrections for bacterial uptake of dissolved organic compounds in natural waters when Watson *et al.*, (1977) conducted experiments to determine the bacterial number and biomass in the marine environment. Hoppe (1978) studied the relation between active bacteria and heterotrophic potential in the sea. Equra *et al.*, (1974) studied the seasonal difference in bacterial counts and heterotrophic bacterial flora in Akkeshi Bay. Sewage derived bacteria were monitored by Trollope and Al Salihi (1984) in a marine water column by means of captive massules. Lee *et al.*, (1994) studied the distribution, biovolume and extra cellular activities of heterotropic bacteria in the sea near Kunsan, Korea.

Jorgenson (1977) studied sulfate reduction within reduced micro inches of oxidised marine sediments and he also (1978) made a comparison of methods for the gratification of bacterial sulfate reduction in coastal marine sediments. Meyer *et al.*, (1980) studied the interrelationship between microbial and chemical parameters of sandy beach sediments during summer season. Jorgensen (1980) conducted studies on

mineralisation and the bacterial cycling of carbon, nitrogen and sulfur in marine sediments. Rublee (1982) studied the seasonal distribution of bacteria in salt marsh sediments in North Carolina. Newell and Fallon (1982) studied the bacterial productivity in the water column and sediments of the Georgia (USA) coastal zone, estimated via direct counting and parallel measurements of thymidine incorporation. Heterotrophic activity throughout a vertical profile of seawater and sediment in Halifae harbour was investigated by Novitsky (1983). Lee and Lee (1991) studied the seasonal distribution and character of heterotrophic marine bacteria in the intertidal zone of the yellow sea near Kunsan, Korea.

Ducklow and Carlson (1972) investigated on the oceanic bacterial production and reported the bacterial presence in the intertidal sediments and factors related to their distribution was described. Jannaseh and Taylor (1984) studied the deep-sea microbiology in detail. Fergusonwood and Johannes (1975) edited a book on bacterial standard for marine bathing water suggested by WHO. Sebastian *et al.*, (1981) studied the marine pollution diagnosis and therapy. They describe the nutritional condition at which *E. coli* and *Salmonella* sp. survive and multiply in seawater. Ramaiah *et al.*, (1996) studied the bacterial abundance and production in the central and eastern Arabian Sea. They described the seasonal and spatial variations in bacterial and phytoplankton abundance and bacterial production in several stations in the Arabian Sea.

Donald *et al.*, (1979) describes a rapid 7-h faecal coliforms (FC) test for the detection of FC in water using a highly buffered lactose-based medium (m-7-h FC medium). Lawrence and William (1993) studied the energy sources for microbial food webs and they suggest that the energy source of microbes could invariably include the dead phytoplankton and organic release of zooplankton also. Shome *et al.*, (1995) described certain marine bacteria capable of oil degradation. Nishihira (1987) describes the natural and human interference with coral reef and coastal environments in Okinawa Islands. They described reddish clay run off from land erosion by development and construction.

Sathyamurthy. K *et al.*, (1990) studied the heterotrophic bacteria from mangrove. Bouvy (1989) studied the micro heterotrophic activity in a subantartic intertidal sediment relative to nutrient supply. Duyl and Kof (1990) described the seasonal

patterns of bacterial production and biomass intertidal sediments of the Western Dutch Walden Sea. Microbial activity in natural and organically enriched intertidal sediments near Nelson, New Zealand, was studied by Gillespie and Mac Kenzie (1996). Annual bacterial production in relation to benthic microalgal production and sediment oxygen uptake is intertidal sand flat and an intertidal mud flat by Cammen (1991).

Alavandi *et al.*, studied the heterotrophic bacteria in the coastal waters of Cochin. Bijumon *et al.*, (1999) studied the primary production, chlorophyll *a* and related hydrography of Lakshadweep islands, Kavaratti and Kalpeni. Anil Kumar *et al.,* (1997) studied water quality and microbial population of the Kavaratti lagoon. Madhusoodanan Pillai *et al.*, (1998) conducted studies on the indicator microbial population and pathogenic microbes in surface waters along southwest coast of India. Bijumon *et al.*, (1998) studied the ecosystem degradation of coastal environment of Kerala due to titanium effluents. Bijumon *et al.*, (2000) studied the effect of a factory effluent on the biological productivity of coastal marine system at Veli. Sarthre Alex *et al.*, (2002) studied the impact of coconut husk retting at Paravur estuary. Madhusoodanan Pillai *et al.*, (1997) also reported the impact of titanium effluents on the microbial population. Anilkumar *et al.*, (1997) conducted semi-diurnal studies in the water quality and microbial population in the lagoonal waters of Kavaratti attol. Walter *et al.*, (2001) conducted studies on the plankton and their productivity along the coastal waters of Kavaratti Island, Lakshadweep Sea. Madhusoodanan Pillai *et al.*, (2001) conducted investigations on the tidal influence of ground water quality on Kavaratti in terms of bacterial contamination. Sarthre *et al.*, (2001) investigated the pathogenic microbes along the waters of Kerala coast.

Meyer–Reil (1984) carried out investigations on the seasonal variations in bacterial biomass and decomposition of particulate organic material in sediments. Energetics of microbial food web was studied by Pomeroy (1988) and was across made on system overview the bacterial production in fresh and salt-water ecosystem by Cole *et al.* (1988). Plusquellec *et al.*, (1990) studied the contamination of mussel, *Mylitus edulis* (Linnaeus). An improved sample preparation was suggested for enumeration of aggregated substrate bacteria by Velji and Albright (1993). Schut *et al.*, (1993) described the isolation of typical marine bacteria by dilution culture with regards to growth maintenance and characterisation of the isolates under laboratory conditions.

Ducklow (1984) studied the geographical ecology of marine bacteria in terms of their physical and biological variability at the mesoseak. Chandu *et al.*, (1995)studied ground water exploration in a micro watershed in Aravatti Region. Rai (1964) conducted bacteriological studies on the river Yamuna, Delhi. Geldreich (1972) has given an account of water borne pathogens in water pollution Microbiology.Jones (1972) carried out studies on on fresh water bacteria algae and alkaline phosphate activity. Wimpeny *et al.*, (1972) recorded details on Surveillance of drinking water qualityin rural area. Pitt (1976) studied the ground water quality in selected area serviced by septic tanks in Florida, USA. Anon (1978) gave details of water quality protection in chgristina basin. Sandhya and Parhad (1988) described a methodology form removing *Salmonella* from multicell wastewater ponds. Skilton and Wheeler (1998) conducted bacteriophage tracer experiments in ground water. Sharma (1991) studied the suitability of bore well water in Udaipur city, India Mahapatra *et al.*, (1995) carried out studies on insecticide pollution in Indian rivers. Bartram and Balance (1996) published a practical guide to water quality monitoring regarding the design and implementation of fresh water fresh water quality studies and monitoring programmes. Mwachiro and Durve (1997) studied the bacterial status of the lake Bari, India.

A systematic study on the levels of pollutants over a period of time is a pre-request for planning strategies in any developmental programmes. Research on the chemistry, microbiology and biology will give an in depth picture about the life, stability and ecology of any living system. This has to be conducted periodically at different stations in order to assess the spatial and temporal status of pollution in a particular area. This holds critical significance to the coral Islands, as the corals are very sensitive organisms to even slight changes in the physico-chemical characteristics of the water body in which they grow. Since Kavaratti is a coral Island and increased density of human population has attained a critical stage with respect to natural resource utilization, sustainable resource management has become very essential. The environmental strategy of the Island has reached a stage where the ecological virginity should not be affected by human interference. In Kavaratti, drinking water present in thin lens, which floats over the seawater, as the only source of drinking water, also processes damage due to seawater intrusion and sewage contamination. Due to mechanised withdrawal, the water lens, available, becomes characterized by the possibility of sudden intrusion of seawater. The absence of proper sewerage system, the domestic sewage can get mixed

with the fresh water lens and produce great catastrophe. This is particularly relevant in such a way that the dug wells are very shallow, and the depth to water table is generally 0.5 to 4.0 m below ground level while the septic tanks/leach pits are about 2.0 to 2.5 m deep with overflow provision at an average depth of 0.5 to 1.0 m below ground level ie, many of the dug wells are constructed to tap the aquifer in to which these effluents are discharged. The population increase and the resultant over construction of houses without proper safety measures in this direction add to this problem. Monitoring of drinking water quality is hence very essential to alienate contamination from sewage and to prevent intrusion of saline water. Available data/ information on hydrological aspects in the island is limited, especially since groundwater is important not only from the point of view of the survival of humanity in the islands, but also from the point of view of ecology of the islands. An integrated study comprising the microbiological, chemical and biological parameters in the Seas around the island along with the drinking water quality is thus very essential in order to assess the environmental status of the Island.

Referring to the literature it is found that piece meal studies at different interval have been made to assess the status of the Island with regard to marine and fresh water pollution. It is therefore essential to have an integrated study incorporating all the environmental parameters into seas around the island and the drinking water sources. An attempt has been made to evaluate the integrated status of marine and fresh water system for a considerable period of four years. This thesis refers to the variation in microbiological, physico-chemical and biological nature of the seawater as well as microbiological and physico-chemical characteristics of drinking water sources of Kavaratti Island for 1997, 1999, 2000 & 2001.

Fig.1: Sampling Locations at Sea, Kavaratti

2. MATERIALS AND METHODS

2.1 Sample stations

In the present study, three transects were chosen. They are 1) Helipad, 2) Light House and 3) Lagoon area. Four stations viz. nearshore, 2.5, 5 & 12.5 km in open sea were fixed on a line perpendicular to the coast at every transect of Helipad and Light House while three stations were fixed in Lagoon area (Fig. 1). In Lagoon stations were fixed at nearshore, centre and reef.

2.1.1 Sample collection: Surface samples were collected from all the stations during December 1997 (post monsoon), April 1999 (pre monsoon), August 2000 (monsoon) and May 2001(monsoon).

2.1.2 Samples for microbiological analysis: Water samples for bacteriological analysis were collected in sterilised glass bottles with an overlapping rim of 300ml capacity. These samples were preserved in an icebox and analysed within three hours of collection.

2.1.3 Samples for physico-chemical analysis: Samples were collected using a clean plastic bucket. Samples for Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) were collected in narrow mouthed glass-stoppered bottles of 125ml and 300ml capacities respectively without turbulence and agitation and fixed by adding 0.5 to 1 ml of Winkler A (WA) and Winkler B (WB) and the bottles were kept in dark until analysis. Samples for the analysis of nutrients were collected in clean plastic bottles and acidified with 2 N HCl. All the wares were cleaned by soaking in 6 N HCl and subsequently washed in double distilled water. Samples for petroleum hydrocarbon analysis were collected in 2.5litre amber coloured bottle (Strickland and Parsons, 1972; Grasshoff, 1983 & APHA, 1995).

2.1.4 Samples for productivity and plankton: Samples for primary productivity measurement were collected in three BOD bottles of 300ml capacity of which two are light bottles and third one is dark bottle. One of the light bottles is treated as control and the other as light bottle. All the bottles were filled through a polythene tube fitted with a coarse nylon net piece of 180μ pore size for avoiding the entry of zooplankton. Phytoplankton and zooplankton samples were collected in plastic bottles using standard plankton nets of mesh size 55μ and 180μ respectively. 10litre water was filtered through the phytoplankton net and a 250 ml aliquot was collected. One-litre samples were collected in dark coloured plastic bottles for the estimation of chlorophyll pigment in order to analyse the phytoplankton standing crop. Zooplankton samples were collected in 250ml plastic bottles by the subsurface hauling.

Fig. 2: Map showing well stations at Kavaratti Island

2.2 Collection of dug well water samples

Water samples were collected from 30 dug wells and 2 tube wells covering the entire Island (fig.2). Samples for bacteriological analysis were collected using sterilised BOD bottles tied in a clean rope where as samples for physico-chemical analysis were collected using clean plastic bucket. The samples for bacteriogical analysis were immediately brought to the Lakshadweep Science & Technology/ PWD laboratory for analysis. Depth, diameter, presence/absence and proximity of leach pits/septic tanks to the dug wells were also noted. Possible pollution sources in the surroundings like the presence of poultry farm, coconut husk retting centre etc., were also noted down. The mode of withdrawal of water such as using conventional or mechanised mode was also noted.

2.2.1 Details of well stations

Well No.	Address of the wells	Location [10°-N; 072°-E]		Total Depth (m)	Diameter (m)	Potability status	Mode of withdrawal	Distance of septic tanks/ leach pit
1	Well near J.B School	34'52.86''	38'47.7''	3.45	1.35	Yes	Conventional	Nil
2	Well near Ottavathil Palli	34'8.16''	38'57.12''	3.77	1.50	Yes	Conventional	8 m
3	Near Chekkillam House	34'18.78''	38'35.04''	2.90	1.36	Yes	Pumping	10 m
4	c/o Kadat palli	34'27.48''	38'29.82''	2.60	1.13	Yes	Conventional	Nil
5	Well near Bader Palli	34'17.16''	38'21.12''	5.48	1.67	Yes	Conventional	Nil
6	Well c/o Puthiya palli	34'1.44''	38'10.86''	4.50	1.34	Yes	Pumping	Nil
7	Well c/o Puratha Palli	33'47.82''	38'17.94''	2.90	1.22	Yes	Pumping	Nil
8	Well c/o Andam Palli	33'39.72''	38'30.78''	3.45	1.45	Yes	Pumping	Nil
9	Well c/o Circuit House	33'28.08''	38'16.68''	4.0	1.90	Yes	Pumping	15 m
10	Well c/o Govt. Press	33'38.58''	38'3.78''	2.52	1.80	No	Conventional	10 m
11	Well c/o old Police barracks	33'20.46''	37'44.64''	4.40	1.40	No	Pumping	10 m
12	Well c/o MPSAF Quarter	33'16.44''	37'54.36''	4.05	1.46	Yes	Conventional	20 m
13	Well near Helipad	32'34.92''	37'6.24''	1.70	76	Yes	Conventional	Nil

14	Public well opposite S.B. School	34'6.54''	38'14.82''	5.12	3.75	Yes	Pumping	Nil
15	Ujara Palli	34'8.16''	38'44.94''	1.0	1	Yes	Conventional	Nil
16	TI Madrasa near north J.B School	33'52.86''	38'47.7''	3.45	1.35	No	Conventional	Nil
17	Near Kamiyana Palli	34'3.12''	38'34.08''	3.12	1.05	Yes	Conventional	20 m
18	Marakara Palli	34'6.12''	38'25.14''	3.14	1.66	Yes	Conventional	Nil
19	SB School premises	34'5.52''	38'18.24''	2.65	1.42	Yes	Conventional	
20	Front of PWD central stores	33'41.7''	37'59.22'	5.35	1	Yes	Pumping	20 m
21	Handicraft premises	33'43.86''	38'6.48''	3.05	1.78	Yes	Pumping	10 m
22	Behind Post office quarters	33'35.16''	38'24''	4.05	1.04	Yes	Pumping	15 m
23	Vetenery hospital premises	33'23.94''	38'5.16''	2.83	1.25	No	Pumping	Nil
24	PWD lab premises	33'9.9''	37'42.6''	3.05	1.5	Yes	Pumping	Nil
25	Putthi Illam, humairath house	34'16.26''	38'55.02''	3.37	2 x 2	Yes	Pumping	Nil
26	Mukkari Illam Beefuthumma house	34'15.42''	38'48.54''	4.42	1.70	Yes	Pumping	8 m
27	Kavarom Kakkada	34'24.96''	38'44.7''	3.08	1.02	Yes	Pumping	Nil
28	Bebiyoda	34'33''	38'43.5''	2.0	1.33	Yes	Pumping (occasionally)	Nil
29	Chamayatha pura	34'36.24''	38'30.84''	2.70	1.40	Yes	Pumping	Nil
30	Thithottam	34'28.44'	38'22.56''	4.52	1.20	Yes	Pumping	13 m
31	Shallow tube well in PWD lab compound	33'9.9''	37'42.6''	9.35		No		Nil
32	Deep tube well in PWD lab compound	33'9.9''	37'42.6''	15.4		No		Nil

2.3 Analytical techniques

2.3.1 Microbiological analysis

Both the sea water and dug well samples were analysed for Total Viable Count (TVC), Total coliforms (TC), Faecal coliforms (FC), Faecal streptococci (FS), *Salmonella* like organisms (SLO), *Shigella* like organisms (SHLO), *Proteus, Klebsiella* like organisms (PKLO), *Vibrio cholera* like organisms (VCLO), *Vibrio parahaemolyticus* like organisms (VPLO) and *Pseudomonas aeruginosa* like organisms (PALO). Analysis of seawater samples was carried out using spread plate technique with 0.1 to 0.5 ml sample. Membrane filter method with 1.0 to 100ml sample was used for analysis of well water.

i) Total Viable Count (TVC)

The estimation of total viable count was carried out on Nutrient Agar medium at 37°C for 24 - 96 hrs. All the colonies in the range of 30 to 300 numbers were counted as TVC.

Nutrient Agar media

Ingredients (Grams/litre) : Beef extract, 3.0; Peptic digest of animal tissue, 5.0; Agar, 15.0; Final pH 6.8 $\pm$ 0.2

23.0 grams of the dehydrated medium (M/s Hi-Media Lab. Ltd., Bombay, India) was suspended in 1000 ml of distilled water, boiled to dissolve completely, sterilised by autoclaving at 15 lbs pressure (121°C) for 15 minutes. Cooled to < 45°C and 12-15 ml of the cooled medium was poured over sterile petri plates.

ii) Total coliforms (TC)

The enumeration of total coliforms was carried out using Mac Conkey's Agar at 37°C for 24-48 hrs. Colonies having shades of pink to red colours were counted as TC.

Mac Conkey Agar

Ingredients (Grams/litre): Peptic digest of animal tissue, 17.0; Protease peptone, 3.0; Lactose, 10.0; Bile salts, 1.5; Sodium chloride, 5.0; Neutral red, 0.03; Agar, 15.0; Final pH 7.1 $\pm$ 0.2.

55.1 grams of the dehydrated medium (M/s Hi-Media Lab. Ltd., Bombay, India) was suspended in 1000 ml of distilled water, boiled to dissolve completely, sterilised by autoclaving at 15 lbs pressure (121°C) for 15 minutes. Cooled to < 45°C and 12-15 ml of the cooled medium was poured over sterile petri plates.

iii) Faecal coliforms (FC)

The faecal coliforms were estimated using M-FC Agar at 44.5°C for 24 hrs. Seawater and dug well samples were analysed for faecal coliforms using Membrane filter technique (APHA, 1995).

M-FC Agar
Ingredients (Grams/litre)

Tryptose, 10.0; Protease peptone, 5.0; Yeast extract, 3.0; Sodium chloride, 5.0; Lactose, 0.2.

2 grams of the dehydrated medium (M/s Hi-Media Lab. Ltd., Bombay, India) was suspended in 990 ml of distilled water, heated to dissolve completely, 10 ml of rosolic acid was added and heated for one more minute. Cooled to < 45°C and 12-15 ml of the cooled medium was poured over sterile petri plates.

iv) *Salmonella* like organisms (SLO)

Salmonella like organisms were screened using XLD (Xylose Lysine Deoxycholate) Agar medium for 24 - 48 hrs at 37°C and identified as red colonies with black centre.

v) *Shigella* like organisms (SHLO)

Shigella like organisms were screened using XLD (Xylose Lysine Deoxycholate) Agar for 24 - 48 hrs at 37°C and the red colonies were identified as SHLO.

vi) *Proteus & Klebsiella* like organisms (PKLO)

Proteus & Klebsiella like organisms were screened using XLD (Xylose Lysine Deoxycholate) Agar medium for 24-48 hrs at 37°C and yellow colonies are identified as PKLO.

Xylose Lysine Deoxycholate Agar (XLD)

Ingredients (Grams/litre)

Yeast extract, 3.0; L-Lysine, 5.0; Lactose, 7.5; Sucrose, 7.5; Xylose, 3.5; Sodium chloride, 5.0; Sodium Deoxycholate, 2.5; Sodium thiosulphate, 6.8; Ferric ammonium citrate, 0.8; Phenol red, 0.08; Agar, 15; Final pH, 7.4 $\pm$ 0.2

56.68 grams of the dehydrated medium was suspended in 1000 ml of distilled water and boiled to dissolve completely. Cooled to < 45°C and 12-15 ml of the cooled medium was

poured over sterile petri plates.

vii) *Vibrio cholera* like organisms (VCLO)

Vibrio cholera like organisms was screened using TCBS (Thiosulphate Citrate Bile Salt Sucrose Agar) medium at 37°C for 24 hrs. VCLO looks yellowish and were counted.

viii) *Vibrio parahaemolyticus* like organisms (VPLO)

Vibrio parahaemolyticus like organisms were screened using TCBS (Thiosulphate Citrate Bile Salt Sucrose Agar) medium at 37°C for 24 hrs.*V parahaemolyticus* like organisms form greenish colonies.

TCBS Agar

Ingredients (Grams/litre)

Peptone, special, 10.0; Yeast extract, 5.0; Sodium thiosulphate, 10.0; Sodium citrate, 10.0; Sodium cholate, 3.0; Oxgall, 5.0; Sucrose, 20.0; Sodium chloride, 10.0; Ferric citrate, 1.0; Bromothymol blue, 0.04; Agar, 15; Final pH, 8.8 $\pm$ 0.2

89.0 grams of the dehydrated medium was suspended in 1000 ml of distilled water and boiled to dissolve completely. Cooled to < 45°C and 12-15 ml of the cooled medium was poured over sterile petri plates.

ix) *Pseudomonas aeruginosa* like organisms (PALO)

PALO were isolated using Cetrimide Agar at 37°C for 24 - 48 hrs. Colonies of PALO are colourless.

Cetrimide Agar

Ingredients (Grams/litre)

Beef extract , 10.0; Peptone, 10.0; Sodium chloride, 5.0; Cetrimide, 0.3; Agar, 12; Final pH, 7.3 $\pm$ 0.1.

37.5 grams of the dehydrated medium was suspended in 1000 ml of distilled water and sterilised by autoclaving at 15 lbs pressure (121°C) for 15 minutes. Cooled to < 45°C and 12-15 ml of the cooled medium was poured over sterile petri plates.

x) Faecal streptococci (FS)

Faecal streptococci were enumerated on M-Enterococcus Agar medium at an incubation temperature of 37°C for 24 - 48 hrs. The FS colonies were identified as maroon coloured.

M-Enterococcus Agar
Ingredients (Grams/litre)
Casein enzymic hydrolysate, 15.0; Papaic digest of soyameal, 5.0; Yeast extract, 5.0; Dextrose, 2.0; Dipotassium phosphate, 4.0; Sodium azide, 0.4; 2, 3, 5 triphenyl tetrazolium chloride, 0.1; Agar, 15; Final pH, 7.2 $\pm$ 0.2

41.5 grams of the dehydrated medium (M/s Hi-Media Lab. Ltd., Bombay, India) was suspended in 1000 ml of distilled water and boiled to dissolve completely. Cooled to < 45°C, 0.5 ml of Tween 80 and 2.0 ml of sodium carbonate was added, and 12-15 ml of the cooled medium was poured over sterile petri plates.

2.3.2 Physico-chemical parameters

i) Temperature

Temperature measurements were made with calibrated mercury filled Celsius thermometer with an accuracy of 0.1°C and results were reported to the nearest 0.1 or 1.0 °C depending on need.

ii) pH

Principle

The basic principle of electrometric pH measurement is determination of the activity of the hydrogen ions by potentiometric method. pH was measured using a standard pH meter.

iii) Total suspended solids

Principle

A well mixed sample is filtered through a pre weighed 0.45 micron cellulose nitrate filter and the residue retained on the filter is dried to a constant weight at 103 105 °C. The increase in weight of the filter represents the total suspended solids.

Procedure

a) Preparation of glass-fiber filter disk.

Insert disk with wrinkled side up in filtration apparatus. Apply vacuum and wash disk with 3 successive 20 ml portions of distilled water. Continue suction to remove all traces of water, and discard washing. Remove filter from filtration apparatus and transfer to

Aluminum or stainless steel planchet as a support. Dry in an oven at 103 –105°C for 1 hr. Cool in a dessicator to balance the temperature and weighed.

Calculation

Milligrams of total suspended solids/litre $= \frac{(A - B) \times 1000}{\text{Volume of sample ml.}}$

Where, A = weight of filter + dried residue

B = weight of filter

iv) Dissolved Oxygen (DO)

DO in water samples were determined by Winkler method. Dissolved oxygen in water reacts with manganese hydroxide in strongly alkaline medium forming manganese (trivalent) hydroxide. When acidified to a pH less than 2.5, the manganese hydroxide dissolves to liberate divalent manganese. Iodine, equivalent to the original dissolved oxygen content of the water is liberated and is titrated against a standard thiosulphate solution using starch as indicator.

Reagents

Winkler- A (WA): Dissolved 400g manganous chloride in 1000ml distilled water (DW) and stored in a polyethylene bottle.

Winkler-B (WB): Separately dissolved and mixed together, 360g potassium Iodide and 100g sodium hydroxide in 1000ml DW Stored in a polyethylene bottle.

Hydrochloric acid (50%): Carefully added 50ml conc. HCl to 50 ml DW. Stored in a ground stoppered glass bottle.

Sodium thiosulphate solution (Approximately 0.02 N): Dissolved 5g sodium thiosulphate in DW and made up to 1000ml in a volumetric flask. Stored in a ground stoppered glass bottle.

Starch indicator solution: Dissolved 1g starch in 100ml hot distilled water, quickly heated the suspension to boil in order to complete the dissolution of starch, and cooled.

Standard iodate solution (0.01N): Accurately weighed 0.3567g of potassium iodate (AR) and dissolved in 1000ml DW in a volumetric flask.

Analysis

Fixed DO by adding 0.5ml of WA followed by 0.5ml of WB in a 125ml DO bottle containing the sample. Shaken well and allowed the precipitate to settle. 1ml of 1:1H_2S0_4 was added and shaken vigorously till the precipitate dissolves. 100ml of the clear solution was transferred to conical flask and titratred against thiosulphate solution till a pale yellow color appears. Added 1 ml starch solution and continued the titration until the blue color disappeared. The burette reading was noted.

Calculation. The amount of DO in 1L of sample was given by

DO (mg/l) = 8 X N X BR X V/V-1X1000/a Where N = Normality of thiosulphate solution, BR= Burette reading, V= Volume of the sampling bottle, a = Volume of the sample titrated

Note: The factor V/V-1 was included to correct the volume of reagents added to the sample bottle.

v) Inorganic phosphate

Phosphate in sea water is allowed to react with acid – ammonium molybdate, forming a phosphomolybdate complex, which is reduced by ascorbic acid in the presence of antimonyl ions (to accelerate the reaction) to a blue coloured complex containing 1:1 atomic ratio of phosphate and antimonyl ions. The extinction of the blue colour is measured at 882 nm using 5cm cell. To avoid interference by silicate, the pH is kept below 1.

Reagents

1. Sulphuric acid (9.0 N) Added carefully 250 ml concentrated sulphuric acid to a 1 litre volumetric flask containing 750 ml distilled water and dilute to 1000 ml.
2. Ammonium molybdate solution: Dissolved 1.25 g ammonium molybdate tetra hydrate (AR) in 125 ml distilled water. Stored in a plastic or glass bottle.
3. Potassium antimonyl tartrate solution: Dissolved 0.5 g potassium antimonyl tartrate (AR) in 20 ml distilled water. Stored in glass bottle.
4. Mixed reagent: Added slowly while stirring 125 ml molybdate solution to 350 ml 9.0 N H_2SO_4. Then added 20 ml tartrate solution. Mixed by shaking and stored in a glass bottle.

5. Ascorbic acid solution: Dissolved 10 g ascorbic acid in 50 ml distilled water and add 50 ml 9.0 NH_2SO_4. The reagent was stored in an amber coloured bottle, in refrigeration, and could be used for a week.
6. Phosphate standard solution: Weighed 0.1361g of potassium dihydrogen phosphate (AR) already dried at 110 ^{O}C in an oven and cooled in a dessicator and dissolved in 100 ml DW containing 1 ml of 9.0 N H_2SO_4. This solution contains 10,000 µmol PO_4^{-3} p/L.

7. Oxidation solution:

   Procedure: Transferred 5 ml of phosphate standard solution and a 500 ml volumetric flask and the volume made with distilled water. This solution contained 100 µmol PO_4^{-3} –P/L and then diluted 10 times to get 10 µmol PO_4^{-3} –P/L. 25 ml DW was taken in three tubes for blank determination. Prepared working standard solutions of 2.5µmol PO_4^{-3} –P/L and 5 µmol PO_4^{-3} –P/L and measured out 25 ml each in 3 test tubes and added to each tube, 0.5 ml of ascorbic acid reagent and mixed well. 0.5 ml of mixed reagent was added, mixed and kept for 10 minutes to develop blue complex. Absorbance of blank A (b) and standard A (st) was measured at 882 nm in a spectrophotometer using distilled water as the reference.

   25 ml of the sample was taken in glass tube and the reagents added as in the case of standard solutions. Measured the absorbance A(s) in 5 cm cuvette at 882 nm. When the samples were turbid, the absorbance A(t) was measured separately on addition of 0.5 ml ascorbic acid.

Calculations

F = 1.0

A(st)-A(b) ; Where A (st) = Means absorbance of standards,

A(b) = Means absorbance of blanks.

PO_4^{-3} -P mmol/l = F x A (s) – A (t) - A (b); where A(s) = Mean absorbance of sample.

A(t) = Mean absorbance of turbidity.

vi) Determination of reactive silicate

Principle

The seawater sample is allowed to react with molybdate under conditions, which result in the formation of silicomolybdate, phosphomolybdate and arsenomolybdate complexes. A

reducing solution, containing metol and oxalic acid is then added which reduces the silicomolybdate complex to give a blue reduction compound and simultaneously decompopses any phosphomolybdate so that interference from phosphate and arsenate is eliminated.

Reagents

1.Molybdate reagent: Dissolved 4.0g of analytical reagent quality ammonium paramolybdate, $(NH)_{46} MO_7 O_{24}.4H_2O$ in about 300ml of distilled water. Added 12 ml of concentrated hydrochloric acid, mixed and made the volume to 500ml with distilled water. Store the solution in polythene bottle.

2. Metol-sulphate solution: Dissolved 6.0g of anhydrous sodium sulphite , $Na_2 SO_3$, in 500ml of distilled water and then added 10ml of metol (p-aminophenol sulphate).

3. Oxalic acid solution: Prepared a saturated oxalic acid solution by shaking 50g of analytical reagent quality oxalic acid dihydrate $(COOH)_2, 2H_2O$ with 500ml distilled water; decant the solution from the crystals for use.

4. Sulphuric acid solution (50%v/v): Poured slowly 250ml of concentrated H_2SO_4 into 250ml of distilled water, cooled and made up to 500ml with distilled water.

5. Reducing agent: Mixed 100ml of metol-sulphate solution with 60ml of oxalic acid solution. Added slowly with mixing 60ml of the 50 % sulphuric acid solution and made the mixture to a volume of 300ml with distilled water.

Procedure

1. Added 10ml of molybdate solution into a dry 50ml conical flask and poured 25ml of water sample into the conical flask, mixed solutions and allowed to stand for 10min.
2. Added 15ml of reducing agent and mixed immediately.
3. After 2hrs measured the extinction (O.D) of the solution in a 1cm cell against distilled water at a wavelength of 810nm.

Standard

a) Dissolved 0.96g of silicofluoride, Na_2SiF_6 in 100ml distilled water and diluted to exactly 1000ml and stored this stock solution in a polyethylene container.

1ml= 5 μg at Si

b) Diluted 10ml of the stock solution to 500ml with synthetic water (25g NaCl + 8 g MgSO4. 7H2O/litre of distilled water).

25ml of the diluted standard solution is taken and carried out the silicon determination as given in the procedure.

d) Measure the extinction (O.D) in a 1cm cell at 810nm. Approximate factor value:1.O.D.

vii) Total phosphorus and Total nitrogen

Principle

Total phosphorus represents all forms of dissolved inorganic and organic species of phosphorus. Organically bound phosphorus is completely decomposed to phosphate by a strong oxidising agent (alkaline persulphate). Inorganic forms of lower oxidation state are also oxidised to inorganic phosphate. The pH of the reaction is maintained at 9.7 so that after oxidation the pH remains between 4 and 5.

Reagents

1. Ammonium free water (double distilled water)
2. Sodium hydroxide (0.375 M): Dissolved 15.0 g sodium hydroxide and diluted to 1000 ml with double distilled water, stored in a tightly stoppered polythene bottle.
3. Oxidising reagent: Dissolved 5.0 g purified potassium persulphate ($K_2S_2O_8$) and 3.0 g phosphoric acid (H_3PO_3) (AR) in 0.375 N NaOH, mixed well and stored in a tightly stoppered polythene bottle and covered with aluminium foil.
4. Standard stock organic nitrogen solution: Dissolved EDTA disodium salt (0.1862 g) in ammonia free distilled water (100 ml) and stored in a glass bottle and refrigerated. The standard contained 10μmol organic nitrogen/ml.

Calibration and determination of blank

Separately diluted each of the stock solutions of phosphate and organic nitrogen with 100 ml of ammonium free distilled water each. Pipetted out 10 ml of each solution into 250 ml volumetric flasks and volume made with ammonia free distilled water. This diluted standard solution contained 40μmol organic nitrogen/litre.

50 ml each of ammonia free distilled water and combined standard solutions were measured out in triplicate in oxidation flasks. Added 5.0 ml oxidising reagent to all the six flasks and autoclaved for 30 minutes. Swirled the flasks to dissolve any precipitate and allowed to cool. The contents of the flasks were transferred to 50 ml volumetric flask

ands diluted to the mark with distilled water. This solution contained 4 μmol NO_3=N (total)/litre.

Calculate the calibration factor (F total NO_3 μmol) = $\frac{4.0}{A\,(st) - A\,(b);}$

Where A (st) = mean absorbance of standard and A (b) = mean absorbance of blanks

For total phosphorus calibration, 25 ml digested solution was measured in glass tubes and proceeded for calibration. The calibration factor (F total P) was found out from

F total P = $\frac{4.0}{A\,(st) - A\,(b)}$

50 ml seawater sample was taken and added 5.0 ml oxidising agent and digested as described above. For total nitrogen analysis 5 ml sample was diluted to 10 times and digested. Transfer 25 ml of digested sample into clean graduated tubes and the absorbance A (s) was found out at 882 nm.

Calculated total nitrogen and total phosphorus from

Total N (μmol)/l = F total NO_3 x A (s) – A (b)

Total P (μmol)/l = F total P x A (s) – A (b); Where A (s) = mean absorbance of the sample and A (b) = mean absorbance of the blank. The results were reported in two decimal.

viii) Ammonia-nitrogen

Ammonia (NH_3^+,NH_4^+) in sea water is allowed to react with Hypochlorite in moderately alkaline solution to form Monochloramine in presence of phenol, catalytic amounts of Nitroprusside ion and excess of Hypochlorite, gives an Indophenol Blue complex between pH 8 and 11.5.To prevent precipitation of Calcium and Magnesium Hydroxide and Carbonate present in sea water Citrate buffer is added. The Absorbance is measured spectrophotometrically at 630nm.

Reagents

1. NaOH (1N)
2. Phenol Reagent (Phenol + Sodiumnitroprusside)
3. Tri-Sodium citrate buffer
4. Hypochlorite Reagent

Standard Stock Solution was prepared by using dry Analar grade Ammonium Chloride and a drop of Chloroform was added for preservation.

ix) Determination of nitrite and nitrate

The method of nitrite determination depends on reaction with an aromatic amine, sulfanilamide to form a diazonium compound, which is then coupled with N-(1-napthyl)-ethylenediamine, to form an azo dye. The absorbance of the dye is measured spectrophotometrically at 540 nm. The nitrate is first reduced to nitrite before its determination. The reduction is carried out in reductor of cadmium granules. The cadmium is either coated with Hg or Cu. The conditions are so adjusted that the nitrate is quantitatively reduced to NO_2^- but not further to NO.

Nitrite nitrogen

The nitrite in seawater was allowed to react with sulfanilamide in an acid solution. The resulting diazocompound was reacted with N-(1-naphthyl) – ethylene diamine to form a highly coloured azo dye, the absorbance of which was measured at 540 nm.

Reagents

Double distilled water (check for absence of nitrite)

Sulfanilamide solution (1%): dissolved 2.5 g sulfanilamide in 25 ml conc. hydrochloric acid and made upto 250 ml with distilled water. Stored in an amber coloured glass bottle.

n-(1-naphthyl) – ethylene diamine dihydrochloride (1%) Dissolved 0.25 g in 250 ml water and stored in an amber coloured glass bottle. Nitrite standard solution: Dissolved 0.690 g anhydrous sodium nitrite (dried at 100°C for 1 hr) in 100 ml water and diluted to 1000 ml in a volumetric flask. The solution contains 10 μmol NO_2-N/ml; the solution was stored in an amber coloured glass bottle. Nitrite working standard solution: Pipetted out 10 ml of stock solution into a 500 ml volumetric flask and diluted to 500 ml mark. Transferred 5.0 ml of this solution to another 500 ml flask and the volume made upto the mark. This standard has 2 μmol NO_2-N/l.

Procedure

25 ml each of distilled water and the working standard solution was taken in three glass tubes each. To each tube added 0.5 ml of sulfanilamide, mixed and kept for 4 minutes. 0.5 ml of n-(1-naphthyl) – ethylene diamine dihydrochloride solution was added and allowed

the reaction to proceed for 10 minutes after mixing the contents. The absorbencies of blanks and standards were measured in a 5.0 cm cell against water as reference at 543 nm.

Calculations

Calculated the factor from the relation,

$$F = \frac{\text{Conc. of standard solution}}{A(st) - A(b)}$$

where A(st) = Mean absorbance of standards

A(b) = Mean absorbance of blanks

Calculated the concentration from the relation

Nitrite-N mmol/l = F [A(s) – A(b)] where A(s) = Mean absorbance of the sample

The results were reported to one place of decimal.

Nitrate-Nitrogen

The nitrate in seawater is reduced, almost quantitatively to nitrite, by passing through a column containing copperised cadmium filings. The nitrite thus produced is determined by diazotising with sulfanilamide and coupling with N- (1-naphthyl)-ethylene diamine as described for NO_2-N. Nitrite in the sample will pass through the reduction column without change. Hence the total nitrate plus nitrite will be determined by the method. Nitrate can be found by difference.

Reagents

Double distilled water (checked for absence of nitrate and nitrite)

Ammonium chloride buffer: Dissolved 10.0 g of ammonium chloride (AR) in 1000 ml water. Stored in a polyethylene bottle and the pH adjusted to 8.5 with ammonia.

Sulfanilamide solution and N-(1-naphthyl)-ethylene diamine dihydrochloride solution: Refer the case of NO_2-N. Nitrite standard solution: Dissolved 1.011 g dry potassium nitrite (previously dried at 105°C to constant weight) in 100 ml water and made upto 1000 ml in distilled water. The stock solution contained 10 μmol/ml NO_3-N.

Nitrite working standard: The stock solution is diluted in a volumetric flask to prepare a standard having a concentration of 5 μmol NO_3-N/l. For this 5 ml of the stock solution was diluted to 1000 ml and out of this 10 ml was again diluted to 100 ml with distilled water.

Cadmium metal filings: 40-60 mesh size (E Merck No. 120882)

Copper sulphate solution (1%): 10 g CuSO4.5H2O dissolved in 1000 ml water.

Preparation of the reductor

Commercially available granulated cadmium (E Merck) was sieved and the fraction between 40 and 60 mesh was used. Removed the traces of iron particles, if any, from the cadmium filings by a magnet. Washed with acetone to remove grease and oil. Washed with 2N HCl with stirring to make the metal surface free from oxides, washed with copious amounts of water to remove all the chloride ions. Placed the cadmium in a 125 ml stoppered glass bottle and filled with copper sulphate solution. Stoppered the bottle taking care that without the air bubbles trapped inside. The bottle was rotated slowly for 2 minutes and the copper sulphate solution drained out. Washed thoroughly with distilled water until the water drained out was clear. The copperised cadmium granules were kept under water.

Packaging the reductor column

Placed a plug of glass wool at the bottom end of the column and the reservoir was filled with distilled water. The copperised cadmium filings were transferred into the column reservoir. Allowed the filings to fall freely into the column taking care that no air cavities was formed. After transferring the filings in the column, placed another piece of glass wool on the top of the filings. The cadmium filings were kept under water always to avoid getting dried.

Activation of column

Passed 50 ml of activator solution plus 50 ml of buffer through the column at a rate of 50 ml in 8 minutes and discarded these elute. Another 50 ml water plus 50 ml buffer passed through the column. Stopped the elution, leaving the water just above the filings in the column.

Procedure

Blank: Passed 50 ml water plus 50 ml buffer through the column. Discarded the first 25 ml and collected next two portions of 25 ml in the stoppered glass tubes and preserved.

Standard: Passed 50 ml of standard 5 μmol NO_3-N/l plus 50 ml buffer through the column at the rate mentioned above. Discarded the first 25 ml and collected the next two portions of 25 ml and preserved. The elution was continued till the water level was just above the filings.

Blank: Passed 50 ml water plus 50 ml buffer through the column at the same rate. The first 25 ml was discarded and the next two 15 ml portions preserved. Elution continued till the water level was just above the filings.

Sample analysis

Passed 50 ml sample plus 50 ml buffer through the column, rejected the first 25 ml and the next two portions preserved.

Blank: Collected two 25 ml portions after discarding 25 ml on passing 50 ml water plus 50 ml buffer through the column. The samples were preserved and the column left with the buffer solution.

There are six blanks, two standards and two sample solutions. 1 ml of sulfanilamide was added to each tube and kept for four minutes. Added 1 ml N-(1-napthyl) ethylene diamine dihydrochloride, mixed and waited fore 10 minutes. Measured the absorbance at 540 nm in a 1 cm cell against water.

Calculations

Factor F for nitrate was calculated from the formula

$$F = \frac{\text{Conc. of standard solution}}{A(st) - A(b)}$$

where A(st) = Mean absorbance of standards;

A(b) = Mean absorbance of blanks

The concentration of nitrate + nitrite was calculated from the relation

$C(NO_2+NO_3)$ μmol/l = F [A(s) – A(b)] where A(s) = Mean absorbance of samples

The values for nitrate was corrected using the relation

$C(NO_3)$ μmol/l = $C(NO_2+NO_3)$ – $C(NO_2)$ where the $C(NO_2)$ was the concentration of nitrite in μmol/l determined earlier.

x) Biochemical Oxygen Demand (BOD)

BOD is the amount of oxygen required by microorganisms to stabilise the degraded substances in water. Here the dissolved oxygen is analysed by Winkler method both at the start and after incubation at 20° C in a BOD incubator for five days. The amounts of DO reduced after 5 days is calculated in mg/l and termed as BOD.

Reagents: Same as in DO.

Procedure: Three BOD bottles were filled with sample making sure that no air bubble was trapped inside. DO in one bottle was found out as initial DO and the remaining two bottles incubated in a BOD incubator for 5 days to find out the final DO. The difference in the 'Initial DO' and the 'Final DO' was calculated as the measure of BOD, expressed in mg/l.

xi) Petroleum hydro carbon

Petroleum Hydrocarbon in surface seawater is defined as the compounds of crude oil and oil products containing straight, branched, saturated and aromatic rings of hydrocarbon in combination with S, N, O, Ni and Olefinic Hydrocarbons. Petroleum hydrocarbon in seawater was extracted with n-Hexane. The extract was evaporated to dryness in a Rotary evaporator at 30°C under reduced pressure and the concentrate was taken –up in n-Hexane and Fluorescence was measured at 360nm with excitation at 310nm (Fluorescence spectrophotometer).

xii) Dissolved trace metals

For the determination of dissolved trace metals, a larger volume of water was required. For this purpose, a prefiltration by GF/C and a subsequent Millipore filtration was undertaken. Prior to filtration the GF/C filter papers were cleaned with 0.01 N HCl and rinsed with distilled water. 800ml of water samples was used for the pre-concentration of metals as described by Sen Gupta *et. al.*, (1978). The organic extract was back extracted with HNO3 and the aqueous layer (A) collected. The organic layer, after back extraction was treated with perchloric acid, evaporated to dryness and re-dissolved in 0.1N HCl (B). Both the extracts (A+B) were taken in a beaker, evaporated to dryness and made to a volume of 8ml using 0.1 N HCl and analysed for metals using AAS (Perkin Elmer, AAnalyst 200). Metals free seawater was prepared by extracting twice using this technique. Spiked metal standards were added to the metal free seawater and extractions were done as described for water samples. For each set of spiked standards, three replicate analyses were conducted and calibration curve drawn. Five replicate analyses were done for one sample from each set collected during different seasons. These gave coefficients of variation of 4.20 % for Cu, 6.4-8.2% for Zn, 5.2 -6.8% for Cd, 2.3 -4.4% for Pb, 6.4-9.3% for Ni and 3.1-5.26% for Fe.

xiii) Conductivity

Conductivity is measured using a standard conductivity meter.

xiv) Chloride

Chloride is measured by argentometric method.

Argentometric method

In a neutral or slightly alkaline solution, potassium chromate can indicate the end point of $AgNO_3$ titration of chloride. AgCl is precipitated quantitatively before red Ag_2CrO_4 is formed.

Sulphide, thiosulphate and sulphate ions interfere but can be removed by treatment with H_2O_2. Orthophosphate in excess of 25 mg/l interferes by precipitating as silver phosphate. Iron in excess of 10 mg/l interferes by marking the end point.

Reagents

K_2CrO_4 solution: Dissolved 50 g K_2CrO_4 in distilled water and diluted to 1 litre with distilled water.

Standard $AgNO_3$ solution (0.0141N): Dissolved 2.395 g $AgNO_3$ in distilled water and diluted to 1 litre. Standardised against 0.0141N NaCl and stored in a brown coloured bottle. 1 ml of this solution = 500 mg of Cl^-

Standard NaCl solution (0.0141N): dissolved 824 mg of dried NaCl in distilled water and diluted to 1000 ml. 1 ml solution = 500 mg of Cl^-

Procedure

Use 100 ml sample or a suitable portion sample diluted to 100 ml. Directly titrated the samples in the pH range 7 to 10. Adjust sample pH 7 to 10 with H_2SO_4 or NaOH if it is not in this range. Added 1 ml of K_2CrO_4 indicator. Titrated with standard $AgNO_3$ titrant to pinkish yellow end point.

Standardize $AgNO_3$ titrant and establish reagent blank value by above mentioned titration method.

Calculation

$$\text{Milligrams of Cl/litre} = \frac{(A-B) \times N \times 35450}{\text{Volume of sample in ml}}$$

where, A=Volume of $AgNO_3$ for sample

B = Volume of $AgNO_3$ for blank

N = Normality of $AgNO_3$

xv) Total solids

Total solids refer to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total solids include total suspended solids, the portion of total solids retained by a filter, and total dissolved solids, the portion that passes through the filter.

Principle

A well-mixed sample was evaporated in a pre weighed dish and dried to constant weight in an oven at 103 to 105 ^{0}C. The increase in weight over that of the empty dish represents the total solids.

Preparation of evaporating dish

If volatile solids are to be measured ignite clean evaporating dish at 550 $\pm$ 50^{O}C for 1 hr in a muffle furnace. If only total solids are to be measured, heat clean dish to 103 – 105 ^{0}C, for 1 hr. Store dish in dessicator until needed. Then weighed.

Sample analysis

Choose a sample volume that will yield a residue between 2.5 mg – 200 mg. Transfer a measured volume of well-mixed sample to pre-weighed dish and evaporate to dryness on a steam bath or in a drying oven. Dry the evaporated sample for at least 1 hr in an oven at 103 - 105 ^{O}C, cool the dish in dessicator to balance temperature and weighed.

Calculation

$$\text{Milligrams of total solids/litre} = \frac{(A - B) \times 1000}{\text{Volume of sample in ml}}$$

Where,

A = (weight of dried residue + dish) B = (weight of dish).

xvi) Total alkalinity

The total content of substances in water that causes an in creased concentration of hydroxide ions either upon dissociation or as a result of hydrolysis is called alkalinity of water. Total alkalinity of water is determined by the amount of acid neutralised together with a methyl orange indicator for water titration. Total alkalinity of water is not only due to the presence of bicarbonate, carbonate, hydroxide ions, but also due to other ions that react

with acid, including humates. The presence of salts of some weak organic acids (humates) also leads alkalinity to natural waters.

Reagents

1. 0.02N H_2SO_4 ie 1 ml 0.02N H_2SO_4 = 1 mg $CaCO_3$
2. Phenolphthalein indicator
3. Methyl orange indicator

Procedure

100ml of filtered sample was taken in a conical flask and few drops of alcoholic phenolphthalein indicator were added to it. Titrated the solution with 0.02N H_2SO_4 until become colourless. If the sample was colourless after the addition of phenolphthalein indicator, added few drops of aqueous methyl orange indicator and titrated against the acid till an orange pink colour was obtained at the end point. The nature of alkalinity was then predicated from the titration as follows:-

1. If the titration to the phenolphthalein end point was zero, alkalinity was regarded as due to bicarbonate alone.
2. When there was no further titration to the methyl orange end point after the phenolphthalein end point, the alkalinity was only due to hydroxides.
3. When the phenolphthalein end point titration was half the total titration, only carbonate alkalinity was expected to be present.
4. When the phenolphthalein end point titration was greater than half the total titration, the alkalinity is due to both carbonate and hydroxides.
5. When the phenolphthalein end point was less than half the total titration, the alkalinity was due to carbonate and bicarbonates.

Calculation

$$\text{Milligrams of CaCO3/l} = \frac{\text{Volume of acid (titrant) x 1000}}{\text{Volume of sample taken}}$$

xvii) Total hardness

The hardness of water is due to the ions of calcium, magnesium and strontium dissolved in water and is determined by complexometric titration. Because calcium and magnesium are usually present in significant concentrations in natural water, hardness is defined as

the characteristic of water that represents the total concentration of just the Ca and Mg ions expressed as $CaCO_3$. Hardness of water is of two types temporary or carbonate hardness and permanent or non-carbonate hardness.

Principle

Ethylene diamine tetra acetic acid (EDTA) and its sodium salts form a chelated soluble complex when added to solution of certain metal cations. If a small amount of dye such as Erichrome Black T is added to an aqueous solution containing ca and Mg ions at a pH of 10 ± 0.1, then the solution becomes wine red. If EDTA is added as a titrant, the Ca and Mg ions will be complexed. When all of the Mg and Ca and has been complexed, the solution turns from wine red to blue. This is the end point of the titration. Mg ions must be present to yield a satisfactory end point in the titration.

Reagents

Buffer solution: dissolved 16.9 g of NH4CL in 143 ml of NH4OH, diluting this to 250 ml with deionised water.

Erichrome Black T indicator: 0.2 g dye was dissolved in 15 ml of triethanol amine with the addition of 5 ml of absolute ethanol to reduce the viscosity. Added two drops of indicator per 50 ml of the solution to be titrated.

Standard EDTA solution (0.01 M): Weighed out 3.723g of A R sodium ethylene diamine tetra acetate dihydrate (EDTA) dissolved in water and diluted to 1000 ml.

1 ml 0.01 M EDTA solution = 1 mg of $CaCO_3$

Standard calcium solution: Weighed out 1 g anhydrous $CaCO_3$ powder into a 500 ml Erlenmeyer flask. 1:1HCL was added, little at time, until all $CaCO_3$ has dissolved. Added 200 ml distilled water and boil for few minutes to expel CO_2. Cooled and added a few drops of methyl red indicator, and adjusted to the intermediate orange colour by adding (3N NH_4OH + 1; 1HCl) as required. This was diluted to 1000 ml, with distilled water. 1 ml Ca solution = 1 mg of $CaCO_3$.

Sodium hydroxide (0.1 M): 0.4 g NaOH was dissolved in 1000 ml distilled water.

Procedure

Selected a suitable volume of the sample. Added 1 to 2 ml of NH_4Cl-NH_4OH buffer solution to maintain the pH above 10. The absence of sharp end point colour change in the titration means that the indicator has deteriorated. One to two drops of the Eriochrome

Black T indicator was added. EDTA solution is then added slowly with continuous stirring. At the end point, the colour changes from wine red to blue.

Calculation

Hardness as milligrams of CaCO3/l = $\frac{A \times B \times 1000}{\text{Vol. of sample in ml}}$

where, A = Vol. of EDTA in ml required for the sample

B = Milligrams of $CaCO_3$ equivalent to 1 ml of EDTA titrant.

xviii) Calcium hardness

Principle

When EDTA is added to water containing both Calcium and Magnesium, it first combines with Ca. Ca can be determined directly with EDTA, when the pH is made sufficiently high that the Mg is largely precipitated as the hydroxide and an indicator is used that combines with Ca only.

Reagents

1.Sodium hydroxide (1 N)

4g NaOH is dissolved in 100 ml.

2. Murexide (ammonium purpurate)

0.2g murexide was mixed with 100g NaCl and ground well to get a uniform coloured mixture. Titrate immediately after adding indicator because it is unstable under alkaline conditions. This indicator changes from pink to purple at the end point.

3. Standard EDTA solution (0.01M)

Weigh out 3.723g of AR Sodium ethylene diamine tetra acetate dihydrate dissolved in water and diluted to 1000ml.

1ml 0.01m EDTA solution = 1mg of $CaCO_3$.

Procedure

50ml sample or a smaller portion diluted to 50ml was used for the test so that the Ca content is about 5 to 10mg. Added 2ml NaOH solution to increase the pH to 12 to 13. Stirred the solution and added 0.1 to 0.2g of indicator. EDTA solution was slowly added with continuous stirring to the proper end point. 1 to 2 excess drops of the titrant were added to ascertain that no further colour change was occurred.

Calculation

Milligrams of Calcium/l = $\frac{A \times B \times 0.4008}{\text{Vol. of sample in ml}}$

Calcium hardness as milligrams of $CaCO_3$/l = $\frac{A \times B \times 1000}{\text{Vol. of sample in ml;}}$

Where, A = Volume of EDTA in ml; B = Milligrams of $CaCO_3$ equivalent to 1 ml of EDTA titrant at the Ca indicator end point.

xix) Magnesium

Magnesium is estimated as the difference between total hardness and Calcium as $CaCO_3$, if interfering metals are present in non-interfering concentrations in the Calcium titration and suitable inhibitors are used in the Hardness titration.

Milligrams of Magnesium/l = [Total hardness (as milligrams of $CaCO_3$/l) – Calcium hardness (as milligrams of $CaCO_3$/l)] x 0.243]

xx) Fluoride

Fluorine, also of the halogen group, is quite from other elements in the group in its geochemistry. Unlike chloride, bromine and iodine, many of the compounds of fluorine have a low solubility. Natural concentrations of fluoride commonly range from about 0.01 to 10.0 ppm. A few water samples have been analysed which have more than 10.0 ppm, the highest reported is 67 ppm from the Union of South Africa.

It is estimated by spectrophotometrically using Spadens reagent

xxi) Sulphate

Sulphate is determined following turbidimetric method using $BaCl_2$ salt to precipitate sulphate present in the sample as Barium sulphate. The measurement is carried out spectrophotometrically at 420nm using sulphuric acid as standard.

Calculation

mg of SO_4^{2-} = Mg SO_4^{2-} x 1000/ vol. of sample

2.3.3 Biological parameters

i) Primary Productivity

Productivity was measured by light and dark oxygen bottle experiment after six hours *in-situ* incubation. The dissolved oxygen of the control bottle is measured initially and the difference in dissolved oxygen content in the light and dark bottles is calculated per day using Winkler method.

Calculation

$$\text{Gross primary productivity} = \frac{(\text{Light DO} - \text{Dark DO}) \times (12/32) \times 1000}{(\text{PQ}) \times \text{Time of incubation}}$$

Where PQ = photosynthetic coefficient which is 1.25

12/32 is a factor used to convert oxygen to carbon ie, 1 mole of O_2 (32 g) is released for each mole of carbon (12 g) fixed.

ii) Chlorophyll *a*

Chlorophyll concentration is one of the indicators of phytoplankton standing crop.

Reagents

1. $MgCO_3$ suspension 1%
2. 90 % aqueous acetone

The water sample collected for chlorophyll was filtered through Whatman GF/C filter paper of 0.47μ wetted with 1ml of $MgCO_3$ suspension to prevent the pigment degradation. Filtration was carried out with the help of vacuum pump. The paper was taken out with a clean forceps and ground in a mortor and pestle with 2-3ml acetone and added to a test tube with 90% acetone to make up the final volume to 10 ml. The tube was covered with aluminum foil and kept in refrigerator at 4°C for 24 hrs to complete the extraction of the pigment. The extract was then centrifuged at 5000rpm for 20 minutes. The supernatant was then transferred to a photometric cell and the absorbance measured with 664 nm and 750 nm. Acidified the extract in the cell with 0.1 ml, 0.1 N HCl, gently agitated and read at 665 nm and 750 nm after 90 seconds.

Calculation

Chlorophyll *a* (mg/m^3) $= 26.7\ (664b-665a)\ V_1 / V_2 \times l$

where V_1 = volume of extract in litres

V_2 = volume of sample in m^3

l = light path

664b and 665a = Optical Density of 90% acetone before and after acidification.

