ASSESSMENT OF SOME SELECTED NUTRIENT PROFILE IN RIVER CHITRAPUZHA

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CERTIFICATE

This is to certify that the Thesis bound herewith is an authentic record of the research carried out by Sri. Babu Jose .P., M. Phil., under my supervision and guidance in the School of Environmental Studies, in partial fulfilment of the requirements for the Ph. D. degree of Cochin University of Science and Technology and no part thereof has been presented before for any other degree in any University.

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ABBREVIATIONS

^{0}C : degree celsius

cm : centimeter(s)

DO : dissolved oxygen

Eh : redox potential

l : litre(s)

m meter(s)

mg : milli gram = 10^{-3} g

mg l^{-1} : milli gram per litre

mg at l^{-1} : milli gram atoms per litre

μg : micro gram = 10^{-6} g

μg l^{-1} : micro gram per litre

μg at l^{-1} : micro gram atoms per litre

μg NO_3^- N l^{-1} : micro gram nitrate - nitrogen per litre

μg NO_2^- N l^{-1} : micro gram nitrite - nitrogen per litre

μg NH_3 N l^{-1} : micro gram ammonia - nitrogen per litre

μg PO_4^{3-} P l^{-1} : micro gram phosphate - phosphorus per litre

CHAPTER - I

INTRODUCTION

1.1. Chemical Reactivity of Estuaries

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1.3. Nutrients in Cochin Estuary

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Industrial effluents are the major sources of water pollutants and the disposal of these effluents without affecting the biota of the surrounding system has become a serious concern of the day. Balancing human demands on the environment with the overall welfare of the biosphere is one of our greatest challenges. The limits of use and abuse of fresh water rivers and estuaries which supply fresh water to and receive effluents from most of the industries are determined by many biogeochemical processes which can affect the quality of water.

Estuaries play a significant role in the natural life cycle of some aquatic organisms and recently they are recognised as areas of industrial, commercial and recreational activities. Even though the development of estuaries has contributed to considerable economic development and social changes, it has also caused severe environmental problems. While a few estuaries have been able to assimilate the pollution load depending on factors like rate of mixing, flushing time and nature of pollutant, many other estuaries are in danger all over the world due to indiscriminate exploitation of the nature by man.

Cochin estuary is a semi-enclosed coastal body of water which has free access with open sea and with in which the sea water is measurably diluted with fresh water derived from land drainage and hence in full agreement with the definition of Pritchard (1967) . The argument of Fairbridge (1980) that the tidally influenced freshwater region should be considered as integral part of any estuary is also applicable to Cochin estuary which includes the backwater and the lower reaches of a number of rivers. A number of earlier workers (Haridas *et. al.*, 1973; Balakrishnan and Shynamma, 1976; Lakshmanan *et. al.*, 1987, Nambisan *et. al.*, 1987; Anirudhan, 1988; Nair *et. al.*, 1993) have classified the Cochin estuary as a positive one.

Several man made changes have occurred in this ecological system in recent years which affect the hydrographical parameters of the estuary. The construction of Thannirmukkam bund led to the deterioration and stagnation of water in the agricultural Kuttanadu region resulting in large changes in the quality of Cochin backwaters. The inter- basin transfer of water from river Periyar to river Muvattupuzha caused changes in the pattern of water flow resulting in new management problems.

The Cochin estuary is subjected to increasing human interferences and it receives considerable amount of pollutants from industrial units, domestic sewage, fishery industries, coconut husk retting yards and the Cochin sea port which handles large quantities of petroleum products and industrial chemicals. The influence of industrial effluents on the general hydrography of Cochin estuary is high and it deteriorates the quality of water by loading with large quantities of pollutants which often exceeds the carrying capacity of the aquatic system causing complete destruction of the biota. Complaints of massive fish kills and associated problems are common in some parts of Cochin estuary.

1.1. Chemical Reactivity of Estuaries

The Chemistry of estuaries should be considered along with physical processes like water circulation and mixing which can control the distribution of dissolved and particulate substances (Aston, 1978). The interaction between processes arising from river discharge on one side and the tidal current on the other leads to estuary circulation (Officer, 1976; and Bowden, 1980) . When the river discharge is dominant, the fresh water flows out of the estuary forming a surface layer above an nutrients arrive through rivers, ground water and the atmosphere. Nutrient fluxes through these routes have been increased by human activity. In areas where upwelling is prominent, it also contribute in bringing nutrient rich water to the surface from the deeper layers. In all these cases, the impacts arising from the inputs of these nutrients are felt where there is restricted water exchange. Elsewhere, the nutrient fluxes through the coastal zone appear to be dominated by large inputs from the open occean and there is little evidence of anthropogenic pertarbation. (Jickells, 1998). In estuaries where the water exchange is restricted the fate of this nutrients depends on many physical, geochemical and biological processes promoting a possible variation in the ratio of inorganic nitrogen and phosphorus with space and time.

Estuaries are regarded as one of the most productive aquatic systems and the nutrient supply from fresh water inputs is important in sustaining high rates of primary production. Estuaries function as important sinks and transformers of nutrients, and they can change the quantity and quality of nutrients transported from land to sea (Jordan *et. al.*, 1991).

The productivity of a given estuary depends mainly on two conditions viz., the riverine or marine supply of fresh nitrogenous compounds and the effective regeneration on a rapid time scale. The assimilation of inorganic nitrogen compounds by primary producers cause a decrease in inorganic forms by converting them into dissolved and particulate organic forms. The particulate organic forms are usually transported in suspension and are ultimately remineralised or settled at the bottom as sediment (Rhoads *et. al.*, 1975; Nixon and Pilson, 1983). The release of nitrogen compounds from estuarine sediments may be a possible source of nutrients in the overlying waters (Hartwig, 1976).

A number of estuaries receive nutrient additions over 1000 times than the fertilizer loads added to agricultural area (Nixon *et. al.*, 1986). The resulting nitrogen and phosphorus inputs lead to elevated phytoplankton productivity (Ryther and Dunston, 1971; Nixon and Pilson, 1983) which in turn can lead to eutrophication. There has been an increase in recent years in the rates of eutrophication of rivers, lakes and estuaries due to the release of nitrates and phosphates from excess fertilizers and sewage effluents (O' Neill, 1985).

The distribution and variation of nutrients in estuarine systems are controlled by varied of physical, geological, chemical and biological processes (Aston, 1980; Pritchard and Schubel, 1981) A successful understanding of the role of estuaries as nutrient traps, filters and exporters require a knowledge of the distribution of nutrients as well as their rates of input, loss and accumulation in coastal waters. The point source inputs from rivers and sewage treatment plants into a number of aquatic systems have been assessed (Loder and Gillert, 1980; Jaworski, 1981; Nixon and Pilson , 1983 ; Childers and Day, 1988). The more spatially variable inputs from surface runoff, ground water sepage, offshore waters and precipitation are much more difficult to quantify.

The variability of nutrient behaviour during mixing changes from one estuary to another depending on the environmental conditions. Some estuaries in which the nutrient concentrations depend only on physical processes of mixing and dilution, project a conservative behaviour and are independent of biogeochemical processes (Imberger *et. al.*, 1983) Some other estuaries show non conservative behaviour where the nutrient concentrations depend on both the physical processes and biogeochemical reactions (Peterson *et. al.*, 1975 & Hobbie *et. al.*, 1975). From nutrient salinity correlation studies Sharp (1983) suggested that low nutrient estuaries show essentially conservative mixing while high nutrient estuaries show variations from conservative to non conservative mixing.

Non conservative behaviour of dissolved nutrients in estuaries which can be attributed primarily to biological production and degradation processes has been reported (Peterson *et. al.*, 1975; Hobbie *et. al.*, 1975 ; Wollast, 1978) Nevertheless there is enough evidence to prove that non biological reactions may also contribute to the control of nutrient distribution in estuaries (Carritt & Goodgal , 1954; Jitts, 1959; Pomeroy *et. al.*, 1965; Burns & Salomon 1969; Butler & Tibbits, 1972; Sholkovitz, 1976; Morris *et. al.*, 1981).

The important form of nitrogen involved in the biogeochemical processes in estuaries are the water soluble inorganic species like nitrate, nitrite, and ammonia. In well oxygenated water body, the most abundant inorganic form of nitrogen is the nitrate which is the most stable of nitrogen species. The conservative behaviour of nitrate has been reported in non urban tropical estuaries by Van Bennekom *et. al.*, (1978) and Fanning & Maynard (1978). Morris *et. al.*, (1981) have reported conservative nutrient behaviour in Tamar estuary . However Mackay and Leatherland (1976) have reported that nitrate frequently behaves in a non conservative manner in Clyde (Scotland) estuary. Desousa *et. al.*, (1981) have also reported similar non conservative nitrate behaviour in Mandovi estuary . Ammoniacal nitrogen can be the next most abundant form of inorganic nitrogen in surface waters where a greater part of nitrate nitrogen has been removed by phytoplankton growth. The non conservative behaviour of ammonia in Potomac river estuary has been reported by Jaworski (1981).

Phosphorus is a major nutrient regulating the growth and production of phytoplankton. and its concentration helps to predict the total biomass of phytoplankton. The most important form of phosphorus involved in the biogeochemical processes in estuaries is the phosphates we find in various dissolution, precipitation, adsorption, desorption processes. Estuarine sediments are generally rich in phosphorus which may be liberated to overlying waters under favourable conditions. The reverse process of precipitation is also common under suitable conditions and hence the hydrographical conditions have important effect on the productivity of these waters. The precipitation and regeneration of phosphorus from sediments into the aquatic system results in marked difference in concentration between interstitial and overlying waters. Mortimer (1971) has reported the diffusion of regenerated phosphorus leading to the enrichment of overlying water.

Industrial effluents, particularly from fertilizer plants contain large quantities of nutrient elements like nitrogen and phosphorus mainly in the form of inorganic salts such as nitrate, nitrite , ammonia, phosphate and related compounds. Wide variation in the concentration of the above compounds in an aquatic system can affect the quality of water and make it harmful to the biota.

Continuous discharge of industrial effluents into an estuary tends to increase the pollutant load in the aquatic system and its excess eventually leads to eutrophication. More attention has been drawn in recent years to the problem of nutrient loading and control of eutrophication. Meybeck (1982) has made his observations & inferences on the source of nutrients, their transport, and the status of eutrophication of some of the major rivers ranging from Mississippi in USA, Solimoes in Brazil, Nile in Egypt to Iton in France. Wahby *et. al.*, (1978) reported the degree of water pollution and probable causes of the decrease in fish production in a polluted lake Maryut in Egypt. Quantitative study of nutrient fractionation and stoichiometric model of the Baltic sea has been reported by Sen Gupta and Koroleff, (1973) and Pastuszak, (1985). The studies on chemical characteristics of estuaries like Hudson, USA (Simpson *et. al.*, 1975); Tamer, UK (Morris *et. al.*, 1981); Mandovi - Zuari, India (Qasim and Sen Gupta, 1981) and Delaware, USA (Sharp *et. al.*, 1982) have been useful in water quality assessment in those aquatic bodies. Biney (1985) has studied the major chemical characteristics of seven estuaries along the gulf of Guinea in Ghana with an aim of providing data on nutrient loading and eutrophication.

1.3 Nutrients in Cochin Estuary

The Cochin estuary, a tropical estuary with a a chain of shallow brackish water lagoons and swamps, is rich in aquatic life. The major sources of freshwater are Periyar a large river in the north, Muvattupuzhayar a small river in the south and Chitrapuzha. A channel, about 450 m wide at Cochin gut, is a permanent link with the Arabian sea which transmits the tidal energy and saline water into the estuary. The barmouth at Azhikode also helps the estuary to interact with the sea, though the influence is only to a lesser extent due to the shallow nature of the channel. Rainfall and fresh water discharge influence the penetration effect of saline water into the estuary. During south west monsoon the estuary is virtually converted into a freshwater basin except in areas around the barmouth.

Considerable amount of work has already been carried out on chemo estuarine variability of nutrients in the Cochin estuary by Qasim and Sankaranaraynan, (1972); Joseph , (1974); Manikoth and Salih, (1974); Rama Raju *et. al.*, (1979); Lakshmanen *et. al.*, (1987); Anirudhan, (1988); Balchand *et. al.*, (1990).

Most of the industries in Cochin are clustered at two centres - one at Eloor on the banks of Periyar and another at Ambalamughal by the side of Chitrapuzha.

A host of industries including a major fertilizer plant, chemical factories, aluminium and zinc production units and a monazite processing plant are crowded along a small stretch of land by the side of Periyar. A cluster of industries including a major fertilizer complex, a petroleum refinery, an organic chemical factory are located at Ambalamughal. Many of these industries have their intake source of freshwater and effluent disposal outlets into the river . Alteration of physico-chemical characteristics of water has been reported by many investigators (Jayapalan *et. al.*, 1976; Paul and Pillai, 1978; Sarala Devi *et. al.*, 1979; Remani *et. al.*, 1980; Sankaranarayanan *et. al.*, 1986; Joy, 1989; Joy *et. al.*, 1990). Occasional instances of fish kill have also been reported (Silas and Pillai, 1976; Shynamma *et. al.*, 1981).

1.4. Scope of the Study

The general hydrographic parameters and the nutrient distribution of Cochin estuary has been influenced by increasing human activities, waste discharges from many industrial establishments and sewage through canals and rivers. Eventhough, there are numerous references on hydrographical features of Cochin estuary in general, very little is known about the physico-chemical parameters and the nutrient concentration profile of river Chitrapuzha.

The present study focuses attention on the various hydrographical parameters and the nutrient chemistry of the lower reaches of Chitrapuzha river which is a part of Cochin estuary. An awareness of the various aspects of the physico-chemical parameters of this estuary is essential for water quality assessment and better estuarine management. Information on the physico-chemical processes in Chitrapuzha river is quite significant since it carries effluents from some major industries including fertilizer plants. The quantity of effluents discharged from these industries into Chitrpuzha river is estimated to be around 80 million litres per day. There are longstanding local complaints about water pollution causing fish kills and serious damage to paddy and other agricultural crops contributing to extensive unemployment in the area. Prawn farming is yet another area that may be adversely affected by the variation in the physico-chemical parameters of water in Chitrapuzha river. In addition to the above socio economic aspects it has a commercial dimension too, since the lower reaches of Chitrapuzha river is a part of National Waterways.

The overall study of the various hydrographical parameters like temperature, salinity, dissolved oxygen, pH, acidity, alkalinity, redox potential and transparency along with the concentrations of ammonia, nitrite, nitrate and phosphate would help in understanding the extent of water pollution and the potential availability of life supporting elements, since the concentration and distribution of nutrients have a dominant role in the productivity of the aquatic system.

The investigation was planned with the objective of studying the estuarine nutrient behaviour along with the general hydrography. The studies were mainly directed at identifying the sources, dynamics and sinks of nutrients. The amount of nutrients entering the estuary is very large and its fate is relevant to water quality management. This is an attempt to study the distributional variability of hydrochemical parameters with special reference to the concentration profile of some selected nutrients, in river Chitrapuzha.

1.5. Scheme of the work.

The work incorporated in this thesis deals with the systematic study of hydrographical parameters along with concentrations of nitrate, nitrite, ammonia and phosphate. Monthly collections were made from nine stations over a period of 16 months starting from a post-monsoon period and extending to pre-monsoon, monsoon and again next post-monsoon period.

The work is presented in six chapters. Chapter one gives an introduction of the subject and spells out the aims and scope of the present study. Chapter two gives the details of the area under investigation and information on sampling procedures and the various techniques employed in the analysis of the different constituents.

Chapter three presents the hydrographical parameters like temperature, salinity, dissolved oxygen, pH, acidity, alkalinity, redox potential and transparency. Seasonal, and spatial variations of these parameters and their interrelationship are investigated and discussed..

Chapter four is devoted to the studies of the dissolved inorganic forms of nitrogen in the estuary. Concentration levels of various dissolved nitrogenous nutrients like nitrate, nitrite and ammonia are given. Large variations in the concentrations of these nutrients are explained on the basis of general hydrographic conditions and the influence of discharge of domestic and industrial effluents . Statistical analysis and regression between nitrogenous nutrients and other hydrographic parameters are worked out.

Chapter five deals with the phosphate concentrations in surface and bottom waters. Factors leading to the variation in concentrations are examined in detail. Seasonal and spatial variations are discussed in relation to hydrographical parameters.

An attempt has been made in chapter six, to quantify the influence of the hydrographic parameters and nutrient concentrations on the water quality and to derive a mathematical model of Chitrapuzha. A water quality index has been derived by giving proper emphasis to some selected nutrient concentrations with due weightages to reflect their harmful effects, so that the quality or even the pollution load of different waterbodies can be compared on a numerical scale.

The results and salient features of the studies conducted are summarised, supplemented by a list of references. The values of the various parameters measured are given in tables which are appended at the end while the corresponding figures are incorporated in the text itself.

CHAPTER 2

MATERIALS AND METHODS

2.1. Description of location

2.2. Analytical techniques

2.2.1. Sampling procedure

2.2.2. Methods of analysis

2.1. Location

The Cochin estuarine system (09° 40’- 10° 12’ N; 76° 10’ - 76° 30’ E) is connected to the Arabian Sea through two permanent openings at Cochin and Azhikode and a seasonal opening during monsoon (June to September) period at Anthakaranazhi (Fig. 2.1.1.). The mouth of Cochin bar is 450 m wide maintained at a depth of 10-13 m for navigational purpose and is influenced by tidal flow.

Chitrapuzha and Kadambirapuzha are two rivers drawing water from eastern and south eastern parts of Ernakulam district, of which Chithrapuzha receives effluents from the industrial units at Ambalamughal. Both rivers and several other aqueducts reach Cochin estuary through deepened Chambakkara canal besides the natural route.

The average depth of the rivers and canals does not exceed 5 m but at the confluence with Cochin estuary it is about 10 m.

Samples for salinity, dissolved oxygen, pH, acidity, alkalinity, redox potential, nitrate, nitrite, ammonia and phosphate concentrations are preferred from stations one to nine. (Fig. 2.1.2.)

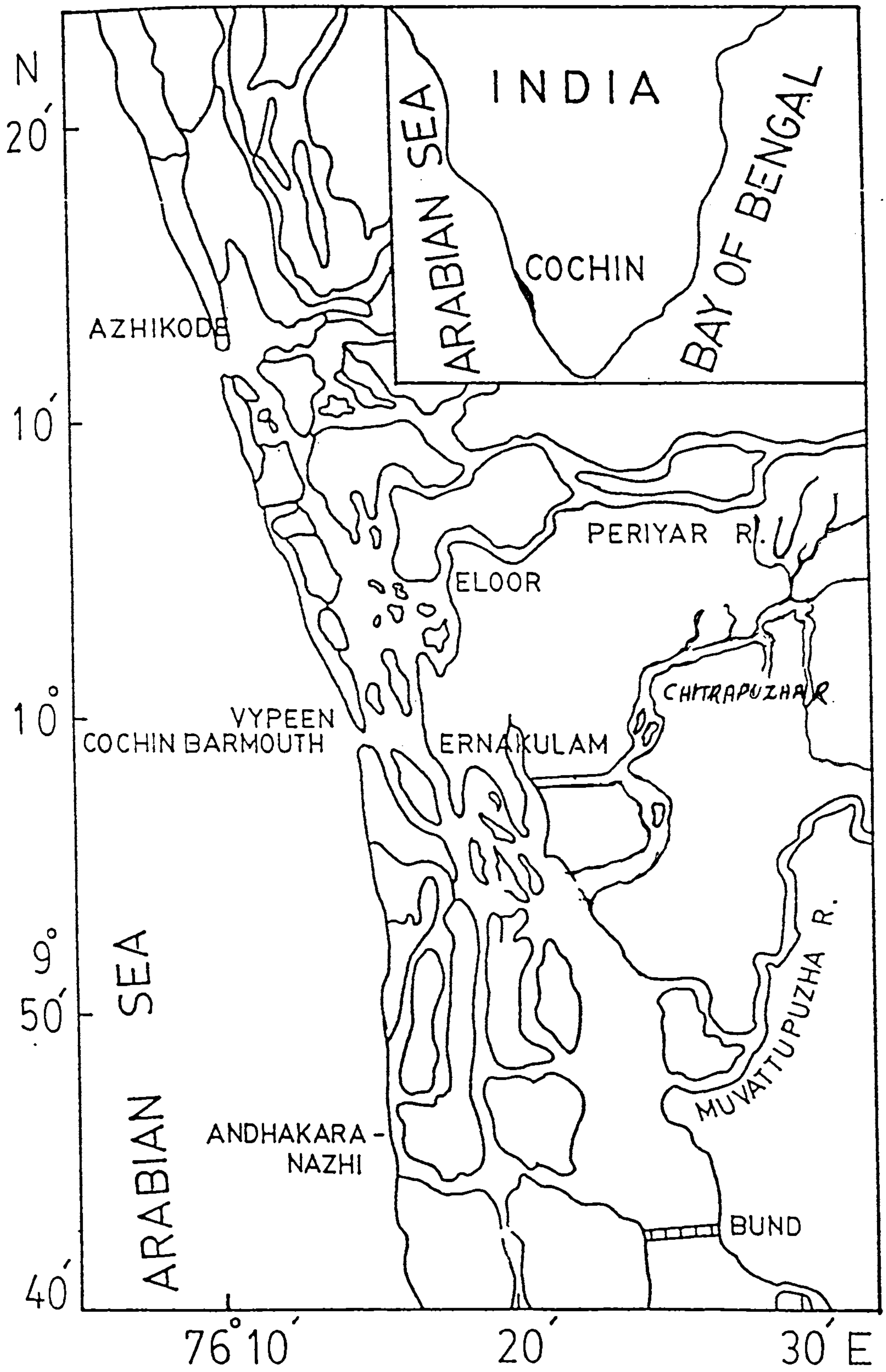


Fig. 2.1.1 Map of Cochin estuary

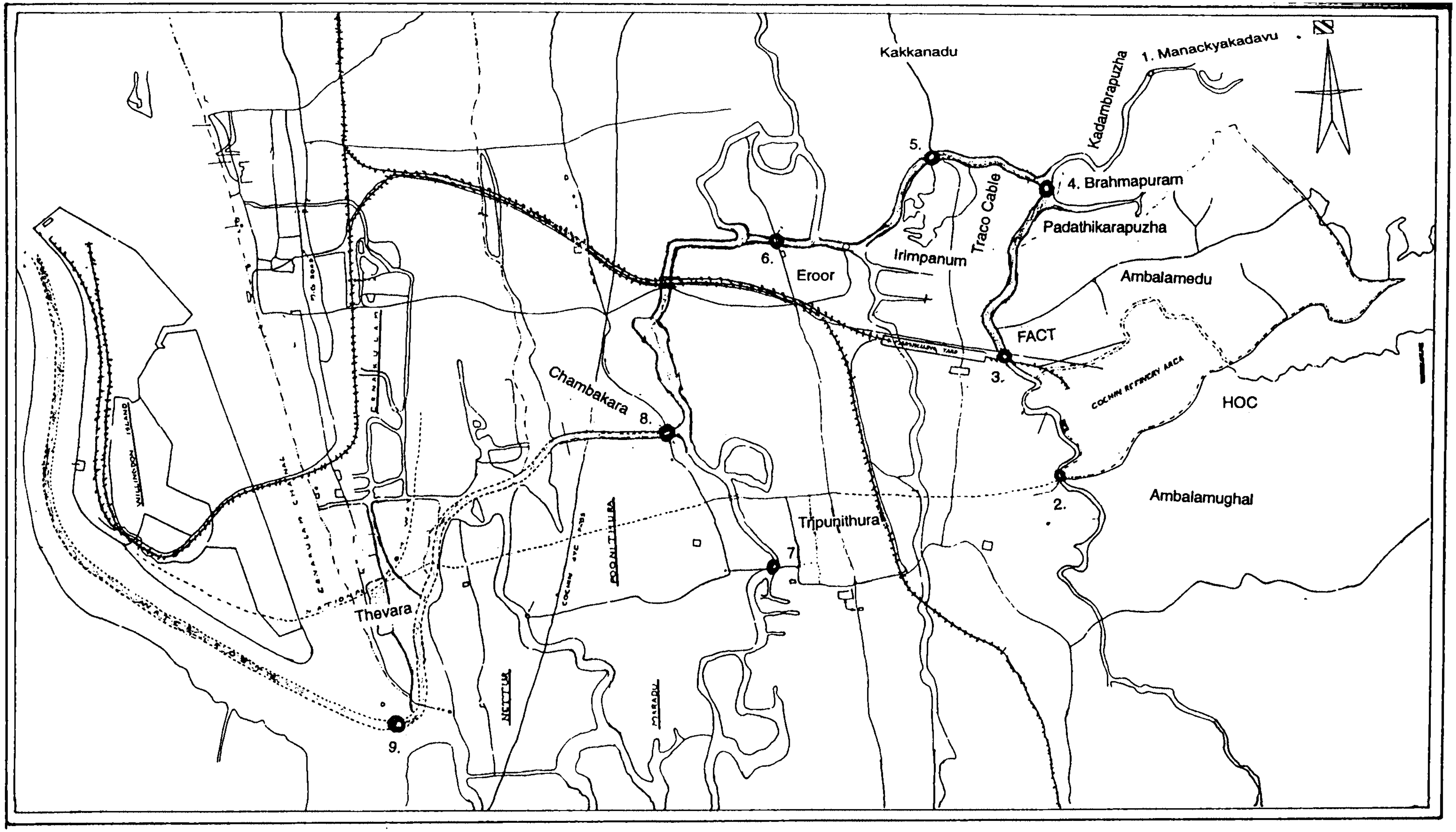


Fig. 2.1.2 Map of river Chitrapuzha showing location of stations

Station one is beyond the influence of industrial pollution and has an average depth of 2.1 m. The intrusion of saline water is prevented by a temporary bund during dry season. Station two is also beyond the influence of industrial pollution, where the average depth is 1.9 m. The intrusion of saline water is prevented by a temporary bund. Station three is near to the outlets from major industries namely Cochin Refineries Ltd., The Hindustan Organic Chemicals Ltd. and Fertilizers and Chemicals Travancore Ltd (Cochin division) and has a depth of 3 m. At station four the effluent ladened water mixes with water drained from agricultural runoff and has a depth of 3.3 m. Stations five, six, eight and nine are distributed in the maintained canal having an average depth of 3.7 m, 4.1 m, 3.7 m and 9 m Respectively. Station seven is situated in natural portion of the river where the depth is 5.5 m.

2.2. Analytical Techniques

2.2.1. Sampling procedures

Surface and bottom water samples from nine stations were collected at monthly intervals using a modified Hytech water sampler, from October 1990 to January 1992. Samples for nutrient analysis were collected and stored in clean one litre polythene bottles at 4° C.

2.2.2. Methods of analysis

The analytical methods employed in the present study are summarised below.

2.2.2.1. Temperature

Temperatures of air and water samples were mesured immediately after collection using mercury in glass thermometer with accuracy ±0.10°C.

2.2.2.2. Salinity

Electrical conductivity of water samples were measured using a conductivity meter - systronics model 304. The instrument was calibrated using standard potassium chloride solution. Salinity of water samples were calculated from corresponding electrical conductivity (Lewis, 1978) as presented in APHA (1989).

2.2.2.3. Dissolved Oxygen

Dissolved oxygen was estimated by modified Winkler method (Grasshoff, 1983) Dissolved oxygen was fixed using manganese sulphate solution and alkale - iodide - azide reagent,immediately after collection of water samples. Fixed samples were carried to the laboratory and dissolved oxygen was estimated on the same day by liberating iodine from potassium iodide in acid medium and titrating the liberated iodine against standard sodium thiosulphate solution using starch indicator and it is expressed in mg l^{-1}

2.2.2.4. potentia Hydrogenii (pH)

pH of the water samples were measured on the same day of collection,after transferring the samples to the laboratory by electrometrically using a pH meter.

2.2.2.5. Acidity

Acidity of water samples collected were measured by titration method on the same day. Both methyl orange acidity ie. upto pH 3.7 and phenolphthalein acidity or total acidity ie.upto pH 8.3 were determined by titrating a known volume of the water samples against standard sodium hydroxide solution using methyl orange and phenolphthalein indicators respectively. Acidity of water samples is expressed as mg calcium carbonate per litre ie.(mg $CaCO_3$ l^{-1}). (APHA, 1989).

2.2.2.6. Alkalinity

Alkalinity of water samples were measured on the same day of sample collection y titrmetric method. Both phenolphthalein alkalinity ie upto pH 8.3 and total alkalinity ie upto pH 3.7 were determined by titrating a known volume of the water sampler against standard hydrochloric acid using phenolphthalein and methyl orange indicators respectively. Alkalinity is expressed as mg. calcium carbonate per litre. ie (mg. $CaCO_3$ l^{-1}). (APHA, 1989).

2.2.2.7. Redox Potential (Eh)

Eh of the water samples collected were measured on the same day in the laborotary using Eh meter.

2.2.2.8. Transparency

Transparency of water was measured usinga Secchi disc. the average value of the depth at which Secchi disc disappears and the depth at which it reappears was taken as the transparency.

2.2.2.9. Ammonia

Ammonia was estimated by phenate method Koroleff, (1983). An intensely blue compound, indophenol was formed by the reaction of ammonia, hypochlorite, and phenol catalyzed by a manganous salt. Absorbance was measured using a spectrophotometer at 630 nm. The measured ammonia include both free dissolved ammonia gas and the ammonium ions.

2 2.2.10. Nitrite

Nitrite was estimated by colorimetric method of Bendschneider and Rebinson, (1952). Nitrite, (NO_2^-) was determined through formation of a reddish purple azo dye produced at pH of 2.0 to 2.5 by coupling diazotized sulphanilamide with N-(1-naphthyl) - ethylene diamine hydrochloride. Absorbance was measured using a spectrophotometer at 543 nm.

2.2.2.11. Nitrate

Nitrate was estimated by nitrate electrode method (APHA, 1989). The nitrate ion electrode is a selective sensor that develops a potential across a thin, porous, inert membrane that holds in place a water immiscible liquid ion exchange. The electrode responds to nitrate ion activity between about 10^{-5} and 10^{-1}. The electrode was dipped in the sample and the concentration of nitrate ion was read directly from calibration curve using Orion EA 940 ion analyzer.

2.2.2.12. Phosphate

Determination of inorganic phosphate involves the measurement of the concentrations of orthophosphate ions by the formation of an intensely coloured reduced phosphomolybdenum blue complex in an acid solution containing molybdic acid, ascorbic acid and potassium antimonyl tartarate. The most popular method based on this reaction developed by Murphy and Riley (1962) is given by Strickland and Parson (1972) is adopted in this investigation and the absorbance is measured at 880 nm.

CHAPTER 3

HYDROGRAPHY

3.1 . Temperature

3.2 . Salinity

3.3. Dissolved Oxygen

3.4. pH

3.5. Acidity

3.6 . Alkalinity

3.7. Redox Potential

3.8 . Transparency.

The study of the hydrographical parameters of the estuarine environment is of great importance to characterise the general features, distribution pattern and relative abundance of nutrients. These studies are also significant with regards to water management and pollution control. The hydrographical conditions in an estuary mainly depend on the intrusion of sea water and the influx of fresh water from rivers. The coagulation and precepitation of dissolved solids and evaporation of water also have profound effect on the hydrographical conditions of an estuary.

The hydrography of the Cochin estuary has been investigated by several workers (Ramamirthan and Jayaraman, 1963; Sankaranarayanan and Qasim, 1969; Shynamma and Balakrishnan, 1973; Haridas *et. al.*,1973; Joseph,1974; Balakrishnan and Shynamma, 1976; Lakshmanan *et. al.*, 1982 and 1987; Nambisan *et. al.*, 1987; Anirudhan *et. al.*, 1987; Anirudhan, 1988; Nair *et. al.*, 1993. But the information available on the various hydrographical parameters of the lower reaches of Chitrapuzha river which is a part of cochin estuary is limited. The knowledge of the various hydrographical parameters of this part of Cochin estuary is of much significance since it carries effluents from a large number of industrial units which include the Fertilizers and Chemicals Travancore Limited (Cochin division), The Cochin Refineries Limited and the Hindustan Organic Chemicals Limited.

The present study on the hydrography, attempts to elucidate the seasonal and spatial distribution of temperature, salinity, dissolved oxygen, pH, acidity, alkalinity, redox potential and transparency and their interrelationship during the period of survey (October1991 to January 1992.)

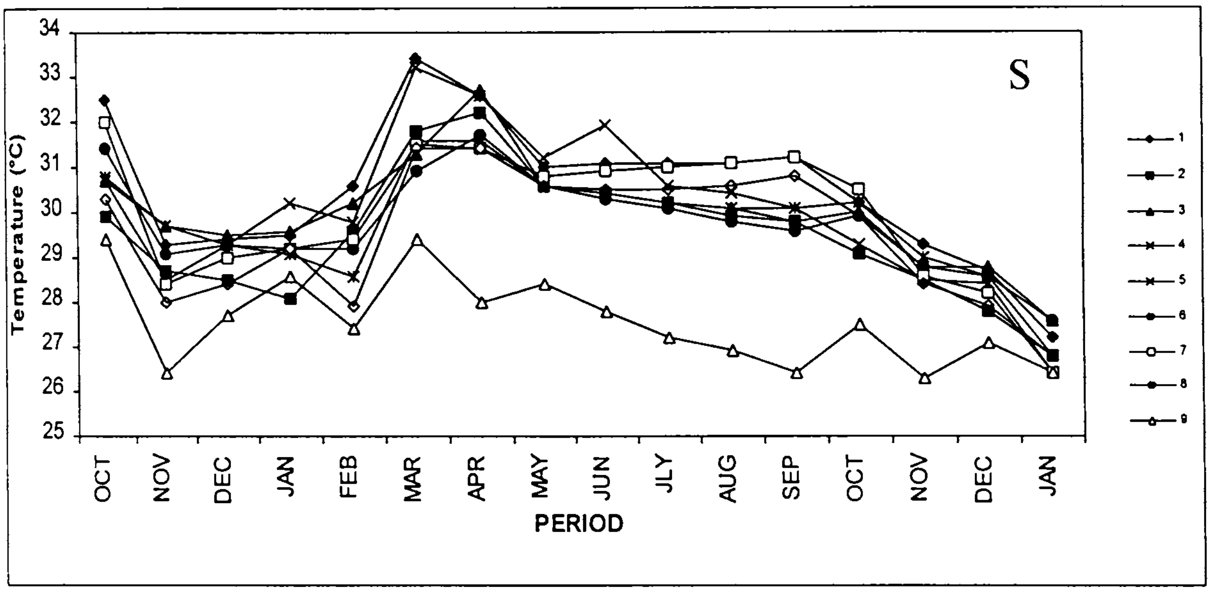
3.1. Temperature

Temperature of estuaries affects the physical properties of water such as density, vapour pressure, surface tension, viscosity, solubility, diffusion of gases etc. Temperature can cause stratification in ambient water, which may result in the overflow or underflow of the incomming water of different densities. Chemically temperature affects not only the rate of reaction but also shifts the equilibrium to either side.

The distribution of temperature in estuaries depends on the mixing of tidally influenced seawater (Ramamirthan and Jayaraman, 1963), flow of fresh water from rivers (Sankaranarayanan and Qasim 1969) and processes like exchange of heat from atmosphere and other localised phenomena.

Temperatures of surface and bottom waters at different locations during the period of survey are given in table 3.1.1.(Annexures). Distribution and seasonal variations of temperature at all stations during the period of survey at surface and bottom are represented by graphs (Fig. 3.1.1. and 3.1.2.).

In the stations studied the surface water temperature varied from 33.4°C during March 1991 at station one to 26.3° C during November 1991 at station nine, eventhough the average temperature is lowest in January 1992. Bottom water temperature varied from 32.2°C during April - May 1991 to 26.3°C during January



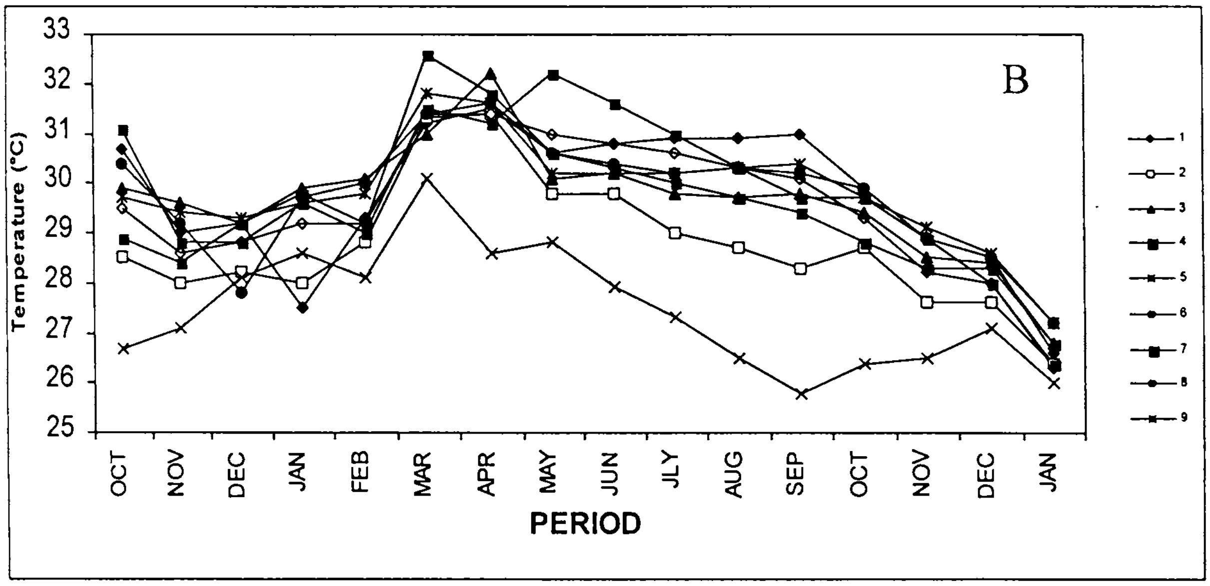


Fig. 3.1.1.
Monthly variation of temperature at various stations
S-Surface B-Bottom

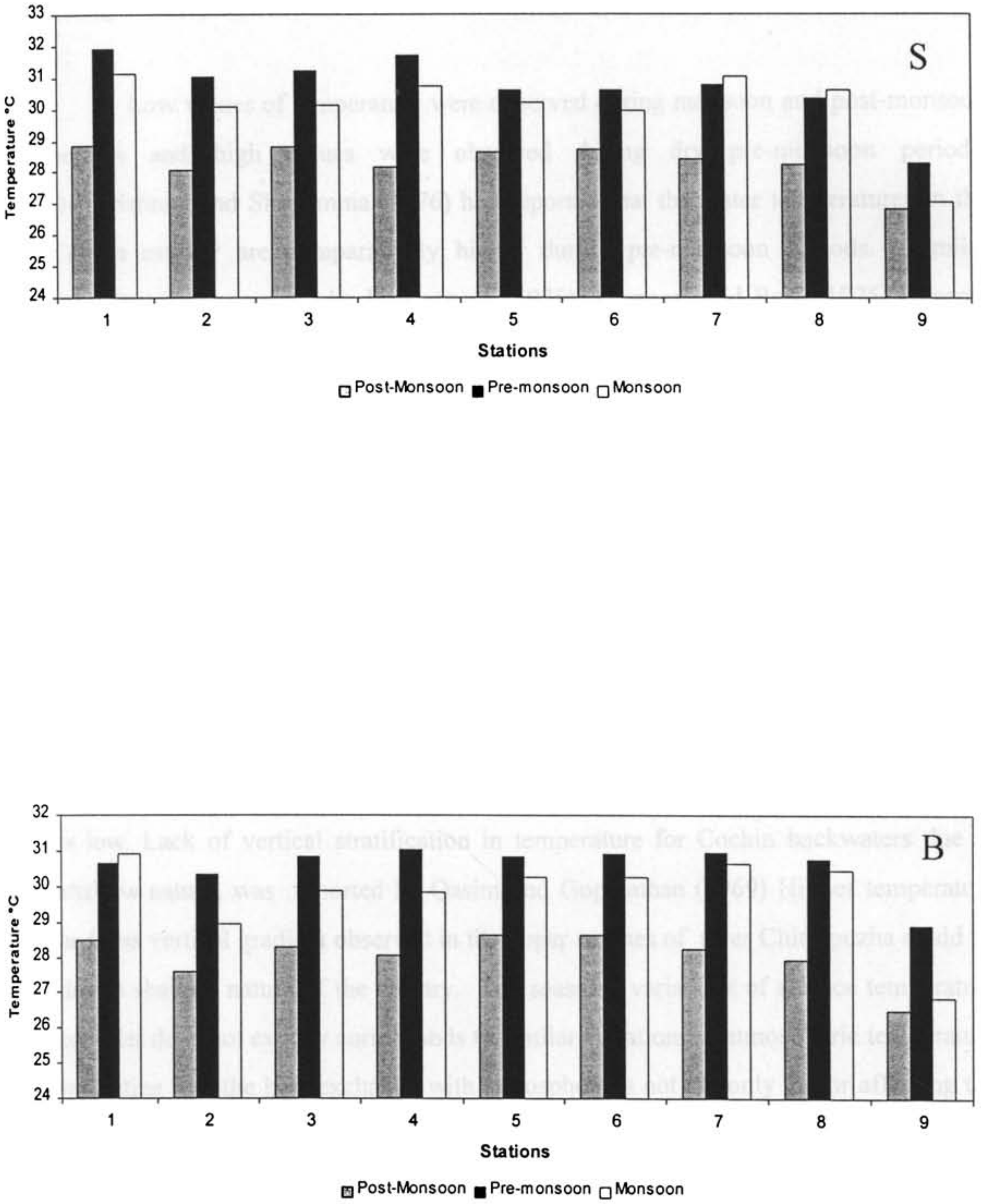


Fig. 3.1.2
Spacial variation of Temperature during different seasons

1992. Atmospheric temperature varied from 35.6°C during March 1991 to 23.0°C during January 1992.

Low values of temperature were observed during monsoon and post-monsoon periods and high values were observed during dry pre-monsoon periods. Balakrishnan and Shynamma (1976) had reported that the water temperatures in the Cochin estuary are comparatively higher during pre-monsoon periods. Similar variations were reported by Pillai *et. al.*,(1975); Kumaran and Rao, (1975); Joseph, (1988) and Sivadasan, (1996).

The temperature values show an increasing trend from down stream to upstream. Low water temperature observed in downstream may be due to the intrusion of comparatively cooler water from the sea. Sankaranarayanan and Qasim (1969) stated that influx of freshwater into the estuarine system is not the sole factor influencing the water temperature in the estuary, but the influx of cold water from the sea may also be a significant factor.

The vertical gradient in temperature at all stations during the period of survey is low. Lack of vertical stratification in temperature for Cochin backwaters due to shallow nature, was reported by Qasim and Gopinathan (1969) Higher temperature and less vertical gradient observed in the upper reaches of river Chitrapuzha could be due to shallow nature of the estuary. The seasonal variations of surface temperature of water does not exactly corresponds to similar variations in atmospheric temperature indicating that the heat exchange with atmosphere is not the only factor affecting the surface temperature in estuaries.

To study the significance of variation of temperature with period and station, two way analysis of variance was employed.

From ANOVA of temperature of surface waters, it is found that there is significant variation between periods and between stations ($P>0.05$). The least significant difference at 5% were worked out for periods and for stations. Periods six

(March 1991) and seven (April 1991) gave significantly higher temperature and periods sixteen (January 1992) gave significantly lower temperature. Among the spacial variations, stations one (Manackakadavu), three (Ambalamedu) and four (Brahmapuram) gave significantly higher values and station nine (Thevara) gave significantly lower temperature.

There is significant variation in temperature between periods and between stations ($P<0.05$) in bottom waters. Period six (March 1991) and seven (April 1991) gave significantly higher temperatures and period sixteen (January 1992) gave significantly lower temperture. Among stations, station seven (Tripunithura) gave significantly higher value and station nine (Thevara) gave significantly lower temperture.

To study the dependency of parameters, matrix of correlation was formed separately for surface and bottom waters which are given in tables 3.1.5. and 3.1.6. respectively.

There is significant negative correlation of temperature with transparency ($P< 0.001$) and salinity ($P<0.01$) in surface waters. The negative correlation of temperature with salinity may be due to the fact that the variation in temperature shows a decreasing trend from upstream where the water characteristics are mainly riverine nature, to downstream where the water characteristics are mainly marine nature. Hence salinity values shows an increasing trend of variation from upstream to downstream. In bottom waters the negative correlation with salinity is not significant but the negative correlation with pH ($P<0.01$) becomes significant. The positive correlation of temperature with acidity ($P<0.01$) and redox potential ($P<0.01$) is significant in bottom waters.

3.2. Salinity.

Salinity is considered as an important parameter in investigation of the process of mixing of sea water with freshwater in estuaries. Wide fluctuations in salinity

3.1.5: Matrix of Correlation of Different Hydrographic Parameters in Surface Water

```
Correlations:  TEMPERAT   SALINITY   DO         PH         ACIDITY    ALKALINE

  TEMPERAT     1.0000     -.2390*     .1393     -.1373      .1509     -.1234
  SALINITY     -.2390*    1.0000     -.3300**    .1424     -.0687      .1053
  DO            .1393     -.3300**   1.0000     -.0083     -.0765     -.2423*
  PH           -.1373      .1424     -.0083     1.0000     -.7969**    .6181**
  ACIDITY       .1509     -.0687     -.0765     -.7969**   1.0000     -.3585**
  ALKALINE     -.1234      .1053     -.2423*     .6181**   -.3585**   1.0000
  REDOX_PO      .1592     -.1626      .0335     -.9850**    .8123**   -.6021**
  TRANSPAR     -.3385**    .1949*    -.0940      .3116**   -.2822**    .1936


Correlations:  REDOX_PO   TRANSPAR

  TEMPERAT      .1592     -.3385**
  SALINITY     -.1626      .1949*
  DO            .0335     -.0940
  PH           -.9850**    .3116**
  ACIDITY       .8123**   -.2822**
  ALKALINE     -.6021**    .1936
  REDOX_PO     1.0000     -.3184**
  TRANSPAR     -.3184**   1.0000

1-tailed Signif:  * - .01   ** - .001
```

3.1.6: Matrix of Correlation of Different Hydrographic Parameters in Bottom Water

```
Correlations:  TEMPERAT   SALINITY   DO         PH         ACIDITY    ALKALINE

  TEMPERAT     1.0000     -.0684     -.1149     -.2400*     .2544*    -.1810
  SALINITY     -.0684     1.0000     -.2701**    .1421     -.0614      .2081*
  DO           -.1149     -.2701**   1.0000      .1477     -.1839     -.1443
  PH           -.2400*     .1421      .1477     1.0000     -.7908**    .5487**
  ACIDITY       .2544*    -.0614     -.1839     -.7908**   1.0000     -.3298**
  ALKALINE     -.1810      .2081*    -.1443      .5487**   -.3298**   1.0000
  REDOX_PO      .2375*    -.1629     -.1302     -.9788**    .7963**   -.5363**

Correlations:  REDOX_PO

  TEMPERAT      .2375*
  SALINITY     -.1629
  DO           -.1302
  PH           -.9788**
  ACIDITY       .7963**
  ALKALINE     -.5363**
  REDOX_PO     1.0000

1-tailed Signif:  * - .01   ** - .001
```

values are observed in estuaries ranging from almost marine conditions to strictly freshwater conditions. salinity in estuaries usually depends on the intrusion of sea water through bar mouth, discharge of fresh water from rivers, isolated rainfall ,evaporation etc.

Results on salinity at surface and bottom at all stations during the period of survey are given in table 3.2.1 (Annexures). The distribution of the Seasonal and spacial variations of salinity at surface and bottom are given in Fig. 3.2.1 and 3.2.2 respectively.

Very low salinity values were recorded at stations one (Manackakadavu) and two (Ambalamughal) which are not influenced by tidal effects and the values ranges from 1.01 x 10^{-3} to 0.01 x 10^{-3} during the period of survey. Even though the intrusion of sea water extends upto station three during pre-monsoon periods, such effects are not reflected in the salinity values at stations one and two. It may be due to the construction of a temporary bund at Bhramapuram which prevents intrusion of salinity to station one and the control of water flow between stations two and three by a permanent arrangement protects station two from influences of salinity.

Very low salinity values were recorded during monsoon period at all stations except at station nine (Thevara) which is the nearest to the harbour entrance where the highest values observed during monsoon periods were 6.45 x 10^{-3} and 7.04 x 10^{-3} for surface and bottom waters respectively during the month of September 1991. A gradual increase in salinity was observed as the season progressed to post-monsoon and the highest values were recorded during pre-monsoon periods. The highest salinity values recorded at station nine were 24.30 x 10^{-3} in surface waters and 25.79 x 10^{-3} in bottom waters during the month of April 1991.

These results are comparable with the observations of several previous workers along the south west coast of India. Haridas *et. al.*, (1973); Balakrishnan and Shynamma, (1976); Sivenkutty (1977); Gopakumar (1991); Maqbool (1993). have reported wide fluctuation in salinity of tropical estuaries due to extreme conditions of

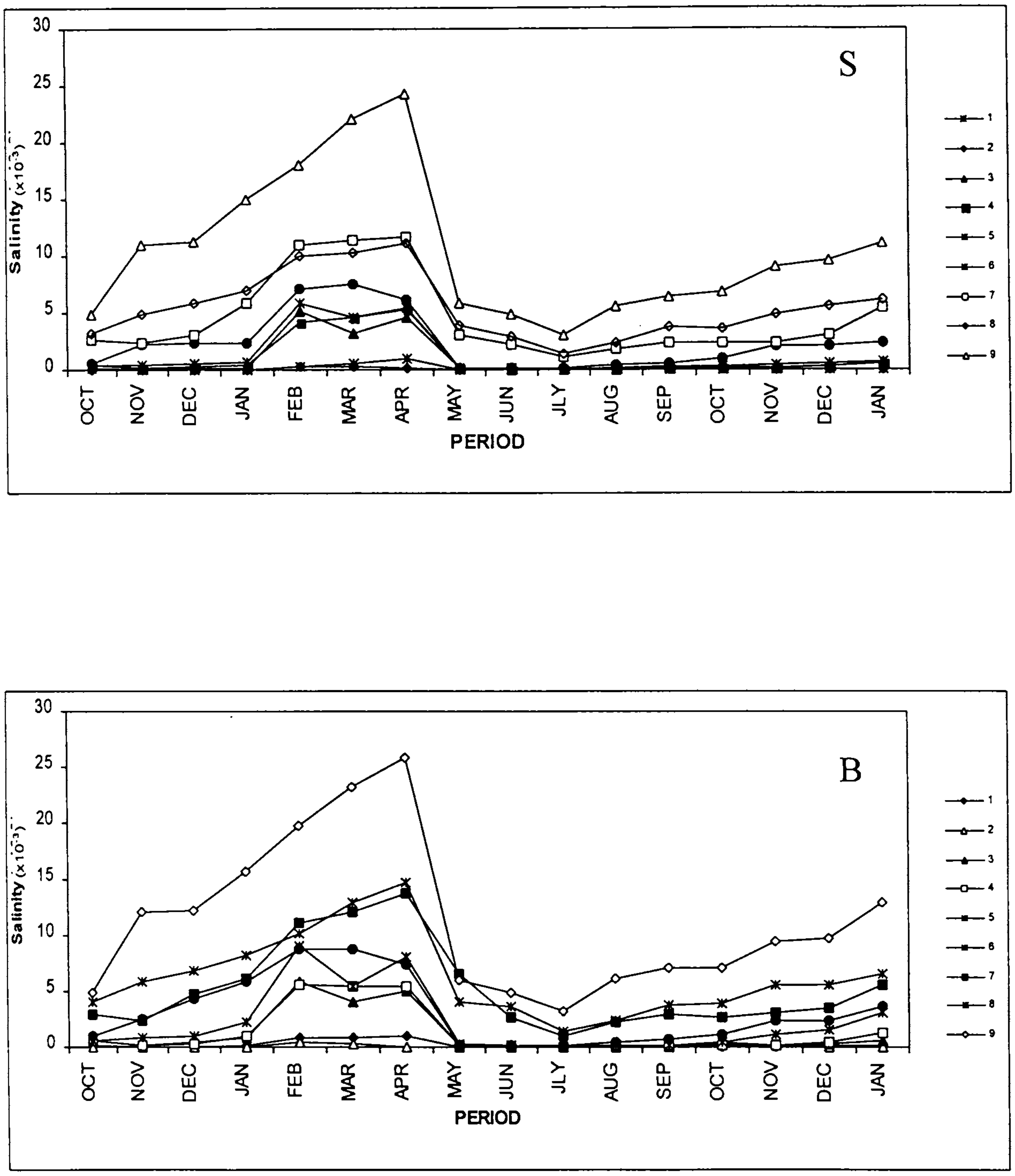


Fig. 3.2.1.
Monthly variation of Salinity at various stations
S-Surface B-Bottom

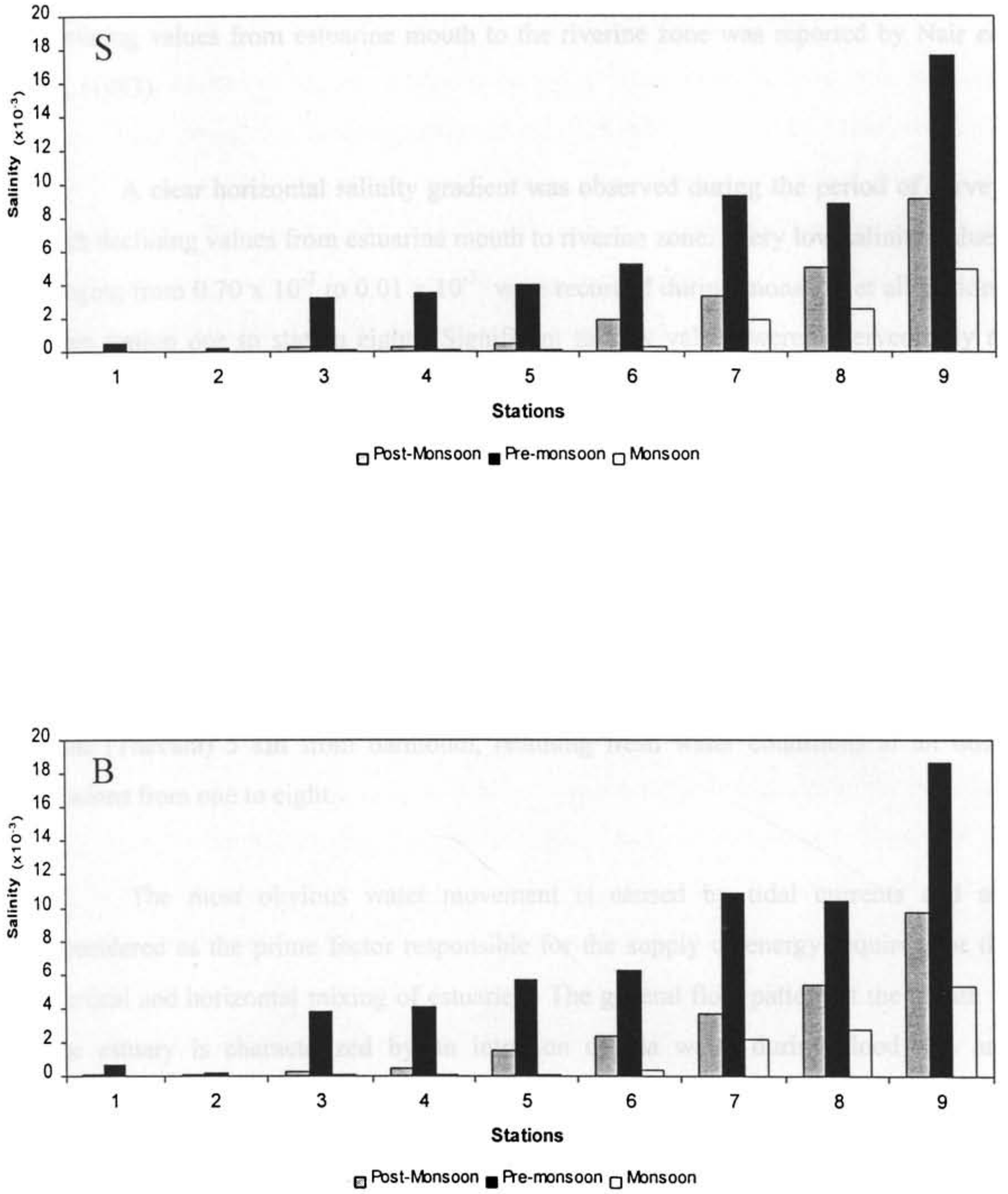


Fig. 3.2.2
Spacial variation of Salinity during different seasons

draught and monsoon affecting the estuarine environment. A distinct seasonal pattern of salinity in the Ashtamudi estuary with highest values during pre-monsoon and declining values from estuarine mouth to the riverine zone was reported by Nair *et. al.*, (1983).

A clear horizontal salinity gradient was observed during the period of survey with declining values from estuarine mouth to riverine zone. Very low salinity values ranging from 0.70×10^{-3} to 0.01×10^{-3} were recorded during monsoon at all stations from station one to station eight. Significant salinity values were observed only at station nine (Thevara) 5 km from the barmouth during monsoon period. As season progresses to post-monsoon period, the influence of intrusion of sea water extended to station seven (Tripunithura) 12 km from the barmouth. During pre-monsoon period significant salinity values were observed at all stations from nine to three (Ambalamedu) 20 km from the barmouth, leaving only stations one and two out of the marine influences. Minimum salinity was recorded during July 1991 with highest value of 3.05×10^{-3} for surface waters and 3.17×10^{-3} for bottom waters at station nine (Thevara) 5 km from barmouth, retaining fresh water conditions at all other stations from one to eight.

The most obvious water movement is caused by tidal currents and are considered as the prime factor responsible for the supply of energy required for the vertical and horizontal mixing of estuaries. The general flow pattern at the mouth of the estuary is characterized by an intrusion of sea water during flood tide and excrusion during ebb tide.

Salinity values increase gradually with time and the salinity intrusion extends upto station eight (Chambakara)10 km from the barmouth during the month of November 1990 and even November 1991. The marine influence extends upto station seven (Tripunithura) 12 km from the barmouth during the month of January 1992. A similar pattern was seen during the month of January 1991 extending the sea water intrusion limit even upto station six (Eroor) 14 km from the barmouth in bottom waters. The salinity influence reaches upto the station three (Ambalamedu) 20 km from the barmouth during the month of February 1991 and this effect was retained till the onset of mosoon.

The extend of salinity intrusion during different seasons have been reported from many estuaries. Sankaranarayanan *et. al.*, (1986), observed saline intrusion upto 25 km, in the Periyar river estuary during pre-monsoon period and only upto 5 km. during monsoon. Salinity was limited to 5 km, from the river mouth during monsoon season as recorded by Nambudirippad and James, (1987) and Nataraj *et. al.*, (1987) . While intrusion of sea water was extended even upto 28 km. from the barmouth during pre-monsoon period as reported by James and Sreedharan, (1983), in Beypore estuary on the Malabar coast. Similar values were reported by Jose Xavier (1993), in Chaliyar River estuary, the barmouth of which is at Beypore. A salinity wedge extending only upto 10 km. was observed in Mandovi and Zuari estuaries during monsoon by Qasim and Sen Gupta, (1981).

Generally bottom salinity values at all stations are higher than the salinity values for surface water during the period of survey. The low vertical salinity gradient at all stations indicates no distinct stratification during the entire period of survey. Sanakaranarayanan *et. al.*, (1986), found well developed stratification at the barmouth of Cochin estuary during monsoon. Absence of such a stratification during monsoon in the area under the present investigation, may be due to thorough mixing of shallow waters. Dominant tidal motions in shallow estuaries were reported by Officer (1976); Ketchum, (1983) and Murakami,(1986).

Variation of salinity of surface waters along period and stations space are significant ($P<0.05$)., Periods five (February 1991), six (March 1991) and seven (April 1991) showed significantly higher salinity and period ten (July 1991) showed significantly lower salinity. Along space, the station nine (Thevara) gave significantly higher value and stations two (Ambalamughal) and one (Manakakadavu) gave significantly lower salinity.

Variation of salinity of bottom waters between periods and between stations are significant ($P<0.05$) . Period seven (April 1991) showed significantly higher salinity and period ten (July 1991) observed significantly lower salinity. Significantly higher salinity was seen at station nine (Thevara) and significantly lower salinity was observed at stations two (Ambalamughal) and one (Manackakadavu).

There is significant negative correlation of salinity with dissolved oxygen ($P<0.001$) and temperature ($P<0.01$) and significant positive correlation with alkalinity ($P<0.01$) in surface waters. In bottom waters the negative correlation between salinity and dissolved oxygen is significant ($P<0.01$) but the negative correlation with temperature is not significant. Salinity shows significant positive correlation with alkalinity ($P<0.01$) in bottom waters.

3.2.1 Dilution of Sea water.

Estimation of fresh water content as a fraction of the total amount of water at different stations in estuaries can be used for the determination of dilution of sea water. Bowden (1980) suggested that the amount of fresh water removed by flushing is the same as that is being added by river discharge.

The fraction of fresh water present at any given location in an estuary can be formulated as $F = 1 - S_1/S_2$, where F is the fraction of fresh water in the sample, S_1 is the salinity of the sample collected from the location within the estuary and S_2 is the salinity of the coastal water (Officer,1976). Figure 3.2.3. gives the surface and bottom freshwater fractional values as plotted against the stations for different seasons.

Wide seasonal variation in fresh water content, both for surface and bottom waters at station nine was observed.. During monsoon, station nine recorded a maximum value of 0.90 at surface, at bottom indicating freshwater conditions. With the advent of the post-monsoon the values gradually decreased and during pre-monsoon the fractional value decreased to record 0.22 at surface and 0.17 at bottom indicating nearly saline conditions during this period.

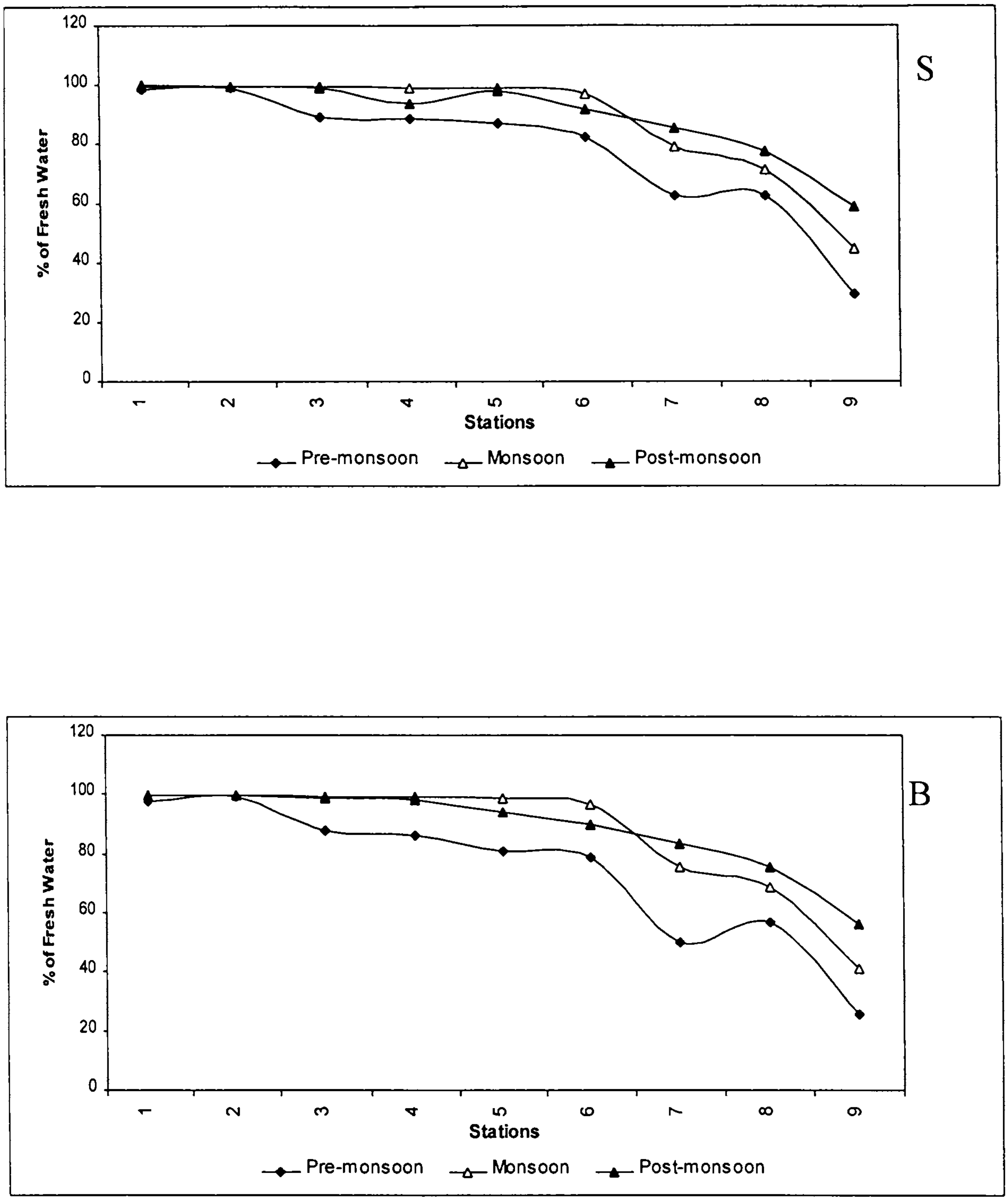


Fig. 3.2.3

The Seasonal distribution of percentage of fresh water content

At stations one and two no siginificant seasonal variation in freshwater content both for surface and bottom waters was observed. The fractional values are constantly high indicating almost freshwater conditions at these two stations throughout the period of survey. The seasonal variations gradually increase from station three to station nine. The fractional values are generally higher for surface waters than bottom waters at all station during all seasons.

With the onset of monsoon, hydrographic conditions in the estuary undergo remarkable changes and the estuary becomes dominated by fresh water (Wyatt and Qasim,1973). During monsoon the intensity of tidal influx into the estuary is very much reduced due to the heavy outflow of fresh water from rivers. Hence, flood tides during the monsoon season cause sea water influx limited to bottom layers.

3.3. Dissolved oxygen.

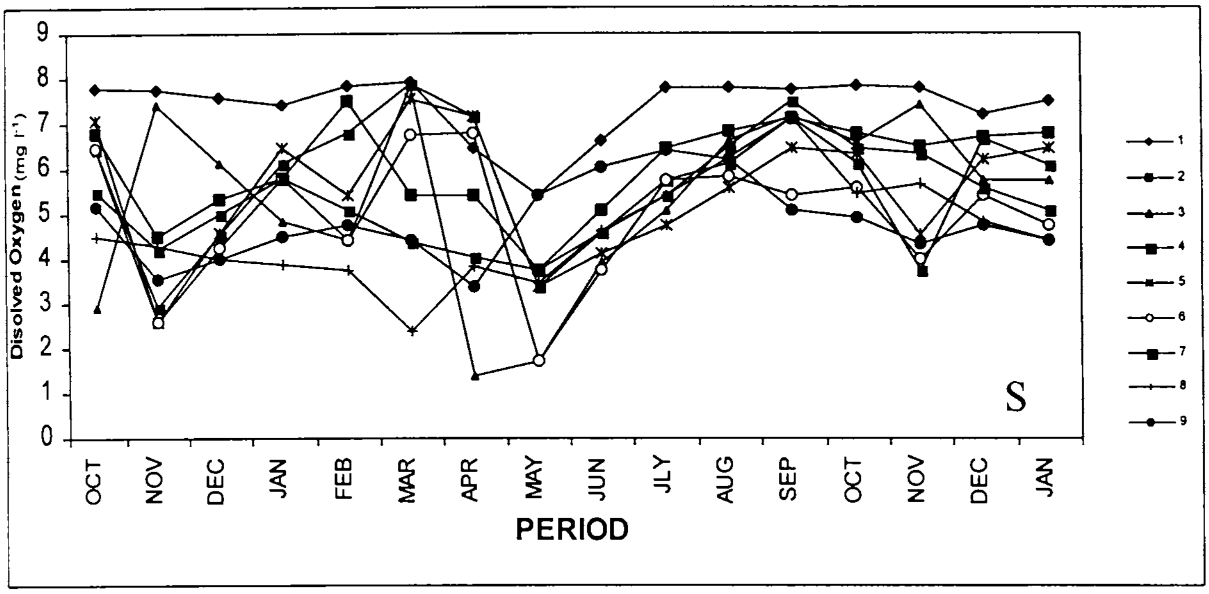
Dissolved oxygen (DO) is an important water quality parameters in water quality assessment. Solubility of atmospheric oxygen in fresh water is low, only 10.66 mg l^{-1} at 10°C and 7.13 mg l^{-1} at 30° C under normal atmospheric pressure. The amount of dissolved oxygen in natural waters depends upon temperature, salinity, turbulance of the water and atmospheric pressure. The depletion of oxygen content in water leads to undesirable obnoxious odours under anaerobic conditions (Doudoroff shumway and Peter,1970; Nelson,1978) and damage to aquatic life. Adequate amounts of dissolved oxygen is essential for the survival of fish and other aquatic organisms. The dissolved oxygen requirement is dependent upon temperature and varies from organisms to organisms. The decomposition of organic waste and oxidation of inorganic waste may reduce the dissolved oxygen to extremely low levels which may prove harmful to organisms in the aquatic environment. Johannessen and Dahl(1996) have reported decline in dissolved oxygen as a result of increased nutrient load. Hart (1974) has suggested a desired limit of 5 mg l^{-1} of dissolved oxygen. The minimum acceptable limit of dissolved oxygen for fish life is 3 mg l^{-1}.

The concentration of dissolved oxygen in natural water depends on various factors such as temperature, partial pressure of oxygen in the atmosphere, salinity, biological processes like oxidation and reductin, degradation of organic matter, respiration etc. Rate of depletion of oxygen has been used to investigate the quality of water bodies. (Wahley *et. al.*, (1978). Studies on salinity dependent oxygen solubility may help to elucidate the various physical, chemical and biological processes taking place in estuarine waters (Desousa and Sen Gupta, 1986).

The amount of dissolved oxygen in surface waters is usually greater than that in bottom waters. This may be attributed to the partial utilization of dissolved oxygen by organic rich sediments. Oxygen can diffuse in surface waters to support aerobic processes. The variation in the amounts of dissolved oxygen is also attributed to the seasonal and tidal fluctuations of both surface and bottom waters. (Pillai *et. al.*, 1975); Vijayan *et. al.*, 1976).

Values of dissolved oxygen in surface and bottom waters at the stations studied are given in table 3.3.1 (Annexure). Distribution pattern and seasonal variations of dissolved oxygen at surface and bottom are represented in Fig.3.3.1 and 3.3.2. Both seasonal and spacial variations are well reflected in the DO patterns. On the upper stretch of stations one and two DO values ranges from 7.81 mg l^{-1} during August 1991 to 3.73 mg l^{-1} during May 1991 at surface and 7.79 mg l^{-1} during October 1991 to 2.37 mg l^{-1} during May 1991 at bottom. At station three where the probability of industrial pollution is maximum, DO values ranges from 7.81 mg l^{-1} during March 1991 to 1.36 mg l^{-1} during April 1991 at surface and 7.48 mg l^{-1} during March 1991 to 0.63 mg l^{-1} during April 1991 at bottom. On the lower stretch from stations four to nine DO values ranges from 7.52 mg l^{-1} during March 1991 to 1.69 mg l^{-1} during May 1991 at surface and 7.12 mg l^{-1} during September 1991 to 1.02 mg l^{-1} during May 1991.

During monsoon DO values ranges from 7.81 mg l^{-1} to 3.75 mg l^{-1} at surface and 7.47 mg l^{-1} to 2.94 mg l^{-1}at bottom. The post-monsoon values vary between 7.79 mg l^{-1} and 2.59 mg l^{-1} at surface and 7.27 mg l^{-1} and 1.97 mg l^{-1} at bottom. The pre-



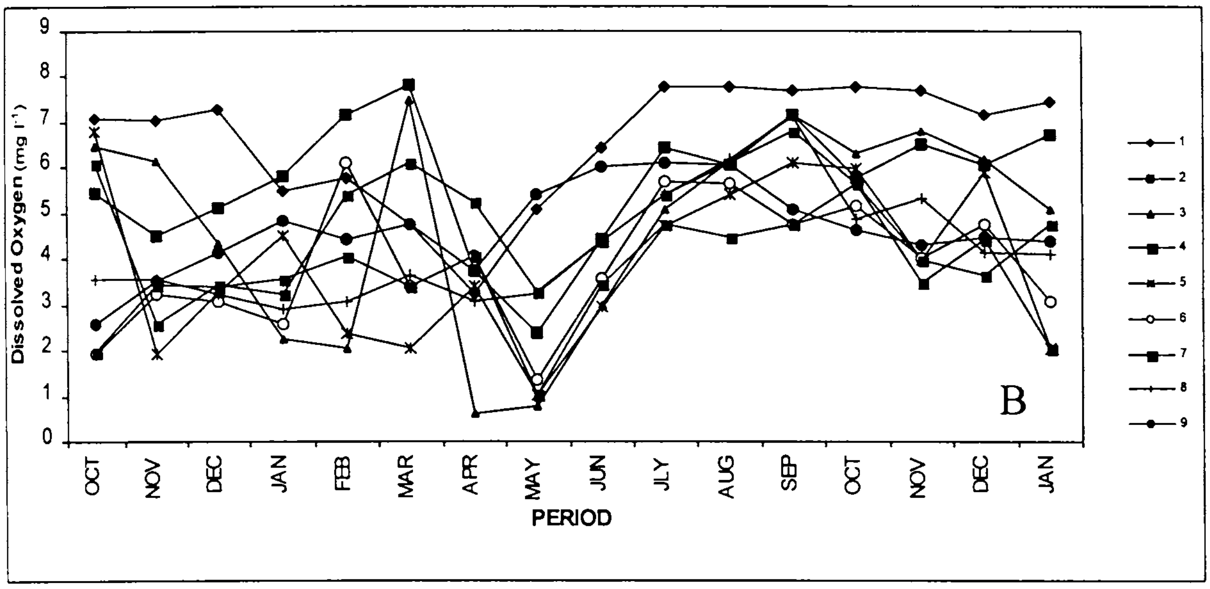


Fig. 3.3.1.

Monthly variation of Dissolved Oxygen at various stations
S-Surface B-Bottom

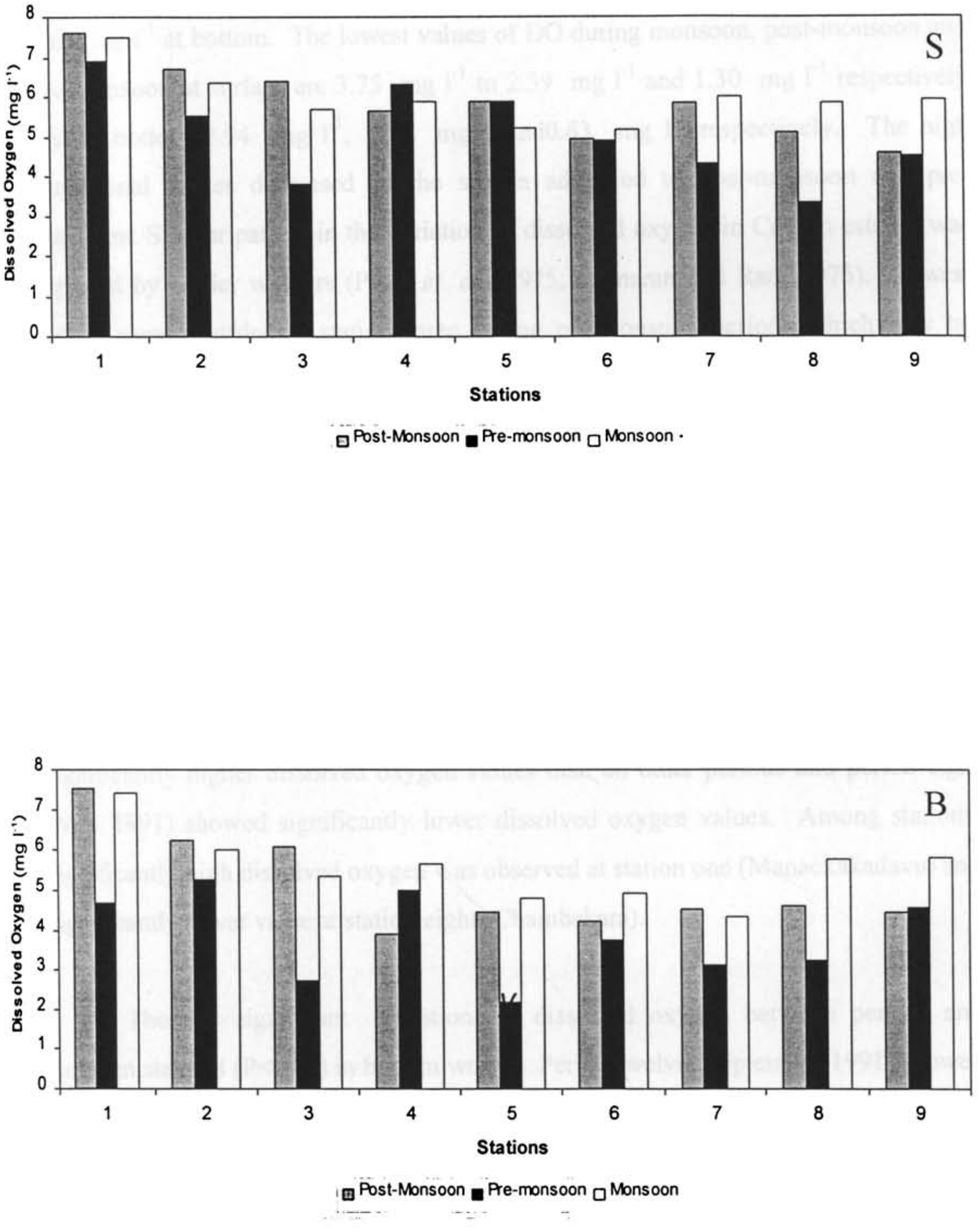


Fig. 3.3.2

Spacial variation of Dissolved Oxygen during different seasons monsoon values range from 7.89 mg l^{-1} to 1.30 mg l^{-1} at surface and 7.48 mg l^{-1} to 0.63 mg l^{-1} at bottom. The lowest values of DO during monsoon, post-monsoon and pre-monsoon at surface are 3.75 mg l^{-1} to 2.59 mg l^{-1} and 1.30 mg l^{-1} respectively and at bottom 2.94 mg l^{-1}, 1.97 mg l^{-1}and0.63 mg l^{-1} respectively. The high monsoonal values decreased as the season advanced to post-monsoon and pre-monsoon. Similar pattern in the variation of dissolved oxygen in Cochin estuary was reported by earlier workers (Pillai *et. al.*, 1975; Kumaran and Rao, 1975). Lowest values were recorded at station three during pre-monsoon periods which may be interpreted as the combined effect of effluents discharged from industries around station three and low solubility of oxygen in high saline waters. Relatively higher values observed at the upper reaches of Chitrapuzha river as compared to the lower reaches of the estuary may be due to the higher solubility of oxygen in less saline waters.

Significant variations of dissolved oxygen were observed between periods and between stations ($P<0.05$) in surface waters. Period twelve (September 1991) showed significantly higher dissolved oxygen values than all other periods and period eight (May 1991) showed significantly lower dissolved oxygen values. Among stations, significantly high dissolved oxygen was observed at station one (Manackakadavu) and significantly lower value at station eight (Chambakara).

There is significant variations in dissolved oxygen between periods and between stations ($P<0.05$) in bottom waters. Period twelve (September 1991) showed significantly higher dissolved oxygen and period eight (May 1991) gave significantly lower dissolved oxygen. Significantly higher dissolved oxygen was observed at stations one (Manackakadavu) and two (Ambalamughal) and significantly lower values of dissolved oxygen were observed at stations seven (Tripunithura), six (Eroor) and five (Irimpanum).

There is significant negative correlation of dissolved oxygen with salinity ($P<0.001$) and alkalinity ($P<0.01$) in surface waters. The significant negative correlation between dissolved oxygen and salinity ($P<0.001$) is present even in bottom waters while the negative correlation with alkalinity is not significant in bottom waters.

3.4. potentia Hydrogenii - (pH).

Many of the life processes are dependent on the hydrogen ion concentration in the surrounding medium. The pH of a medium depends on factors like photosynthetic activity, discharge of industrial effluents, nature of dissolved materials, rainfall etc. Variation in pH due to chemical and other industrial discharges renders a stream unsuitable not only for recreational purposes but also for the rearing of fish and other aquatic life (Webb, 1982). The pH of natural water ranges from 6.0 to 8.5. The industrial effluents discharged into the aquatic system may significantly lower or elevate the pH of water depending on the nature of the effluents. The pH of water affect the treatment processes and can contribute to the corrosion of distribution lines and household plumbing fixtures. Under extreme conditions the survival of the biota becomes a serious problem. The tolerance range for most organisms is quite narrow and critical (George, 1979). Close monitoring of pH values enable to identify zones of pollution and other quality conditions of water (Clarks *et. al.*, 1977).

Data on pH of the area under investigation are given in table 3.4.1 (Annexure). Distribution pattern, seasonal and special varation of pH at surface and bottom waters during the period of survey are represented by the graphs 3.4.1 and 3.4.2 . At the stations one and two, the pH values fluctuate in narrow ranges from 8.68 during October1990 to 6.14 during May 1991 at surface and 8.62 during October 1990 to 5.91 during May 1991 at bottom. The narrow range of pH values at these stations may be due to the fact that these stations are not much influenced by the industrial effluents discharged into the estuary by virtue of downflow of fresh water during monsoon and post-monsoon periods and construction of temporary bund during pre-monsoon periods.