Phaeophytin (mg/m^3) = 26.7 (1.7 x 665a-664b) (V_1 / V_2) x l

Where, 26.7 is the absorbance correction and is equal to A x K

And A = absorbance coefficient for chlorophyll *a* at 664 nm = 11

K = Ratio expressing correction for acidification

iii) Phytoplankton

Phytoplankton samples were concentrated by membrane filtration technique using Whatman No. 42 filter and the concentrate was used for identification under biological microscope (Olympus CH 20)) Triplicate analyses were carried out for each sample. The density was expressed in cell nos/litre and the abundance of genera was noted following the method of Santhanam *et al.*, 1987.

iv) Zooplankton

Zooplankton identification was carried out with the help of binocular stereo zoom microscope (Olympus SZ 60) and biomass was found out by displacement volume measurement. The zooplankton samples were filtered through a piece of net of same mesh used for the collection. The filtered sample was then transferred to a measuring cylinder having a known volume of 4% formalin. From the difference between the initial and final reading, the volume of sample was calculated and expressed value in ml/m^3

10cfu/ml was recorded during 1997 and 1999. It was not detected during 2000 when it ranged from nil (5.0 and 12.5 km) to 25cfu/ml (nearshore station) during 2001 (chart 12). *Salmonella* like organisms were not reported during 1997, 1999 and 2000 whereas, only 5 cfu/ml was reported from the nearshore during 2001(chart 13). SHLO varied from nil (5.0 and 12.5 km stations) to 25 cfu/ml (nearshore) during 1997, 15 cfu/ml (5.0 km) to 35 cfu/ml (nearshore) during 1999, nil (5.0 and 12.5 km stations) to 40 cfu/ml (nearshore) during 2000 and nil (5.0 and 12.5 km offshore) to 50 cfu/ml (2.5 km) during 2001(chart 14). *Proteus* and *Klebsiella* like organisms ranged from nil (2.5 km station) to 15 cfu/ml (nearshore) during 1997, 10 cfu/ml (5.0 km) to 45 cfu/ml (nearshore) in 1999, nil at 5.0 km onwards to 15 cfu/ml (nearshore) in 2000 and nil (12.5 km) to 45 cfu/ml (nearshore) during 2001(chart 15). The count of *Vibrio cholera* like organisms varied from 45 cfu/ml (nearshore) to 120 cfu/ml (5.0 km) in 1997, nil (5.0 km station) to 145 cfu/ml (nearshore) during 1999, 25 cfu/ml (12.5 km station to 205 cfu/ml (nearshore) in 2000 and nil (2.5 km) to 85 cfu/ml (5.0 km offshore) during 2001(chart 16). VPLO ranged from nil (5.0 and 12.5 km offshore) to 110 cfu/ml (2.5 km station) in 1997, 25 cfu/ml (12.5 km) to 75 cfu/ml (nearshore) in 1999, 15 cfu/ml (12.5 km offshore) to 115 cfu/ml (nearshore) during 2000 and nil (nearshore and 2.5 km stations) to 115 cfu/ml (12.5 km offshore) during 2001(chart 17). *Pseudomonas* sp. was not recorded from any station during 1997, 1999 and 2000 when a maximum count of 10cfu/ml was recorded from the nearshore during 2001. SFLO ranged from nil (at all other stations) to 100 cfu/ml (nearshore) in 1997 and nil (5.0 and 12.5 km) to 15 cfu/ml (nearshore) and (2.5 km) in 1999, nil (5.0 km onwards) to 80 cfu/ml (nearshore) during 2000. During 2001, they were enumerated only from the nearshore (chart 18).

230 cfu/ml (nearshore station) respectively in 2000 and 2001 (Chart6). *Vibrio cholera* like organisms (VCLO) varied from 100 cfu/ml (2.5 and 5.0 km offshore) to 200cfu/ml (nearshore) in 1997, 20 cfu/ml (5.0 km station) to 130 cfu/ml (nearshore) during 1999, 40 cfu/ml (5.0 km) to 130 cfu/ml (nearshore) in 2000 and nil (nearshore) to 40 cfu/ml (5.0 km and 12.5 km offshore) during 2001 (Chart7). *V. parahaemolyticus* like organisms (VPLO) ranged from nil (nearshore and 2.5 km stations) to 90 cfu/ml (12.5 km offshore) in 1997, 25 cfu/ml (5.0 and 12.5 km) to 120 cfu/ml (2.5 km station) in 1999, nil (nearshore and 2.5 km) to 80 cfu/ml (12.5 km offshore) during 2000 and 45 cfu/ml (12.5 km offshore) to 80 cfu/ml (5.0 km offshore) during 2001(Chart8). *Pseudomonas aeruginosa* like organisms (PALO) were not recorded from any station during all the sampling periods. *Streptococcus faecalis* like organisms (SFLO) ranged from nil (all other stations) and 40 cfu/ml (nearshore) in 1997 and nil (nearshore, 5.0 and 12.5 km stations) to 10cfu/l (2.5 km) in 1999. It showed a maximum count of 150cfu/ml and 10cfu/ml (nearshore) respectively during 2000 and 2001 when all the other stations did not enumerate them.

Helipad transect

TVC in water samples varied from 120 cfu/ml (2.5 km station) to 280 cfu/ml (nearshore) in 1997, 240 cfu/ml (12.5 km offshore) to 1850 cfu/ml (nearshore) in 1999, 875 cfu/ml (12.5 km) to 1480 cfu/ml (nearshore) in 2000 and 425 cfu/ml (5.0 km) to 730 cfu/ml (12.5 km offshore) during 2001 (chart 10). TC varied from nil (5.0 km and 12.5 km stations) in 1997 to 45 cfu/ml (nearshore) and 10 cfu/ml (12.5 km) to 235 cfu/ml (nearshore) in 1999, nil (5.0 and 12.5 km station)s to 220 cfu/ml (nearshore station) in 2000 and nil (5.0 km and 12.5 km stations) to 55 cfu/ml (nearshore) during 2001(chart 11). *E.coli* like organisms ranged from nil at all stations except the nearshore where 10cfu/ml was recorded during 1997 and

1999. It was not detected during 2000 when it ranged from nil (5.0 and 12.5 km) to 25cfu/ml (nearshore station) during 2001 (chart 12). *Salmonella* like organisms were not reported during 1997, 1999 and 2000 whereas, only 5 cfu/ml was reported from the nearshore during 2001(chart 13). SHLO varied from nil (5.0 and 12.5 km stations) to 25 cfu/ml (nearshore) during 1997, 15 cfu/ml (5.0 km) to 35 cfu/ml (nearshore) during 1999, nil (5.0 and 12.5 km stations) to 40 cfu/ml (nearshore) during 2000 and nil (5.0 and 12.5 km offshore) to 50 cfu/ml (2.5 km) during 2001(chart 14). *Proteus* and *Klebsiella* like organisms ranged from nil (2.5 km station) to 15 cfu/ml (nearshore) during 1997, 10 cfu/ml (5.0 km) to 45 cfu/ml (nearshore) in 1999, nil at 5.0 km onwards to 15 cfu/ml (nearshore) in 2000 and nil (12.5 km) to 45 cfu/ml (nearshore) during 2001(chart 15). The count of *Vibrio cholera* like organisms varied from 45 cfu/ml (nearshore) to 120 cfu/ml (5.0 km) in 1997, nil (5.0 km station) to 145 cfu/ml (nearshore) during 1999, 25 cfu/ml (12.5 km station to 205 cfu/ml (nearshore) in 2000 and nil (2.5 km) to 85 cfu/ml (5.0 km offshore) during 2001(chart 16). VPLO ranged from nil (5.0 and 12.5 km offshore) to 110 cfu/ml (2.5 km station) in 1997, 25 cfu/ml (12.5 km) to 75 cfu/ml (nearshore) in 1999, 15 cfu/ml (12.5 km offshore) to 115 cfu/ml (nearshore) during 2000 and nil (nearshore and 2.5 km stations) to 115 cfu/ml (12.5 km offshore) during 2001(chart 17). *Pseudomonas* sp. was not recorded from any station during 1997, 1999 and 2000 when a maximum count of 10cfu/ml was recorded from the nearshore during 2001. SFLO ranged from nil (at all other stations) to 100 cfu/ml (nearshore) in 1997 and nil (5.0 and 12.5 km) to 15 cfu/ml (nearshore) and (2.5 km) in 1999, nil (5.0 km onwards) to 80 cfu/ml (nearshore) during 2000. During 2001, they were enumerated only from the nearshore (chart 18).

Lagoon transect

The TVC in water samples varied from 480 cfu/ml (nearshore station) to 640 cfu/ml (centre) in 1997, 540 cfu/ml (the reef region) to 2230 cfu/ml (nearshore) in 1999, 1480 cfu/ml (the reef) to 2460 cfu/ml (nearshore) in 2000 and 1230 cfu/ml (nearshore) station to 14500 cfu/ml (reef station) during 2001 (chart 19). TC count varied from 175 cfu/ml (nearshore) to 370 cfu/ml (the centre) in 1997, 45 cfu/ml (the reef station) to 215 cfu/ml (nearshore) in 1999, 590 cfu/ml (the reef) to 860 cfu/ml at the centre in 2000 and 48 cfu/ml (nearshore and centre regions) to 4000 cfu/ml (the reef region) during 2001 (chart 20). *E.coli* like organisms ranged from nil (the nearshore) to 40 cfu/ml (the centre) during 1997, nil (the reef) to 140 cfu/ml (the nearshore) in 1999. They were not detected during 2000, when varied from nil (nearshore and the reef) to 5 cfu/ml (the centre) during 2001 (chart 21). *Salmonella* sp. was not reported from centre and reef whereas the nearshore reported a count of 10 cfu/ml during 1997, nil (centre and the reef) to 25 cfu/ml (nearshore) in 1999 and nil during 2000 and 2001 ((chart 22). SHLO varied from 30 cfu/ml at centre to 110 cfu/ml at the reef during 1997, from 30 cfu/ml at reef to 120 cfu/ml (the nearshore) during 1999, 35 cfu/ml (the reef) to 60 cfu/ml at the centre during 2000 and 190 cfu/ml at the nearshore to 400 cfu/ml at the reef during 2001 (chart 23). *Proteus* and *Klebsiella* like organisms ranged from 20 cfu/ml at the nearshore to 40 cfu/ml at the centre during 1997, 25 cfu/ml at the reef to 145 cfu/ml at the nearshore in 1999, 25 cfu/ml (nearshore and the reef) to 30 cfu/ml (the centre) in 2000 and 72 cfu/ml (the centre) to 500 cfu/ml (the reef) during 2001 (chart 24). The count of *Vibrio cholera* like organisms varied from 70 cfu/ml (nearshore) to 120 cfu/ml (the reef) in 1997, 70 cfu/ml (the reef station) to 280cfu/ml at the

nearshore during 1999, 145 cfu/ml at the centre to 180 cfu/ml (nearshore) in 2000 and 45 cfu/ml (centre) to 700 cfu/ml (the reef) during 2001 (chart 25). VPLO ranged from nil at (the reef station) to 20 cfu/ml (the centre) in 1997, nil (the reef) to and 85 cfu/ml (nearshore) in 1999, 110 cfu/ml (the reef) to 165 cfu/ml at (nearshore) during 2000 and nil (nearshore station) to 500 cfu/ml (the reef) during 2001 (chart 26). *Pseudomonas* sp. was not recorded from any station during the study. SFLO ranged from 70 cfu/ml (the reef) to 120 cfu/ml (the nearshore) in 1997, 60 cfu/ml (the reef) to 95cfu/ml (the nearshore) during 1999, 210 cfu/ml (the centre) to 400 cfu/ml (the nearshore) in 2000 and nil (nearshore) to 1400 cfu/ml at the reef during 2001(chart 27).

In Lighthouse, the highest TVC noticed was 1800 cfu/ml during 1999 April and 2000 August; and in Helipad transect, the highest count being in 1999 (4850 cfu/ml) followed, 480 cfu/ml during 2000 August. Higher bacterial population was observed during 2001 May from the reef waters. Among the seaward transects, wide variation in TVC was noticed. Nearshore samples recorded the highest counts in the lagoon indicating the input of more assimilable organic matter into the lagoon. Highest bacterial population was reported earlier at subsurface waters (Nair *et al.*, 1979 and Paul *et al.*, 1976). In the present study the TVC values are higher as compared to the earlier reports. Earlier reports by Santha Nair recorded the marine TVC around 50 cfu/ml. Higher bacterial densities of about $1x10^9$ cells/l were observed during inter-monsoon periods of September and April/May in Central and Eastern Arabian Sea by Ramaiah *et al.*, 1996. They found that TVC was higher during inter-monsoon period compared to southwest monsoon period of July/August and winter monsoon period of February/March. Although primary production was low during April/May, bacterial production was higher during this period unlike July/August. Lee and Lee, 1991, also studied the seasonal distribution and character of

heterotrophic marine bacteria in the inter tidal zone of the yellow sea near Kusan Korea were the population ranged from 7.5 x 10^2 to 1.1 x 10^5cfu/ml in water. This shows that the heterotrophic activity in the Lakshadweep water is much lower. The studies conducted by Alavandi in 1989 in the coastal waters of Cochin showed the TVC in the range of 0.5 to 24.5 x 10^5cfu/ml. This also proves that the heterotrophic population in Lakshadweep is much lower.

Total coliforms were also high during May-June period of 2001 during the onset of monsoon season compared to sea side transects, the nearshore waters in the lagoon during 2000 August showed higher counts of coliforms. This can be attributed to the waste discharged to the Sea during rain. The offshore stations being a distance of 2.5 km seldom showed the presence of coliforms. This was true in the case of faecal coliforms too, which contamination is immediately seen only in the nearshore waters. Even in lagoonal waters, the faecal contamination is limited up to the central part of the nearshore region. The bacterial standard for marine bathing water suggested by the WHO is less than 350 faecal coliform or 1000 total coliform per 100 ml. (Ferguson and Johannes, 1975). In Kavaratti lagoon, this limit is also found often exceeded. Under normal conditions *E.coli* can not multiply in marine environment (Enzinger and Cooper, 1976), but when seawater contains more than 100 mg/l of organic substances, *E.coli* grows and holds its own against marine bacteria.

Salmonella can multiply in water outside the host animal, if the protein concentration in the water is high enough (Gerlach, 1981). *Shigella* like organisms (SHLO) and *Proteus*, *Klebsiella* like organisms (PKLO) were also noticed in large number from the lagoonal waters and open sea, though the numbers were high in lagoon samples. Organisms like *Vibrio cholera* and *V*

parahaemolyticus in high numbers in the lagoon and in the nearshore region is also a clear indication of contamination.

Though organism like *Pseudomonas aeruginosa*, pathogen causing wound infections, is rarely seen in sea water, *Streptococus faecalis* like organisms (SFLO), the rapid indicator of faecal contamination were enumerated from the lagoon irrespective of season. SFLO was noticed from nearshore samples of the sea side transects but not in offshore indicating anthropogenic activity. Their absence in the offshore samples indicates their inability to survive in the seawater for longer periods.

Potential pathogens such as *Salmonella* like organisms, though rare were also noticed in lagoon during 1997, nearshore region of lighthouse during 1999 and helipad during 2001. This observation is attributed to the habits of open defecation in seashore still prevalent in the island.

For bathing, contact water sports and commercial fishing, the faecal coliform density fixed by pollution control board (Central Pollution Control Board, 1986) was 100 cfu/100 ml with the average value not exceeding 200 cfu/100 ml in 20 percent of samples in an year and in three consecutive samples in monsoon months. The lagoon waters of Kavaratti often exceeded this limit and found even extending the counts to 140 x 10^2 cfu/100 ml. This is true many times in the case of Lighthouse and Helipad transect were it is recorded up to 25 x 10^2 cfu/100 ml. Though the faecal coliforms in the nearshore waters of seaside are high, there occurrence in the offshore samples could not be detected. Care has to be exercised in the case of using lagoon waters for recreation purpose where the faecal contamination was observed up to the reef region.

Table 1. Microbiological characteristics of surface waters of Lighthouse transect; 1997-2001

Unit: Colony Forming Units/ml (CFU/ml)

Year	Distance from the shore	TVC	TC	ECLO	SLO	SHLO	PKLO	VCLO	VPLO	PALO	SFLO
1997	NEARSHORE	320	62	30	ND	10	ND	200	ND	ND	40
1999		1800	815	70	10	25	35	130	115	ND	ND
2000		1800	245	ND	ND	30	25	130	ND	ND	150
2001		490	45	15	ND	155	230	ND	65	ND	10
1997	2.5KM	200	40	ND	ND	ND	15	100	ND	ND	ND
1999		1170	160	ND	ND	20	15	40	120	ND	10
2000		1470	90	ND	ND	ND	20	45	ND	ND	55
2001		230	10	8	ND	100	100	10	50	ND	ND
1997	5.0KM	120	ND	ND	ND	10	25	100	75	ND	ND
1999		800	ND	ND	ND	ND	ND	20	25	ND	ND
2000		1025	ND	ND	ND	ND	ND	40	20	ND	ND
2001		385	15	ND	ND	ND	ND	40	80	ND	ND
1997	12.5KM	100	ND	ND	ND	15	30	110	90	ND	ND
1999		1300	ND	ND	ND	10	ND	30	25	ND	ND
2000		910	ND	ND	ND	ND	ND	110	80	ND	ND
2001		230	ND	ND	ND	ND	ND	40	45	ND	ND

TVC- Total Viable Count; TC- Total Coliforms; ECLO- *E.coli* like organisms; SLO- *Salmonella* like organisms; SHLO- *Shigella* like organisms;
PKLO-*Proteus*, *Klebsiella* like organisms; VCLO- *Vibrio cholera* like organisms; VPLO- *V. parahaemolyticus* like organisms;
PALO- *Pseudomonas aeruginosa* like organisms; SFLO- *Streptococcus faecalis* like organisms
ND - Not detected at the time of enumeration.

Table 2. Microbiological characteristics of surface waters at Helipad transect; 1997-2001

Unit: Colony Forming Units/ml (CFU/ml)

Year	Distance from the shore	TVC	TC	ECLO	SLO	SHLO	PKLO	VCLO	VPLO	PALO	SFLO
1997	NEARSHORE	280	45	10	ND	25	15	45	70	ND	100
1999		1850	235	10	ND	35	45	145	75	ND	15
2000		1480	220	ND	ND	40	15	205	115	ND	80
2001		550	55	25	5	40	45	15	ND	10	20
1997	2.5KM	120	10	ND	ND	10	ND	100	110	ND	ND
1999		1160	110	ND	ND	30	35	135	60	ND	15
2000		1390	10	ND	ND	35	10	75	65	ND	10
2001		480	28	16	ND	50	20	ND	ND	ND	ND
1997	5.0KM	190	ND	ND	ND	ND	10	120	ND	ND	ND
1999		575	30	ND	ND	15	10	ND	45	ND	ND
2000		935	ND	ND	ND	ND	ND	40	30	ND	ND
2001		425	ND	ND	ND	ND	10	85	70	ND	ND
1997	12.5KM	150	ND	ND	ND	ND	10	60	ND	ND	ND
1999		240	10	ND	ND	25	35	110	25	ND	ND
2000		875	ND	ND	ND	ND	ND	25	15	ND	ND
2001		730	ND	ND	ND	ND	ND	75	115	ND	ND

TVC- Total Viable Count; TC- Total Coliforms; ECLO- *E.coli* like organisms; SLO- *Salmonella* like organisms; SHLO- *Shigella* like organisms;
PKLO-*Proteus*, *Klebsiella* like organisms; VCLO- *Vibrio cholera* like organisms; VPLO- *V. parahaemolyticus* like organisms;
PALO- *Pseudomonas aeruginosa* like organisms; SFLO- *Streptococcus faecalis* like organisms
ND - Not detected at the time of enumeration.

Table 3. Microbiological characteristics of the Lagoon waters; 1997-2001

Unit: Colony Forming Units/ml (CFU/ml)

Year	Distance from the shore	TVC	TC	ECLO	SLO	SHLO	PKLO	VCLO	VPLO	PALO	SFLO
1997	NEARSHORE	480	175	ND	10	40	20	70	18	ND	120
1999		2230	215	140	25	120	145	280	85	ND	95
2000		2460	660	ND	ND	45	25	180	165	ND	400
2001		1230	48	ND	ND	190	85	90	ND	ND	ND
1997	CENTRE	640	370	40	ND	30	40	110	20	ND	80
1999		1860	60	40	ND	40	110	175	10	ND	80
2000		1860	860	ND	ND	60	30	145	145	ND	210
2001		1480	48	5	ND	240	72	45	15	ND	145
1997	REEF	600	200	15	ND	110	30	120	ND	ND	70
1999		540	45	ND	ND	30	25	70	ND	ND	60
2000		1480	590	ND	ND	35	25	170	110	ND	250
2001		14500	4000	ND	ND	400	500	700	500	ND	1400

TVC- Total Viable Count; TC- Total Coliforms; ECLO- *E.coli* like organisms; SLO- *Salmonella* like organisms; SHLO- *Shigella* like organisms;
PKLO-*Proteus*, *Klebsiella* like organisms; VCLO- *Vibrio cholera* like organisms; VPLO- *V. parahaemolyticus* like organisms;
PALO- *Pseudomonas aeruginosa* like organisms; SFLO- *Streptococcus faecalis* like organisms
ND - Not detected at the time of enumeration.