A wide range of pH values were observed at stations three, four, five and six which are most affected by discharge of industrial effluents. The pH value ranges

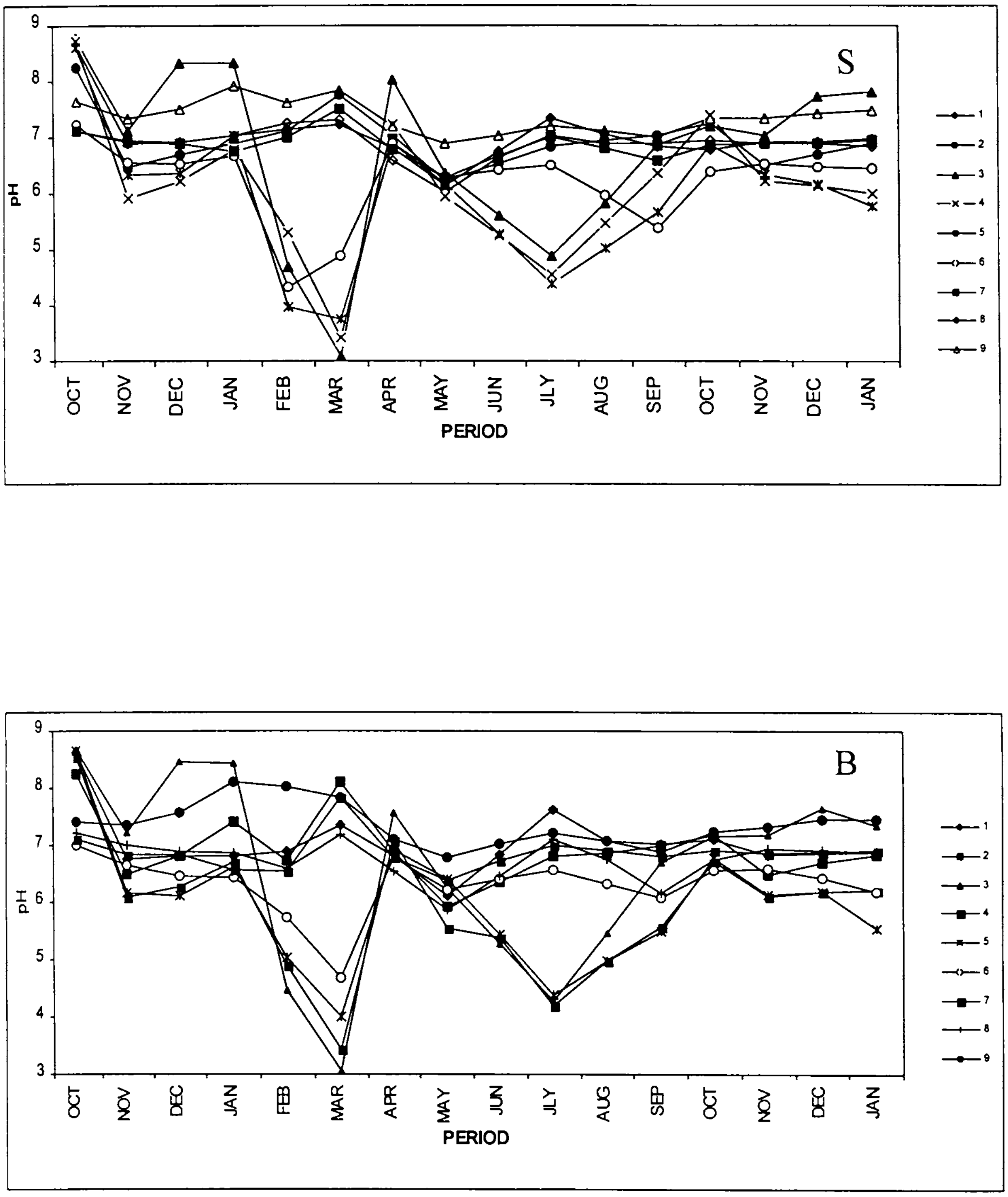


Fig. 3.4.1.
Monthly variation of pH at various stations
S-Surface B-Bottom

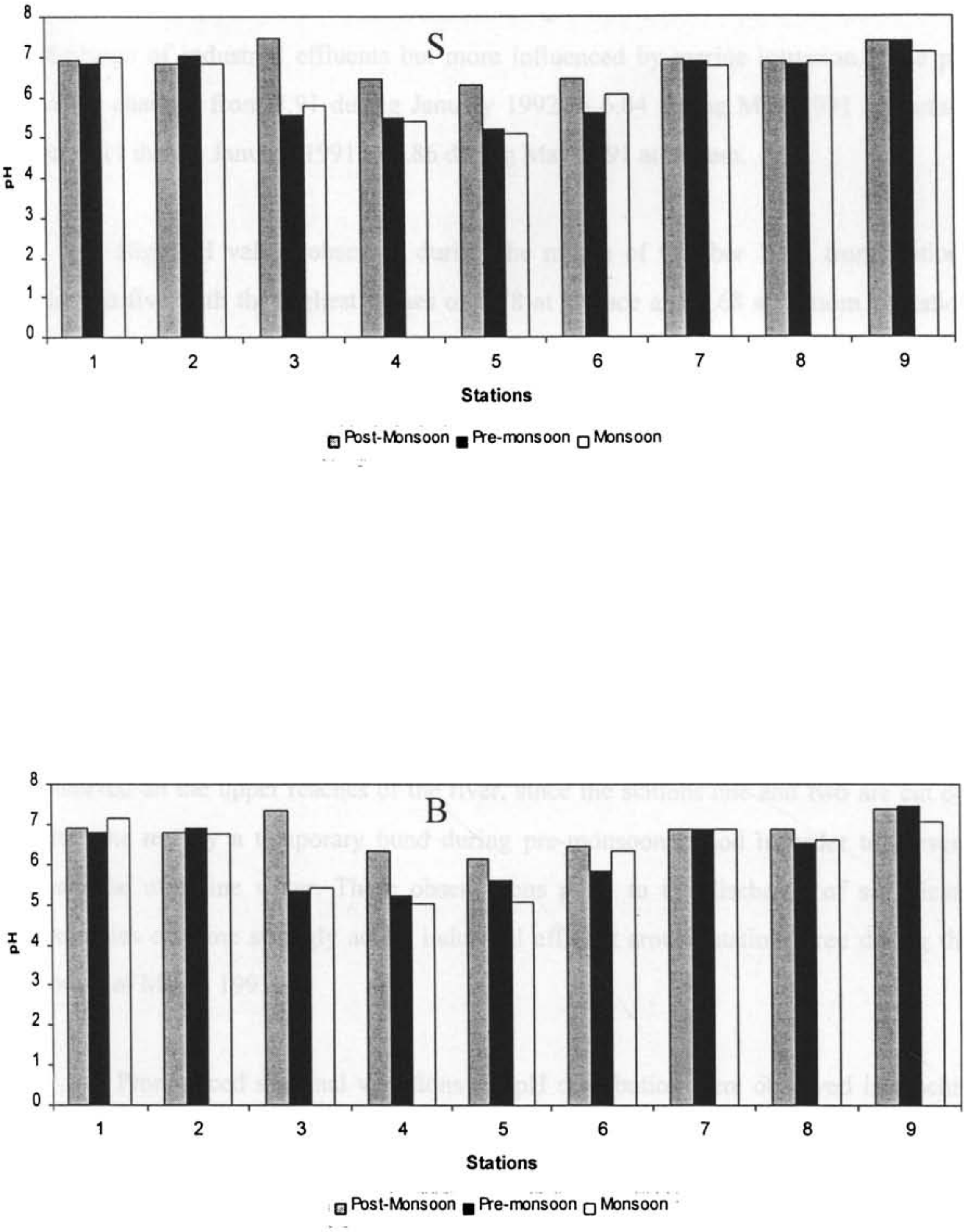


Fig. 3.4.2
Spacial variation of pH during different seasons

between 8.78 during October 1990 and 3.07 during March 1991 at surface and 8.68 during October 1990 and 3.06 during March 1991 at bottom. The changes in pH values are less pronounced at stations seven, eight and nine which are less affected by discharge of industrial effluents but more influenced by marine intrusion. The pH values changes from 7.91 during January 1992 to 6.04 during May 1991 at surface and 8.11 during January 1991 to 5.86 during May 1991 at bottom.

High pH values observed during the month of October 1990 from stations three to five with the highest values of 8.78 at surface and 8.68 at bottom at station three and the gradual decrease in pH values to station one on one side and to stations four, five,six etc.on the other side can be explained only with an assumption of discharge of some alkaline industrial effluent around station three in the month of October 1990.

Very low pH values of 3.07 at surface and 3.06 at bottom were observed at station three during the month of March 1991. The pH value gradually changes from 3.07 at station three to 7.49 at station seven for surface water and from 3.06 at station three to 7.84 at station seven for bottom water.No such horizontal gradation was observed on the upper reaches of the river, since the stations one and two are cut off from the rest by a temporary bund during pre-monsoon period in order to prevent intrusion of saline water. These observations point to the discharge of significant quantities of some strongly acidic industrial effluent around station three during the month of March 1991.

Pronounced seasonal variations in pH distribution were observed in Cochin estuary by earlier workers. Anirudhan (1988) reported natural pH values during monsoon months at surface when fresh water influx occurs. The pH values increase seasonally upto post-monsoon period and is attributed to the excessive photosynthetic activity of algae, which results in depletion in the amount of carbondioxide and hence increase in pH values. The high phytoplanktonic production during post-monsoon period in Cochin estuary was recorded by Silas & Pillai, (1975) and Nair *et. al.*, (1975). No such clear seasonal trend is visible in the present study. Very low pH values were recorded during some months and high pH values were recorded during some other months irrespective of the season, particularly at station three. Very low pH values were recorded at station three during the months of February, March, June, July and August 1991 both at surfce and bottom indicating acidic industrial discharge around station three during these months. High pH values were observed during the months of October and December 1990 and January 1991 at station three indicating alkaline industrial discharge during the above months.

Nair *et. al.*, (1983) observed a clear decrease in pH from marine to fresh water zone in the Astamudi estuary. The same trend was reported by Anirudhan(1988) in the Cochin estuary. No such horizontal trend is observed in the present study. The lowest and highest pH values were recorded at station three during different months and the values show horizontal gradation along downstream and attain normal values from station seven onwards. This pattern clearly indicates discharge of highly acidic effluents during the months of February, March, June, July and August 1991 and strongly alkaline effluents during the months of October and December 1990 and January 1991, into Chitrapuzha river around station three.

There is significant variation in pH between periods and between stations ($P<0.05$) in surface waters. Period one (October 1990) gave significantlty high value of pH and period six (March 1991) gave significantly low value of pH. Along horizontal distribution significantly higher pH was observed at station nine (Thevara) and significantly lower pH at station five (Irimpanum).

Significant difference is observed in pH between periods and between stations ($P<0.05$) in bottom waters. Significantly higher pH value was observed during period one (October 1990) and period four (January 1991) and significantly lower value of pH was observed during period six (March 1991). Among stations, station nine (Thevara) and station one (Manackakadavu) gave significantly higher pH values and stations four (Brahmapuram) and five(Irimpanum) showed significantly lower pH values.

There is significant positive correlation of pH with alkalinity ($P<0.001$) and significant negative correlation with redox potential ($P<0.001$), acidity) ($P<0.001$) and temperature ($P<0.01$) in surface waters. The same pattern of correlation is seen in bottom waters.

3.5. Acidity

Acidity or base capacity of water is its capacity to neutralise a strong base to a designated pH. It is caused by the presence of strong mineral acids, weak acids like carbonic acid, acetic acid etc. and hydrolysing salts like sulphates, nitrates, chlorides of ferrous, ferric aluminium or manganese. Methyl orange acidity upto pH 3.7 is due to the presence of strong mineral acids while acidity from pH 3.7 to 8.3 i.e. the difference in values between methyl orange acidity and phenolpathalein acidity is mainly due to the presence of free carbon dioxide in water. In natural unpolluted fresh water the acidity is mainly due to the presence of free carbon dioxide in the form of carbonic acid.

Data on total acidity or phenolphtalein acidity of the area under investigation during the period of survey are given in table 3.5.1 (Annexure). Distribution pattern and seasonal variations of total acidity at surface and bottom waters at all stations during the period of survey is given as figures 3.5.1 and 3.5.2.

Methyl orange acidity upto pH 3.7 values were observed only at two centres at stations three and four during the month of March 1991. Acidity values upto pH 3.7 of 6.0 mg $CaCO_3$ l^{-1} at station three and 2.6 mg $CaCO_3$ l^{-1} at station four were observed for surface waters and 6.1 mg $CaCO_3$ l^{-1} at station three and 2.6 mg $CaCO_3$ l^{-1} at station four for bottom waters were recorded. This observation clearly indicates the addition of strongly acidic materials like mineral acids around station three during the month of March 1991 which was carried downstream causing acidity of lesser magnitude at station four.

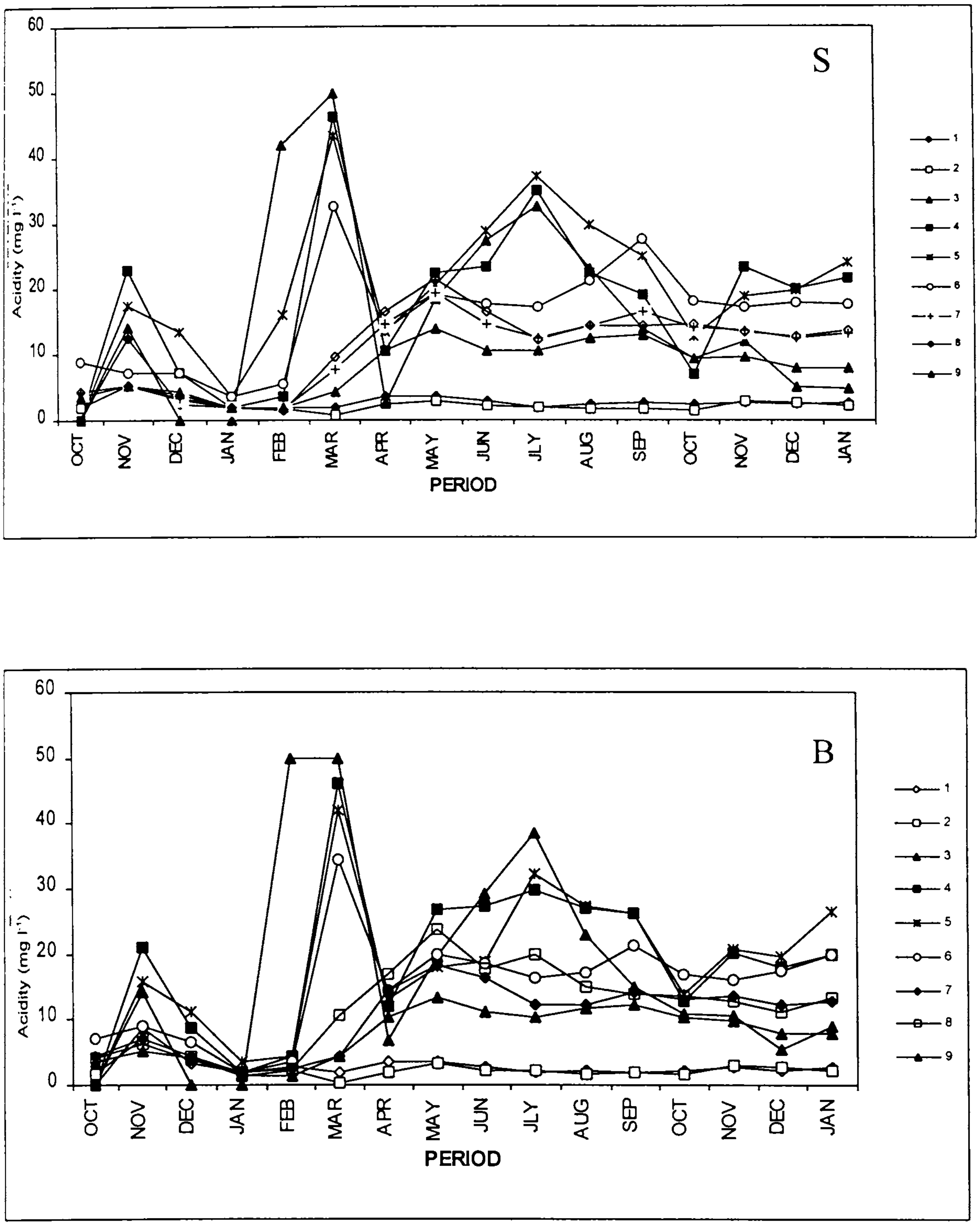


Fig. 3.5.1.
Monthly variation of Acidity at various stations
S-Surface B-Bottom

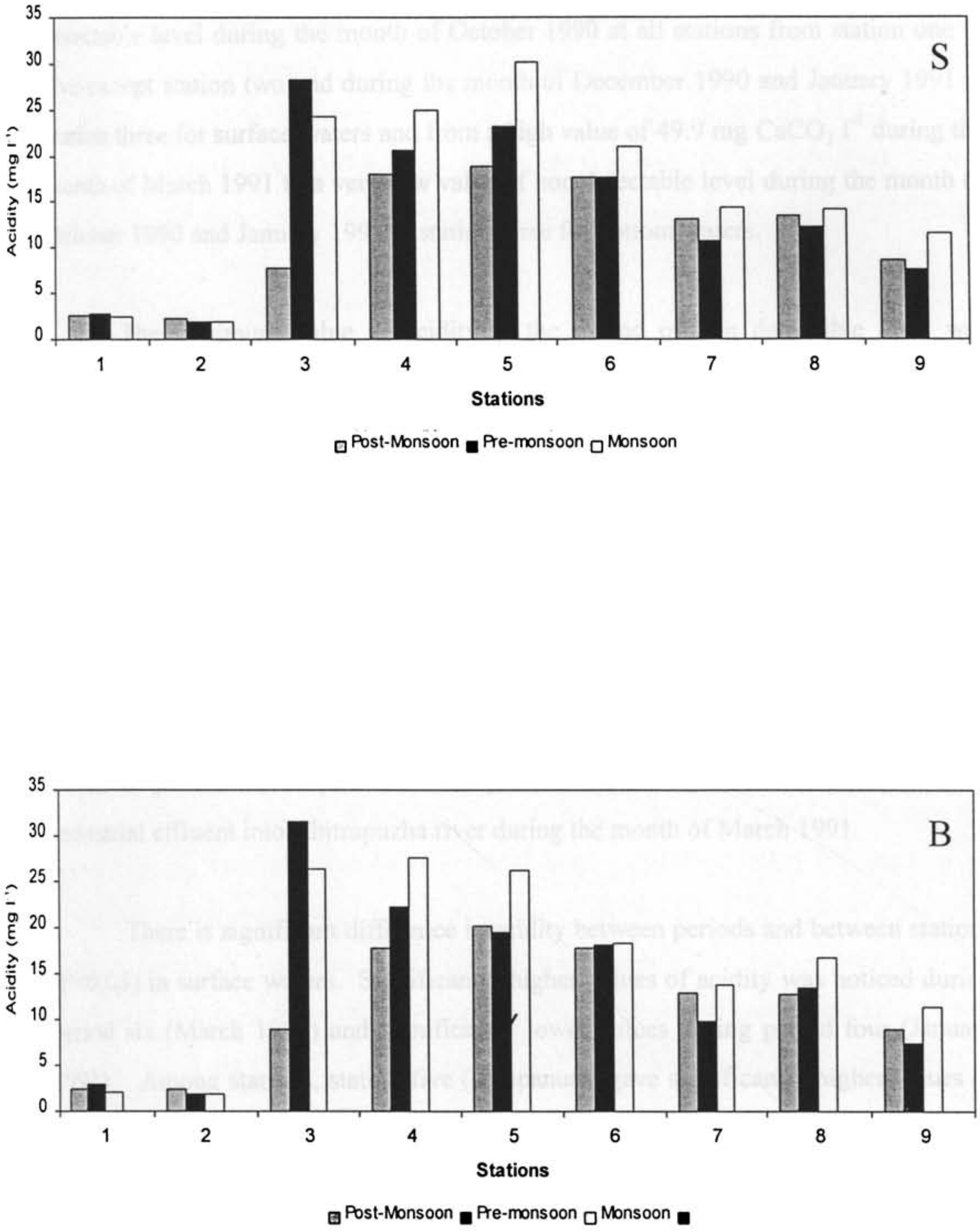


Fig. 3.5.2
Spacial variation of Acidity during different seasons

Total acidity upto pH 8.3 fluctuate widely from a high value of 49.8 mg $CaCO_3$ l^{-1} during the month of March 1991 at station three to a very low value of non detectable level during the month of October 1990 at all stations from station one to five except station two and during the month of December 1990 and January 1991 at station three for surface waters and from a high value of 49.9 mg $CaCO_3$ l^{-1} during the month of March 1991 to a very low value of non detectable level during the month of October 1990 and January 1991 at station three for bottom waters.

The minimum value of acidity to the extend of non detectable level was recorded for both surface and bottom waters during the month of October and December 1990 January 1991 at station three and a similar pattern in values of pH and redox potential during the same period at station three,which is close to the outlets of three major industrial units indicate discharge of some alkaline industrial effluent into Chitrapuzha river during the period.

The maximum values of 49.8 mg $CaCO_3$ l^{-1} at surface and 49.9 mg $CaCO_3$ l^{-1} at bottom during the month of March 1991 at station three and a similar pattern in the values of pH and redox potential clearly indicate discharge of some strongly acidic industrial effluent into Chitrapuzha river during the month of March 1991.

There is significant difference in acidity between periods and between stations ($P<0.05$) in surface waters. Significantly higher values of acidity was noticed during period six (March 1991) and significantly lower values during period four (January 1991). Among stations, station five (Irimpanum) gave significantly higher values of acidity and station two (Ambalamughal) gave significantly lower values.

Significant difference in acidity is observed between periods and between stations ($P<0.05$) in bottom waters. Period six (March 1991) gave significantly higher acidity and period four (January 1991) showed significantly lower acidity. Stations four (Brahmapuram) and five (Irimpanum) gave significantly higher acidity and stations two (Ambalamughal) and one (Manackakadavu) gave significantly lower acidity.

There is significant positive correlation of acidity with redox potential ($P<0.001$) and significant negative correlation with pH ($P<0.001$), alkalinity ($P<0.001$) and transparency ($P<0.001$) in surface waters. In bottom waters too there is significant positive correlation of acidity with redox potential ($P<0.001$) and significant negative correlation with pH ($P<0.001$) and alkalinity ($P<0.001$). There is significant positive correlation between acidity and temperature ($P<0.01$) in botom waters.

3.6. Alkalinity

Alkalinity or acid capacity of water is its capacity to neutralize a strong acid to a designated pH. It is generally imparted by the presence of salts of weak acids such as carbonates, bicarbonates, phosphates, borates, silicates etc. together with free hydroxyl ions in solution. However the alkalinity of fresh water is mainly due to carbonates and bicarbonates with little concentration of other anions which can cause alkalinity.

Determination of alkalinity of water is significant in many of its uses and treatment of natural waters and waste waters. Alkalinity may be used in the interpretation and control of waste water treatment processes. Domestic waste water has an alkalinity almost equal to that of water supply. On proper treatment with anaerobic digesters the alkalinity values may increase considerably and attain a high range of 2000 mg $CaCO_3\ l^{-1}$ to 4000 mg $CaCO_3\ l^{-1}$ (Pohland and Bloodgood 1963).

Data on methyl orange alkalinity or total alkalinity of the area under investigation are given in table 3.6.1 (Annexure). Distribution pattern and seasonal variations of total alkalinity at surface and bottom waters at all stations during the period of survey are given as figures 3.6.1,and 3.6.2.

Phenolphthalein alkalinity (upto pH 8.3) values were observed only at stations one, three, four and five. At station three phenolphthalein alkalinity was recorded

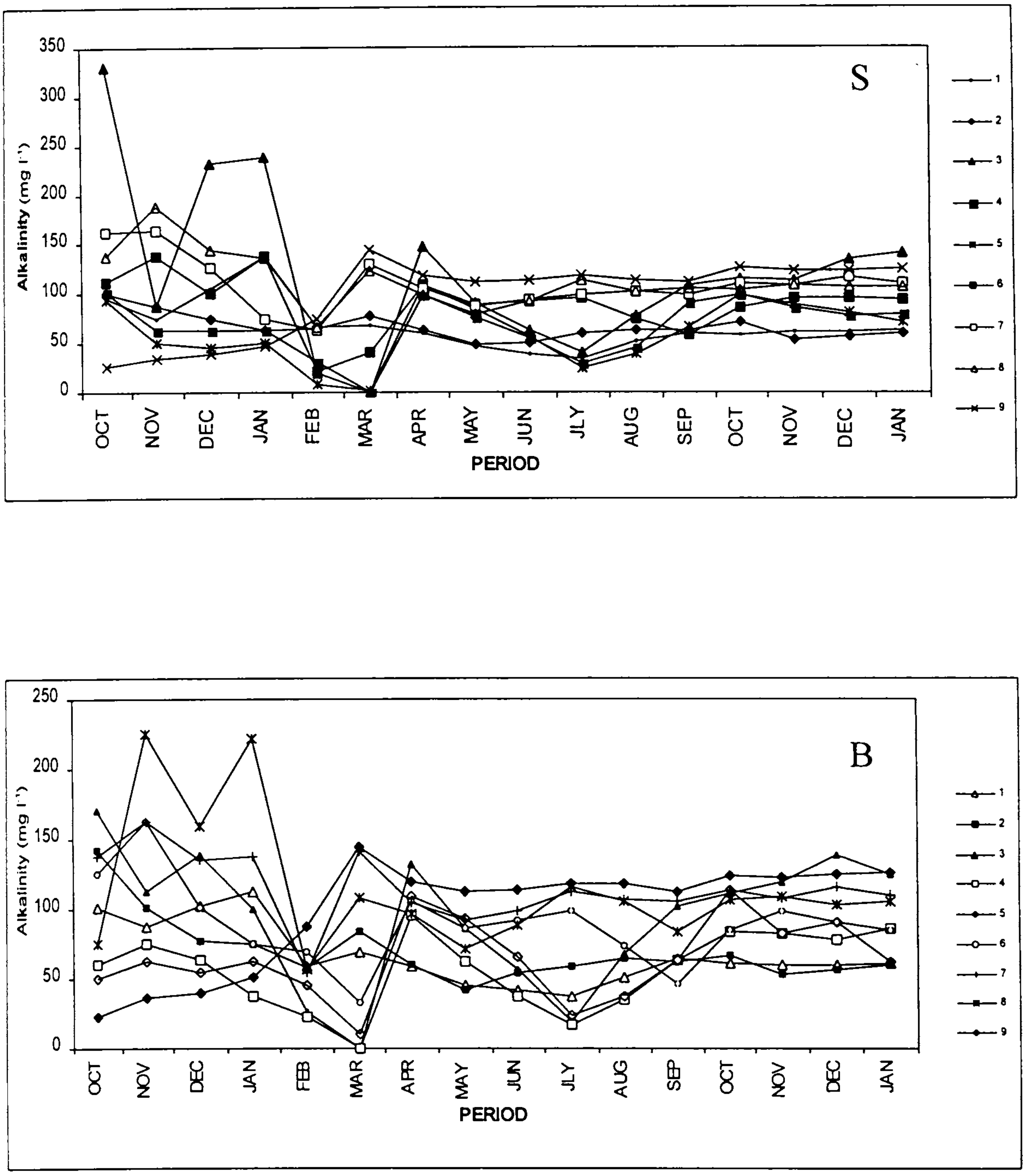


Fig. 3.6.1.
Monthly variation of Alkalinity at various stations
S-Surface B-Bottom

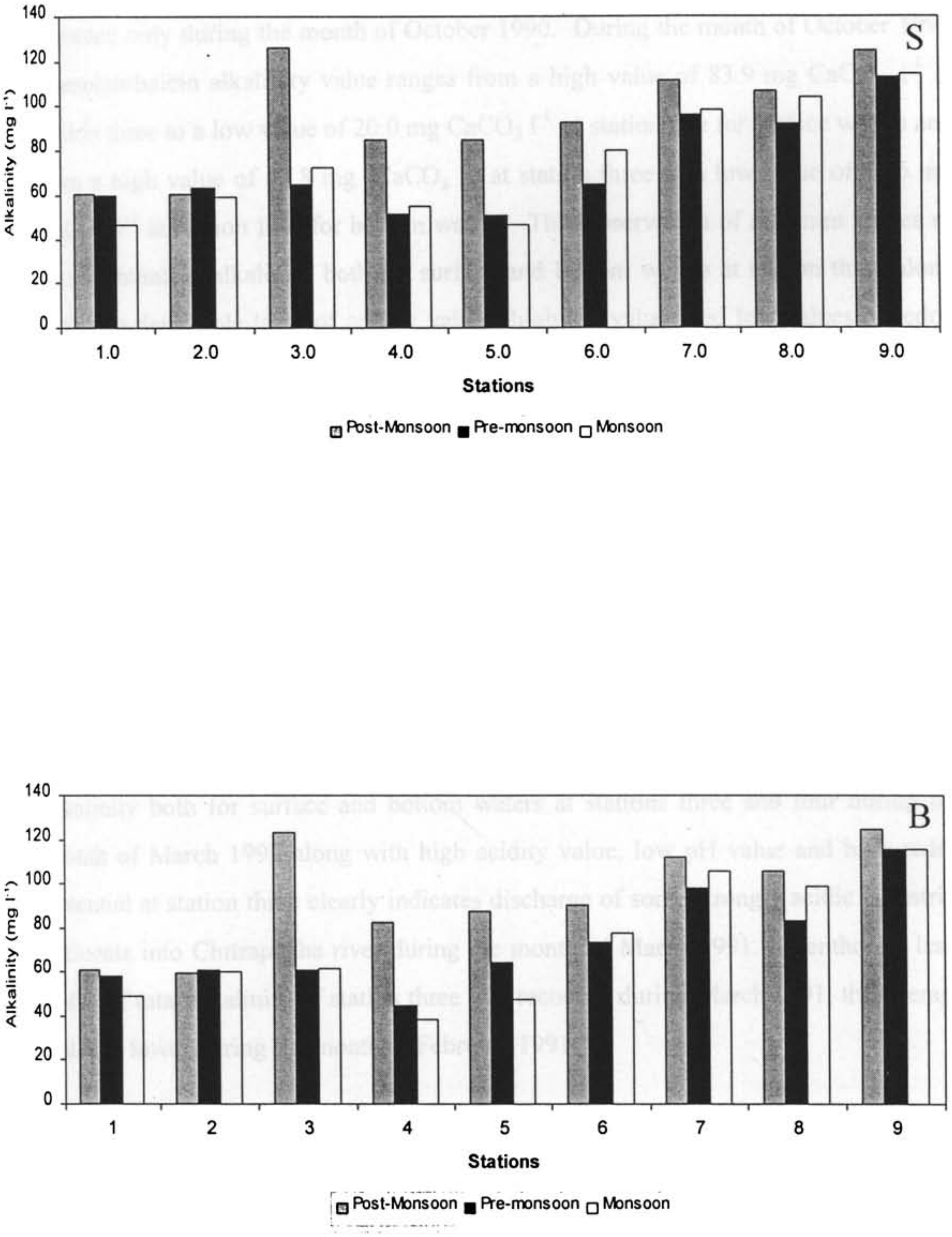


Fig. 3.6.2
Spacial variation of Alkalinity during different seasons

during the months of October and December 1990 and January 1991. At the remaining three stations i.e.station one, four and five, phenolphthalein alkalinity was recorded only during the month of October 1990. During the month of October 1990 Phenolphthalein alkalinity value ranges from a high value of 83.9 mg $CaCO_3$ l^{-1} at station three to a low value of 20.0 mg $CaCO_3$ l^{-1} at station one for surface waters and from a high value of 53.8 mg $CaCO_3$ l^{-1} at station three to a low value of 12.6 mg $CaCO_3$ l^{-1} at station four for bottom waters. This observation of maximm values of phenolphthalein alkalinity both for surface and bottom waters at station three along with non detectable level of acidity values, high pH values and low values of redox potential during the months of October and December 1990 and January 1991 clearly indicates discharge of some alkaline effluent into Chitrapuzha river during the period.

Total alkalinity (upto pH 3.7) fluctuate widely from a high value of 331.3 mg $CaCO_3$ l^{-1} at station three during the month of October 1990 to a very low value of non detectable level at station three and four during the month of March 1991 for surface waters and from a high value of 225.0 mg $CaCO_3$ l^{-1} at station eight during the month of November 1990 to a very low value of non detectable level at stations three and four during the month of March 1991. The minimum value of total alkalinity both for surface and bottom waters at stations three and four during the month of March 1991 along with high acidity value, low pH value and high redox potential at station three clearly indicates discharge of some strongly acidic industrial effluents into Chitrapuzha river during the month of March 1991. Eventhough least value of total alkalinity of station three was recorded during March 1991, the average value is lower during the month of February 1991.

The phenolphthalein alkalinity values recorded at station three during the months of October and Decembr 1990 and January 1991 and at stations one, four and five during the month of October 1990 are less than half of the total alkalinity values. Hence the alklinity due to hydroxyl ions at all stations during the period of survey was zero. Carbonate alkalinity is only two times the phenolphthalein alkalinity is also very low compared to bicarbonate alkalinity which is the major cause of alkalinity in the estuary under investigation.

Alkalinity shows significant variation between periods and between stations ($P<0.05$) in surface waters. Significantly higher alkalinity was noticed during period one (October 1990) and significantly lower alkalinity during period five (February 1991). Station three (Amabalamedu) gave significantly higher alkalinity and station five (Irimpanum) gave significantly lower alkalinity among stations.

Alkalinity shows significant variation between periods and between stations ($P<0.05$) in bottom waters. Period two (November 1990) gave signficantly higher alkalinity and period five (February 1991) gave significantly lower alkalinity. Among stations, stations seven (Tripunithura) and eight (Chambakara) showed significantly higher alkalinity and station four (Brahmapuram) showed significantly lower alkalinity.

There is significant positive correlation of alkalinity with pH ($P<0.001$) and significant negative correlation with redox potential ($P<0.001$), acidity ($P<0.001$) and dissolved oxygen ($P<0.01$) in surface waters. In bottom waters too there is significant positive correlation of alkalinity with pH ($P<0.001$) and significant negative correlation with redox potential ($P<0.001$) and acidity ($P<0.001$). The negative corrrelation of alkalinity with dissolved oxygen is not significant in bottom waters whereas the positive correlation with salinity ($P<0.01$) is significant in bottom waters.

3.7. Redox potential

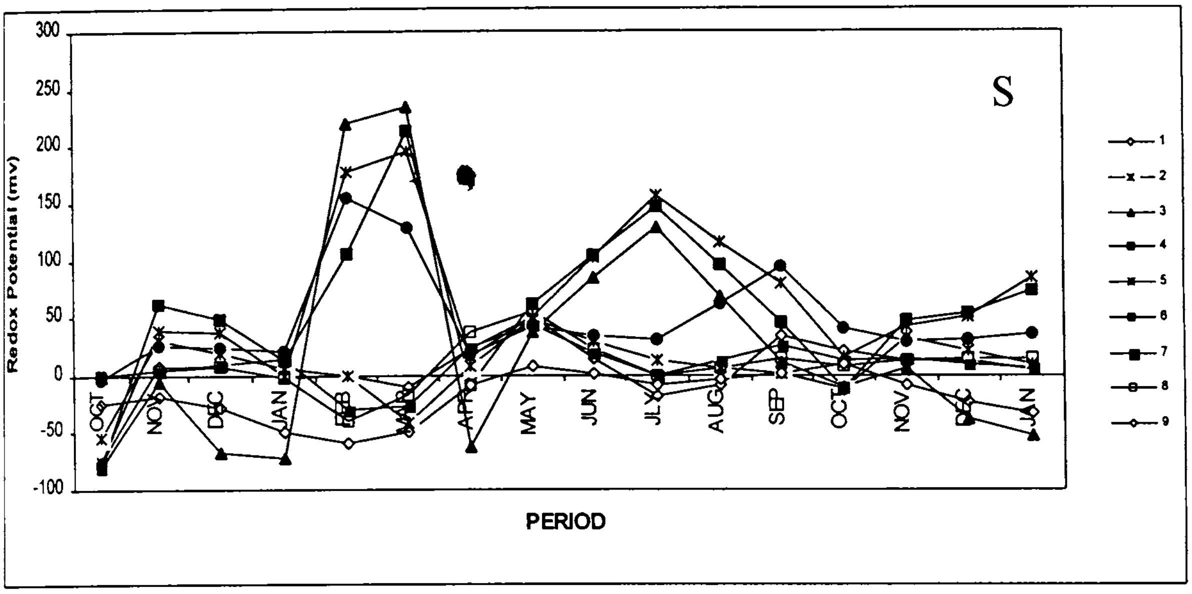
Reduction oxidation potential or redox potential is a measure of availability of electrons and their activity in water. It controls the competing processes of electron donation or reduction and electron acceptance or oxidation. Many chemical processes occuring in nature depend on the redox potential of the medium. All positive values of redox potential of the aqueous medium indicate greater reduction potential or weak oxidation potential causing an oxidising environment for chemical processes (aerobic processes). When the redox potential values are strongly negative in the range of -200 mv or less, the medium has stronger oxidation potential than reduction potential causing a reducing environment for chemical processes (anaerobic processes). Values between zero and -200 mv indicate transition character of the medium where aerobic or anaerobic processes may occur under such condition depending on other factors.

Redox potential of an estuary is an important factor which decides the status of many ions like nitrate, nitrite, sulphate, sulphite, sulphide etc.in solution, consequently which may affect concentration of many metal ions in solution. An anaerobic reducing condition in an ecosystem may lead to microbial conversion of sulphates to sulphides which may cause precipitation of metal ions such as mercury, cadmium, nickel etc. as their sulphides.

Data on redox potential or Eh of the area under investigation are given in table 3.7.1. (Annexure). Distribution pattern of Eh at surface and bottom waters at all stations during the period of survey is given as Fig.3.7.1. and 3.7.2. The Eh values fluctuate between 235 mv during March 1991 and -81 mv during October 1991 at surface and 237 mv during March 1991 and -86 mv during December 1991. The minimum monthly average value was recorded during October 1991. Both the maximum and the minimum values were observed at station three for surface and bottom waters. Most of the values indicate aerobic processes while the remaining values are of transitional character. No value is less than -200 mv indicating the absence of anerobic condition in the area under the study during the period of survey.

There is significant difference in redox potential of surface waters between periods and between stations in the case of redox potential also ($P<0.05$). Significantly higher positive redox potential during period six (March 1991) and significantly lower negative redox potential during period one (October 1990) were observed. Station five (Irimpanum) showed significantly higher positive redox potential while station nine (Thevara) exhibited significantly lower negative redox potential.

Significant difference in redox potential of bottom waters is observed in redox potential between periods and between stations ($P<0.05$). Significantly higher positive redox potential was observed during period six (March 1991) and significantly lower



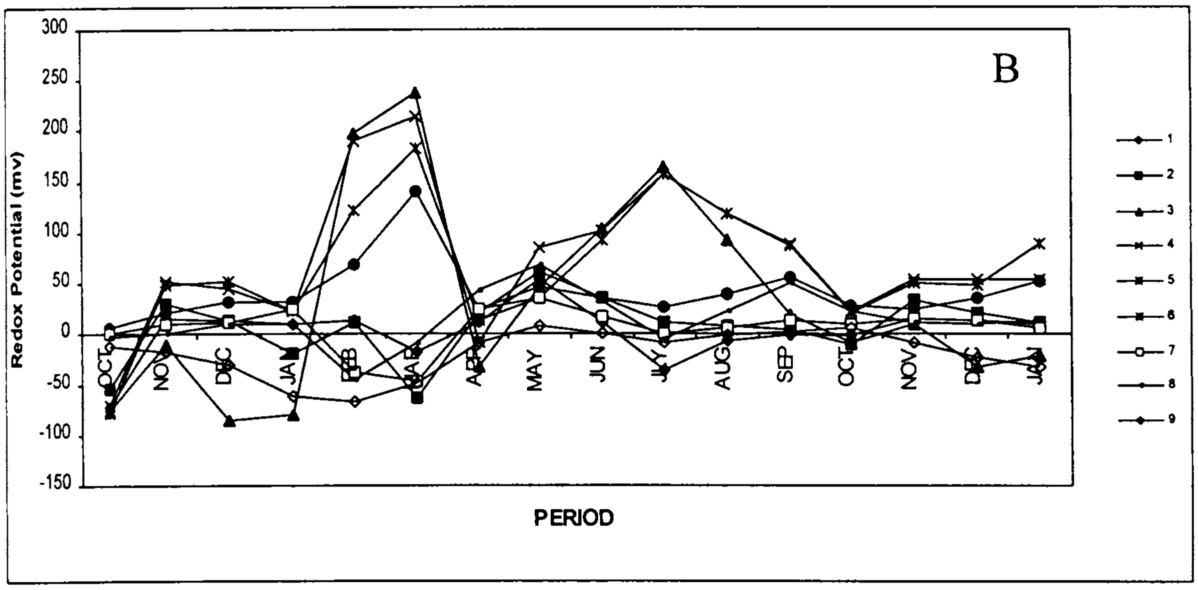


Fig. 3.7.1.
Monthly variation of Redox Potential at various stations
S-Surface B-Bottom

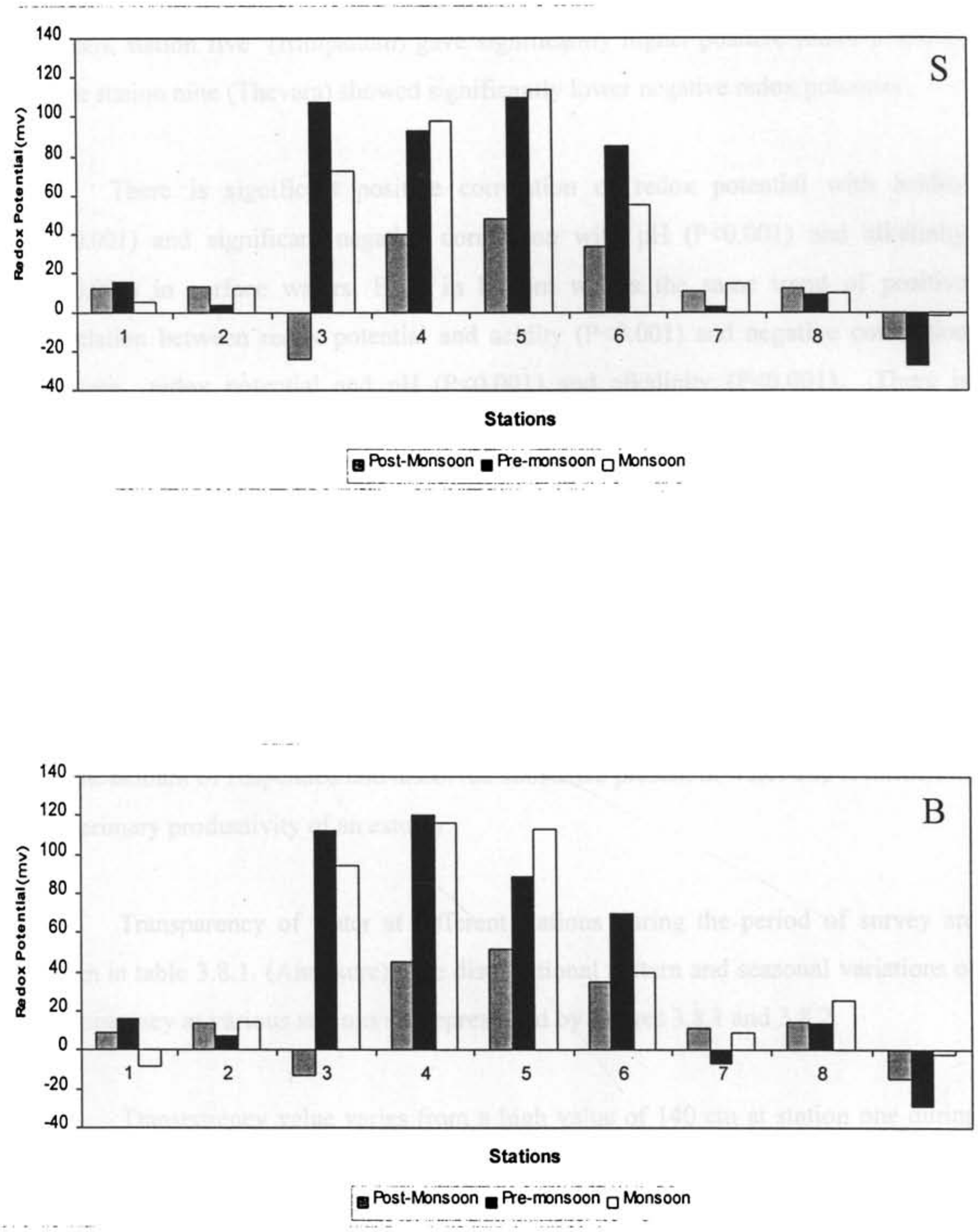


Fig. 3.7.2

Spacial variation of Redox Potential during different seasons negative redox potential was observed during period one (October 1990). Among stations, station five (Irimpanum) gave significantly higher positive redox potential while station nine (Thevara) showed significantly lower negative redox potential.

There is significant positive correlation of redox potential with acidity ($P<0.001$) and significant negative correlation with pH ($P<0.001$) and alkalinity ($P<0.001$) in surface waters. Even in bottom waters the same trend of positive correlation between redox potential and acidity ($P<0.001$) and negative correlation between redox potential and pH ($P<0.001$) and alkalinity ($P<0.001$). There is signficant positive correlation between redox potential and temperature ($P<0.01$) in bottom waters while the positive correlation between the above two parameters is not significant in surface waters.

3.8. Transparency

Transparency of water is a measure of light penetration which mainly depends on the amount of suspended and dissolved substance present in water and it influences the primary productivity of an estuary.

Transparency of water at different stations during the period of survey are given in table 3.8.1. (Annexure), The distributional pattern and seasonal variations of transparency at various stations are represented by figures 3.8.1 and 3.8.2.

Transparency value varies from a high value of 140 cm at station one during November 1990 to a low value of 22 cm at station four during February 1991 eventhough a minimum average transparency was recorded during March 1991, high values were observed during post-monsoon periods and low values are observed during pre-monsoon periods at all stations except at station eight and nine. Low values of transparency during pre monsoon periods may be explained as due to intrusion of sea water through the shallow river causing thorough mixing up of water. High values of transparency during post-monsoon periods may be due to influx of clear fresh water through the river.

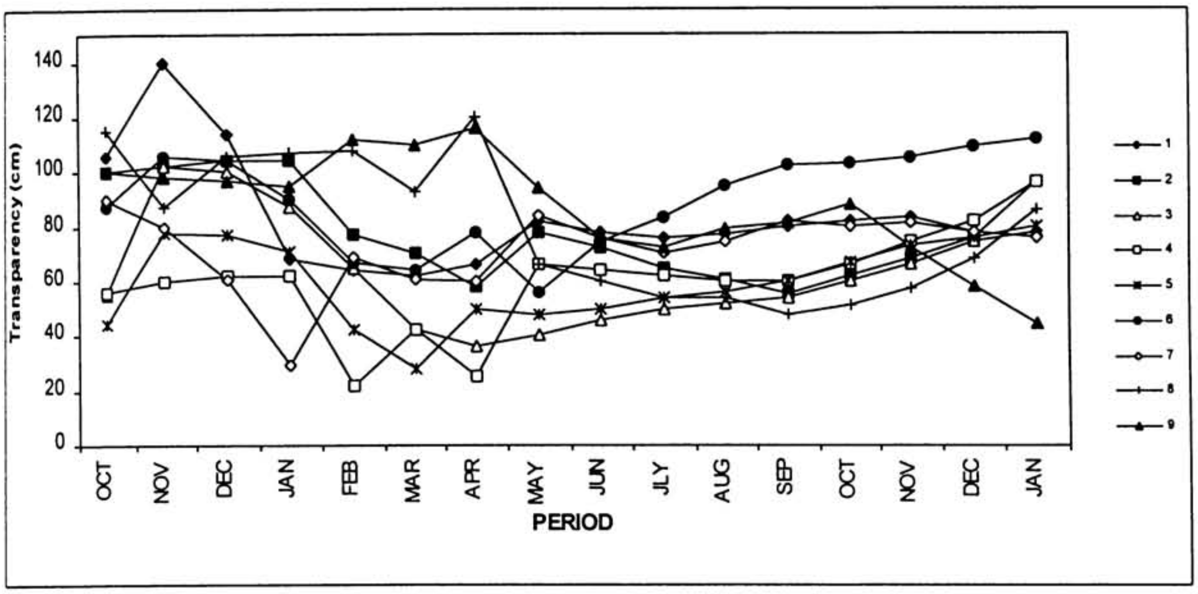


Fig. 3.8.1.
Monthly variation of Transparency at various stations

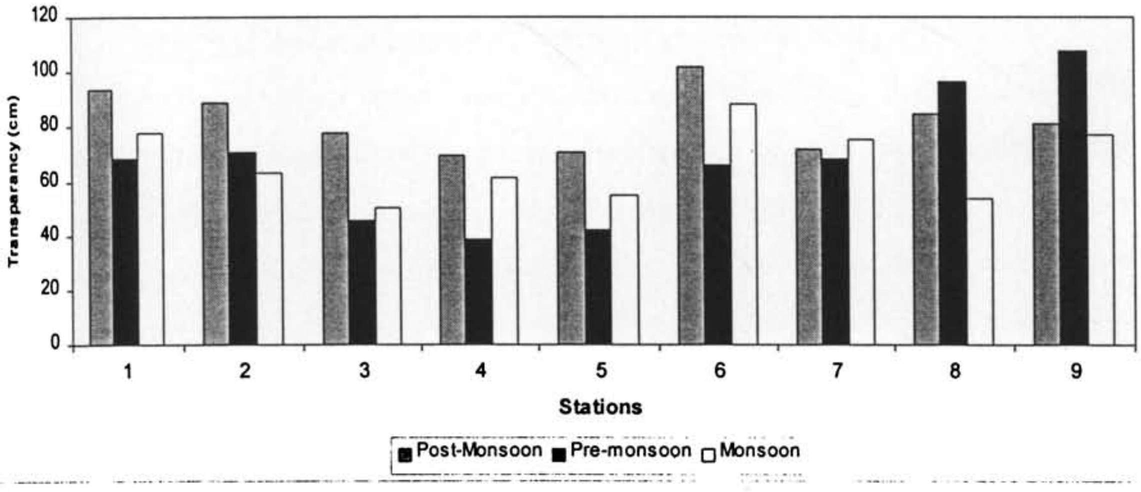


Fig. 3.8.2
Spacial variation of Transparency during different seasons

There is significant difference between periods and between stations in transparency values ($P<0.05$). Significantly higher value was observed during the period two (November 1990) and significantly lower value was shown during the period six (March 1991). Among stations, station six (Eroor) gave significantly higher value and station five (Irimpanum) showed significantly lower value of transparency.

There is significant positive correlation of transparency with pH ($P<0.001$) and salinity ($P<0.01$) and significant negative correlation with temperature ($P<0.001$), acidity ($P<0.001$) and redox potential ($P<0.001$).

CHAPTER 4

NITROGEN

4.1 Nitrate - Nitrogen

4.2 Nitrite - Nitrogen

4.3 Ammonia - Nitrogen

4.4. Total soluble inorganic Nitrogen.

Nitrogen exists in nine oxidation states (from +5 to -3), all of which have significant roles in the marine environment (Martin, 1970). The hydrosphere contains about 23 x 10^{12} tons of nitrogen in soluble form which represent only about 0.5% of the total available nitrogen on the globe. Nitrate and nitrite constitute about 65% of the soluble form of nitrogen (Martin , 1970). The concentrations of various forms of nitrogen in an estuary at a given time is controlled by factors like input rates, the interconversion reactions occurring within the water column, incoming tides, freshwater discharge, denitrification, deposition etc.

Thermodynamically nitrate (with nitrogen in an oxidation state of +5) is considered as the most stable form of nitrogen, in presence of oxygen in sea water (Sillen, 1961, Grasshoff, 1983). Most natural waters contain some nitrate ions, but their concentrations are generally very low, usually less than 1 mg l^{-1} . However, considerable contribution of nitrate ions occur from anthropogenic sources. Human and animal waste, fertilizers and some industrial waste effluents, particularly from fertilizer plants can contribute substantial amounts of nitrate ions to the aquatic system. Since high nitrate ion concentrations affect the oxygen carrying capacity of blood (methemoglobinemia) an upper limit of 10 mg $NO_3^-.N$ l^{-1} is recommended by most authorities. Many estuaries receive considerable amounts of atmospheric nitrogen, usually in the form of nitrate, derived largely from land drainage, agricultural run off and application of nitrogenous fertilizers (Cole and Gessel, 1965).

Nitrate is removed from estuaries by biological utilization (i.e. uptake by autotrophs and denitrification by bacteria. Hill (1979) recognised the possibility of denitrification in silt/mud sediment which may result in the loss of nitrate from stream waters despite the fact that the water is well oxygenated. But Desousa *et. al.*,(1981) stated that nitrate loss due to denitrification could be ruled out in shallow and well oxygenated estuaries. Denitrification when occurs is dependent upon the concentration of nitrate ions in overlying waters and logarithmically related to the concentration of nitrate reducing bacteria. Levels of nitrate values reported in most estuarine waters range between 10.0 and 40.0 μg at Nl $^{-1}$. (Sharp, 1983), though higher values of more than 100 μg at Nl $^{-1}$ are also reported (Meybeck,1982).

Nitrite (nitrogen with oxidation number of +3) is formed during the oxidation of ammonia to nitrate and during reduction of nitrate to ammonia. Nitrites can enter the aquatic system through effluents from industries using nitrites as corrosion inhibitors (Owens, 1978) and certain biologically purified wastes which may also contain large amounts of nitrites. In most estuaries except which are subjected to discharge of sewage and industrial effluents, nitrite concentration seldom exceeds 10% of the total oxidised nitrogen (Head, 1985). Levels of nitrite concentration in estuaries range between 0.5 to 6.0 μg at N l^{-1} and is usually very high when compared to sea water in which it is <0.1 μg at N l^{-1}. Nitrite concentration of some estuaries in Kerala as reported by Sarala Devi *et. al.*, (1983) range between 0.05 to 2.16 μg at N l $^{-1}$.

Nitrite is unstable in the presence of oxygen and hence occurs mainly as an intermediate form between ammonia and nitrate. Only minute quantities occur in surface water where dissolved oxygen is comparatively high. However, discharge of industrial effluents or nitrite containing effluents from sewage plants may cause increase in the concentration levels of nitrite which can eventually affect the water quality. Nitrite is much more toxic to man and animals than nitrate.

Ammonia (nitrogen with an oxidation number of -3) occurs in two forms- the toxic unionised ammonia and the non toxic ammonium ions in an equilibrium which is pH and temperature dependent.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^- .$$

As pH increases, concentration of unionised ammonia (NH_3) increases relative to ionised ammonium (NH_4^+) ions.

Ammonia is the first inorganic product formed during regeneration of nitrogen from organic compounds. An increase in concentration of ammonia in estuarine water is observed when aquatic organisms are dying off. At the same time it has been shown to be the most preferred form of nitrogen for planktonic assimilation and it inhibits the utilization of other forms such as nitrite and nitrate in its presence (Mc Carthy *et. al.*, 1977). In the estuaries of Kerala the reported values of ammonia range from 3 to 15 µg at N l^{-1} (Sarala Devi *et. al.*, 1983).

Several investigators have reported that nitrogen is the limiting nutrient to primary productivity in marine and estuarine systems (Ryther and Dunstan, 1971; Nixon and Pilson, 1983). So the primary productivity of an estuary depends on the effectiveness of regeneration of nitrogen in the required form on a rapid lime scale and the supply of new nitrogen from marine and riverine sources (Aston,1980).

Studies on variations in concentrations of different nitrogen species with time and space were carried out at Pamlico river estuary (Hobbie *et. al.*, 1975), Clyde estuary (Mackay and Leatherland, 1976), Mississippi river estuaries (Ho and Barrett, 1977), Tamar estuary (Morris *et. al.*, 1981), Morlaix estuaries (Wafar, 1981), Himmerfjard estuaries (Wilmost *et. al.*, 1985) and Rhode river estuary (Jordan *et al*, 1991). Maguer *et.al.*, (1996); Couwet and Sidorov, (1996); Satpathy, (1996) and Sanders *et.al.*, (1997) have also reported seasonal variations in concentration of nutrients.

In India studies in the variations of different forms of nitrogenous compounds were done in Cochin estuary (Sankaranarayanan and Qasim,1969; Manikoth and Salih, 1974; Lakshmanan *et. al.*, 1987; Anirudhan,1988), in Mandovi Zuari estuarine system (De Sousa *et. al.*, 1981; De Sousa, 1983) and Mahanadi estuary (Sen Gupta and Upadhyay 1987).

4.1. Nitrate Nitrogen

The nitrate concentrations in surface and bottom waters at all stations during the period of survey are given in table 4.1.1. The distribution pattern of nitrite nitrogen in surface and bottom waters are represented in figures 4.1.1. and 4.1.2 respectively. Representative seasonal distribution of nitrate nitrogen in surface and bottom waters are also given in figure 4.1.3. and 4.1.4.

The nitrate concentrations at stations one and two are lower than all other stations during the period of survey and it varied from 560 $\mu g\ NO_3^-\ N\ l^{-1}$ to 240 $\mu g\ NO_3^-\ N\ l^{-1}$ in surface waters and from 470 $\mu g\ NO_3^-\ N\ l^{-1}$ to 280 $\mu g\ NO_3^-\ N\ l^{-1}$ in bottom waters during post-monsoon period, from 840 $\mu g\ NO_3^-\ N\ l^{-1}$ to 270 $\mu g\ NO_3^-\ N\ l^{-1}$ in surface waters and from 840 $\mu g\ NO_3^-\ N\ l^{-1}$ to 280 $\mu g\ NO_3^-\ N\ l^{-1}$ in bottom waters during pre-monsoon period and from 1120 $\mu g\ NO_3^-\ N\ l^{-1}$ to 700 $\mu g\ NO_3\ N\ l^{-}$ in surface waters and from 980 $\mu g\ NO_3^-\ N\ l^{-1}$ to 420 $\mu g\ NO_3^-\ N\ l^{-1}$ in bottom waters. High concentration of nitrate during monsoon period reflect the general trend of nitrate leaching from land drainage reaching the river waters.

Very high values of nitrate concentration were observed from station three to station five in the diminishing order during the month of October 1990. The observed values are 9960, 9920 and 9620 $\mu g\ NO_3^-\ N\ l\text{-}^{1}$ in surface waters and 10390, 9540 and 9220 $\mu g\ NO_3^-\ N\ l^{-1}$ in bottom waters at stations three, four and five respectively and some of these values exceeds the upper limit proposed by Rand *et. al.*, (1976) for drinking water to prevent infant methemoglobinemia. Nitrate concentration at all stations from station six to station nine are slightly higher than the normal range of

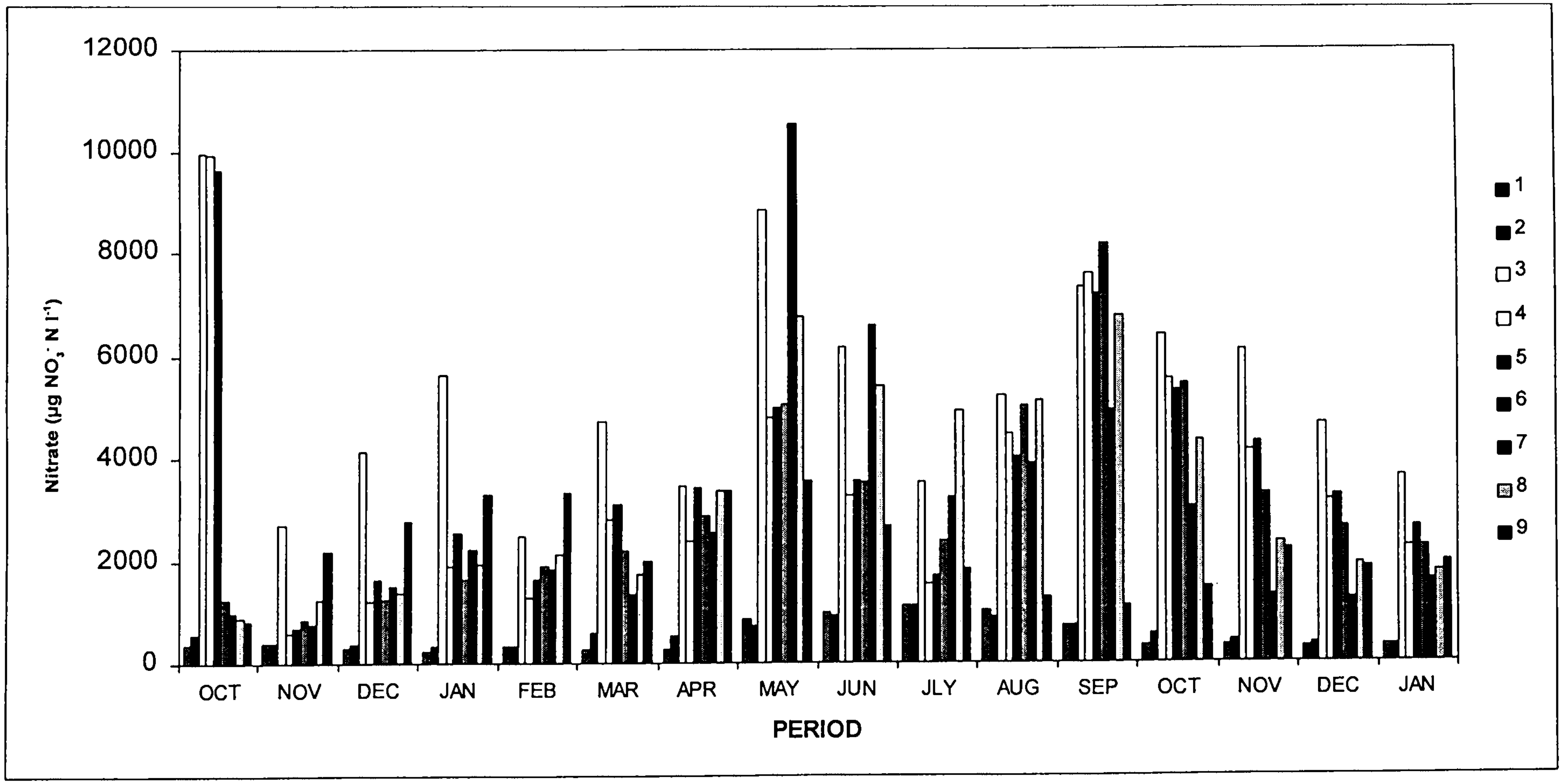


Fig. 4.1.1
Monthly variation of Nitrate at various stations
Surface

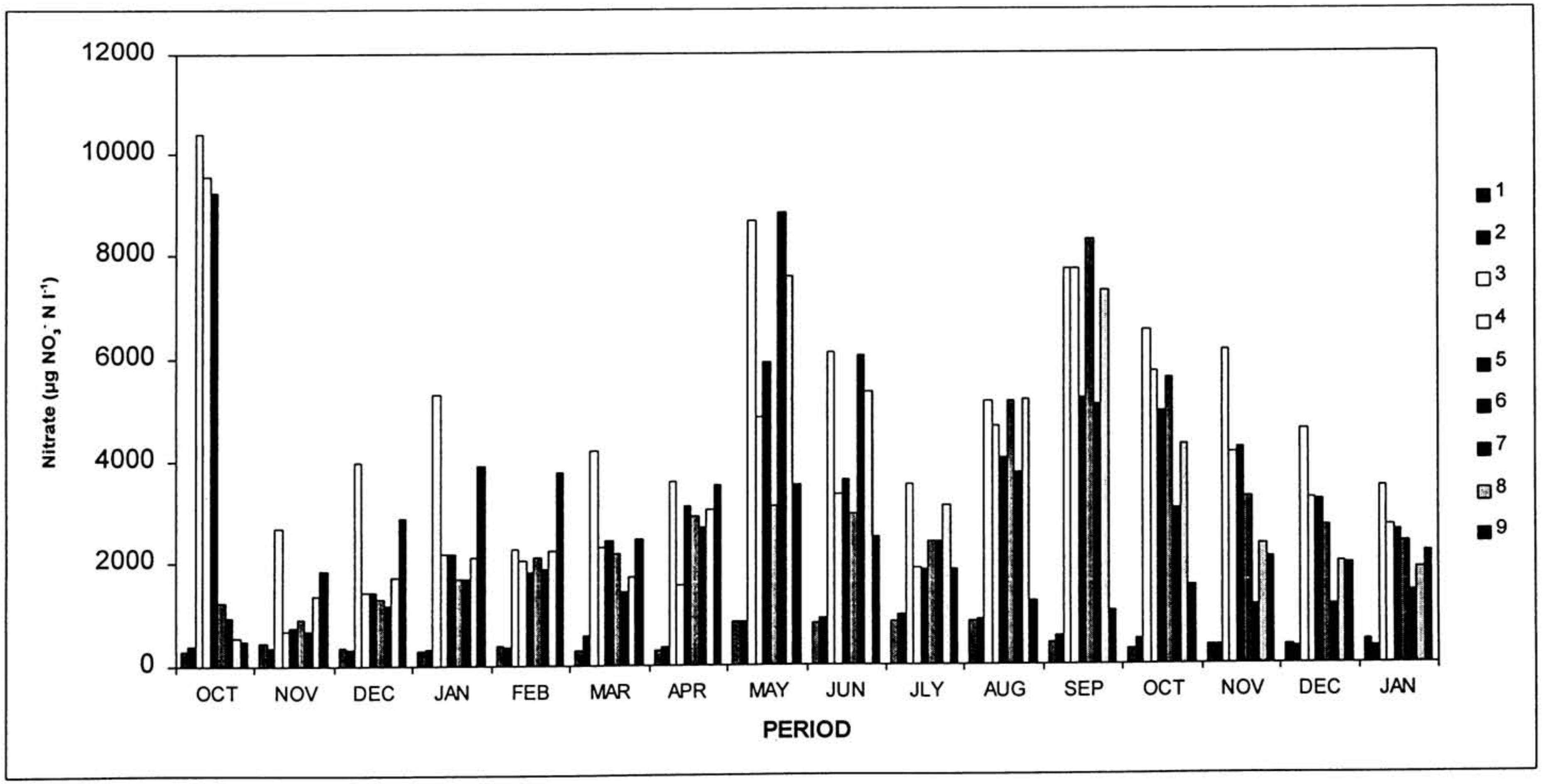


Fig. 4.1.2
Monthly variation of Nitrate at various stations
Bottom

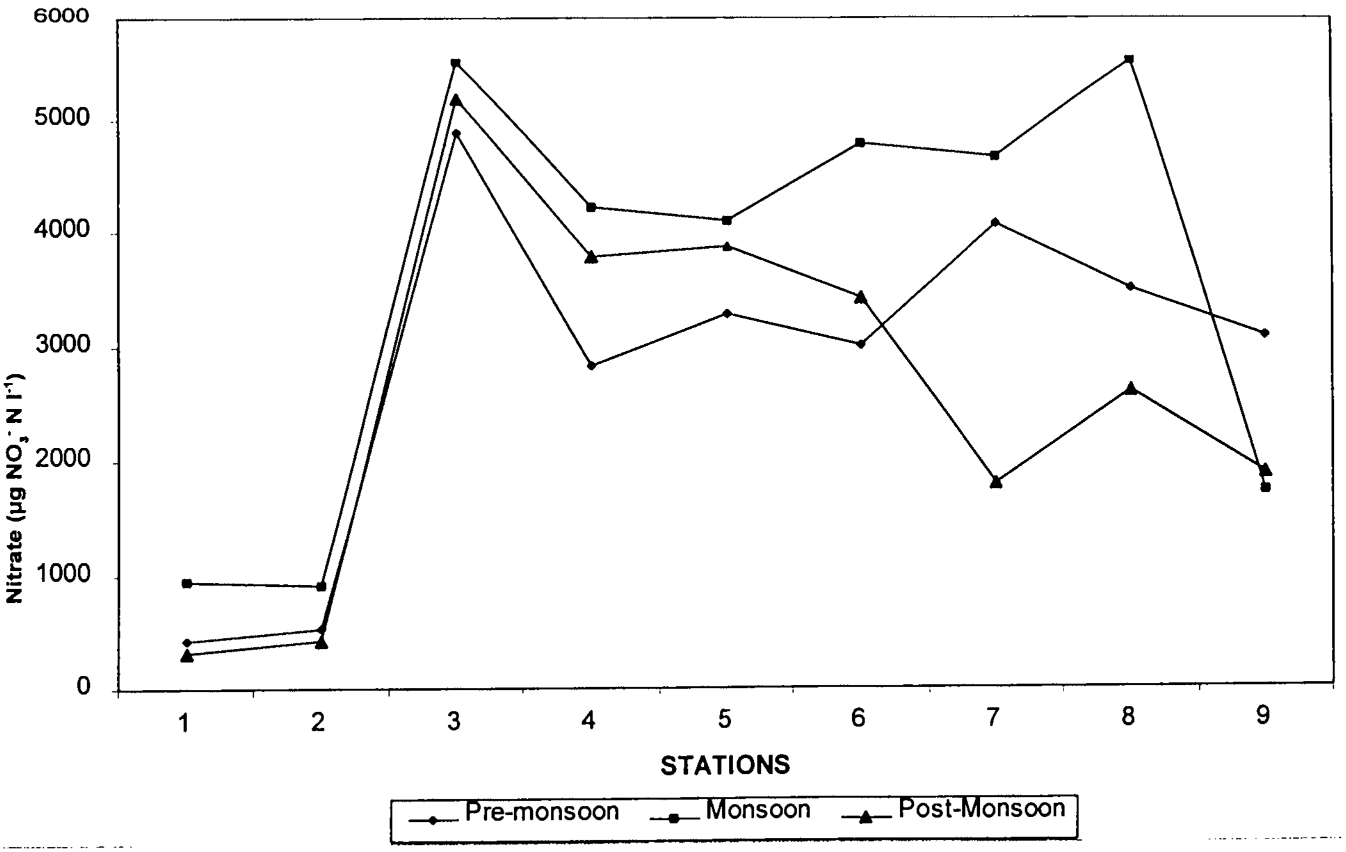


Fig. 4.1.3
Spacial variation of Nitrate during different seasons
Surface

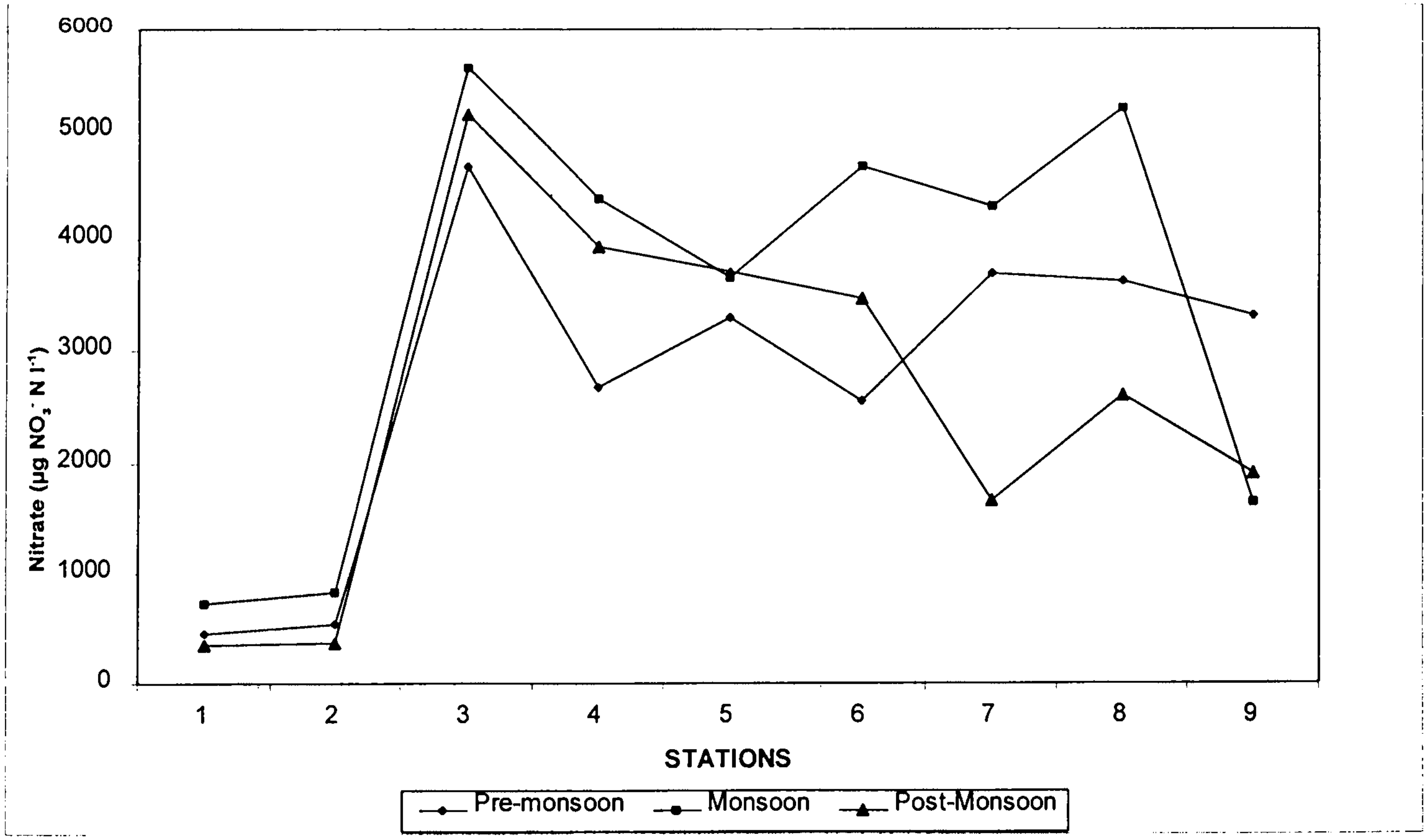


Fig. 4.1.4
Spacial variation of Nitrate during different seasons
Bottom

values with the same pattern of diminishing order with the highest values of 1240 and 1210 µg NO_3^- N l^{-1} in surface and bottom waters respectively at station six and the lowest value of 800 and 470 µg NO_3^-N l^{-1} in surface and bottom waters respectively at station nine. Nitrate ion concentration with abnormally high values at station three and the diminishing trend from station three to station nine clearly indicates external addition of some effluents rich in nitrogenous compounds into the estuary around station three during the month of October 1990.

A general pattern in nitrate ion concentration with normal values at stations one and two, then a drastic increase at station three and then gradual decrease at all stations from station three to station nine, irrespective of the seasonal changes was observed during the period of survey. Maximum variation was observed at station three during the month of October 1990 though the average value of nitrate concentration was higher during May 1991. This is followed by May, September, October, June, November 1991 in that order. Such irregular variations were observed with lesser magnitude during the entire period of survey from October 1990 to January 1992. All these observations clearly indicate the discharge of some effluents with very high proportion of nitrogenous compounds into the estuary during the period of investigation causing water pollution. Station seven which is not along the main river shows extremely high variation in concentration of nitrate during the month of May 1991. This may be explained as due to the addition of nitrate through agricultural runoff and municipal sewage.

There is significant difference in nitrate nitrogen between periods and between stations ($P<0.05$) in surface waters. Period eight (May 1991) has significantly higher value while period two (November 1990) has significantly lower value. Among stations, station three (Ambalamedu) has significantly higher value and station one (Manackakadavu) has significantly lower value.

There is significant difference in nitrate concentration between periods and between stations ($P<0.05$) in bottom waters. Significantly higher values were observed during period eight (May 1991) and period twelve (September 1991) while significantly lower value was noted during period two (November 1990). Station three (Ambalamedu) gave significantly higher concentration of nitrate nitrogen while stations one (Manackakadavu) and two (Amabalamughal) gave significantly lower values.

To study the dependency of concentration of nitrate, nitrite and ammonia on different hydrographic paramaters, matrix of correlation was formed separetely for surface and bottom waters which are given in tables 4.1.5 and 4.1.6 respectively.

There is significant positive correlation of nitrate concentration with acidity ($P<0.001$); ammonia concentration ($P<0.001$), nitrite concentration ($P<0.001$), total soluble inorganic nitrogenous nutrients ($P<0.001$) and alkalinity ($P<0.01$) and significant negative correlation with the ratio of nitrite concentration to total inorganic nitrogen ($P<0.001$) in surface waters. The positive correlation of nitrate concentration with nitrite concentration and acidity is significant during the whole period of observation while the positive correlation with ammonia concentration is significant only during monsoon and post-monsoon periods and is not significant during pre-monsoon periods. On the other hand the negative correlation between nitrate concentration and dissolved oxygen is significant during pre-monsoon while it is not significant during monsoon and post-monsoon periods.

A similar pattern of correlation of nitrate concentration with the above parameters is observed in bottom waters. There is significant positive correlation between nitrate concentration with acidity ($P<0.001$), ammonia concentration ($P<0.001$), nitrite concentration ($P<0.001$), total soluble inorganic nitrogenous nutrients ($P<0.001$) and temperature ($P<0.01$) and significant negative correlation with the ratio of nitrite nitrogen concentration to total inorganic nitrogen ($P<0.01$) in bottom waters. The positive correlation of nitrate with nitrite is significant during the entire period of observation, while the positive correlation with ammonia and acidity is significant only during monsoon and post-monsoon periods and is not significant during pre-monsoon periods. On the contrary the negative correlation with dissolved oxygen is significant during pre-monsoon periods while it is not significant during

4.2.5 : Matrix of Correlation of Different Hydrographic Parammeters in Surface Water

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Correlations:  TEMPERAT    SALINITY    DO          PH          ACIDITY     ALKALINE

 TEMPERAT     1.0000      -.2390*      .1393      -.1373       .1509      -.1234
 SALINITY     -.2390*     1.0000      -.3300**     .1424      -.0687       .1053
 DO            .1393      -.3300**    1.0000      -.0083      -.0765      -.2423*
 PH           -.1373       .1424      -.0083      1.0000      -.7969**     .6181**
 ACIDITY       .1509      -.0687      -.0765      -.7969**    1.0000      -.3585**
 ALKALINE     -.1234       .1053      -.2423*      .6181**    -.3585**    1.0000
 REDOX_PO      .1592      -.1626       .0335      -.9850**     .8123**    -.6021**
 TRANSPAR     -.3385**     .1949*     -.0940       .3116**    -.2822**     .1936
 AMMONIA       .0234       .1295      -.0545       .0149       .2001*      .1827
 NITRITE       .0443      -.2292*     -.1308      -.2430*      .4393**     .0727
 NITRATE       .1914      -.0643      -.1637      -.0138       .3319**     .2292*
 TOTAL_N       .1616      -.0722      -.1589      -.0520       .3670**     .2170*
 NH3N_TN      -.1154       .5092**    -.2073*     -.0418       .1274       .1560
 NO2N_TN      -.2473*     -.2156*     -.1332      -.2175*      .0753      -.1252
 NO3N_TN       .2911**    -.0378       .2262*      .2275*     -.1327       .0449

Correlations:  REDOX_PO    TRANSPAR    AMMONIA     NITRITE     NITRATE     TOTAL_N

 TEMPERAT      .1592      -.3385**     .0234       .0443       .1914       .1616
 SALINITY     -.1626       .1949*      .1295      -.2292*     -.0643      -.0722
 DO            .0335      -.0940      -.0545      -.1308      -.1637      -.1589
 PH           -.9850**     .3116**     .0149      -.2430*     -.0138      -.0520
 ACIDITY       .8123**    -.2822**     .2001*      .4393**     .3319**     .3670**
 ALKALINE     -.6021**     .1936       .1827       .0727       .2292*      .2170*
 REDOX_PO     1.0000      -.3184**     .0088       .2550*      .0242       .0662
 TRANSPAR     -.3184**    1.0000      -.1056      -.3969**    -.2778**    -.3036**
 AMMONIA       .0088      -.1056      1.0000       .5042**     .6457**     .7443**
 NITRITE       .2550*     -.3969**     .5042**    1.0000       .5810**     .7083**
 NITRATE       .0242      -.2778**     .6457**     .5810**    1.0000       .9783**
 TOTAL_N       .0662      -.3036**     .7443**     .7083**     .9783**    1.0000
 NH3N_TN       .0446       .1250       .7350**     .1818       .1789       .2836**
 NO2N_TN       .2075*     -.1293      -.1836       .4432**    -.2788**    -.1653
 NO3N_TN      -.2193*      .0635      -.1763      -.5098**     .1804       .0221


Correlations:  NH3N_TN     NO2N_TN     NO3N_TN

 TEMPERAT     -.1154      -.2473*      .2911**
 SALINITY      .5092**    -.2156*     -.0378
 DO           -.2073*     -.1332       .2262*
 PH           -.0418      -.2175*      .2275*
 ACIDITY       .1274       .0753      -.1327
 ALKALINE      .1560      -.1252       .0449
 REDOX_PO      .0446       .2075*     -.2193*
 TRANSPAR      .1250      -.1293       .0635
 AMMONIA       .7350**    -.1836      -.1763
 NITRITE       .1818       .4432**    -.5098**
 NITRATE       .1789      -.2788**     .1804
 TOTAL_N       .2836**    -.1653       .0221
 NH3N_TN      1.0000      -.1519      -.3333**
 NO2N_TN      -.1519      1.0000      -.8813**
 NO3N_TN      -.3333**    -.8813**    1.0000

1-tailed Signif:  * - .01   ** - .001
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Correlations:  TEMPERAT   SALINITY   DO         PH         ACIDITY    ALKALINE

TEMPERAT       1.0000     -.0684     -.1149     -.2400*     .2544*    -.1810
SALINITY       -.0684     1.0000     -.2701**    .1421     -.0614      .2081*
DO             -.1149     -.2701**   1.0000      .1477     -.1839     -.1443
PH             -.2400*     .1421      .1477     1.0000     -.7908**    .5487**
ACIDITY         .2544*    -.0614     -.1839     -.7908**   1.0000     -.3298**
ALKALINE       -.1810      .2081*    -.1443      .5487**   -.3298**   1.0000
REDOX_PO        .2375*    -.1629     -.1302     -.9788**    .7963**   -.5363**
AMMONIA         .1134      .1604      .0085      .0525      .1557      .1160
NITRITE         .0637     -.2310*    -.1597     -.2454*     .4132**   -.0626
NITRATE         .2360*    -.0327     -.0525     -.0378      .3324**    .0411
TOTAL_N         .2122*    -.0495     -.0683     -.0685      .3589**    .0354
NH3N_TN         .0573      .5528**   -.2628**    .0301      .0744      .2164*
NO2N_TN        -.2673**   -.2377*    -.1429     -.2199*     .0978     -.0795
NO3N_TN         .2329*    -.0157      .2548*     .1992*    -.1276     -.0192

Correlations:  REDOX_PO   AMMONIA    NITRITE    NITRATE    TOTAL_N    NH3N_TN

TEMPERAT        .2375*     .1134      .0637      .2360*     .2122*     .0573
SALINITY       -.1629      .1604     -.2310*    -.0327     -.0495      .5528**
DO             -.1302      .0085     -.1597     -.0525     -.0683     -.2628**
PH             -.9788**    .0525     -.2454*    -.0378     -.0685      .0301
ACIDITY         .7963**    .1557      .4132**    .3324**    .3589**    .0744
ALKALINE       -.5363**    .1160     -.0626      .0411      .0354      .2164*
REDOX_PO       1.0000     -.0281      .2775**    .0543      .0913     -.0327
AMMONIA        -.0281     1.0000      .5104**    .6556**    .7496**    .7101**
NITRITE         .2775**    .5104**   1.0000      .5740**    .7141**    .1654
NITRATE         .0543      .6556**    .5740**   1.0000      .9762**    .1861
TOTAL_N         .0913      .7496**    .7141**    .9762**   1.0000      .2772**
NH3N_TN        -.0327      .7101**    .1654      .1861      .2772**   1.0000
NO2N_TN         .2248*    -.1553      .4614**   -.2535*    -.1254     -.1530
NO3N_TN        -.2028*    -.1652     -.5194**    .1624     -.0018     -.2961**

Correlations:  NO2N_TN    NO3N_TN

TEMPERAT       -.2673**    .2329*
SALINITY       -.2377*    -.0157
DO             -.1429      .2548*
PH             -.2199*     .1992*
ACIDITY         .0978     -.1276
ALKALINE       -.0795     -.0192
REDOX_PO        .2248*    -.2028*
AMMONIA        -.1553     -.1652
NITRITE         .4614**   -.5194**
NITRATE        -.2535*     .1624
TOTAL_N        -.1254     -.0018
NH3N_TN        -.1530     -.2961**
NO2N_TN        1.0000     -.8986**
NO3N_TN        -.8986**   1.0000

1-tailed Signif:   * - .01   ** - .001
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monsoon and post-monsoon periods. The positive correlation with temperature is significant during post-monsoon periods while it is not significant during pre-monsoon and monsoon periods.

4.2 Nitrite - nitrogen

Concentration levels of nitrite - nitrogen in surface and bottom waters at all stations during the period of survey are given in table 4.2.1. The distribution pattern of nitrite concentration in surface and bottom waters are represented in figures 4.2.1 and 4.2.2. Average seasonal distributions of nitrite-nitrogen are also shown in figures 4.2.3. and 4.2.4.

The nitrite concentration at station one corresponds to the normal values and it ranges from 2 to 40 μg NO_2^{-1} N l^{-1} in surface waters and 2 to 60 μg NO_2^- N l^{-1} in bottom waters during the period of survey except during the onset of monsoon in the last part of May and June 1991, when the values extends upto 170 and 220 μg NO_3^-N l^{-1} in surface and bottom waters respectively.

Higher nitrite concentrations were observed at station two except during the month of April 1991 when the values observed are 4 and 3 μg NO_2^- N l^{-1} in surface and bottom waters. Highest values were recorded during monsoon and it ranged between 570 to 1070 μg NO_2^- N l^{-1} in surface waters and 540 to 1070 μg NO_2^- N l^{-1} in bottom waters. During post-monsoon and pre-monsoon periods the nitrite concentrations observed are lower than monsoon values and the range is between 220 and 450 μg NO_2^- N l^{-1} in surface waters and 180 and 460 μg NO_2^- N l^{-1} in bottom waters.