Chart 1: Total viable count in Seawater at Light house transect; 1997-2001

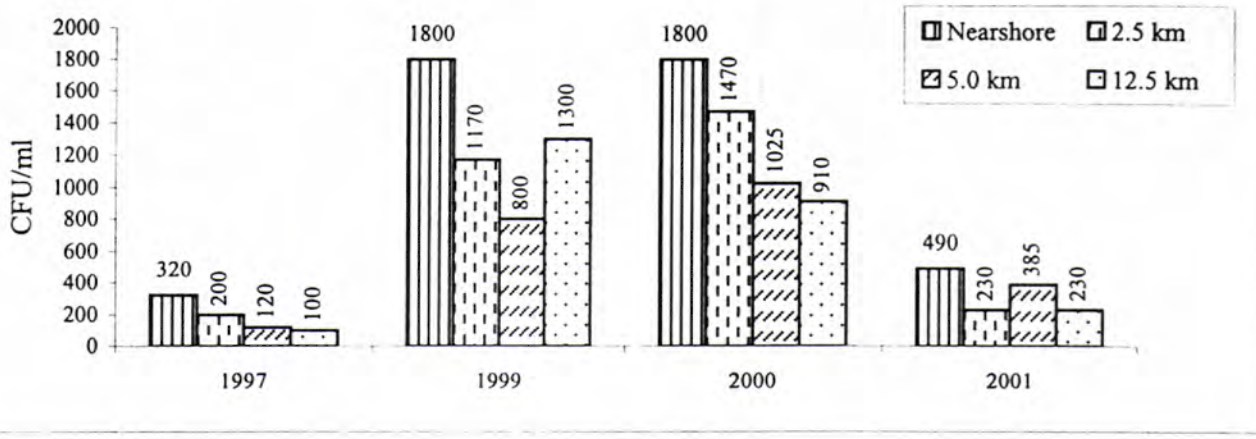


Chart 2: Total coliforms in Seawater at Light house transect; 1997-2001

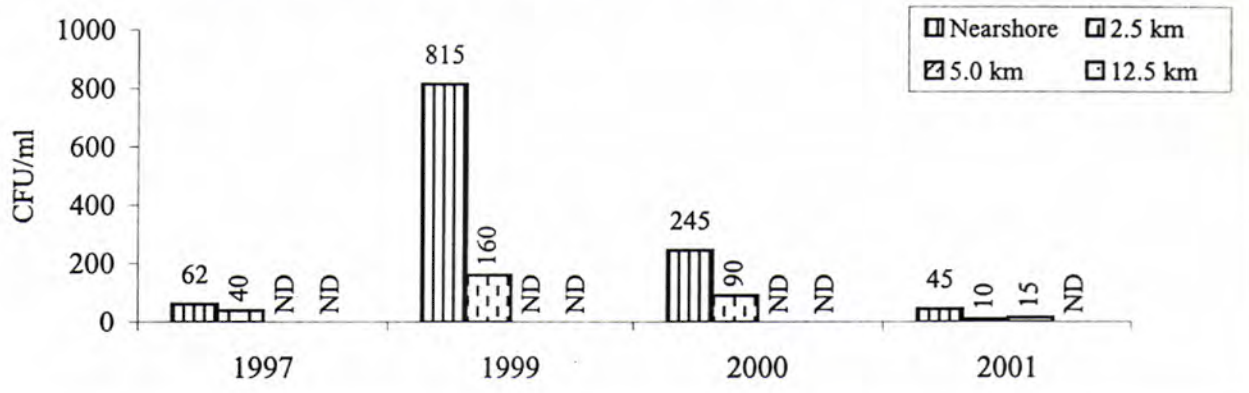


Chart 3: ECLO in Seawater at Light house transect; 1997-2001

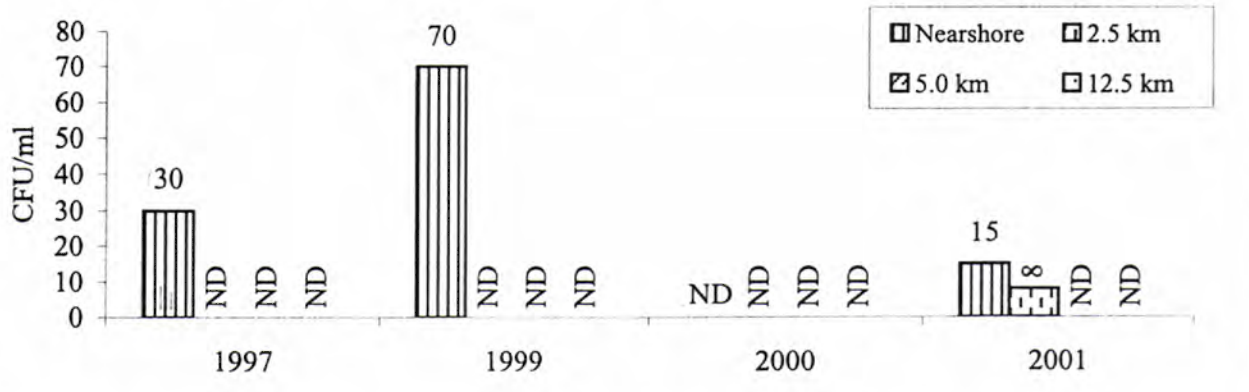


Chart 4: SLO in Seawater at Light house transect; 1997-2001

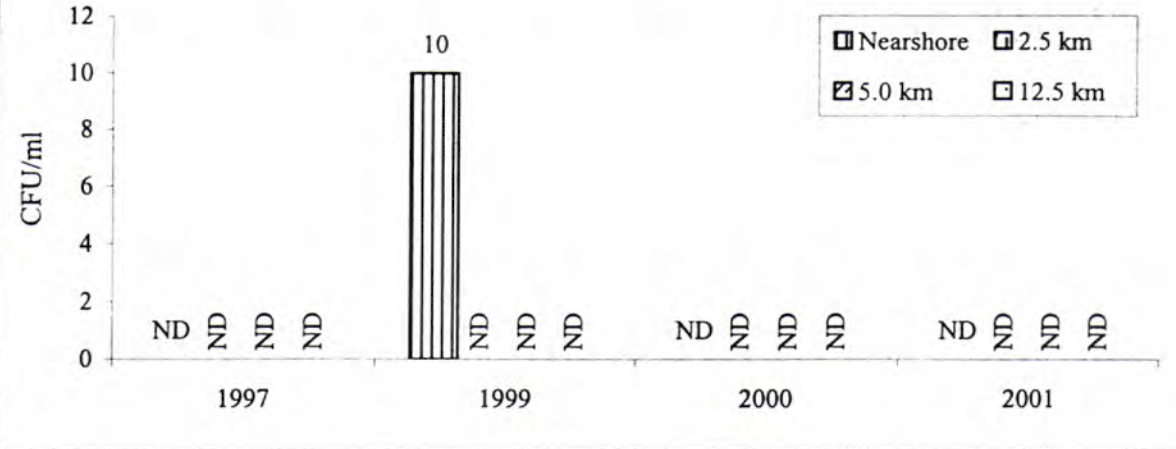


Chart 5: SHLO in Seawater at Light house transect; 1997-2001

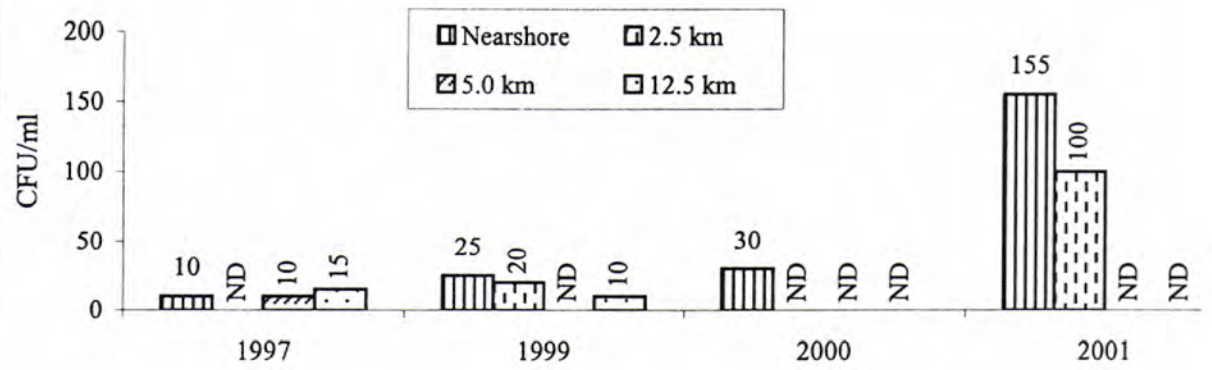


Chart 6: PKLO in Seawater at Light house transect; 1997-2001

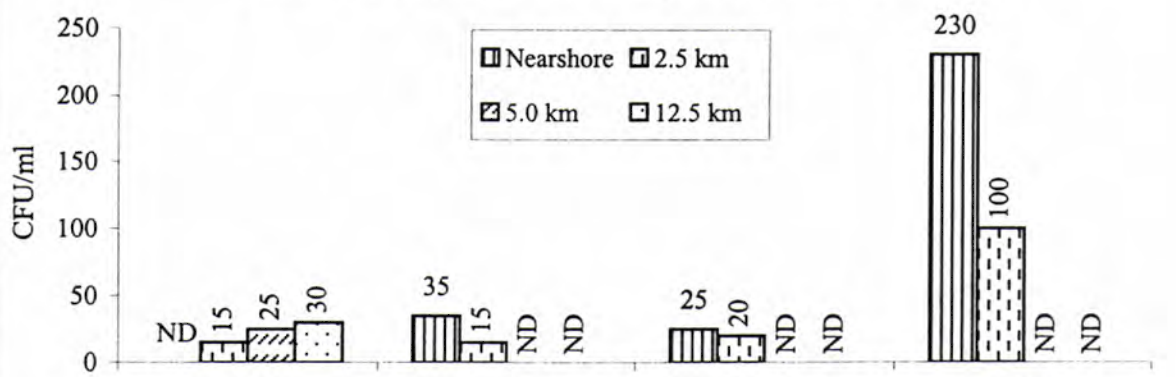


Chart 7: VCLO in Seawater at Light house transect; 1997-2001

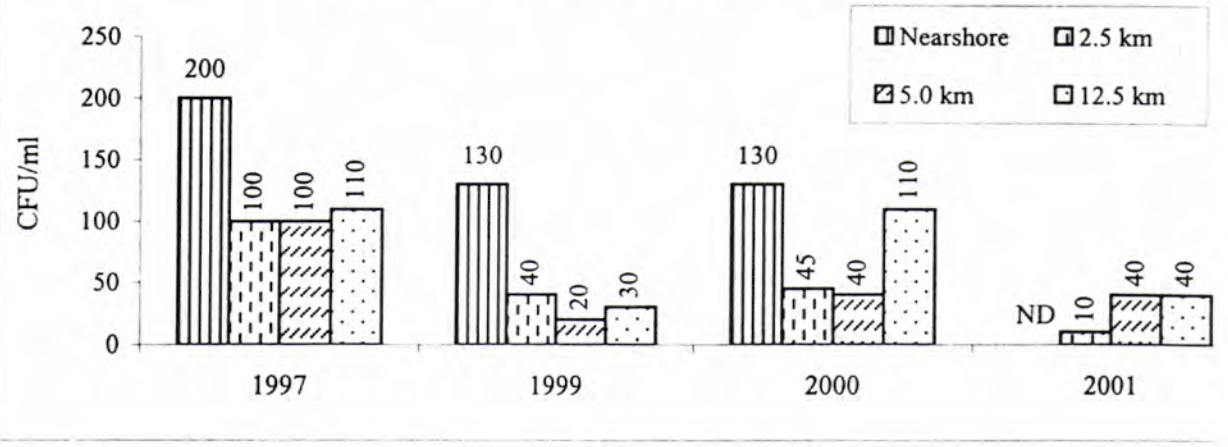


Chart 8: VPLO in Seawater at Light house transect; 1997-2001

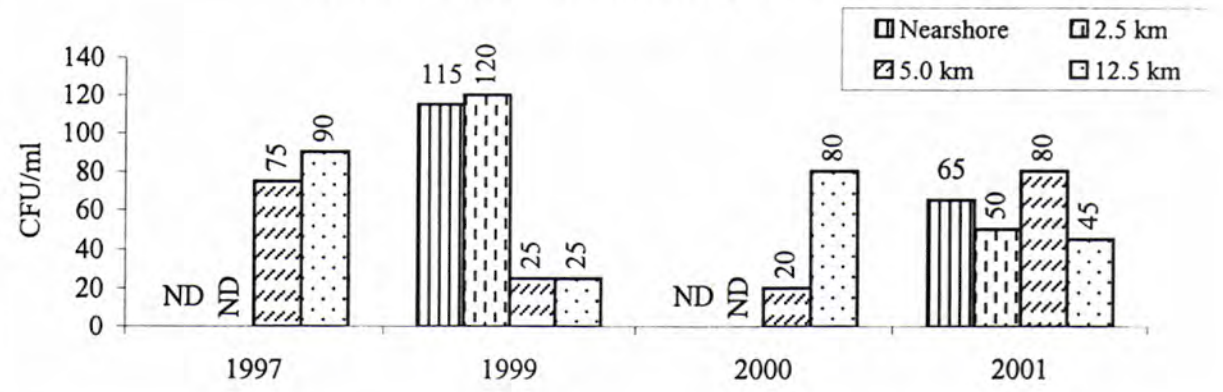


Chart 9: SFLO in Seawater at Light house transect; 1997-2001

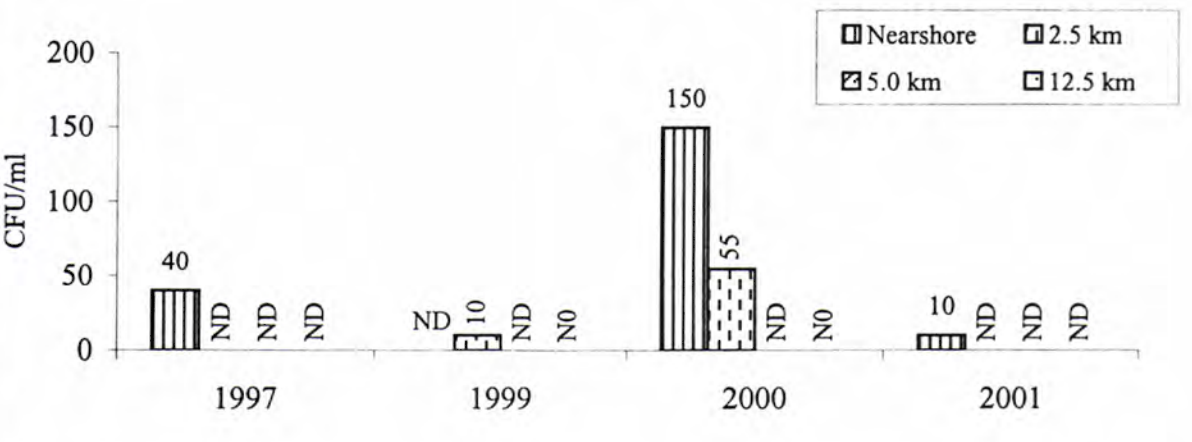


Chart 10: Total viable count in Seawater at Helipad transect; 1997-2001

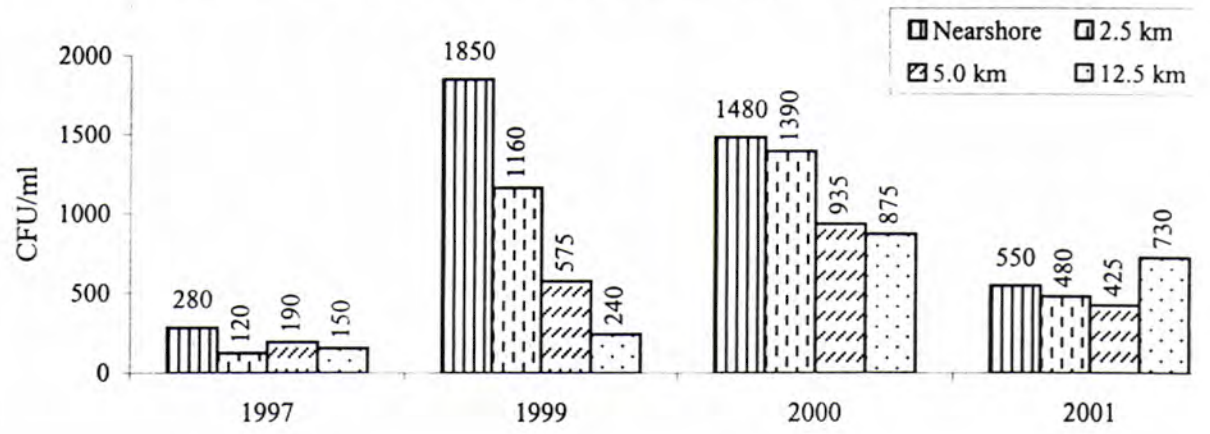


Chart 11: Total coliforms in Seawater at Helipad transect; 1997-2001

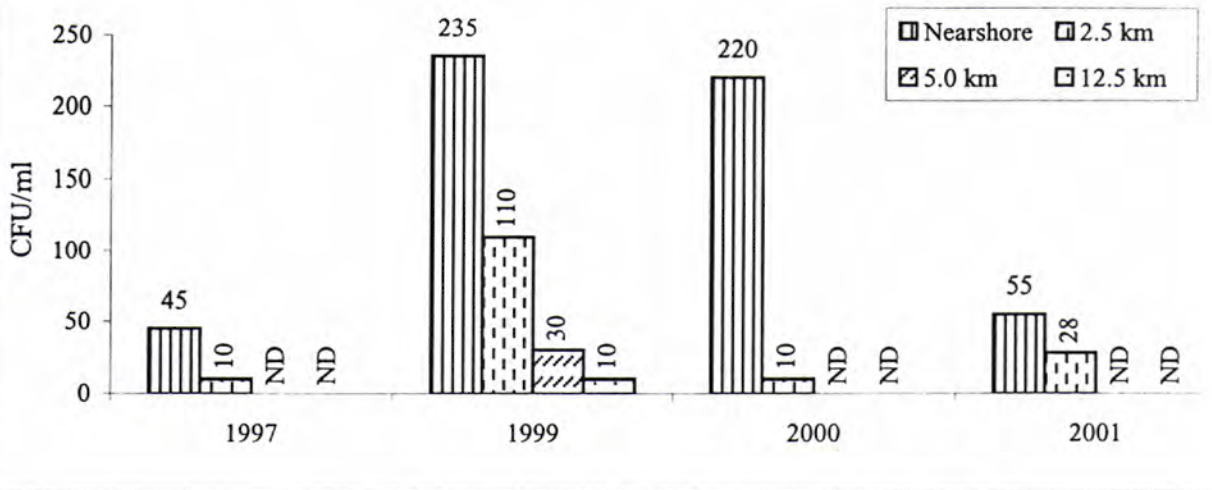


Chart 12: ECLO in Seawater at Helipad trasect; 1997-2001

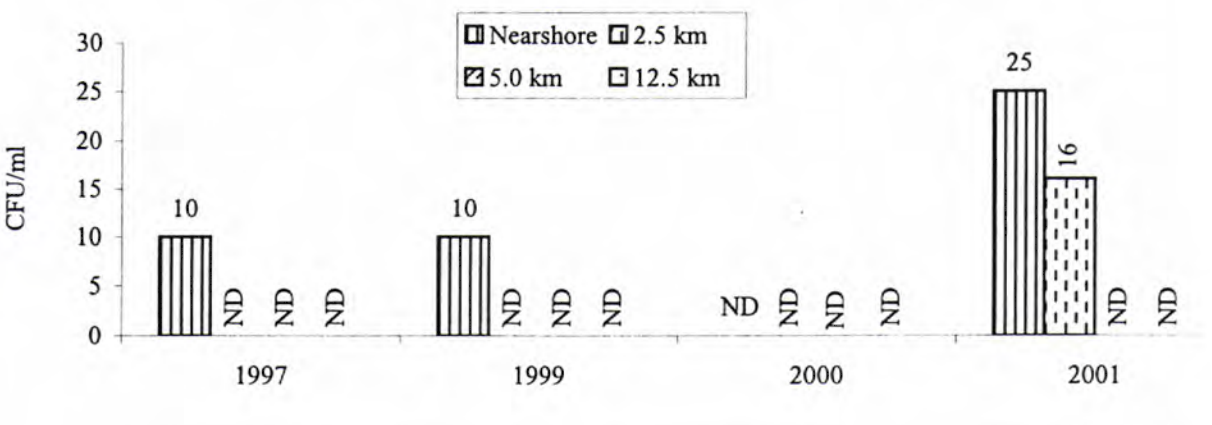


Chart 13: SLO in Seawater at Helipad transect; 1997-2001

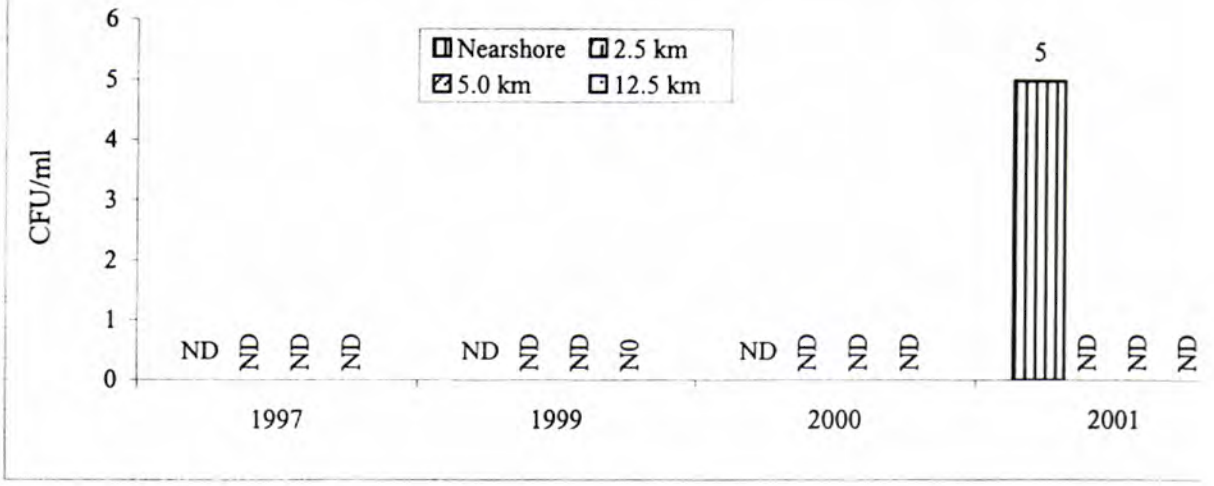


Chart 14: SHLO in Seawater at Helipad transect; 1997-2001

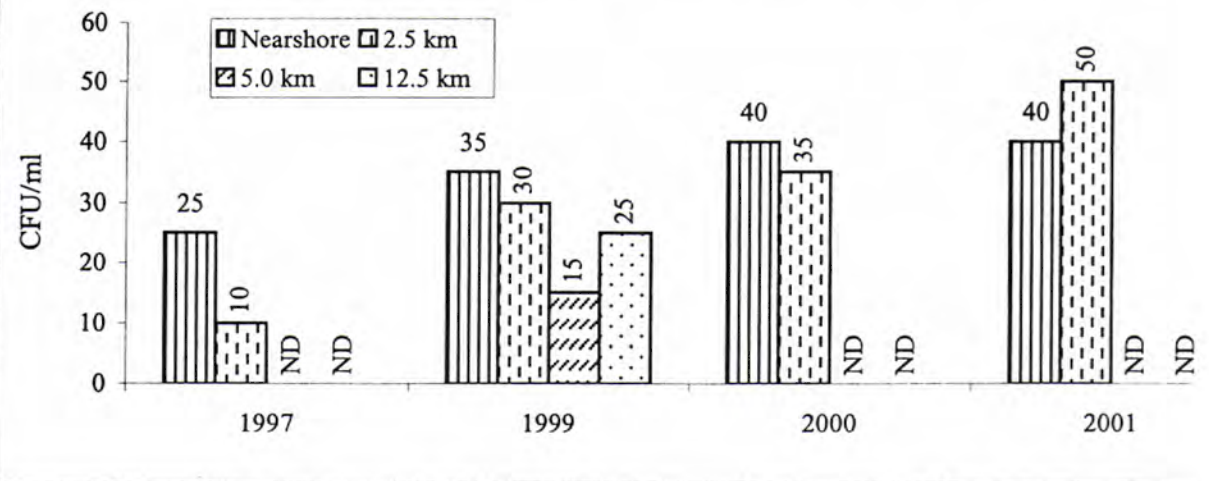


Chart 15: PKLO in Seawater at Helipad transect; 1997-2001

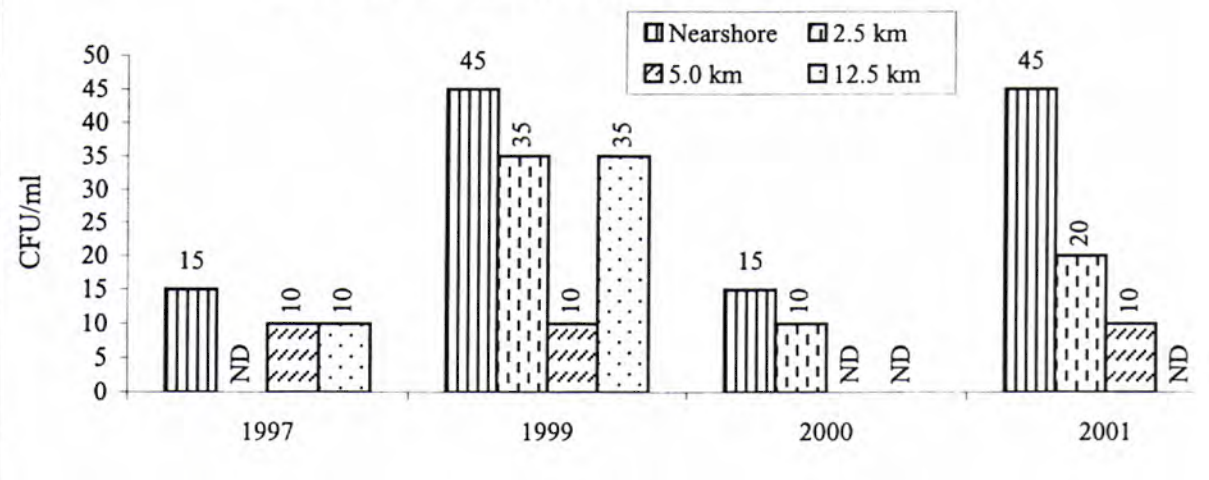


Chart 16: VCLO in Seawater at Helipad transect; 1997-2001

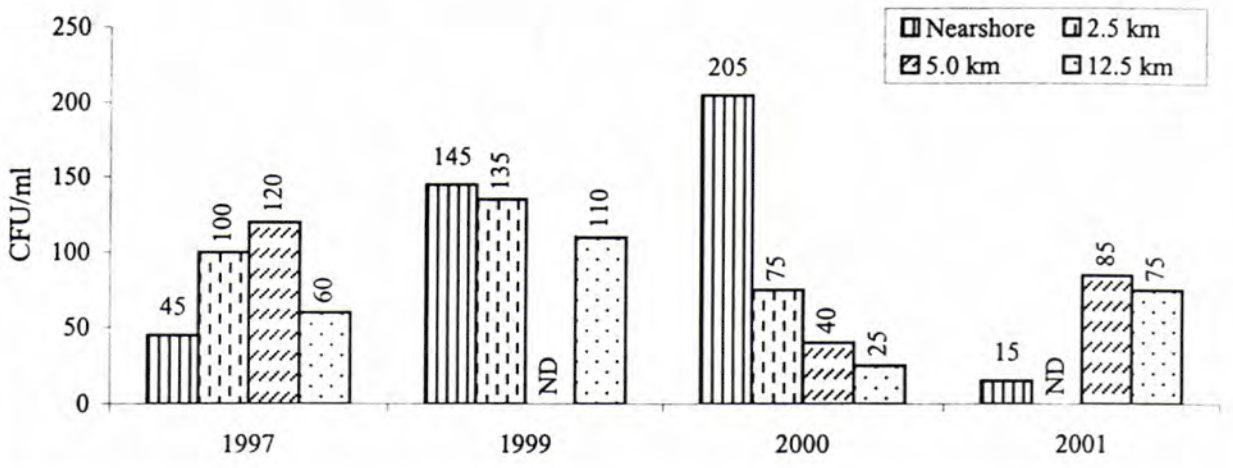


Chart 17: VPLO in Seawater at Helipad transect; 1997-2001

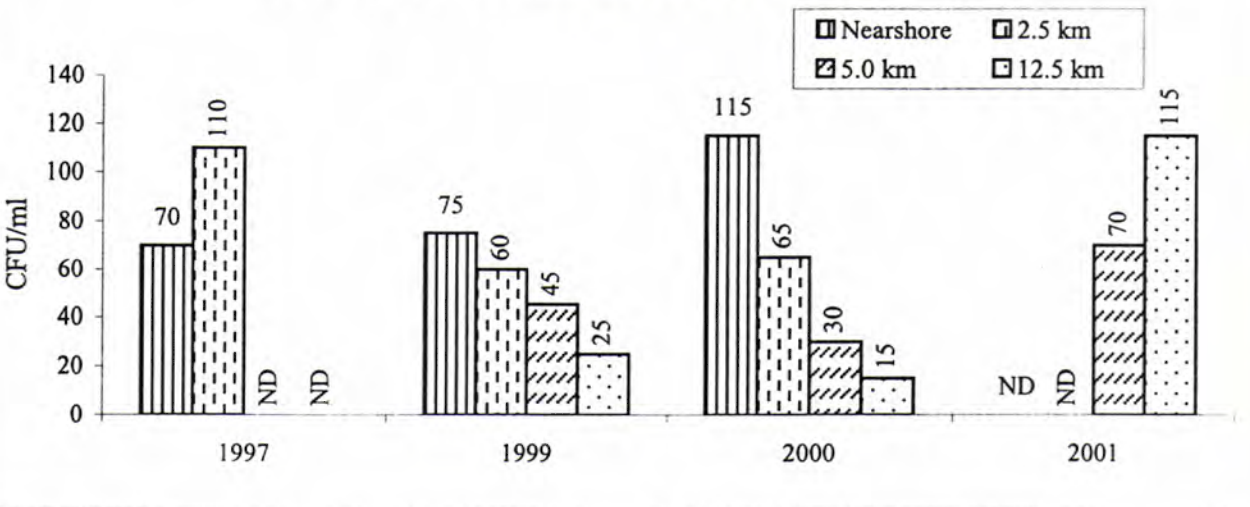


Chart 18: SFLO in Seawater at Helipad transect; 1997-2001

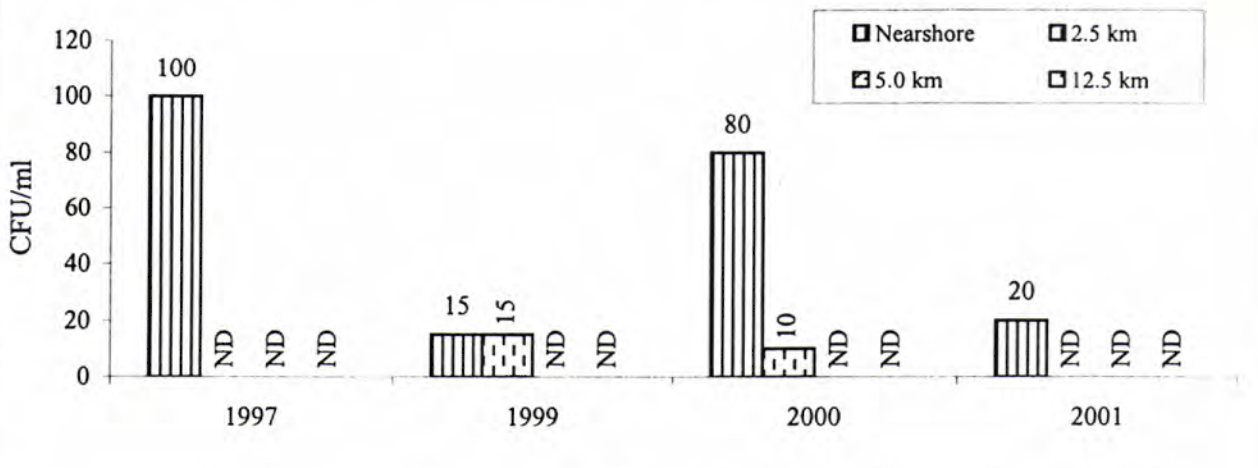


Chart 19: Total viable count at Lagoon water; 1997-2001

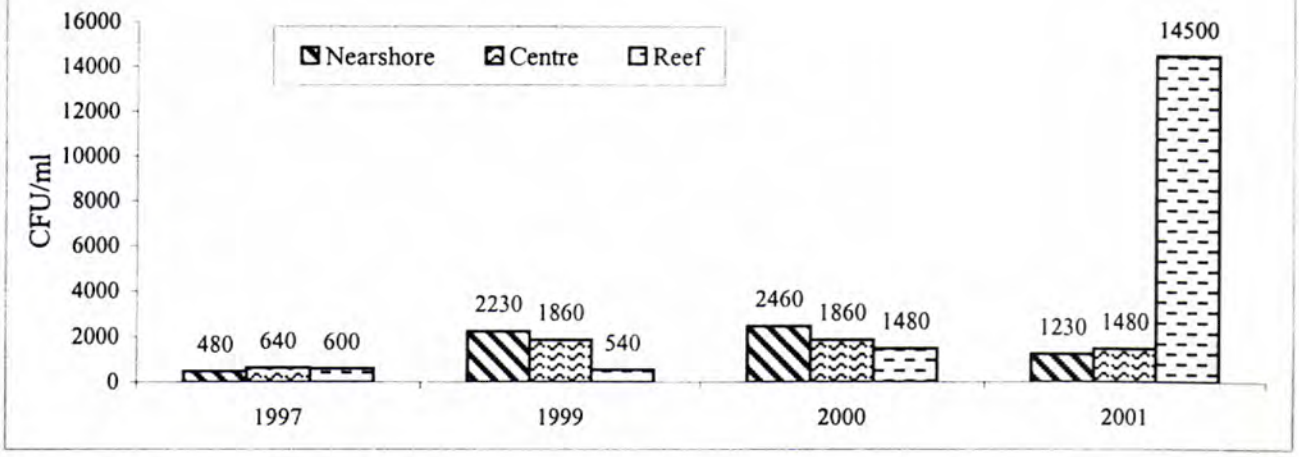


Chart 20: Total coliforms at Lagoon water; 1997-2001

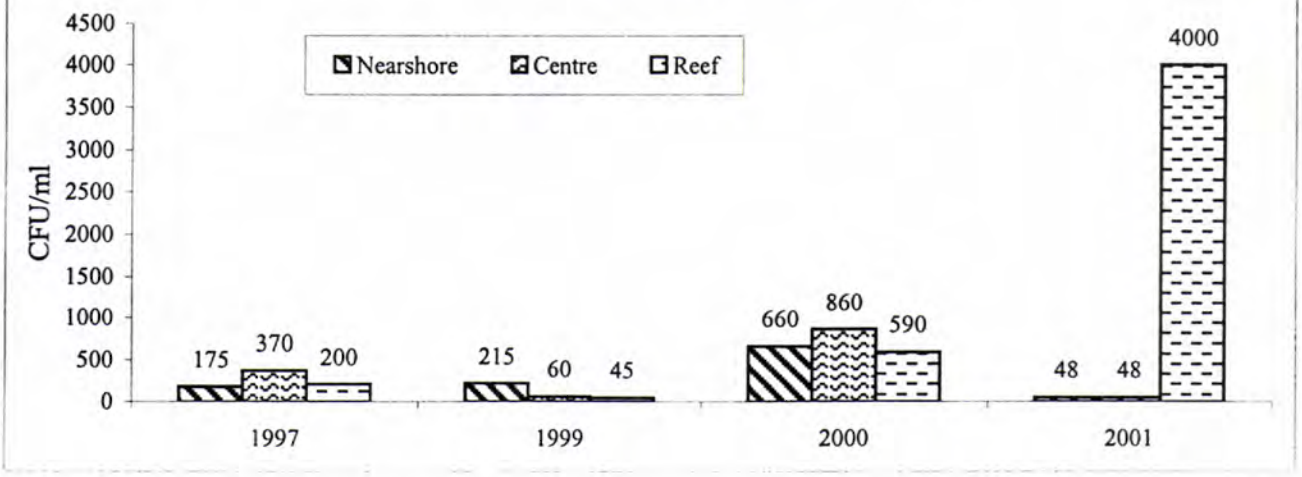


Chart 21: ECLO at Lagoon water; 1997-2001; 1997-2001

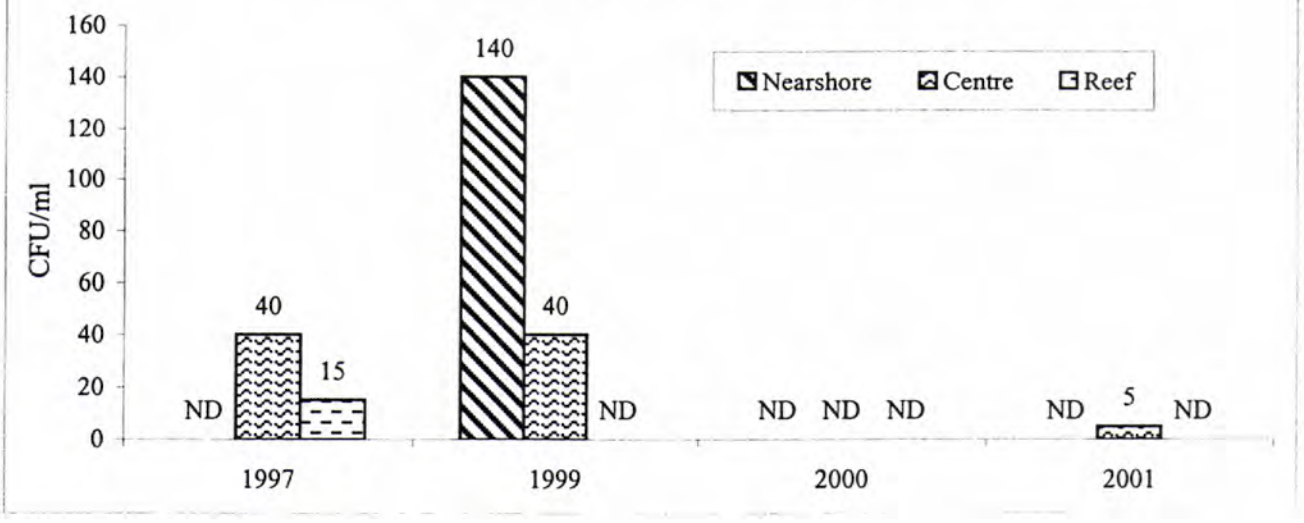


Chart 22: SLO at Lagoon water; 1997-2001

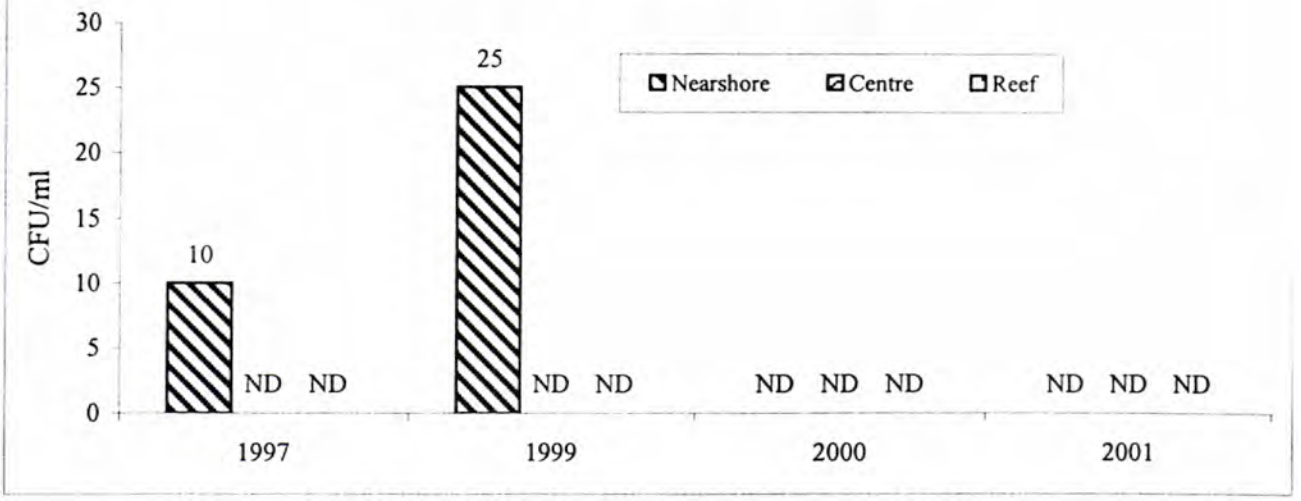


Chart 23: SHLO at Lagoon water; 1997-2001

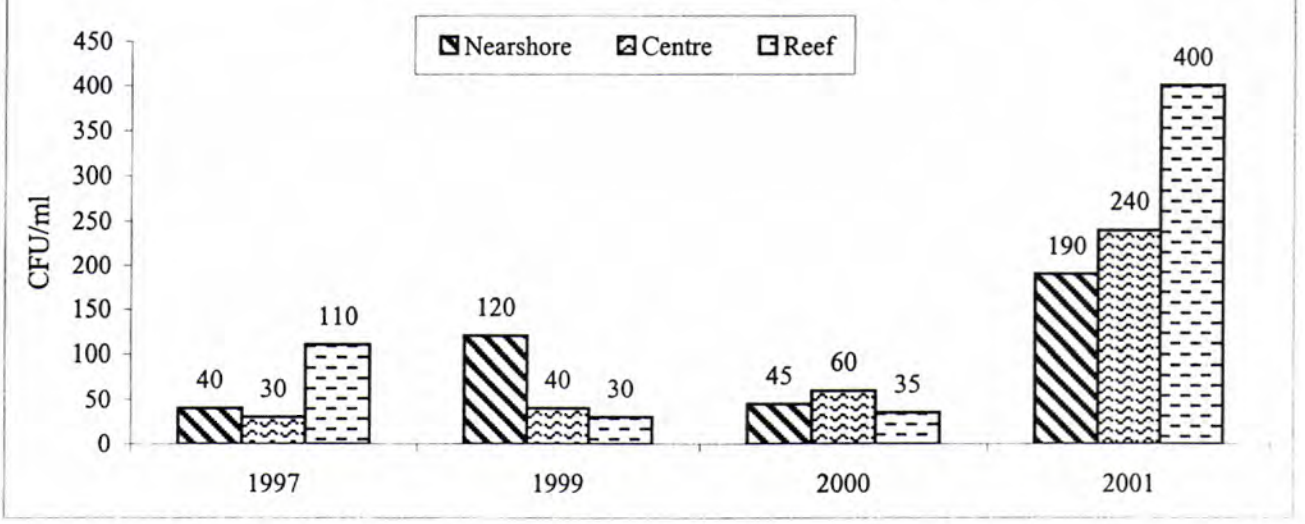


Chart 24: PKLO at Lagoon water; 1997-2001

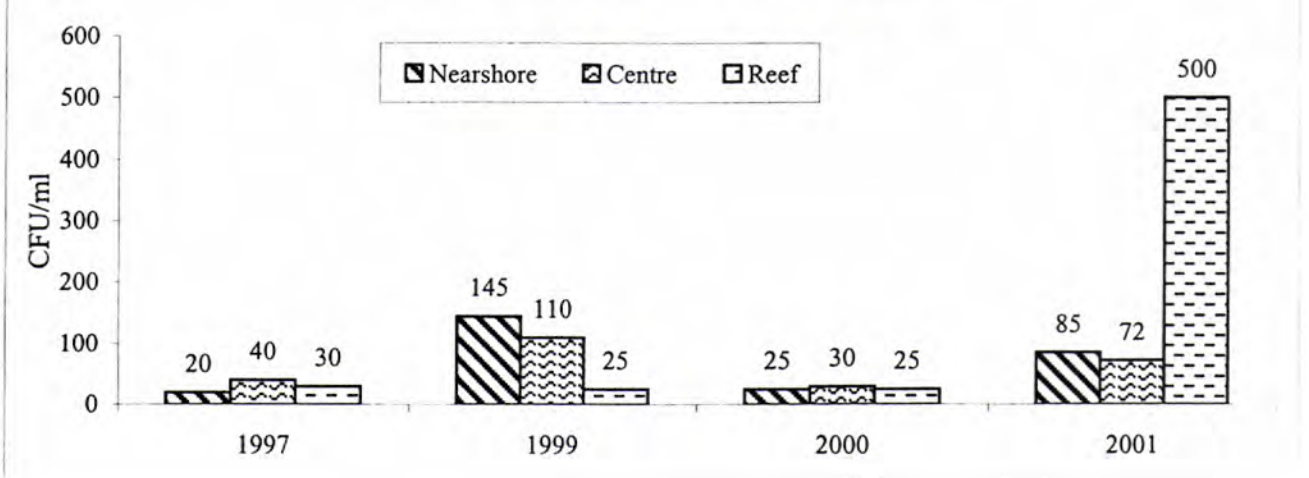


Chart 25: VCLO at Lagoon water; 1997-2001

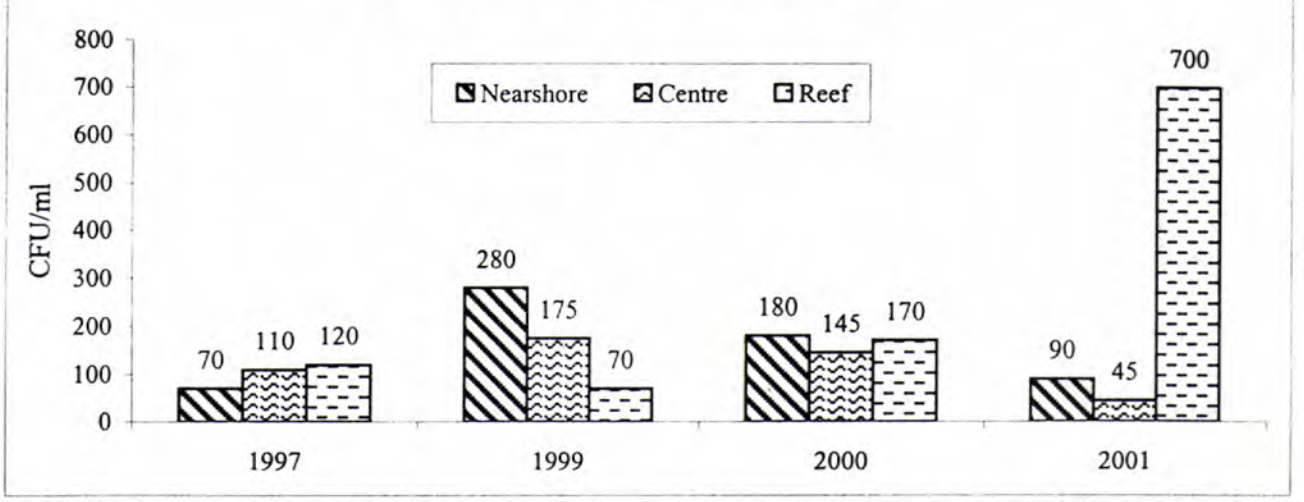


Chart 26: VPLO at Lagoon water; 1997-2001

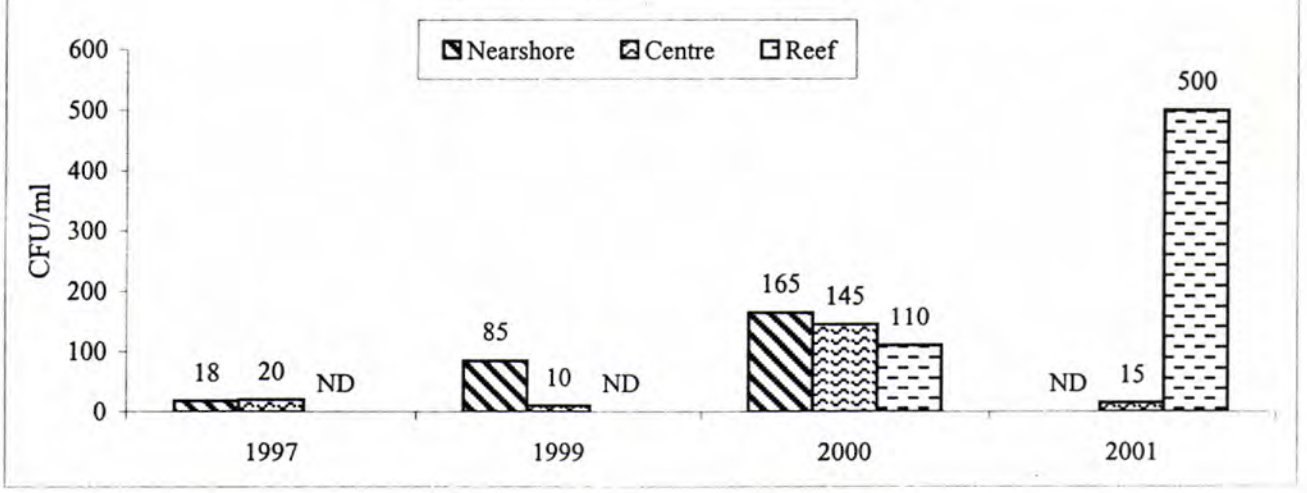
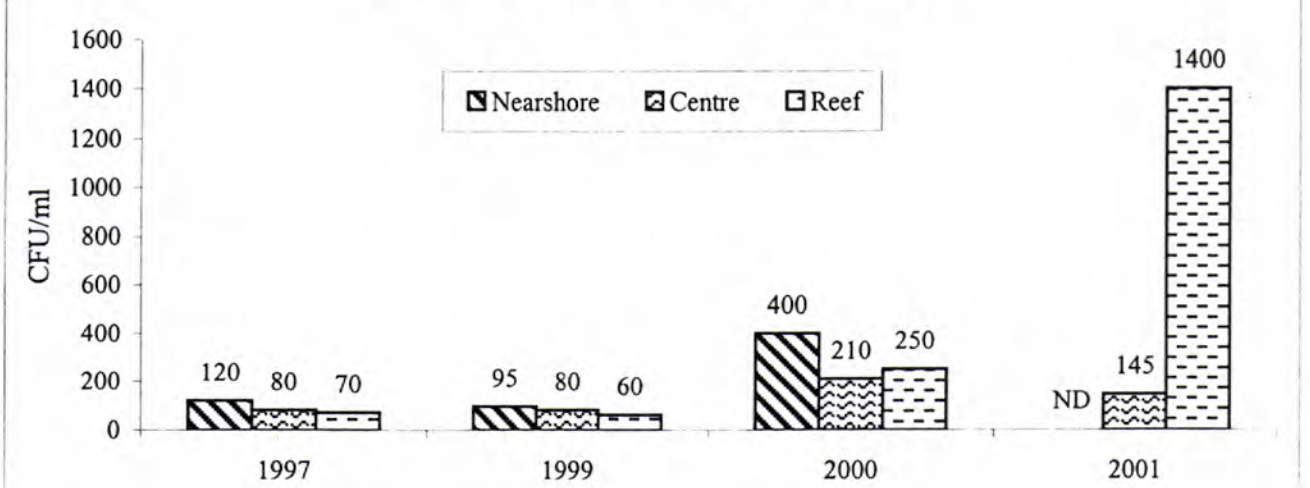


Chart 27: SFLO at Lagoon water; 1997-2001



3.1.2 Physico-chemical parameters (Table 4-6 & Chart 28-42)

Lighthouse transect

The water temperature varied from 28.9°C at nearshore to 30.5°C at 5.0 km in 1997, 27.5°C at 2.5 km to 29°C at 12.5 km in 1999, 29°C at 2.5 km to 30°C at 12.5 km in 2000 and 30°C at all stations except 5.0 km, whereas at 5.0 km it recorded 31°C. The lowest TSS concentration (4.11 mg/l) was recorded at 12.5 km offshore whereas the highest value (5.04 mg/l) was recorded at 5.0 km station during 1997. During 1999, the minimum (3.0 mg/l) value was recorded from 5.0 km station and the maximum (3.8 mg/l) value from the nearshore station. During 2000, it ranged from 3.5 mg/l at 12.5 km offshore station to 18.2 mg/l at the nearshore while in 2001; the variation was from 2.86 ppm at 5.0 km station to 10.5 mg/l at the nearshore station.

The dissolved oxygen content varied from 3.45 mg/l at nearshore to 4.51 mg/l in 1997, 3.32 mg/l at nearshore and 4.5 mg/l at 12.5 km in 1999, 2.54 mg/l at nearshore to 4.8 mg/l at 2.5 km in 2000 and 5.2 mg/l at nearshore to 6.16 mg/l at 5.0 km in 2001 (Chart 30). Inorganic phosphate concentration ranged from 0.31 μmol/l at 5.0 km offshore to 0.92 μmol/l at 2.5 km during 1997. In 1999, the offshore sample reported the minimum (0.57 μmol/l) value and the nearshore sample recorded the maximum value (0.71 μmol/l). 5.0 km station reported the minimum (0.92 μmol/l) whereas the maximum value (1.79 μmol/l) was recorded from the nearshore during August 2000. During 2001, it ranged from 0.87 μmol/l at the offshore to 3.25 μmol/l at the nearshore.

During 1997, the lowest (0.46 μmol/l) silicate concentration was recorded from 2.5 km when the highest (0.91 μmol/l) value was reported from the nearshore, 3.09 μmol/l (12.5

km) to 6.97 µmol/l (2.5 km) during 1999, 4.01µmol/l (12.5 km) to 5.98 µmol/l (2.5 km) during 2000 and 3.85 µmol/l (12.5 km) to 7.38 µmol (nearshore) during 2001.

Total phosphorus concentration was the maximum (1.83 µmol/l) at 2.5 km and minimum (0.95 µmol/l) at nearshore sample during 1997. During 1999 also, the highest value (2.05 µmol/l) was up to 2.5 km, but the minimum value (0.91) from the 12.5 km offshore. Nearshore recorded the highest (3.62 µmol/l) and the lowest (1.52 µmol/l) at 12.5 km during 2000. During 2001 also, nearshore showed the highest value (4.35 µmol/l) when 12.5 km offshore recorded the lowest (1.05 µmol/l).

Ammonia ranged from 0.012 µmol/l at 5.0 km to 0.05 µmol/l at nearshore in 1997, 0.002 µmol/l from offshore to 0.025 µmol/l at nearshore during 1999, 0.008 µmol/l from offshore to 0.095 µmol/l at nearshore during 2000 and 0.008 µmol/l from 12.5 km station to 0.09 µmol/l at 5.0 km station during 2001. Nitrite fluctuated from nil at nearshore and 2.5 km to 0.03 µmol/l at 12.5 km offshore. In 1999, it varied from 0.06 at 5.0 km to 0.95 µmol/l at the nearshore. The minimum value (0.09 µmol/l) was recorded from 5.0 km station and the maximum (1.87 µmol/l) from 2.5 km station during 2000. In 2001 also, the nearshore recorded the highest value (1.05 µmol/l) when 2.5 km station recorded the lowest (0.02 µmol/l).

During 1997, Nitrate also showed the minimum concentration (0.12 µmol/l) at nearshore while the maximum value (2.81 µmol/l) was estimated from 5.0 km station. In 1999, the offshore reported the lowest value (2.78 µmol/l) while 5.0 km station reported the highest value (3.1 µmol/l). It varied from 2.25 µmol/l at 5.0 km station to 2.97 µmol/l at 12.5 km

during 2000 and 2.5 at 2.5 km to 3.58 μmol/l at nearshore during 2001. Total-N concentration fluctuated from 1.84 at nearshore to 4.14 μmol/l at 5.0 km station in 1997, 5.2 at offshore to 6.28 μmol/l at nearshore during 1999. The values ranged from 6.32 at nearshore to 7.29μmol/l at 5.0 km during 2000 and 4.42 μmol/l at 12.5 km offshore to 7.35 μmol/l at nearshore during 2001.

BOD value fluctuated from 0.94 mg/l at offshore to 2.17 mg/l at nearshore during 1997, 0.92 mg/l at 5.0 and 12.5 km to 1.12 mg/l at 2.5 km distance during 1999, from 0.74 mg/l (12.5 km) to 1.8 mg/l (nearshore) during 2000 and 0.97 mg/l (12.5 km) to 2.7 mg/l (nearshore) during 2001.

PHC varied from 3.15 μg/l at 12.5 km to 4.18 μg/l at nearshore during 1997. It varied from 3.21 (5.0 km) to 4.1 μg/l (nearshore) during 1999, 3.10 μg/l (2.5 km) to 3.6 μg/l (5.0 km) during 2000 and 3.2 μg/l (nearshore and 5.0 km) to 3.41 μg/l (12.5 km) during 2001. Dissolved Cd in water samples varied from 0.11 ppb at 12.5 km station to 0.24 ppb at 5.0 km in 1997, 0.11 ppb at 2.5 km to 0.20 ppb at 12.5 km in 1999, 0.13 ppb at 2.5 km to 0.22 ppb at 12.5 km station during 2000 and 0.12 ppb at 5.0 km to 0.18 ppb at 2.5 km station during 2001. Pb fluctuated from 1.21 ppb at 12.5 km to 2.02 ppb at 5.0 km in 1997, 1.55 ppb at 2.5 km to 1.99 ppb at 12.5 km in 1999, 1.52 ppb at 12.5 km to 1.89 ppb at nearshore in 2000 and 1.75 ppb at nearshore to 2.3 ppb at 12.5 km during 2001. Dissolved Hg varied from 32 ng/l at 12.5 km to 42 ng/l at 2.5 km during 1997, 29.5 ng/l at 12.5 km station to 47 ng/l at nearshore during 1999, 35 ng/l at 12.5 km to 51 ng/l at nearshore during 2000 and 30.3 ng/l at 12.5 km to 49 ng/l at nearshore during 2001.

Helipad transect

The water temperature varied from 28.5°C at 12.5 km to 31°C at 5.0 km in 1997, 29.5°C at nearshore to 30°C at 2.5 km in 1999, 28.2°C at nearshore and 2.5 km to 28.9°C in 2000 and 30°C at 12.5 km to 31°C at 5.0 km in 2001. TSS varied from 3.17 at 2.5 km to 4.08 mg/l at 5.0 km during 1997 when it varied from 3.6 at 2.5 km offshore to 4.1 mg/l at 5.0 km station in 1999. In 2000, it varied from 4.1 mg/l at 12.5 km to 5.3 mg/l at the nearshore and 2.92 mg/l at offshore to 9.2 mg/l at nearshore.

Dissolved Oxygen varied from 3.63 mg/l (2.5 km) to 3.97 (12.5 km) in 1997 and 3.32 mg/l (5.0 km) to 3.95 mg/l (12.5 km) in 1999. In 2000, it varied from 3.82 mg/l at the offshore to 4.0 mg/l at 5.0 km and from 4.1 mg/l at the nearshore to 5.35 mg/l at 12.5 km during 2001. Inorganic phosphate varied from 0.3 μmol/l at 12.5 km to 0.67 μmol/l at the nearshore in 1997, 0.57 μmol/l at 5.0 km to 0.78 μmol/l at nearshore in 1999, 0.76 μmol/l at 12.5 km to 0.94 μmol/l at 2.5 km station during 2000 and 0.87 μmol/l at 5.0 km to 3.53 μmol/l at 2.5 km. Silicate value fluctuated from 4.98 μmol/l at nearshore to 6.8 μmol/l at 5.0 km during 1997, 3.95 μmol/l at 12.5 km to 7.18 μmol/l at the nearshore in 1999, 4.2 μmol/l at 12.5 km to 5.92 μmol/l at 2.5 km in 2000 and 4.48 μmol/l at the offshore to 9.38 μmol/l at the nearshore during 2001. Total phosphorus ranged from 0.98 μmol/l at the offshore to 2.01 μmol/l at 2.5 km during 1997, from 1.05 μmol/l at 5.0 km to 1.86 μmol/l at the nearshore in 1999, 1.69 μmol/l at 2.5 km station to 2.34 μmol/l at the nearshore in 2000 and 2.35 μmol/l from the offshore to 4.2 μmol/l at 2.5 km station during 2001.

Ammonia concentration in 1997 ranged from 0.012 μmol/l at 5.0 km to 0.03 μmol/l at nearshore. 0.007 μmol/l at 12.5 km to 0.027 μmol/l at nearshore during 1999, 0.021 μmol/l

at 12.5 km to 0.059 μmol/l at nearshore during 2000 and 0.048 μmol/l at 2.5 km station to 0.09 μmol/l at 12.5 km during 2001. Nitrite varied from nil at the nearshore and 2.5 km to 0.022 μmol/l at the 5.0 km station during 1997. In 1999, it ranged from 0.02 μmol/l at 2.5 km to 1.45 μmol/l at nearshore. In 2000, it ranged from 0.195 μmol/l at nearshore to 1.10 μmol/l at 12.5 km, in 2001 from 0.52 μmol/l at 2.5 km to 0.98 μmol/l at 5.0 km offshore. Nitrate varied from 0.35 μmol/l at 2.5 km station to 1.22 μmol/l at the offshore in 1997, 1.05 μmol/l at 2.5 km station to 3.6 μmol/l at the nearshore during 1999, 1.25 μmol/l at 5.0 km to 2.85 μmol/l at the offshore during 2000 and 1.05 μmol/l at 2.5 km station to 2.81 μmol/l at 5.0 km during 2001. Concentration of total nitrogen varied from 2.02 μmol/l at nearshore to 3.14 μmol/l at 5.0 km station during 1997, from 4.95 μmol/l at 12.5 km to 8.24 μmol/l at the nearshore in 1999, 4.62 μmol/l at 5.0 km station to 5.47 μmol/l at the nearshore in 2000 and from 4.32 μmol/l at 5.0 km to 5.01 μmol/l at 2.5 km station during 2001. BOD fluctuated from 1.0 mg/l at 5.0 km to 1.23 μmol/l at 2.5 km in 1997, from 0.97 μmol/l at 12.5 km to 1.3 μmol/l at nearshore during 1999, 1.0 μmol/l at the offshore to 1.52 μmol/l at the nearshore during 2000 and from 0.92 μmol/l at nearshore and 2.5 km to 1.0 μmol/l at the offshore during 2001.

PHC ranged from 2.16 μg/l at 5.0 km station to 5.21 μg/l at the nearshore in 1997, 4.2 μg/l at nearshore to 4.5 μg/l at nearshore in 1999, 4.2 μg/l at 12.5 km to 5.2 μg/l at 5.0 km in 2000 and 3.8 μg/l at 12.5 km to 5.3 at 2.5 km in 2001. The dissolved cadmium concentration varied from 0.16 ppb at 12.5 km to 0.31 ppb at 2.5 km in 1997, 0.10 at 5.0 km to 0.13 ppb at 12.5 km in 1999, 0.14 at nearshore to 0.2 ppb at 5.0 and 12.5 km in 2000 and 0.16 at nearshore to 0.2 ppb at 5.0 km in 2001. The dissolved lead concentration varied

from 1.18 ppb at 2.5 km to 1.53 ppb at 5.0 km in 1997, 0.99 at 2.5 km to 1.54 ppb at 5.0 km in 1999, 1.38 at 5.0 km to 1.46 ppb at 2.5 km in 2000 and 1.02 at 5.0 km to 1.82 ppb at 2.5 km in 2001.

Lagoon transect

Water temperature ranged from 29.5°C at the nearshore station to 31°C at the reef during 1997, 29°C at the centre to 30°C at nearshore during 1999, 29°C during 2000 and 29.5°C at the nearshore to 31.5°C at the reef during 2001. TSS ranged from 3.09 mg/l at the nearshore to 3.65 mg/l at reef during 1997, 3.7 mg/l at the reef station to 4.3 mg/l at the centre in 1999, from 4.7 mg/l at the reef to 6.4 mg/l at the nearshore during 2000 and 5.2 mg/l at the nearshore to 5.9 mg/l in the reef station during 2001.

DO varied from 3.5 mg/l at the nearshore to 3.8 mg/l at the reef in 1997, 3.29 mg/l at the centre to 3.31 mg/l at the reef in 1999, 3.8 mg/l at all places in the lagoon in 2000 and 4.24 mg/l at the nearshore and 4.95 mg/l at the reef during 2001. Inorganic phosphate concentration in water samples varied from 0.46 μmol/l at the centre to 0.84 μmol/l at the nearshore in 1997, from 0.79 μmol/l at the centre to 0.86 μmol/l at the nearshore in 1999, 1.02 μmol/l at the nearshore to 1.10 μmol/l at the centre in 2000 and 1.6 μmol/l at the centre to 3.51 μmol/l at the reef during 2001.

Total phosphorus varied from 1.07 μmol/l at the centre station to 1.72 μmol/l at the reef in 1997, 2.09 μmol/l at reef to 2.66 μmol/l at the centre in 1999, 2.98 μmol/l at nearshore to 3.01 μmol/l at both the other stations in 2000 and 2.42 μmol/l at the nearshore to 2.8 μmol/l at the reef during 2001. Silicate values varied from 5.09 μmol/l at centre to 5.18 μmol/l at

the reef during 1997, 7.1 μmol/l at reef to 7.26 μmol/l at the nearshore in 1999, 8.13 μmol/l at the reef to 8.21 μmol/l at the nearshore in 2000 and 8.2 μmol/l at reef to 8.5 μmol/l at the nearshore during 2001. Nitrite nitrogen varied from 0.01 μmol/l at the nearshore to 0.02 μmol/l at centre during 1997, from 1.72 μmol/l at nearshore to 1.85 μmol/l at the reef during 1999, 0.25 μmol/l at nearshore and centre to 0.26 μmol/l at reef in 2000 and nil at nearshore and reef to 0.102 μmol/l in centre station during 2001. Nitrate nitrogen varied from 0.7 μmol/l at the nearshore to 1.0 μmol/l at the centre in 1997, 2.95 μmol/l at centre to 3.85 μmol/l at nearshore in 1999, 1.02 μmol/l in nearshore to 1.5 μmol/l in the centre during 2000 and nil at reef to 1.85 μmol/l at the centre during 2001. Ammonia nitrogen showed a fluctuation of 0.022 μmol/l at the nearshore to 0.2 μmol/l at reef in 1997, 0.022 μmol/l at centre to 0.25 μmol/l at nearshore during 1999, 0.02 μmol/l at centre and reef stations to 0.2 μmol/l at nearshore in 2000 and 0.01 μmol/l at the centre to 0.26 μmol/l at reef during 2001. Total nitrogen concentration varied from 0.95 μmol/l at nearshore to 1.85 μmol/l at centre in 1997, 7.95 μmol/l at reef to 9.26 μmol/l at nearshore during 1999, 4.2 μmol/l at nearshore to 4.9 μmol/l at the centre in 2000 and 5.8 μmol/l at nearshore to 7.4 μmol/l at the centre in 2001. BOD values ranged from 1.94 μmol/l at reef to 1.96 mg/l at the nearshore in 1997, 1.27 mg/l at reef to 1.42 mg/l at the nearshore during 1999, 1.42 mg/l at centre and reef to 1.5 mg/l at nearshore during 2000 and 1.5 mg/l at centre to 1.68 mg/l at reef during 2001.

Petroleum hydrocarbon varied from 1.85 μg/l at nearshore to 4.18 μg/l at centre during 1997, 0.62 μg/l at nearshore to 0.7 μg/l at centre during 1999, 0.13 μg/l at all places during 2000 and 1.24 μg/l at centre to 1.95 μg/l at the nearshore during 2001. Dissolved

concentration of Cadmium varied from 0.11 ppb at reef to 0.14 ppb at centre in 1997, 0.11 ppb at nearshore to 0.16 ppb at centre in 1999, 0.21 ppb at centre and reef to 0.22 ppb at nearshore in 2000 and 0.14 ppb at reef to 0.25 ppb at nearshore in 2001. Dissolved Pb varied from 1.23 ppb at reef to 1.73 ppb at nearshore in 1997, 1.25 ppb at nearshore to 1.5 ppb at reef in 1999, 1.9 ppb at centre to 1.98 ppb at nearshore in 2000 and 1.3 ppb at nearshore to 1.55 ppb at reef in 2001. Dissolved Hg varied from 45 ng/l at nearshore to 51 ng/l at the reef in 1997, 39 ng/l at reef to 48 ng/l at centre in 1999, 42 ng/l at reef to 45 ng/l at nearshore in 2000 and 42 ng/l at reef to 45 ng/l at nearshore during 2001.

Water temperature recorded a variation from 29 to 31.5°C inside lagoon and 31.0°C in the Sea. Mathew and Gopakumar (1986) also noticed the surface temperature in the range of 28-31°C. The maximum temperature recorded during the onset of monsoon 2001 is in the lagoon. There is slight but notable increase in temperature in the lagoon reef as well as in the sea outside. This observation is similar to the findings of Sankaranarayan (1973) who reported that temperature in the lagoon varied from 30.2 to 32.4°C, whereas sea outside lagoon from 29.1 to 31.0°C. High temperature recorded may be attributed to high atmospheric temperature within the lagoon and also poor inflow of oceanic waters from outside the reef into the lagoon causing maximum saturation with the water inside the lagoon. Bhattathiri (1987) observed narrow variation of surface temperature in the Laccadive Sea during October, December and March. Girija Vallabhavan *et al.* (1997) also reported high temperature in March period in the Kavaratti lagoon area. The results of the present study are in agreement with these reports, but the trend shows that that there is a slight increase in surface water temperature from 1997 to 2001. The pattern of surface water temperature shows that there is not much variation between transects

and seasons. There was a slight increase in water temperature in the nearshore to offshore region, upto a distance of 5.0 km in Lighthouse and Helipad transects.

Total suspended solids varied from 3.5 mg/l in May 1997 to 6.86 mg/l in May-June 2001, in the lagoon, showing an increase over the year. The highest value was noticed during the end of monsoon in 2000 from the lighthouse nearshore. The sharp increase is due to the coir retting activities prevalent during the period. Barring this observation, TSS at all other regions did not exhibit any variability.

Dissolved oxygen was in the order of 2.54-5.35 mg/l during March-April. Oxygen concentration at surface was higher in December when compared to the values of October. The changes in the dissolved oxygen might be due to water movements, circulation and mixing, different marine organisms including phytoplankton, seaweeds and sea grass. The dissolved oxygen values recorded in the lagoonal waters were comparatively lower during 1997-2000. Girija Vallabhavan *et al.*, (1987) reported similar trend that dissolved oxygen varied from 2 ml to 6 ml/litre.

Inorganic phosphate content showed an increase from the period 1997 to 2001. Lagoon waters showed rather lower phosphate content possibly due to the active uptake by the benthic algae in the lagoon. The inorganic phosphate and the total phosphorus concentration of lagoon shows that inorganic content is less. The lower concentration of inorganic phosphate may be due to active uptake of benthic algae present in the lagoon. Similar observation was noticed by Sankaranarayanan (1973). Mc Roy *et al.*, (1970) also reported the absorption of phosphate by Eel grass (*Zostera marina*). Higher inorganic phosphorus formed near the reef is reflecting the high metabolic activity of the corals. This was found substantiating the findings of Qasim and

Sankaranarayanan (1970) that high particulate organic matter is present in reef waters than the sea area.

The silicate values in water varied from 3.09 μmol/l in the offshore station during 1999 to 8.50 μmol/l in the nearshore waters of lagoon. Sengupta *et al.*, 1979 reported silicate values between nil and 35 μg at/l in Lakshadweep waters. The total phosphate content of these waters show that much of the present is bound organically. Mc Roy *et al.*, (1970) have reported the absorption of phosphate by Eel grass (*Zostera marina*) based on experiments using ^{32}P.

Sengupta *et al.*, (1975) reported that ammonia are normally low at Arabian Sea but occasional high values were reported and this could be due to precipitation or fixation of nitrogen by blue green algae. This is in agreement with observations in surface layers in oligotrophic area where an excess of ammonia was observed when nitrate and nitrite were absent (Biley and Chester, 1971).

Nitrate-nitrogen fluctuated from nil in the reef region during 2001 to 3.85 μmol/l at the nearshore of lagoon during 1999. Sengupta *et al.*, during the 10^{th} cruise in Lakshadweep waters reported nitrate nitrogen values up to 4.21 μg/l. The results do not show any temporal or spatial variation. It can be assumed from the distribution of values that there is phytoplankton blooms in the Lakshadweep Sea as reported by Devassy *et al.* (1978). Wafar *et al.* (1986) conducted similar studies relating the nitrogenous nutrients and primary production in tropical oceanic Lakshadweep waters. They find inorganic nitrogen accounted for less than 10% and dissolved organic nitrogen (DON) for more than 90% of the total dissolved nitrogen in the emphatic zone. They have seen that addition of nitrate, ammonia and urea as nitrogen source stimulated carbon

fixation at all depth and this together with ambient concentration of inorganic nitrogen compounds, demonstrates that the phytoplankton in these waters are nitrogen limited. Nitrate disappeared totally from the surface layers while phosphate was present always in a measurable quantity. So nitrate is found to have a stronger influence than phosphate regulating primary productivity. D' Souza and Sastry (1975) also reported that the surface layer in the Arabian Sea is nutrient depleted during south-west monsoon season. Nasik and Gupta (1975) reported that due to photosynthetic processes the upper layer of natural water bodies are never be in equilibrium with respect to any chemical system.

Singh *et al.*, (1990) reported lower concentration of nutrients at surface and 100 m depth of all stations at Lakshadweep Sea when high concentrations were encountered at deeper depths with low values of dissolved oxygen. The harbour waters are characterized by high proportions of inorganic nutrients. Earlier study by Navas and Mathew, 1995, on the ecological characteristics of environment showed that the variation in temperature, salinity, dissolved oxygen and nutrients in the lagoon and reefs were within the limit of lethal levels. The average concentration of mercury in the Lakshadweep Sea has been reported as 91 ng/litre (range 60-120 ng/litre) (Sanzgiri *et al.,* 1979). In the coastal waters of the Arabian Sea, the average surface value was 136 mg/litre (Sanzgiri and Sengupta, 1978). The reported values elsewhere are 0.5-225 at Atlantic (Chester *et al.*, 1973), south west coast of Kerala, India (Ouseph, 1987), 9-74 at southern Indian Ocean, 6-51 at China and Japan (Chester *et al.*, 1973) and 0-221 at northern Indian Ocean (Singbal *et al.*, 1978). The values recorded in the present study are comparable with the results of the cited studies. The dissolved concentration of Pb for the Cochin estuary is 1.8 to 2.1 μg/l for monsoon, 2.2 to 3.4 μg/l in non-monsoon and 2.8 to 4.2 μg/l for pre-monsoon season. Dissolved cadmium reported from Cochin estuary is 1.8 μg/l to 3.4 μg/l (Ouseph, 1992).

Table 4. Physico-chemical characteristics of surface waters at Lighthouse transect; 1997-2001

Parameters	1997	1999	2000	2001	1997	1999	2000	2001	1997	1999	2000	2001	1997	1999	2000	2001
	NEARSHORE				2.5KM				5.0KM				12.5KM			
Water temp (°C)	28.9	28	29.5	30.0	30	27.5	29	30.0	30.5	28.5	29.7	31.0	29	29	30.0	30.0
TSS (mg/l)	4.61	3.8	18.2	10.5	5.03	3.3	16.1	5.1	5.04	3.0	8.7	2.86	4.11	3.2	3.5	2.9
DO (mg/l)	3.45	3.32	2.54	5.2	3.47	4.0	4.8	4.98	3.62	4.30	4.39	5.16	4.51	4.5	4.29	5.30
In. PO_4 (µmol/l)	0.44	0.71	1.79	3.25	0.92	0.68	1.23	3.23	0.31	0.61	0.92	1.2	0.60	0.57	0.98	0.87
Silicate (µmol/l)	0.91	6.95	4.24	7.38	0.46	6.97	5.98	7.15	0.77	5.15	5.91	5.33	0.72	3.09	4.01	3.85
Total P (µmol/l)	0.95	1.73	3.62	4.35	1.83	2.05	3.02	4.20	1.20	0.98	1.98	2.8	1.24	0.91	1.52	1.05
Ammonia (µmol/l)	0.05	0.025	0.095	0.031	0.02	0.022	0.028	0.028	0.012	0.018	0.012	0.09	0.021	0.002	0.008	0.008
Nitrite (µmol/l)	ND	0.95	1.12	1.05	ND	0.76	1.87	0.02	0.02	0.06	0.09	0.49	0.03	0.92	0.19	0.98
Nitrate (µmol/l)	0.12	2.95	2.42	3.58	0.54	2.86	2.27	2.5	2.81	3.10	2.25	3.28	1.84	2.78	2.97	2.80
Total -N (µmol/l)	1.84	6.28	6.32	7.35	2.03	6.1	7.23	5.01	4.14	6.00	7.29	4.90	3.32	5.20	6.89	4.42
BOD (mg/l)	2.17	0.98	1.8	2.70	1.38	1.12	1.25	1.60	1.08	0.92	0.78	0.98	0.94	0.92	0.74	0.97
PHC (µg/l)	4.18	4.10	3.25	3.20	3.18	3.50	3.10	3.40	3.85	3.21	3.60	3.20	3.15	3.11	3.20	3.41
Dissolved Cd (ppb)	0.20	0.14	0.16	0.16	0.16	0.11	0.13	0.18	0.24	0.18	0.16	0.12	0.11	0.20	0.22	0.16
Dissolved Pb(ppb)	1.61	1.61	1.89	1.75	1.55	1.55	1.58	1.92	2.02	1.64	1.72	2.0	1.21	1.99	1.52	2.30
Dissolved Hg (ng/l)	36	47.0	51.0	49.0	42	35.0	38.0	38.0	36	37.2	38.2	38.3	32	29.5	35.0	30.3

Table 5. Physico-chemical characteristics of surface waters at Helipad transect; 1997-2001

Parameters	1997	1999	2000	2001	1997	1999	2000	2001	1997	1999	2000	2001	1997	1999	2000	2001
	NEARSHORE				2.5KM				5.0KM				12.5KM			
Water temp (°C)	29.0	29.5	28.2	30.4	29.5	30.0	28.2	30.5	31	29.5	28.5	31.0	28.5	29.5	28.9	30.0
TSS (mg/l)	3.63	3.8	5.3	9.2	3.17	3.6	4.3	5.1	4.08	4.10	4.2	3.09	3.78	2.90	4.1	2.92
DO (mg/l)	3.71	3.35	3.98	4.1	3.63	3.72	3.9	4.98	3.67	3.32	4.01	4.10	3.97	3.95	3.82	5.35
In. PO_4 (µmol/l)	0.67	0.78	0.92	3.48	0.63	0.63	0.94	3.53	0.55	0.57	0.82	0.87	0.30	0.59	0.76	1.09
Silicate (µmol/l)	4.98	7.18	5.28	9.38	5.65	7.0	5.92	7.35	6.8	5.30	5.82	4.95	5.7	3.95	4.2	4.48
Total P (µmol/l)	1.54	1.86	2.34	2.48	2.01	1.52	1.69	4.20	1.34	1.05	1.96	2.45	0.98	1.34	1.72	2.35
Ammonia (µmol/l)	0.03	0.027	0.059	0.08	0.027	0.02	0.04	0.048	0.012	0.015	0.036	0.085	0.015	0.007	0.021	0.09
Nitrite (µmol/l)	ND	1.45	0.195	0.91	ND	0.02	0.28	0.52	0.022	0.14	0.98	0.98	0.018	0.29	1.10	0.65
Nitrate (µmol/l)	0.67	3.61	2.25	1.85	0.35	1.05	1.29	1.05	1.20	2.74	1.25	2.81	1.22	2.66	2.85	2.68
Total -N (µmol/l)	2.02	8.24	5.47	4.35	2.14	5.82	4.72	5.01	3.14	4.98	4.62	4.32	3.11	4.95	5.28	4.41
BOD (mg/l)	1.13	1.30	1.52	0.92	1.23	0.98	1.4	0.92	1.0	1.25	1.26	0.97	1.08	0.97	1.0	1.0
PHC (µg/l)	5.21	4.20	5.14	4.52	4.25	4.50	5.15	5.30	2.16	4.36	5.20	5.12	3.81	4.41	4.20	3.8
Dissolved Cd (ppb)	0.20	0.12	0.14	0.16	0.31	0.12	0.16	0.17	0.28	0.10	0.20	0.20	0.16	0.13	0.20	0.18
Dissolved Pb(ppb)	1.51	1.38	1.42	1.45	1.18	0.99	1.46	1.82	1.53	1.54	1.38	1.02	1.29	1.41	1.40	1.23
Dissolved Hg (ng/l)	44	32.8	34.2	44.0	35	33	35.8	40.0	37	34	34.7	30.4	24	36	32.6	31.2

Table 6. Physico-chemical characteristics of surface waters at Lagoon; 1997-2001

Parameters	1997	1999	2000	2001	1997	1999	2000	2001	1997	1999	2000	2001
	NEARSHORE				CENTRE				REEF			
Water temp (°C)	29.5	30	29	29.5	30	29.0	29	31.0	31	29.5	29	31.5
TSS (mg/l)	3.09	4.0	4.4	5.2	3.1	4.3	5.2	5.7	3.65	3.7	4.7	5.9
DO (mg/l)	3.5	3.30	3.8	4.24	3.7	3.29	3.8	4.95	3.8	3.31	3.8	4.86
In. PO_4 (µmol/l)	0.84	0.86	1.02	1.54	0.46	0.79	1.10	1.60	0.58	0.84	1.08	1.51
Silicate (µmol/l)	5.12	7.26	8.21	8.5	5.09	7.24	8.19	8.4	5.18	7.10	8.13	8.2
Total P (µmol/l)	1.25	2.40	2.98	2.42	1.07	2.66	3.01	2.5	1.72	2.09	3.01	2.80
Ammonia (µmol/l)	0.022	0.25	0.20	0.024	0.19	0.022	0.020	0.01	0.20	0.029	0.020	0.026
Nitrite (µmol/l)	0.01	1.72	0.25	ND	0.02	1.78	0.25	0.102	0.019	1.85	0.26	ND
Nitrate (µmol/l)	0.70	3.85	1.02	0.02	1.00	2.95	1.50	1.85	0.98	3.14	1.19	ND
Total -N (µmol/l)	0.95	9.26	4.2	5.8	1.85	8.79	4.90	7.4	1.35	7.95	4.49	6.3
BOD (mg/l)	1.96	1.42	1.50	1.65	1.95	1.38	1.42	1.50	1.94	1.27	1.42	1.68
PHC (µg/l)	1.85	0.62	0.13	1.95	4.18	0.70	0.13	1.24	3.18	0.64	0.13	1.26
Dissolved Cd (ppb)	0.12	0.11	0.22	0.25	0.14	0.16	0.21	0.17	0.11	0.13	0.21	0.14
Dissolved Pb (ppb)	1.73	1.25	1.98	1.30	1.56	1.34	1.9	1.48	1.23	1.5	1.97	1.55
Dissolved Hg (ng/l)	45	41	45	45.0	50	48	44	44	51	39	42	42.0