At station three the nitrite concentrations show a quantum jump and provide higher values than all other stations during the entire period of survey irrespective of the seasonal changes. The values ranges from a high value of 1820 μg NO_2^- N l^{-1} during the month of October 1990 to a low value of 1120 μg NO_2^- N l^{-1} during the

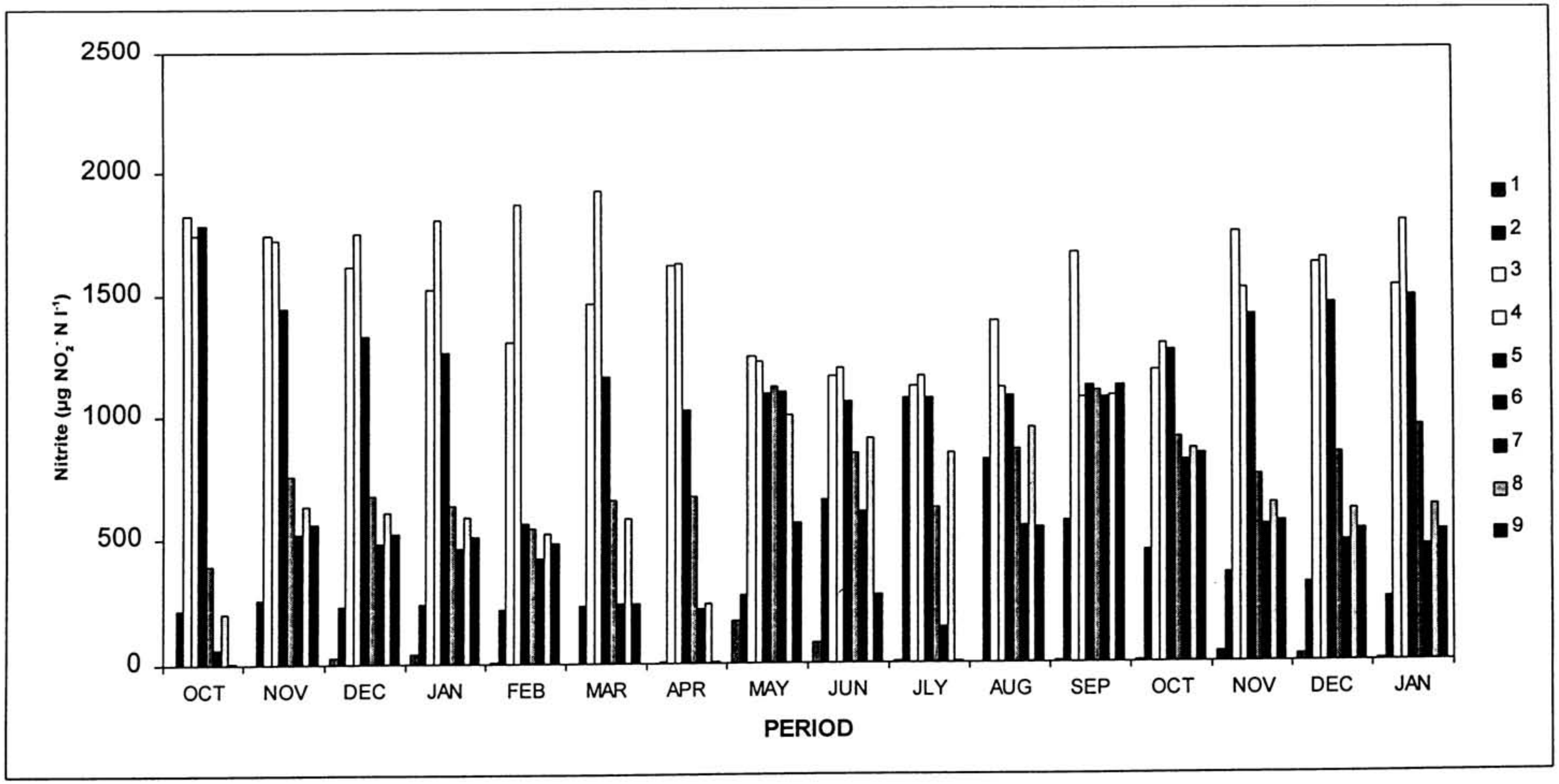

Fig. 4.2.1
Monthly variation of Nitrite at various stations
Surface

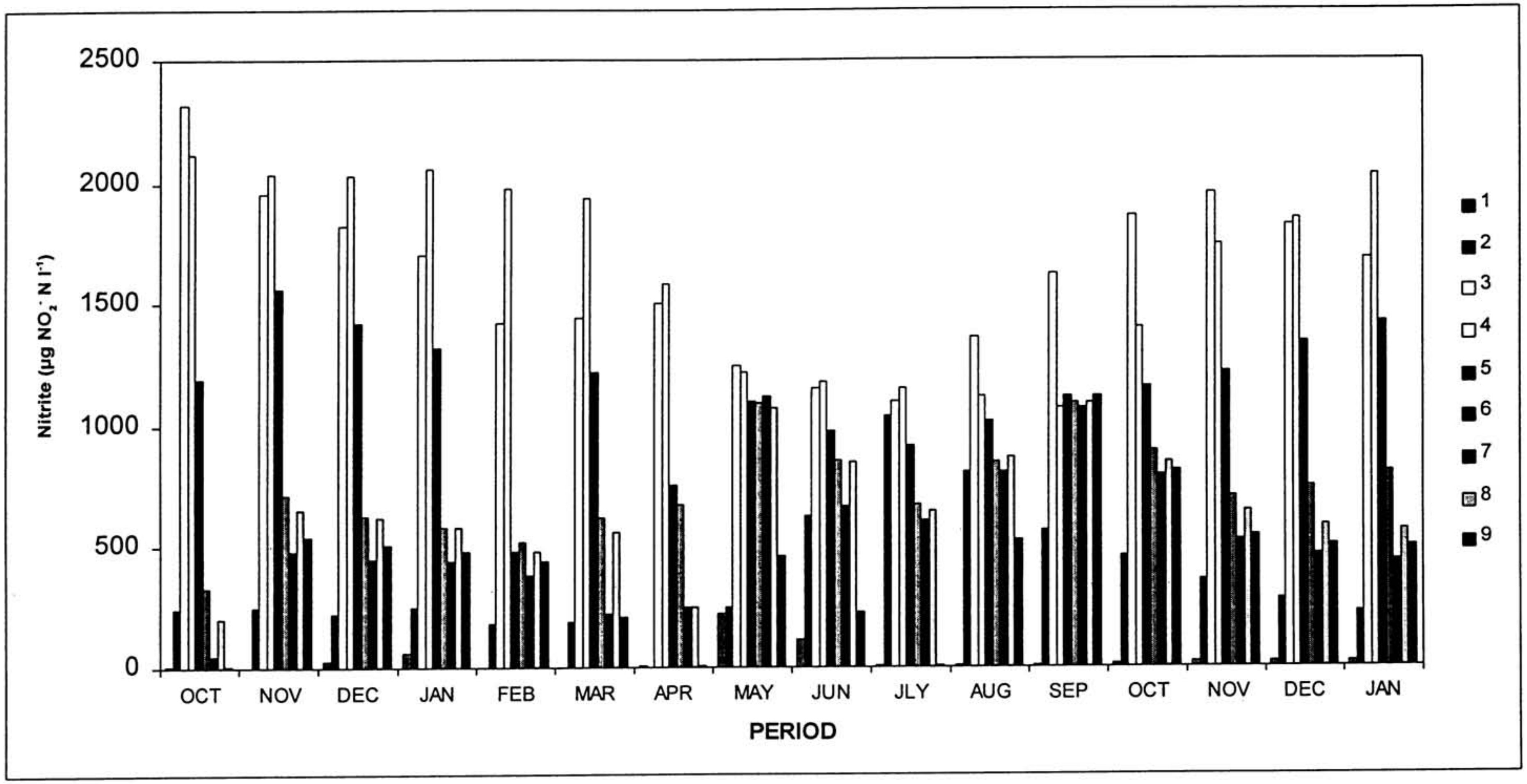

Fig. 4.2.2
Monthly variation of Nitrite at various stations
Bottom

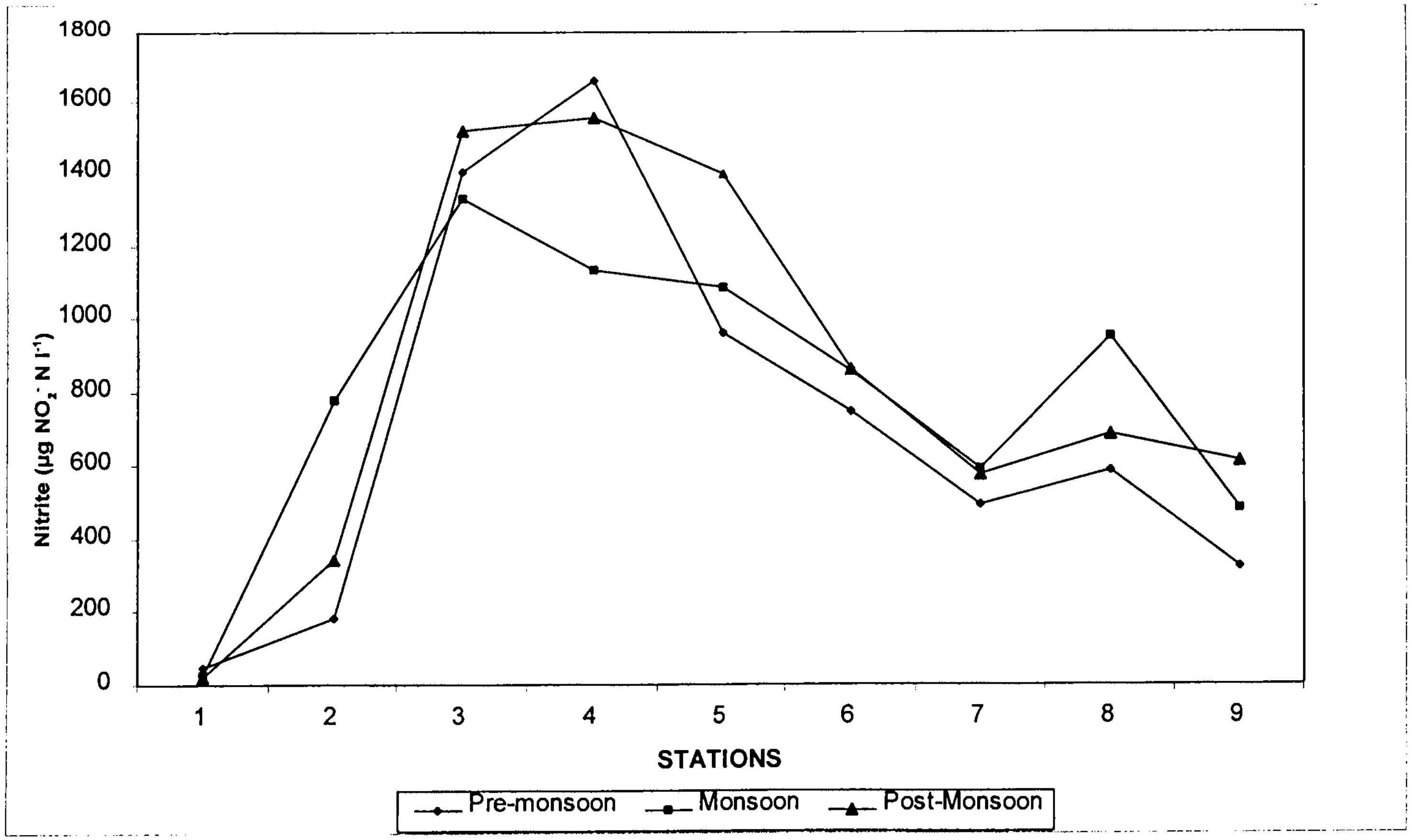

Fig. 4.2.3
Spacial variation of Nitrite during different seasons
Surface

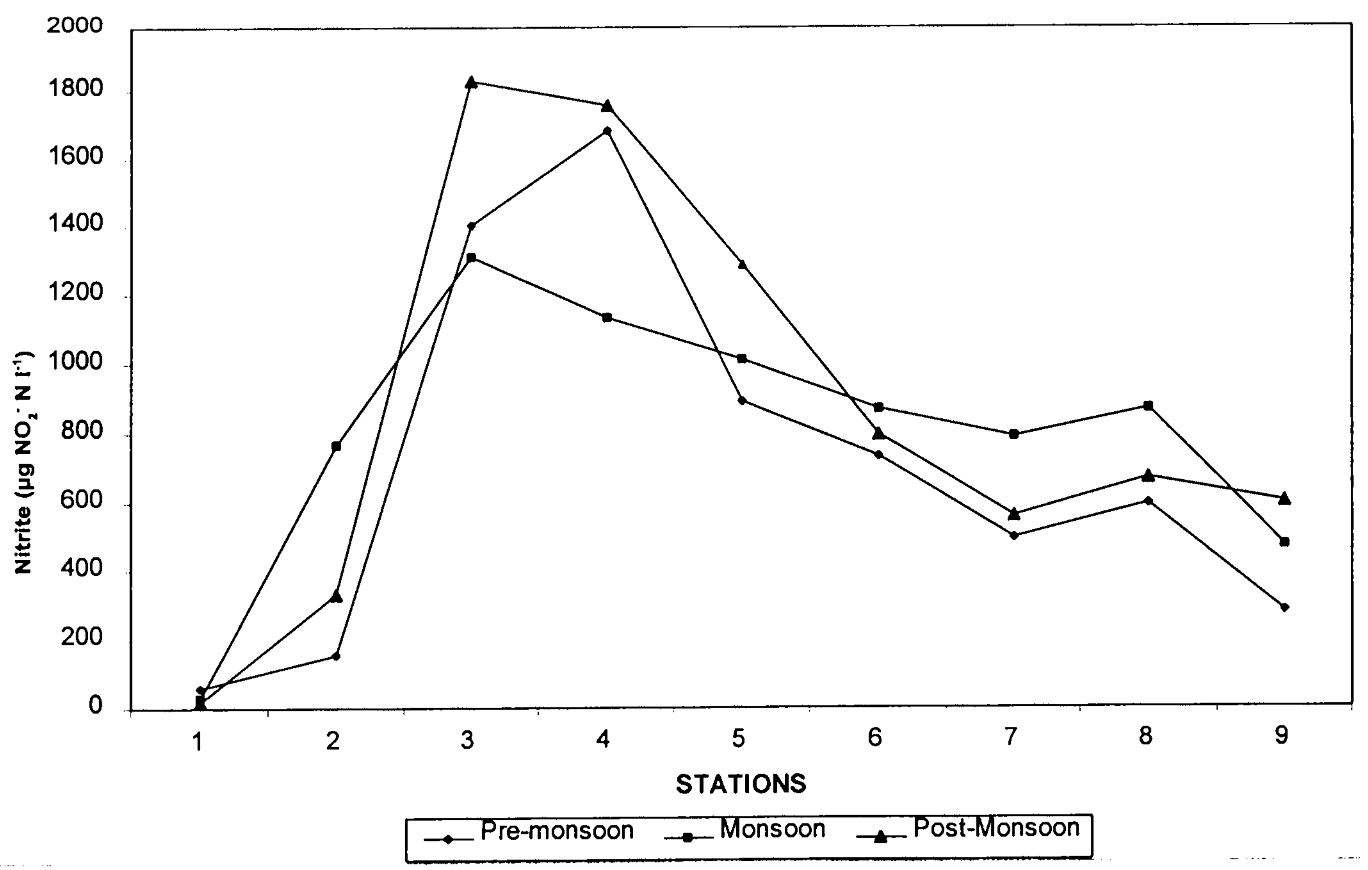

Fig. 4.2.4
Spacial variation of Nitrite during different seasons
Bottom

month of July 1991 at surface and a high value of 2320 μg NO_2^- N l^{-1} during the month of October 1990 to a low value of 1100 μg NO_2^-N l^{-1} during the month of July 1991 at bottom. Nitrite ion concentrations show a horizontal gradation and the values decrease from station three to station nine except at station seven. The values at station seven which is not along the main stream show some irregularity when compared with the values at other stations. At station seven maximum nitrite concentration values are observed during monsoon both in surface and bottom waters. The values decreases as the season progresses to post monsoon and pre monsoon periods, the minimum values being during the pre-monsoon periods.

Very high values for nitrite ion concentration both for surface and bottom waters at station three during the entire period of survey, the horizontal gradation from station three to station nine and a similar pattern in nitrate ion concentration supports the earlier conclusion that some nitrogenous compounds are being added to the estuary from some external source around station three.

There is no significant difference in the concentration of nitrite between periods, but the variation in concentration between stations is significant ($P<0.05$). Stations four (Brahmapuram) and three (Ambalamedu) gave significantly higher values while station one (Manackakadavu) gave significantly lower value.

There is no significant difference in nitrite concentration between periods but there is significant variation between stations ($P<0.05$). Station four (Brahmapuram) and three (Ambalamedu) gave significantly higher value of nitrite nitrogen concentration while station one (Manackakadavu) gave significantly lower value.

There is significant positive correlation of nitrite concentration with acidity ($P<0.001$), ammonia concentration ($P<0.001$), nitrate concentration ($P<0.001$) and redox potential ($P<0.01$) and significant negative correlation with transparency ($P<0.001$) salinity ($P<0.01$) and pH ($P<0.01$) in surface waters. The positive correlation of nitrite with acidity and nitrate concentration is significant throughout the entire period of survey while the positive correlation with ammonia concentration is significant only during monsoon and post-monsoon periods and is not significant during pre-monsoon periods. The positive correlation between nitrite concentration and redox potential is significant only during pre-monsoon and monsoon periods and is not significant during post-monsoon periods. Similar pattern is shown by the negative correlation of nitrite concentration with transparency and pH value. These negative correlations are also significant during pre-monsoon and monsoon periods and is not significant during post-monsoon periods in surface waters.

In bottom waters the nitrite concentration is significantly corelated to acidity, redox potential, ammonia concentration, nitrate concentration, salinity and pH. There is significant positive correlation of nitrite with acidity ($P<0.001$), redox potential ($P<0.001$), ammonia ($P<0.001$), nitrate ($P<0.001$) and significant negative correlation with salinity ($P<0.01$) and pH ($P<0.01$). The positive correlation of nitrite with nitrate and acidity is observed during the entire period of survey. The positive correlation with ammonia is significant during monsoon and post-monsoon periods and is not significant during pre-monsoon periods. The positive correlation of nitrite with redox potential and negative correlation with pH are significant only during pre-monsoon and monsoon periods and are not significant during post-monsoon periods.

4.3 Ammonia - nitrogen.

Concentration levels of ammonia-nitrogen in surface and bottom waters at all stations during the period of survey are given in table 4.3.1. The distribution pattern of ammonia -nitrogen in surface and bottom waters are represented in figures 4.3.1. and 4.3.2. Average seasonal distributions of ammonia - nitrogen are also given by figures 4.3.3. and 4.3.4.

The ammonia concentrations at stations one and two both in surface and bottom waters are within the normal range and changes from a high value of 36.8 µg NH_3 N l^{-1} to a low value of 2.1 µg NH_3 N l^{-1} in surface waters and a high value of 33.9 µg NH_3 N l^{-1} to a low value of 2.1 µg NH_3 N l^{-1} in bottom waters.

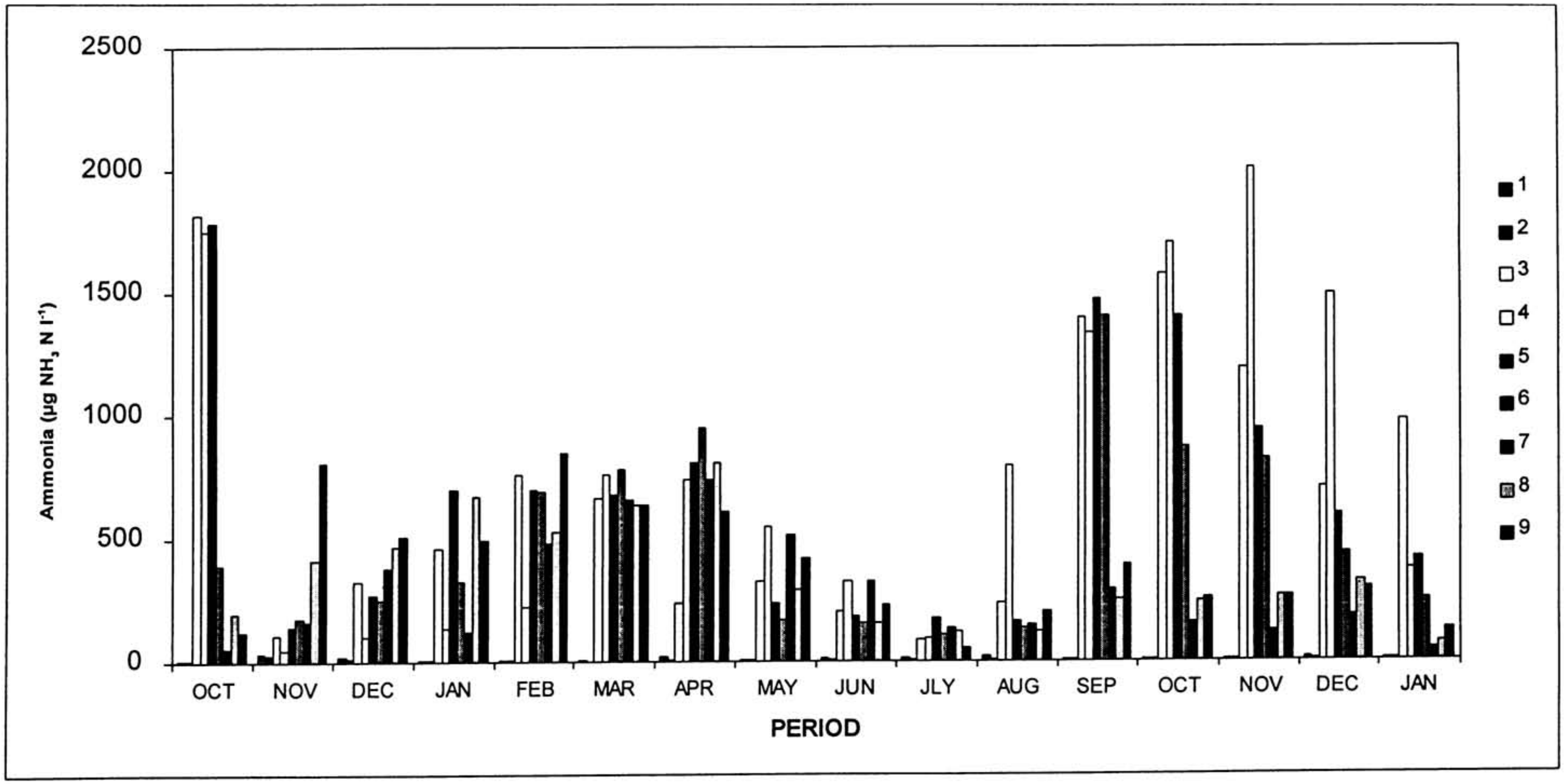

Fig. 4.3.1
Monthly variation of Ammonia at various stations
Surface

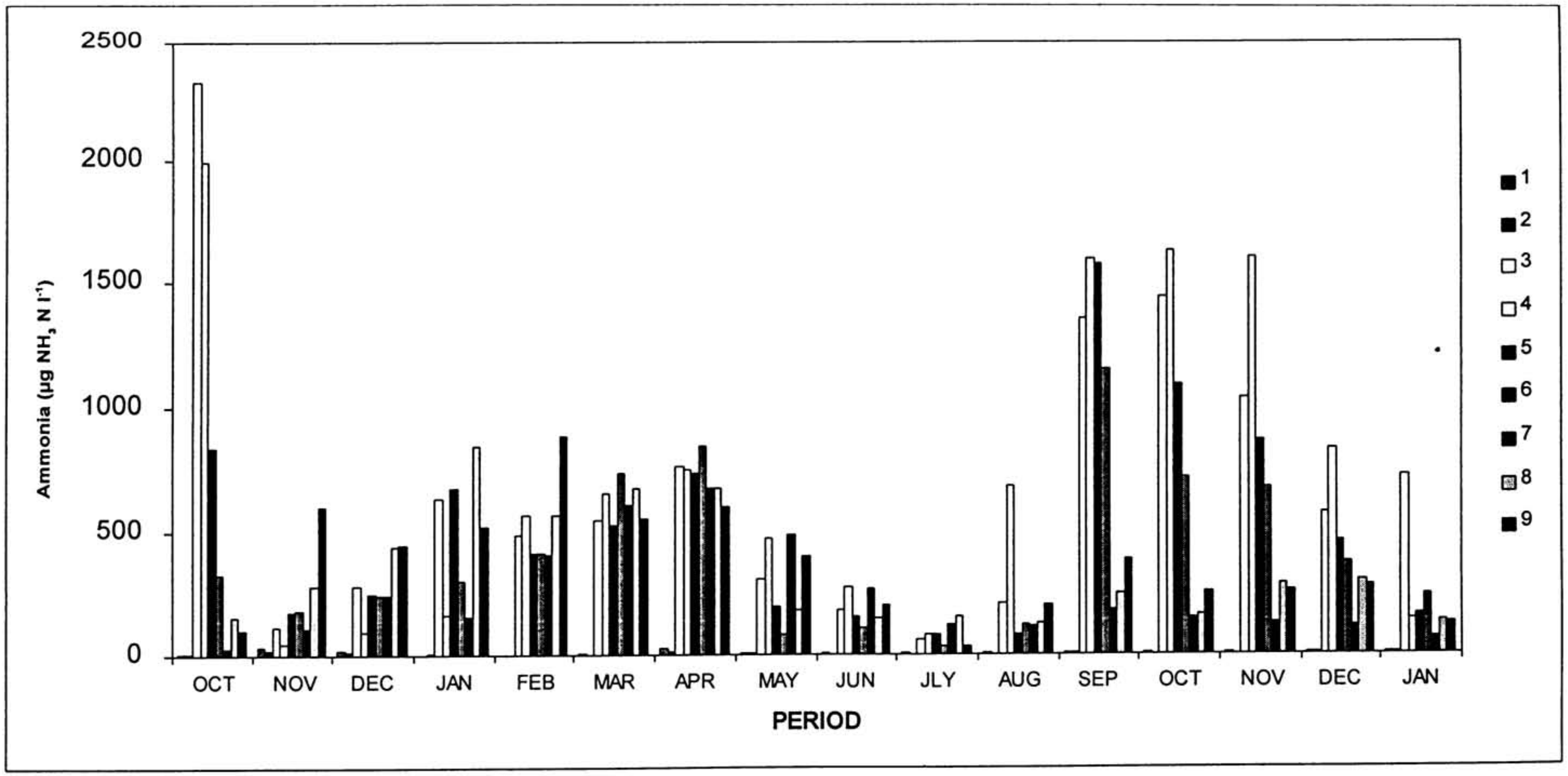

Fig. 4.3.2
Monthly variation of Ammonia at various stations
Bottom

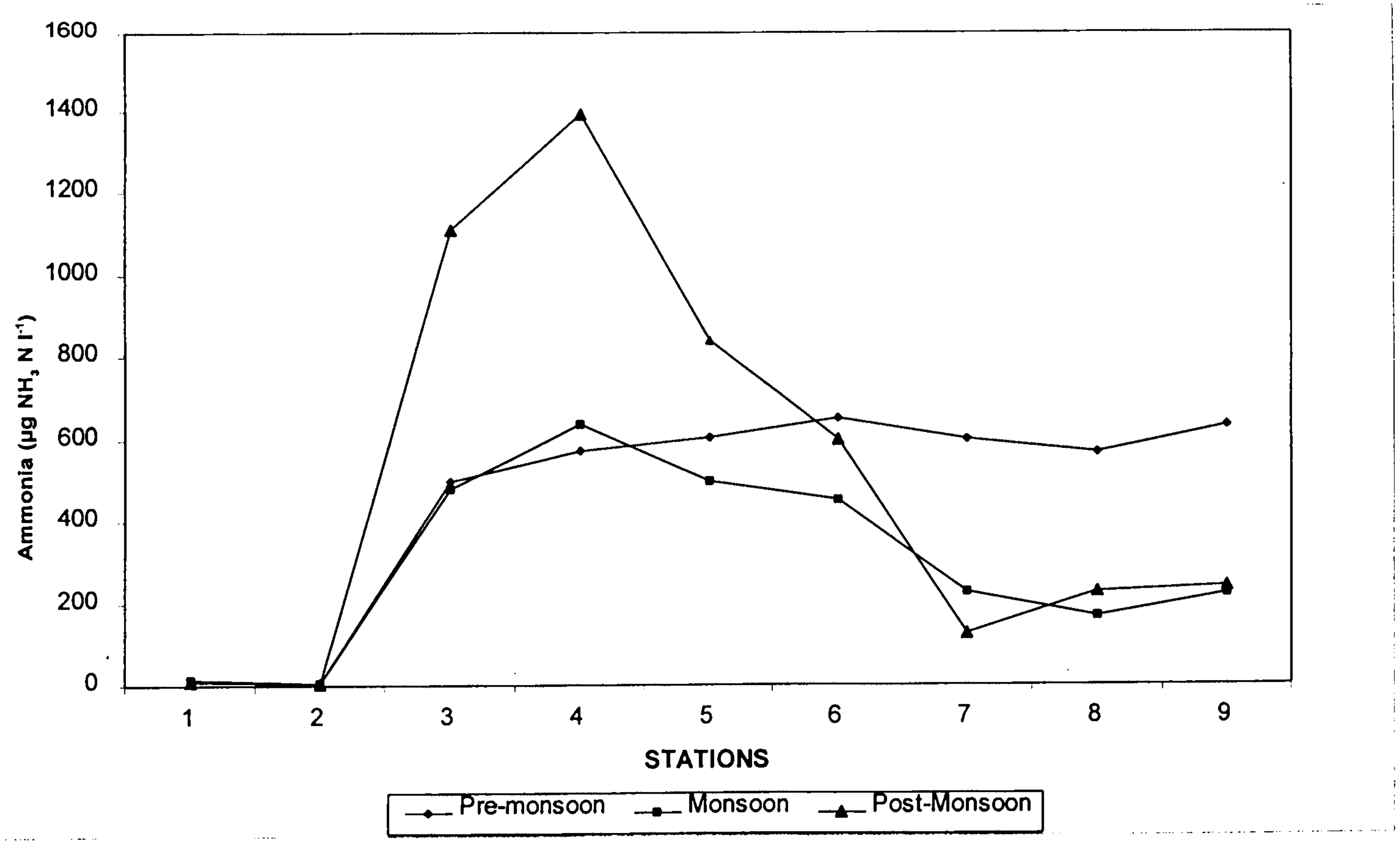

Fig. 4.3.3
Spacial variation of Ammonia during different seasons
Surface

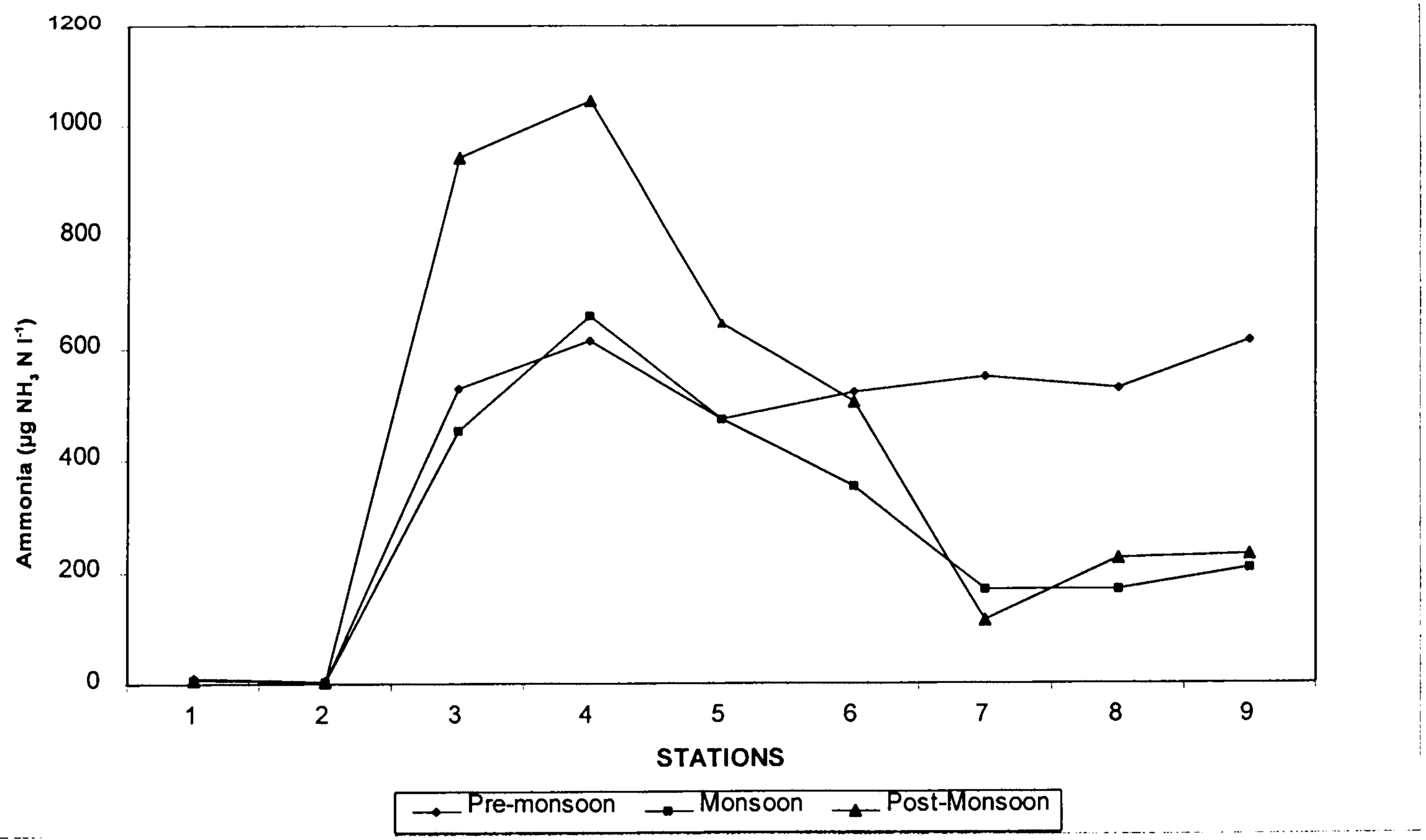

Fig. 4.3.4
Spacial variation of Ammonia during different seasons
Bottom

At station three the ammonia concentrations show a sharp increase throughout the period of survey without any definite seasonal pattern. The concentration of ammonia - nitrogen varies from a high value of 1815 µg NH_3 N l^{-1} during the month of October 1990 to a low of 86.5 µg NH_3 N l^{-1} during the month of July 1991 at surface and a high value of 2320 µg NH_3 N l^{-1} during the month of October 1990 to a low value of 61.0 µg NH_3 N l^{-1} during the month of July 1991 at bottom. Similar higher values of 1390, 1563, and 1184 µg NH_3 N l^{-1} for surface waters and 1346 1436 and 1032 µg NH_3 N l^{-1} for bottom waters were observed during the months of September, October and November 1991. Very high values were recorded both in surface and bottom waters at stations four, five and six during the same months as mentioned above, but in the diminishing magnitude from stations three to six.

The ammonia concentration values at stations seven, eight and nine are lower than at stations one and two. The concentration varies from a high value of 395.1 µg NH_3 N l^{-1} during the month of September 1991 to a low value of 51.0 µg. NH_3 N l^{-1} during the month of July 1991 in surface waters and from a high value of 390.1 µg NH_3 N l^{-1} during the month of September 1991 to a low value of 31.0 µg NH_3 l^{-1} during the month of July 1991 in bottom waters, all these limiting values are being at station nine.

There is significant variation in concentration of ammoniacal nitrogen in surface waters between periods and between stations ($P<0.05$). Significantly higher ammonia concentration during period twelve (September 1991) and significantly lower ammonia concentration during period ten (July 1991) were observed. Station four (Brahmapuram) gave significantly higher concentration of ammonia while station two (Amabalamughal) showed significantly lower concentration of ammonia.

There is significant variations in concentration of ammoniacal nitrogen in bottom waters between periods and between stations ($P<0.05$). Period twelve (September 1991) showed significantly higher ammonia concentration while period ten (July 1991) gave significantly lower ammonia concentration. Significantly higher concentration of ammonia was observed at station four (Brahamapuram) and station three (Ambalamedu) while significantly lower concentration of ammonia was observed at stations two (Ambalamughal) and one (Manackakadavu).

There is significantly positive correlation of ammonia concentration with nitrite concentration ($P<0.001$), nitrate concentration ($P<0.001$) and acidity ($P<0.01$) in surface waters. The positive correlation with nitrite and nitrate concentrations are significant only during monsoon and post-monsoon periods and is not significant during pre-monsoon periods. The positive correlation of ammonia with acidity becomes significant during pre-monsoon and post-monsoon periods and non-significant during monsoon. There is significant correlation between ammonia and salinity during pre-monsoon periods.

Ammonia concentration shows positive significant correlation with nitrite concentration ($P<0.001$) and nitrate concentration ($P<0.001$) in bottom waters. These positive correlations are significant only during monsoon and post-monsoon periods and are not significant during pre-monsoon periods. Ammonia concentration is significantly correlated in a positive manner with salinity during pre-monsoon periods and acidity during post-monsoon periods.

The above observations with normal values of ammonia concentrations at stations one and two, abrupt increase in ammonia concentration at station three, horizontal gradation along down stream and similar pattern in concentration values of nitrate and nitrite ions clearly supports the earlier conclusion of introduction of some industrial effluents with very high proportion of nitrogenous compounds around the station three during the period of survey.

4.4. Total soluble Inorganic Nitrogen

Total concentration of soluble inorganic nitrogen which is the sum of concentrations of nitrate, nitrite and ammonia in surface and bottom waters at all stations during the period of survey are given in table 4.4.1. The distribution pattern of total soluble inorganic nitrogen in surface and bottom waters are given as graphical representation in figures 4.4.1 and 4.4.2. Average seasonal distribution of total soluble inorganic nitrogen in surface and bottom waters are also given by figures 4.4.3. and 4.4.4.

There is significant variation in total inorganic nitrogen content between periods and between stations ($P<0.05$) in surface waters. Period twelve (September 1991) has significantly higher value while period two (November 1991) has significantly lower value. Horizontal variation showed significantly higher value at station three (Ambalamedu) and significantly lower value at station one (Manackakadavu).

There is significant variation in total inorganic nitrogen content between periods and between stations ($P<0.05$) in bottom waters. Significantly higher values of total inorganic nitrogen was observed during the periods twelve (September 1991) and eight (May 1991) . Among stations, station three (Ambalamedu) gave significantly higher value while station one (Manackakadavu) gave significantly lower value of total inorganic nitrogen concentration.

There is significant positive correlation of total inorganic nitrogenous nutrients (TN) with acidity ($P<0.001$), nitrate concentration ($P<0.001$), nitrite concentration ($P<0.001$), ammonia concentration ($P<0.001$), alkalinity ($P<0.01$) and negative correlation with transparency ($P<0.001$) in surface waters. The positive correlation of TN with acidity, nitrate and nitrite concentrations are significant throughout the entire period of observation while the positive correlation with ammonia concentration is significant during monsoon and post-monsoon periods. The positive correlation with alkalinity is significant only during post-monsoon periods.

There is significant positive correlation between total inorganic nitrogenous nutrients (TN) and acidity ($P<0.001$), nitrate concentration ($P<0.001$), nitrite concentration ($P<0.001$), ammonia concentration ($P<0.001$) and temperature ($P<0.01$), in bottom waters. The positive correlation with acidity, nitrate, nitrite and ammonia is observed throughout the period of survey. Total inorganic nitrogen shows positive significant correlation with alkalinity during post-monsoon periods and negative significant correlation with dissolved oxygen during pre-monsoon periods in bottom waters.

There is significant variation in the ratio of nitrate nitrogen to total inorganic nitrogen between periods and between stations ($P<0.05$) in surface waters. The ratio was significantly higher during period eight (May 1991) and significantly lower during period two (November 1990). Significantly higher value was observed at station one (Manackakadavu) and significantly lower ratio was shown at station four (Brahmapuram).

The difference in the ratio of the nitrate nitrogen to total inorganic nitrogen between periods and between stations is significant ($P<0.05$) in bottom waters. Significantly higher ratio was recorded during period eight (May 1991) while significantly lower ratio was observed during period two (November 1990). Station one (Manackakadavu) gave significantly higher ratio while station four (Brahmapuram) showed significantly lower ratio.

There is significant negative correlation between the ratio of nitrate concentration to total inorganic nitrogenous nutrients and nitrite concentration ($P<0.001$) both in surface and bottom waters. This negative correlation is found to be significant throughout the period of survey. The positive correlation of the ratio of nitrate to total nitrogen with temperature ($P<0.001$ in surface and $P<0.01$ in bottom waters), dissolved oxygen ($P<0.01$) and pH ($P<0.01$) and negative correlation with redox potential ($P<0.01$) are significant. There is significant negative correlation between the ratio and ammonia concentration during pre-monsoon periods.

There is significant variation in the ratio of nitrite nitrogen to total inorganic nitrogen between periods and between stations ($P<0.05$) in surface waters. Period two (November 1990) gave significantly higher ratio while periods one (October 1990) and seven (April 1991) gave significantly lower ratio. Among stations, station two (Amabalamughal) observed significantly higher ratio while station one (Manackakadavu) showed significantly lower ratio.

Significant difference in the ratio of nitrite nitrogen to total inorganic nitrogen is observed between periods and between stations ($P<0.05$) in bottom waters. Significantly higher ratio was recorded during period two (November 1990) while significantly lower value was reported during period seven (April 1991). Significantly higher ratio was noted at station two (Ambalamughal) while significantly lower ratio was reported from station one (Manackakadavu).

The ratio of nitrite concentration to total inorganic nitrogenous nutrients has significant negative correlation with nitrate concentration ($P<0.001$), temperature ($P<0.01$), salinity ($P<0.01$) and pH ($P<0.01$) both in surface and bottom waters. There is a negative significant correlation of the ratio with transparency ($P<0.01$) during pre-monsoon periods in surface waters while there is positive significant correlation of the ratio with acidity ($P<0.01$) and negative significant correlation with alkalinity ($P<0.01$) during pre-monsoon periods in bottom waters.

There is significant difference in the ratio of ammoniacal nitrogen to total inorganic nitrogen between periods and between stations ($P<0.05$) in surface waters. Period six (March 1991) observed significantly higher ratio while period ten (July 1991) showed significantly lower ratio. Among stations, station six (Eroor) and station nine (Thevara) showed significantly higher ratio while station two (Ambalamughal) showed significantly lower ratio.

There is significant difference in the ratio of ammoniacal nitrogen to total inorganic nitrogen between periods and between stations ($P<0.05$) in bottom waters. Significantly higher ratios were observed during the period seven (April 1991) and period six (March 1991) while significantly lower ratios were seen during period ten (July 1991). Significantly higher ratio was reported from station nine (Thevara) while significantly lower value was recorded at station two (Ambalamughal).