Chart 28: Fluctuation in water temperature in Seawater; 1997-2001

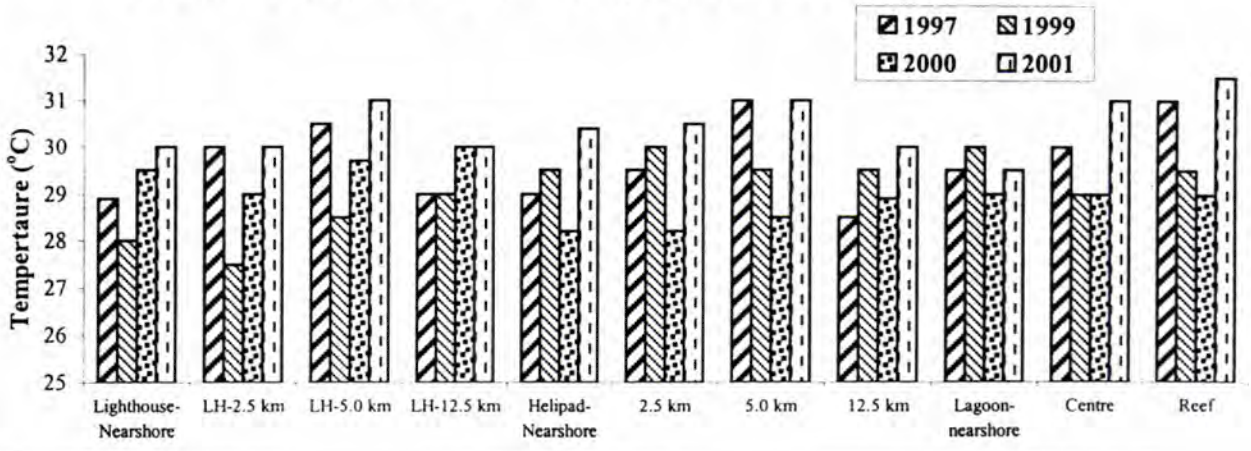


Chart 29: Variation of total suspended solids in Seawater; 1997-2001

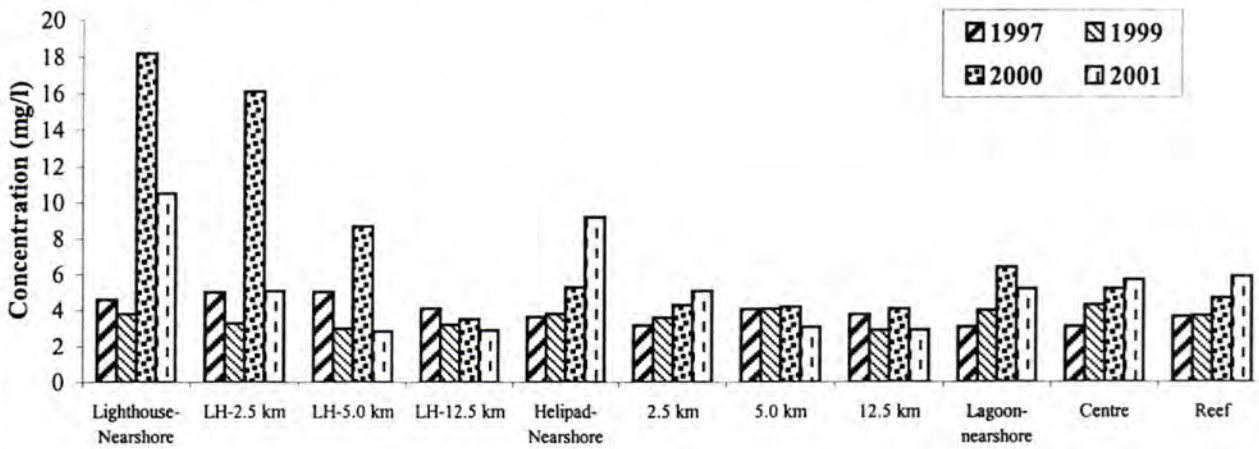


Chart 30: Fluctuation in dissolved oxygen in Seawater; 1997-2001

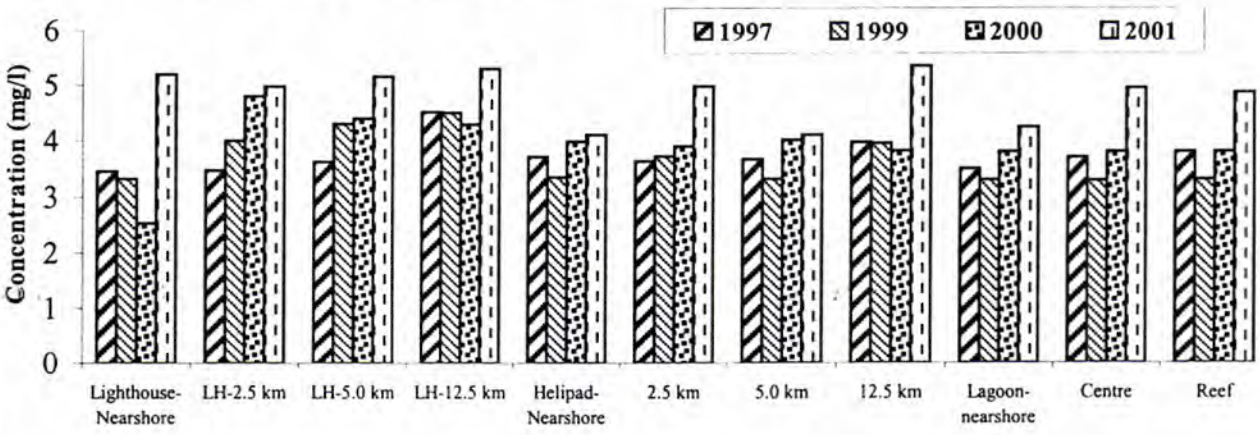


Chart 31: Variation of inorganic phosphate in Seawater; 1997-2001

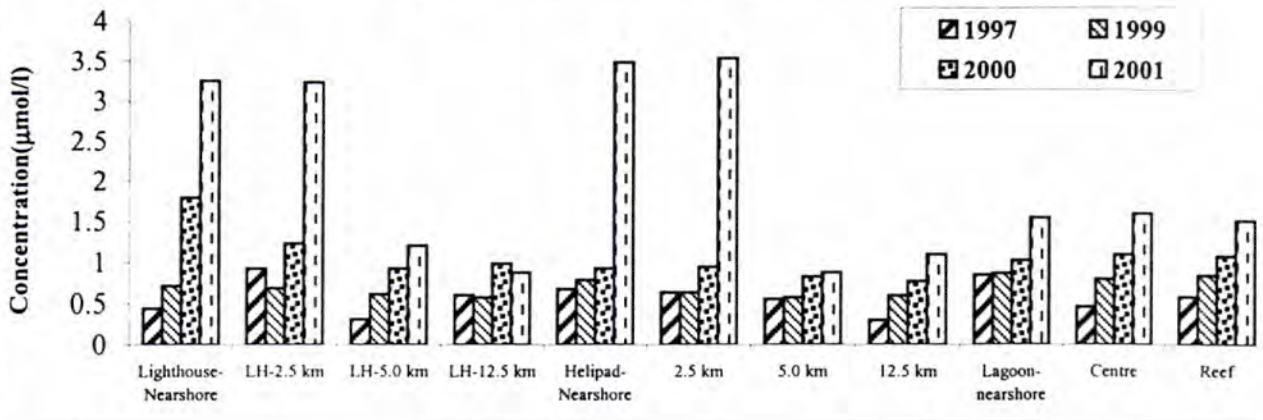


Chart 32: Variation of silicate in Seawater; 1997-2001

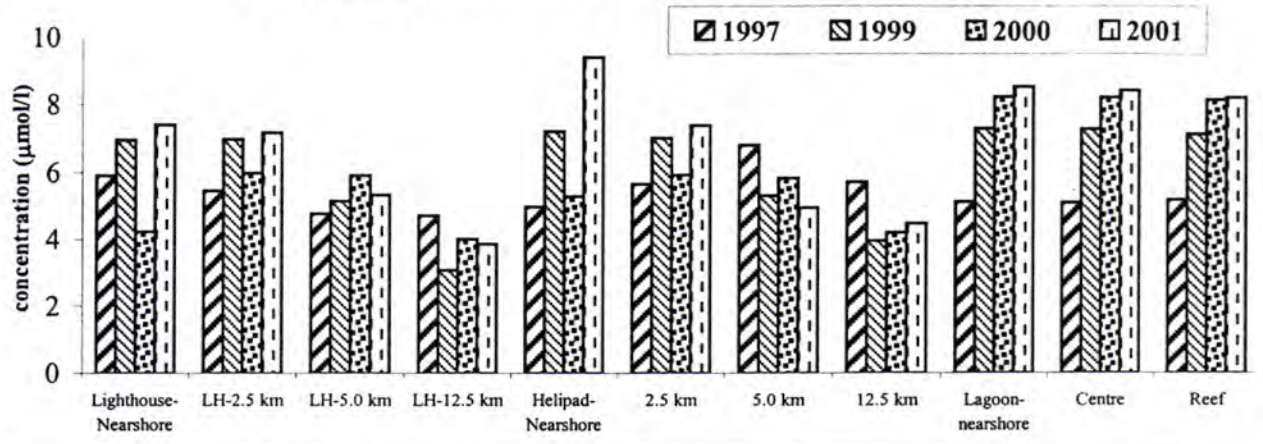


Chart 33: Variation of Total phosphorus in Seawater; 1997-2001

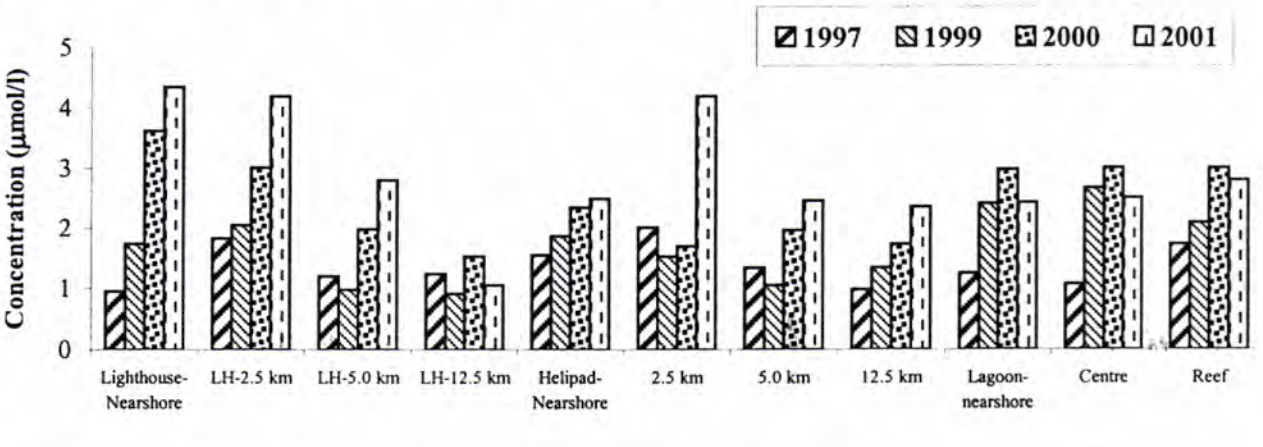


Chart 34: Fluctuation in Ammonia nitrogen in Seawater; 1997-2001

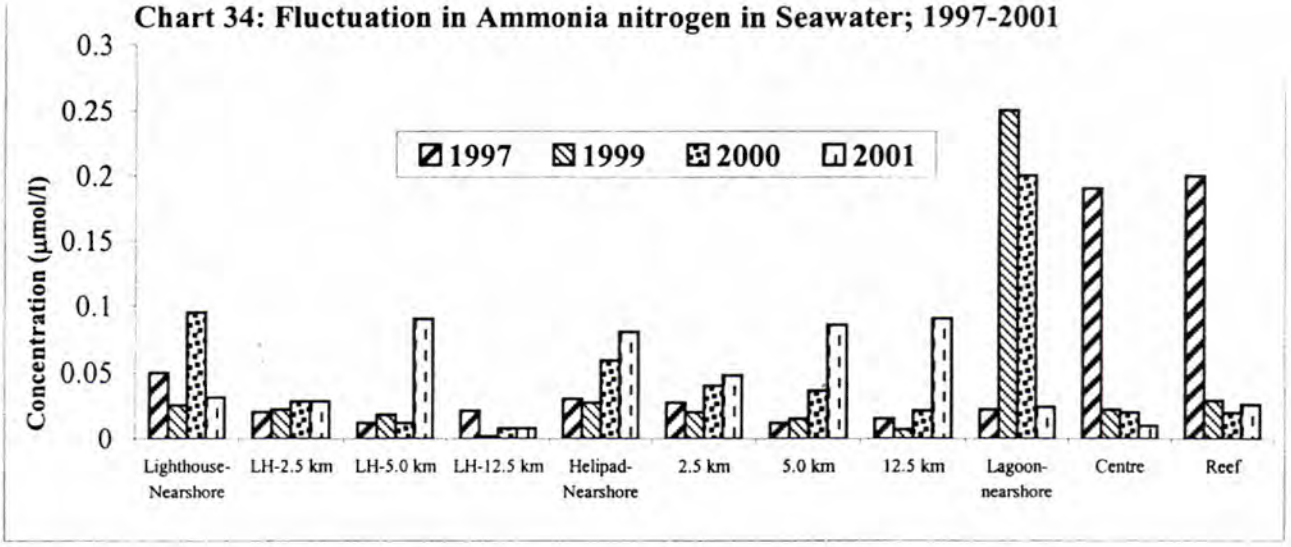


Chart 35: Variation of Nitrite nitrogen in seawater; 1997-2001

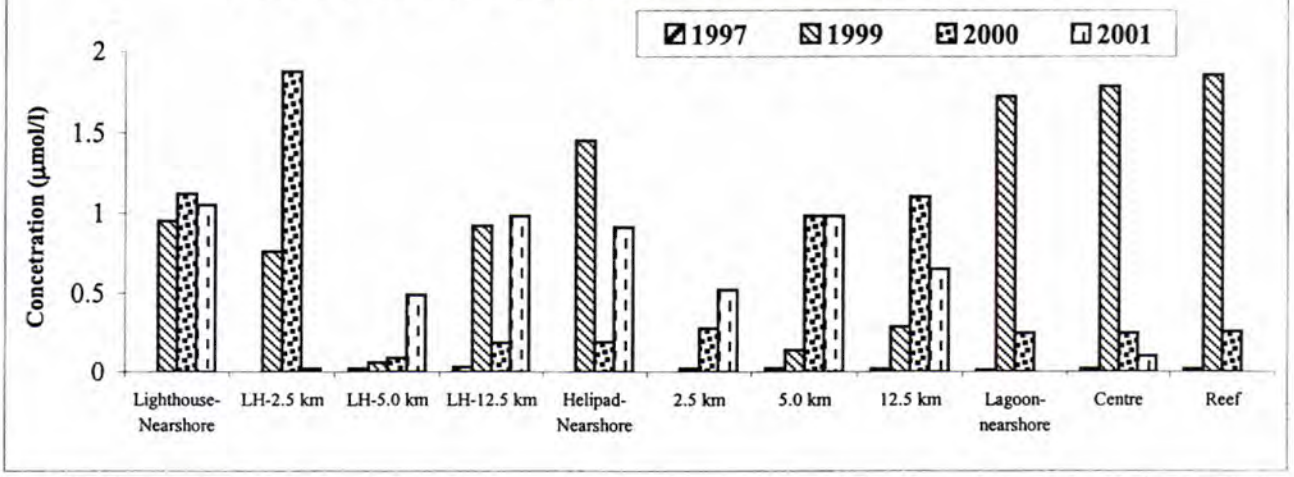


Chart 36: Variation of Nitrate nitrogen in Seawater; 1997-2001

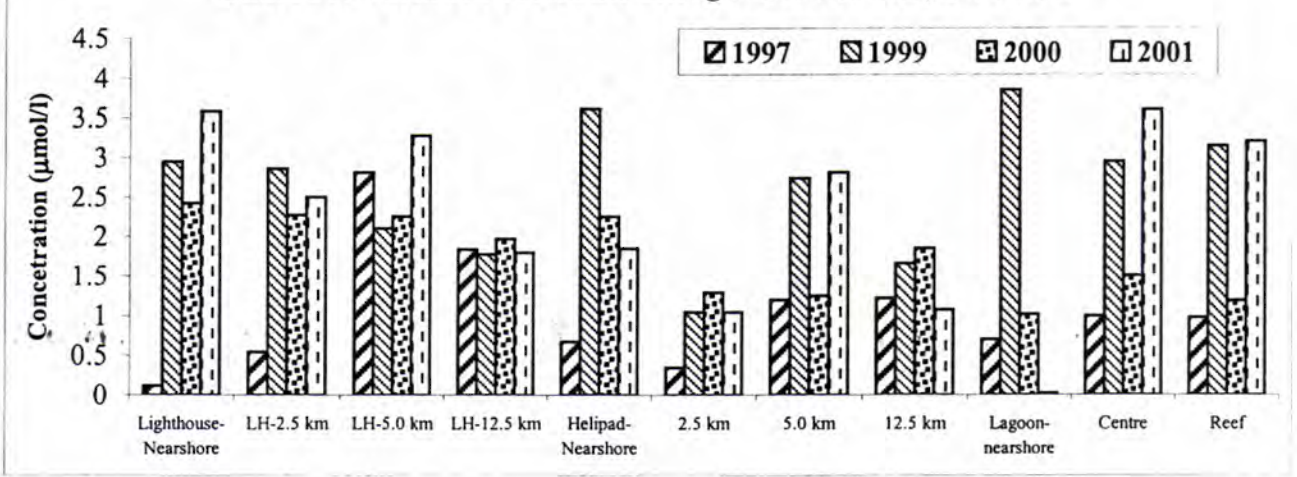


Chart 37: Variation of Total nitrogen in Seawater; 1997-2001

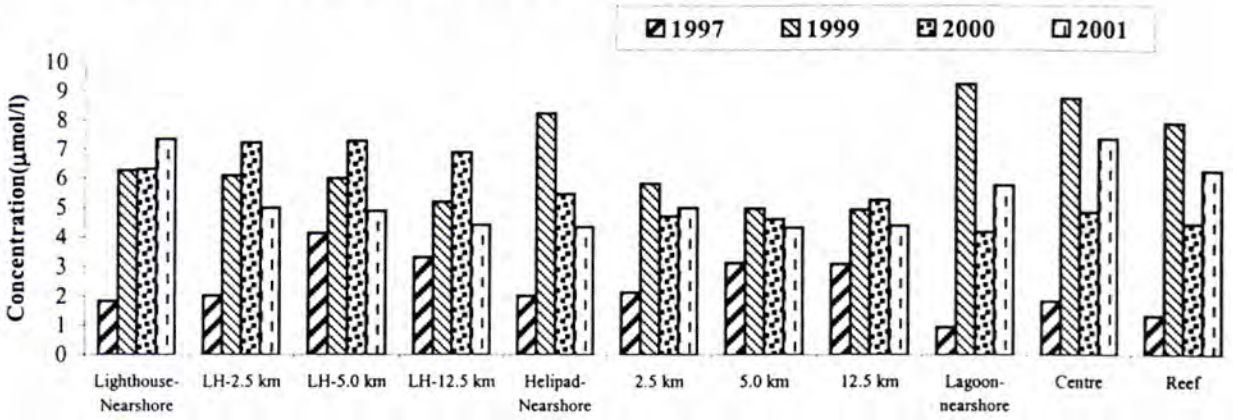


Chart 38: Variation of Biological oxygen demand in Seawater; 1997-2001

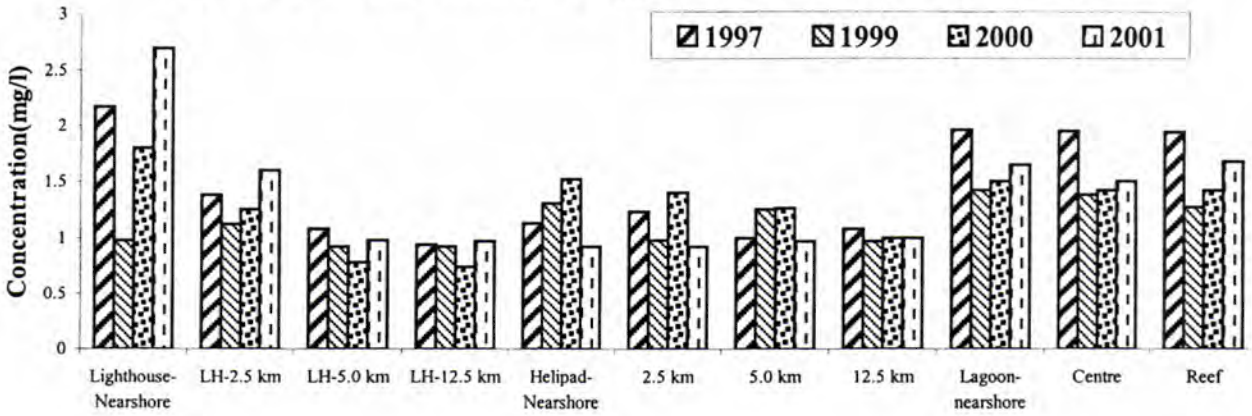


Chart 39: Variation of Petroleum Hydrocarbon in Seawater; 1997-2001

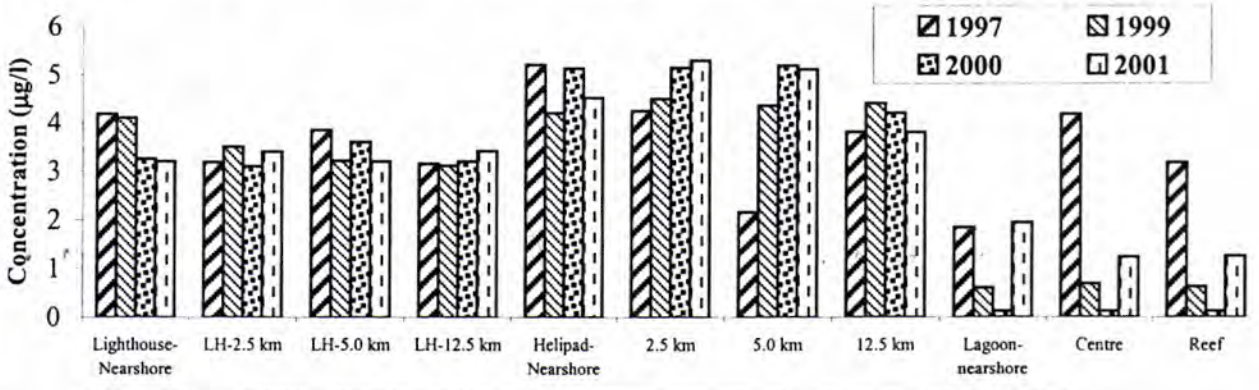


Chart 40: Variation of Dissolved Cadmium in Seawater; 1997-2001

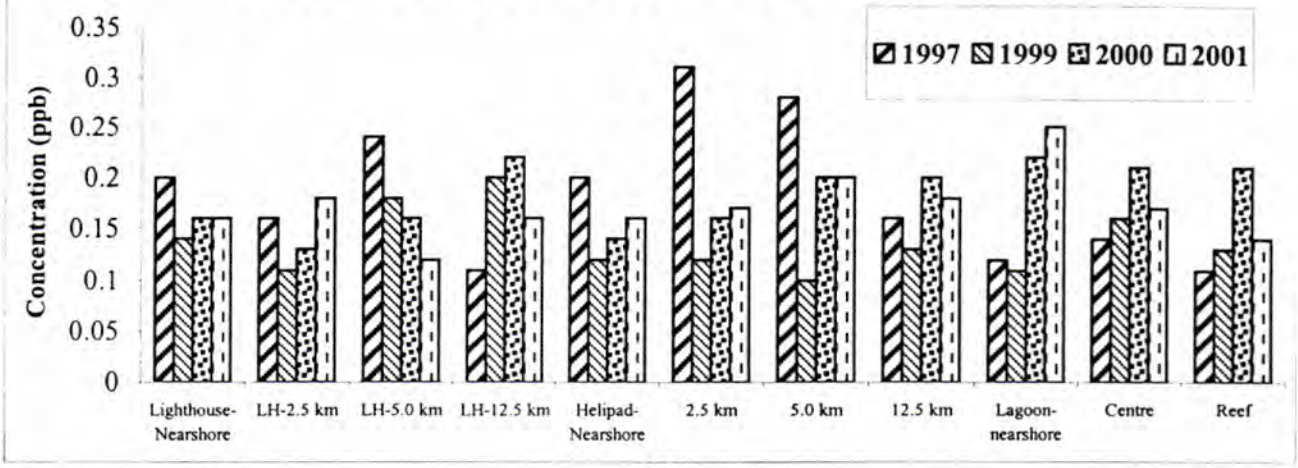


Chart 41: Variation of Dissolved Lead in Seawater; 1997-2001

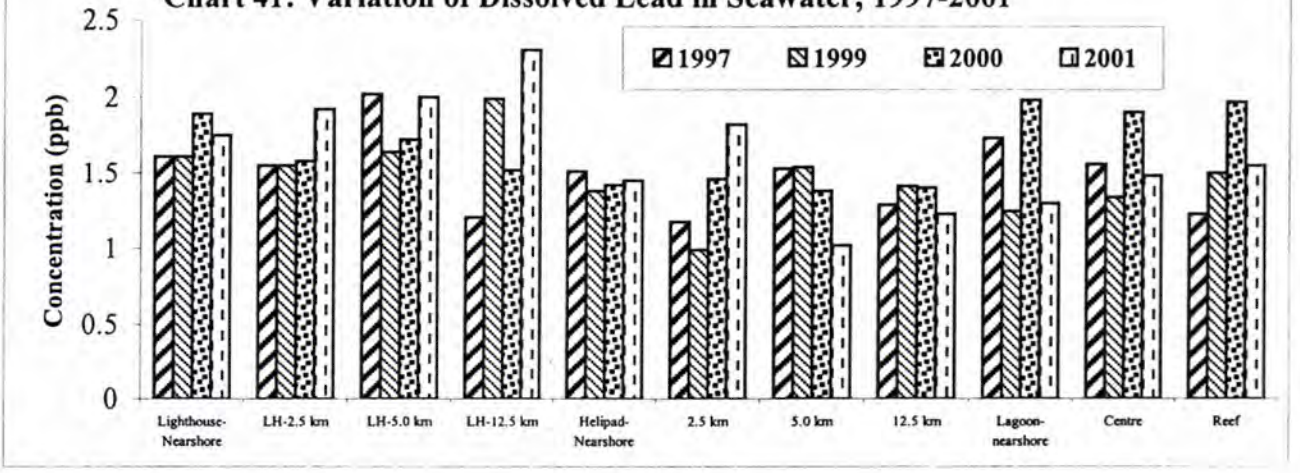
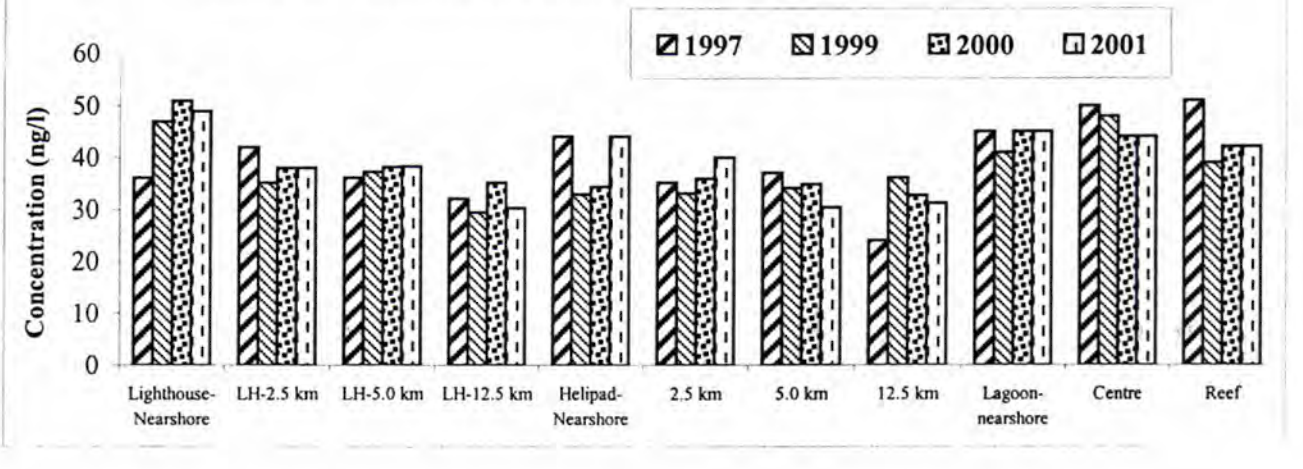


Chart 42: Variation of Dissolved mercury in Seawater;1997-2001



3.1.3 Biological parameters (Table 7-9 & Chart 43-57)

Lighthouse transect

Primary productivity varied from 22.1 mgC/m^3/day at 5.0 km offshore to 26.7 mgC/m^3/day at 12.5 km station in 1997, 22.1 mgC/m^3/day at nearshore to 28.0 mgC/m^3/day at 2.5 km offshore in 1999, 0.16 mgC/m^3/day at nearshore to 23.2 mgC/m^3/day at 5.0 km offshore in 2000 and 10.8 mgC/m^3/day at nearshore to 27.5 mgC/m^3/day at 12.5 km station during 2001. Chlorophyll *a* pigment varied from 0.50 mg/m^3 at 12.5 km offshore to 0.77 mg/m^3 at 5.0 km station in 1997, 0.72 mg/m^3 at nearshore to 1.20 mg/m^3 at 2.5 km in 1999, 0.24 mg/m^3 at the nearshore to 1.21 mg/m^3 at 5.0 km station in 2000 and 0.41 mg/m^3 at nearshore to 0.97 mg/m^3 at 5.0 km in 2001. Phytoplankton total count varied from 6519 nos/l at 12.5 km offshore to 9610 nos/l at 2.5 km in 1997, 6060 nos/l at the nearshore to 8580 nos/l at 12.5 km in 1999, 428 nos/l at nearshore to 5340 nos/l at 5.0 km in 2000 and 3760 nos/l at nearshore to 5780 nos/l at 5.0 km during 2001. Zooplankton biomass fluctuated from 0.12 ml/m^3 at the nearshore to 0.36 ml/m^3 at 12.5 km offshore in 1997, 0.14 ml/m^3 at 2.5 km to 0.35 ml/m^3 at nearshore in 1999, 0.22 ml/m^3 at 12.5 km to 0.68 ml/m^3 at 2.5 km during 2000 and 0.29 ml/m^3 at nearshore to 0..58 ml/m^3 at 2.5 km in 2001. Zooplankton total count varied from 248 no/m^3 at nearshore to 434 no/m^3 at 12.5 km in 1997, 395 no/m^3 at 2.5 km to 610 no/m^3 at nearshore in 1999, 422 no/m^3 at12.5 km to 708 no/m^3 at nearshore in 2000 and 528 no/m^3 at nearshore to 741 no/m^3 at 2.5 km station during 2001.

Helipad transect

Primary productivity ranged from 18.5 mgC/m^3/day at 5.0 km offshore to 27.0 mgC/m^3/day at nearshore station in 1997, 20.2 mgC/m^3/day at 12.5 km station to 29.8 mgC/m^3/day at 5.0 km offshore in 1999, 12.5 mgC/m^3/day at the nearshore to 23.2 mgC/m^3/day at the 5.0 km station in 2000 and 18.4 mgC/m^3/day at 5.0 km offshore to 26.6 mgC/m^3/day at 2.5 km station in 2001. Chlorophyll *a* ranged from 0.25 mg/m^3 at 5.0 km offshore to 0.43 mg/m^3 at the 2.5 km station in 1997, 0.59 mg/m^3 at the 2.5 km station to 1.22 mg/m^3 at 5.0 km station in 1999, 0.82 mg/m^3 at 12.5 km offshore to 0.98 mg/m^3 at 2.5 km station in 2000 and 0.83 mg/m^3 at nearshore to 2.02 mg/m^3at 12.5 km offshore during 2001. Phytoplankton total counts ranged from 4340 nos/l at 5.0 km station to 8950 nos/l at the nearshore in 1997, 4180 nos/l at nearshore to 9200 nos/l at 5.0 km station in 1999, 1860 nos/l at 12.5 km offshore to 5630 nos/l at 2.5 km sample during 2000 and 6872 nos/l at the nearshore to 7654 nos/l at 5.0 km station during 2001. Zooplankton biomass varied from 0.22 ml/m^3 at nearshore and 12.5 km offshore to 0.38 ml/m^3 at 5.0 km in 1997, 0.24 ml/m^3 at nearshore to 0.75 ml/m^3 at 12.5 km offshore in 1999, 0.38 ml/m^3 at 12.5 km station to 0.80 ml/m^3 at 2.5 km station in 2000 and 0.39 ml/m^3 in 12.5 km station to 0.92 ml/m^3 at nearshore during 2001. The zooplankton density ranged from 337 no/m^3 at the nearshore to 482 no/m^3 at 5.0 km in 1997, 335 no/m^3 at 12.5 km offshore to 632 no/m^3 at 2.5 km offshore in 1999, 550 no/m^3 at the 12.5 to 722 no/m^3 at the 2.5 km in 2000 and 461 no/m^3 at the 12.5 km offshore to 954 no/m^3 at nearshore during 2001.

Lagoon transect

The primary productivity varied from 5.3 mgC/m^3/day at reef to 8.4 mgC/m^3/day at centre in 1997, 3.5 mgC/m^3/day at centre to 5.6 mgC/m^3/day at reef during 1999, 2.5 mgC/m^3/day

at reef to 6.8 mgC/m^3/day at nearshore during 2000 and 2.4 mgC/m^3/day at centre to 5.1 mgC/m^3/day at nearshore during 2001. Pigment concentration ranged from 0.60 mg/m^3 at centre to 0.73 mg/m^3 at reef in 1997, 0.70 mg/m^3 at nearshore to 0.30 mg/m^3 at Centre in 1999, 0.24 mg/m^3 at nearshore to 0.93 mg/m^3 at reef during 2000 and 0.46 mg/m^3 at reef to 0.72 mg/m^3 at centre during 2001. Phytoplankton total count varied from 6350nos/l at reef to 9518 nos/l at centre in 1997, 2350 nos/l at reef to 6260 nos/l at centre in 1999, 1690 nos/l at reef to 2600 nos/l at Centre in 2000 and 3165 nos/l at reef to 4128 nos/l at centre in 2001. Zooplankton biomass varied from 0.24 ml/m^3 at centre to 0.36 ml/m^3 at nearshore in 1997, 0.21 ml/m^3 at centre to 0.27 ml/m^3 at reef during 1999, 0.28 ml/m^3 at Centre to 0.36 ml/m^3 at reef during 2000 and 0.38 ml/m^3 at nearshore to 0.52 ml/m^3 at reef during 2001. Zooplankton total count fluctuated from 351 no/m^3 at reef to 385 no/m^3 at nearshore during 1997, 365 no/m^3 at nearshore to 385 no/m^3 at reef in 1999, 386 no/m^3 at reef to 565 no/m^3 at nearshore in 2000 and 420 no/m^3 at nearshore to 476 no/m^3 at reef in 2001.

The results of primary productivity studies reveal that the offshore stations of Lighthouse transect are the most productive during all the seasons except the nearshore during August 2000. The sharp decline in productivity and pigment concentration in the nearshore of Lighthouse transect during the period could be attributed to the coir retting activities. Lower productivity and phytoplankton count noticed in the lagoon may be attributed to the non-availability of inorganic nutrients, which has reportedly been fast assimilated by macro algae like Eel grass (*Zostera marina*) (Sankaranayaranan, 1973). The highest productivity in the lagoon region was noticed during post-monsoon season of 1997, but a decreasing trend was noticed over the years (chart 45). Though there was a reduction in productivity at Lighthouse and Helipad transects during 2000 and 2001, it was mainly confined to the

nearshore region. The average primary productivity earlier reported during post-monsoon (October-December) was higher than the pre-monsoon season (Bhattathiri and Devassy, 1979). The present study also agrees with this observation.

Even though the general distribution pattern of chlorophyll do agree with the earlier findings (Bhattathiri and Devassy, 1979), comparison of productivity and chlorophyll *a* values indicated how widely they fluctuated during different periods of study. Though the primary productivity values are higher than reported values (0.44 $mgC/m^3/hr$) for Lakshadweep Sea (Goes and Devassy, 1986) it was lower compared to that reported for the northern Arabian Sea (698 $mgC/m^2/day$) (Radhakrishnan *et al.*, 1978).

In agreement with the primary productivity values, higher phytoplankton count and pigment concentration were also recorded from the offshore stations of Lighthouse transect.

Zooplankton density and biomass showed a slight increase in the nearshore region during 2000 and 2001 period. Zooplankton density did not show wide fluctuation at different stations in the lagoon and in the open Sea. Lower zooplankton count was noticed during 1997 and 1999 compared to 2000 and 2001 in all transects. Though the zooplankton density was higher in the offshore stations, where the productivity and pigment were also higher, its density was not considerably low in the lagoon too.

Compared to phytoplankton count, zooplankton density was not lower in lagoon. The abundance of zooplankton noticed in the lagoon during the present study is similar to that reported earlier (Teater and George, 1972; Goswami, 1973 and Wafar, 1977). This indicates that the zooplankton derive nutrition from sources other than phytoplankton. The alternative source identified was the organic aggregates whose abundance in reef waters is

of much ecological significance (Qasim and Sankaranarayanan, 1970). Earlier studies reported that the contribution of larger phytoplankton to the reef production was also not significant (Wafar, 1997). Zooplankton abundance from the samples collected proves that copepods were the dominant constituent of zooplankton population in most of the seasons; except during May 1999 where fish eggs were the dominant constituents in the lagoon. The dominance of copepods was earlier reported by Goswami, 1979. In general, biomass values estimated were higher than the reported values (Goswami, 1979). From these observations, it can be noticed that the biological characteristics of the Lakshadweep Sea show slight variation from May/June/August from those of October/December and the difference can be attributed to changes in physico-chemical characteristics.

Table 7. Primary productivity and plankton diversity in the Lighthouse transect; 1997-2001

Year	Distance from the shore	Primary productivity ($mgC/m^3/day$)	Chlorophyll *a* (mg/m^3)	Phytoplankton		Zooplankton		
				Total count (Nos/l)	Major genera/species	Biomass (ml/m^3)	Density (No/m^3)	Major species
1997	Near shore	26.3	0.53	8350	*Coscinodiscus, Rhizosolenia, Chaetoceros*	0.12	248	Copepods, Foraminiferans, Gastropods
1999		22.1	0.72	6060	*Coscinodiscus, Trichodesmium, Ceratium*	0.35	610	Copepods, Chaetognaths, Nauplii
2000		0.16	0.24	428	*Coscinodiscus, Leptocylindrus*	0.43	708	Copepods, Nauplii, Radiolarians
2001		10.8	0.41	3760	*Coscinodiscus, Ceratium*	0.29	528	Copepods, Foraminiferans
1997	2.5 KM	22.6	0.72	9610	*Coscinodiscus, Rhizosolenia, Chaetoceros*	0.25	328	Copepods, Polychaetes, Foraminiferans
1999		28.0	1.20	8200	*Coscinodiscus, Trichodesmium, Navicula*	0.14	395	Copepods, Fish eggs, Decapod larvae
2000		8.24	0.69	2900	*Trichodesmium, Coscinodiscus*	0.68	622	Copepods, Nauplii, Radiolarians
2001		15.7	0.60	5168	*Coscinodiscus, Ceratium*	0.58	741	Copepods, Foraminiferans
1997	5.0 KM	22.1	0.77	7458	*Coscinodiscus, Rhizosolenia, Chaetoceros*	0.29	335	Copepods, Fish eggs, Amphipods
1999		26.7	0.80	6700	*Coscinodiscus, Trichodesmium, Rhizosolenia*	0.30	499	Copepods, Fish eggs, Fish larvae
2000		23.2	1.21	5340	*Coscinodiscus, Leptocylindrus*	0.38	537	Copepods, Foraminiferans, Mysids
2001		26.2	0.97	5780	*Ceratium, Coscinodiscus*	0.54	612	Copepods, Gastropod larvae, Lamellibranch larvae
1997	12.5 KM	26.7	0.50	6519	*Rhizosolenia, Coscinodiscus, Pleurosigma*	0.36	434	Copepods, Polychaetes, Siphonophores
1999		25.5	1.0	8580	*Coscinodiscus, Trichodesmium, Thalassiosira*	0.21	416	Copepods, Fish larvae, Polychaetes
2000		19.8	0.45	3110	*Coscinodiscus, Leptocylindrus*	0.22	422	Copepods, Fish eggs, Tintinnids
2001		27.5	0.57	4350	*Coscinodiscus, Ceratium*	0.46	568	Copepods, Foraminiferans

Table 8. Primary productivity and plankton diversity in the Helipad transect; 1997-2001

Year	Distance from the shore	Primary productivity ($mgC/m^3/day$)	Chlorophyll *a* (mg/m^3)	Phytoplankton		Zooplankton		
				Total count (Nos/l)	Major genera/species	Biomass (ml/m^3)	Density (No/m^3)	Major species
1997	Nearshore	27.0	0.33	8950	*Coscinodiscus, Pleurosigma, Navicula, Chaetoceros*	0.22	337	Copepods, Decapod larvae, Fish eggs
1999		21.1	0.61	4180	*Rhizosolenia, Coscinodiscus, Trichodesmium*	0.24	395	Copepods, Chaetognaths, Fish eggs
2000		12.5	0.87	3119	*Coscinodiscus, Leptocylindrus*	0.79	636	Radiolarians, Foraminiferans
2001		20.8	0.83	6872	*Coscinodiscus, Ceratium*	0.92	954	Copepods, Foraminiferans
1997	2.5 KM	22.0	0.43	8100	*Coscinodiscus, Rhizosolenia, Pleurosigma*	0.36	426	Copepods, Decapod larvae, Appendicularians
1999		23.2	0.59	6060	*Coscinodiscus, Trichodesmium Rhizosolenia*	0.35	632	Copepods, Fish eggs, Fish larvae, Chaetognaths
2000		16.2	0.98	5630	*Leptocylindrus, Triceratium*	0.80	722	Copepods, Nauplii
2001		26.6	1.30	7420	*Coscinodiscus, Ceratium*	0.62	628	Copepods, Foraminiferans, Acantharians
1997	5.0 KM	18.5	0.25	4340	*Pleurosigma, Rhizosolenia, Coscinodiscus*	0.38	482	Copepods, Fish eggs, Mysids, Decapod larvae
1999		29.8	1.22	9200	*Coscinodiscus, Trichodesmium, Rhizosolenia*	0.28	465	Copepods, Fish larvae, Polychaetes
2000		23.2	0.91	4570	*Coscinodiscus, Rhizosolenia, Trichodesmium*	0.66	653	Copepods, Tintinnids
2001		18.4	1.80	7654	*Coscinodiscus, Ceratium*	0.42	525	Copepods, Foraminiferans, Acantharians
1997	12.5 KM	22.2	0.28	5830	*Coscinodiscus, Pleurosigma, Blue green algae*	0.22	350	Copepods, Decapod larvae, Medusae
1999		20.2	0.65	5300	*Trichodesmium, Coscinodiscus Rhizosolenia*	0.75	335	Copepods, Fish eggs, Fish larvae
2000		14.8	0.82	1860	*Coscinodiscus, Trichodesmium, Planktoniella*	0.38	550	Copepods, Foraminiferans, Fish eggs
2001		21.3	2.02	7485	*Coscinodiscus, Ceratium*	0.39	461	Copepods, Foraminiferans, Acantharians

Table 9. Primary productivity and plankton diversity in the Lagoon; 1997-2001

Year	Station	Primary productivity ($mgC/m^3/day$)	Chlorophyll *a* (mg/m^3)	Phytoplankton		Zooplankton		
				Total count (Nos/l)	Major genera/species	Biomass (ml/m^3)	Density (No/m^3)	Major species
1997	Nearshore	8.3	0.64	8350	*Coscinodiscus, Rhizosolenia, Pleurosigma*	0.36	385	Copepods, Ostracods, Chaetognaths
1999		4.3	0.70	2700	*Coscinodiscus, Rhizosolenia, Navicula*	0.24	365	Fish eggs, Echinoderm larvae, Protozoea larvae
2000		6.8	0.24	2360	*Coscinodiscus, Leptocylindrus*	0.35	565	Copepods, Nauplii, Radiolarians
2001		5.1	0.60	3711	*Coscinodiscus, Ceratium*	0.38	420	Copepods, Acantharians
1997	Center	8.4	0.60	9518	*Coscinodiscus, Rhizosolenia, Pleurosigma*	0.24	365	Copepods, Mysids, Medusae, Appendicularians
1999		3.5	1.30	6260	*Coscinodiscus, Rhizosolenia, Pleurosigma*	0.21	367	Fish eggs, Protozoea larvae, Copepods
2000		3.4	0.64	2600	*Trichodesmium, Coscinodiscus*	0.28	415	Copepods, Nauplii, Radiolarians
2001		2.4	0.72	4128	*Coscinodiscus, Ceratium*	0.41	456	Copepods, Acantharians
1997	Reef	5.3	0.73	6350	*Coscinodiscus, Rhizosolenia, Pleurosigma*	0.27	351	Copepods, Mysids, Medusae, Appendicularians
1999		5.6	0.90	2350	*Coscinodiscus, Rhizosolenia, Ceratium, Pleurosigma*	0.27	385	Fish eggs, Protozoea larvae, Copepods
2000		2.5	0.93	1690	*Coscinodiscus, Leptocylindrus*	0.36	386	Copepods, Foraminiferans, Mysids
2001		3.8	0.46	3165	*Coscinodiscus, Ceratium*	0.52	476	Copepods, Foraminiferans, Acantharians

Chart 43: Primary productivity at Lighthouse transect; 1997-2001

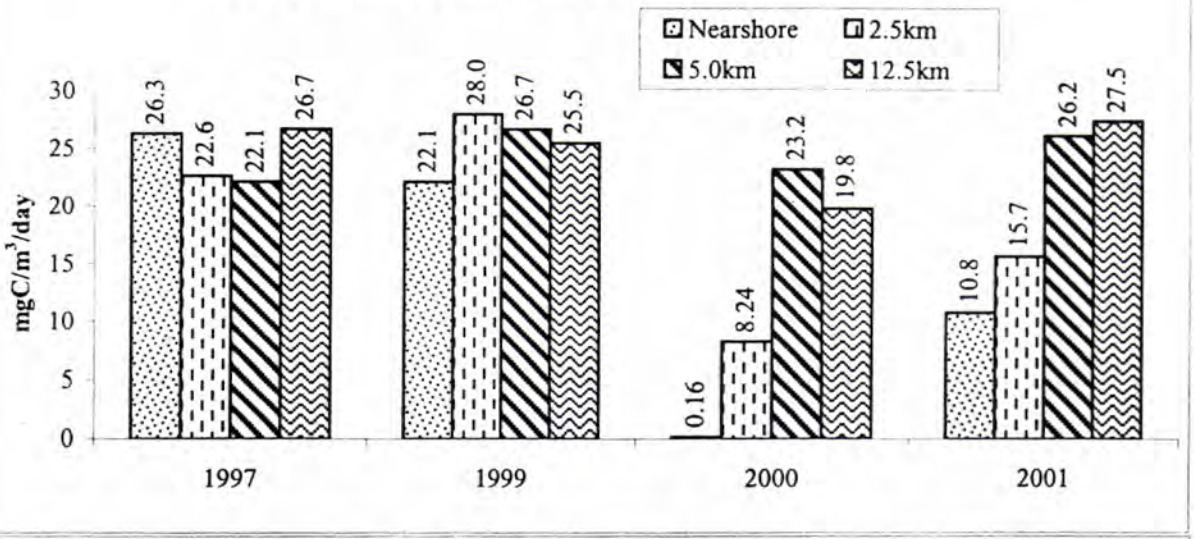


Chart 44: Primary productivity at Helipad, 1997-2001

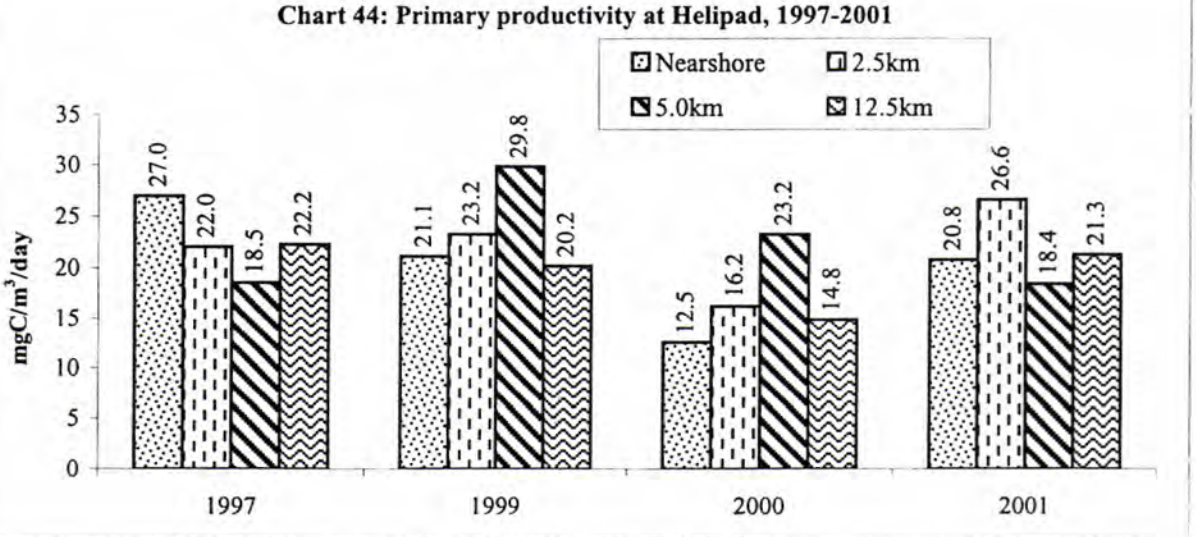


Chart 45: Primary productivity at Lagoon, 1997-2001

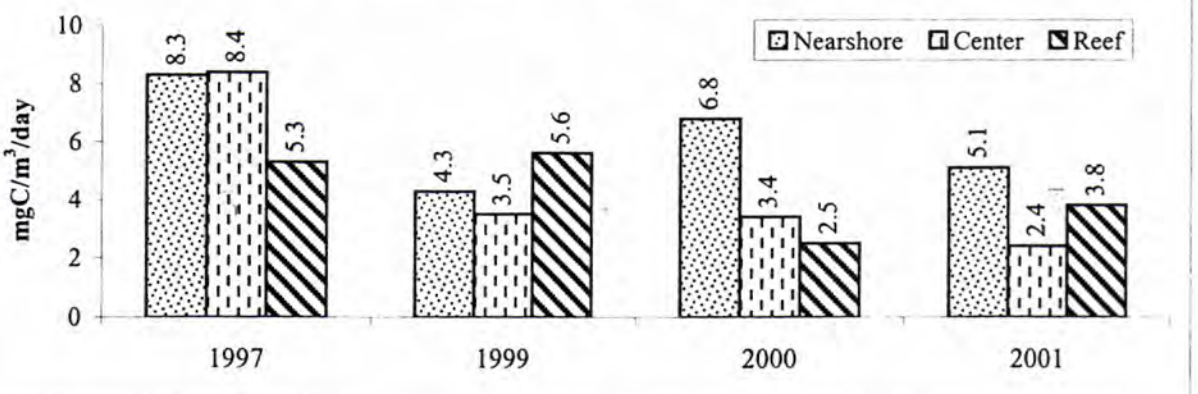


Chart 46: Chlorophyll *a* at Light house transect; 1997-2001

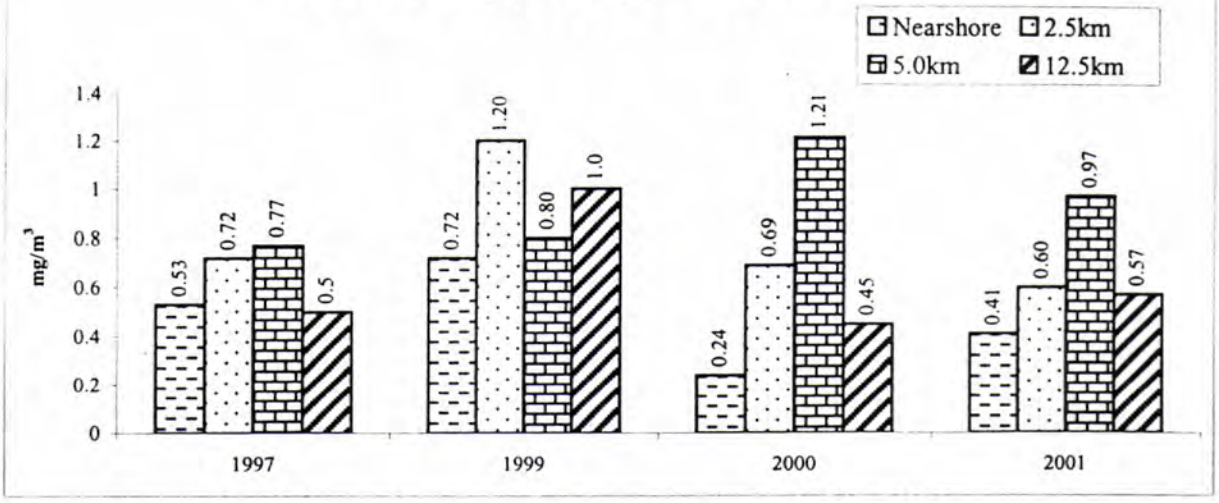


Chart 47: Chlorophyll *a* at Helipad transect; 1997-2001

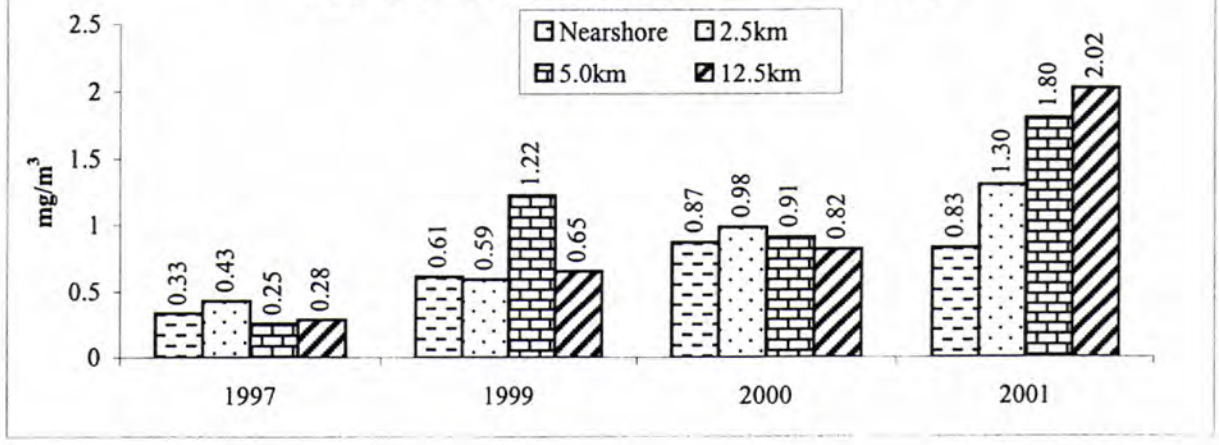


Chart 48: Chlorophyll *a* at Lagoon; 1997-2001

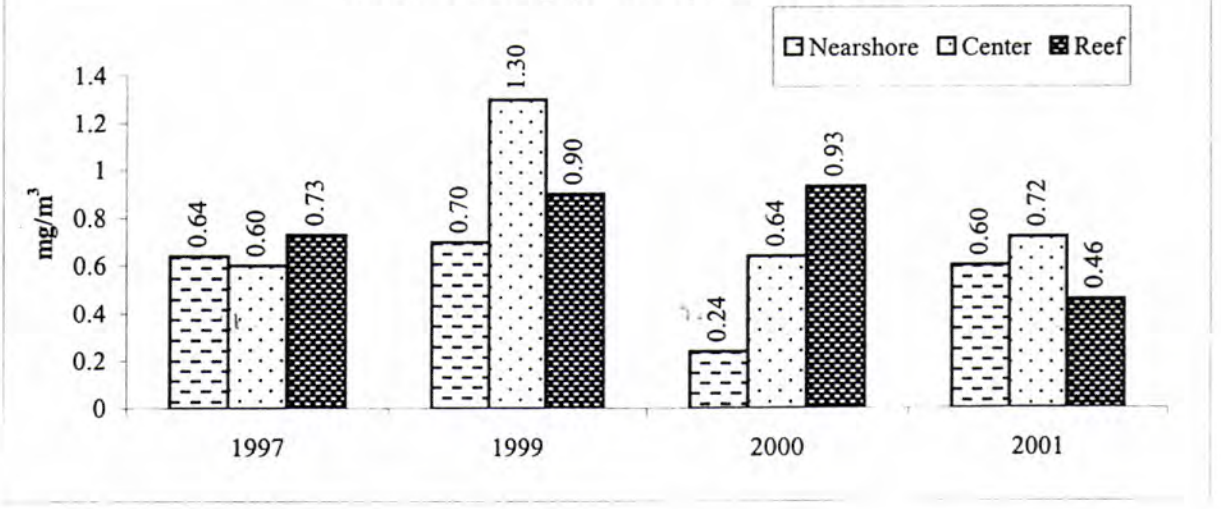


Chart 49: Phytoplankton count at Lighthouse transect; 1997-2001

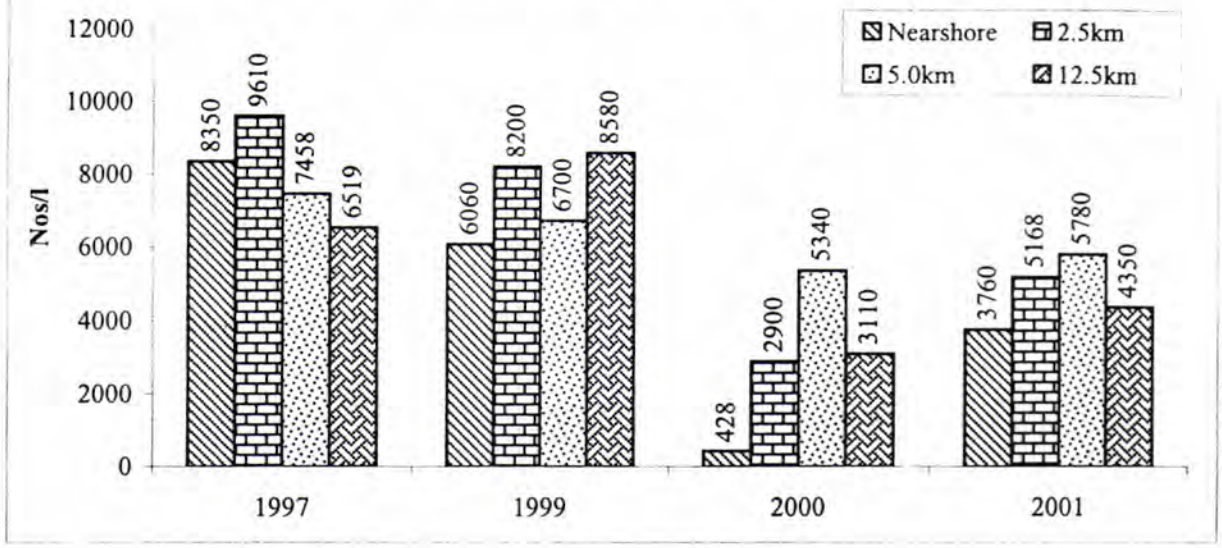


Chart 50: Phytoplankton count at Helipad transect; 1997-2001

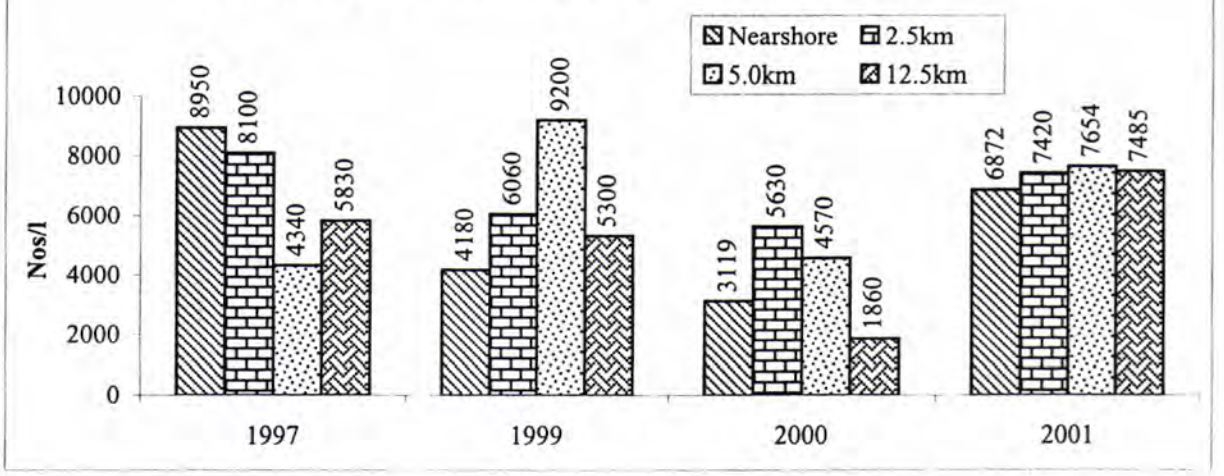


Chart 51: Phytoplankton count at Lagoon; 1997-2001

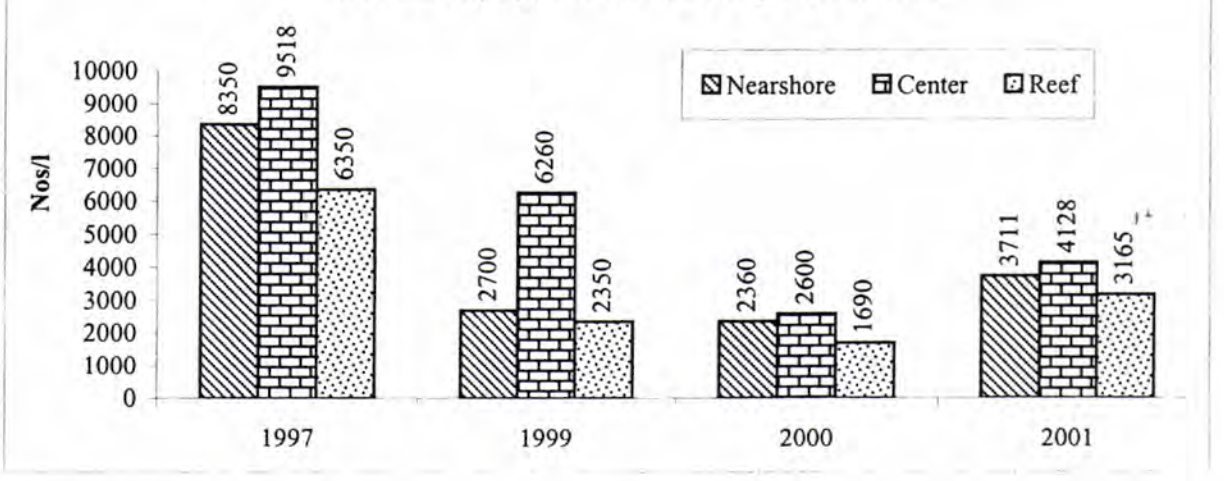


Chart 52: Zooplankton density at Lighthouse transect; 1997-2001

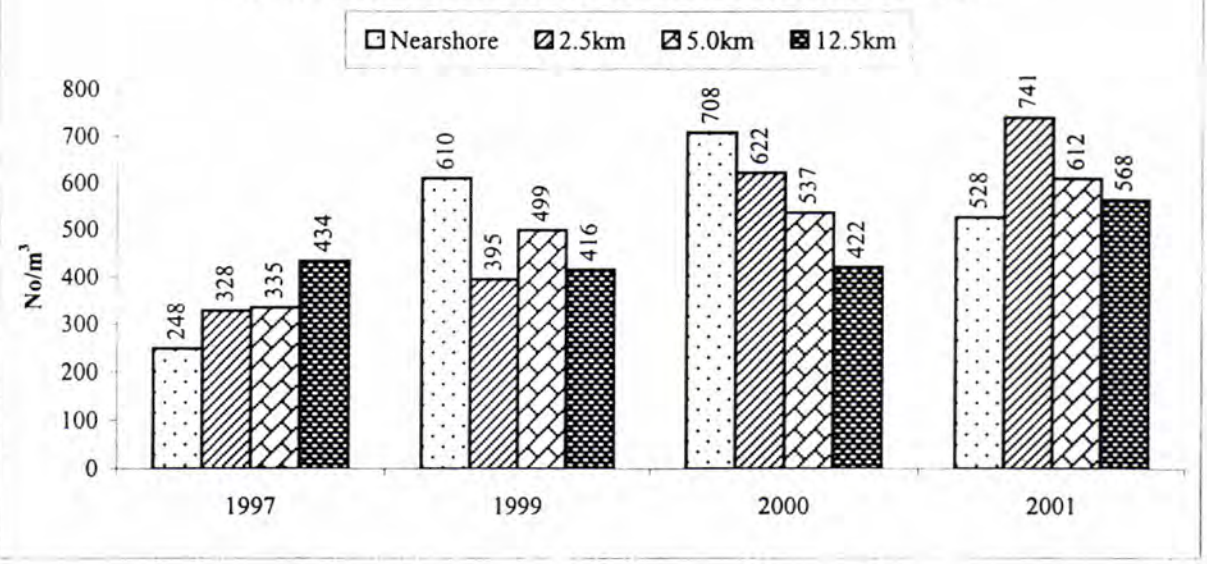


Chart 53: Zooplankton density at Helipad transect; 1997-2001

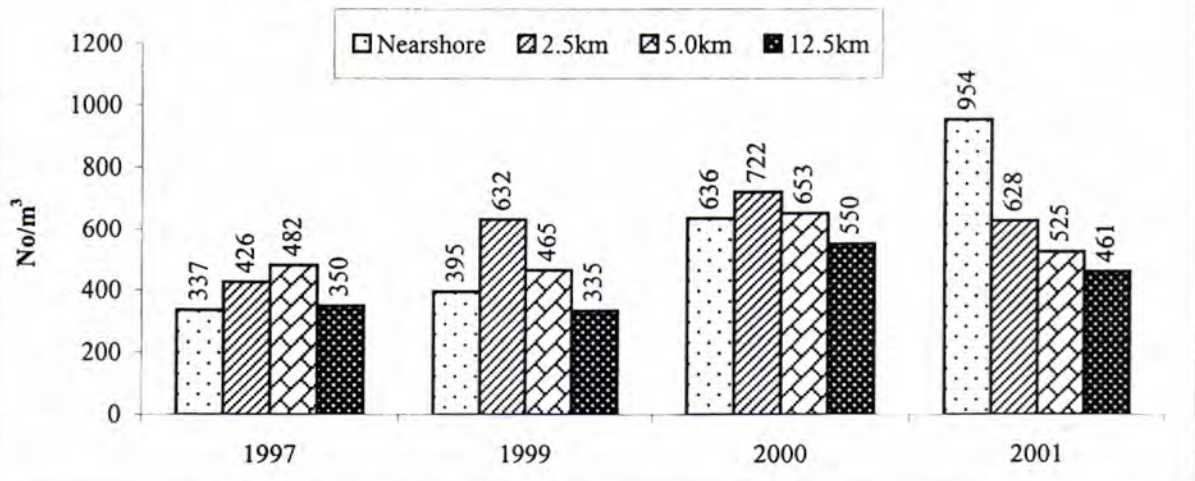


Chart 54: Zooplankton density at Lagoon; 1997-2001

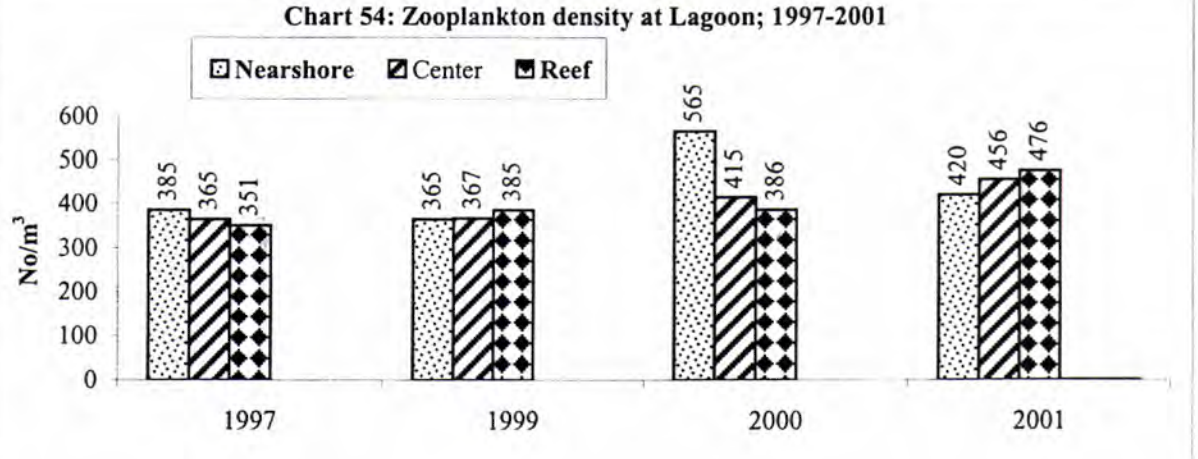


Chart 55: Zooplankton Biomass at Lighthouse transect; 1997-2001

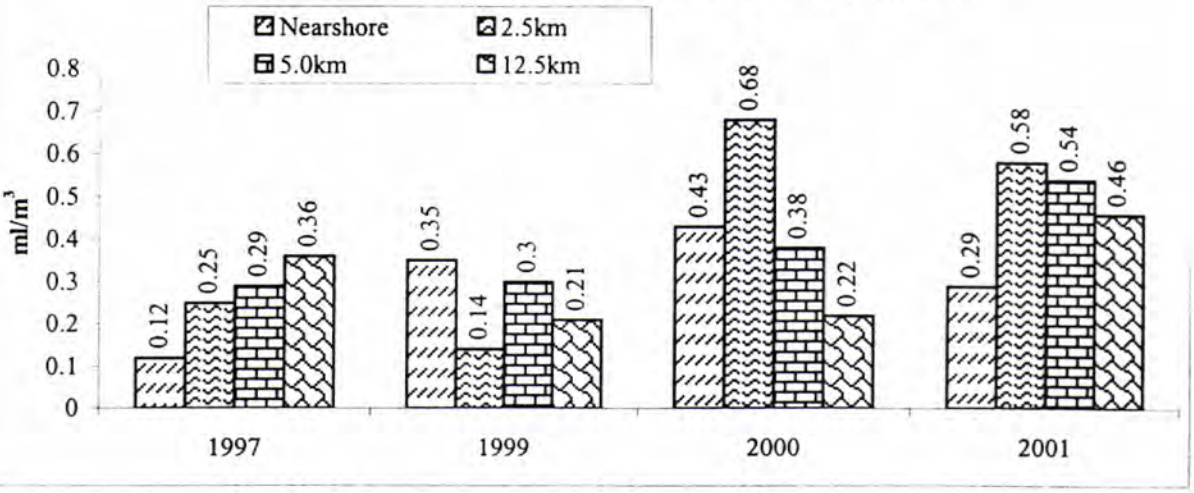


Chart 56: Zooplankton Biomass at Helipad transect; 1997-2001

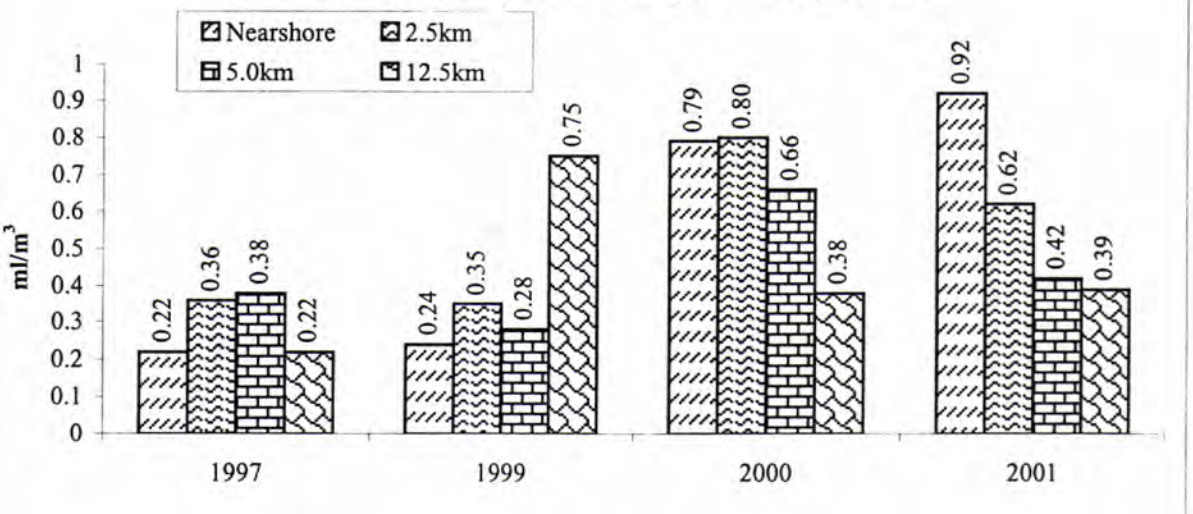
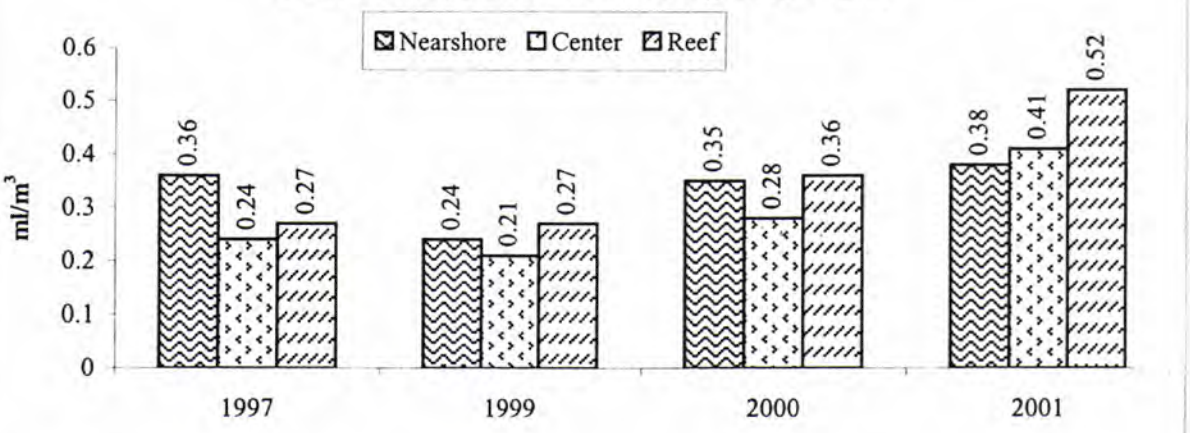


Chart 57: Zooplankton Biomass at Lagoon, 1997-2001



3.2. Ground water analysis

The results are shown in table 10-17 and charts 58-149

3.2.1 Microbiological characteristics (Table 10-13 and charts 58-93)

Total viable count (TVC) (Chart 59-61)

TVC varied from $13x10^3$ cfu/100 ml in well no. 13 to $83.5x\ 10^4$ in well no. 2 during 1997, $10\ x10^3$ cfu/100 ml in well no. 26 to $87\ x10^3$ cfu/100 ml in well no. 25 in 1999, $25\ x10^2$ cfu/100 ml in well no. 13 to $12.5\ x10^5$ cfu/100 ml in well no. 28 in 2000 and $8\ x10^3$ cfu/100 ml in well no. 8 to $26\ x10^5$ cfu/100 ml in well no. 14 in 2001. In 1997, five wells showed high TVC while two wells (6 & 26) recorded values in between. This reveals that the distribution of heterotrophic population is highly fluctuating in the study period (charts 58-61). In general, the high counts are noticed during the post-monsoon season (December, 1997). This may be attributed to the nutrient availability after the monsoon period. Lower counts were noticed in the tube wells (no.31&32) irrespective of the seasons.