The ratio of ammonia concentration to total inorganic nitrogenous nutrients shows positive significant correlation with salinity ($P<0.001$) and negative significant correlation with dissolved oxygen ($P<0.01$) both in surface and bottom waters. This ratio has positive significant correlation with concentrations of nitrate and nitrite only during monsoon and post-monsoon periods and with acidity only during post-monsoon periods, both in surface and bottom waters. The ratio has a negative correlation with transparency which is significant only during monsoon in surface waters and a positive correlation with alkalinity during post-monsoon periods in bottom waters.

CHAPTER 5

PHOSPHORUS

5.1. Introduction

Phosphorus is present in estuaries in various inorganic and organic forms in dissolved, colloidal or particulate state. Dissolved inorganic phosphate exists in different forms like $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-} and their relative concentrations in aquatic system are pH dependent.

$$H_3PO_4 \rightleftarrows H_2PO_4^- + H^+$$
$$H_2PO_4^- \rightleftarrows HPO_4^{2-} + H^+$$
$$HPO_4^{2-} \rightleftarrows PO_4^{3-} + H^+$$

Information of the pH dependent distribution of the above species is required to interpret the solubility behaviour, complex formation and sorption processes of phosphorus in an aquatic system (Stumm & Morgan, 1970). The most commonly estimated species among the dissolved forms is the orthophosphate as PO_4^{3-} ions as it is the predominant form of phosphorus which participate in a wide variety of chemical and biochemical processes.

Abundance of condensed phosphates such as polyphosphates and metaphosphates are not yet reported in marine systems. These condensed phosphates in solution are hydrolysed to monophosphates. Contributions of monophosphates from such hydrolysis are expected in estuaries as a result of pollution from detergents (Koroff, 1983, b).

In hydrosphere, the occurrence of phosphorus in the organic form is usually associated with complex cellular substances (Wetzel, 1975). The release of orthophosphate from organic forms occurs by the activity of alkaline phosphatase, which is found to be negatively correlated with orthophosphate concentration in water (Hashimoto *et. al.*, 1985; Pick, 1987).

Particulate phosphorus exists in both inorganic and organic forms. The conversion of particulate phosphorus to dissolved phosphorus occurs as a result of the bacterial action, followed by uptake by phytoplankton with subsequent transformation into the dissolved forms.

The biogeochemical cycle of phosphorus in estuaries and its distribution and seasonal variations have been reported by many authors (Correll *et. al.*, 1975, Aston, 1980). Biogeochemistry of phosphorus in estuaries is controlled by a combination of physical, chemical and biological processes like addition of phosphorus to the system by input, decomposition of particulate matter; removal of phosphorus from the system by precipitation and uptake or concentration of phosphorus by living organisms (Martin, 1970).

Rivers are the major source of phosphorus input to estuaries. The riverine influx of phosphorus in estuaries may be substantially modified by precipitation or dissolution causing changes in the concentration of phosphorus (Fox *et. al.*, 1985). The weathering of insoluble calcium and ferric phosphate rocks and land drainage especially from agricultural run off also delivers phosphorus to estuaries (Martin, 1970). The external sources bringing phosphorus to estuaries are from domestic sewage and industrial effluent particularly from fertilizer plants producing phosphatic fertilizers. A concentration range of 1.6 to 32.0 µg at P l^{-1} have been reported for agricultural drainage (Snoeyink and Jenkins, 1980) and 16 µg at Pl^{-1} has been reported in domestic waste water (Stumm and Morgan, 1970). These reports clearly shows the magnitude of phosphorus transport.

The formation of complex chelates and insoluble salts between major cations and various phosphate anions has profound effect on the phosphate distribution in estuaries (Stumm and Morgan, 1970). Great variation in dissolved phosphorus in estuaries can be done to biological production and degradation processes (Hobbie *et.*

al. 1975, Wollast, 1978) and also due to non biological reactions (Carritt and Goodgal, 1954; Jitts, 1959; Pomeroy *et. al.*, 1965; Burns and Salomen, 1969; Butler and Tibbits, 1972; Sholkovitz, 1976; Morris *et. al.* 1981).

Phosphorus concentration in the surface waters and phytoplankton density follow an inverse relation to one another indicating the fact that the variations in concentration in phosphorus are mainly brought about by biological production. Phosphorus is an essential nutrient and it can be the nutrient limiting the primary productivity of an estuary. Phytoplankton normally satisfy their requirement of phosphorus by the direct assimilation of orthophosphates (Riley and Chester, 1971, b). The mechanism of cycling of phosphorus as a nutrient with the growth of phytoplankton and zooplankton depends on a set of complex biologically mediated reactions. The inorganic soluble phosphate is converted to adenosine triphosphate (ATP) and adenosine diphosphate (ADP) in the biota which supply the energy required for all biochemical reactions occurring in the cells of the organism. Phytoplanktons take up phosphates and nitrates in relatively constant proportions and release these elements during their decomposition. Abundant phosphate availability in water stimulates undesirable plankton bloom, a phenomenon generally known as "eutrophication" (Rend *et. al.*, 1976). Subsequent decay of plants and organisms cause oxygen depletion; along with rapid conversion of the organic compounds present in the tissues to the dissolved forms which on bacterial oxidation release the phosphates in the ionic forms.

In polluted waters the sediments remove a large proportion of dissolved phosphates so that the chances of eutrophication is reduced (Stirling and Wormald, 1977). However it is also reported that the adsorption of phosphate on sediments is a reversible process and sediments act as a phosphate buffer for keeping the phosphate concentration in the overlying waters constant (Pomeroy *et. al.*, 1965 and Harter, 1968). Considerable work has been carried out on dissolved orthophosphate in the Cochin estuary by Qasim and Sankaranarayanan, (1972); Joseph, (1974); Lakshmanan *et. al.*, (1987); Anirudhan, (1988); Balchand *et. al.*, (1990). Phosphate fractionation in the sediments along the south west coast of India, has been done by Nair *et. al.*, (1993), quantifying the nutrient uptake and regeneration as well as the role of the species of phosphorus as a limiting nutrient. Although phosphates are not toxic to man, animals or fish, water guidelines have been proposed because phosphorus may stimulate algal growth and thus create taste and odour problems. The Canadian and Australian standards (Hart, 1974) suggest a limit of 200 µg PO_4^{3-} l^{-1}. While the US, EPA (1973) suggest a limit of 100 µg PO_4^{3-} l^{-1}.

5. 2. Results and discussions

The phosphate concentration in surface and bottom waters at the stations studied during the period of survey are given in table 5.2.1. The distribution pattern of phosphate-phosphorus in surface and bottom waters are represented in figures 5.1.1. and 5.1.2. Representative seasonal distributions of phosphate-phosphorus in surface and bottom waters are also given in figures 5.1.3. and 5.1.4 respectively.

The phosphate concentration at station one varies from 100 µg PO_4^{3-} P l^{-1} to 64 µg PO_4^{3-} P l^{-1} in surface waters and from 96 µg PO_4^{3-} P l^{-1} to 70 µg PO_4^{3-} P l^{-1} in bottom waters during monsoon period, from 88 µg PO_4^{3-} P l^{-1} to 11 µg PO_4^{3-} P l^{-1} in surface waters and from 89 µg PO_4^{3-} P l^{-1} to 09 µg PO_4^{3-} P l^{-1} in bottom waters during post-monsoon period and from 66 µg PO_4^{3-} P l^{-1} to 03 µg PO_4^{3-} P l^{-1} in surface waters and from 74 µg PO_4^{3-} P l^{-1} to 02 µg PO_4^{3-} P l^{-1} in bottom waters during the pre-monsoon period. High concentration of phosphate during monsoon period reflects the general trend of phosphate leaching from land drainage reaching the river water.

Phosphate distribution in Cochin estuary shows a marked seasonal variation. Several workers have reported high concentration of dissolved phosphate in Cochin estuary during pre-monsoon period which exceed the limit of water pollution standards and low values during monsoon period, (Joseph, 1974; Lakshmanan *et. al.*, 1987 & Anirudhan, 1988). The low values observed during monsoon period was explained as due to the combined effect of dilution of Cochin estuarine water by

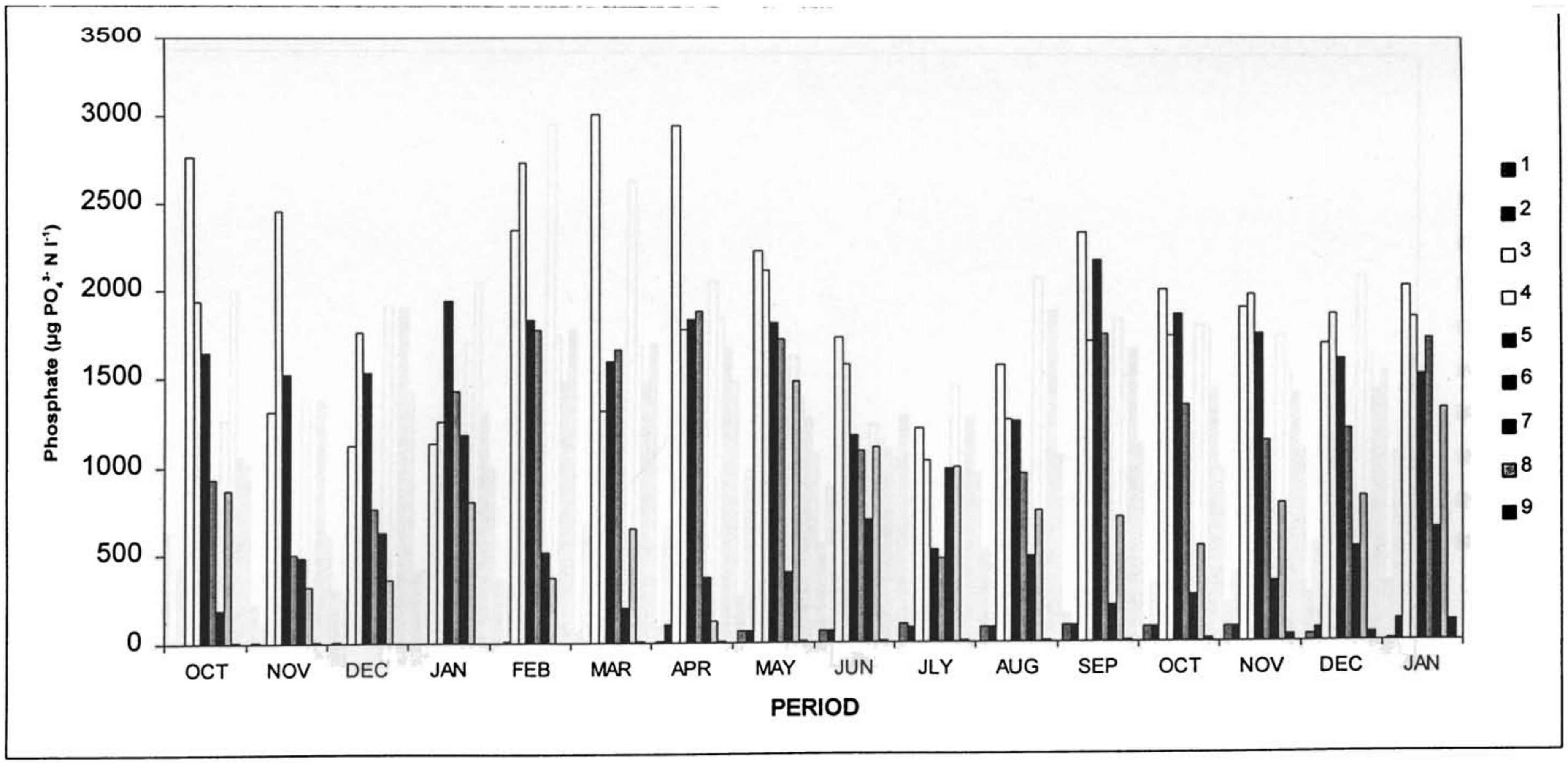

Fig. 5.1.1
Monthly variation of Phosphate at various stations
Surface

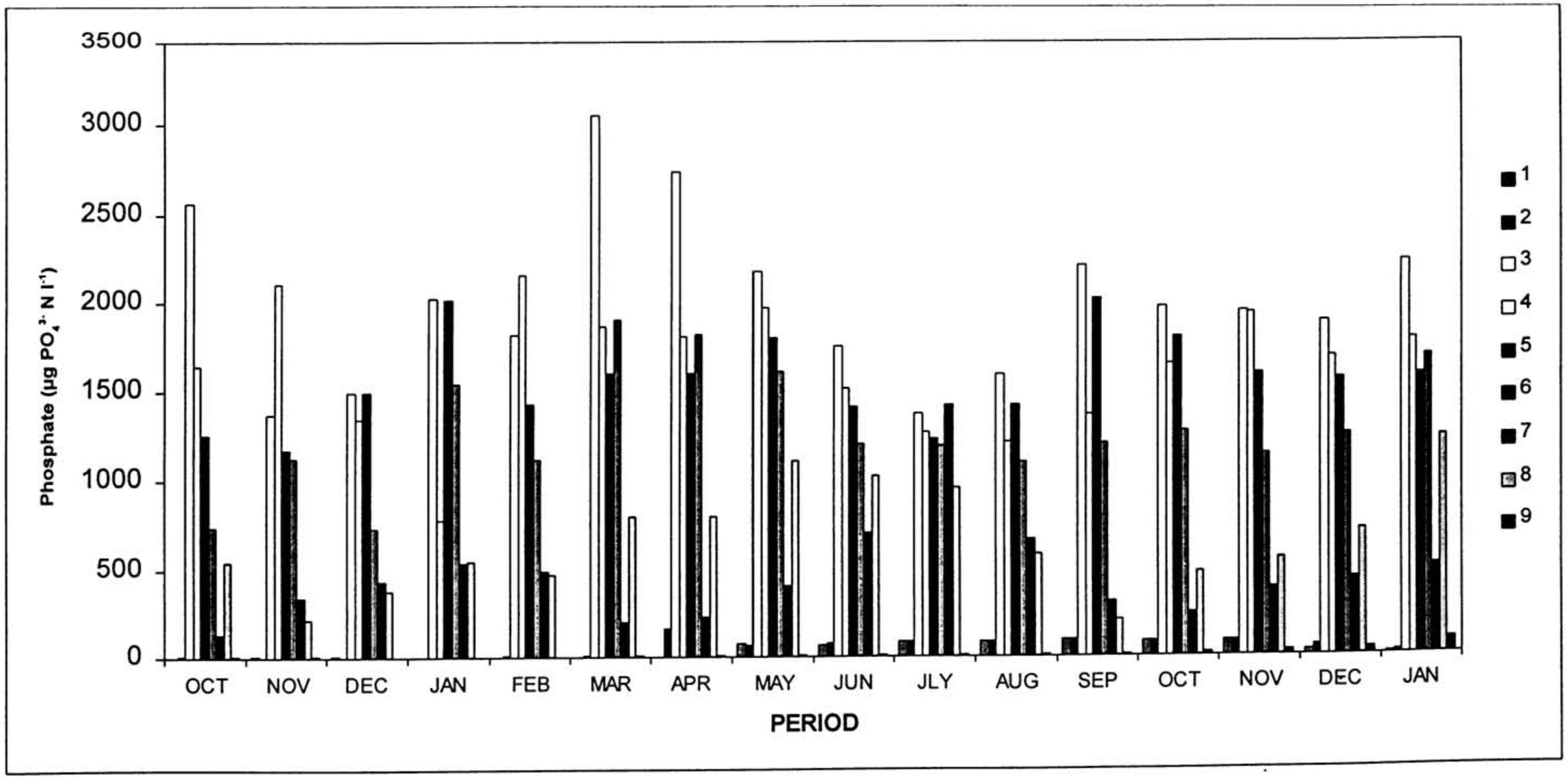

Fig. 5.1.2
Monthly variation of Phosphate at various stations
Bottom

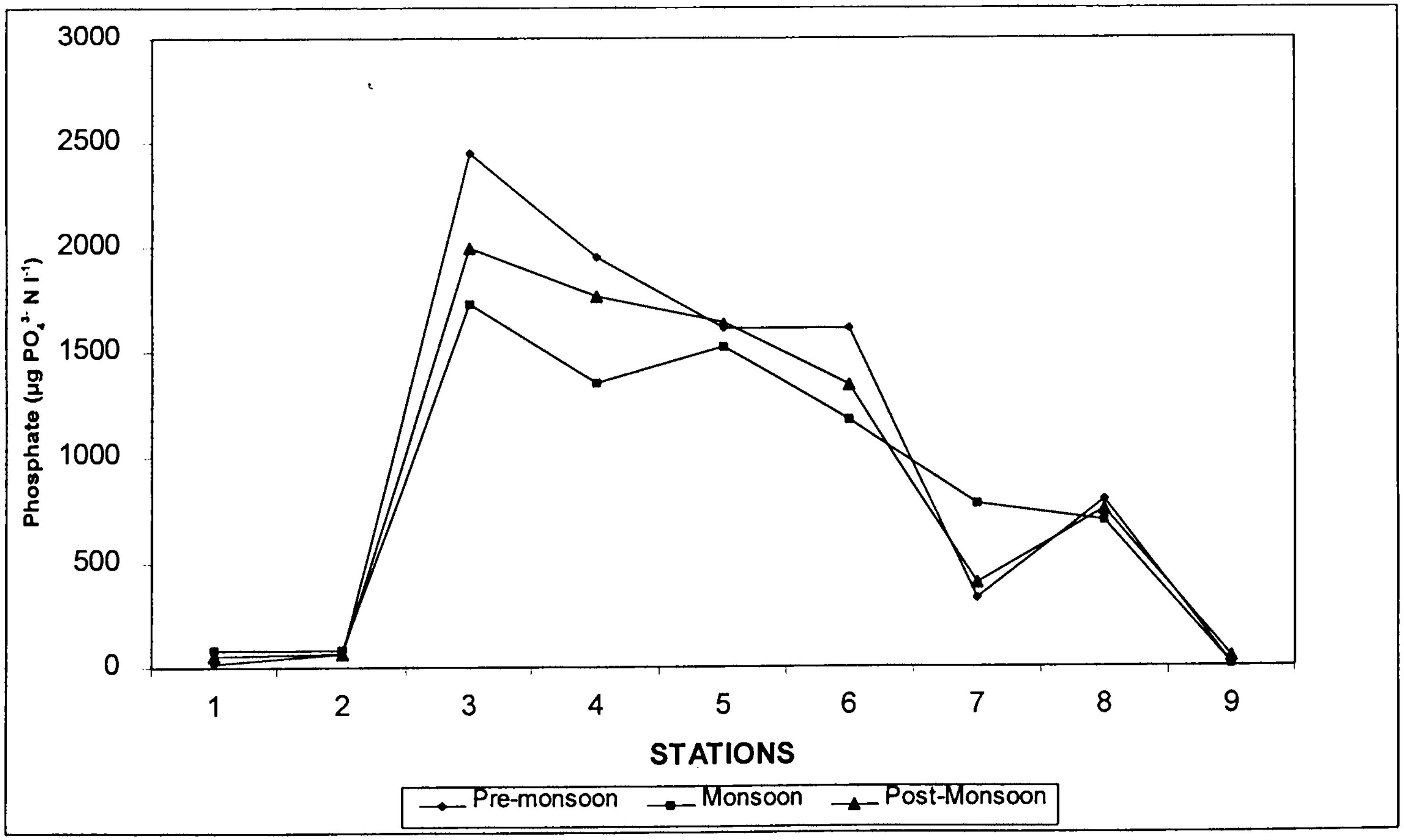

Fig. 5.1.3
Spacial variation of Phosphate during different seasons
Surface

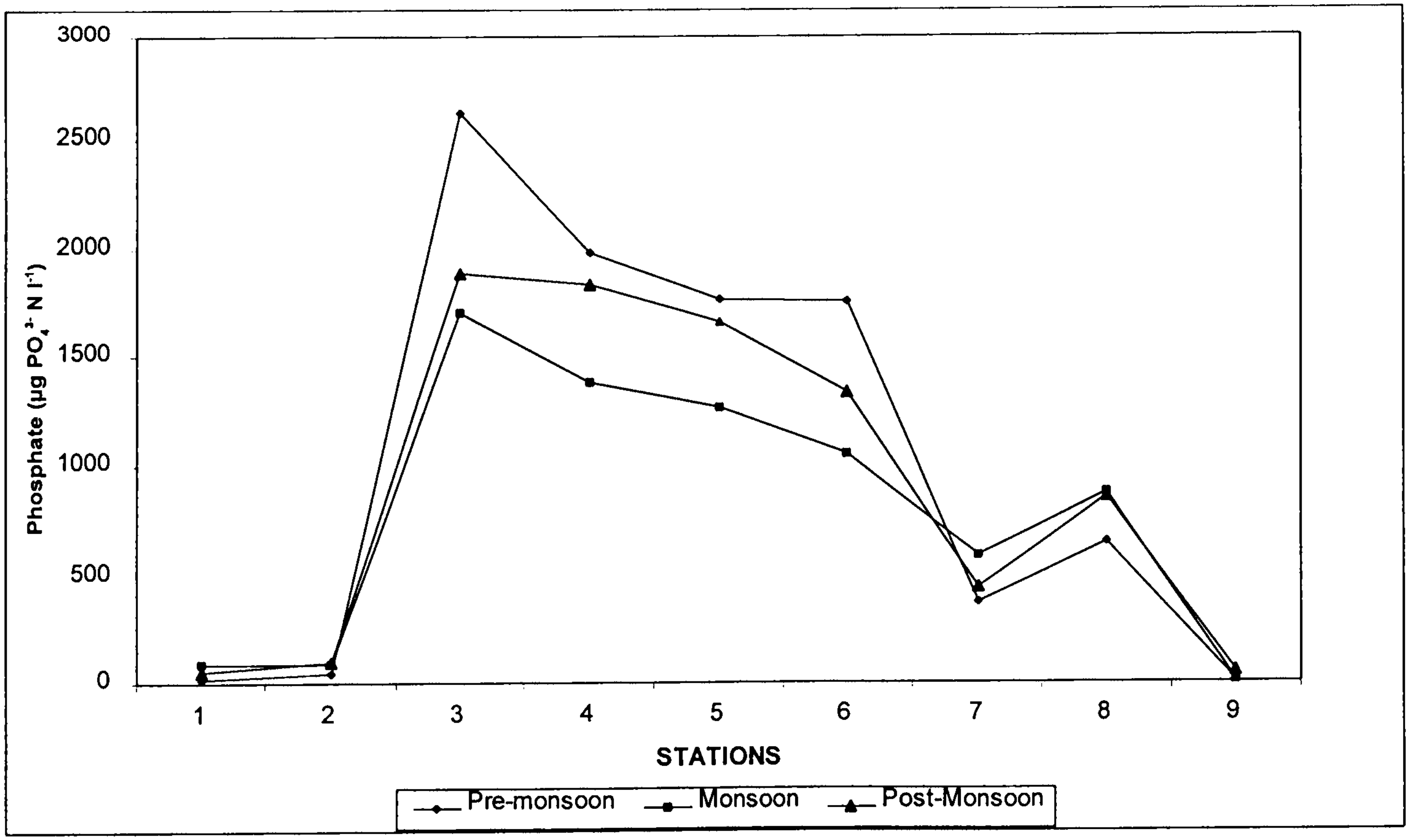

Fig. 5.1.4
Spacial variation of Phosphate during different seasons
Bottom

riverine fresh water containing low phosphate content and the removal by adsorption caused by the influx of silt laden fresh water. Increased riverine discharge during monsoon periods results in low salinity & pH and high dissolved oxygen favouring the removal of phosphorus from the overlying waters by sedimenting particles. Other workers have also reported that the removal of phosphate from the overlying water by suspended sediments is enhanced by low salinity, low pH and high dissolved oxygen (Pomeroy *et. al.* , 1965; Liss, 1976; Nagarajaiah and Gupta, 1983).

However Sankaranarayanan and Qasim (1969) reported high phosphate values during monsoon and low values during pre-monsoon with vertical homogenity in Cochin estuary. Results of the present work at station one, are in agreement with the above pattern which may be explained due to higher leaching of phosphate from land drainage in the form of agricultural runoff during monsoon periods. The seasonal average of phosphate concentrations are also higher during monsoon periods with a value 86 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and a comparable value of 85 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters. The lowest seasonal average values were observed during pre-monsoon periods with 21 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ both in surface and bottom waters.

The phosphate concentration at station two varies from 97 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 65 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 92 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 74 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during monsoon periods; 126 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 88 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during post-monsoon periods and from 109 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 4 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 159 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 5 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during pre-monsoon periods. The recorded values of phosphate concentration at station two do not reflect any seasonal pattern. Higher values were observed during certain months when extremely high phosphate concentrations were recorded both in surface and bottom waters at station three. This can be explained as due to penetration of phosphate ions from station three to station two. Similar high values were not recorded at station one indicating that station one is beyond the penetrating influence of phosphate ions from station three. However the high phosphate concentration at station three can exert a higher degree of influence on station two irrespective of the seasonal variation and it may be explained as due to the fact that the penetrating effect of the phosphate ions through the aquatic medium depends on the direction and magnitude of the water current and independent of seasonal variations.

The phosphate concentrations at station three are very high throughout the period of survey and it varies from 2313 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ to 1206 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ in surface waters and from 2198 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ to 1367 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ in bottom waters during monsoon period, from 2764 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ to 1123 $\mu g\ PO_4^{3-}\ Pl^{-1}$ in surface waters and from 2560 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ to 1373 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ in bottom waters during post-monsoon period and from 2998 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ to 2218 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ in surface waters and from 3049 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ to 1815 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ in bottom waters during pre-monsoon period.

Very high values of phosphate concentration at station three which is close to the outlet of industrial effluent from a large fertilizer plant producing phosphate fertilizers indicates discharge of some effluent rich in phosphorus compounds. The highest values were recorded during pre-monsoon period while phosphate concentration values were comparatively lower during monsoon period. The lower values during monsoon can be attributed to high dilution factor and consequently higher rates of flushing of phosphate by fresh water from river. This trend is contrary to the general trend of phosphate leaching from land drainage reaching the river waters during monsoon period as reported at station one. The highest values of phosphate concentrations 2995 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ in surface waters and 3049 $\mu g\ PO_4^{3-}\ P\ l^{-1}$ in bottom waters were recorded during pre-monsoon period when the phosphate concentration both in surface and bottom waters at station one were comparatively lower. This clearly establishes the fact that the main factor contributing to the high value of phosphate concentration at station three is not from the agricultural runoff carried over by the river as observed at station one but the discharge of industrial effluent into the aquatic system.

Earlier workers have also reported higher concentration of phosphate near the effluent discharge site of another fertilizer factory in the river Periyar (Joseph *et. al.*, 1984; Joy *et al.*, 1990) which is also a part of Cochin estuary. The high concentration values of phosphate observed during the present investigation are comparable with the values reported by Joy *et. al*, (1990). They also reported the fact that the inhibitory action of a high level of phosphate cause an adverse effect on phytoplankton flora. But Sankaranarayanan and Qasim (1969) observed the fact that instantaneous concentration of nutrients in Cochin backwaters as inorganic salts have no significant relation to primary production. However Gopinathan *et. al.* (1984) reported correlation between primary productivity and environmental factors such as phosphate, nitrate, dissolved oxygen and temperature in Cochin estuary.

The values of phosphate concentration decrease gradually downstream from station three to stations four, five and six in that order. At station four, the phosphate concentration varies from 1690 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1020 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 1514 $\mu g\ PO_4{}^{3-}\ Pl^{-1}$ to 1212 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during monsoon period; from 1954 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1254 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 2099 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 779 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during post-monsoon period and from 2724 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1306 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 2146 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1803 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during pre-monsoon period.

At station five the phosphate concentration varies from 2152 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 522 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 2008 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1227 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during monsoon period, from 1932 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1497 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 2012 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1174 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during post-monsoon period and from 1825 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1584 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in surface waters and from 1789 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 1430 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ in bottom waters during pre-monsoon period.

The phosphate concentration at station six also varies from 1730 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to 473 $\mu g\ PO4{}^{3-}\ P\ l^{-1}$ in surface waters and from 1202 $\mu g\ PO_4{}^{3-}\ P\ l^{-1}$ to

1098 μg PO_4^{3-} P l^{-1} in bottom waters during monsoon period, from 1694 μg PO_4^{3-} Pl^{-1} to 500 μg PO_4^{3-} P l^{-1} in surface waters and from 1682 μg PO_4^{3-} P l^{-1} to 734 μg PO_4^{3-} P l^{-1} in bottom waters during post-monsoon period and from 1871 μg PO_4^{3-} P l^{-1} to 1651 μg PO_4^{3-} P l^{-1} in surface waters and from 1891 μg PO_4^{3-} P l^{-1} to 1121 μg PO_4^{3-} P l^{-1} in bottom waters during pre-monsoon period.

The above values of phosphate concentrations at stations four, five and six do not show any seasonal pattern of change except the fact that the concentrations are higher during the entire period of survey and the values gradually decrease from station three to station six. This observation substantiates the earlier conclusion of some discharge of phosphate to the aquatic system around station three, which is carried over downstream by the river. The irregular pattern also indicates that the phosphate concentration in this aquatic system mainly depends on the concentration, quantity and time of discharge of phosphate around station three.

At station seven the phosphate concentration varies from 979 μg PO_4^{3-} P l^{-1} to 206 μg PO_4^{3-} P l^{-1} in surface waters and from 1416 μg PO_4^{3-} P l^{-1} to 307 μg PO_4^{3-} P l^{-1} in bottom waters during monsoon, from 1174 μg PO_4^{3-} P l^{-1} to 191 μg PO_4^{3-} P l^{-1} in surface waters and from 536 μg PO_4^{3-} P l^{-1} to 130 μg PO_4^{3-} P l^{-1} in bottom waters during post-monsoon period and from 512 μg PO_4^{3-} P l^{-1} to 197 μg PO_4^{3-} P l^{-1} in surface waters and from 491 μg PO_4^{3-} P l^{-1} to 196 μg PO_4^{3-} P l^{-1} in bottom waters during pre-monsoon period.

The phosphate concentration values at station seven are higher during the entire period of survey indicating that the increased concentration of phosphate in the main stream is carried over to even station seven which is about 2 km away from the main stream along a branch of the river which joins the main stream at a location between the stations six and eight. However, these values of phosphate concentration at station seven though comparable with, are lower than the corresponding values at stations six and eight and this may be attributed to the fact that the undercurrent in this branch may be weak.

At station eight the phosphate concentration values vary from 1104 μg PO_4^{3-} P l^{-1} to 704 μg PO_4^{3-} P l^{-1} in surface waters and from 1026 μg PO_4^{3-} P l^{-1} to 210 μg PO_4^{3-} P l^{-1} in bottom waters during monsoon period, from 1306 μg PO_4^{3-} P l^{-1} to 322 μg PO_4^{3-} P l^{-1} in surface waters and from 1228 μg PO_4^{3-} P l^{-1} to 217 μg PO_4^{3-} P l^{-1} in bottom waters during post-monsoon period and from 1471 μg PO_4^{3-} P l^{-1} to 119 μg PO_4^{3-} P l^{-1} in surface waters and 1103 μg PO_4^{3-} P l^{-1} to 466 μg PO_4^{3-} P l^{-1} in bottom waters during pre-monsoon period. These values are comparable with values at station six with a decrease in magnitude due to further dilution downstream.

The phosphate concentration values vary from 10 μg PO_4^{3-} P l^{-1} to 7 μg PO_4^{3-} P l^{-1} in surface waters and from 9 μg PO_4^{3-} P l^{-1} to 8 μg PO_4^{3-} P l^{-1} in bottom waters during monsoon period. The values show wide changes between the first post-monsoon period and second post-monsoon period. During the initial post-monsoon period the value varies from 7 μg PO_4^{3-} P l^{-1} to 4 μg PO_4^{3-} P l^{-1} in surface waters and from 7 μg PO_4^{3-} P l^{-1} to 3 μg PO_4^{3-} P l^{-1} in bottom waters and during the second post-monsoon period the value varies from 111 μg PO_4^{3-} P l^{-1} to 22 μg PO_4^{3-} P l^{-1} in surface waters and 82 μg PO_4^{3-} P l^{-1} to 18 μg PO_4^{3-} P l^{-1} in bottom waters . The phosphate concentration values vary from 8 μg PO_4^{3-} P l^{-1} to 3 μg PO_4^{3-} P l^{-1} in surface waters and 7 μg PO_4^{3-} P l^{-1} to 2 μg PO_4^{3-} P l^{-1} in bottom waters during pre-monsoon period.

During the initial twelve months of the study, the phosphate concentration at station nine was low, even though the values were higher from station three to station eight, indicating that the influence of the discharge of phosphate into the aquatic system around station three extends only upto station eight and station nine was free from those influences. But during the latter period of the study the phosphate concentration in both surface and bottom waters at station nine increased gradually indicating the fact that the influence of phosphate discharge around station three has extended even upto station nine over a period of time.

The highest values of phosphate concentration both in surface and bottom waters at station nine were recorded towards the last phase of the period of survey when very high values were recorded at all stations from station three to station eight. The only station where the phosphate concentration values both in surface and bottom waters were normal values, is the station one. At station two the values during the same period were comparable with the values at station nine indicating that the influence of discharge around station three extends both vertically and horizontally in both direction upstream and downstream and covers the whole stretch of the river from station two to station nine.

No significant variation in phosphate concentration was observed between periods but there is significant difference between stations ($P<0.05$) in surface waters. Among stations, station three (Ambalamedu) showed significantly higher value while station nine (Thevara) gave significantly lower value.

There is no significant variation in phosphate concentration between periods ($P>0.05$) in bottom waters. The difference in phosphate concentration between stations is significant ($P<0.05$). Significantly higher phosphate concentration was seen at station three (Ambalamedu) while significantly lower phosphate concentration was recorded at station nine (Thevara)