Total coliforms (TC) (Chart 62-65)

Total coliforms count ranged from nil cfu/100 ml in well no. 29 to $14\ x10^4$ cfu/100 ml in well no. 3 in 1997, nil in well no. 28 to $21\ x10^3$ cfu/100 ml in well no. 10 in 1999, nil in well nos. 24, 27 and 29 to $85\ x10^2$ cfu/100 ml in well no. 22 in 2000 and nil in well nos. 6, 8 and 21 to $27\ x10^3$ cfu/100 ml in well no. 17 in 2001. The results shows that coliform contamination is nearly complete in the dug well waters covering all seasons. The occurrence of coliforms even in deep tube well (well no.32) reveals the severity of contamination.

Faecal coliforms (FC) (Chart 66-69)

FC was not enumerated in well numbers 1, 4, 8, 13, 14, 15, 18, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31 and 32 during 1997. The maximum count of faecal coliforms was 40 $x10^2$ cfu/100 ml in well no. 6 during 1997, nil in 12 wells to 38 $x10^2$ cfu/100 ml in well no. 10 during 1999, and 4 $x10^2$ cfu/100 ml in well no. 28 during 2000 and 176 cfu/100ml in well no. 4 during 2001. Faecal contamination was noticed in 14 wells in 1997, 19 wells in 1999, 20 wells in 2000 and15 wells in 2001. This clearly depicts that about 50 percent or more of the well samples are contaminated with pathogenic bacteria.

***Salmonella* like organisms (SLO) (Chart 70-73)**

SLO recorded their maximum count (3.15 $x10^2$ cfu/100 ml) in well no. 21 in 1997, in well no. 10 (11 $x10^2$ cfu/100 ml) during 1999, well no. 28 (13 $x10^2$ cfu/100 ml) in 2000 and in well no.24 (38 cfu/100 ml) during 2001. 21 wells in 1997, 15 wells in 1999, 17 wells in 2000 and 6 wells in 2001 recorded the presence of *Salmonella* like organisms. The presence of these organisms even in the absence of faecal coliforms may be due to their occurrence in water as natural inhabitants. However, presence of these organisms in high numbers as possible pathogens causing typhoid fever is alarming case of drinking water pollution.

***Shigella* like organisms (SHLO) (Chart 74-77)**

SHLO varied from nil in well numbers 14, 15, 16 and 32 to 48 $x10^2$ cfu/100 ml in well no.1 during 1997, 5 cfu/100ml in well no. 2 to 53 $x10^2$ cfu/100 ml in well no. 10 during 1999, nil in well nos.2 and 21 to 60 $x10^2$ cfu/100 ml in well no. 25 in 2000 and 20 cfu/100ml in well no. 5 to 55 $x10^2$ cfu/100 ml in well no.10 during 2001. These organisms were enumerated from most of the well waters irrespective of the seasons.

***Proteus, Klebsiella* like organisms (PKLO) (Chart 78-81)**

PKLO count varied from 13 (well no.5) to $23x10^2$ cfu/100ml (well no.10) during 1997, 15 cfu/100ml (well no. 25) to 60 $x10^2$ cfu/100ml (well no.9) in 1999, nil (well no.2) to 90 cfu/100ml (well no.21) to $36x10^2$ cfu/100ml (well no.18) in 2000 and (well no.6) to $63x10^2$ cfu/100ml (well no.10) in 2001. The presence of PKLO was noticed in all wells throughout the study period. However, in tube wells PKLO could not be recorded during the period 1999-2001.

***Vibrio cholera* like organisms (VCLO) (Chart 82-85)**

VCLO count varied from nil at five wells to $41x10^2$ cfu/100ml at well no. 10, 12 during 1997, 15 cfu/100ml at well no. 25 to $60x10^2$ cfu/100ml at well no. 9 in 1999, nil in five wells to $2.8x10^2$ cfu/100ml at well nos. 6 & 7 in 2000 and nil at eight wells to $21x10^2$ cfu/100ml at well no. 7 in 2001. 27 wells in 1997, in all wells during 1999, 27 wells in 2000 and 24 wells in 2001 recorded the presence of VCLO.

***Vibrio parahaemolyticus* like organisms (VPLO) (Chart 86-89)**

VPLO count varied from nil at seven wells to $18x10^2$ cfu/100ml at well no. 30 during 1997, nil in four stations to $3x10^2$ cfu/100ml at well no. 15 in 1999, nil at eleven wells to $2.5x10^2$ cfu/100ml at well no. 14 in 2000 and nil at nine wells to $27x10^2$ cfu/100ml at well no. 19 in 2001. 25 wells in 1997, 28 wells during 1999, 21 wells in 2000 and 23 wells in 2001 recorded the presence of VPLO. The trend in the counts of these organisms show that they are mostly present in post-monsoon season and pre-monsoon periods, but a lowering of counts occurs during monsoon period. This may be due to the influence of fresh water.

***Pseudomonas aeruginosa* like organisms (PALO)**

PALO varied from 3 cfu/100ml at well no. 5 to $43x10^2$ cfu/100ml at well no.6 during 1997, 89 cfu/100ml at well no. 30 to $45x10^2$ cfu/100ml at well no. 25 in 1999, 100 cfu/100ml at well no. 6 to $44x10^2$ cfu/100ml at well no.23 in 2000 and nil at well no. 6, 8 and 12 wells to $27x10^2$ cfu/100ml at well no. 23 in 2001.

Faecal streptococci (SFLO) (Chart 90-93)

SFLO varied from nil in five wells to $41x10^2$ in well no. 11 in 1997, nil at well numbers 28, 30 and 32 to 44 $x10^2$ cfu/100 ml in well no. 8 in 1999, 12 cfu/100 ml in well no. 10 to 75 $x10^2$ cfu/100 ml in 2000, nil to $10x10^2$ cfu/100ml in 2001. Faecal streptococci were present in almost all the wells during 1997,1999, 2000 and 2001. Widespread presence of these organisms is an indication of contamination from the unplastered septic tanks/leach pits situated close to many wells.

Though the heterotrophic bacterial population (TVC) has not been generally considered under quality parameters, high concentration of such bacteria is not desirable in drinking water as it is an indirect indication of the organic load in the media. It is highly desirable that drinking water should be of the highest possible purity especially when one system serves large numbers of people, in order to prevent any possibility of water borne disease. Of the diseases on which improvement in domestic water supply can have an impact, enteric infections, has greatest public health importance. They can be transmitted in drinking water, but also by various other feco-oral routes. These other routes are also facilitated by conditions of poor domestic hygiene and are therefore related to the availability of water for hygienic purposes rather than its quality.

Umar *et al.*, 2001, reported that 33 % of samples from hand pumps and 20 % from tube well samples in Aligarh city were found contaminated with coliforms and faecal

coliforms. The possible reason attributed to this includes the physical environment around the well site, frequent broken state of platforms, accumulations of waste water and sources like sewage drainage, hospital discharge etc. Similar situations were also noted in case of the dug wells at Kavaratti where the bacteriological quality of dug well waters, open wells and surface water was studied by Madan Nanoti in 1989. The study reported that all these sources invariably contain coliforms. Out of a total of 126 samples from 9 islands, only 3 were free from coliform and these include 2 private hand pumps and an open well with pH 9.0. A study by Kaza Somasekhara Rao *et al.*, 1986, in Nuzvid Town (A.P) showed that 35% of dug well samples contain coliform (MPN count) as high as 1800. The case of Kavaratti is far higher to this value reported from the mainland.

Expanding human population worldwide exacerbates the degree and frequency of pathogens exposure. The hygiene related behaviour is also very important to interrupt the transmission of the enteric pathogens. One Guatemalan study showed that a hygiene education programme among 106 mothers reduced the incidence of diarrhea in their children by 14 % and for the 4 months peak diarrhea season, the reduction was 32% (Ralph Mitchell, 1992) and another study in Bangladesh showed that by providing free soap and water pitches along with awareness lecture reduced the incidence of secondary cases of Shigella dysentery by 84% (GEMS/DATABASE, 1989). The GEMS/DATABASE study reported that In India, out of the 3,119 cities only 217 have partial or full sewage treatment facilities. The study showed that the river Yamuna, which flows through New Delhi, enters the capital with 7500 coliforms per 100 ml water after receiving an estimated 200 million litres of untreated sewage. Pathogens originated in human sewage may diffuse with rainwater and domestic wastewater through the sandy soil and reach the fresh water lens. In case of Kavaratti, this might also be affected by the leach

pit overflow as the pits are constructed near the dug wells. It is possible that during tidal influx, the wastewater from the pits could overflow and to mix with the fresh water source. In this respect, the *Salmonella* species that cause typhoid fever and having numerous serotypes enumerated in high numbers from well waters of Kavaratti is alarming. In Kavaratti, water table is generally 0.5-4.0 m below ground level with an elevation between 0.5 m to 5.74 m a.m.s.l. The septic tanks/leach pits are about 2-2.5m deep with overflow provision at an average depth of 0.5-1.0 m below ground level, ie, the dug wells are constructed to tap the same aquifer into which these effluents are discharged. Thus the septic tanks/leach pits, by design, allow entry of its effluents, into the water table (Madhusoodanan Pillai *et al.*, 2001). Compared to the well waters of Kerala, the bacterial counts in the study area are amazingly high. Mujeeb Rahman *et al.*, 2001 conducted studies in well waters from Ponnani and reported the total coliform range between 40 and 11000 per 100 ml. The mean values reported for faecal coliforms and faecal streptococci were 3640 and 1714 per 100 ml respectively. These values were lower compared to the results obtained in the present study.

Faecal streptococci are enteric bacteria found in the intestine of warm-blooded animals; including human. *Streptococcus faecalis* is a representative of this group and their occurrence in water is also indicative of faecal pollution. The most common water borne bacterial pathogens in contaminated drinking water supply in the USA during 1961-1983 were *Shigella*, *Salmonella*, toxigenic *E.coli*, *Vibrio* and *Yersenia* (Mentzing, 1981).

In Lakshadweep, due to limited capacity of receiving well waters to assimilate the burden of wastes from human activities, the pollution source has to be alienated from the water source. High population densities with point source discharges of untreated domestic waste are the contributing factors that cross-contaminate the well waters rather than

preventing contamination. Since the natural self-purification capacity of this receiving water is impaired, faecal contamination over base line water quality increases by 1 to 3 orders of magnitude. Here, the very low depth of wells also enhances the surface contamination of water sources from the accumulated wastes. The study proves that water quality management remains critical in Lakshadweep Islands since the ground water lens is continuously subjected to overdraft and bacterial contamination. The rise of water levels during high tide also found to be contributing to the increase of faecal bacteria of epidemiological significance in drinking water (Madhusoodanan Pillai *et al.*, 2001). The authors reported 2 to 100 fold increase in the count of faecal coliforms from the dug well waters taken during low and high tide period in Kavaratti. The studies conducted at Kadamat Island during 1999 also showed the drastic increase in the bacteriological and physico-chemical characteristics of the dug well waters. The study showed the conductivity values ranged from 410 to 5030 μmhos while faecal coliform varied from nil to 242 cfu/ml, faecal streptococci from 0 to 37 cfu/ml and *Vibrio cholera* like organisms (VCLO) from 0 to 97 cfu/ml in dug wells. These counts are also high compared to the values obtained from mainland. At high conductivity, the faecal coliforms cannot survive because of the increased ionic concentration (Madhusoodanan Pillai and Ouseph, 2000).

Table 10: Bacterial distribution in dug wells during 1997

Date of Sampling: 29.12.1997 **Date of Enumeration: 31.12.1997**

Wells	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TVC	$27.5x10^4$	$83.5x10^4$	$63 x10^4$	$77 x10^4$	$12.5x10^4$	$67x10^4$	$23 x10^3$	$8 x10^4$	$7 x10^4$	$27 x10^4$	$53 x10^3$	$14 x10^3$	$13 x10^3$	$43x10^3$	$8x10^4$	$24x10^4$
TC	$85 x10^2$	$10.3x10^2$	$14 x10^4$	$20.5x10^2$	$7.6 x10^2$	$51 x10^2$	$4.2 x10^2$	$11 x10^2$	$18 x10^2$	$16 x10^2$	$4 x10^2$	$6 x10^2$	$1.4 x10^2$	$28x10^2$	$18x10^2$	$76x10^2$
FC	ND	$1.5x10^2$	$1.3 x10^2$	ND	$3 x10^2$	$40 x10^2$	$4 x10^2$	ND	$1.9 x10^2$	$1.6 x10^2$	15	$4 x10^2$	ND	ND	ND	18
SLO	ND	$10x10^2$	15	ND	4	ND	5	ND	75	46	ND	35	75	185	10	85
SHLO	$48 x10^2$	$23x10^2$	$23 x10^2$	$49 x10^2$	45	$11 x10^2$	$1.3x 10^2$	$7 x10^2$	$13 x10^2$	$41 x10^2$	$7 x10^2$	$22 x10^2$	45	ND	ND	ND
PKLO	$13 x10^2$	$16x10^2$	$7 x10^2$	$21 x10^2$	13	98	$2.2x10^2$	$6 x 10^2$	$17 x 10^2$	$23 x 10^2$	$6x10^2$	$8x10^2$	$24x10^2$	$5.8x10^2$	$1.1x10^2$	$13.7x10^2$
VCLO	$1.2 x10^2$	$14x10^2$	$3 x10^2$	55	$1.75x10^2$	$4.2 x10^2$	$2.8x10^2$	$4 x 10^2$	$21 x 10^2$	$41 x 10^2$	$22x10^2$	$41x10^2$	$16x10^2$	$1.4x10^2$	$1.8x10^2$	$7.3x10^2$
VPLO	$10 x10^2$	70	93	40	98	$2.7 x10^2$	$12 x 10^2$	$2 x 10^2$	$4 x 10^2$	$6 x 10^2$	$13x10^2$	$6 x 10^2$	$7 x 10^2$	$1.1x10^2$	95	ND
PALO	$1.34x10^2$	100	$5 x10^2$	$6 x10^2$	3	$43 x10^2$	$18 x 10^2$	$8 x 10^2$	$18 x 10^2$	$8 x 10^2$	$8 x 10^2$	$7 x 10^2$	$6 x 10^2$	$2.2x10^2$	15	ND
SFLO	$20 x10^2$	$17x10^2$	$14 x10^2$	$13 x10^2$	17	$23 x10^2$	75	ND	ND	$41x10^2$	$27x10^2$	$1.5x10^2$	ND	$7.3x10^2$	$4.8x10^2$	$2.1x10^2$

Table 10 contd.....

Wells	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 (TW)	32 (TW)
TVC	$6x10^4$	$59x10^4$	$22x10^4$	$70x10^3$	$10x10^4$	$41x10^3$	$15x10^4$	$13x10^4$	$8x10^5$	$19x10^2$	$8x10^4$	$78x10^4$	$70x10^4$	$14x10^3$	$18 x10^3$	$17 x10^3$
TC	$35x10^2$	$22x10^2$	$26x10^2$	$28x10^2$	$8x10^2$	$28x10^2$	$6x10^2$	$5x10^2$	$22x10^2$	78	43	$28x10^2$	ND	$7 x10^2$	$7.5 x10^2$	$16 x10^2$
FC	10	ND	21	40	ND	ND	ND	ND	ND	105	ND	ND	ND	ND	ND	ND
FS	70	45	$3.15x10^2$	75	63	83	55	$2.7x10^2$	36	$1.55x10^2$	15	20	35	ND	ND	ND
SLO	$11x10^2$	ND	ND	ND	20	ND	22	38	ND	35	15	430	ND	$6 x10^2$	15	50
SHLO	$1.35x10^2$	$3.2x10^2$	20	$14.6x10^2$	$3.8x10^2$	$3.4x10^2$	$13.4x10^2$	$38x10^2$	$35x10^2$	$18x10^2$	$1.4x10^2$	$1.1x10^2$	$7x10^2$	$1.7x10^2$	$11x10^2$	ND
PKLO	$2.4x10^2$	$19x10^2$	40	$4.3x10^2$	$4.3x10^2$	$5.1x10^2$	15	$1.4x10^2$	$2.0x10^2$	$2.3x10^2$	$2.6x10^2$	$2.8x10^2$	$2.3x10^2$	$2 x 10^2$	$4x10^2$	100
VCLO	ND	10	25	15	35	25	$1.15x10^2$	ND	ND	5	$1.1x10^2$	ND	ND	55	$2 x 10^2$	$2x10^2$
VPLO	5	5	80	ND	ND	30	55	ND	ND	57	5	ND	ND	$18x10^2$	$3 x 10^2$	$5 x 10^2$
PALO	$1.2x10^2$	$6.8x10^2$	$3.1x10^2$	$2.3x10^2$	$23x10^2$	$3.8x10^2$	$4.3x10^2$	$12x10^2$	$3.1x10^2$	$4.4x10^2$	$4.2x10^2$	$12x10^2$	$2.3x10^2$	ND	ND	$4 x 10^2$

ND-Not detected at the time of enumeration; Unit: Colony forming units/100 ml (CFU/100 ml)

Table 11: Bacterial distribution in dug wells during 1999

Date of Sampling: 25.05.1999 **Date of Enumeration: 27.05.1999**

Wells	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TVC	$36x10^3$	64×10^3	73×10^3	$124x10^3$	$14x10^4$	22×10^3	50×10^3	9×10^4	8×10^4	34×10^4	78×10^3	20×10^3	20×10^2	$67x10^3$	12×10^4	$36x10^4$
TC	$11x10^2$	24×10^2	35×10^2	23×10^2	$8.5x10^2$	11×10^2	$5.6x10^3$	18×10^2	23×10^2	21×10^3	12×10^2	21×10^2	$1.2x10^2$	$22 x10^2$	18×10^2	$17 x10^2$
FC	ND	3×10^2	14×10^2	4×10^2	2×10^2	50	6×10^2	ND	25×10^2	38×10^2	5	5×10^2	ND	ND	ND	36
SLO	ND	ND	4×10^2	ND	1×10^2	ND	ND	1×10^2	4×10^2	11×10^2	ND	50	ND	ND	ND	74
SHLO	6×10^2	5	14×10^2	5×10^2	13×10^2	8×10^2	2×10^2	11×10^2	28×10^2	$53x10^2$	8×10^2	32×10^2	2×10^2	$5 x10^2$	60	$4 x10^2$
PKLO	$2.3x10^2$	$1.6x10^2$	3×10^2	$4.3x10^2$	80	6×10^2	9×10^2	11×10^2	14×10^2	5×10^2	$1.4x 10^2$	$2.8x10^2$	2×10^2	$1.8 x10^2$	$2.4 x10^2$	$1.4x10^2$
VCLO	80	78	2×10^2	$1.3x10^2$	$2.5x10^2$	$1.9x10^2$	110	7×10^2	60×10^2	$1.7x10^2$	85	$1.4x10^2$	$1.45x10^2$	$1.7 x10^2$	89	56
VPLO	$2.7x10^2$	30	45	20	$1.2x10^2$	85	68	ND	ND	6	21	ND	10	$2.3 x10^2$	$3 x10^2$	$2.9x10^2$
PALO	8×10^2	5×10^2	4×10^2	$6.3x 10^2$	$18x10^2$	4×10^2	13×10^2	6×10^2	13×10^2	9×10^2	9×10^2	6×10^2	$3.5x10^2$	$5.1 x10^2$	$6.3 x10^2$	$1.8x10^2$
SFLO	20	$21x10^2$	$24 x10^2$	$15 x10^2$	$3 x10^2$	$22 x10^2$	$20 x10^2$	$44 x10^2$	$10 x10^2$	$5 x10^2$	$34 x10^2$	$14 x10^2$	$41 x10^2$	$1.8 x10^2$	13	$1 x10^2$

Table 11 contd...

Wells	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 (TW)	32 (TW)
TVC	$17x10^4$	$67x10^4$	$20x10^4$	$77x10^3$	$12x10^4$	$40 x10^3$	$22 x10^4$	$32 x10^4$	$87 x10^4$	$10 x10^3$	$26 x10^4$	$11 x10^3$	$25x10^3$	$26x10^3$	$28x10^3$	$20x10^3$
TC	$44 x10^2$	$25 x10^2$	$13 x10^3$	$54 x10^2$	$16 x10^2$	$78 x10^2$	$13 x10^2$	$3.5 x10^2$	$42 x10^2$	$7 x10^2$	$4 x10^2$	ND	$6x10^2$	$8 x 10^2$	$8.9x10^2$	$28 x 10^2$
FC	ND	31	70	$5.6 x10^2$	ND	40	2	ND	ND	255	24	ND	35	ND	$14 x 10^2$	ND
SLO	ND	ND	ND	5	67	26	20	$2.1 x10^2$	13	46	ND	ND	10	ND	20	ND
SHLO	$4.6 x10^2$	$7 x10^2$	$6 x10^2$	$1.3 x10^2$	$8.9 x10^2$	$18 x10^2$	$21 x10^2$	$48 x10^2$	$39 x10^2$	$28 x10^2$	$4.3 x10^2$	$1.4 x10^2$	$3.5x10^2$	$4 x 10^2$	ND	100
PKLO	$3.2 x10^2$	$5 x10^2$	$7 x10^2$	$7.8 x10^2$	$9 x10^2$	$8.6 x10^2$	$3 x10^2$	$5 x10^2$	$4.5 x10^2$	$7.2 x10^2$	$6 x10^2$	$4 x10^2$	$5.5x10^2$	38	ND	ND
VCLO	88	$1.2 x10^2$	99	98	$6 x10^2$	75	$1.8 x10^2$	43	15	45	$1.7 x10^2$	$2.3 x10^2$	$4.5x10^2$	115	40	68
VPLO	41	57	45	54	44	35	56	10	ND	70	85	75	80	47	68	53
PALO	$2 x10^2$	$8.9 x10^2$	$3.6 x10^2$	$4.4 x10^2$	$38 x10^2$	$3.1 x10^2$	$45 x10^2$	$28 x10^2$	$32 x10^2$	$6 x10^2$	$7 x10^2$	89	$1.8x10^2$	$4.2x10^2$	$2.2x10^2$	$3.8x10^2$
SFLO	73	56	$3.6 x10^2$	$1.3 x10^2$	88	$1.1 x10^2$	$1.3 x10^2$	$4.4 x10^2$	56	$3 x10^2$	$2 x10^2$	ND	$6x10^2$	ND	$5 x10^2$	ND

ND-Not detected at the time of enumeration; Unit: Colony forming units/100 ml (CFU/100 ml)

Table 12: Bacterial distribution in dug wells during 2000

Date of Sampling : 24.08.2000 **Date of Enumeration: 26.08.2000**

Wells	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TVC	$40x10^3$	$70x10^3$	$77x10^3$	$11x10^4$	$18x10^4$	$24x10^3$	$74x10^3$	$14x10^4$	$12.1x10^4$	$33x10^3$	$16x10^4$	$26x10^3$	$25x10^2$	$79x10^3$	$15.5x10^4$	$39x10^4$
TC	$25x10^2$	$30x10^2$	$49x10^2$	$26x10^2$	$10x10^2$	$13x10^2$	$26x10^2$	$22x10^2$	$39x10^2$	$31x10^2$	$28x10^2$	$33x10^2$	$6x10^2$	$35x10^2$	25x102	$20.5x10^3$
FC	ND	5	33	12	7	6	7	$2x10^2$	24	54	ND	16	ND	2	ND	40
SLO	ND	ND	90	ND	40	$2x10^2$	ND	$1.5x10^2$	$2x10^2$	$1.4x10^2$	ND	$2x10^2$	$1x10^2$	ND	ND	ND
SHLO	$4.6x10^2$	ND	$1.6x10^2$	$1x10^2$	$1.6x10^2$	$1x10^2$	40	$1.6x10^2$	$4x10^2$	$7x10^2$	$1.1x10^2$	80	20	$9.5x10^2$	$4.6x10^2$	$19.2x10^2$
PKLO	$3x10^2$	$2.8x10^2$	$2x10^2$	$5.4x10^2$	$13.8x10^2$	$8x10^2$	$13x10^2$	$13x10^2$	$18x10^2$	$10x10^2$	$1.25x10^2$	$2.8x10^2$	$1.75x10^2$	$2.9x10^2$	$3x10^2$	$10.4x10^2$
VCLO	$1.1x10^2$	$1x10^2$	$2.5x10^2$	$1.8x10^2$	$2.75x10^2$	$2.8x10^2$	$2.8x10^2$	$8.1x10^2$	70	$1.05x10^2$	$1.1x10^2$	80	$1.85x10^2$	$1.2x10^2$	$1x10^2$	ND
VPLO	$1.95x10^2$	40	65	25	45	70	55	25	ND	10	30	ND	20	$2.5x10^2$	20	ND
PALO	$11.7x10^2$	$6.6x10^2$	$5.4x10^2$	$7.5x10^2$	$13.2x10^2$	$1x10^2$	$6.3x10^2$	$14.9x10^2$	$12x10^2$	$8.1x10^2$	$10.3x10^2$	$7x10^2$	$4.5x10^2$	$12.6x10^2$	$7.6x10^2$	$2.4x10^2$
FS	36	82	92	$1.26x10^2$	34	22	92	$1.82x10^2$	52	12	$1.12x10^2$	32	88	$2.7x10^2$	18	$75x10^2$

Table 12 contd...

Wells	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31(TW)	32(TW)
TVC	$11x10^4$	$78.8x10^4$	$33x10^4$	$88x10^3$	$16x10^4$	$55x10^3$	$20.4x10^3$	$28x10^4$	$10.5x10^4$	$25x10^2$	$55x10^4$	$12.5x10^5$	$85x10^4$	$55x10^3$	$26x10^3$	$28x10^3$
TC	$60x10^2$	$30x10^2$	$14.2x10^3$	$50x10^2$	$20x10^2$	$85x10^2$	$20x10^2$	ND	$50x10^2$	$10x10^2$	ND	$40x10^2$	ND	$13x10^2$	$13x10^2$	$40x10^2$
FC	5	40	88	10	ND	ND	3	ND	ND	$2.7x10^2$	32	ND	ND	$4x10^2$	ND	ND
SLO	$2.9x10^2$	ND	ND	ND	150	ND	70	$3.4x10^2$	10	70	50	$13x10^2$	ND	$1x10^2$	ND	ND
SHLO	$14x10^2$	$6x10^2$	ND	$19.6x10^2$	$6x10^2$	$6.5x10^2$	$18x10^2$	$19x10^2$	$60x10^2$	$32x10^2$	$2.3x10^2$	$20.5x10^2$	$12.5x10^2$	50	ND	ND
PKLO	$3.2x10^2$	$36x10^2$	90	$9.6x10^2$	$8x10^2$	$9.4x10^2$	$7x10^2$	$6x10^2$	$6.1x10^2$	$8.2x10^2$	$7.4x10^2$	$8x10^2$	$2.9x10^2$	$1.75x10^2$	ND	ND
VCLO	ND	ND	60	ND	50	40	$2.5x10^2$	20	ND	10	140	40	30	$1.45x10^2$	60	75
VPLO	ND	20	$1x10^2$	ND	ND	40	70	ND	ND	80	ND	ND	ND	63	45	60
PALO	$2.2x10^2$	$11.2x10^2$	$4x10^2$	$4.4x10^2$	$44x10^2$	$3.4x10^2$	$5.6x10^2$	$32x10^2$	$4.8x10^2$	$7.5x10^2$	$6.2x10^2$	$40x10^2$	$6.5x10^2$	$4x10^2$	$24.5x10^2$	$3.5x10^2$
SFLO	$1x10^2$	88	$7x10^2$	$1.8x10^2$	$1.2x10^2$	$1.2x10^2$	$1.48x10^2$	$4.8x10^2$	70	$2.8x10^2$	38	48	84	20	36	84

ND-Not detected at the time of enumeration; Unit: Colony forming units/100 ml (CFU/100 ml)

Table 13: Bacterial distribution in dug wells during 2001

Date of Sampling : 29.05.2001 **Date of Enumeration: 31.05.2001**

Wells	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TVC	$23x10^3$	$41x10^3$	$23x10^3$	$41x10^3$	$40x10^2$	$20x10^3$	$49x10^3$	$8x10^3$	$98x10^3$	$36x10^3$	$80x10^4$	$14x10^3$	$16x10^3$	$26X10^5$	$20X10^5$	$46X10^4$
TC	$14x10^2$	$16x10^2$	$1.8x10^2$	$2.7x10^2$	50	ND	$14x10^2$	ND	$28x10^2$	$27x10^2$	ND	2	34	$34X10^2$	$21X10^2$	$10X10^3$
FC	4	3	50	176	4	ND	11	ND	29	40	ND	ND	ND	5	ND	35
SLO	ND	ND	ND	ND	ND	ND	ND	ND	5	12	ND	ND	ND	ND	ND	ND
SHLO	$2.1x10^2$	$1x10^2$	$2.5x10^2$	$3.6x10^2$	20	$2.2x10^2$	$2.8x10^2$	40	$31x10^2$	$55x10^2$	$22x10^2$	$1.4x10^2$	$1.9x10^2$	$8X10^2$	$1.1X10^2$	$6X10^2$
PKLO	$1.4x10^2$	$3.2x10^2$	$8.25x10^2$	$2.4x10^2$	$2.2x10^2$	90	$16x10^2$	$2.45x10^2$	$21x10^2$	$63x10^2$	$3.5x10^2$	$1.5x10^2$	$1.35x10^2$	$3X10^2$	$1.2X10^2$	$4X10^2$
VCLO	80	80	ND	ND	ND	ND	$21x10^2$	ND	47	100	50	ND	ND	$13X10^2$	$4X10^2$	$1.4X10^2$
VPLO	$1.2x10^2$	30	25	ND	ND	ND	ND	ND	10	15	ND	ND	ND	$12X10^2$	$3X10^2$	63
PALO	$8x10^2$	$4.9x10^2$	15	$2.85x10^2$	5	ND	$9.3x10^2$	ND	$9x10^2$	$7.8x10^2$	50	ND	$1.15x10^2$	$8X10^2$	$2X10^2$	$3X10^2$
SFLO	43	56	10	ND	ND	ND	70	ND	40	10	ND	ND	20	$2X10^2$	ND	$10x10^2$

Table 13 contd...

Wells	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31(TW1)	32(TW2)
TVC	$23X10^5$	$27.5X10^4$	$11X10^4$	$46x10^3$	$11x10^4$	$75X10^3$	$46x10^4$	$13x10^4$	$92x10^4$	$45x10^4$	$30x10^4$	$82x10^4$	$88x10^4$	$55x10^3$	$21x10^3$	$28x10^3$
TC	$27X10^3$	$5X10^3$	40	$14x10^2$	ND	$14x10^2$	$3x10^2$	$5x10^2$	$12x10^2$	$24x10^2$	$5x10^2$	$13x10^2$	80	$25x10^2$	ND	$40x10^2$
FC	ND	30	ND	ND	ND	ND	2	ND	ND	40	ND	ND	1	9	ND	ND
SLO	ND	ND	ND	8	ND	ND	10	38	ND	ND	5	ND	ND	ND	ND	ND
SHLO	$5.5X10^2$	$8.5X10^2$	$6.6X10^2$	$1.2x10^2$	$9.6x10^2$	$12x10^2$	$24x10^2$	$38x10^2$	$43x10^2$	$3.2x10^2$	$4x10^2$	$5.6x10^2$	$6.3x10^2$	$1.08x10^2$	ND	ND
PKLO	$4.4X10^2$	$6.3X10^2$	$8X10^2$	$7.2x10^2$	$14x10^2$	$9.1x10^2$	$6x10^2$	$1.4x10^2$	$5x10^2$	$8x10^2$	$6x10^2$	$4.3x10^2$	$5.2x10^2$	12	ND	ND
VCLO	$1.2X10^2$	$1.8X10^2$	80	$1.3x10^2$	$8x10^2$	$1.2x10^2$	$7x10^2$	$1.0x10^2$	25	55	$1.5x10^2$	$3x10^2$	$4x10^2$	ND	70	80
VPLO	56	73	$27X10^2$	73	80	40	55	27	20	60	45	$1.2X10^2$	$1.4X10^2$	ND	50	70
PALO	$2.6X10^2$	$8X10^2$	$4.4X10^2$	$4.6x10^2$	$27x10^2$	$3.4x10^2$	$4.3X10^2$	$22x10^2$	$4.3x10^2$	$4.5x10^2$	$2x10^2$	$3x10^2$	$2x10^2$	ND	$1.8x10^2$	$2.9x10^2$
SFLO	90	77	ND	40	ND	60	40	$2.7x10^2$	ND	$2.0x10^2$	ND	5	ND	ND	ND	25

ND-Not detected at the time of enumeration; Unit: Colony forming units/100 ml (CFU/100 ml)

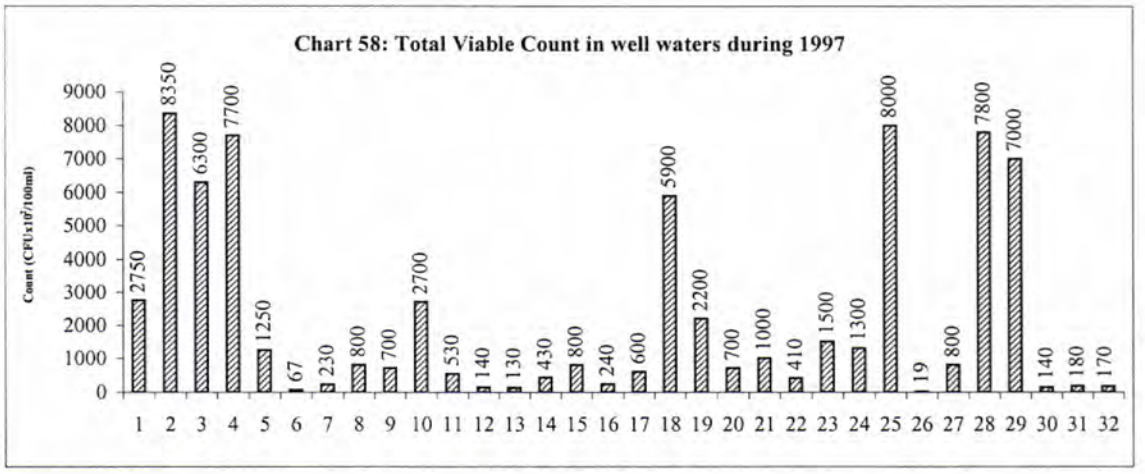


Chart 58: Total Viable Count in well waters during 1997
Count (CFUx10²/100ml)
2750 8350 6300 7700 1250 67 230 800 700 2700 530 140 130 430 800 240 600 5900 2200 700 1000 410 1500 1300 8000 19 800 7800 7000 140 180 170

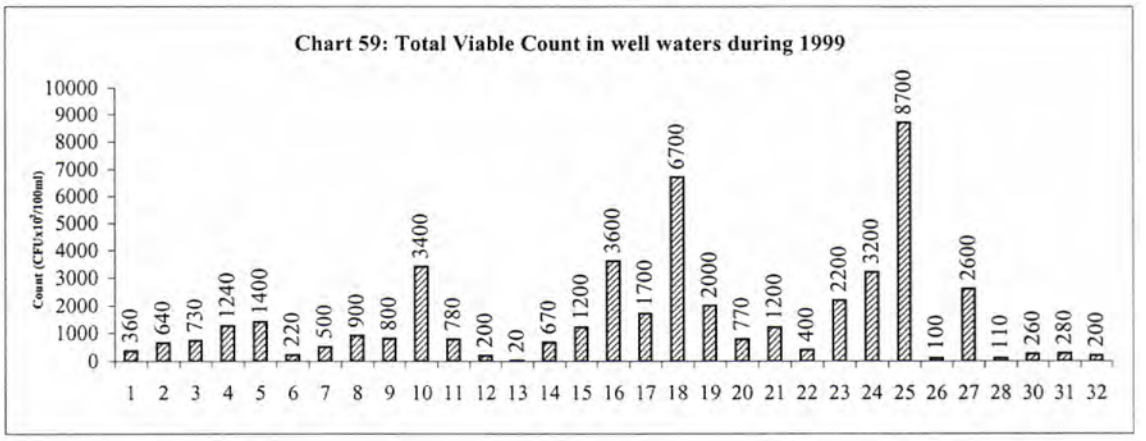


Chart 59: Total Viable Count in well waters during 1999
Count (CFUx10²/100ml)
360 640 730 1240 1400 220 500 900 800 3400 780 200 20 670 1200 3600 1700 6700 2000 770 1200 400 2200 3200 8700 100 2600 110 260 280 200

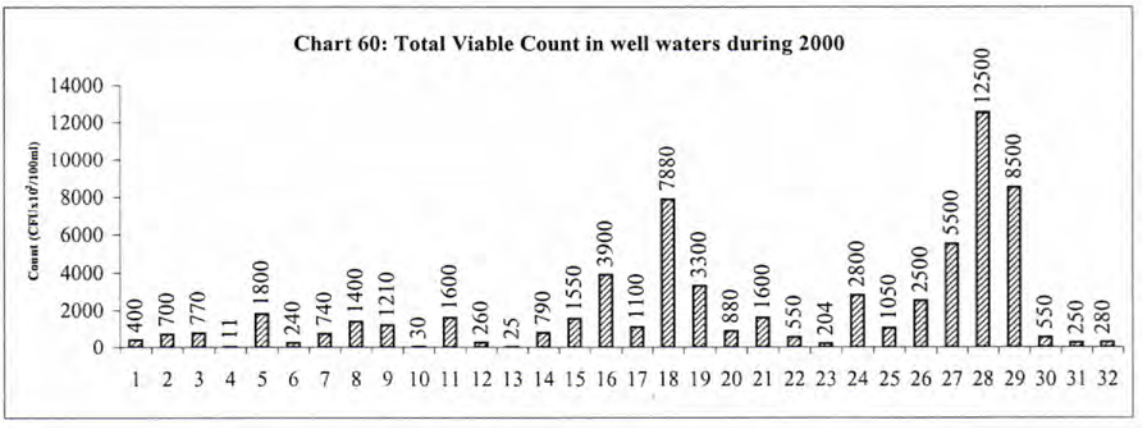


Chart 60: Total Viable Count in well waters during 2000
Count (CFUx10²/100ml)
400 700 770 11 1800 240 740 1400 1210 30 1600 260 25 790 1550 3900 1100 7880 3300 880 1600 550 204 2800 1050 2500 5500 12500 8500 550 250 280

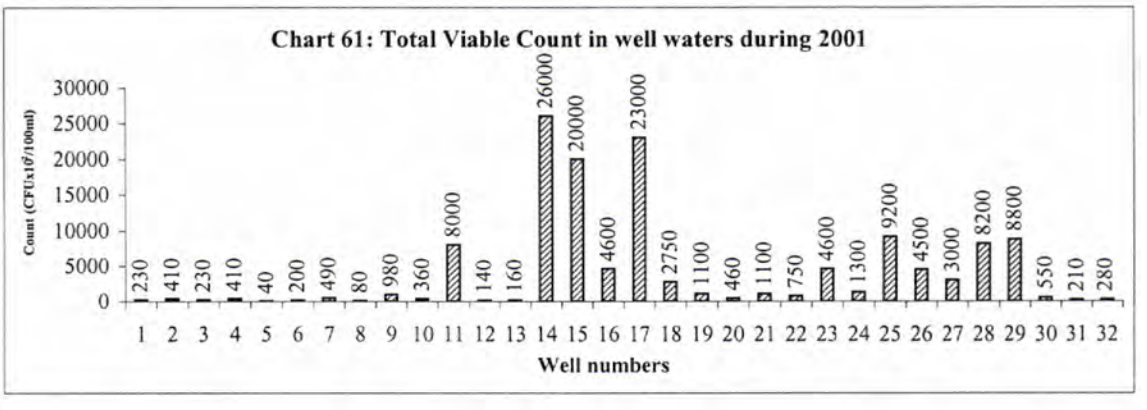


Chart 61: Total Viable Count in well waters during 2001
Count (CFUx10²/100ml)
230 410 230 410 40 200 490 80 980 360 8000 140 160 26000 20000 4600 23000 2750 1100 460 1100 750 4600 1300 9200 4500 3000 8200 8800 550 210 280
Well numbers

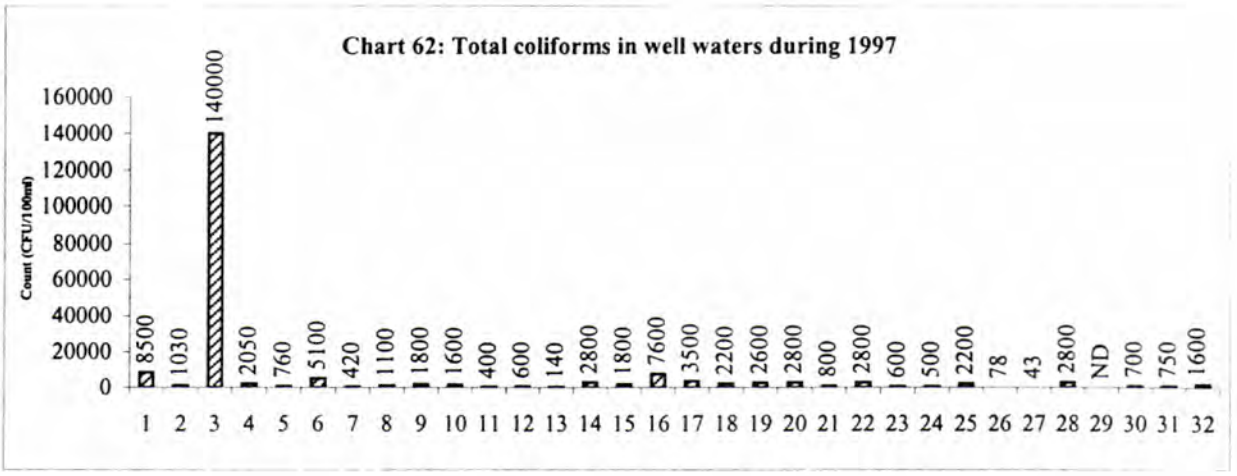


Chart 62: Total coliforms in well waters during 1997
Count (CFU/100ml)
160000
140000
120000
100000
80000
60000
40000
20000
0
8500 1030 140000 2050 760 5100 420 1100 1800 1600 400 600 140 2800 1800 7600 3500 2200 2600 2800 800 2800 600 500 2200 78 43 2800 ND 700 750 1600
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

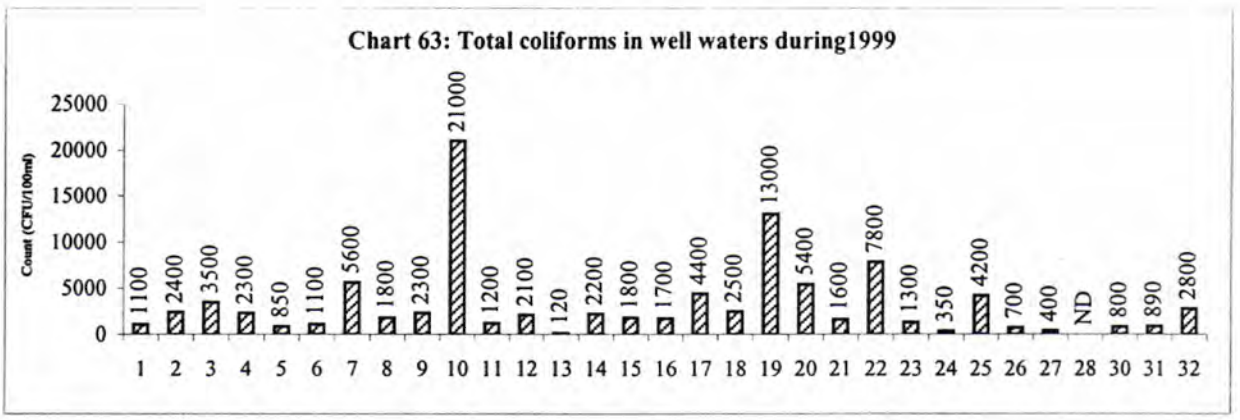


Chart 63: Total coliforms in well waters during1999
Count (CFU/100ml)
25000
20000
15000
10000
5000
0
1100 2400 3500 2300 850 1100 5600 1800 2300 21000 1200 2100 120 2200 1800 1700 4400 2500 13000 5400 1600 7800 1300 350 4200 700 400 ND 800 890 2800
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 30 31 32

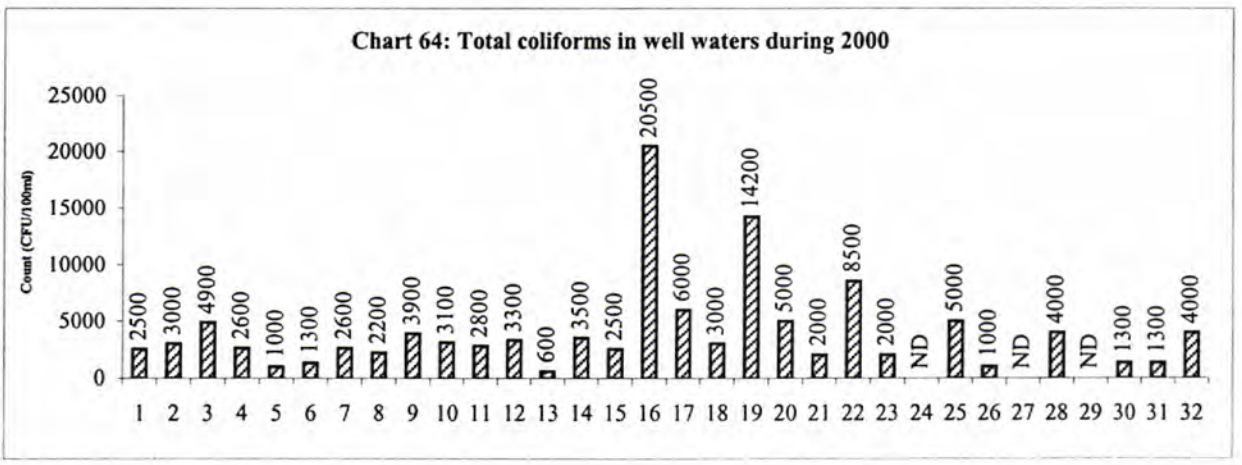


Chart 64: Total coliforms in well waters during 2000
Count (CFU/100ml)
25000
20000
15000
10000
5000
0
2500 3000 4900 2600 1000 1300 2600 2200 3900 3100 2800 3300 600 3500 2500 20500 6000 3000 14200 5000 2000 8500 2000 ND 5000 1000 ND 4000 ND 1300 1300 4000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

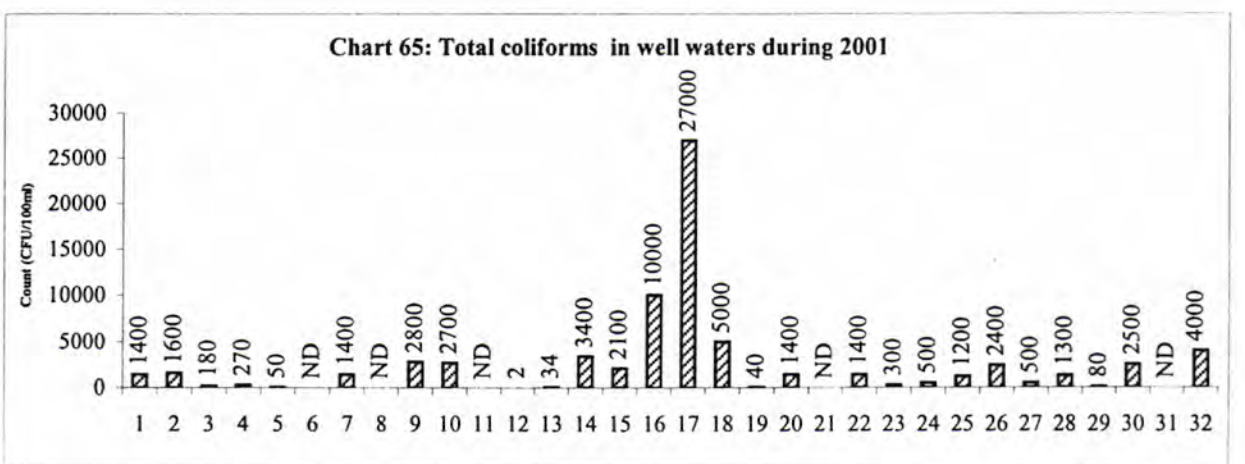


Chart 65: Total coliforms in well waters during 2001
Count (CFU/100ml)
30000
25000
20000
15000
10000
5000
0
1400 1600 180 270 50 ND 1400 ND 2800 2700 ND 2 34 3400 2100 10000 27000 5000 40 1400 ND 1400 300 500 1200 2400 500 1300 80 2500 ND 4000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

Chart 66: Faecal coliforms in well waters during1997

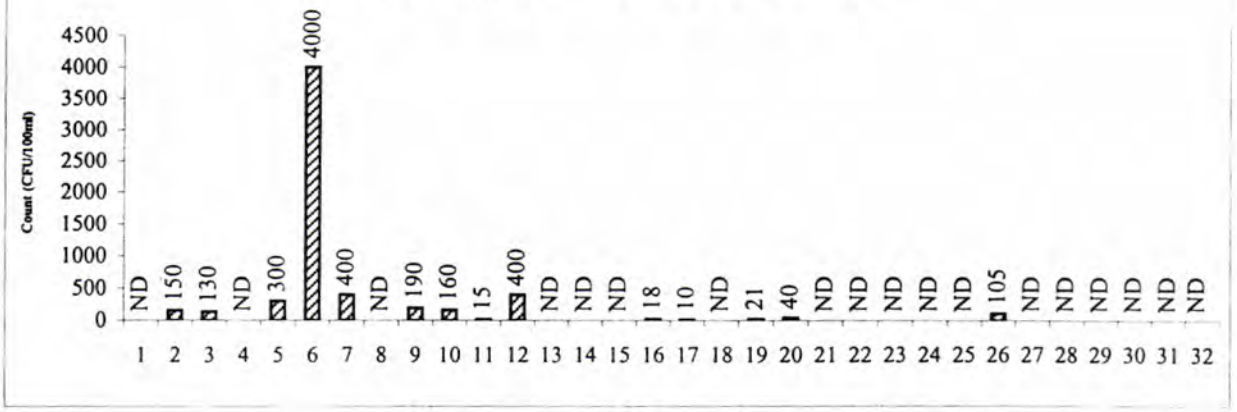


Chart 67: Faecal coliforms in well waters during 1999

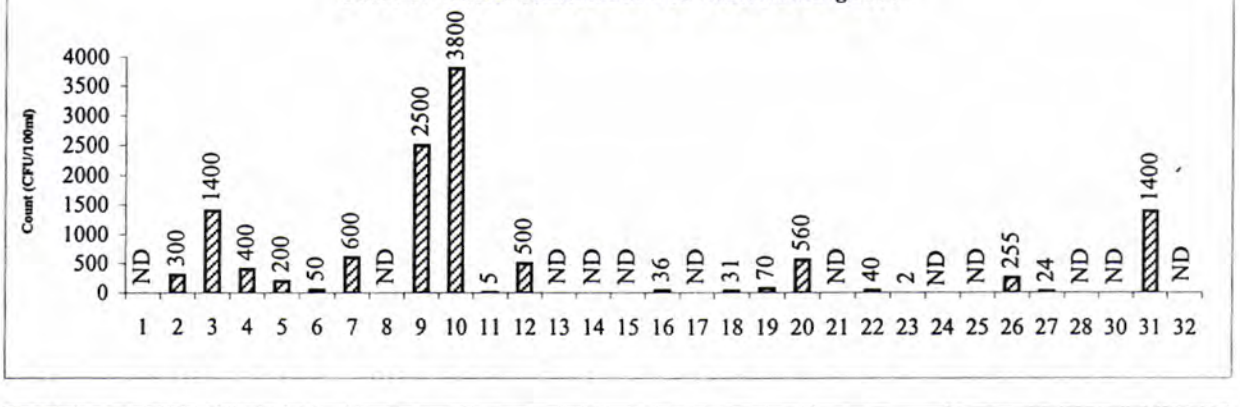


Chart 68: Faecal coliforms in well waters during 2000

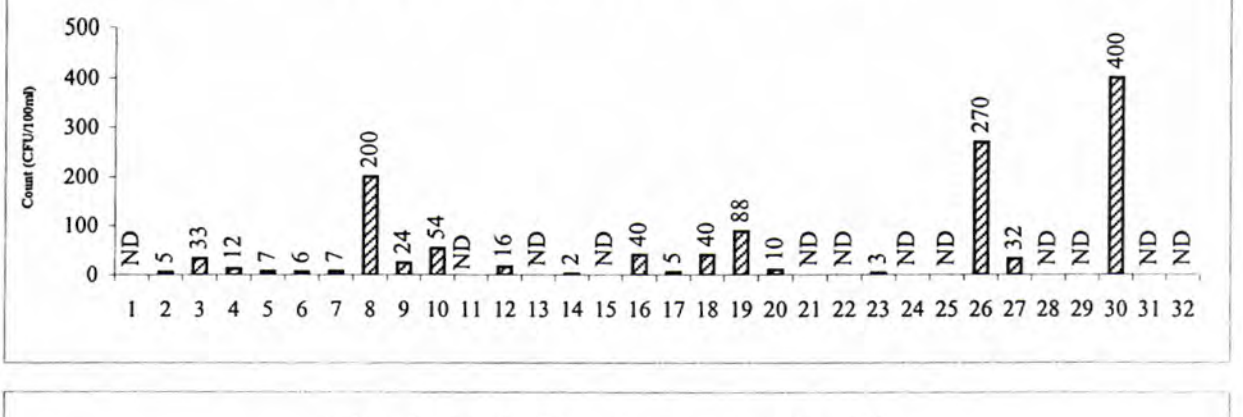


Chart 69: Faecal coliforms in well waters during 2001

Chart 70: SLO in well waters during 1997

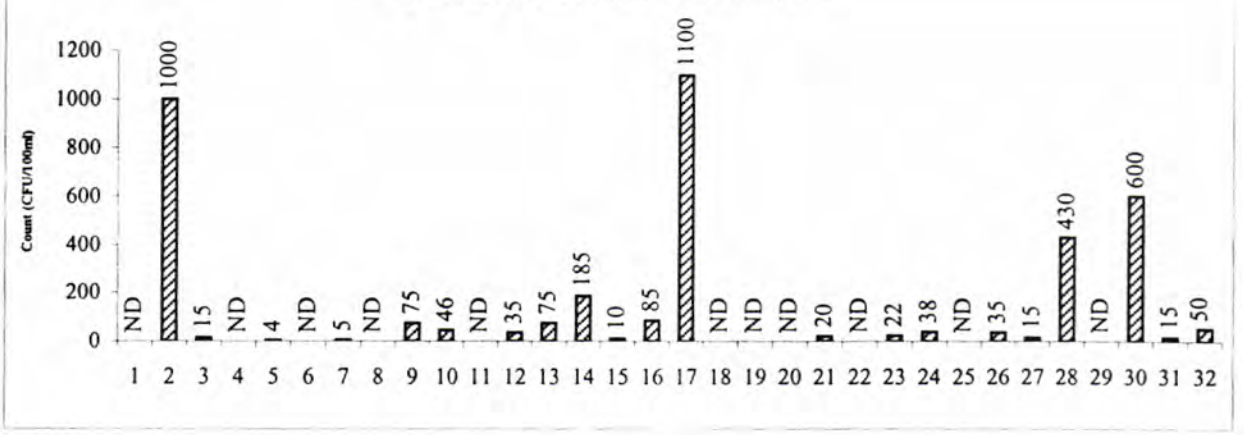


Chart 71: SLO in well waters during 1999

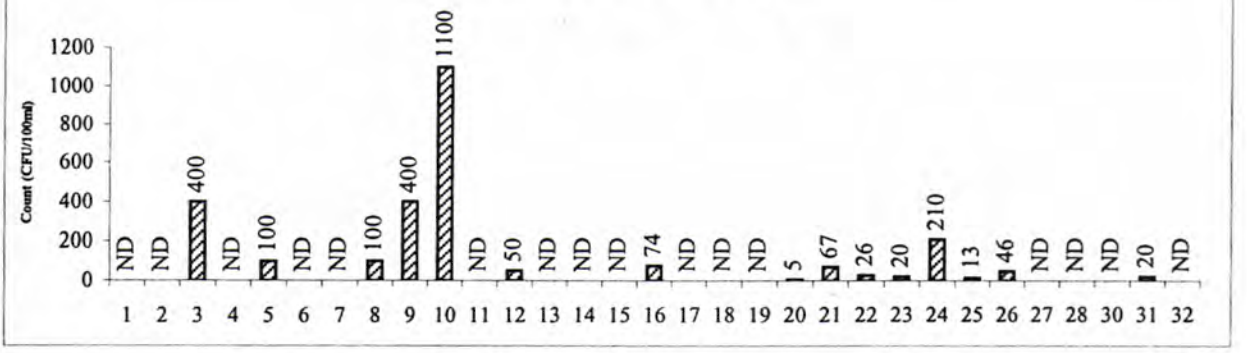


Chart 72: SLO in well waters during 2000

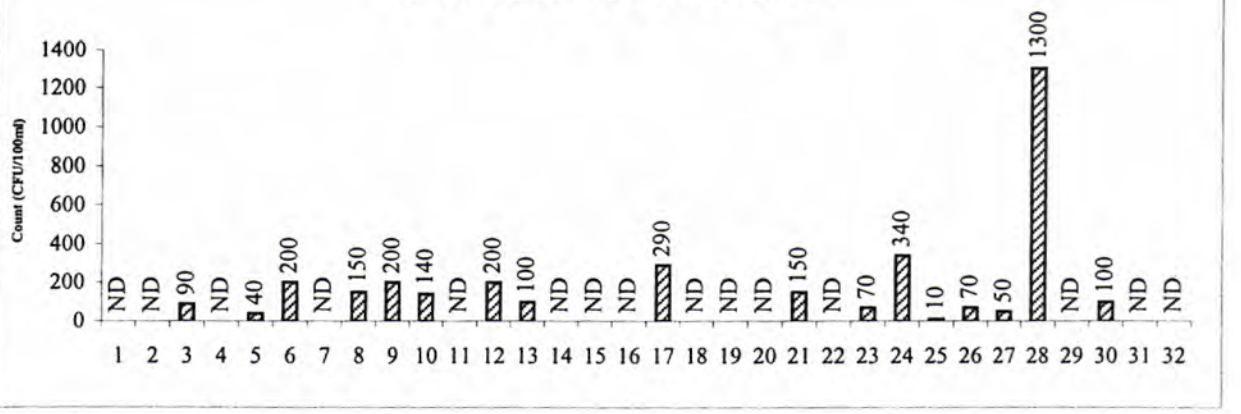


Chart 73: SLO in well waters during 2001

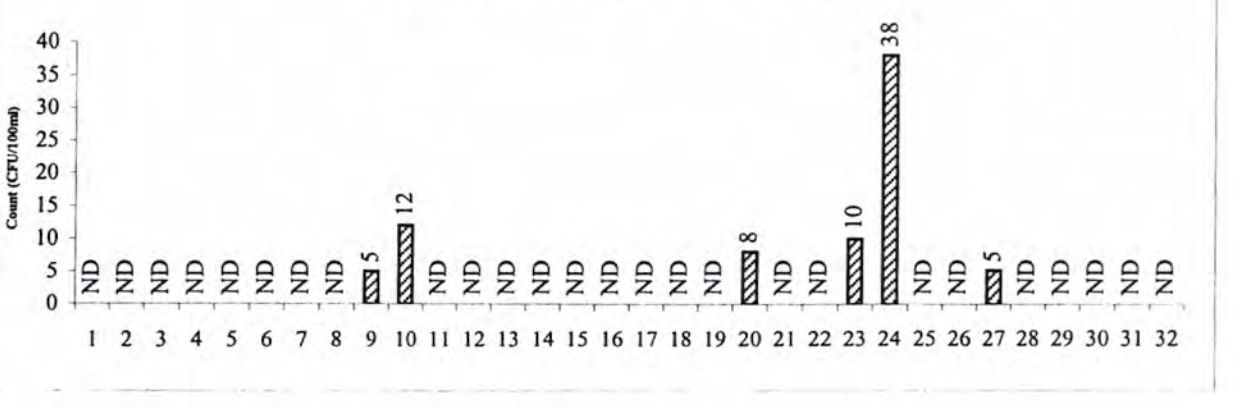


Chart 74: SHLO in well waters during 1997

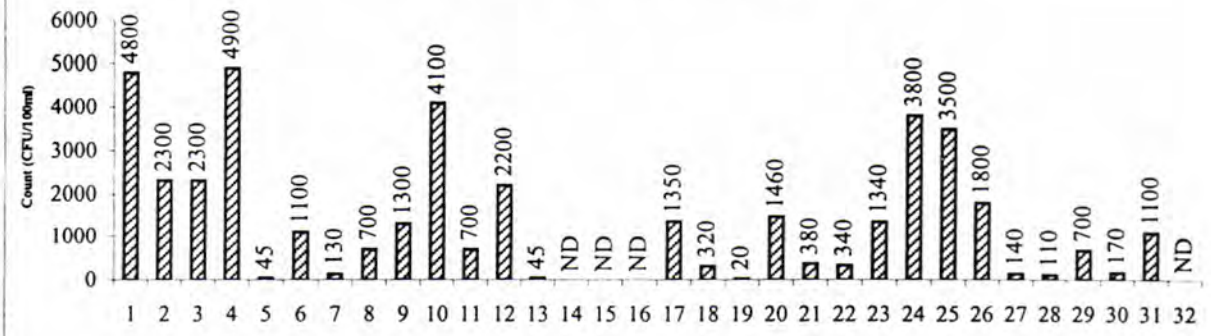


Chart 75: SHLO in well waters during 1999

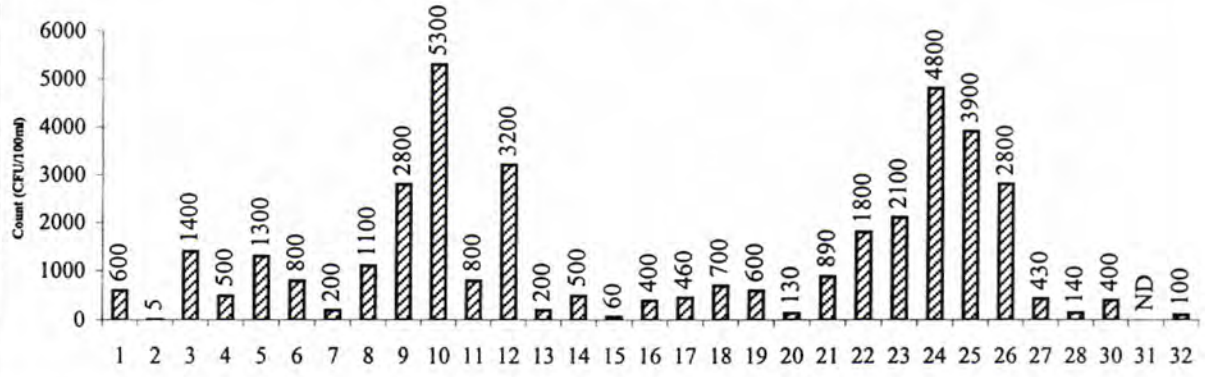


Chart 76: SHLO in well waters during 2000

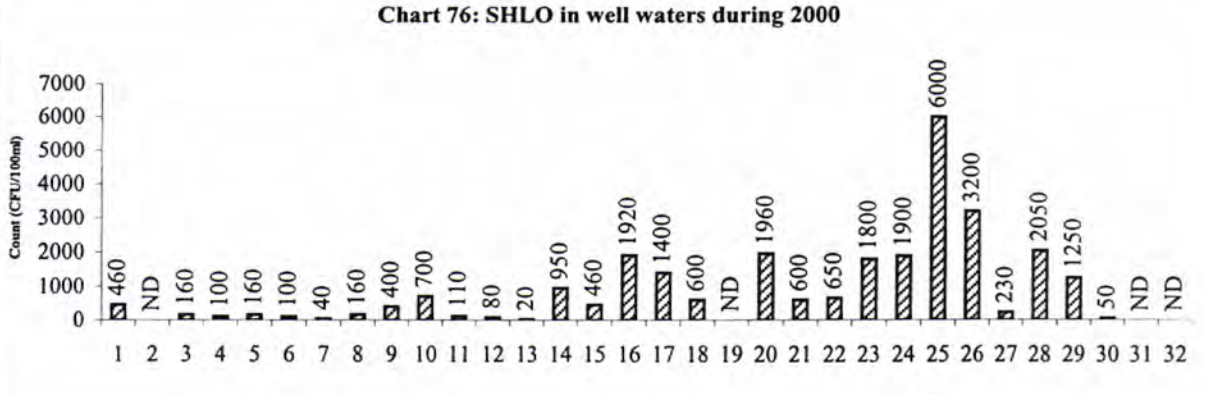


Chart 77: SHLO in well waters during 2001

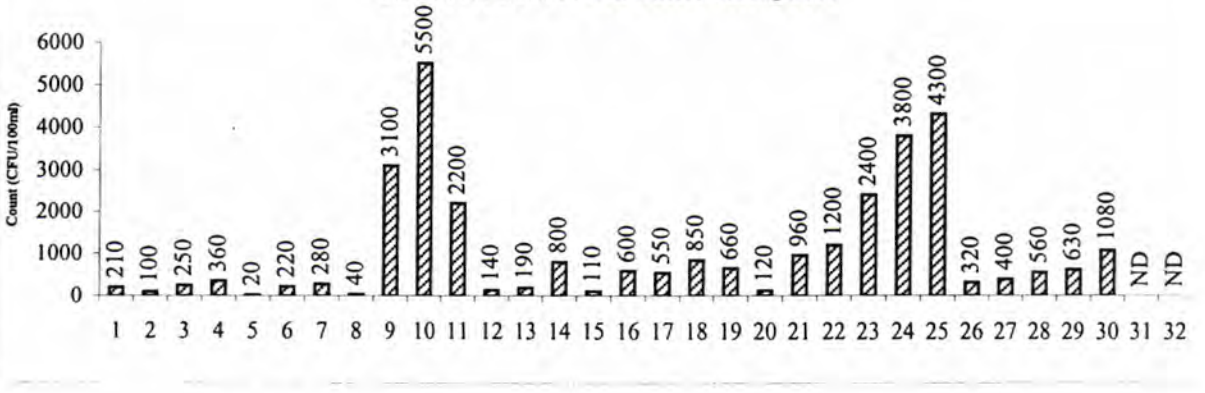


Chart 78: PKLO in well waters during 1997

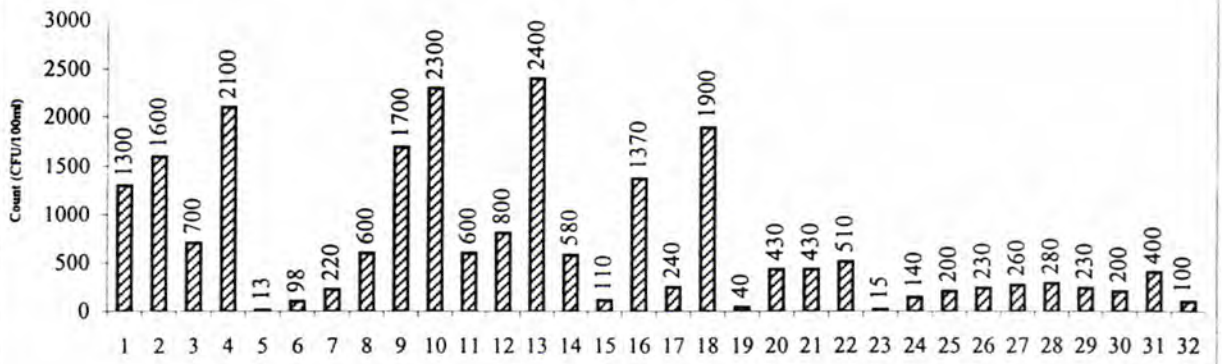


Chart 79: PKLO in well waters during 1999

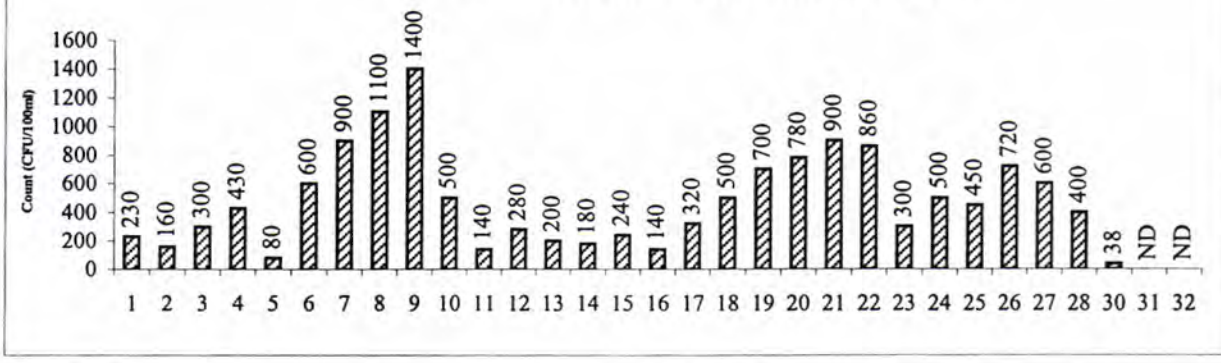


Chart 80: PKLO in well waters during 2000

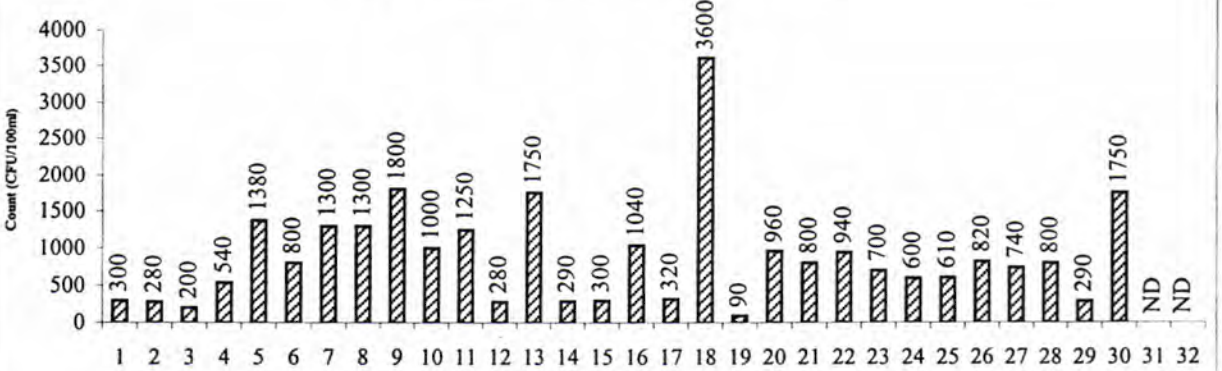


Chart 81: PKLO in well waters during 2001

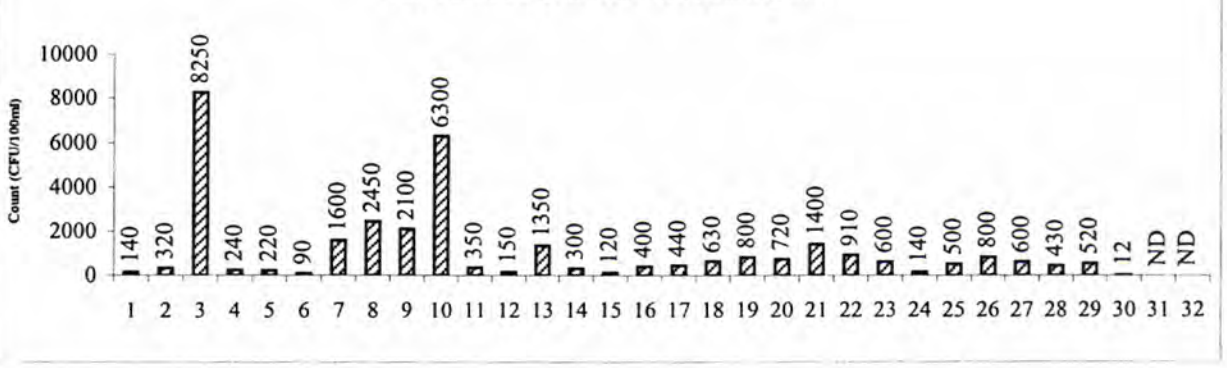


Chart 82: VCLO in well waters during 1997

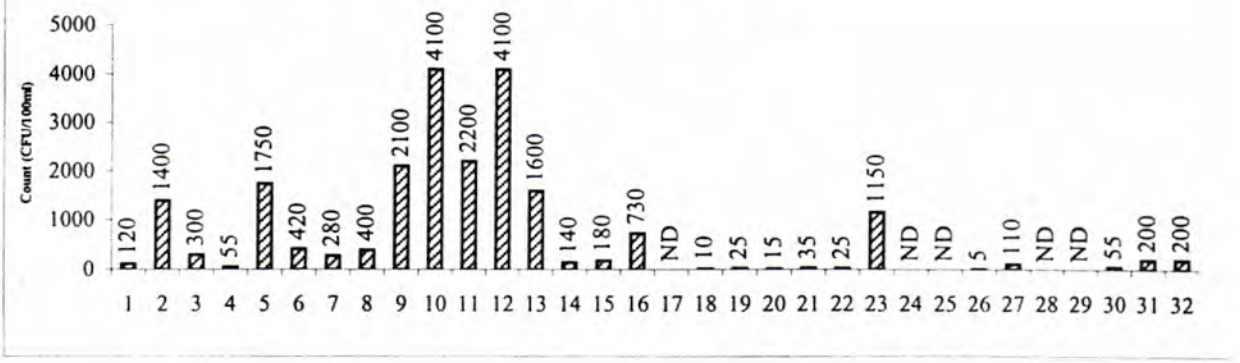


Chart 83: VCLO in well waters during 1999

Chart 84: VCLO in well waters during 2000

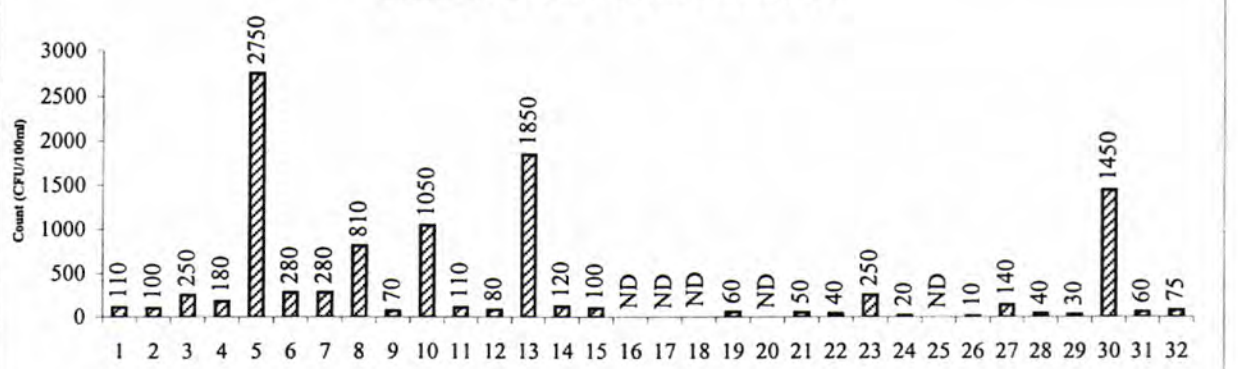


Chart 85: VCLO in well waters during 2001

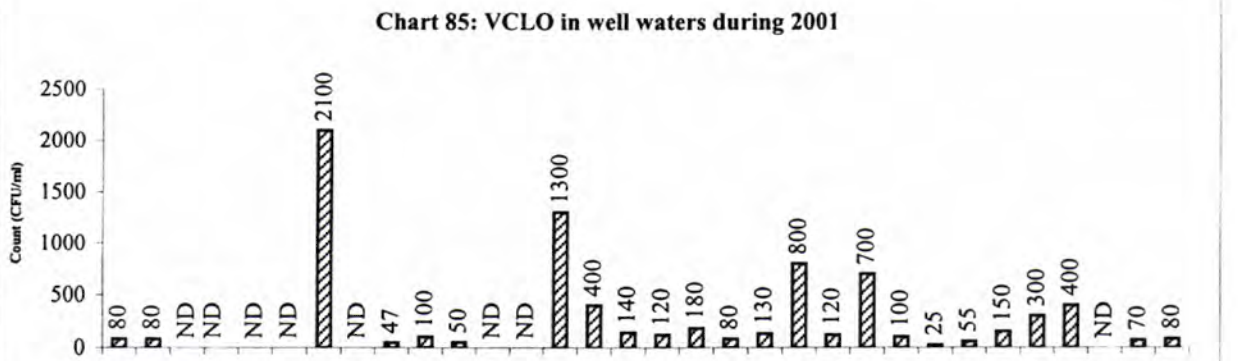


Chart 86: VPLO in well waters during 1997

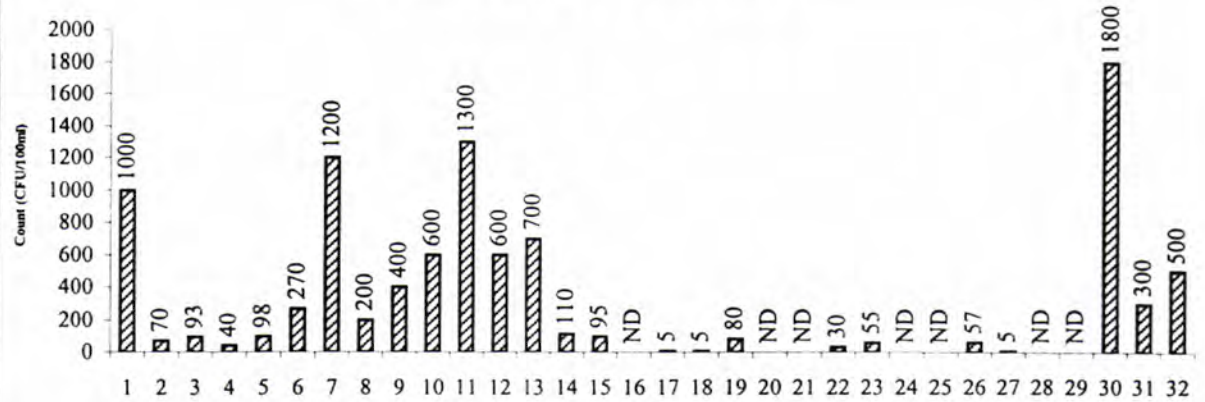


Chart 87: VPLO in well waters during 1999

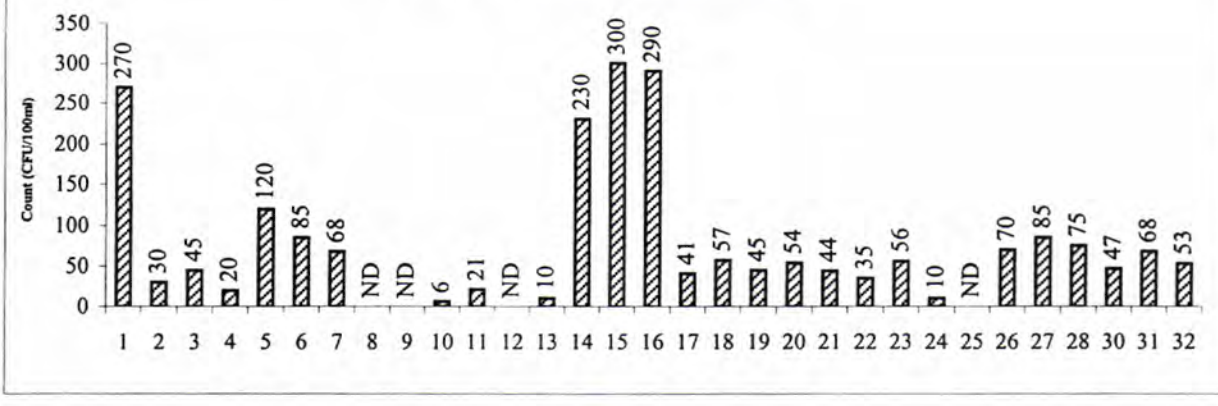


Chart 88: VPLO in well waters during 2000

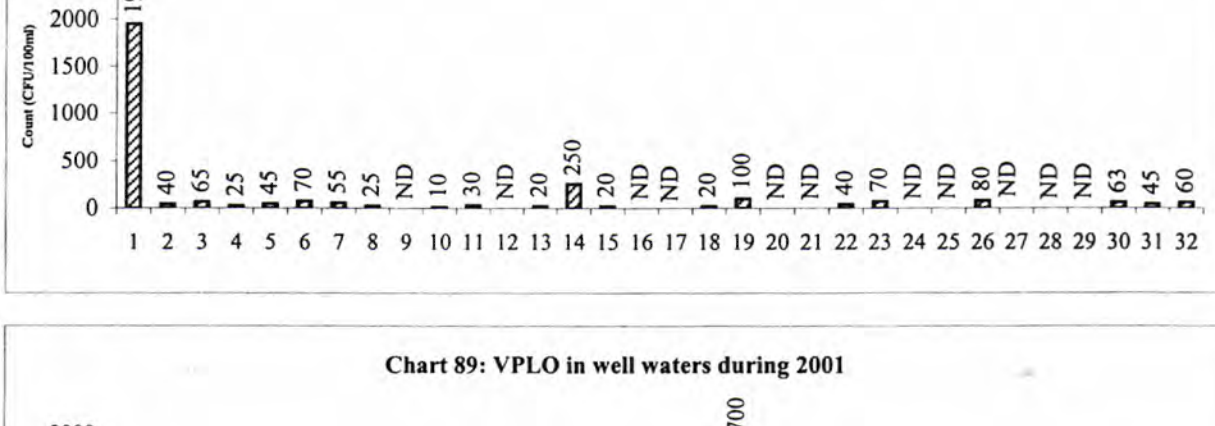


Chart 89: VPLO in well waters during 2001

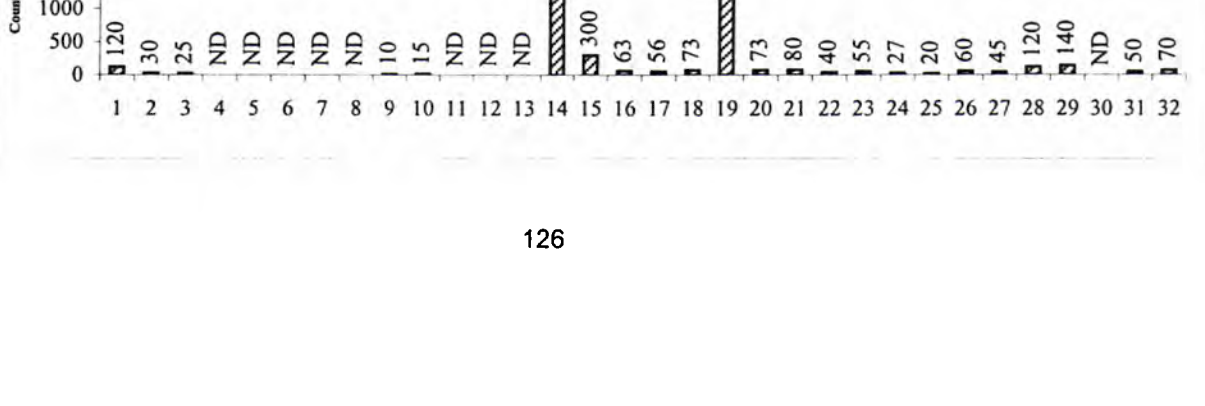


Chart 90: SFLO in well waters during 1997

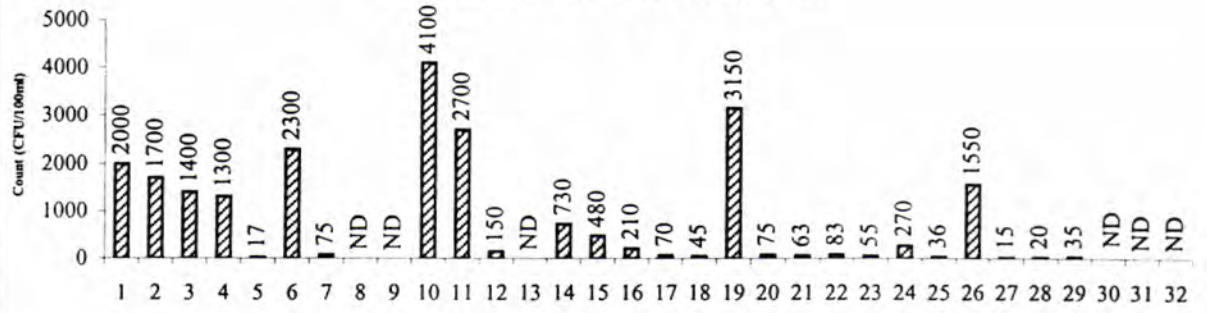


Chart 91: SFLO in well waters during 1999

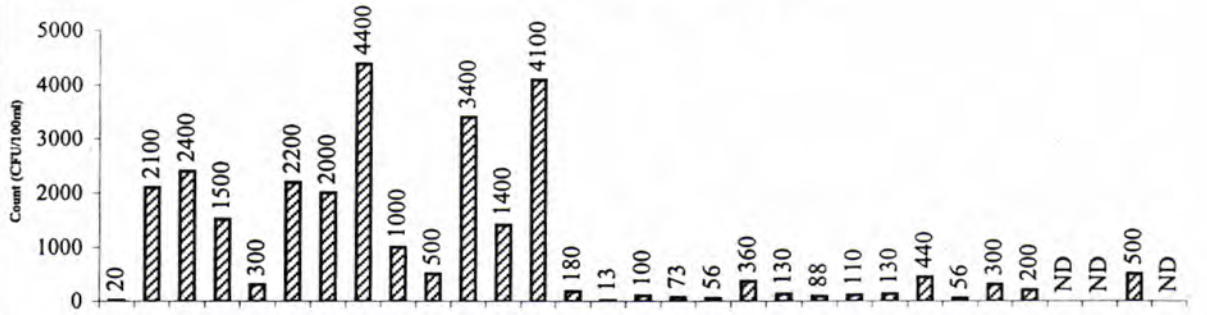
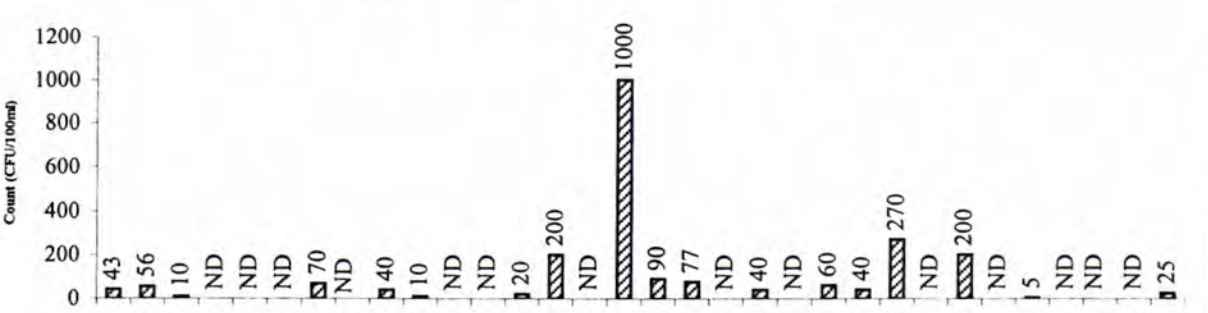


Chart 92: SFLO in well waters during 2000

Chart 93: SFLO in well waters during 2001



3.2.2 Physico-Chemical characteristics (Table 14-17 & Chart 94-149)

3.2.2.1 BIS standards for drinking water (1991)

Parameters	Desirable limit	Permissible limit in the absence of alternate source
pH	6.5-8.5	9.2
Conductivity (μmhos/cm)	1500	3000
Chloride (mg/l)	250	400
Total suspended solids (mg/l)	<100 (WHO)	
Total dissolved solids (mg/l)	500	2000
Total hardness (as mg/l)	300	600
Dissolved Oxygen (mg/l)	>6(WHO)	-
Calcium hardness (mg/l)	75	200
Magnesium hardness (mg/l)	30	100
Total alkalinity (mg/l)	200	600
Nitrite (mg/l)	1.0 (WHO)	
Nitrate nitrogen (mg/l)	45	100
Fluoride (mg/l)	1.0	1.5
Sulphate (mg/l)	200	400

Water temperature

Water temperature varied from 27°C in well number 4 to 29.5°C in well no 30 during 1997. 26 °C in well no 26 to 29.5 °C in well no 14 during 1999. 26 °C in well nos. 5 , 11, 21 and 30 to 28.5 °C in well no 15 and 16 during 2000 and 26 °C in well no 22 to 29.5 °C in well no 13 during 2001. The results showed that temperature in well waters generally fluctuated between 26 °C to 30 °C irrespective of the seasons.

pH (Chart 94-97)

The pH values in well waters ranged from 7.4 in well nos.25, 26 and 29 to 8.12 in well no.14 in 1997, 7.2 in well no.14 and 22 to 8.1 in well no.11 in 1999, 7.14 in well no.23 to 8.09 in well no.14 in 2000 and 7.23 in well no.15 to 8.05 in well no.14 in 2001.The pH generally falls within the prescribed limit (6.5-8.5 as per BIS). The pH of the well water

falls in the range of 7.2 to 8.2, which is slightly alkaline in nature. This trend is expected in the atolls surrounded by Sea. The pH range acceptable as per BIS and WHO is 6.5 to 8.5 and under this category, falls most of the wells studied. Beyond this range, the water will affect the mucous membrane and water supply system. The limit is categorized as essential; however, it may be relaxed up to 9.2 in absence of alternate sources. Out of 32 wells studied, no sample was found above this limit. The impact of season over pH has been found negligible in pH range of the water source during the four years ranged narrowly.

Conductivity (Chart 98-101)

In 1997, conductivity fluctuated from 600 μmhos (well no.1) to 2950 μmhos in well no.27, 587 μmhos in well no.14 to 5246 μmhos in well no. 23 In 1999, it varied from 386 μmhos in well no.14 to 3300 μmhos in well no.25 in 2000 and 315 μmhos in well no.14 to 4815 μmhos in well no.23. Out of 30 dug wells, 13 wells, showed conductivity range between 500 to 1000 μmhos while 10 showed between 1000 to 1500 μmhos; 5 between 1500 to 2000 μmhos and two above 2000 μmhos. The desirable conductivity value as per BIS is 1500 μmhos, though the permissible barrier has been placed up to 3000 μmhos in case of absence of alternative source. The tube wells are showing high conductivity values, which are beyond this extent. In 1999, 11 wells showed conductivity range between 500 to 1000 μmhos 9 between 1000 to 1500 μmhos, 3 between 1500 to 2000 μmhos, 13 wells above 2000 up to 3000 μmhos, and 4 wells above 3000 μmhos. The four wells that showed conductivity above elevated permissible limit could be the result of overdraft, which is being practiced recklessly in Kavaratti Island. During 2000,while one well showed conductivity below 500 μmhos, 17 wells showed values in between 500-1000 μmhos, 19 wells between 1000 to 1500 μmhos, 2 wells between 1500 to 2000 μmhos and

one well above 3000.This may be due to the fact that during rainy season, dilution occurs, lowering the conductivity values (500-1000 μmhos) in 18 wells, but the impact is only partial. In 2001 May, 11 wells showed values in 500 -1000 μmhos range; 8 wells in 1000 - 1500 μmhos range; 4 wells in 1500 to 2000 μmhos range and others above 2000 μmhos of which 3 showed values above 3000 μmhos. This is a clear indication of overdraft prevalent in the Island.

Chloride (Chart 102-105)

The chloride content varied from 23.4 mg/l (well 7) to 268.3 mg/l (well 11) during 1997, 18 mg/l (well 5) to 583 mg/l (well 24) in 1999, 21 mg/l (well 4) to 505 mg/l (well 25) in 2000 and 28.5 mg/l (well 14) to 477 mg/l (well 11) in 2001. This shows that the maximum values in 1997, 1999 and 2000 were above the desirable limit, but however they were below the permissible limit (1000 mg/l) extended in the case of absence of alternate source. During 1997, chloride values in well no.11 exceeded the permissible limit while 6 wells in 1999, 2 wells in 2000 and 6 wells in 2001 exceeded the desirable limit as per BIS standards. This indicate overdraft during 1999 onwards, but slight dilution occurred during the monsoon period of 2000. This further suggests that partial dilution is effective only during rainy season and in post monsoon, the same condition reappears.

Total suspended solids (Chart 106-109)

The total suspended solids varied from 4.1 mg/l in well no 16 to 68.5 mg/l in well no 25 during 1997, 5.9 mg/l in well no 4 to 225.8 in well no 23 during 1999, 9.3 mg/l in well no 4 to 185.3 in well no 25 during 2000 and 6.3 mg/l in well no 4 to 168.5 mg/l in well no 23 during 2001. The results showed that the suspended solids concentration shows wide fluctuation and the sharp increase in certain wells (for e.g. Well nos. 23 & 25) during the

study period is found to be due to the neglect by and poor protection of the wells that the custodians that the addition of suspended matter is not being checked.

Total dissolved solids (Chart 110-113)

During 1997, the total dissolved solids varied from 231 mg/l (well no. 16) to 1770 mg/l (well no.25). It fluctuated from 290 mg/l (well no. 14) to 2032 mg/l (well no.11) in 1999, 213 mg/l (well no.4) to 1980 mg/l (well no.25) and 267 mg/l (well no. 24) to 3170 mg/l (well no.11). Well 16 in 1997, well 11 during 1999 and 2001 and well 25 in 2000 exceeded the desirable limit. Beyond 500 mg/l, the palatability of water decreases and may cause gastro-intestinal irritation. The values indicated that in 1997, 6 wells fall below the desirable limit (500 mg/l); 24 wells above this limit; 5 wells below desirable limit, while 25 wells crossed the limit; 12 wells during 2000 showed values below 500 mg/l while the rest fall above this limit. During 2001, only 8 wells showed TDS below 500 mg/l when all others show values above this desirable limit. This shows that total dissolved solids extent in the fresh water is on increasing trend and most of the well waters have TDS above the desirable limit. This is an indication of seawater intrusion that increases the salinity of waters. Though most of the water does not satisfy the desirable limit of 500 mg/l, but these are, however, within the extendable limit of 2000 mg/l without alternate source. This observation is similar to the data recorded by Madan Nanoti, 1989. He has highlighted that high values in populated area on southeastern side of the island and suggested controlled exploitation of water with a futuristic approach.

Water with a high total dissolved solids indicated more ionic concentration, which is of inferior palatability and can induce an unfavourable physicochemical reaction in the consumers. Excess concentration of total hardness has not known adverse effect on health, but it prevents the formulation of lather with soap and increases the boiling

point of the water. Na^+ restricted diet is recommended to patients suffering from hypertension or congenial heart disease, intake of high Na^+ may prove critical. For people not accustomed to high concentrations of Cl^- in water, it may cause a laxative effect. High concentration of SO_4^{2-} could cause a cathartic action on human beings and can also cause respiratory problems (Subha Rao, 1993).

Dissolved oxygen (Chart 114-117)

Dissolved oxygen values recorded were well above 4 mg/l in almost all the wells, irrespective of seasons, but wide fluctuation was noticed from premonsoon to post monsoon period. High fluctuation in dissolved oxygen in May to December (premonsoon to post monsoon) may be attributed to increase in biological activity that might have initiated during the southwest monsoon. Madan Nanoti (1989) reported dissolved oxygen values in the range of 4.4–9.23 mg/l during premonsoon to 4.5-8.0 mg/l during post monsoon period in the wells adjacent to lagoon, 4.4-8.98 mg/l during premonsoon to 4.46-8.97 mg/l during post monsoon period in the centre region and 4.92-8.92 mg/l during premonsoon to 5.02-8.64 mg/l during post monsoon period in wells adjacent to the stormy beach. Low dissolved oxygen may be attributed to oxidation process in groundwater during monsoon season. Only tube wells showed values less than 4 mg/l.

Total alkalinity (Chart 118-121)

Total alkalinity varied from 166 mg/l in well no. 4 to 518 mg/l in well no. 9 in 1997, 210 mg/l in well no. 19 and 26 to 560 mg/l in well no. 23 in 1999, 185 mg/l in well no. 4 to 730 mg/l in well no. 9 in 2000 and 240 mg/l in well no. 4 and 19 to 540 mg/l in well no. 9 in 2001. Alkalinity values showed that almost all the well waters except well no. 4 are having alkalinity above desirable limit (200 mg/l), but below the permissible limit (600 mg/l) prescribed for the case without alternate source. In 1999

also all the samples fall above desirable limit, but below permissible limit, but in 2000; one well showed value even above the permissible limit. In 2001, all the wells showed concentration above desirable limit, but below permissible extent. Alkalinity values, as an indication of seawater intrusion, are on the rise in Kavaratti and can be enhanced by the continued overdraft.

Total hardness (Chart 122-125)

Total hardness varied from 148 mg/l in well no.16 to 736 mg/l in well no.25 in 1997, 195mg/l in well no. 15 to 941mg/l in well no.23 in 1999, 170mg/l in well no.4 to 890mg/l in well no.25 in 2000 and 186mg/l in well no. 15 to 934mg/l in well no. 25 in 2001. The maximum values in1997, 1999, 2000 and 2001 exceeded even the permissible limit in the absence of alternate source (600 mg/l). During 1997, 9 wells showed total hardness values below the desirable limit and 21 wells, within the permissible limit. In 1999, 15 well waters were below desirable limit and 14 wells within the permissible limit and 4 wells showed values even beyond this limit. During 2000, only two wells showed hardness below the desirable limit and 3 wells above the permissible limit and in 2001, 14 wells showed values below desirable limit, when 5 wells recorded values above permissible limit.

Calcium hardness (Chart 126-129)

The calcium hardness in 1997 ranged from 24.8 in well no. 24 to 85.3 mg/l in well no. 3, in 1999 from 28 mg/l in well no. 4 to 110 mg/l in well no. 11, 20 mg/l in well no. 26 to 120.2 mg/l in well no. 25 during 2000 and 32.5 mg/l in well no. 15 to 124 mg/l in well no. 11. The maximum concentration of calcium during 1997 was slightly above the desirable limit (75 mg/l), but in 1999, 2000 and 2001, the maximum values fall within the permissible limit (200 mg/l) in the absence of alternate source.

It means the calcium hardness during 1997, showed 5 values above desirable limit when all others fall within the desirable limit. In 1999 also 5 values were below desirable limit and the rest within the permissible limit but above the desirable limit. During 2000, 8 wells fall above the desirable limit when other wells between the desirable and permissible limit (75-200 mg/l) and in 2001, 7 wells are within the desirable limit and the rest below the permissible limit.

Magnesium hardness (Chart 130-133)

In case of magnesium hardness, it fluctuated from 15 mg/l in well no.19 to 131.2 mg/l in well no. 25, in 1997, 10.45 mg/l in well no. 16 to 195.8 mg/l in well no. 23 in 1999, 17 mg/l in well no. 4 to 143.4 mg/l in well no. 25 in 2000 and 12.5 mg/l in well no. 16 to 177.5 mg/l in well no. 25 in 2001. Well no. 25 during 1997, 2000 and 2001 and well no. 23 during 1999 showed magnesium content above the permissible limit.

Magnesium hardness showed values in 16 wells within the desirable limit and 13 wells in between desirable and permissible range (30-100 respectively) and well no.25 above the desirable limit (131mg/l) in 1997. In 1999; three wells, in 2000; one well (well no.25) and 4 wells in 2001 showed values above the permissible limit. This shows that quality of dug well waters over the period of 4 years has deteriorated in terms of hardness. The dilution during 2000 is partial and more magnesium content compared to calcium during 2001 is an indication of lowering of water quality. This could be attributed to seawater intrusion that seawater contains more magnesium than calcium.

Nitrite-Nitrogen (Chart 134-137)

Nitrite-nitrogen varied from 0.041 μmol/l in well no. 7 to 0.18 μmol/l in well no. 11 in 1997, nil in well nos. 13, 14 and 29 to 2.88 μmol/l in well no. 6 in 1999, 0.06 μmol/l in well no. 19 to 0.5 μmol/l in well no. 16 in 2000 and nil in well nos. 13, 14, 15 and 16 to

4.26 μmol/l in well no. 6 in 2001. The nitrite content showed wide fluctuation. The sharp increase at certain wells (well no 6) during 1999 and 2001 may be an indication of infiltration from the domestic sewage. Even then these figures are lower in most of the wells in comparison with internationally accepted levels (1.0 mg/l) (WHO, 1984).

Nitrate-nitrogen (Chart 138-141)

Nitrate-nitrogen fluctuated from 5.38 μmol/l in well no. 2 to 49.6 μmol/l in well no 4 during 1997, 4.7.μmol/l in well no 2 to 43.05 μmol/l in well no 30 during 1999, 4.06 μmol/l in well no 26 to 74.6 μmol/l during 2000 and 6.7 μmol/l in well no 9 to 86.3 μmol/l during 2001. The nitrate values recorded during the study period were well bellow the desirable limit (45 mg/l). The values were only in μmol ranges. Nanoti Madan in 1989 reported that 43 wells in Kavaratti showed values up to 45 mg/l and 13 wells between 46 to 100 mg/l and concluded that high nitrate in water was caused by the usage of fertilizer. The results show that 1997-2001 period, the fertilizer utilization was considerably reduced and the drinking water standards for nitrates are well maintained. In view of the difficulty in establishing that any cases of methaemoglobinemia are caused by nitrate levels of less than 10 mg/l NO_3-N for drinking water, the WHO has set a recommended guideline value of 10mg/l No_3-N for drinking water. Bureau of Indian Standards (BIS) has set the desirable and permissible level in case of absence of alternate source to 45 mg/l and 100mg/l.

Fluoride (Chart 142-145)

Fluoride content in the water samples ranged from nil (well 4 & 20) to 1.9mg/l (well 8) in 1997, nil (well nos. 1, 5, 30 & shallow tube well)) to 1.8 mg/l (wells 14) in 1999, nil in six wells to 1.3 mg/l (well 1,3 & deep tube well) in 2000 and nil in six wells to 1.9 mg/l (well 8) during 2001. During 1977, though most of well waters showed fluoride content within

content above the permissible limit (1.5 ppm). In 1999 also 12 wells showed values above desirable and one well above the permissible limit. In 2000 and 2001 also well no.8 showed fluoride content above 1.5 ppm, but majority of the wells recorded considerably low values. This indicated that fluoride contamination in well waters of Kavaratti is not severe that treatment in this direction, as of now, is not required. These values are slightly below the reported values (Nanoti Madan,1989). He reported 2.6ppm fluoride in Kavaratti well waters in an open well, which was not potable. In Kerala state also, Rajagopal et al; 1989 reported fluoride content above 2.0 ppm in deep wells of Palghat district where many cases of dental carries were reported.

Sulphate (Chart 146-149)

Sulphate concentrations ranged from 13.4 mg/l in well no 20 to 106.8 mg/l in well no 14 during 1997, 13.6 mg/l in well no 3 to 121 mg/l in well no 13 during 1999. 18.9 mg/l in well no 4 to 163.8 in well no 13 during 2000 and 9.3 mg/l in well no 8 and 134.6 in well no 13 during 2001. The results showed that the well waters are having sulphate values below desirable units (200 mg/l) irrespective of the seasons.

Najeeb (1995) reported the relationship between rainfall and groundwater quality of the Island and suggested that heavy rainfall could revert the decreasing conductivity in some part of the Island. The present study showed that the effect of rain on lowering conductivity, chloride and TDS is only marginal, where the concentration has not exceeded the permissible limit and the withdrawal is minimum, and immediately after rain the original state was found re-established. In fact, Jacob in 1978 reported that the lens in these Islands are very thin and any large scale withdrawal was likely to disturb the equilibrium condition resulting in the rise of salt water. Jacob et al., 1987 also determined the ground water resource potential and its possible optimum exploitation in Kavaratti Island. They also reported the experience of a series of short duration pump tests and a

long duration pump tests and showed that the aquifer parameters determined are comparable with those obtained for similar Islands. They have also noticed the deterioration of water quality with continual pumping. The picture would be clear from the unpublished data of PWD Lab (civil), Kavaratti, Lakshadweep, 2002 which showed that, out of 180 well waters studied during premonsoon period, 150 well water exceeded the desirable limit for total hardness and 39 well water exceeded even the permissible limit (in the absence of alternate source). During 2001, these numbers was 144 and 28 respectively for desirable and acceptable limit ie. 26% of the total wells using now, has hardness values above permissible limits and in a condition to be rejected. This situation is visibly due to the overdraft. Alternate sources like rainwater harvesting is the need of the hour.