Phosphate concentration has significant positive correlation with acidity ($P<0.001$), redox potential ($P<0.001$), ammonia concentration ($P<0.001$), nitrite concentration ($P<0.001$) and nitrate concentration ($P<0.001$) and significant negative correlation with pH ($P<0.001$), transparency ($P<0.001$) and salinity ($P<0.01$) in surface waters. The positive correlation of phosphate with acidity and nitrite concentration is found to be significant throughout the period of investigation, while the positive correlation with ammonia and nitrate are significant during monsoon and post-monsoon periods and the positive correlation with redox potential and negative correlation with pH are significant during pre-monsoon and monsoon periods. The negative correlation of phosphate concentration with transparency is significant only during pre-monsoon periods in surface waters.

```
rrelations:  TEMPERAT    SALINITY    DO          PH          ACIDITY     ALKALINE

TEMPERAT     1.0000      -.2390*      .1393      -.1373       .1509      -.1234
SALINITY     -.2390*     1.0000      -.3300**     .1424      -.0687       .1053
DO            .1393      -.3300**    1.0000      -.0083      -.0765      -.2423*
PH           -.1373       .1424      -.0083      1.0000      -.7969**     .6181**
ACIDITY       .1509      -.0687      -.0765      -.7969**    1.0000      -.3585**
ALKALINE     -.1234       .1053      -.2423*      .6181**    -.3585**    1.0000
REDOX_PO      .1592      -.1626       .0335      -.9850**     .8123**    -.6021**
TRANSPAR     -.3385**     .1949*     -.0940       .3116**    -.2822**     .1936
AMMONIA       .0234       .1295      -.0545       .0149       .2001*      .1827
NITRITE       .0443      -.2292*     -.1308      -.2430*      .4393**     .0727
NITRATE       .1914      -.0643      -.1637      -.0138       .3319**     .2292*
TOTAL_N       .1616      -.0722      -.1589      -.0520       .3670**     .2170*
NH3N_TN      -.1154       .5092**    -.2073*     -.0418       .1274       .1560
NO2N_TN      -.2473*     -.2156*     -.1332      -.2175*      .0753      -.1252
NO3N_TN       .2911**    -.0378       .2262*      .2275*     -.1327       .0449
PHOSPHAT      .1764      -.2293*     -.1664      -.3594**     .4782**     .0141
NPRATIO      -.2822**     .5573**    -.1257       .2451*     -.1989*     -.0486

rrelations:  REDOX_POT   TRANSPAR    AMMONIA     NITRITE     NITRATE     TOTAL_N

TEMPERAT      .1592      -.3385**     .0234       .0443       .1914       .1616
SALINITY     -.1626       .1949*      .1295      -.2292*     -.0643      -.0722
DO            .0335      -.0940      -.0545      -.1308      -.1637      -.1589
PH           -.9850**     .3116**     .0149      -.2430*     -.0138      -.0520
ACIDITY       .8123**    -.2822**     .2001*      .4393**     .3319**     .3670**
ALKALINE     -.6021**     .1936       .1827       .0727       .2292*      .2170*
REDOX_PO     1.0000      -.3184**     .0088       .2550*      .0242       .0662
TRANSPAR     -.3184**    1.0000      -.1056      -.3969**    -.2778**    -.3036**
AMMONIA       .0088      -.1056      1.0000       .5042**     .6457**     .7443**
NITRITE       .2550*     -.3969**     .5042**    1.0000       .5810**     .7083**
NITRATE       .0242      -.2778**     .6457**     .5810**    1.0000       .9783**
TOTAL_N       .0662      -.3036**     .7443**     .7083**     .9783**    1.0000
NH3N_TN       .0446       .1250       .7350**     .1818       .1789       .2836**
NO2N_TN       .2075*     -.1293      -.1836       .4432**    -.2788**    -.1653
NO3N_TN      -.2193*      .0635      -.1763      -.5098**     .1804       .0221
PHOSPHAT      .3756**    -.4423**     .5609**     .7994**     .5594**     .6640**
NPRATIO      -.2681**     .3384**     .0150      -.2349*     -.0794      -.1019

Correlations:  NH3N_TN   NO2N_TN     NO3N_TN     PHOSPHATE   NPRATIO

TEMPERAT     -.1154      -.2473*      .2911**     .1764      -.2822**
SALINITY      .5092**    -.2156*     -.0378      -.2293*      .5573**
DO           -.2073*     -.1332       .2262*     -.1664      -.1257
PH           -.0418      -.2175*      .2275*     -.3594**     .2451*
ACIDITY       .1274       .0753      -.1327       .4782**    -.1989*
ALKALINE      .1560      -.1252       .0449       .0141      -.0486
REDOX_PO      .0446       .2075*     -.2193*      .3756**    -.2681**
TRANSPAR      .1250      -.1293       .0635      -.4423**     .3384**
AMMONIA       .7350**    -.1836      -.1763       .5609**     .0150
NITRITE       .1818       .4432**    -.5098**     .7994**    -.2349*
NITRATE       .1789      -.2788**     .1804       .5594**    -.0794
TOTAL_N       .2836**    -.1653       .0221       .6640**    -.1019
NH3N_TN      1.0000      -.1519      -.3333**     .2951**     .1364
NO2N_TN      -.1519      1.0000      -.8813**     .1929      -.1339
NO3N_TN      -.3333**    -.8813**    1.0000      -.3252**     .0625
PHOSPHAT      .2951**     .1929      -.3252**    1.0000      -.3547**
NPRATIO       .1364      -.1339       .0625      -.3547**    1.0000

N of cases:   144        1-tailed Signif:  * - .01   ** - .001

" . " is printed if a coefficient cannot be computed
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     BOTTOM

Correlations:  TEMPERAT   SALINITY   DO         PH         ACIDITY    ALKALINE

TEMPERAT       1.0000     -.0684     -.1149     -.2400*     .2544*    -.1810
SALINITY       -.0684     1.0000     -.2701**    .1421     -.0614      .2081*
DO             -.1149     -.2701**   1.0000      .1477     -.1839     -.1443
PH             -.2400*     .1421      .1477     1.0000     -.7908**    .5487**
ACIDITY         .2544*    -.0614     -.1839     -.7908**   1.0000     -.3298**
ALKALINE       -.1810      .2081*    -.1443      .5487**   -.3298**   1.0000
REDOX_PO        .2375*    -.1629     -.1302     -.9788**    .7963**   -.5363**
AMMONIA         .1134      .1604      .0085      .0525      .1557      .1160
NITRITE         .0637     -.2310*    -.1597     -.2454*     .4132**   -.0626
NITRATE         .2360*    -.0327     -.0525     -.0378      .3324**    .0411
TOTAL_N         .2122*    -.0495     -.0683     -.0685      .3589**    .0354
NH3N_TN         .0573      .5528**   -.2628**    .0301      .0744      .2164*
NO2N_TN        -.2673**   -.2377*    -.1429     -.2199*     .0978     -.0795
NO3N_TN         .2329*    -.0157      .2548*     .1992*    -.1276     -.0192
PHOSPHAT        .2770**   -.2160*    -.2412*    -.4064**    .5528**   -.1155
NPRATIO        -.2033*     .5039**    .0301      .2635**   -.1873     -.0051

Correlations:  REDOX_POT  AMMONIA    NITRITE    NITRATE    TOTAL_N    NH3N_TN

TEMPERAT        .2375*     .1134      .0637      .2360*     .2122*     .0573
SALINITY       -.1629      .1604     -.2310*    -.0327     -.0495      .5528**
DO             -.1302      .0085     -.1597     -.0525     -.0683     -.2628**
PH             -.9788**    .0525     -.2454*    -.0378     -.0685      .0301
ACIDITY         .7963**    .1557      .4132**    .3324**    .3589**    .0744
ALKALINE       -.5363**    .1160     -.0626      .0411      .0354      .2164*
REDOX_PO       1.0000     -.0281      .2775**    .0543      .0913     -.0327
AMMONIA        -.0281     1.0000      .5104**    .6556**    .7496**    .7101**
NITRITE         .2775**    .5104**   1.0000      .5740**    .7141**    .1654
NITRATE         .0543      .6556**    .5740**   1.0000      .9762**    .1861
TOTAL_N         .0913      .7496**    .7141**    .9762**   1.0000      .2772**
NH3N_TN        -.0327      .7101**    .1654      .1861      .2772**   1.0000
NO2N_TN         .2248*    -.1553      .4614**   -.2535*    -.1254     -.1530
NO3N_TN        -.2028*    -.1652     -.5194**    .1624     -.0018     -.2961**
PHOSPHAT        .4309**    .5400**    .7958**    .5453**    .6552**    .2833**
NPRATIO        -.2716**    .0538     -.2054*    -.0212     -.0485      .1321

Correlations:  NO2N_TN    NO3N_TN    PHOSPHATE  NPRATIO

TEMPERAT       -.2673**    .2329*     .2770**   -.2033*
SALINITY       -.2377*    -.0157     -.2160*     .5039**
DO             -.1429      .2548*    -.2412*     .0301
PH             -.2199*     .1992*    -.4064**    .2635**
ACIDITY         .0978     -.1276      .5528**   -.1873
ALKALINE       -.0795     -.0192     -.1155     -.0051
REDOX_PO        .2248*    -.2028*     .4309**   -.2716**
AMMONIA        -.1553     -.1652      .5400**    .0538
NITRITE         .4614**   -.5194**    .7958**   -.2054*
NITRATE        -.2535*     .1624      .5453**   -.0212
TOTAL_N        -.1254     -.0018      .6552**   -.0485
NH3N_TN        -.1530     -.2961**    .2833**    .1321
NO2N_TN        1.0000     -.8986**    .2024*    -.1567
NO3N_TN        -.8986**   1.0000     -.3214**    .0929
PHOSPHAT        .2024*    -.3214**   1.0000     -.3132**
NPRATIO        -.1567      .0929     -.3132**   1.0000

N of cases:    144        1-tailed Signif:  * - .01   ** - .001

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In bottom waters phosphate concentration has positive significant correlation with temperature ($P<0.001$), acidity ($P<0.001$), redox potential ($P<0.001$), nitrate concentration ($P<0.001$), nitrite concentration ($P<0.001$) and ammonia concentration ($P<0.001$) and negative significant correlation with pH ($P<0.001$), salinity ($P<0.01$) and dissolved oxygen ($P<0.01$). The positive correlation of phosphate with acidity, nitrite concentration and ammonia concentration are significant throughout the period of investigation. The positive correlation of phosphate with redox potential and negative correlation with pH are significant during pre-monsoon and monsoon periods while the positive correlation with nitrate concentration is significant during monsoon and post-monsoon periods. The positive correlation with temperature and negative correlation with salinity are significant only during monsoon periods in bottom waters.

There is no significant difference in the ratio of total inorganic nitrogen to phosphate phosphorus between periods, but there is significant difference between stations. ($P<0.05$). Station nine (Thevara) showed significantly higher ratio while station four (Brahmapuram) gave significantly lower ratio.

The variation in the ratio of total inorganic nitrogen to phosphate phosphorus in bottom waters is not significant ($P>0.05$) between periods, while the difference in the ratio between stations is significant ($P<0.05$). Significantly higher value was recorded at station nine (Thevara) while significantly lower ratio was recorded at stations six (Eroor) and five (Irimpanum).

The N:P ratio gives positive significant correlation with salinity ($P<0.001$), transparency ($P<0.001$), pH ($P<0.01$) and negative significant correlation with temperature ($P<0.001$), redox potential ($P<0.001$), acidity ($P<0.01$) and nitrite concentration ($P<0.001$), in surface waters. The positive significant correlation between N:P ratio and salinity is seen throughout the period of survey while the negative correlation with temperature is significant during pre-monsoon and monsoon periods and the positive correlation with transparency is significant only during pre-monsoon periods in surface waters.

In bottom waters the N:P ratio has positive significant correlation with salinity ($P<0.001$), pH ($P<0.001$) and negative significant correlation with redox potential ($P<0.001$), temperature ($P<0.01$) and nitrite concentration ($P<0.01$). The positive correlation of N:P ratio with salinity and the negative correlation with temperature are significant throughout the period of observation while the positive correlation with pH is significant only during post-monsoon periods in bottom waters.

CHAPTER 6

WATER QUALITY INDEX AND A MODEL FOR RIVER CHITRAPUZHA

6.1. Water Modelling

Multiple regression model of river Chitrapuzha was worked out by taking each of the following parameters as dependent treating the others as independent. The parameters are designated as follows.

x_1 - temperature
x_2 - salinity
x_3 - dissolved oxygen
x_4 - pH
x_5 - acidity
x_6 - alkalinity
x_7 - redox potential
x_8 - transparency
x_9 - nitrate
x_{10} - nitrite
x_{11} - ammonia
x_{12} - phosphate

6.1.1. Temperature

The regression model of river Chitrapuzha, taking temperature as the dependent variable and others as independent variables, is as follows:

$$\begin{aligned} x_1 = & -0.040548\, x_2 - 0.045691\, x_3 + 0.440840\, x_4 + \\ & 0.010186\, x_5 - 0.004552\, x_6 + 0.006094\, x_7 - \\ & 0.016962\, x_8 + 0.002434\, x_9 - 0.018575\, x_{10} - \\ & 0.002496\, x_{11} + 0.020455\, x_{12} + 28.385615 \end{aligned}$$

$F = 0.7347$

This multiple regression model explains 23.7% variability which is statistically significant ($p < 0.001$).

The relative importance of the parameters in the predicted model of river Chitrapuzha indicates that nitrate concentration is significantly more prominent in explaining the variation in temperature, compared to the other parameters. Other significantly important parameters explaining the variation in temperature are alkalinity, ammonia concentration, transparency and phosphate concentration in that order of significance.

6.1.2 Salinity

The multiple regression model of the aquatic system, taking salinity as the dependent variable and others as independent variables, is as follows:

$$\begin{aligned} x_2 = {} & -0.301676\ x_1 - 1.277695\ x_3 - 1.505201\ x_4 + \\ & 0.141900\ x_5 + 0.000110\ x_6 - 0.040770\ x_7 - \\ & 0.021265\ x_8 - 0.005379\ x_9 - 0.025060\ x_{10} + \\ & 0.083054\ x_{11} - 0.080220\ x_{12} + 31.925445 \end{aligned}$$

$F = 7.76049$

This fitted model of the water body explains 39.3% variability which is statistically significant ($p < 0.001$).

The relative importance of the parameters in the predicted model of the river indicates that nitrate concentration is significantly more prominent in explaining the variation in salinity, compared to the other parameters. Other important parameters explaining the variation in salinity are alkalinity, nitrite concentration, ammonia concentration and transparency in that order of significance.

6.1.3. Dissolved Oxygen

The fitted model of the river, taking dissolved oxygen as the dependent variable and others as independent variables, is as follows:

$$x_3 = -0.038850\,x_1 - 0.146019\,x_2 + 0.933300\,x_4 + 0.010208\,x_5 - 0.009744\,x_6 + 0.011155\,x_7 - 0.011268\,x_8 - 0.001150\,x_9 - 0.002421\,x_{10} + 0.019962\,x_{11} - 0.028152\,x_{12} + 2.401578$$

$F = 6.15366$

This multiple regression model of the aquatic system explains 33.9% variability which is statistically significant ($p < 0.001$).

The relative importance of the parameters in the predicted model of the water body shows that nitrate concentration is significantly more prominent than all other parameters in explaining the variation of dissolved oxygen. Other prominent parameters in explaining the variation of dissolved oxygen are alkalinity, nitrite concentration, ammonia concentration, transparency and phosphate concentration in that order of significance.

6.1.4. pH

The multiple regression model of the aquatic system, taking pH as the dependent variable and others as independent variable may be represented as follows:

$$x_4 = 0.006804\,x_1 - 0.003123\,x_2 + 0.016943\,x_3 - 0.001365\,x_5 + 0.001125\,x_6 - 0.015901\,x_7 - 0.000235\,x_8 - 0.000076\,x_9 + 0.000399\,x_{10} + 0.000855\,x_{11} - 0.000533\,x_{12} + 6.674700$$

$F = 412.898$

This regression model of the river explains 97.2% variability in pH which is statistically significant ($p < 0.001$).

The predicted model may be used to assess the relative importance of the parameters in explaining the variation in pH. The above model indicates that nitrate concentration is the most significantly prominent parameter in explaining the variation in pH, compared to all other parameters. Other significantly prominent parameters explaining the variation of pH are alkalinity, redox potential, nitrite concentration, ammonia concentration and transparency in that order of importance.

6.1.5. Acidity

The fitted model of river Chitrapuzha derived from multiple regression analysis by treating acidity as the dependent variable and others as independent variables is as follows:

$$\begin{aligned} x_5 = {} & 0.144185\, x_1 + 0.269968\, x_2 + 0.169937\, x_3 - \\ & 1.251468\, x_4 + 0.023824\, x_6 + 0.134193\, x_7 + \\ & 0.049725\, x_8 + 0.019446\, x_9 + 0.026217\, x_{10} - \\ & 0.038172\, x_{11} + 0.024462\, x_{12} - 0.006628 \end{aligned}$$

$F = 42.39495$

This regression model of the water body explains 77.9% variability which is statistically significant ($p < 0.001$).

The relative importance of the parameters in the predicted model indicates that nitrate concentration is the most significantly prominent parameter than all other parameters in explaining the variation of acidity. This model also indicates that the other significantly prominent parameters in explaining the variation in acidity are alkalinity, nitrite concentration, ammonia concentration, transparency, phosphate concentration and redox potential in that order of importance.

6.1.6. Alkalinity

The fitted model of the river obtained from multiple regression analysis treating alkalinity as the dependent variable and all other parameters as independent variable may be given as follows:

$$\begin{aligned} x_6 = {} & -2.200468\,x_1 + 0.007125\,x_2 - 5.540124\,x_3 + \\ & 35.220064\,x_4 + 0.813635\,x_5 + 0.018168\,x_7 + \\ & 0.086618\,x_8 + 0.006566\,x_9 - 0.051116\,x_{10} + \\ & 0.016878\,x_{11} + 0.280601\,x_{12} - 77.403319 \end{aligned}$$

$F = 11.54452$

This regression model of the water body explains 49.0% variability which is statistically significant ($p < 0.001$).

This predicted model can be used to assess the relative importance of different parameters in explaining variation in alkalinity and this model of the river indicates that nitrate concentration is the most prominent parameter than all other parameters in explaining variation in alkalinity. This model also points to nitrite concentration, ammonia concentration and transparency as other prominent parameters in explaining variation of alkalinity in that order of significance.

6.1.7. Redox Potential

The multiple regression model of the river by treating redox potential as the dependent variable and all others as independent variables may be represented as follows:

$$
\begin{aligned}
x_7 = {} & 0.317389\, x_1 - 0.285394\, x_2 + 0.683285\, x_3 - \\
& 53.652514\, x_4 + 0.493740\, x_5 + 0.001957\, x_6 - \\
& 0.051600\, x_8 - 0.016351\, x_9 + 0.002608\, x_{10} + \\
& 0.048983\, x_{11} + 0.027052\, x_{12} + 367.823383
\end{aligned}
$$

$F = 434.91228$

This regression model of the aquatic system explains 97.3% variability which is statistically significant ($p < 0.001$).

The relative prominence of the parameters in the predicted model of the water body indicates that nitrate concentration is significantly more important than all other parameters in explaining variation in redox potential. Other prominent parameters in explaining variation in redox potential are alkalinity, nitrite concentration, ammonia concentration and transparency in that order of significance.

6.1.8. Transparency

The fitted model of river Chitrapuzha treating transparency as the dependent variable and all other parameters as independent variables is as follows:

$$
\begin{aligned}
x_8 = & -3.113209\,x_1 - 0.524590\,x_2 - 2.432279\,x_3 - \\
& 2.795679\,x_4 + 0.644770\,x_5 + 0.032887\,x_6 - \\
& 0.181850\,x_7 - 0.030393\,x_9 - 0.130541\,x_{10} + \\
& 0.186104\,x_{11} - 0.227018\,x_{12} + 207.821997
\end{aligned}
$$

$F = 6.32706$

This multiple regression model of the river explains 34.5% variability which is statistically significant ($p < 0.001$).

The relative prominence of the parameters in the predicted model of the water body indicates that nitrate concentration is the most significantly prominent parameter than all other parameters, in explaining variation in transparency. This model also tells us the fact that alkalinity, nitrite concentration and ammonia concentration are the other prominent parameters in explaining variation in transparency, in that order of importance.

6.1.9. Nitrate

The multiple regression model of river Chitrapuzha by taking nitrate concentration as the dependent variable and all other parameters as independent variables may be represented as follows:

$$
\begin{aligned}
x_9 = & \; 14.210868\,x_1 - 4.220155\,x_2 - 7.896322\,x_3 - \\
& 28.717824\,x_4 + 8.019621\,x_5 + 0.079288\,x_6 - \\
& 1.832716\,x_7 - 0.966621\,x_8 + 0.856526\,x_{10} + \\
& 2.553376\,x_{11} - 0.521109\,x_{12} - 65.476131
\end{aligned}
$$

$F = 20.72033$

This regression model of the river explains 63.3% variability which is statistically significant ($p < 0.001$).

The parameter alkalinity is significantly more prominent than all other parameters in explaining variation in nitrate concentration as per the predicted water model.. Other prominent properties that can explain the variation in nitrate concentration are nitrite concentration, ammonia concentration and transparency in that order of significance.

6.1.10. Nitrite

The fitted regression model of river Chitrapuzha, treating nitrite concentration as the dependent variable and all other parameters as independent variables, is as follows:

$$\begin{aligned} x_{10} = & -5.154607\,x_1 - 0.934691\,x_2 - 0.790283\,x_3 + \\ & 7.179689\,x_4 + 0.513971\,x_5 - 0.029342\,x_6 + \\ & 0.013897\,x_7 - 0.197368\,x_8 + 0.040717\,x_9 + \\ & 0.028610\,x_{11} + 1.054244\,x_{12} + 140.441515 \end{aligned}$$

$F = 30.87724$

This multiple regression model of the river explains 72.0% variability which is statistically significant ($p < 0.001$).

The relative prominence of the parameters in the predicted model of the water system indicates that nitrate concentration is the most significantly important parameter than all other parameters in explaining variation in nitrite concentration. Other prominent parameters in explaining variation in nitrite concentration are alkalinity, ammonia concentration, transparency and phosphate concentration in that order of significance.

6.1.11. Ammonia

The multiple regression model of river Chitrapuzha by treating ammonia concentration as the dependent variable and all other parameters as independent variables is as follows:

$$
\begin{aligned}
x_{11} = {} & -0.521415\, x_1 + 2.331819\, x_2 + 4.904172\, x_3 + \\
& 11.573305\, x_4 - 0.563312\, x_5 + 0.007293\, x_6 + \\
& 0.196463\, x_7 + 0.211802\, x_8 + 0.091369\, x_9 + \\
& 0.021536\, x_{10} + 0.680784\, x_{12} - 119.268345
\end{aligned}
$$

$F = 21.58962$

This regression model of the river explains 64.3% variability which is statistically significant ($p < 0.001$).

The relative importance of the parameters in the predicted model of the aquatic system shows that nitrate concentration is significantly more prominent than all other parameters in explaining variation in ammonia concentration. Other prominent parameters in explaining variation in ammonia concentration are alkalinity, nitrite concentration and transparency in that order of significance.

6.1.12. Phosphate

The fitted model of river Chitrapuzha derived from multiple regression analysis by treating phosphate concentration as the dependent variable and all other parameters as independent variables is shown below:

$$x_{12} = 1.669535\,x_1 - 0.880077\,x_2 - 2.702528\,x_3 - 2.817582\,x_4 + 0.141061\,x_5 + 0.047378\,x_6 + 0.042398\,x_7 - 0.100957\,x_8 - 0.007286\,x_9 + 0.310091\,x_{10} + 0.266019\,x_{11} - 8.595578$$

$F = 45.59526$

This regression model of the river explains 79.2% variability which is statistically significant ($p < 0.001$).

The relative importance of the parameters in the predicted model of the water body indicates that nitrate concentration is significantly more prominent in explaining the variation in phosphate concentration compared to the other parameters . Other significantly important parameters in explaining the variation in phosphate concentration are alkalinity, nitrite concentration, ammonia concentration and transparency in that order of prominence.

6.1.13. Multiple regression model with N:P ratio

In the multiple regression model of river Chitrapuzha, when two biologically important derived parameters, total inorganic nitrogen and N:P ratio, are added to the independent parameters, the fitted model explains more than 99% variability (in the case of nitrate 99.96% in surface waters and 99.95% in bottom waters; 99.3% both in surface and bottom waters in the case of nitrite, 99.1% in surface waters in the case of ammonia and 99.98% and 99.97% respectively in surface and bottom waters in the case of total inorganic nitrogen). Since this regression model explains almost all variabilities in the data, this can well be considered as a mathematical model of the river Chitrapuzha.

Details of variabilities explained by the fitted model are given in the following table.

Dependent variable	% variability		significance	
	Surface	Bottom	Surface	Bottom
Temperature	25.436	25.922	$p < 0.001$	$p < 0.001$
Salinity	51.087	49.307	$p < 0.001$	$p < 0.001$
Dissolved oxygen	32.228	30.844	$p < 0.001$	$p < 0.001$
pH	97.388	96.207	$p < 0.001$	$p < 0.001$
Acidity	78.575	75.368	$p < 0.001$	$p < 0.001$
Alkalinity	58.006	44.343	$p < 0.001$	$p < 0.001$
Redox potential	97.537	96.128	$p < 0.001$	$p < 0.001$
Transparency	39.878	—	$p < 0.001$	—
Nitrate	99.962	99.951	$p < 0.001$	$p < 0.001$
Nitrite	99.330	99.311	$p < 0.001$	$p < 0.001$
Ammonia	99.056	98.679	$p < 0.001$	$p < 0.001$
Total nitrogen	99.977	99.971	$p < 0.001$	$p < 0.001$
Phosphorus	76.974	78.337	$p < 0.001$	$p < 0.001$
N:P ratio	49.075	40.892	$p < 0.001$	$p < 0.001$

6.2. Water Quality Index

Water is a universal solvent and in nature it carries large number of substances with it. The probability of finding pure water in nature is very low. Pollution of water has become a matter of great concern of the Environmentalists particularly with the fast rate of growth of industries and increasing volume of industrial waste effluents. The problem of water pollution has been aggravated with the increased use of chemical fertilizers, weedicides and pesticides and increased volume of sewage with increase in population.

The quality of water is dependent on the nature of materials present and the potential use which can derive from it. The water quality requirements are not always the same but may vary with use. The domestic user prefers a high sodium soft water, agriculture needs a high calcium hard water and industries need yet another category of water.

Environmental monitoring in many countries over the last few years, has produced large amount of data on many aspects of pollution of natural waters. Many workers have identified the parameters causing major stresses to the system (Chamberlain and Hayward 1996). One of the effective ways of communicating the available knowledge of the quality of water is to use certain indices which can easily be computed mathematically. An index is a quantitative measure, which aggregates and summarises the available data on a particular problem to illustrate the existence and trends of significant conditions (Doan, and East, 1977). The water quality index allows comparison of quality status of two or more water bodies from different localities and also helps to evaluate pollution control programme.

Brown et. al., (1970) developed a general water quality index which was not directed toward any specific water use. They defined qi as a quality function dependent on the concentration of a single parameter and was given an integer value from zero to hundred. The value 100 would imply a sample of water with maximum quality as far as that particular parameter was concerned and the value 0 would imply a sample of water with minimum quality or worthless water as far as that particular parameter was concerned.

Since some of the parameters were more important than the other parameters, relative weightages wi were also assigned to each value. From these numerical values of qi and wi for each of the 'n' parameters monitored, a numerical value of the water quality index was derived.

$$\mathrm{WQI} = \mathop{\varepsilon}\limits_{i=1}^{n} \; w_i \; q_i$$

This additive index for water quality lacked sensitivity to reflect adequately the effect of extreme state of pollution in respect of one or more parameters. Hence Brown *et. al.*, (1972) modified the above equation and used the multiplicative index instead of the initial additive index.

$$\mathrm{WQI} = \mathop{\varepsilon}\limits_{i=1}^{n} \; {q_i}^{w_i}$$

Prati, *et. al.*, (1971); Walski, and Parker, (1974); Inhaber, (1975); Ross, (1977); Bolton, *et. al.*, (1977); Stoner, (1978) and Handa, (1980) have put forwarded various procedures both graphical and mathematical for computation of water quality indices.

Water quality of an aquatic system decreases with pollution which is usually reflected in the water quality index accordingly. However, water quality of an unpolluted water source may also change with space and time depending on internal factors like rate of flow, precipitation, regeneration, etc. and external factors like input, outflow, tidal effect, climatic conditions etc., thereby making it difficult to ascertain the base value for different parameters. Hence the usual practice is to link the water quality index with the permissible concentration of various parameters as described by the statutory local authorities.

The quality function (QF) of each of the individual water quality parameters is usually assigned a value between 0 and 100. The quality function of a particular parameter for a sample of water at the recommended, highest desirable concentration has arbitrarily been set at zero value and a sample of water with zero concentration has been fixed at the value hundred. When the magnitude of a particular parameter exceeds the highest desirable magnitude, then the quality function of water with reference to that particular parameter becomes negative. The more the limit is exceeded, the larger is the negative value. For a sample of water, some of the quality functions with reference to certain parameters may be positive while the quality functions with reference to certain other parameters may be negative.

The sum of all quality functions for different parameters for a sample of water gives the net water quality index. After assigning numerical values to quality functions of each of the parameters, the values are to be adjusted with due weightages to reflect their relative importance. The factor used to adjust the numerical value of quality function is referred as the ranking factor (RF), the boundary condition for ranking factor is that their sum must be equal to unity.

$$(RF)_1 + (RF)_2 + (RF)_3 + \ldots\ldots + (RF)_n = 1.$$

To simplify the problem of computation, parameters are usually arranged in groups. Equal weightage is given to all parameters in a group. The weightage for different groups should reflect the relative importance of parameters in that group. Individual values are determined by assigning numerical values for properties b to n in relation to the value of the highest ranking property a.

$p\ (RF)\ a + q\ x_1\ (RF)\ b + r\ x_2\ (RF)\ c + \ldots\ldots + z\ x_{(n-1)}\ (RF)\ n = 1$, where p, q, r etc are the number of properties in each group and x_1, x_2, x_3 etc. are the terms used to relate the importance of properties of respective groups to the highest ranking group (RF) a.

A simple function relating concentration values to the ranking factors is then determined. The contribution from each of the parameter to the overall water quality index is obtained by multiplying the quality function by the ranking factor. The sum of all quality functions with their corresponding weightages gives the water quality index. When the sum of individual quality functions is negative, the water quality index becomes negative, indicating a high degree of pollution and may be considered as positive water pollution index. The water quality index (WQI) and water pollution index are related to one another by the following equation.

$$WQI + WPI = 0.$$

This water quality index may be used as a scale to compare the 'goodness' or 'worthlessness' of different samples of water for some specific use.

Three mathematical equations representing the linear function $y = ax + b$; the parabolic equation $y = ax^2 + b$ and the two headed parabolic equation $y = ax^2 + bx + c$ have been used to explain the effect of quality functions of each of the water quality parameter on the water quality index.

The Central Board for the Prevention and Control of Water Pollution in India has suggested the use of 52 parameters in monitoring pollution in a water body. Since the use of such a large number of parameters is a difficult task, only a few parameters which are relevant to that particular type of aquatic system, are usually incorporated into the water quality index. Ross (1977) used only four parameters for computation of water quality index while Bolton *et. al.*, (1977) used ten parameters and Stoner, (1978) used forty nine parameters.

It is possible that in some exceptional cases, the water may be polluted with respect to only one or two parameters. The significant values of quality function from other parameters may give the water body a better index and mask the harmful effects of the parameters causing pollution. In such cases it would be desirable to cut down the number of parameters and confine to the pertinent ones as suggested by Handa (1980). In the case of river Chitrapuzha pollution is mainly expected from inorganic constituents discharged into the aquatic system in the form of industrial effluents from fertilizer plants and hence the organic and metallic pollutants are ignored.

In the present assessment of river Chitrapuzha, with a special emphasis to nutrient profile, only seven prominent parameters which significantly alter the quality of water are selected and their quality functions are computed. The parameters used in this assessment are ammonia concentration, nitrite concentration, nitrate concentration, phosphate concentration, dissolved oxygen, pH and transparency.

The above seven parameters are grouped into three groups. Group 'a' consists of two parameters ammonia and nitrite, Group 'b' consists of four parameters - nitrate, phosphate, dissolved oxygen & pH and group 'c' consists of only one parameter - transparency. The following values are assigned to the various groups, 'a' being the most significant group in determining the quality of water is assigned the value one, group 'b' the value of 0.667 and group 'c' the value of 0.333. This means that the weightage for different parameters in group 'a', 'b' and 'c' are in the ratio 3:2:1. The ranking factor for each of these groups are determined by the method described earlier. Let the numerical weightage given for group 'c' parameter be x, so that the weightages for different parameters in group 'b' and 'a' are 2x and 3x respectively. Since there are two parameters in group 'a' and four parameters in group 'b',

$$2 \times 3x + 4 \times 2x + x = 1$$

$$15x = 1$$

$$x = 1/15 = 0.0667$$

Weightage for parameters in group b = 2x = 0.1333

Weightage for parameters in group c = 3x = 0.2000

Group	RF	No. of parameters	Magnitude
'a'	0.20000	2	0.4000
'b'	0.13333	4	0.5333
'c'	0.06667	1	0.0667
			1.0000

6.2.2 Computation of water quality index

6.2.2.1. Quality function - Ammonia

Ammonia is considered as an index of pollution. Toxicity of ammonia depends on the pH of the medium. The unionized form is toxic which is the major form present in the equilibrium mixture when pH is higher while the ionized form is non toxic which is the predominant form when pH is lower. The USSR standards as quoted by Reeder (1979) lay down a maximum limit of 2mg $NH_3 N\ l^{-1}$, while the US, EPA, (1973) and the Canadian Standards (1969) recommend a limit of 0.5mg NH_3 N l^{-1}. The Australian standards as reported by Hart, (1974) suggests a limit varying from 0.1 to 0.5 mg NH_3 N l^{-1}. In this present analysis a maximum desirable limit of 0.5 mg NH_3 N l^{-1} has been selected and assigned a quality function value of zero. A simple linear equation is used to compute the effect of ammonia concentration as a quality function on the water quality index.

$$QF\ (NH_3 - N) = 100 - 200\ (mg\ NH_3\ N\ l^{-1})$$

6.2.2.2. Quality function - Nitrite

Natural waters contain only minute qualities of nitrite ions. It is unstable in presence of dissolved oxygen and occurs mainly as an intermediate form between nitrate and ammonia. However discharge of industrial effluents often increase nitrite ion concentration significantly causing harmful effects on aquatic organisms. Nitrite is more toxic to man and animals than nitrate. US, EPA (1973) has suggested an upper limit of 1.0 mg NO_2– N l^{-1} and is accepted as the maximum limit in this analysis and assigned a quality function value of zero. A simple parabolic equation is used to explain the effect of nitrite concentration as a quality function on the water quality index.

$$QF\ (NO_2^-\ N) = 100 - 100(mg\ NO_2^-\ N\ l^{-1})^2$$

6.2.2.3. Quality function - Nitrate

Natural waters contain low concentration of nitrate ions. However considerable contribution of nitrate ions occur from human and animal wastes, fertilizers and industrial effluents. High nitrate ion concentrations affect the oxygen carrying capacity of blood (methemoglobinemia) and hence an upper desirable limit of 10 mg NO_3– N l^{-1} has been suggested by most authorities. In this analysis the above value has been assigned a quality function value of zero. A simple parabolic equation is used to compute the effect of nitrate concentration as a quality function on the water quality index.

$$QF\ (NO_3^-\ N) = 100 - 1\ (mg\ NO_3^-\ N\ l^{-1})^2$$

6.2.2.4. Quality function - Phosphate

Natural waters contain low concentration of phosphates. However domestic sewage containing human excrement and detergents, agricultural run off and discharge of industrial effluents may contribute phosphorus to fresh water bodies. Although phosphate is not toxic to man, animals or fish, it may stimulate algal growth and thus cause odour and taste problems and hence certain quality guidelines have been proposed. The Canadian (1969) and Australian standards as reported by Hart (1974) suggest a limit of 0.2 mg PO_4^{3-} P l^{-1}. In the present analysis the above standards is used as the maximum desirable concentration of phosphate and assigned the quality function value as zero. A simple linear equation is used to explain the effect of phosphate concentration as a quality function on the water quality index.

$$QF\ (PO_4^{3-}\ P) = 100 - 500\ (mg\ PO_4^{3-}\ P\ l^{-1})$$

6.2.2.5. Quality function - Dissolved Oxygen

The quality of dissolved oxygen present in a water body depends on factors like temperature, salinity, transparency, atmospheric pressure and chemical environment of the medium. Adequate amounts of dissolved oxygen is required for the survival of aquatic organisms. The requirement of dissolved oxygen in a water system depends on the temperature and the nature of organisms present in the system. Oxidation of inorganic wastes and decomposition of organic wastes reduce the dissolved oxygen to extremely low levels which may become harmful to the aquatic organisms present in the environment.

Hart (1974) has suggested a minimum limit of 5 mg l^{-1} of dissolved oxygen and this has been used in this analysis as the minimum desired value and assigned a quality function value of zero. The solubility of dissolved oxygen at atmospheric pressure at a temperature of 25 ^{0}C is around 8 mg l^{-1} and this has been given a quality function value of 100. The quality function of a sample of water with reference to dissolved oxygen may be computed using a simple parabolic equation.

$$QF\ (DO) = 2.564\ (mg\ DO\ l^{-1})^2 - 64.1$$

6.2.2.6. Quality function - pH

The pH of unpolluted natural water ranges from 6.0 to 8.5. Discharge of industrial effluents into the water body may cause significantly large variation in pH value which may be harmful to the aquatic organisms. The pH range recommended for potable waters varies to some extend with various authorities viz. Canada 6.5 to 8.3, Australia 6.5 to 9.0, US, EPA 5.0 to 9.0 and ICMR 7.0 to 8.5. In this analysis the limits set by ICMR have been accepted and the ideal value has been arbitrarily set at 7.5. A two headed parabolic equation is used to reflect the effect of pH as a quality function on the total water quality index.

$$QF\ (pH) = -200\ (pH)^2 + 3100\ (pH) - 11900$$

6.2.2.7. Quality function - Transparency

Transparency is a measure of light penetration through water. Presence of suspended particles such as silt, clay, organic matter, plankton and other micro organisms cause reduction in transparency. Discharge of industrial waste effluents, sewage, algal bloom and insoluble solid materials carried over to rivers during monsoon periods may also contribute to reduction in transparency. The EEC guidelines as reported by Handa (1980) suggest a desirable level of 2 m which has been assigned a value of 100 and a minimum limit of 1 m which has been assigned a value of zero. A simple linear equation is used to calculate the quality function of transparency.

$$QF\ (\text{transparency}) = (\text{transparency in cm}) - 100$$

The water quality index equations for the above seven parameters, after incorporating the corresponding ranking factor terms are given in table 6.2.1.

This index is designed to impart information of trends in water quality with special reference to the nutrient profile of river Chitrapuzha. This water quality index provides directly comparable numbers such that the extend of pollution of various waters can be judged. This index also allows study of pollution status of natural waters over a period of time. This index, however, does not provide information on the concentration and distribution of the individual water quality parameters. It merely represents the relative degree of pollution as per criteria used in deriving this index.

Table 6.2.2. shows the distributional pattern of water quality index of river Chitrapuzha during the period of survey which is represented in the form of a graph in fig. 6.2.1. Table 6.2.3 gives the variation of water quality index with space. Table 6.2.4 represents a comparative account of water quality index of a number of aquatic systems which is reflected in fig. 6.2.2. Although these indices have been computed on limited data, they indicate the overall pollution status and applicability of the water body for specific uses.

The water quality index of river Chitrapuzha gives negative value during the period of survey indicating the fact that the water body is heavily polluted

Table 6.2.1. Water quality index equations

Parameter	RF	Ideal	Limit	Equation
Group 'a'				
NH_3 (mg NH_3 N l^{-1})	0.2000	0	0.5	$20 - 40$ (mg NH_3 N l^{-1})
NO_2^- (mg NO_2^- N l^{-1})	0.2000	0	1.0	$20 - 20$ (mg NO_2^- N $l^{-1})^2$
Group 'b'				
NO_3^- (mg NO_3^- N l^{-1})	0.1334	0	10.0	$13.34 - 0.1334$ (mg NO_3^- N $l^{-1})^2$
PO_4^{3-} (mg PO_4^{3-} P l^{-1})	0.1334	0	0.2	$13.34 - 66.7$ (mg PO_4^{3-} P l^{-1})
DO (mg DO l^{-1})	0.1334	8	5.0	0.342 (mg DO $l^{-1})^2 - 8.550$