Table 14: Physico-chemical characteristics of dug well waters during 1997

Date of sampling: 30.12.1997

Well nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Water temp. (°C)	28.5	28	28.5	27	28	28.5	28.5	27.5	28	28	28.5	28.5	29	29.5	28	28.5
pH	8.05	8.05	7.95	8.05	7.6	8.05	8	7.75	7.68	7.8	7.85	7.9	8.01	8.12	7.43	7.6
Conductivity(µmhos/cm)	600	1310	1513	1132	1090	1027	738	1015	1680	920	2042	1640	960	950	856	885
Chloride (mg/l)	37.3	85.6	63.7	36.8	33.8	35.1	23.4	32.3	210.5	56.7	268.3	77.2	152.3	56.5	43	45.3
TSS(mg/l)	16.7	21.2	16	4.3	12	14.8	8.2	12.3	19	15.6	10.1	23.5	16.8	9.26	8.6	4.1
TDS (mg/l)	324	748	899	660	621	616	420	568	875	552	1025	875	558	563	445	231
Dis. oxygen (mg/l)	5.4	4.6	6	5.4	4.8	5.6	4.6	6.7	5.2	5.9	6.6	6.2	6.5	6.6	2.78	2.92
Total alkalinity (mg/l)	300	324	320	166	380	390	260	505	518	276	433	248	475	290	340	332
Total hardness($mgCaCO_3$)	340	450	340	210	280	270	330	420	450	310	385	420	285	345	165	148
Calcium (mg/l)	71.3	73.2	85.3	48.8	63.4	62.4	78.2	66.7	68.2	68	75.2	69.2	69.5	64.2	34.6	33.6
Magnesium (mg/l)	40	64.8	34	21.5	29.6	27.7	49.6	61.5	67.8	36.2	48.1	60	35	45.8	19	15.5
Nitrite-Nitrogen(µmol/l)	0.07	0.08	0.06	0.103	0.061	0.062	0.041	0.052	0.149	0.12	0.18	0.11	0.18	0.17	0.169	0.155
Nitrate nitrogen (µmol/l)	6.6	5.38	21.5	49.6	46.8	27.5	23.4	34	6.3	2.18	22.6	33.6	18.3	36.4	36	28.5
Fluoride (ppm)	1.2	1.2	1.2	ND	1.4	0.9	1.2	1.9	0.7	0.8	0.8	0.7	1.2	2	0.9	1.2
Sulphate (mg/l)	28.2	79.7	16.8	23.8	16.8	16.4	23.7	26.1	14.3	26.7	40.8	67.3	84.5	106.8	38.2	44.3

Well chem-1997 contd ...																
Well nos.	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	31(TW)	31(TW)
Water temp. (°C)	28.5	28	28.5	27	28	28.5	28.5	27.5	28	28	28.5	28.5	29	29.5	29	29
pH	7.8	7.9	7.53	7.8	7.9	7.7	7.6	7.55	7.4	7.4	7.5	7.8	7.4	7.45	8.2	8.25
Conductivity (µmhos/cm)	885	960	1030	1680	960	1440	1480	680	2950	1540	956	868	1205	1218	5155	6480
Chloride (mg/l)	43.7	58	59.5	64	47.5	78.5	77.8	39.5	148	157.3	48.9	50	83.6	84.9	918.4	1430
TSS (mg/l)	14.3	16	11.7	15.3	9.5	16.3	14	4.5	68.5	18.5	9.3	6.8	7.3	7.9	18.2	28
TDS (mg/l)	513	595	618	994	498	836	873	367	1770	893	559	530	710	755	2930	3369
Dissolved oxygen(mg/l)	6.9	6.8	7.1	6.3	6.4	5.9	5.8	6.9	5.1	5.9	6.4	6.6	5.2	5.1	2.95	2.83
Total Alkalinity(mg/l)	361	370	340	325	380	315	320	280	460	340	276	310	380	465	380	665
Total Hardness(mgCaCO3)	163	185	193	315	179	247	251	138	736	241	188	191	219	226	740	890
Calcium (mg/l)	35	44.9	52.5	53.5	61.5	75.4	70.6	24.8	78.5	66.5	45.2	40.3	53.5	54.8	110.6	73.5
Magnesium (mg/l)	18.35	17.68	15	44	6.56	14.3	17.1	18.5	131.2	18.2	18.2	22.1	20.7	21.6	112.6	171.8
Nitrite nitrogen(µmol/l)	0.07	0.05	0.05	0.09	0.085	0.078	0.08	0.068	0.06	0.11	0.09	0.08	0.08	0.10	0.09	0.24
Nitrate nitrogen (µmol/l)	11.30	6.70	12.80	16.20	17.20	15.50	26.60	26.80	6.30	19.80	28.60	17.60	21.30	18.60	6.40	10.80
Flurode(ppm)	0.8	0.8	0.7	ND	0.7	1.3	0.8	1.3	1.1	0.9	0.8	0.9	0.9	0.8	0.7	1.1
Sulphate (mg/l)	21.40	63.40	15.50	13.40	26.50	23.60	21.40	36.50	39.00	83.50	43.40	54.50	61.15	23.60	118.00	119.30

Table 15: Physico-chemical characteristics of dug well waters during 1999

Date of sampling: 25.04.1999

Well nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Water temp. (°C)	28.5	28	28.5	27	28	28.5	28.5	27.5	28	28	28.5	28.5	29	29.5	28.5	28
pH	7.6	7.85	7.61	7.9	7.8	7.9	7.52	7.52	7.51	7.4	8.1	7.5	7.8	7.2	7.4	7.75
Conductivity(µmhos)	625	1125	898	598	712	588	650	920	1322	775	2890	1885	875	548	980	1030
Chloride (mg/l)	38.8	80.4	28.5	19.6	18.0	25.5	18.6	50.8	184.9	54.5	335	190.8	31.5	18.5	50	64
TSS (mg/l)	19.2	23.2	18.5	5.9	9.3	14.5	7.8	14.5	20.3	9.6	185	101.5	15.2	14.5	20.3	18.2
TDS (mg/l)	370	663	556	346.8	441	352	396	580	872	439	2032	1105	515	290	578	566
Diss. oxygen (mg/l)	6.12	6.28	5.96	5.71	4.5	3.61	4.71	205	3.5	4.31	3.75	4.15	4.23	6.47	6.8	6.9
Total alkalinity (mg/l)	315	329	390	245	384	402	285	405	510	285	400	305	450	281	340	360
Total hardness	278	355	300	221	250	210	245	390	412	255	855	445	265	310	195	198
Calcium	55.2	65.5	85	28	45	38	45	71	80.5	66.2	110	60	75	65.3	36	62
Magnesium	34	46	22	36.4	33.5	29.2	32.3	52	51.3	22.9	141	71.7	19	35.7	25.5	10.45
Nitrite-Nitrogen	0.09	0.28	0.21	0.27	1.10	2.88	0.69	0.09	1.23	2.63	2.10	0.68	ND	ND	0.158	0.161
Nitrate nitrogen (µmol/l)	8.32	4.7	18.3	36.5	40.1	18.3	31.8	5.2	8.8	18.8	28.7	19.6	41.61	42.5	38.2	34.6
Fluoride	ND	1.1	0.7	0.8	ND	0.7	1.2	1.8	1.1	1.2	0.7	0.9	0.9	2	0.8	0.8
Sulphate (mg/l)	31.4	99.3	13.6	24.6	15.75	17.3	24.4	17.75	35.1	55.8	76.4	94.6	121.4	99.4	28.3	57.5

Well chem-1999 contd ...																
Well nos.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31(TW)	32(TW)
Water temp. (°C)	27	28	28.5	27.5	28	27.4	27.6	27.9	26.5	26	26.8	26.5	27	26.5	28.5	28.8
pH	7.6	7.81	7.6	7.36	7.3	7.25	7.2	7.5	7.46	7.6	7.7	7.85	7.5	7.65	8.2	8.2
Conductivity (µmhos/cm)	1280	1780	1045	3985	2610	2825	5246	3950	3410	1985	1206	1380	1270	1470	5820	6135
Chloride (mg/l)	87	165	52.5	345	225	262	540	538.3	511	201	80	83.6	104	115.3	980	1100
TSS (mg/l)	22	79.5	16	112.6	88.2	70.5	225.8	118.7	80	40	24.5	30.5	18.5	15	11.2	13.8
TDS (mg/l)	640	1065	522	1992	1566	1551	2621	1975	1841	972	627	800	749	735	3600	4080
Dissolved oxygen (mg/l)	5.6	4.9	6.4	5	51	5.2	4	5.2	5.4	6.3	6.8	5.6	5.5	4.9	0.29	0.32
Total Alkalinity (mg/l)	325	265	210	440	375	405	560	420	340	210	280	280	260	300	270.5	245.5
Total Hardness (mgCaCO3)	228	348	290	645	394	880	941	510	821	367	238	246	235	253	680	760
Calcium (mg/l)	64	66	78	77	60	49	54	101	73	68	60	68	60	67	122	128
Magnesium (mg/l)	16.5	44.5	53.4	110	59.2	184	195.8	62.5	155	47.9	21.4	18.4	20.7	20.8	164	213
Nitrite nitrogen (µmol/l)	0.015	0.21	0.14	0.98	0.11	0.14	0.17	0.15	0.12	0.13	0.08	0.07	ND	0.25	0.14	0.12
Nitrate nitrogen (µmol/l)	18.8	6.6	14.9	19.5	19.8	16	38.2	34.8	9.05	6.6	13.8	33.5	34.63	43.05	29.6	39.3
Fluoride(ppm)	1.1	1.2	0.9	1.4	0.9	0.8	0.8	1.1	0.8	1.1	0.9	1.1	1.2	ND	ND	1.2
Sulphate (mg/l)	23.6	73.2	18.7	19.2	28.2	29.4	24.5	39.6	43	109.5	50.75	68.3	63.65	26.5	129.5	110.6

Table 16: Physico-chemical characteristics of dug well waters during 2000

Date of Sampling : 24.08.2000

Well nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Water temp. (°C)	26.8	26.5	26.8	27	26	26.8	26.5	27	28	27.5	26	28	28	26.8	28.5	28.5
pH	7.66	7.90	7.69	7.90	7.87	7.77	7.65	7.69	7.51	7.51	7.50	7.48	7.82	8.09	7.16	7.66
Conductivity (µmhos/cm)	677	1485	1030	386	707	758	672	945	1575	890	1908	1360	970	940	719	677
Chloride (mg/l)	30	95	35	21	55	35	30	30	180	55	260	70	150	55	29.97	29.97
TSS (mg/l)	16.3	18.9	9.8	9.3	11.4	12.3	16	20	23	18.5	57.5	28.5	18.5	14.3	9.9	8.5
TDS (mg/l)	393	891	618	213	410	440	370	558	945	499	1145	816	544	531	417	393
Dissolved oxygen (mg/l)	6.2	5.2	5.3	5.9	4.9	6.6	6.8	6.4	4.8	6.1	6.4	6.2	6.5	6.1	5.5	6.4
Total Alkalinity (mg/l)	345	360	290	185	215	230	240	465	730	340	420	260	390	275	310	280
TH($mgCaCO_3/l$)	320	440	320	170	260	230	290	400	430	290	400	400	270	320	370	320
Calcium (mg/l)	60.1	72.1	80.2	40.1	56.1	60.1	76.2	72.14	64.13	64.13	68.14	68.14	68.14	56.11	100.2	60.12
Magnesium (mg/l)	41.3	63.2	29.2	17	29.2	19.4	24.3	53.5	65.6	31.6	55.9	55.9	24.3	43.7	29.2	41.3
Nitrite-Nitrogen	0.05	0.045	0.06	0.103	0.055	0.062	0.046	0.046	0.099	0.14	0.09	0.12	0.19	0.31	0.17	0.17
Nitrate nitrogen (µmol/l)	7.8	10.82	35.3	73.7	74.6	27.3	23.8	36.14	39.43	4.06	49.6	38.11	18.3	41.3	15.6	16.46
Flouride(ppm)	1.3	1.2	1	1.3	1	0.7	0.9	1.9	0.9	1.2	0.9	1	1.2	2	ND	1.1
Sulphate (mg/l)	26.3	118.2	27.41	18.9	24.61	19.8	27.1	20.7	36.9	65.4	90.1	126.2	163.8	106.41	36.3	75.7

Well chem-2000 contd ...																
Well nos.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31(TW)	32(TW)
Water temp (°C)	26.7	27	28	26.8	26	27	28.2	28	27.5	28	26.5	26.8	26.5	26	27.5	28
pH	7.48	7.78	7.46	7.19	7.2	7.16	7.14	7.27	7.37	7.58	7.6	7.73	7.47	7.51	8.08	8.18
Conductivity (µmhos/cm)	762	779	902	1590	806	1088	1369	514	3300	1323	747	844	1022	1165	4670	6300
Chloride (mg/l)	65	70	60	175	25	60	95	20	505	170	25	85	110	85	895	1390
TSS (mg/l)	12.3	14.8	16.9	33.5	18.4	16.2	28.5	25.1	185.3	81.4	22.3	19.4	27.7	37.8	36	34
TDS (mg/l)	442	452	524	954	468	653	794	308	1980	820	434	490	614	699	2802	3780
Dissolved Oxygen (mg/l)	5.6	6.3	5.4	5.2	5.6	5.5	5.3	6.5	4.1	4.5	6.6	6.7	6.8	6.5	3.8	3.2
Total Alkalinity (mg/l)	315	355	295	310	355	290	325	290	400	280	240	300	365	415	280	371.5
T.H (mgCaCO3)	300	310	390	400	390	470	610	270	890	400	350	300	380	410	680	780
Calcium (mg/l)	64.2	64.1	404.2	80.2	96.2	76.2	88.2	68.1	120.2	20.0	92.2	76.2	40.1	72.1	88.22	64.1
Magnesium (mg/l)	34	36.5	31.6	48.6	36.5	68	94.8	24.3	143.4	60.8	26.7	29.2	68	55.9	111.8	150.7
Nitrite nitrogen(µmol/l	0.14	0.2	0.06	0.2	0.14	0.22	0.18	0.17	0.09	0.16	0.14	0.09	0.12	0.18	0.05	0.04
Nitrate nitrogen (µmol/l)	16.83	4.3	13.8	20.6	18.14	36.7	46.4	36.3	10.63	4.06	18.3	47.4	43.4	34.63	28	49
Flouride(ppm)	1.2	0.9	ND	0.7	ND	0.8	1.1	ND	1.2	0.8	1.1	0.8	0.9	ND	1.2	1.3
Sulphate (mg/l)	31.3	95.3	28.3	27.1	33.2	28.6	49.4	46.1	121.3	66.8	45.4	78.7	77.6	24.7	148.5	118.9

Table 17: Physico-chemical characteristics of dug well waters during 2001

Date of sampling: 29.05.2001

Well nos.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Water temp. (°C)	29	28.5	29	27.5	28.5	29	29	29.5	28.5	28.5	29	29	29.5	30	28.5	29
pH	7.56	7.85	7.66	8.0	7.8	7.9	7.49	7.45	7.46	7.3	7.4	7.4	7.7	8.05	7.2	7.7
Conductivity(µmhos)	638	1431	933	661	700	609	653	987	1496	860	2780	1980	980	535	1086	1090
Chloride (mg/l)	67.3	163.2	80	70	55	40	38.3	55	181	48.5	477	325	115	28.5	51.3	62.5
TSS (mg/l)	14.2	18.5	16.3	6.3	11.3	16.8	11.2	15.7	24.6	13.7	22.6	13.4	8.4	6.3	23.6	25.3
TDS (mg/l)	345	790	559	370	470	395	361	550	932	485	1970	1089	503	290	543	540
Diss. oxygen (mg/l)	6.03	6.14	5.92	5.62	4.68	3.74	4.68	1.24	3.58	4.24	3.68	4.02	4.14	5.04	6.2	6.7
Total alkalinity (mg/l)	280	310	360	240	270	240	275	490	540	265	540	490	280	298	310	371
Total hardness	302	398	320	240	270	230	240	430	463	295	625	480	290	315	186	195
Calcium (mg/l)	61.5	74.2	92	60	56	44	47	60	77.41	74.5	124	72	84	73.5	32.5	57.5
Magnesium (mg/l)	36.2	51.6	22	22	32	29	30	68	65.6	26.6	132	73	19	32.3	25.5	12.5
Nitrite-Nitrogen	0.05	0.34	0.24	0.36	1.5	4.26	0.85	0.06	1.85	2.73	2.32	0.74	ND	ND	ND	ND
Nitrate nitrogen (µmol/l)	18.3	86.3	21.2	44.2	63.4	21.8	16.7	39.2	6.7	10.3	21.3	34.7	21.9	46.8	41.4	36.1
Fluoride	ND	0.8	0.8	1.2	0.9	1.3	1.1	1.9	1.3	0.9	1.1	1.2	0.8	2	1.4	1.5
Sulphate (mg/l)	34.6	126.4	24	22.12	18.6	21.3	37	9.3	46.5	70.6	124.6	118.2	134.6	127.6	38.4	64.3

Well chem-2001 contd ...

Well nos.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31(TW)	32(TW)
Water temp. (°C)	28.2	28	27.5	26	28	26	27.5	28	26.5	28	27.5	28	28	27.5	28	28
pH	7.53	7.8	7.53	7.25	7.35	7.25	7.6	8..01	7.45	7.6	7.7	7.65	7.5	7.62	8.15	8.2
Conductivity (µmhos/cm)	1285	1860	1230	2400	2645	2715	4815	535	3960	2140	1386	1420	1800	1586	6430	7280
Chloride (mg/l)	80.5	168	75	190	298	256	418	28.5	471.5	195	99.5	74.3	78.5	67.5	1125	1410
TSS (mg/l)	19.8	27.5	20.4	80.5	88.7	63.5	168.5	16.7	90.5	77.4	56.1	33.8	40	34.8	37.3	40.5
TDS (mg/l)	642	948	768	1240	1375	1438	2407	267	1980	1177	776	795	954	888	3640	4230
Dissolved Oxygen (mg/l)	5.4	4.6	6	5.4	4.8	5.6	4.6	6.7	5.2	5.9	6.6	6.2	6.5	6.6	2.78	2.92
Total Alkalinity (mg/l)	315	280	240	390	340	420	470	435	400	265	295	330	282	335	1410	1620
T.H (mgCaCO3)	206	238	295	685	378	395	832	315	934	610	218	224	244	230	630	720
Calcium (mg/l)	58	63.5	61.5	75.6	55.6	56.2	90.5	73.5	81.4	70.5	43.4	46.7	47.8	53.5	136.3	116.8
Magnesium (mg/l)	14.8	19.3	34.3	12.5	58	61	147	32	177.5	106	26.6	26	30	23.5	190.7	238
Nitrite nitrogen (µmol/l)	0.09	0.12	0.15	0.08	0.21	0.08	0.13	0.15	0.08	0.2	0.17	0.09	0.21	0.19	0.38	0.46
Nitrate nitrogen (µmol/l)	21.3	11.8	19.8	16.5	24.6	10.3	46.7	37.12	10.5	13.4	29.2	49.7	36.8	32.6	44.6	60.2
Fluoride(ppm)	1.1	ND	ND	1.3	ND	1.1	0.9	ND	1.2	0.9	1.3	1.5	ND	0.9	1.2	1.4
Sulphate (mg/l)	26.7	83.4	19.5	21.3	30.8	40.3	26.6	41.8	19.3	60.1	98.3	64.6	74	28.4	138	146.5

Chart 94: pH in well waters during 1997

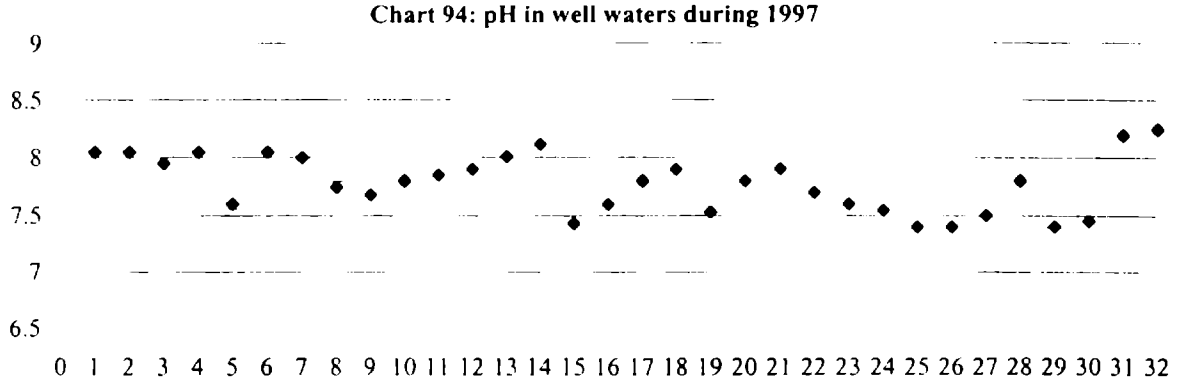


Chart 95: pH in well waters during 1999

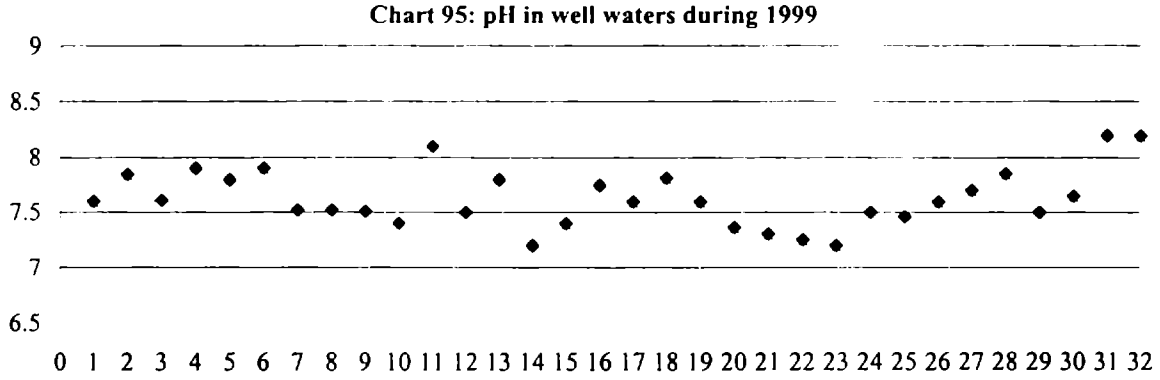


Chart 96: pH in well waters during 2000

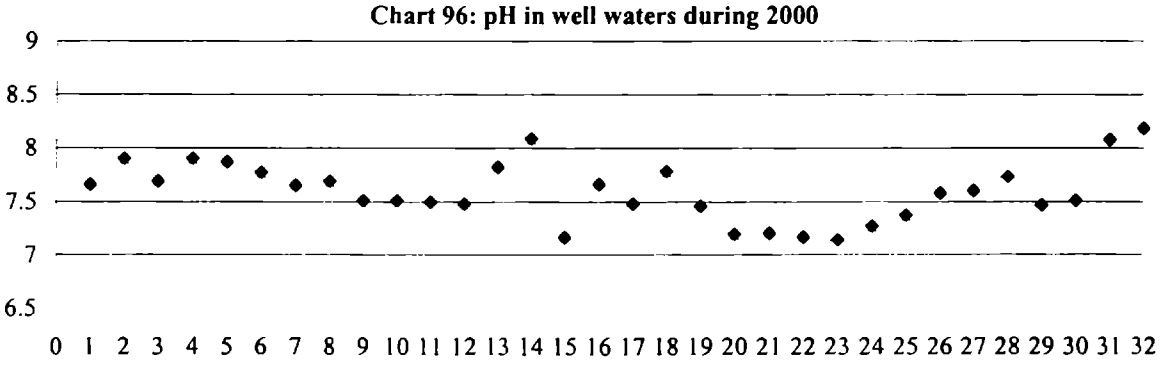


Chart 97: pH in well waters during 2001

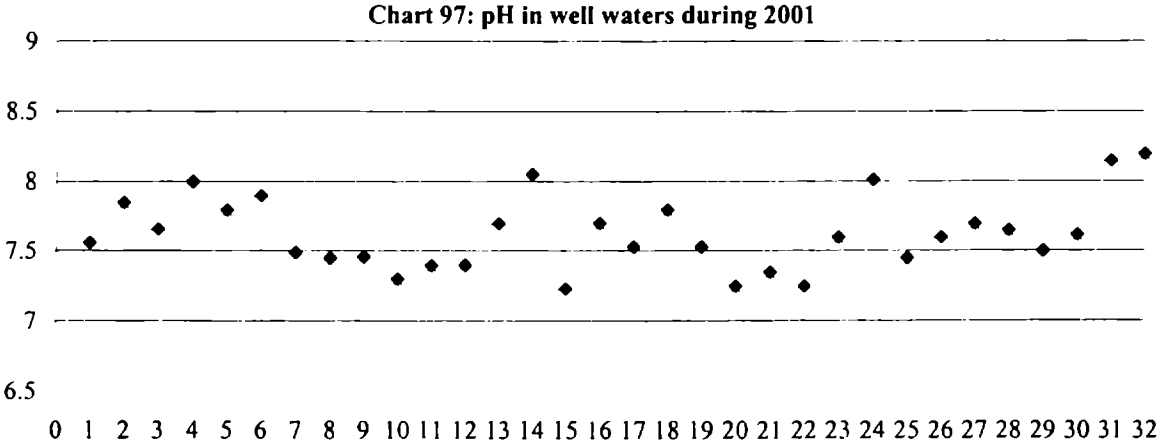


Chart 98: Condctivity in well waters during 1997

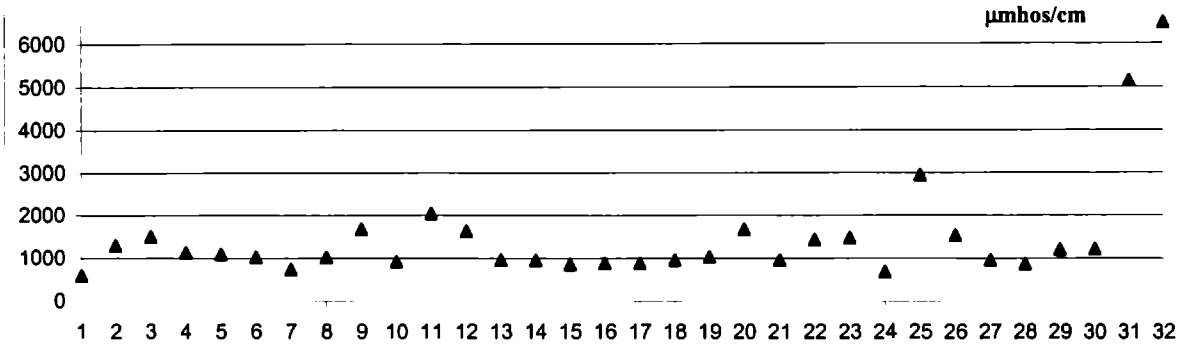


Chart 99: Conductivity in well waters during1999

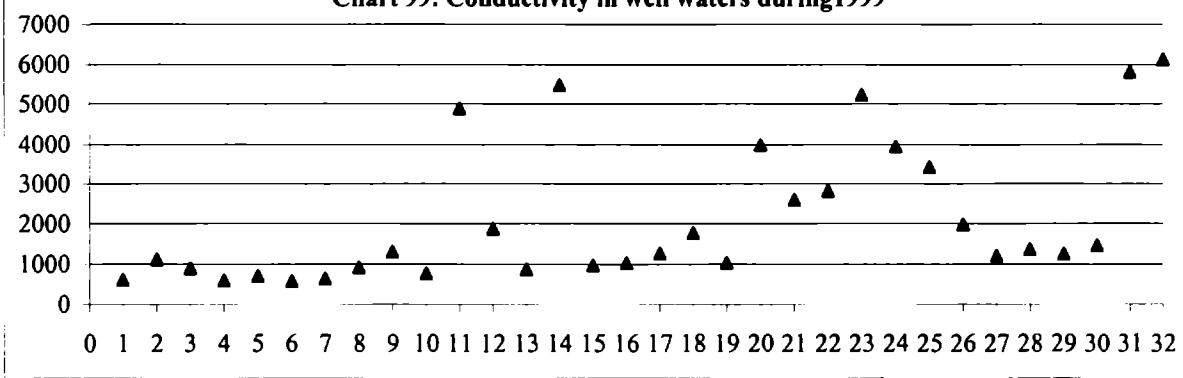


Chart 100: Conductivity in well waters during 2000

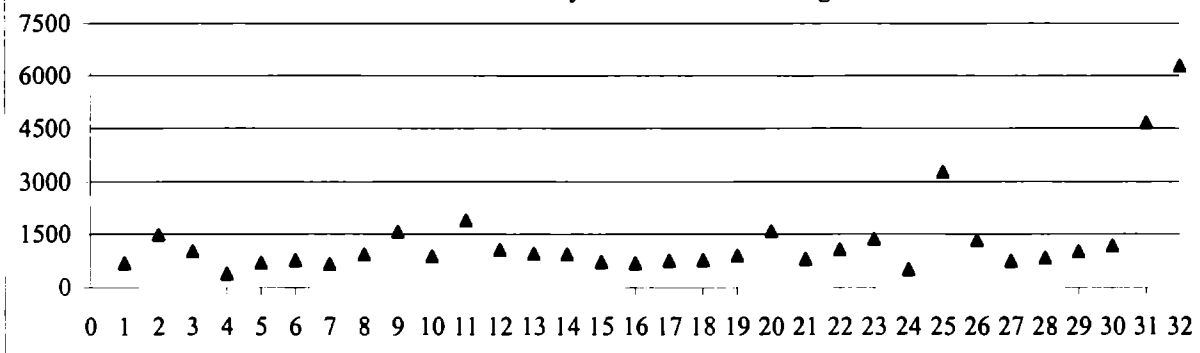


Chart 101: Conductivity in well waters during 2001

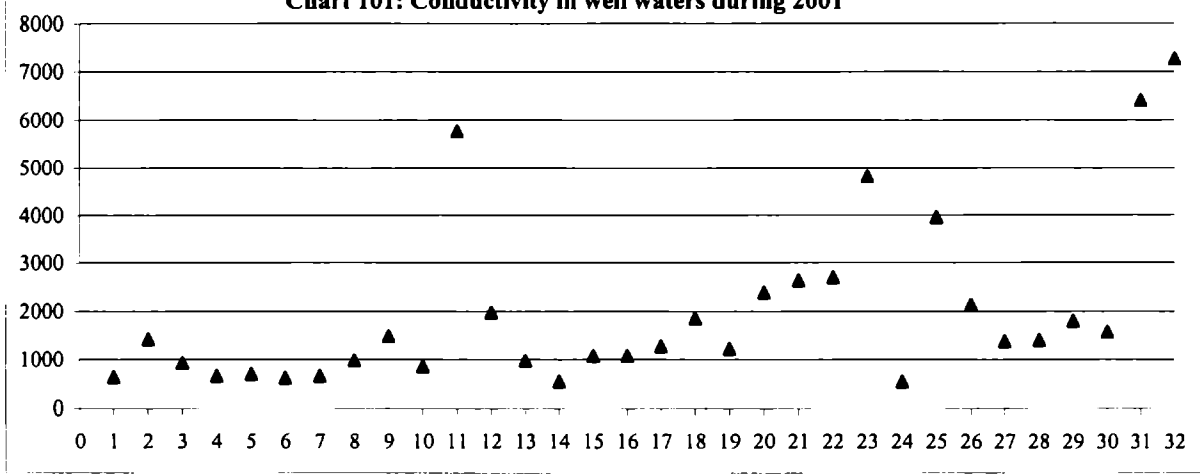


Chart 102: Chloride content in well waters during 1997

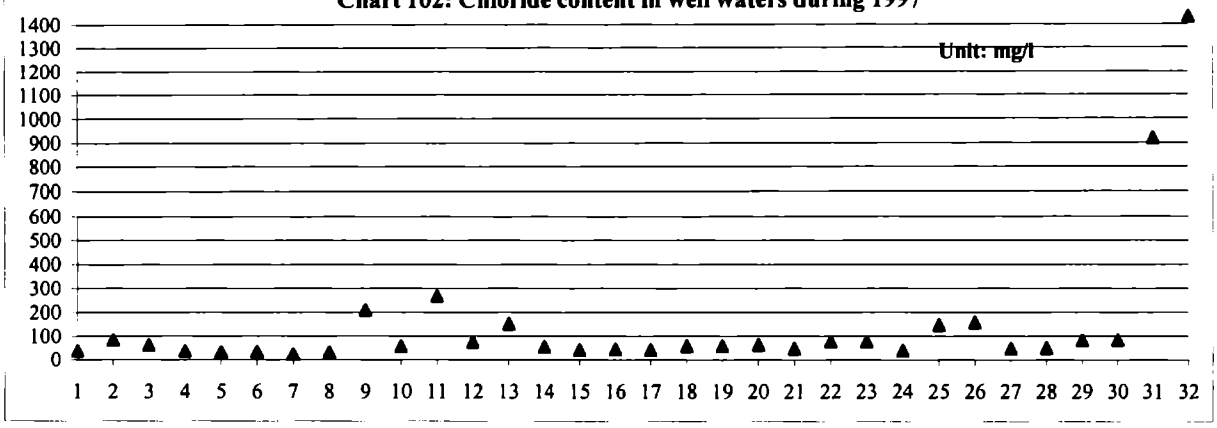


Chart 103: Chloride content in well waters during 1999

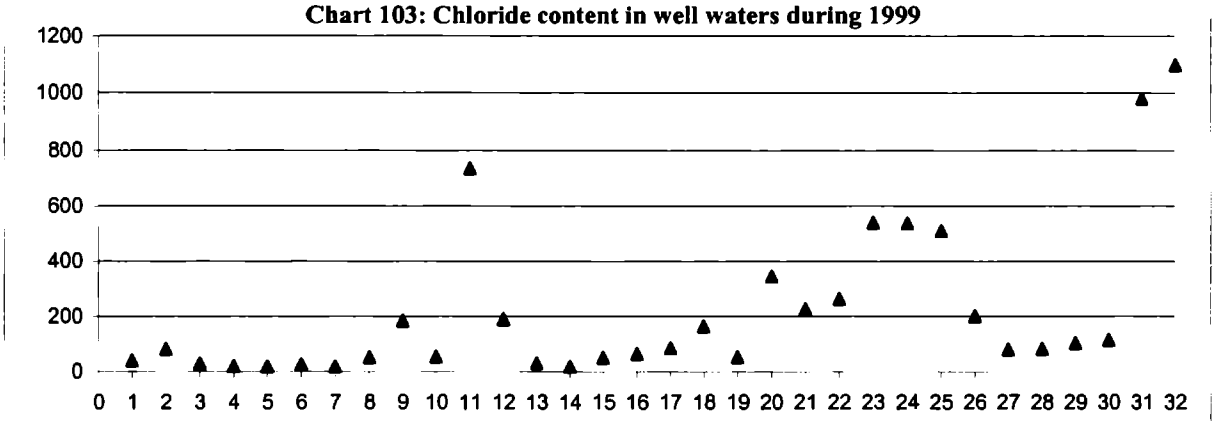


Chart 104: Chloride content in well waters during 2000

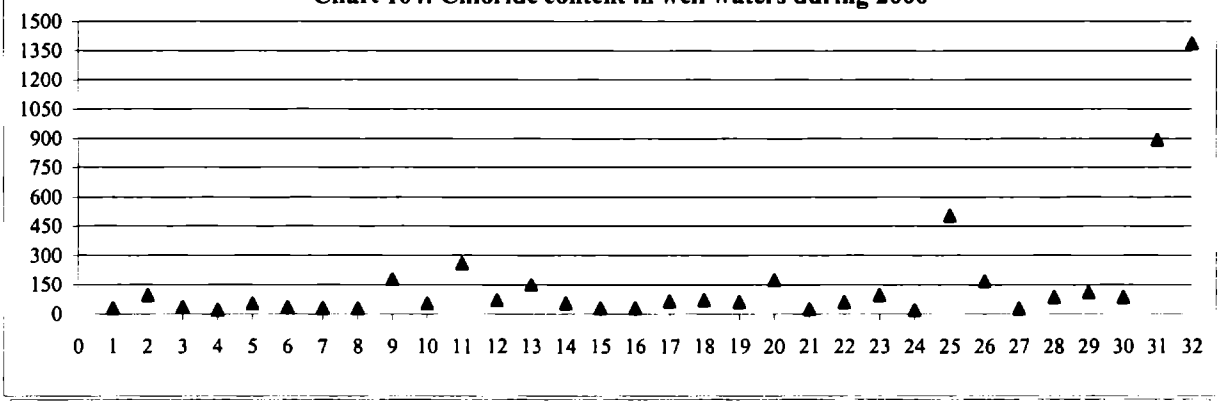


Chart 105: Chloride content in well waters duering 2001

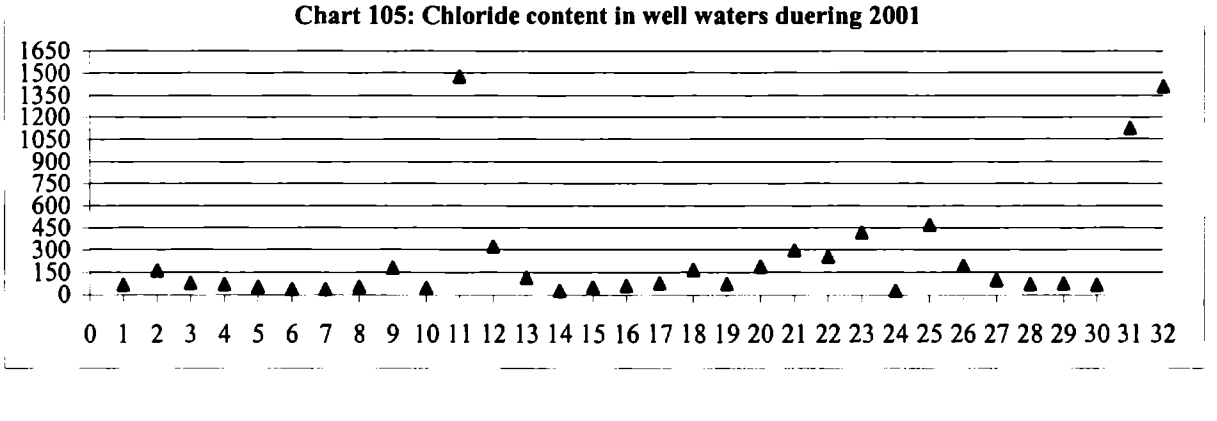


Chart 106: TSS in well waters during 1997

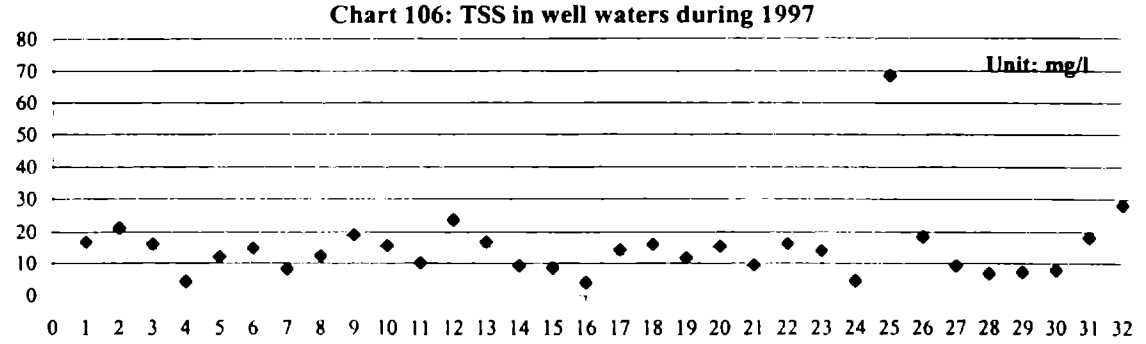


Chart 107: TSS in well waters during 1999

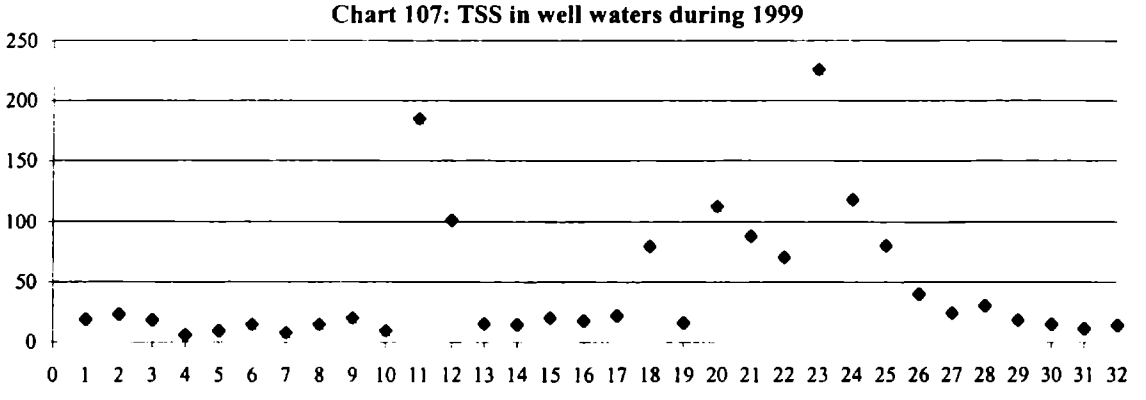


Chart 108: TSS in well waters during 2000

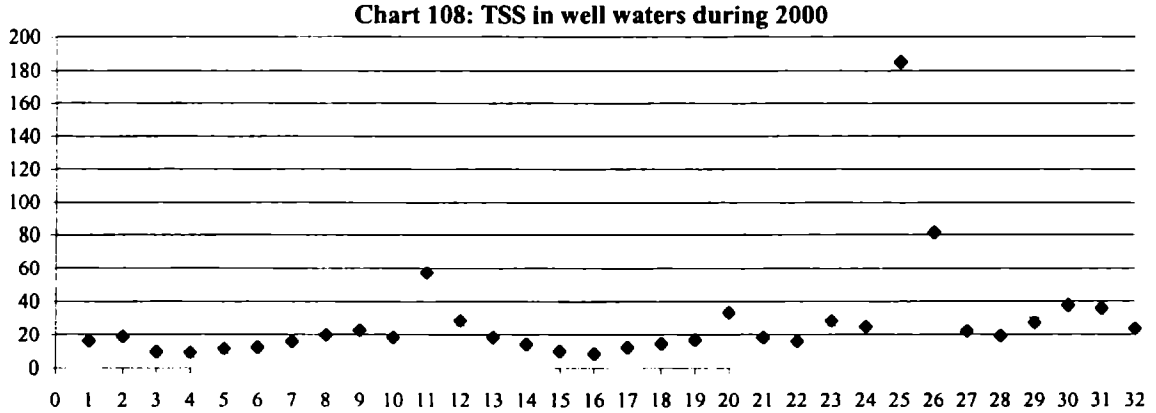


Chart 109: TSS in well waters during 2001

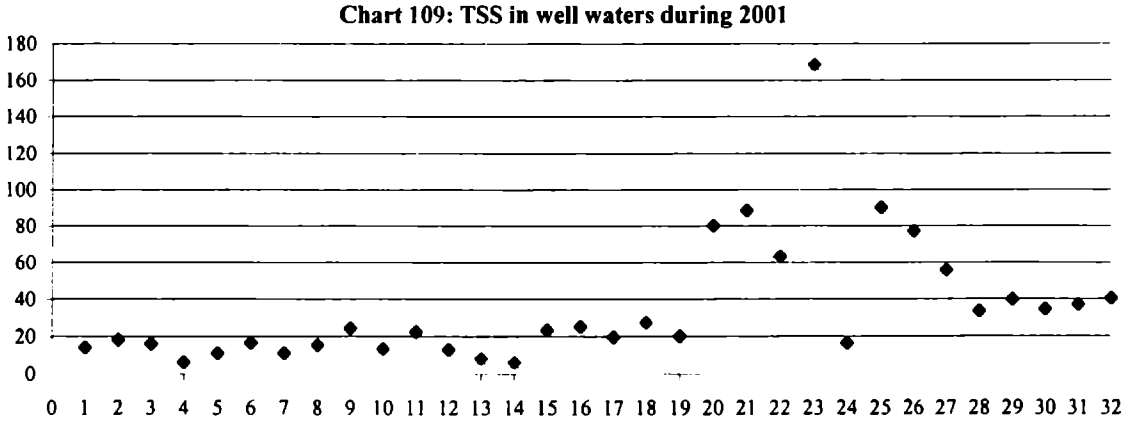


Chart 110: Total Dissolved Solids in well waters during 1997

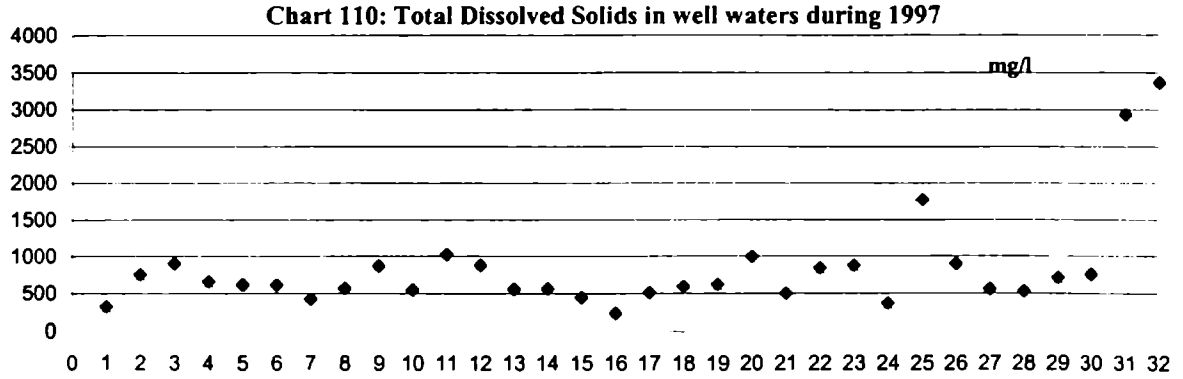


Chart 111: Total Dissolved Solids in well waters during 1999

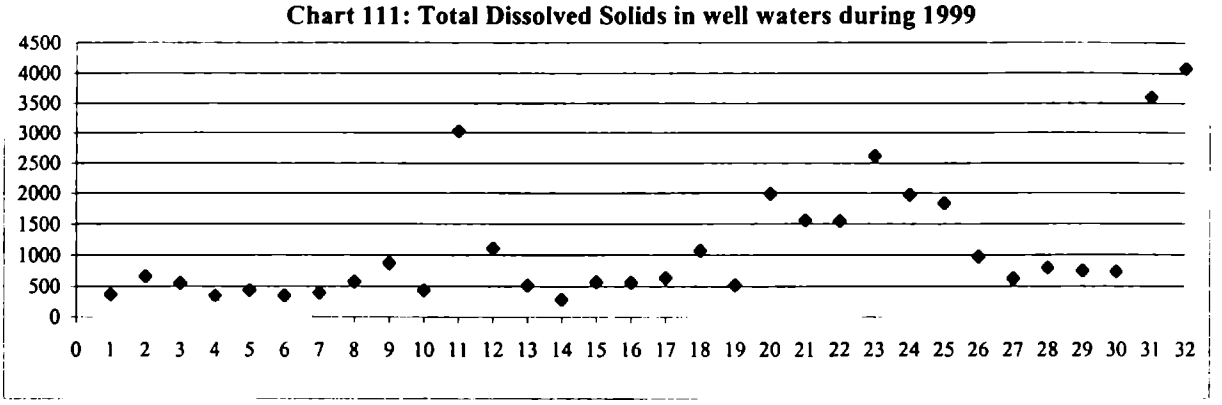


Chart 112:Total Dissolved Solids in well waters during 2000

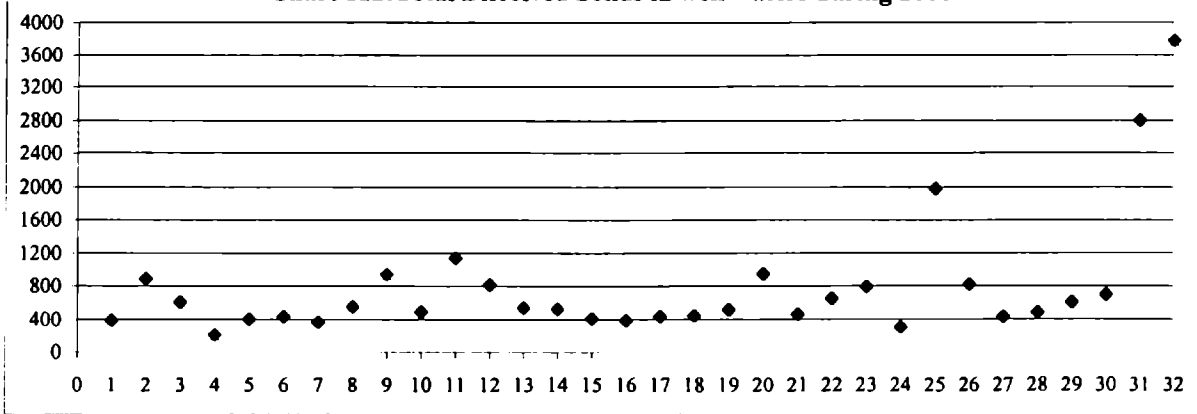


Chart 113: Total Dissolved Solids in well waters during 2001

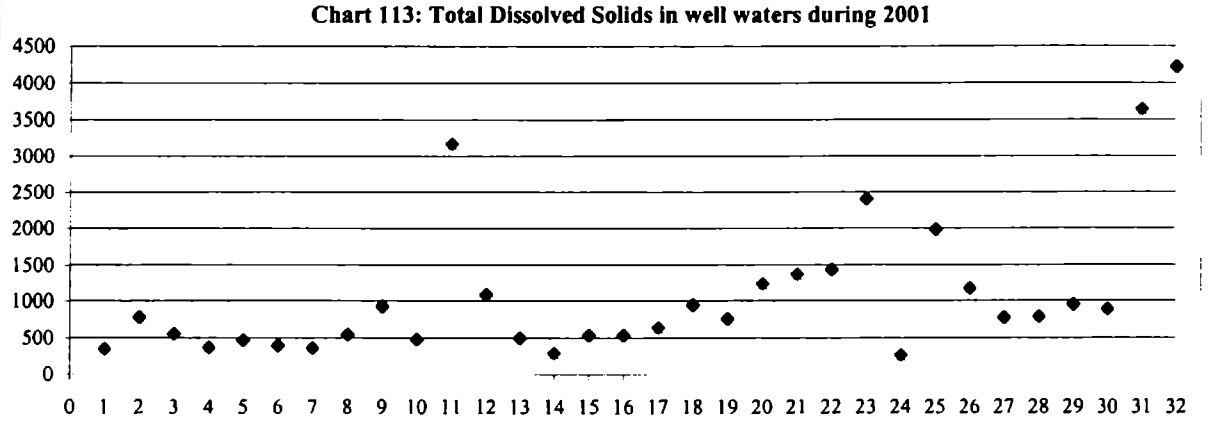


Chart 114: Dissolved oxygen in well waters during 1997

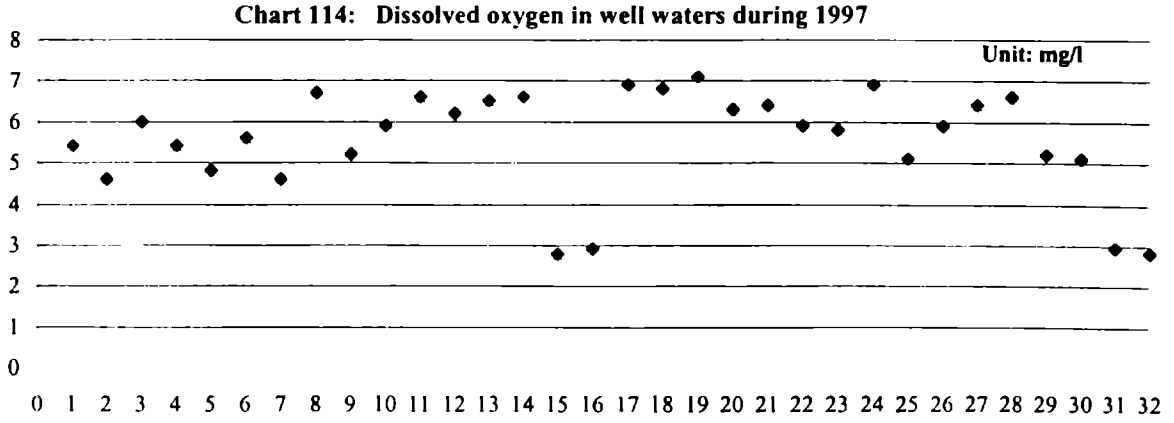


Chart 115: Dissolved oxygen in well waters during 1999

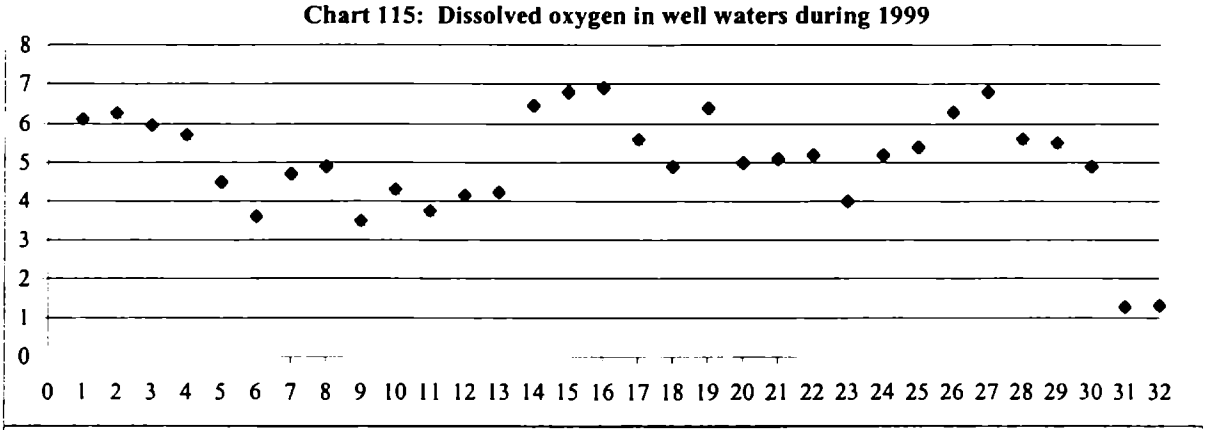


Chart 116: Dissolved oxygen in well waters during 2000

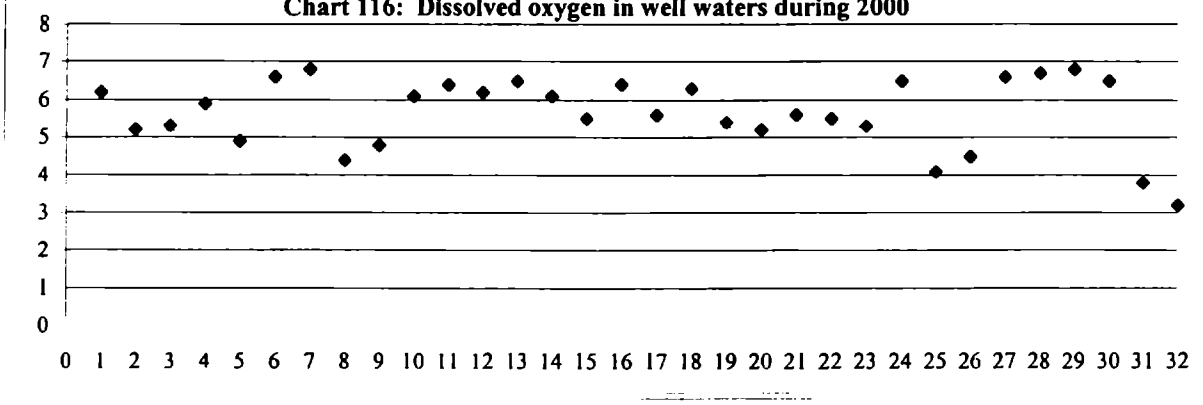


Chart 117: Dissolved oxygen in well waters during 2001

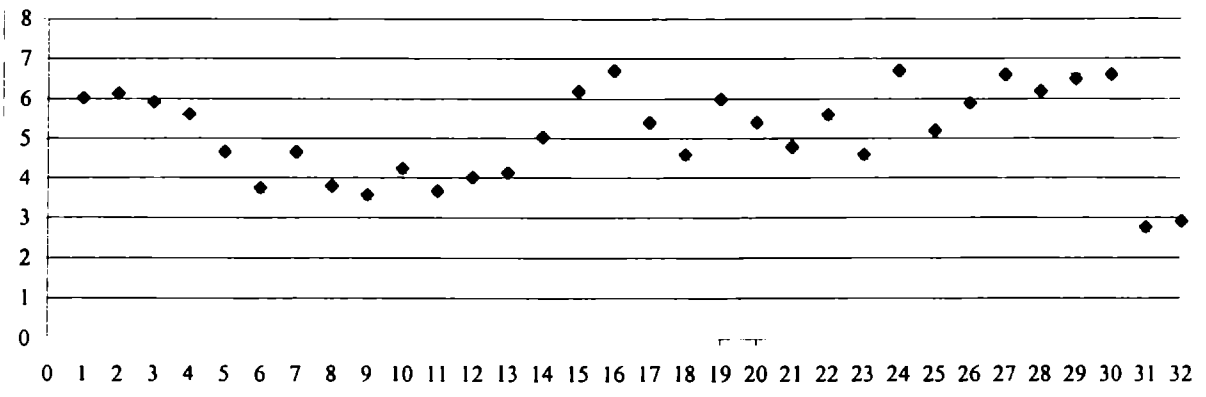


Chart: 118 Total Alkalinity in well waters during 1997

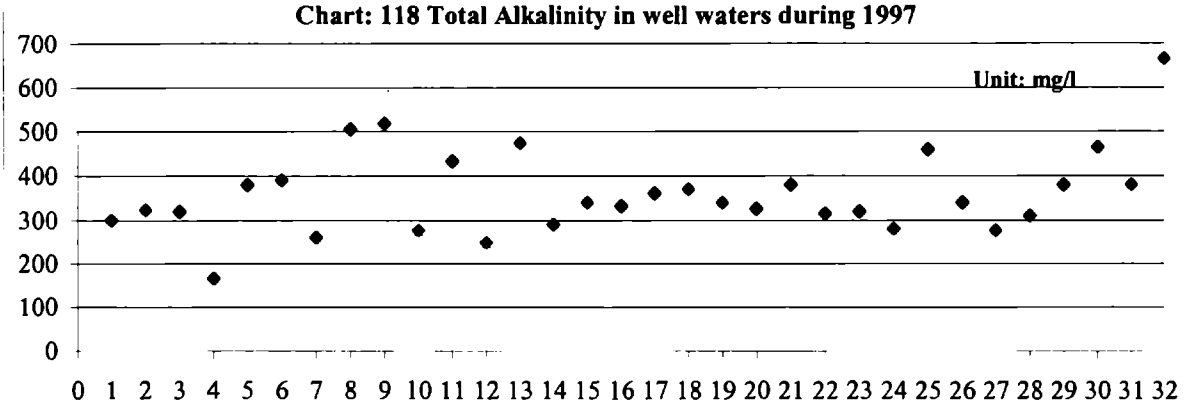


Chart 119: Total Alkilinity in well waters during 1999

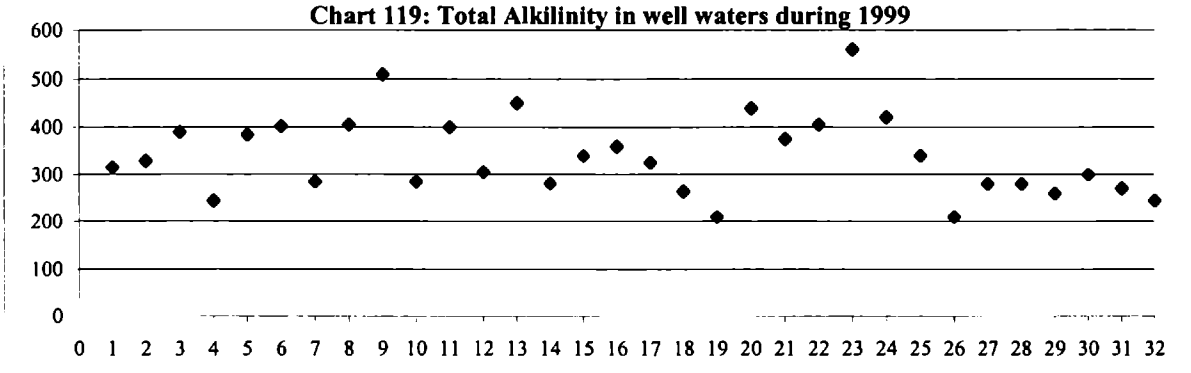


Chart 120: Total Alkalinity in well waters during 2000

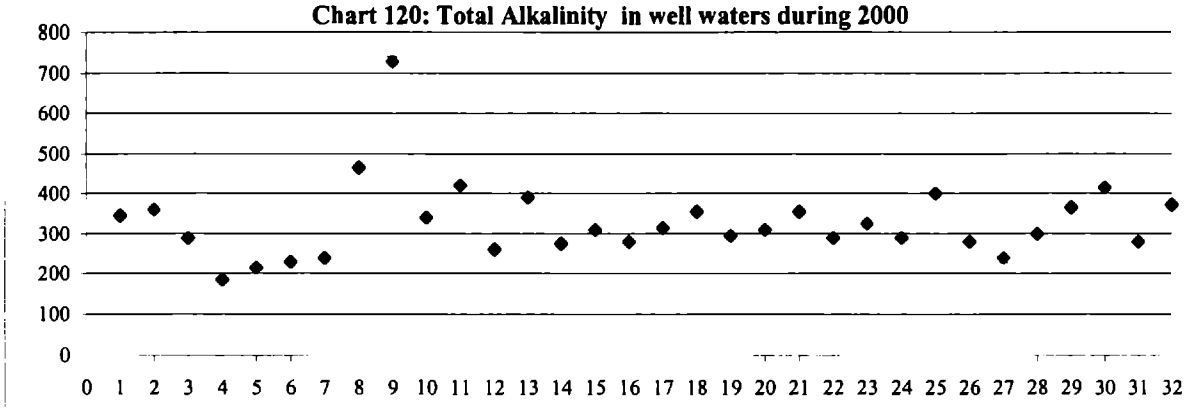


Chart 121: Total alkalinity in well waters during 2001

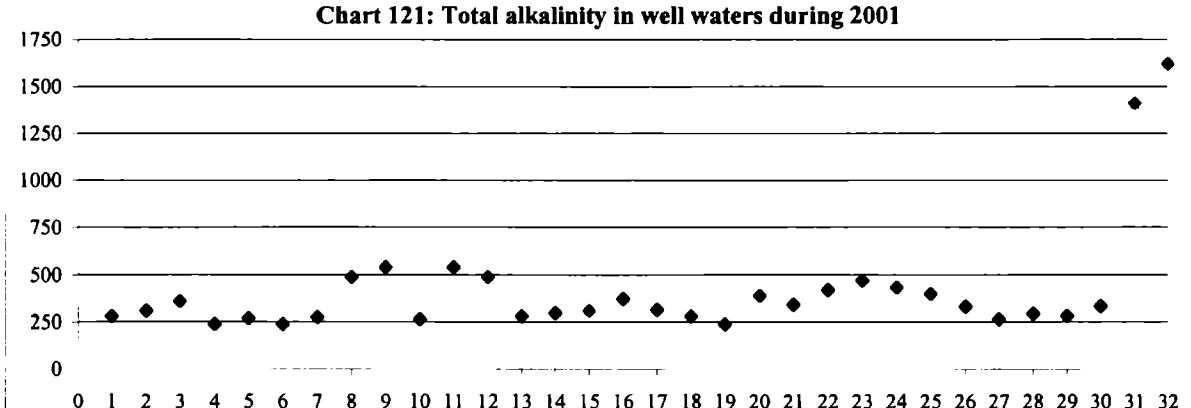


Chart 122: Total hardness in well waters during 1997

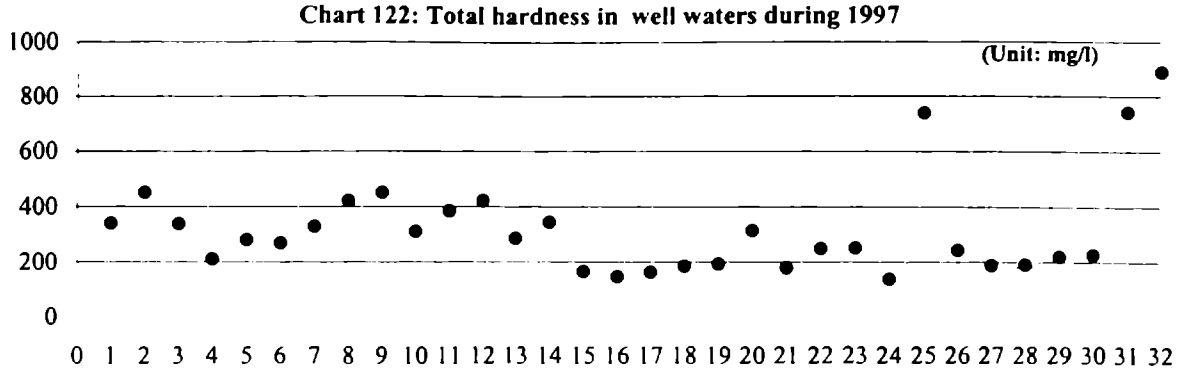


Chart 123: Total Hardness in well waters during 1999

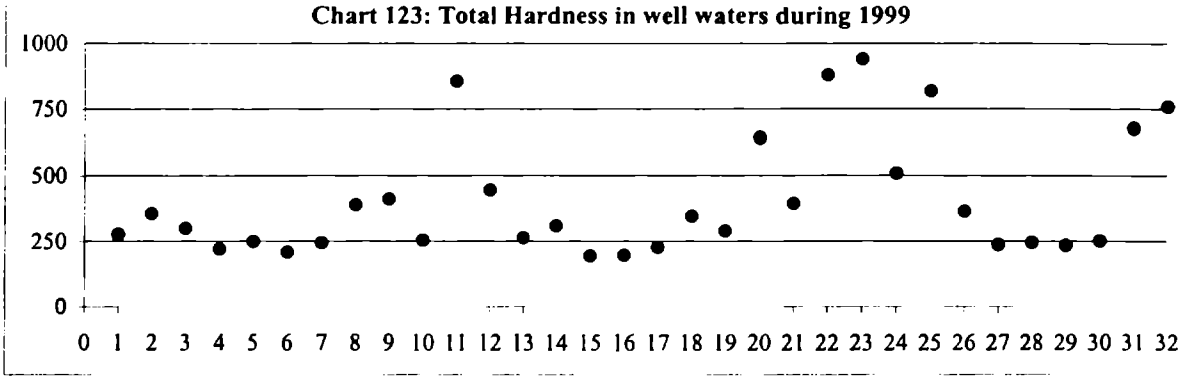


Chart 124: Total hardness in well waters during 2000

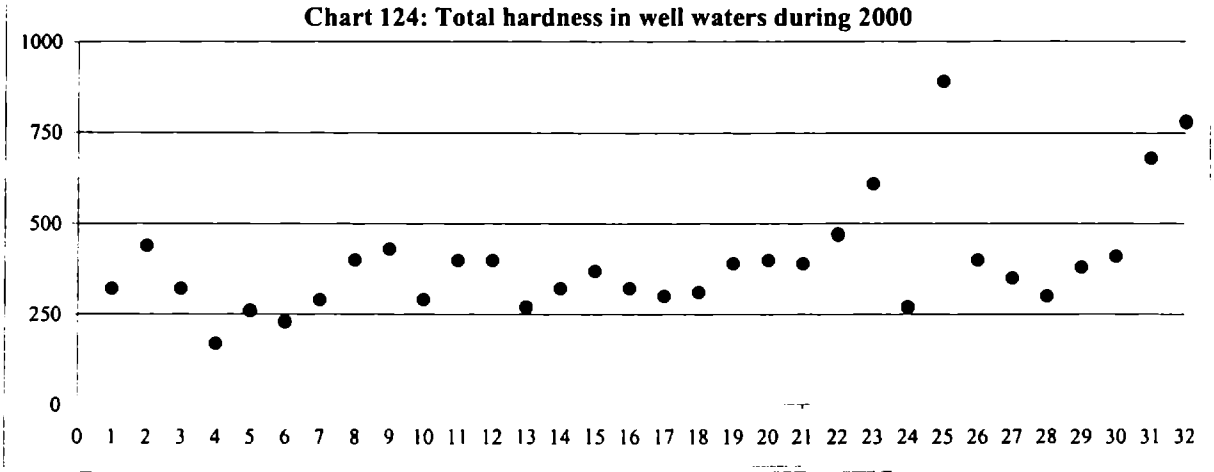


Chart 125: Total hardness in well waters during 2001

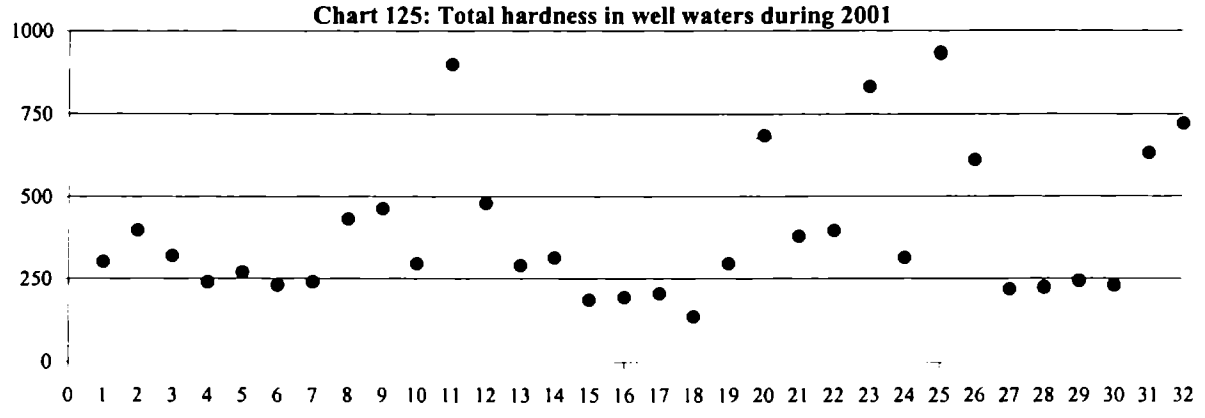


Chart 126: Calcium in well waters during 1997

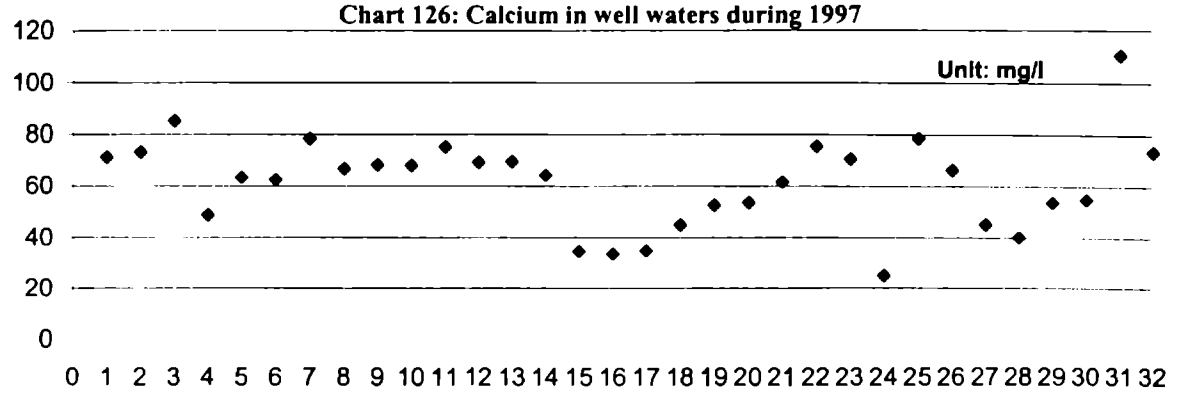


Chart 127: Calcium in well waters during1999

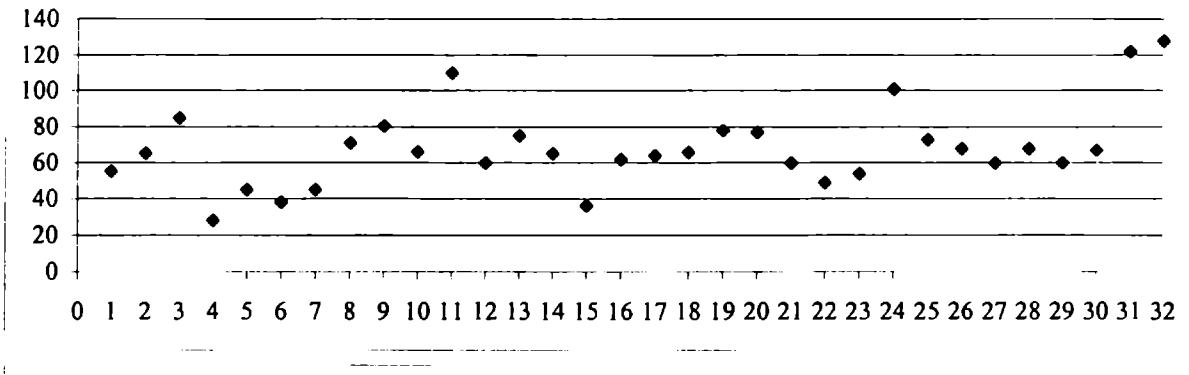


Chart 128: Calcium in well waters during 2000

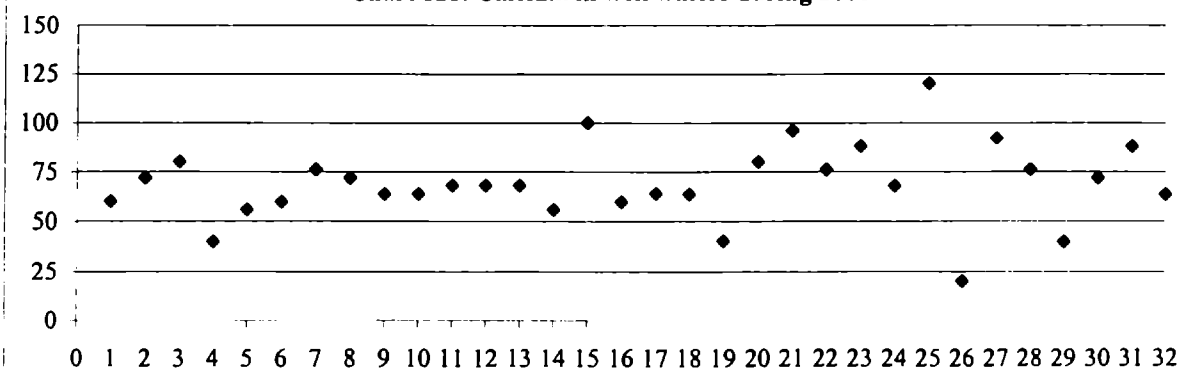


Chart 129: Calcium in well waters during 2001

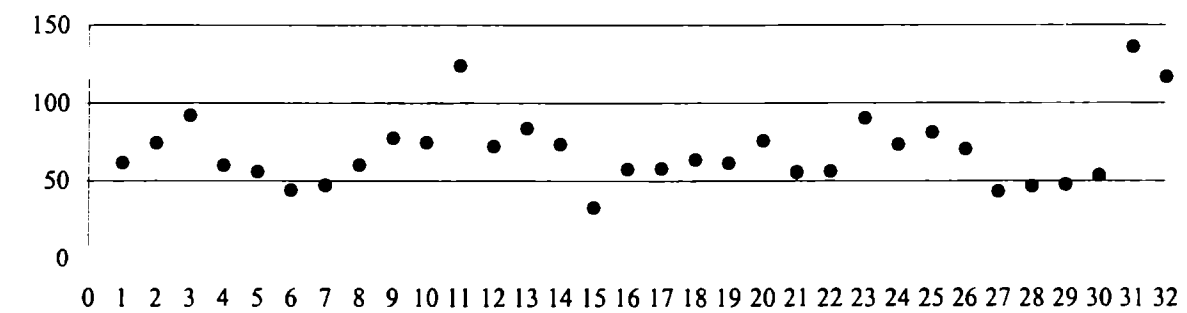


Chart 130: Magnesium in well waters during 1997

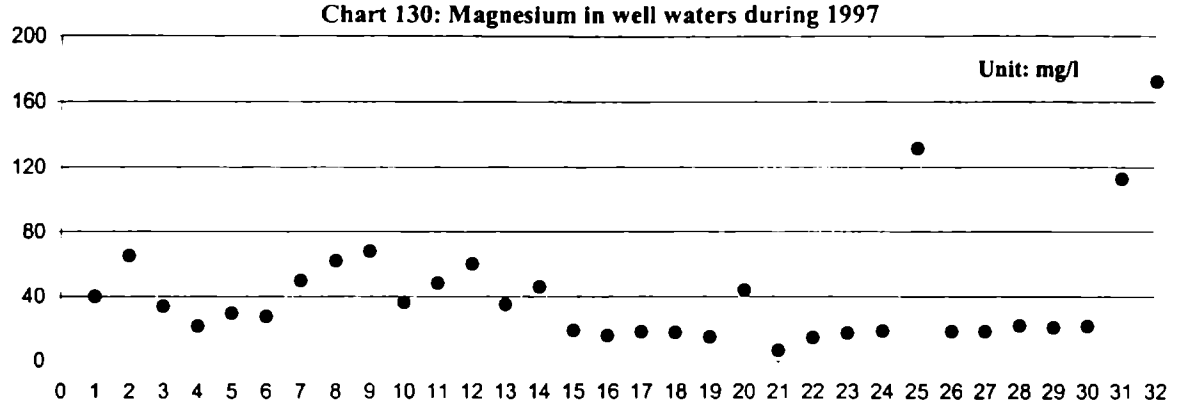


Chart 131: Magnesium in well water during 1999

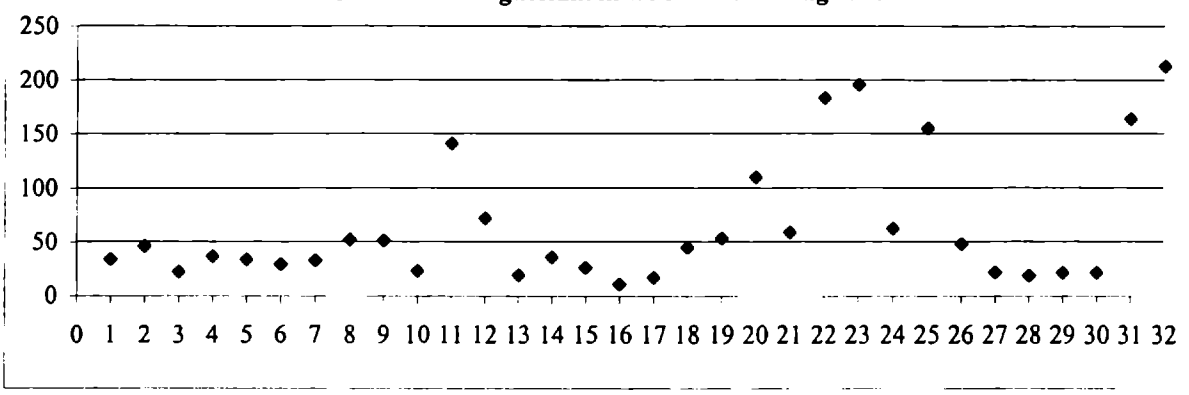


Chart 132: Magnesium in well waters during 2000

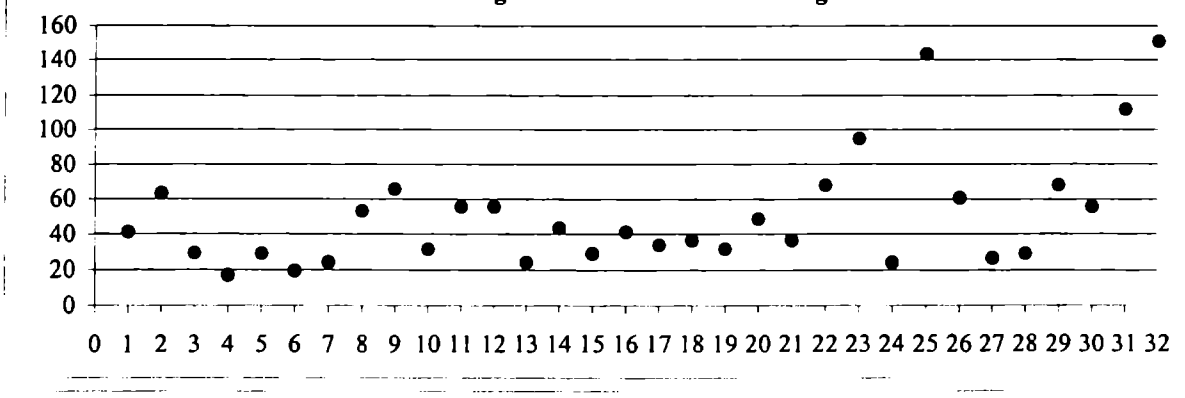


Chart 133: Magnesium in well waters during 2001

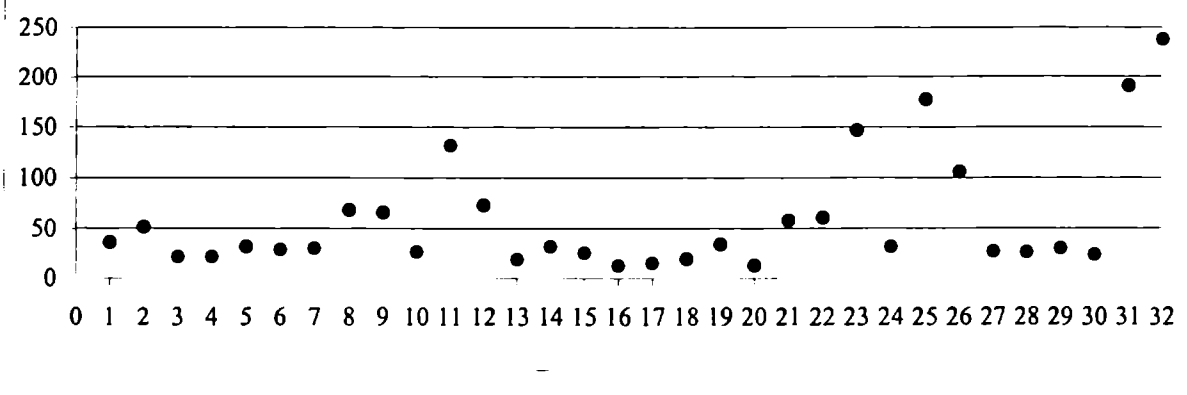


Chart 134: Nitrite-nitrogen in well waters during 1997

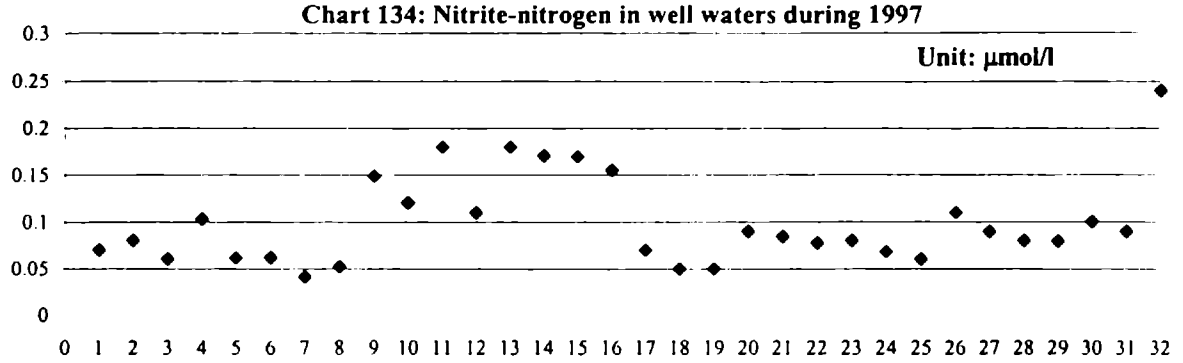


Chart 135: Nitrite-nitrogen in well waters during 1999

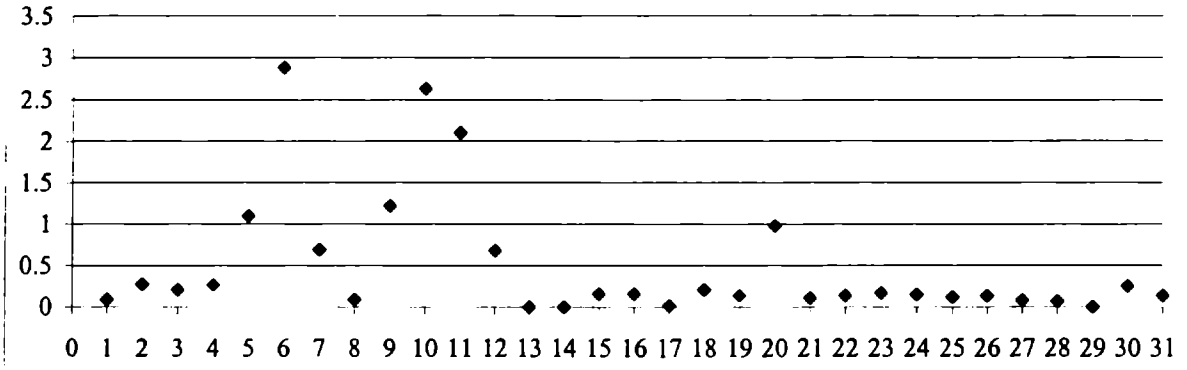


Chart 136: Nitrite-nitrogen in well waters during 2000

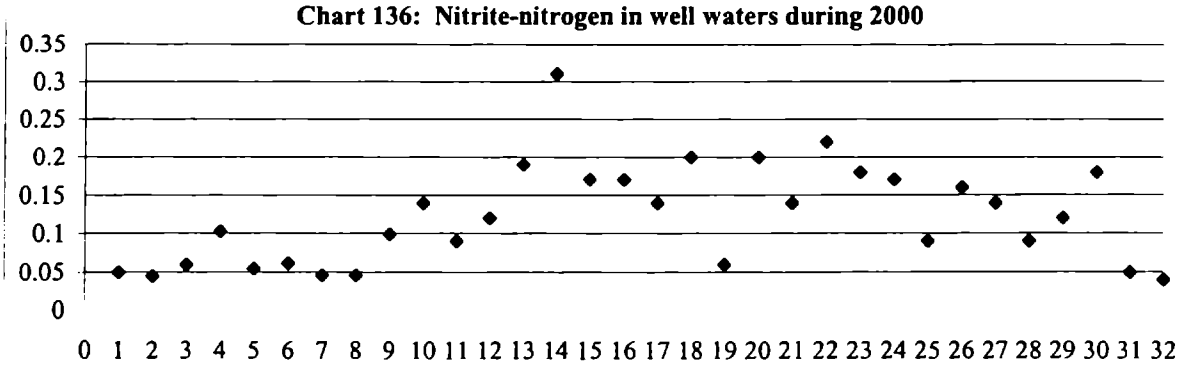


Chart 137: Nitrite nitrogen in well waters during 2001

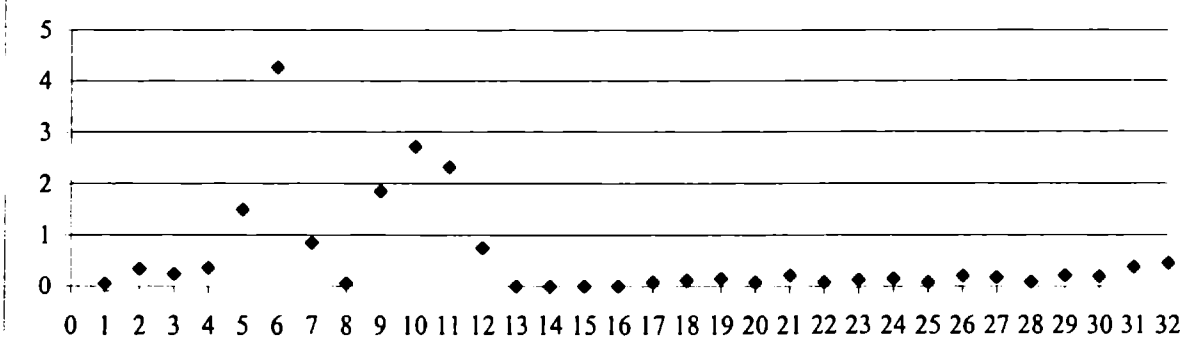


Chart 138: Nitrate nitrogen in well waters during 1997

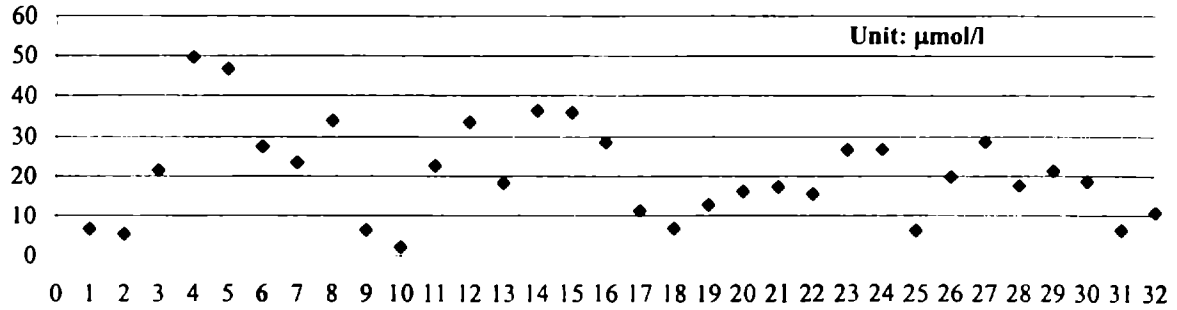


Chart 139: Nitrate nitrogen in well waters during 1999

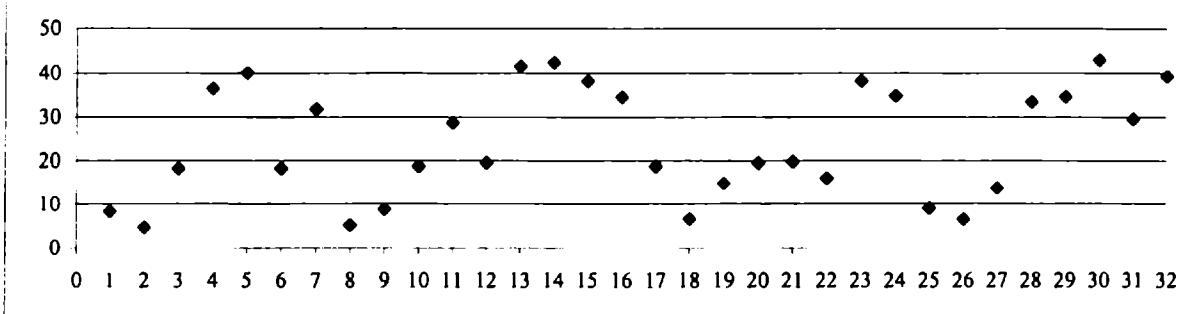


Chart 140: Nitrate nitrogen in well waters during 2000

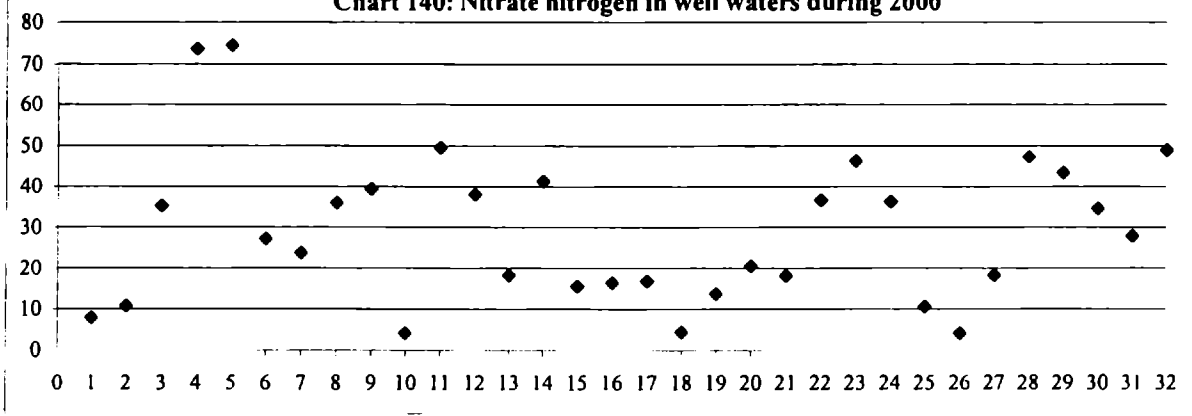


Chart 141: Nitrate nitrogen in well waters during 2001

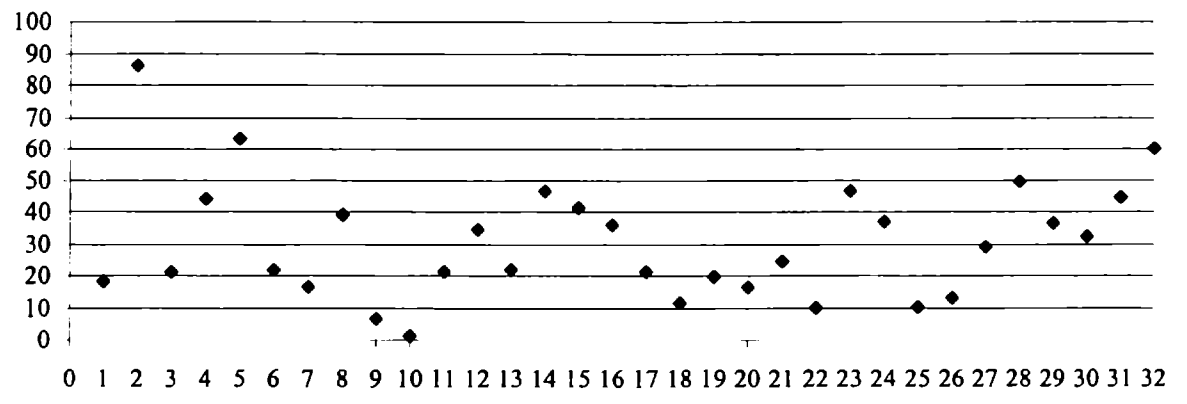


Chart 142: Fluoride content in well waters during 1997

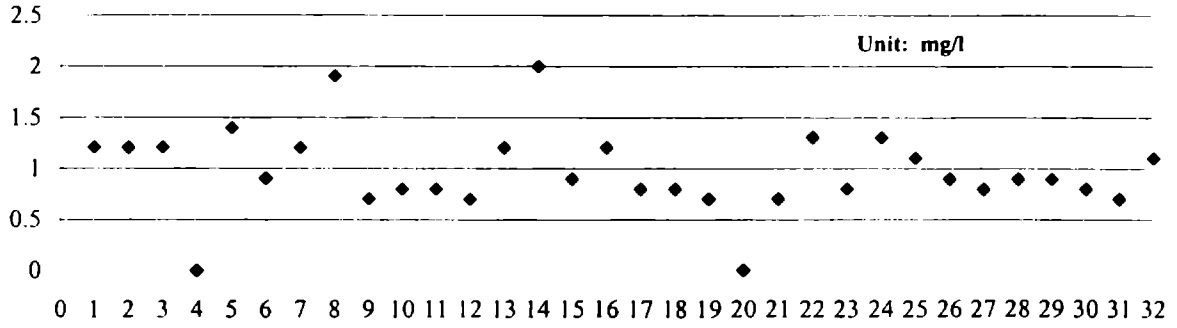


Chart 143: Fluoride content in well waters during 1999

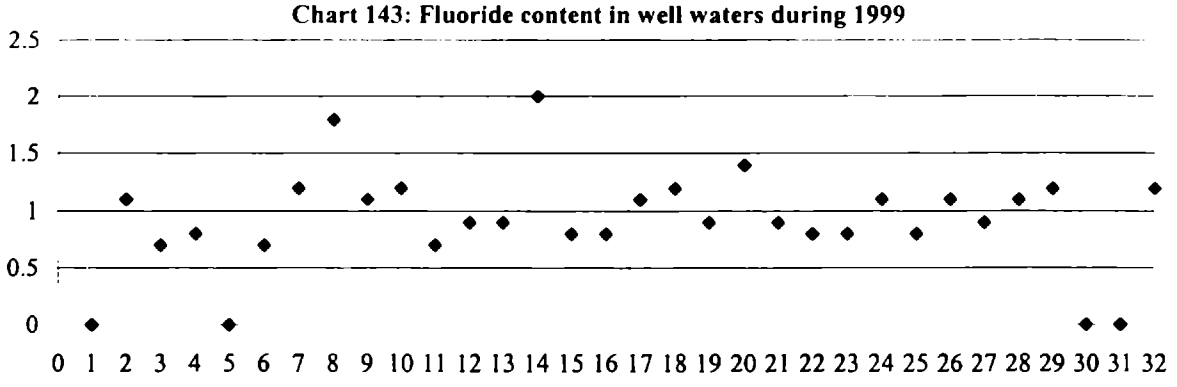


Chart 144: Fluoride content in well waters during 2000

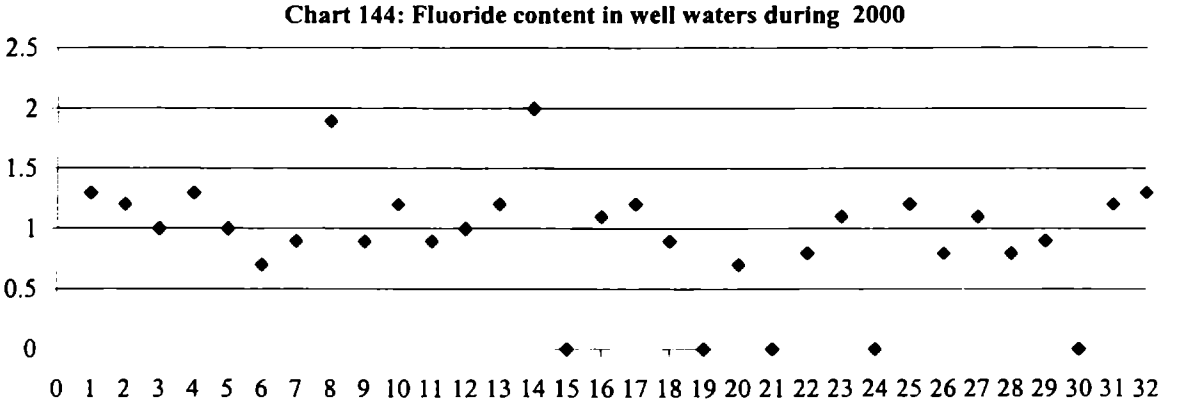


Chart 145: Fluoride content in well waters during 2001

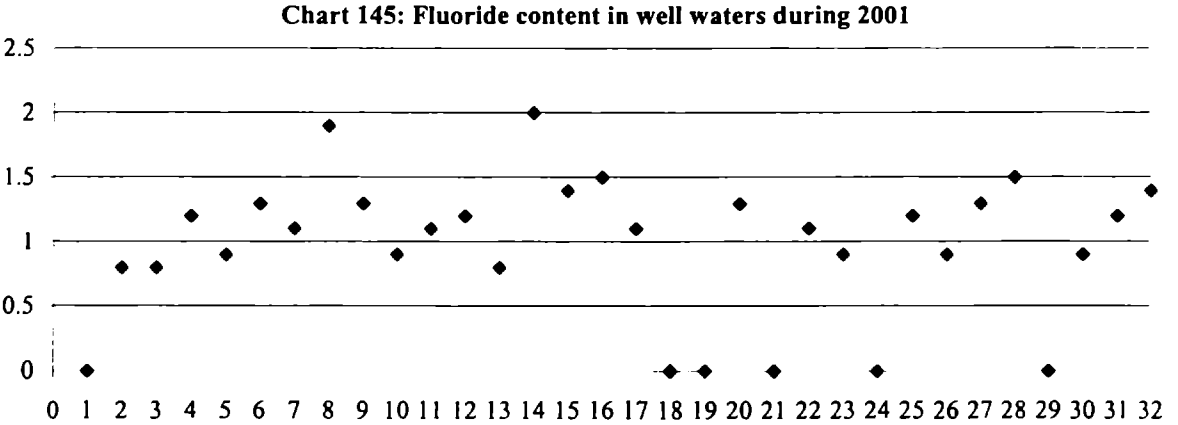


Chart 146. Sulphate in well waters during 1997

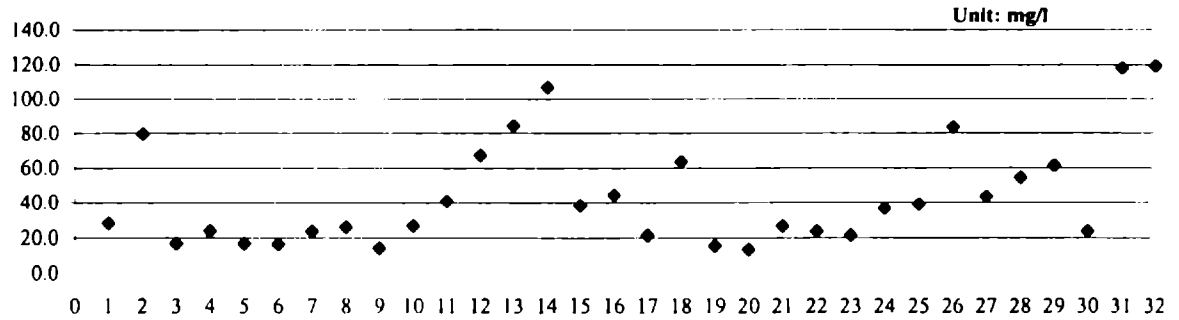


Chart 147. Sulphate in well waters during 1999

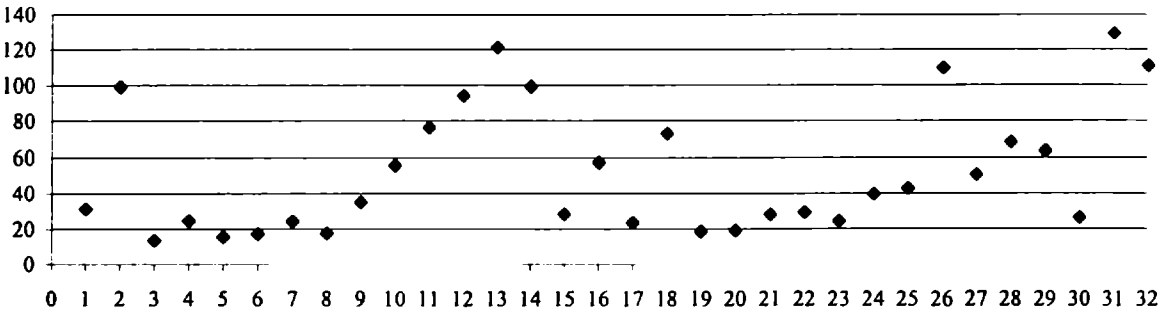


Chart 148. Sulphate in well waters during 2000

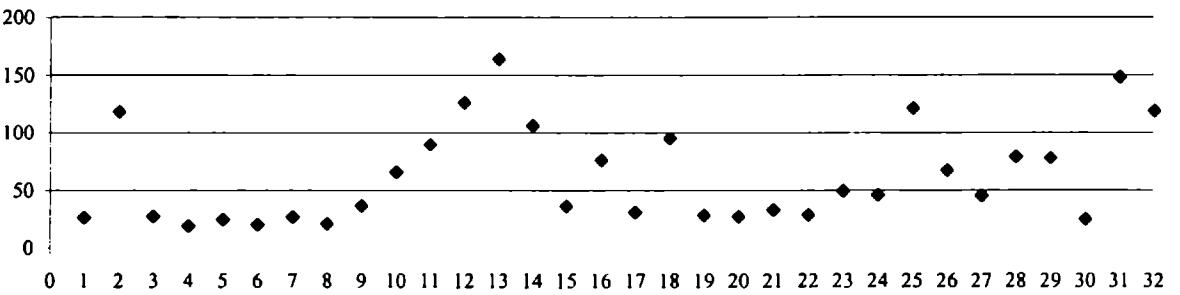
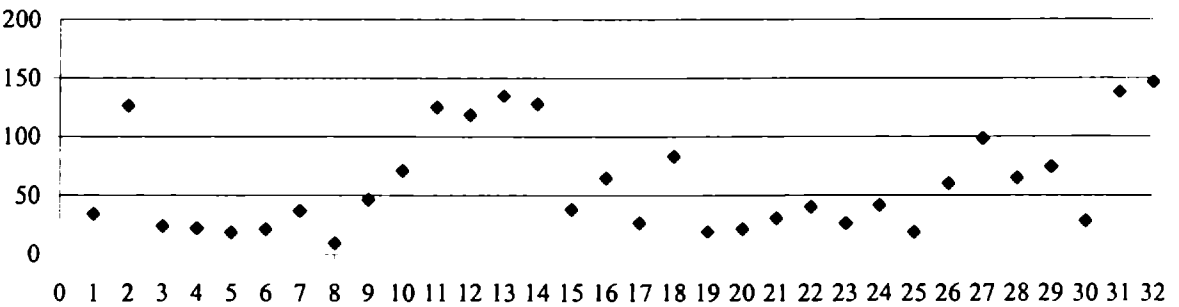


Chart 149. Sulphate in well waters during 2001



4. MAJOR CONCLUSIONS AND RECOMMENDATIONS

This integrated study on coastal and ground water pollution in Kavaratti Island, Lakshadweep sea comprising microbiological, physico-chemical and biological characteristics has the following highlights. The study established a pre-requisite for any pertinent work in the Lakshadweep Sea on microbial status, nutrient dynamics, status of dissolved heavy metals and biological productivity. A systematic analysis on well water quality in terms of bacteriological and physico-chemical variables elucidates the status, source and seasonal variation of well water contaminants. The quantum of data would be useful for any management action plan, which is required to implement in the coral ecosystem.

Marine pollution

Study on water quality highlights that the heterotrophic bacterial population in coastal waters of Kavaratti has considerably increased over the years. The increase in heterotrophic activity can be attributed to the increased input of assimilable organic wastes into the coastal Seas. As the organic nature of the water reduces the overall primary productivity, this will directly affect the very basic sustenance of corals and thus the existence of islands. The sharp increase in the counts of coliforms and faecal coliforms in the lagoon, especially during monsoon is well above the standard limits prescribed for recreational purpose. This has to be accounted in pursuing bathing, contact water sports and other programmes related to tourism promotion in the lagoon of Kavaratti island. *Salmonella* like organisms, *Shigella* like organisms and *Proteus* and *Klebsiella* like organisms isolated in the lagoonal waters of Kavaratti clearly prove the faecal contamination of the coastal waters. Faecal streptococci, an indicator of faecal

contamination were also present in the lagoon in large numbers, irrespective of the season.

Organisms like *Vibrio cholera*, *V.parahaemolyticus* and *Pseudomonas aeruginosa* in large numbers in the lagoon also depict the extent of faecal contamination in the lagoonal waters. The high counts of *V.cholera* like organisms cautions the chances of their occurrence in fish, especially from the lagoon from where fishing is prevalent. The increased count of potential pathogens also cautions the chances of their infiltration into the nearby dug wells. Open defecation, in view of ever increasing faecal contamination of seawater, along the banks of the island has to be strictly prohibited.

The study on bacterial population proved that over the years there is an increased contamination in the nearshore region of Kavaratti, which is a threat to the Island as well as its inhabitants. The pollution, however, is found confined mostly to nearshore region. This information makes the research work more important from the point of societal problems and its management. Based on the data available it is found essential to set up a sewage treatment plant for the Island and dispose the contaminants at an offshore distance in the sea by pipeline.

Physico-chemical characteristics showed that water temperature varied from 29 to 31.5°C inside the lagoon and 27.5 to 31°C in the open sea, which indicate that though the fluctuation between stations is narrow, there was a slight increase from 1997 to 2001 period. The increase is particularly significant that the corals are very sensitive to rise in temperature, which causes leaching of corals.

High amounts of suspended solids recorded during the end of monsoon in the nearshore region of lighthouse during the year 2000 was due to the coir retting activities prevalent then. This has reduced the dissolved oxygen content in the water, which has a direct influence in the overall productivity. Strict adherence to the marine pollution prevention laws should be ensured to limit activities like coir retting along nearshore that may affect the coastal productivity and the local fishery potential.

The overall dissolved oxygen (3.3-5.2 mg/l) in the nearshore region does not depict a healthy picture in general, though there was a slight increase (5.2 mg/l) during May 2001 while the inorganic phosphate concentration in the lagoon was considerably low (0.84-1.60 μmol/l) than seaside transects (0.31-3.53 μmol/l) and this could be attributed to the active uptake of benthic algae. The total phosphorous in the lagoon show that the phosphorous is organic bound rather than in dissolved form. Though the results of nitrite nitrogen, nitrate nitrogen and ammonia do not show any temporal or spatial pattern, the distribution reveals that nitrification is predominant than de-nitrification and there occurs phytoplankton blooms at certain period in Lakshadweep Sea. Comparatively higher values of ammonia observed in the lagoon are due to the disposal of anthropogenic wastes. Higher BOD values recorded in the nearshore stations could be attributed to the disposal of domestic and sewage wastes.

The PHC concentration and dissolved trace metals did not show wide fluctuation among the transects. The dissolved trace metal content observed in the study period were well below the reported values elsewhere.

Low productivity and plankton diversity recorded in the nearshore of Lighthouse in August 2000 reveals the impact of coir retting. The major genera of phytoplankton isolated from the Lakshadweep Sea include *Coscinodiscus*, *Rhizosolenia* and *Trichodesmium*. Comparatively lesser primary productivity, phytoplankton and chlorophyll pigment were noticed in the lagoon. This may be due to non-availability of inorganic nutrients. The zooplankton density and biomass did not vary considerably either spatially or temporally between lagoon and open Sea. The biomass and density in lagoon varied respectively from 0.21 to 0.52 ml/m^3 and 351 to 565 no/m^3, while it fluctuated from 0.12 to 0.92 ml/m^3 to 248 to 954 no/m^3 in the Sea. This indicates that in lagoon, zooplankton production is not wholly dependent on phytoplankton community, but organic detritus and particulate organic matter as well. The overall productivity and plankton density in the Sea showed a slight increase during 2000 and 2001.

The open disposal of organic waste that lead to the enhanced growth of benthic algae which in turn decrease the phytoplankton count, has to be controlled for maintenance of lagoon's fishery potential.

Ground water pollution

Study on the well water samples of the Island has brought out evidence on the frequent occurrence of potential pathogenic microbes in the drinking water sources. It reveals that the counts of potential pathogens have reached up to alarming levels.

The well water quality monitored during the period 1997-2001 clearly reveals that the count of total heterotrophic organisms, TVC, is very high, which is an indication of the increased seepage of waste waster into the fresh water lens. Though, TVC is not generally considered under quality parameters, its high count is not desirable in drinking water.

The enteric group of bacteria, that cause four out of five common water borne diseases, are found prevalent in the dug wells of Kavaratti. The results showed that the coliform contamination is present in almost all the well waters covering all seasons. Their occurrence even in deep tube well reveals the severity of contamination. The possible reason attributed to the increased faecal contamination is the seepage through unplastered walls of the septic tanks/leach pits in to the dug wells. Occurrence of entero pathogenic *E.coli* in more than 50 % of the wells is an alarming case of drinking water pollution. This is particularly significant in terms of the population increase that the chance of causing epidemics is accelerated. The potential pathogens such as *Salmonella* like organisms, though a variety of species of them could be the natural inhabitants, found in large numbers also proves the faecal contamination. Occurrence of this potential pathogens causing typhoid requires special attention.

Shigella like organisms causing *Shigella* dysentery, *Proteus* and *Klebsiella* like organisms causing opportunistic infections also reveals the extent of water pollution. *Vibrio cholera* like organisms causing cholera and *V. parahaemolyticus* like organisms causing food poisoning also warrants thorough disinfection of the fresh water before use.

The physico-chemical analysis reveals that the water temperature fluctuated within a very narrow range (27-29.5°C), which does not show temporal variation. The pH values are with in the BIS desirable limit prescribed for drinking water and generally falls between 7.0-8.5 range. The conductivity values record sharp fluctuation and at many times, the values are found crossing even the permissible barrier. The values were found increasing at certain pockets and could be easily identified as a result of seawater intrusion due to overdraft. The study reveals that out of thirty dug wells, 7 wells in 1997, 16 wells in 1999, 3 wells in 2000 and 11 wells in 2001 showed conductivity values above the desirable limit. Many cases of very high values exceeding the permissible barrier (3000 μmhos/cm), fixed for the case of absence of alternate source, is also seen at many places. When there was no well water that showed values above 3000 μmhos/cm in 1997, 4 wells in 1999 and one well each in 2000 and 2001 showed values above 3000 μmhos/cm. The wells that showed conductivity above the elevated limit is the result of localized overdraft caused by continuous and multiple pumping. Chloride values also clearly reveals overdraft from 1999 onwards. This point put that in order to sustain the vulnerable water lens, both qualitatively and quantitatively; it is high time to evolve strict control measures for the withdrawal of fresh water.

The dissolved solids in the fresh water clearly reveal that out of 30 wells; 24 in 1997; 25 in 1999; 12 in 2000 and 22 in 2001, showed TDS above the desirable limit. This is a clear indication of seawater intrusion. The results, thus, highlights the need for controlled exploitation of this fragile resource that would otherwise become a lens mixed with seawater.

Alkalinity values clearly indicate that the well waters of the island are generally alkaline in nature. Though this is expected from the soil nature of the island, the trend show that over the years, alkalinity is increasing and the values could be easily traced as cases of overdraft. There is a clear increase also in the hardness values over the period of years crossing even the permissible limit. Calcium and magnesium hardness also showed that the quality of wells over the period of 4 years has deteriorated to a large extend and the seawater intrusion is found accelerated by four fold over the four years period.

Fluoride content in the well water were in the range of nil to 1.8 mg/l. Though the upper range is slightly above the permissible limit (1.5 mg/l), general trend shows that fluoride contamination is not severe and water treatment in this direction, as of now, is not required. Nitrite, nitrate and sulphate content are also within the presented standards. This may be due to the decreased utilization of chemical fertilizers.

The general appreciation of the analysis of the tube well water suggests that its quality is beyond the potable standards. This indicates that tube wells cannot be used as fresh water sources in the island and that drilling of tube wells may add to the salinity of the fresh water lens.

Thus the urgent management programme envisaged for the enhancement of water quality is the treatment of domestic sewage. The sewage has to be isolated to one end of the island and disposed off to a distant place at Sea after treatment. The seawater infiltration due to overdraft warrants the requirement to enforce the desirable limit and mode of withdrawal of fresh water. The quantity of ground water that can be withdrawn is to be stipulated and the mechanized mode has to be strictly regulated.

Appropriate technology and engineering has to be used to supply water even in the minimum essential quality and quantity and new standards have to be set up. Increased attention has to be given to institutional development for awareness, community participation and management, particularly regards to women. Charting out water and sanitation problems directed at low cost household technologies which may include science with commonsense for the public is essential. An extension water supply training centre fully equipped with laboratories must be set up immediately at Kavaratti. The system at present working at Kavaratti regards to drinking water management has to be equipped with modern bacteriological methods.

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Slide 1: Onboard sampling at Lighthouse transect

Slide 2: Recording GPS position at Lighthouse transect, Kavaratti

Slide 3: Collecting water samples for physico-chemical analysis, Kavaratti

Slide 4: Zooplankton collection at nearshore off Helipad transect, Kavaratti

Slide 5: *In-situ* measurement of physico-chemical parameters at Sea, Kavaratti

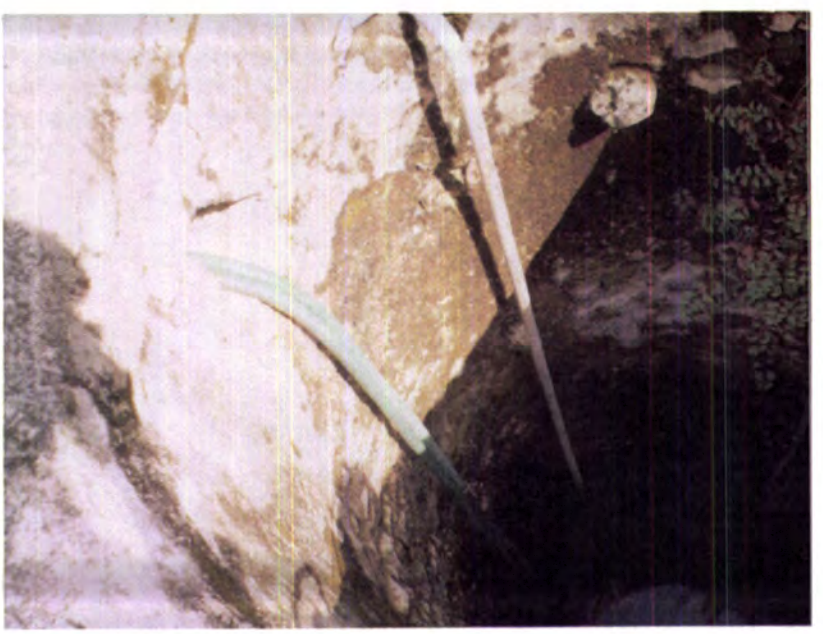
Slide 6: Coir pith being dumped at nearshore of Kavaratti

Slide 7: Intense discolouration of the nearshore seawater of Kavaratti Lighthouse transect due to coconut husk retting

Slide 8: A view of organic waste deposition along the nearshore, Kavaratti lagoon

Slide 9: Water table measurement along with sample collection, Kavaratti

Slide 10: *Insitu* measurement of physico-chemical parameters of well water, Kavaratti



Slide 11: Dug well showing multiple pumping, Kavaratti island

Slide 12: Single dug well with 6 pumps, opposite to Staff Canteen, Kavaratti

Slide 13: Dug well surrounded by garbage, Kavaratti

Slide 14: Enumeration of bacteria in progress at PWD (Civil) Lab, Kavaratti

Slide 15: Chlorophyll filtration in progress, Kavaratti

Slide 16: View of corals during low tide period, Kavaratti

LIST OF PUBLICATIONS

In connection with the thesis, the following research papers are published:

1. Ouseph .P.P, Anilkumar. N.C, **Madhusoodanan Pillai** and Satheesh Kumar C.S, (1998), Semi diurnal distribution of water quality and microbial population of Minicoy lagoon, Lakshadweep. Proceedings of the Tenth Kerala Science Congress, pp. 55-56.

2. **Madhusoodanan Pillai G**, Bijumon K.B and Ouseph P.P (1999), Assessment of Chemical and Bacteriological quality of drinking water in Kadamat Island, Lakshadweep, Proceedings of the Eleventh Kerala Congress, pp.1-4.

3. **Madhusoodanan Pillai G**, Anilkumar N.C, Bijumon K.B and Ouseph P.P (1999), Impact of lagoonal systems on anthropogenic microbial pollution-A case study from Andrott and Kalpeni islands of Lakshadweep, India. In: *Emerging Trends in Environmental Science*, by C.S.P Iyer (Ed.), Asiatech pub, Inc. New Delhi, pp.142-148.

4. **Madhusoodanan Pillai G**, Walter C S, Raviendren R and Ouseph P.P, (2001), Investigation on the tidal influence of ground water quality in Kavaratti, Lakshadweep Islands - A bacteriological perspective, Proceedings of the Thirteenth Kerala Congress, pp. 21-23.

5. **Madhusoodanan Pillai, G.** & Ouseph, P.P. (2000), Water Quality management in wells-A case study. Proceedings of the XII Kerala Science Congress pp. 17-22.