pH	0.1334	7.5	7.0 & 8.5	$-26.68\,(pH)^2 + 413.5\,(pH) - 1587$
Group 'c'				
Transparency (cm)	0.0664	200	100	0.0664 (tran. cm) – 6.64

Table 6.2.2

Distributional pattern of Water quality index of river Chitrapuzha during October 1990 to January 1992

Periods	1 Oct. 90	2 Nov. 90	3 Dec. 90	4 Jan. 91	5 Feb. 91	6 Mar. 91	7 Apr. 91	8 May 91	9 Jun. 91	10 Jul. 91	11 Aug. 91	12 Sept. 91	13 Oct. 91	14 Nov. 91	15 Dec. 91	16 Jan. 92
Ammonia (NH_3)	−6.44	+16.88	+10.28	+6.16	+2.16	−0.32	−2.24	+10.32	+13.48	+16.96	+12.48	−8.88	−5.84	−3.24	+4.44	+11.36
Nitrite (NO_2^-)	+10.06	+4.48	+6.19	+6.98	+11.42	+9.75	+13.3	+5.07	+8.81	+3.86	+6.72	+0.99	+4.44	+5.58	+5.89	+5.58
Nitrate (NO_3^-)	+11.47	+13.18	+13.00	+12.73	+12.92	+12.80	+12.58	+10.01	+11.63	+12.79	+11.78	+10.19	+11.62	+12.38	+12.72	+12.87
Phosphate (PO_4^{3-})	−43.02	−34.62	−31.28	−42.89	−49.82	−52.63	−53.89	−57.08	−43.02	−34.75	−35.42	−48.66	−43.96	−44.89	−43.89	−54.43
Dissolved Oxygen (DO)	−3.3	−7.11	−6.98	−6.92	−6.83	−6.69	−7.09	−7.50	−7.00	−6.57	−6.43	−6.32	−6.50	−6.72	−6.66	−6.83
pH	+13.74	−13.10	−2.58	+4.93	−60.07	−76.08	−0.22	−48.05	−46.43	−52.23	−40.10	−29.19	−1.04	−12.55	−8.37	−11.48
Transparency	−1.088	−0.348	−0.555	−1.384	−2.027	−2.427	−2.153	−2.117	−2.250	−2.324	−2.160	−2.057	−1.784	−1.636	−1.487	−1.154
WQI	−18.58	−20.64	−11.93	−20.41	−92.25	−115.60	−39.71	−89.35	−64.78	−62.26	−53.13	−83.93	−43.06	−51.08	−37.36	−44.10

Table 6.2.3

Distributional pattern of Water quality index along space.

Stations	1	2	3	4	5	6	7	8	9	Average Value
Ammonia (NH_3)	+19.56	+19.72	–7.60	–9.92	–3.68	+1.92	+9.56	+6.28	+4.80	+4.52
Nitrite (NO_2^-)	+19.98	+17.13	–28.10	–30.54	–7.90	+8.60	+14.38	+11.02	+16.06	+2.29
Nitrate (NO_3^-)	+13.31	+13.30	+9.63	+11.63	+11.6	+12.10	+12.28	+11.95	+12.66	+12.05
Phosphate (PO_4^{3-})	+10.54	+9.67	–118.46	–99.58	–91.51	–71.70	–19.01	–33.62	+12.21	–44.61
Dissolved Oxygen (DO)	+8.21	+3.23	+0.10	+0.56	–0.93	–1.84	–1.47	–1.78	–0.87	+0.58
pH	+1.36	–2.31	–17.08	–69.30	–74.12	–43.22	–5.46	–6.41	+11.72	–22.76
Transparency	–0.73	–1.13	–2.46	–2.33	–2.33	–0.67	–1.80	–0.93	–0.47	–1.43
WQI	+72.23	+59.61	–163.97	–199.48	–168.87	–94.81	+8.48	–13.49	+56.11	–49.36

Table 6.2.4

Water quality index for comparison of three rivers

Water Bodies	Chitrapuzha	Periyar *	Chaliyar **
Ammonia NH_3	+4.52	+12.46	+17.79
Nitrite NO_2^-	+2.29	+19.64	+20.00
Nitrate NO_3^-	+12.05	+13.39	+13.33
Phosphate PO_4^{3-}	–44.61	+01.93	+11.99
WQI	–25.75	+47.42	+63.11

* *Base Value - Joy et.al., (1990)* ** *Base Value - Jose Xavier (1993)*

with positive pollution index. The pollution indices vary from 115.60 during the period seven (March 1991) to 11.93 during the period three (December 1990). Highest average values of positive pollution index (84.23) were recorded during pre-monsoon periods and the values gradually decreases to 66.03 as the season advances to monsoon and then to 30.90 as the season proceeds to post-monsoon period which is found to be comparatively less polluted.

There is wide special variation in the water quality index. The values of water quality index at stations one (Manackakadavu), two (Ambalamughal), seven (Tripunithura) and nine (Thevara) are positive with a maximum positive value at station one indicating that the pollution load with reference to the above parameters is within the carrying capacity of the aquatic system. The values of water quality index at the remaining five stations, station three (Ambalamedu), station four (Brahmapuram), station five (Irimpanam), station six (Eroor) and station eight (Chambakara) are negative with very high magnitude at stations three, four and five and then a diminishing trend along stations six and eight. These values indicate that the pollution load of this part of the river is much higher than the carrying capacity and the problem is caused due to discharge of some industrial effluent around stations three, four or five. This conclusion is further supported by the fact that the outlet for discharge of industrial effluent from a major fertilizer plant is situated between stations three and four.

Table 6.2.4 gives a comparison of river Chitrapuzha with two other similar rivers in Kerala. Rivers Periyar and Chitrapuzha carry much of industrial effluents from many industries concentrated at two different clusters around the city of Cochin and river Chaliyar carries effluents from some industries located around the city of Calicut. The present analysis reveals the fact that river Chitrapuzha is more polluted with a negative water quality index of 25.75 while the water quality index of river Periyar is positive 47.42 and river Chaliyar positive 63.11, even though more attention is directed to the problems of rivers Periyar and Chaliyar.

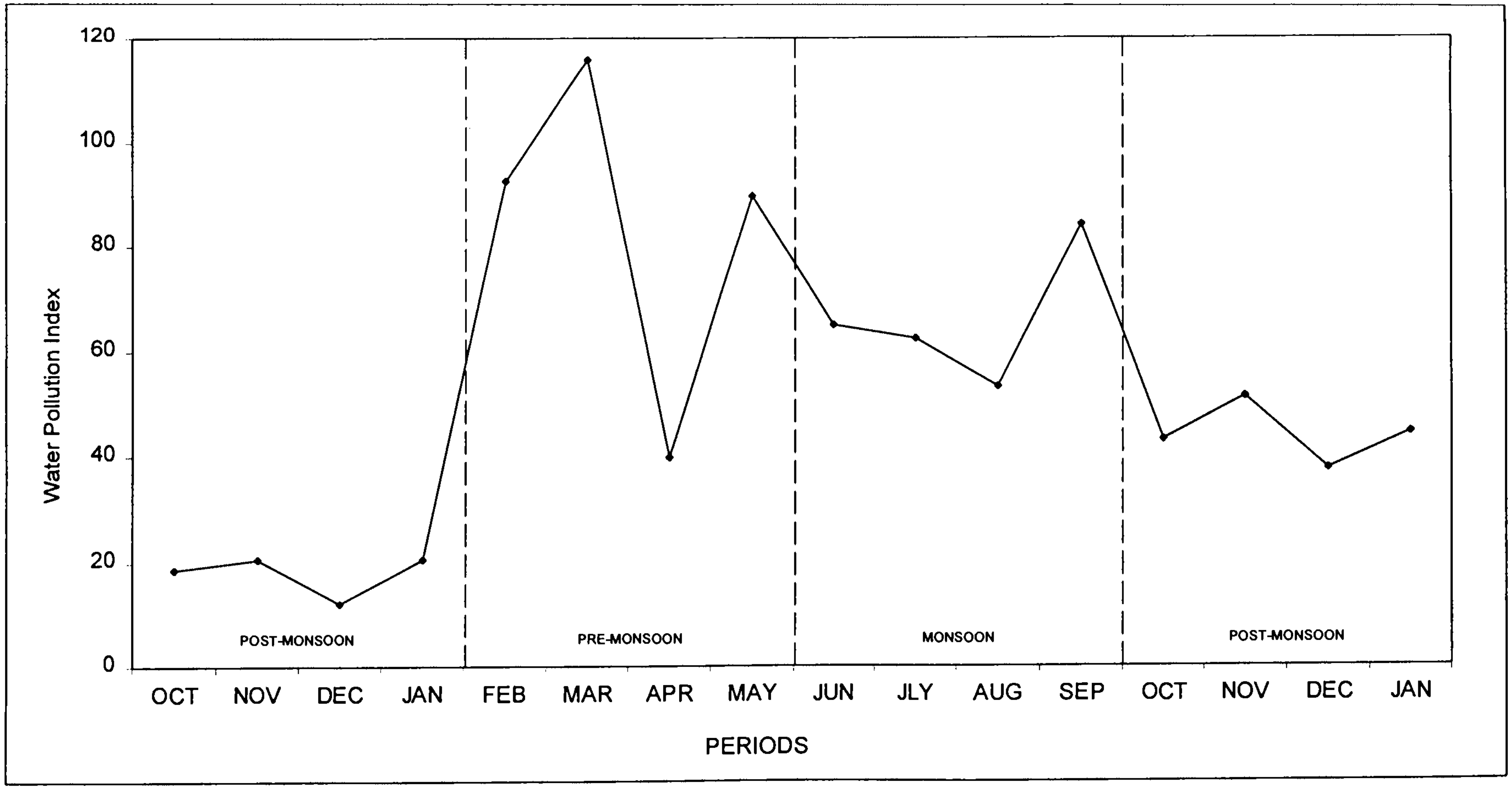

Fig. 6.2.1
Distributional pattern of water pollution index during different seasons.

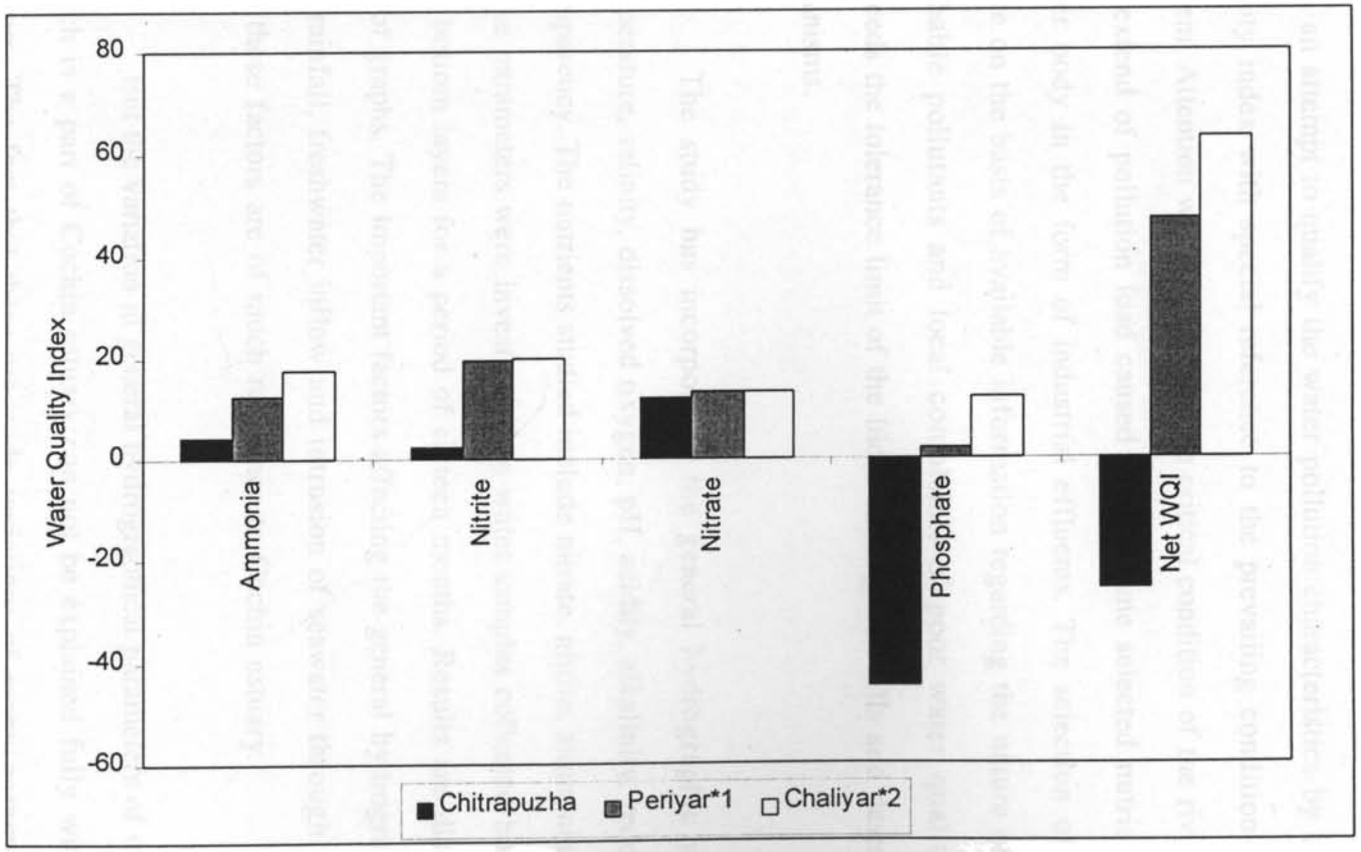

Fig. 6.2.2.
Water quality index of three rivers.

*1 - Joy *et. al.*, (1990)
*2 - Jose Xavier (1993)

Summary

A systematic and comprehensive study on the general hydrography and assessment of some selected nutrients in river Chitrapuzha was made together with an attempt to qualify the water pollution characteristics by deriving a water quality index with special reference to the prevailing conditions of the aquatic system. Attention was focussed on the critical condition of the river and examined the extend of pollution load caused due to some selected nutrients entering the water body in the form of industrial effluents. The selection of nutrients were made on the basis of available information regarding the nature of industries and probable pollutants and local complaints of poor water quality which often exceeds the tolerance limit of the biota causing fish kills and destruction of other organisms.

The study has incorporated the general hydrographic parameters like temperature, salinity, dissolved oxygen, pH, acidity, alkalinity, redox potential and transparency. The nutrients studied include nitrate, nitrite, ammonia and phosphate. These parameters were investigated in water samples collected both from surface and bottom layers for a period of sixteen months. Results are discussed with the aid of graphs. The important factors affecting the general hydrography of estuaries are rainfall, freshwater inflow and intrusion of seawater through the river mouth and these factors are of much relevance to Cochin estuary.

But the variation in general hydrographical parameters of river Chitrapuzha which is a part of Cochin estuary can not be explained fully with these general factors. The fact that there are wide variations of many parameters at stations three and four which are closer to the effluent outlets of some industrial unit indicate that the variations are mainly caused due to the discharge of industrial effluents and the extend of variation depends mainly on the period quantity and quality of effluents discharged into the water body.

Temperature was lower during monsoon and post-monsoon periods and higher during dry pre-monsoon periods. The annual variation in temperature was 7.1°C in surface waters and 5.9°C in bottom waters. Vertical gradient in temperature at all stations was low and it may be due to shallow nature of the river. Horizontal variation in temperature was evident with decreasing trend downwards which may be due to intrusion of comparatively cooler marine water.

The negative correlation of temperature with transparency and salinity in surface waters and with pH in bottom waters are significant. The negative correlation of temperature with acidity and redox potential are also significant in bottom waters.

Salinity was mainly controlled by fresh water discharge through the river and tidal currents. A clear horizontal salinity gradient was observed during the period of survey with declining values from estuarine mouth to riverine zone. During the monsoon periods when the riverine discharge was maximum, saline intrusion was felt only upto station nine about 5 km upstream from the barmouth. Sea water intrusion increased during post monsoon periods and extended upto station seven, 12 km from the barmouth. During pre-monsoon period, significant salinity was observed at all stations from station nine to station three, 20 km from the barmouth leaving only two stations, station one and two, out of marine influence. Bottom salinity values were generally higher than the salinity values for surface waters. No district stratification was observed and the vertical salinity gradient was low.

Salinity has negative correlation with dissolved oxygen and positive correlation with alkalinity. Negative correlation of salinity with temperature is significant in surface water but not in bottom waters.

Dissolved oxygen concentration was higher during monsoon and the values decreased as the season advanced to post-monsoon and pre-monsoon periods.

Relatively higher values were observed at the upper reaches of river Chitrapuzha as compared to the lower reaches of the estuary and it may be due to higher solubility of oxygen in less saline waters. Lowest values were recorded at station three (Ambalamedu) during pre-monsoon periods which may be explained as the combined effect of discharge of industrial effluents around stations three, low freshwater inflow during the pre-monsoon periods, higher saline influence and higher utilisation of oxygen by organic matter.

Negative correlation between dissolved oxygen and salinity is significant both in surface and bottom waters while with alkalinity is significant only in surface waters.

A wide range of pH variations were observed at stations three (Ambalamedu), four (Brahmapuram), five (Irimpanum) and six (Eroor) with a decreasing order from station three to station six, which are most affected by discharge of industrial effluents. Variation of pH were less pronounced at stations seven, eight and nine which are less affected by discharge of industrial effluents but more influenced by marine intrusion. Highest values of pH 8.78 in surface waters and 8.68 in bottom waters were observed during the month of October 1990 at station three indicating discharge of some alkaline industrial effluent around station three. Lowest pH values were also observed at station three, in the range 3.07 in surface waters and 3.06 in bottom waters during March 1991 indicating discharge of some strongly acidic industrial effluent around station three. No clear pattern of seasonal variation in pH was observed during the period of survey.

Positive correlation of pH with alkalinity and negative correlation with redox potential, acidity and temperature are significant both in surface and bottom waters.

Methyl orange acidity upto pH 3.7 were observed only at two centres at station three and four during the month of March 1991. Detection of methyl orange acidity which can be caused only due to the presence of strong mineral acids, at stations three and four with supporting values of pH and redox potential clearly indicates discharge of acidic industrial effluent around station three, which was carried downstream causing methyl orange acidity even at station four. Total acidity or phenolphathalein acidity upto pH 8.3 was observed at all stations with wide variations. Highest values were recorded during March 1991 and the lowest in January 1991, both in surface and bottom waters. Since methyl orange acidity was absent at most of the stations, the total acidity at those locations were mainly due to dissolved carbon dioxide.

Positive correlation of acidity with redox potential and negative correlation with pH and alkalinity are significant both in surface and bottom waters. Negative correlation of acidity with transparency is significant in surface waters while positive correlation with temperature is significant only in bottom waters.

Phenolphthalein alkalinity was observed only at a few stations, with a maximum value at station three both in surface and bottom waters. High phenolphthalein alkalinity along with non detectable level of acidity values, high pH values and low values of redox potential during the months of October and December 1990 and January 1991 clearly indicates discharge of some alkaline effluent into the river during this period. Wide variation was observed in methyl orange or total alkalinity. Maximum values were recorded at station three during October 1990 in surface waters and November 1990 in bottom waters and minimum values of non detectable levels during March 1991 both in surface and bottom waters. This non detectable level of total alkalinity at station three during March 1991 along with high acidity value, low pH value and high redox potential indicates discharge of acidic industrial effluent into the river. Alkalinity due to the presence of hydroxyl ions was zero in the aquatic system, since the phenolphthalein alkalinity recorded at a few stations were less than half of total alkalinity. Alkalinity due to carbonate ions was also less since low phenolphthalein alkalinity were recorded only at a few stations and carbonate alkalinity is only two times phenolphthalein alkalinity. Hence the alkalinity observed in river Chitrapuzha was mainly due to bicarbonate alkalinity.

Positive correlation of alkalinity with pH and negative correlation with redox potential and acidity are significant both in surface and bottom waters. The negative correlation of alkalinity with dissolved oxygen is significant only in surface waters while positive correlation with salinity is significant only in bottom waters.

The Eh values varied between 235 mv and -81 mv in surface waters and between 237 mv and -86 mv in bottom waters. Most of the values indicated aerobic conditions while the remaining values were of transitional characters. No value corresponding to anaerobic condition was recorded during the period of investigation.

Positive correlation of redox potential with acidity and negative correlation with pH and alkalinity are significant both in surface and bottom waters. Positive correlation of redox potential with temperature is significant in bottom waters but not in surface waters.

High transparency values were observed during post-monsoon periods and low values during pre-monsoon periods. Positive correlation of transparency with pH and salinity and negative correlation with temperature, acidity and redox potential are significant.

A general pattern in nitrate ion concentration with normal values at stations one and two followed by a sudden increase at station three and then gradual decrease at all stations from station three to station nine, independent of the seasonal variations, was observed during the period of survey. This pattern of nitrate concentration indicates discharge of industrial effluents rich in nitrogenous compounds around station three and the decrease in concentration from station three to station nine may be due to dilution factor along downstream.

The positive correlation of nitrate concentration. with acidity, ammonia concentration, nitrite concentration, total soluble inorganic nitrogenous nutrients, alkalinity and negative correlation with the ratio of nitrite concentration to total soluble inorganic nutrients are significant both in surface and bottom waters. Dependence of nitrate concentration on temperature is significant only in bottom waters.

The distribution pattern of nitrite concentration is similar to that of nitrate concentration with very high values both in surface and bottom waters at station three and a horizontal gradation from station three to station nine downstream and no clear pattern of seasonal variation was observed. This supports the earlier conclusion of discharge of some industrial effluents with high concentration of nitrogenous compounds around station three.

Positive correlation of nitrite concentration with acidity, ammonia concentration, nitrate concentration and redox potential and negative correlation with salinity and pH are significant both in surface and bottom waters.

The distribution pattern of ammonia is also similar to those of nitrate and nitrite with normal values at stations one and two and then an abrupt increase in ammonia concentration at station three and then gradual decrease downstream from station three to station nine. This observations again supports the earlier conclusion of frequent discharge of some industrial effluent rich in nitrogenous compounds, around station three.

Positive correlation of ammonia concentration with nitrite concentration and nitrate concentration are significant both in surface and bottom waters.

Significant variation in total soluble inorganic nutrient is observed between stations and between periods. Station three (Ambalamedu) has the highest values during all seasons and station one (Manackakadavu) has the lowest values. Higher values were recorded during September while lower values were recorded during the month of November in surface waters and May in bottom waters. No clear seasonal variation pattern was seen again in support of the earlier conclusion of external discharge of nitrogenous compounds in the form of industrial effluents around station three.

The positive correlation of total soluble inorganic nutrient concentration with acidity is significant both in surface and bottom waters, while the positive correlation with alkalinity and negative correlation with transparency are significant in surface waters only and positive correlation with temperature is significant only in bottom waters.

Distribution pattern of phosphate concentration also gives a trend similar to nitrogenous nutrient distribution with almost normal values at stations one and two, then sharp increase in concentration at station three and there after a gradual decrease from station three to station nine. Further higher values were recorded at station three during pre-monsoon and lower values during monsoon periods which is contrary to the trend at station one where higher values were recorded during monsoon and it may be due to phosphate leaching from agricultural runoff. However the trend at station three with higher concentration during pre-monsoon and lower concentration during monsoon and the gradual decrease in concentration of phosphate downstream throughout the period of survey can be explained only with the assumption of discharge of industrial effluent rich in phosphorus quality of water in different rivers. When this index is used to compare river Chitrapuzha with two other major rivers Periyar and Chaliyar, it is found that Chitrapuzha is the most polluted one with a water quality index negative 25.75. The major pollutant causing large negative quality index is the phosphate which may eventually lead to eutrophication of the water body.

REFERENCES

Anirudhan, T.S. (1988) - Studies on the nutrient Chemistry of a tropical estuary. Ph.D. Thesis, Cochin University of Science and Technology, Cochin, India, P. 137-146.

Anirudhan, T.S., Balchand A.N., Nair, S.M. and Nambisan, P.N.K. (1987) - Distribution pattern of salinity and silicon and their interrelationship in Cochin backwaters. *Proc. on National Seminar on Estuarine Management.,* Kerala State Committee on Science, Technology and Environment Trivandrum, Kerala, (Abstracts) E.D. 11.

APHA/AWWA/WPCF (1989) - Standard Methods for the Examination of water and waste water, (Lenore S. Clesceri Arnold E. Greenberg and Rhodes Trussel R., ed.). American Public Health Association, Washington D.C.

Aston, S.R. (1978) - Estuarine Chemistry. In: *Chemical Oceanography,* (Riley, .J.P. and Chester, R., Eds.), 2nd Edition, Academic Press, London. Volume.7: p. 362-440.

Aston, S.R. (1980) - Nutrients, dissolved gases and general biogeochemistry in estuaries. In: *Chemistry and Biogeochemistry of Estuaries.* (Olausson, E. and Cato, I. Eds.) A Wiley - International Publication. 233-262.

Balakrishnan, K.P. and Shyanamma, C.S. (1976) - Diurnal variation in hydrographic conditions during different seasons in the Cochin harbour (Cochin backwaters). *Indian J. Mar. Sci., 5:* 190-195.

Balchand, A.N., Nair, S.M. and Nambisan, P.N.K. (1990) - A survey of the protein content in estuarine waters. *Toxicol. Environ. Chem. 27:* 285-296.

Banoub, M.W. (1980) - Nitrate overdose: effect and consequences in hypertrophic ecosystems. In: *The Hague (Netherlands)*, Vol. 2, (Barica, J. and Mur, L., Eds.), 133-137.

Bendschneider, K. and Robinson, R.J. (1952) - A new spectrophotometric method for the determination of nitrite in sea water. *J. Mar. Res.,11:* 87-96.

Biney, C.A. (1985) - A preliminary physicochemical studies of estuaries along the gulf of guinea in Ghana. *Trop. Ecol., 26(1):* 22-31.

Bolton, P.W., Currie, J.C., Trevet, D.J. and Welsh, W.T. (1977) - An Index to improve water quality classification. *Annual Conf. Inst.Water Pollut.* Sept.1977: 1-12.

Bowden, K.F. (1980) - Physical factors: salinity, temperature, circulation and mixing processes. *In: Chemistry and Biogeochemistry of Estuaries*, (Olausson, E. and Cato, I., Eds.) A. Wiley-Interscience publication. p. 47-70.

Boyd, C.E. and Pillai, V.K. (1984) - Water quality and fish production. In: *Water Quality Management in Aquaculture*, (Rengarajan K., Ed.) CMFRI Publication, No.22 : 1-28.

Brown, R.M., McClelland, N.I., Deininger, B.A. and Tayer, R.G. (1970) - A water quality index crashing the psychological barrier. *Wat. Sew. Wks., 117:* 339-343.

Brown, R.M., McClelland, N.I., Deininger, B.A. and OConnor, M.F. (1972) - A water quality index crashing the psychological barrier. Proc. 6th *Int. Conf. Wat. Pollut. Res.* Jerusalem, 787-794.

Burns, P.A. and Saloman, M. (1969) - Phosphate absorption by Kaolin in saline environments. *Proceedings of the National Shellfish Association 59* :121-125.

Butler, E.I. and Tibbitts, S. (1972) - Chemical survey of the Tamar estuary I. Properties of the waters. *J. Mar. Bio. Ass. U. K., 52 :* 681-699.

Callalway, R.J. and Specht, D.J. (1982) - Dissolved silicon in the Jaquina estuary. *Estuarine coastal shelf sci., 15:* 561-567.

Carritt, D.E., and Goodgal, S. (1954) - Sorption reactions and some ecological implications. *Deep-sea Research 1:* 224-248.

Cauwest, G. and Sidorov, I. (1996) - The biogeochemistry of Lena River: organic carbon and nutients distribution. *Marine Chemistry 53: (3):* 211-227.

Chamberlain, R. and Hayward, D. (1986) - Evaluation of water quality and monitoring in the St.Lucie estuary, Floria: 3, *Water Resources Bulletin 32(4):* 681-696.

Childers, D.L. and Day, J.W. (Jr.) (1988) - Direct quantification of nutrient and material fluxes between microtidal Gulf coast wetlands and the estuarine water column. *Estuarine, Coastal and Shelf Sci., 27:* 483-494.

Clark, J.W., Viessman, W. and Hammer, M.J. (1977) - Water Supply and Pollution Control, Dun-Donnelley Publishers, New York, 242-257.

Cole, D.W. and Gessel, S.P. (1965) - In: *Forest-Soil Relationships in North America.* (Youngberg, C.T., Ed.), Oregon State University Press, Corvallis, 95-110.

Correll. D.L., Faust, M.A. and Severn, D.J. (1975) - Phosphorus flux and cycling in estuaries. In: *Estuarine Research,* Vol.1, (Cronin, L.E., Ed.), Academic Press, New York, p 739.

De Sousa, S.N. (1983) - Studies on the behaviour of nutrients in Mandovi estuary during pre-monsoon. *Estuarine, coastal & Shelf Sci., 16* : 299 - 308.

Department of National Health and Welfare, (1969) : Canadian drinking water standards and objectives, (1968): Ottawa, Ontario.

DeSousa, S.N. and Sen Gupta, R. (1986) - Variation of dissolved oxygen in Mandovi & Zuari estuaries. *Indian J. Mar. Sci., 15:* 67-71.

DeSousa, S.N., Sen Gupta, R., Sanzgiri, S. and Rajagopal, M.D. (1981) - Studies on nutrients of Mandovi and Zuari river systems. *Indian J. Mar. Sci., 10:* 314-321.

Doan, M. and East, C. (1977) - A proposed air quality index for urban areas. *Wat.Air and Soil Pollut.* 8: 441-451.

Doudoroff Shumway, D.L. and Peter (1970) - Dissolved oxygen requirement of freshwaters fishes. FAO (U.N.), *Fish. Tech. Paper 86:* 291

Edmond, J.M., Sivak, A., Grant, B.C., Hu, M.H. and Chen, Z.X. (1984) - Chemical dynamics of the estuary of the chiangjiang river. In: Sedimentation on the continental shelf with special reference to the East China sea, China Ocean Press, Beijing, 251-262.

Eppley, R.W., Venrich, E.L. and Mullin, M.M. (1973) - A study of the plankton dynamics and nutrient cycling in the central gyre of the North Pacific Ocean. *Limnol. Oceangr., 15:* 789-796.

Fairbridge, R.W. (1980) - The estuary: Its definition and geodynamic cycle. In: *Chemistry and Biogeochemistry of Estuaries*, (Olausson, E. and Cato, I..) A. Wiley - Iterscience Publication. p.37-70.

Fanning, K.A. and Maynard, V.I. (1978) - Dissolved boron and nutrients in the mixing plumes of major tropical rivers. *Netherland J. Sea. Res., 12 (384):* 345-354.

Fox, L.E., Sager, S.L. and Wofsy, S.C. (1985) - Factors controlling the concentration of soluble phosphorus in the Mississippi estuary. *Limnol. Oceanogr., 30 (4):* 826-832.

George, T. (1979) - In: *Waste water Engineering: Treatment, Disposal, Reuse.* Metcalf and Eddy, Inc. Publication, T.M.H. Edition, New Delhi,90-98.

Gopakumar, G. (1991) - Studies on the effect of hydrogen sulphide on the penaeid prawns of Kayamkulam lake, south west coast of India. Ph.D. Thesis. Cochin University of Science and Technology, Cochin, India.

Gopinathan, C.P., Nair, P.V.R. and Nair, A.K.K. (1984) - Quantitative ecology of phytoplankton in the Cochin backwater. *Indian J. Fish. 31:* 325-346.

Grasshoff, K. (1983) - Determination of Dissolved oxygen. In: *Methods of sea water Analysis,* (K. Grasshoff, M.Ehrhardt and K. Kremling, Ed.) (2nd Edn.), Verlag Chemie, Weinheim,

Grasshoff, K. (1983) - Determination of nitrate. In: *Methods of Seawater Analysis,* (Grasshoff, K., Ehrhardt, M. and Kremling, K., Ed.), (2nd Edn.), Verlag Chemie, Weinheim, 139-150.

Gutzmer, M.P. and Tomasso, J.R. (1985) - Nitrite toxicity to the cray fish. *Bull. Environ. Contam. Toxicol., 34(3)* 369-376.

Handa, B.K. (1980) - An integrated pollution index for natural waters in India. IAWPC Tech.Annual VI and VII, 15-30.

Haridas, P., Madhu Pratap, M. and Rao, T.S.S. (1973) - Salinity, temperature, oxygen and zooplankton biomass of the backwaters from Cochin to Alleppey. *Indian J. Mar. Sci., 2(2):* 94-102.

Hart, B.T. (1974) - A compilation of Australian Water Quality criteria. Coulfeidl Institute Technology, Australian Water Resources Council, Technical paper No.7. Australian Govt. Publishing Service, Canberra.

Harter. R.D (1968) - Adsorption of phosphorus by lake sediments. *Soil. Sci. Soc. Amer. Proc., 32:* 514-518.

Hartwig, E.O. (1976) - In: *Estuarine* Processes, Vol. I, (Wiley, M., Ed.) Academic Press, New York, p 541.

Hashimoto, S., Fujiwara, K and Fuwa, K. (1985) - Relationship between alkaline phosphatase activity and orthophosphate in the present Tokyo Bay. *J. Environ. Sci. Health, Part A., 20 A:* 781-809.

Head, P.C. (1985) - Salinity, dissolved oxygen and nutrients. In: *Practical estuarine chemistry,* (Head, P.C., Ed.), Cambridge University Press, Cambridge. p.94-125.

Hill, A.R. (1979) - Denitrification in the nitrogen budget of a river ecosystem. *Nature, 281:*291-292.

Ho, C.L. and Barrett, B.B. (1977) - Distribution of nutrients in Louisiana's coastal waters influenced by the Mississippi river. *Estuarine, Coastal and Mar. Sei.,(5) :,* 173 - 195.

Hobbie, J.E., Copeland, B.J. and Harrison, W.G. (1975) - Sources and fates of nutrients of the Pamlico River Estuary, North Carolina. In: *Estuarine Research. Vol.*

1, Chemistry, Biology and the Estuarine system (Crowin, L.E., Ed.). Academic Press, New York, p 287-302.

Hunter, W.D.R. (1970) - In *Aquatic Productivity.* (Hunter, W.D.R., Ed.) Macmillian Publishing Co. New York, p. 197.

Imberger, J., Berman, T., Christian, R.R., Sherr, E.B., Whitney, D.E., Pomeroy, L.R., Weigert, R.G. and Wiebe, W.J. (1983) - The influence of water motion on the distribution and transport of materials in a salt marsh estuary. *Limnol. Oceanogr.* , *28:* 201-204.

Indian Council of Medical Research (1975) - Manual of standards of quality of drinking water supplies. Special Report Ser. No.44: p 20.

Inhaber, H. (1975) - An approach to a water quality index for canada. *Wat. Res. 5*: 821-825.

James, E.J. and Sreedharan, K.E. (1983) - The exchange of fresh and salt waters in the Beypore estuary on the Malabar Coast. *J. Instn. Engrs. (India).*, 64: C1 2,81-87.

Jaworski, M.A. (1981) - Sources of nutrients and the scale of eutrophication problems in estuaries. In: *Estuaries and Nutrients,* (Neilson, B.J. and Cronin, L.E., Eds.) Humana Press, New Jersey, 83-110.

Jayapalan, A.P., Sasidharan, K.M. and Nair, V.A. (1976) - Some aspects of the physico-chemical and biological variation of Periyar water due to the effluent discharge from F.A.C.T. *Bull. Dept. Fish. Kerala,* 1: 47-59.

Jickells, T.D., (1998) - Nutrient biogeochemistry of the coastal zone. *Science* (Washington), Vol. 281, No.5374, p 217 - 222.

Jitts, H.R. (1959) - The adsorption of phosphate by estuarine bottom deposits *Australion Journal of Marine and Freshwater Research 10* : 7-21

Johannessen, T. and Dahl, E. (1996) - Declines in oxygen concentrations along the Norwegion Skagerrak Coast, 1927-1993: A signal of ecosystem changes due to eutrophication. *Limnol. and Oceanogr., 41(4):* 766-778.

Jordan, T.E., Correl, D.L., Miklas, J. and Weller, D.E. (1991) - Nutrients and Chlorophyll at the interface of a watershed and an estuary. *Limnonl. Oceanogr., 36(2):* 251-267.

Jose Xavier, K. (1993) - Studies on the nutrient chemistry of Chaliyar river estuary. Ph.D. Thesis, Cochin University of Science and Technology.Cochin, India.

Joseph, K.J. (1988) - Studies on some aspects of phytoplankton Ph.D. Thesis, Cochin University of Science and Technology, Cochin, India. p 217.

Joseph, K.J., Nambisan, P.N.K., Shyanamma, C.S. and Lakshmanan, P.T. (1984) - Studies on phytoplankton in polluted waters. *J. Mar. Biol. India, 26:* 42-46.

Joseph, P.S, (1974) - Nutrient distribution in the Cochin harbour and its vicinity. *Indian J. Mar. Sci. 3:* 28-32.

Joy, C.M. (1989) - Growth response of Phytoplankton exposed to industrial effluents in river Periyar. Ph.D. thesis, Cochin University of Science and Technology, Cochin, India.

Joy, C.M., Balakrishnan, K.P. and Ammini Joseph (1990) - Effect of industrial discharges on the ecology of phytoplankton production in the river Periyar (India). *Wat. Res.24(6):* 787-796.

Ketchum, B.H. (1983) - Ecosystem of the world 26, Estuaries and enclosed seas, Elsevier scientific publishing Company, Amsterdam.

Koroleff, F. (1983,a) - Determination of ammonia - nitrogen In: *Methods of Sea water Analysis*. (Grasshoff, K., Ehrhardt, M. and Kremling, K., Eds.), (2nd Edn), Verlog Chemie, Weinheim, 150-157.

Koroleff, F. (1983,b) - Determination of phosphorus. In: *Methods of Sea Water Analysis,* (Grasshoff, K., Ehrhardt, M. and Kremlung, K., Eds.), (2nd Edn.), Verlag Chemie, Weinheim 125-139.

Kumaran, S. and Rao, T.S.S.(1975) - Phytoplankton distribution and abundance in the Cochin backwaters during 1971-1972. *Bull Dept. Mar . Sci. Univ. Cochin, 72(1)*: 791-799.

Lakshmanan, P.T., Shynamma, C.S., Balchand A.N. and Nambisan, P.N.K. (1987) - Distribution and variability of nutrients in Cochin backwaters, southwest coast of Inida. *Indian J. Mar. Sci., 16:* 99-102.

Lakshmanan, P.T., Shynamma, C.S., Balchand, A.N., Kurup P.G., and Nambisan, P.N.K. (1982) - Distribution and seasonal variation of temperature and salinity in Cochin backwaters. *Indian J. Mar. Sci., 11:* 170-172.

Lewis, E.L. (1978) - Salinity, its definition and calculation. *J.Geophys. Res*. 83: 466.

Liss, P.S. (1976) - Conservative and non conservative behaviour of dissolved contents during estuarine mixing. In: *Estuarine chemistry, (* Burton, J.D. and Liss, P.S., Eds.) Academic Press. London. 93-130.

Loder, T.C. and Reichard, R.P. (1981) - The dynamics of conservative mixing in estuaries. *Estuaries., 4:* 64-69.

Loder, T.C., and Gilbert, P.M.(1980) - Nutrient variability and fluxes in an estuarine system. In : Estuarine Perspectives.(Kennedy, V.S., ed.), Academic Press, New York. p. 111 - 122.

Mackay, D.W. and Leatherland, T.M. (1976) - Chemical processes in an estuary receiving major inputs of industrial and domestic wastes. In: *Estuarine Chemistry,* (Burton, J.D. and Liss, P.S., Eds.), Academic Press, London 185-218.

Maguer, J.F., Lecorre, P. and Madec, C. (1996) - Seasonal variations in nitrogen uptake in shallow well mixed waters (western English Channel) *Oceanologica Acta 19(5):* 529-537.

Maqbool, T.K. (1993) - Studies on the biology of the clam *Marcia opima* (Gmelin) from Kayamkulam lake. Ph. D. Thesis, Cochin University of Science and Technology, Cochin, India.

Martin, D.F. (1970) - The nitrogen cycle. In: *Marine Chemistry,* Vol. 2, Marcel Dekker, INC., New York, p 267 .

Martin, J.H. (1968) - Phytoplankton - Zooplankton relationship in Narragansett Bay III. Seasonal changes in zooplankton excretion rates in relation to phytoplankton abundance. *Limnol. Oceanogr., 13:* 63-67.

Mc Carthy, J.J., Taylor, W.R. and Taft, J.L. (1977) - Nitrogenous nutrion of the plankton in the Chesapeake Bay. 1. Nutrient availability and phytoplankton preferences. *Limnol. Oceanogr., 22:* 996-1011.

Meybeck, M. (1982) - Carbon, nitrogen, and phosphorus transport by world rivers. *American J. Sci., 282:* 401-450.

Morris, A.W., Bale, A.J. and Howland, R.J.M.(1981) - Nutrient Distribution in an estuary: Evidence of chemical precipitation of dissolved silicate and Phosphate. In: *Estuarine coastal and shelf Sci.,* 12: 205-216.

Morris, A.W. (1985) - Estuarine chemistry and general survey strategy. In: *Practical Estuarine Chemistry,* (Head, P.C., Ed.), Cambridge University Press, Cambridge p.1-60.

Mortimer, C.H. (1971), Chemical exchange between sediments and water in the great lakes - speculations on probable regulatory mechanisms. *Limnol. Oceanogr., 16:* 387-404.

Mullins, T. (1977) - The Chemistry of water pollution In: *Environmental Chemistry,* (Bockris, J.O.M., Ed.), Plenum Press, New York, 331-339.

Murakami, M. (1986) - Dynamical structure of vertically two dimensional estuary in steady state. *J. Oceanogr. Soci. Japan, 42:* 224-239.

Murphy, J. and Riley, J.P.(1962) - A modified single solution method for the determination of phosphate in natural waters. *Analytica. Chem. Acta., 27:* 31-36.

Nagarajaiah, C. S. and Gupta, T.R. (1983) - Physico-chemical characteristics of brackish water ponds along Nethravati estuary, Mangalore. *Indian. J. Mar. Sci., 12:* 81-84.

Nair, C.K., Balchand, A.N. and Jacob Chacko.(1993) - Sediment characteristics in relation to changing hydrography of Cochin estuary. *Indian J. Mar. Sci., 22:* 33-36.

Nair, N.B., Abdul Aziz, P.K., Krishna Kumar, K., Dharmaraj, K., Arunachalam, M. and Balasubramanian, N.K.(1983) - Ecology of Indian estuaries: Part I. Physico-chemical features of water and sediment nutrients of Ashtamudi estuary. *Indian J. Mar. Sci., 12:* 143-150.

Nair, N.B., and Abdul Aziz, P.K., Krishna Kumar, K., Dharmaraj, K. and Arunachalam, (1983) - Ecology of Indian Estuary Part II. Physico chemical features of Akathumuri, Anchuthengu, Kadinamkulam, backwater system, south west coast of India, *Indian J. Mar. Sci. 12:* 154-159.

Nair, P.V.R., Joseph, K.J., Balachandran, V.K. and Pillai, V.K. (1975) - A study of the primary production in the Vembanad Lake. *Bull. Dept. Mar. Sci. Univ. Cochin., 7 (1):* 161-170.

Nair, S. M., Balchand, A.N., and Nambisan, P.N.K. (1993) - Phosphorus fractionation in mud bank sediments from south west coast of India. *Hydrobiologia, 252:* 61-69.

Nambisan, P.N.K. and Anirudhan, T.S. (1987) - On the transport of phosphate and silicate across the Cochin barmouth, Southwest India. *International Union of Geodesy and Geophysics.*, XIX General Assembly Vancouver, Canada, August 9-22, 1987. (Abstracts) V. 3 OPS 7-123, p 1081.

Nambudripad, K.D. and James, E.J. (1987) - Instrumentation and methods of observation for studies on estuarine dynamics with special reference to Malabar coast. *Proc. Natn. Sem. Estuarine Management, Trivandrum.* p 49-51.

Nataraj, A.G., James, E.J. and Ranganna, G. (1987) - Application of tidal prism methods- Beypore estuary. *Proc. Natn. Sem. Estuarine Management,* Trivandrum. p. 21-26.

Nelson, L.N. (1978) - In: *Industrial water pollution - Origin, Characteristics and Treatment.* Addison - Wesley Pub. Co., London, 14-27.

Nixon, S.W. and Pilson, M.E.Q. (1983) - Nitrogen in estuarine and coastal marine ecosystems. In: *Nitrogen in the Marine Environment,* (Carpenter, E.J. and Capone, D.G., Ed.), Academic Press, New York. 565-648.

Nixon, S.W., Oviatt, C.A., Frithsen, J. and Sullivan, B. (1986) - Nutrients and the productivity of estuarine and coastal marine ecosystem. *J. Limnol. Soc. South Africa, 12:* 43-71.

O'Neill, J.G. and Holding, A.J. (1975) - The importance of nitrate reducing bacteria in lakes and rivers. In: *The Effect of Storage on Water Quality, Water Research Centre Symposium,* 24-26, March 1975, 1-24.

Officer, C.B. (1976) - Physical Oceanography of Estuaries and Associated Coastal Waters, John Wiley & Sons, New York 465 p.

O'Neill, P. (1985) - Minor elements and environmental problems. In: *Environmental Chemistry,* George Allen and Unwin (Publishers) Ltd., London. P. 181-214.

Owens, M. (1978) - Nutrients - their source and effects. In: *Elaboration of the scientific bases for monitoring the quality of surface water by hydrological indicators, Pollution Report* , No.3, Dept. of Environment, London., 19-28.

Pastuszak, M. (1985) - Distribution of some nutrient in the southern Baltic in Aug./Sept. 1983 in relation to condition in two previous years. *Oceanologia/Oceanography,* No.21

Paul, A.C. and Pillai, K.C. (1978) - Pollution profile of a river. *L Wat. Air Soil Pollut. 10:* 133-146.

Peterson, D.H., Conomos, T.J., Broenkow, W.W. and Doherty, P.C. (1975) - Location of the non-tidal current null zone in northern san Francisco Bay. *Estuarine Coastal Mer.Sci., 3:* 1-11.

Peterson, D.H., Conomos, T.J., Broenkow, W.W. and Serivani, E.P. (1975) - Process controlling the dissolved silica distribution in San Francisco Bay. In: *Estuarine Research* Vol. 1. (Cronin, L.E., Ed.), Academic Press, New York. pp. 153-187.

Peterson, D.H., Festa, J.F. and Conomos, T.J. (1978) - Numerical simulation of dissolved silica in the San Francisco Bay. *Estuarine coastal Mer. Sci., 7:* 99-116.

Pick, F.R. (1987) - Interpretation of alkaline phosphatase activity in Lake Ontario. *Can. J. Fish. Aquat .Sci. 44:* 2087-2094.

Pillai, V.K., Joseph K.J. and Kesavan Nair, A.K. (1975) - The plankton production in the Vembanad Lake and adjacent waters in relation to the environmental parameters. *Bull. Dept. Mar.Sci. Univ.Cochin, 72(1):* 137-150.

Pomeroy, L.R., Smith, E.E. and Grant, C.M. (1965) - The exchange of phosphate between estuarine water and sediments. *Limnol. and Oceanogr., 10 :* 167-172.

Prati, L., Pavanall, R. And Passarin , F. (1971) - Assessment of surface water quality by a single index of pollution. *Wat. Res. 5*: 741-751.

Pritchard, D.W. (1967) - Observation of circulation in coastal plan estuaries. In: *Estuaries*, (Lauff, G.H. Ed.), Washington.D.C., American Association for the Advancement of Science, 37-44.

Pritchard, D.W. and Schubel, J.R. (1981) - Physical and geological processes controlling nutrient levels in estuaries. In: *Estuaries and Nutrients. (* Neilson, B.J. and Cronin, L.E., Eds.), Humana Press, Clifton, New Jersy. 47-69.

Qasim, S. Z. and Sankaranarayanan, V.N. (1972) - Organic detritus of a tropical estuary. *Mar. Biol., 15:* 193-199.

Qasim, S.Z. and Sen Gupta, R. (1981) - Environmental Characteristics of the Mandovi -Zuari estuarine system in Goa. *Estuarine Coastal and Shelf Sci., 13:* 557-578.

Qasim, S.Z. and Gopinathan, C.K.(1969) - Tidal cycle and the environmental features of Cochin backwater (a tropical estuary). *Proc. Indian Acad. Sci., 69(6):* 336-348.

Rama Raju, V.S., Udayavarma, P. and Pylee, A. (1979) - Hydrographic characteristic and tidal prism at the Cochin harbour mouth. *Indian J. Mar. Sci., 8:* 78-84.

Ramamirthan, C.P. and Jayaraman, R., 1963. Some aspects of the hydrographical conditions of the backwaters around Willingdon Island (Cochin). *J. Mar. Biol. Asso. India,* 2(2), 199-207.

Rand, M.C., Greenberg, A.E. and Taras, M.J. (1989) - Determination of inorganic nonmetallic, constituents. In: *Standard Methods for the Examination of water and waste water,* APHA, AWWA and WPCF, Publication, (17th Edn.) 4/1-210.

Reader, S.W. (1979) - Guidelines for surface water quality. Vol. 1, Inorganic Chemical Substances, Preamble. p 21.

Remani, K.N., Venugopal P., Sarala Devi, K., Lalitha S. and Unnithan, R.V. (1980) - Sediments of Cochin backwater in relation to Pollution. *Indian J. Mar. Sci., 9:*111-114.

Rhoads, D.C., Tenore, K. and Browne, M. (1975) - The role of resuspended bottom mud in nutrient cycles of shallow embayments: In: *Estuarine Research,* Vol. 1, (Cronin, L.E., Ed.) Academic Press, New York, 563-579.

Riley, J.P. and Chester, R. (1971 b) - Micronutrient elements. In: *Introduction to Marine Chemistry,* Academic Press, London, 152-179.

Ross, S.L. (1977) - An index system for classifying river water quality. *J. Wat. Pollut. Control, 76:* 113-121.

Ryther, J.H. and Dunstan, W.M. (1971) - Nitrogen, Phosphorus and entrophication in the coastal marine environment. Science, 171 : 1008 - 1012.

Sanakaranarayanan, V. N. and Qasim, S.Z. (1969) - Nutrients of the Cochin backwater in relation to environmental characteristics. *Mar. Biol., 2 :* 236-247.

Sanders, R. (1997) - Biogeochemical nutrient cycling in the upper great Ouse estuary, Norfolk,UK. *Estuarine coastal and shelf science, 44(5):* 543-555.

Sankaranarayanan, V.N., Udayavarma, P., Balachandran, K.K., Pylee, A. and Joseph, T. (1986) - Estuarine characteristics of the lower reaches of river Periyar (Cochin backwater). *Indian J. Mar. Sci., 15:* 166-170.

Sarala Devi, K., Venugopal. P., Remani, K.N., Zacharias, D. and Unnithan, R.V. (1983) - Nutrients in some estuaries of Kerala. *Mahasagar -Bull. Natn. Inst. Oceanogr., 16(2):* 161-173.

Saraladevi, K.P., Venugopalan, P., Ramani, K.N., Lalitha, A. and Unnithan, R.V. (1979) - Hydrographic features and water quality of Cochin backwaters in relation to industrial pollution. Indian J. Mar.Sci, 8(3) : 141 - 145.

Satpathy, K.K. (1996) - Seasonal distribution of nutrients in the coastal waters of Kalpakkam, east coast of India. *Indian J. Mar. Sci., 25(3):* 221-224.

Sen Gupta, R. and Upadhyay, S.(1987) - Nutrient biogeochemistry of the Mahanadi Estuary. In : Contributions in Marine Sciences. - Dr. S.Z. Qasim Sastyaddapurti felicitation Vol, 291 - 305.

Sen gupta, R. and Koroleff, F. (1973) - A quantitative study of nutrient fractions and a stoichiometric model of the Baltic. *Estuarine coastal Mar. Sci.,* 1: 335-360.

Sharp, J.H., Gulberson, D.H. and Church, T.M. (1982) - The chemistry of Delaware Estuary: General consideration. *Limnol. Oceanogr., 27(6):* 1015-1028.

Sharp, J.H. (1983) - The distribution of inorganic nitrogen and dissolved and particulate organic nitrogen in the sea. In: *Nitrogen in the Marine Environment,* (Carpentor, E.J. and Capone, D.G., Eds.), Academic Press, New York, 1-35.

Sharp, J.H., Pennock, J.R., Church, T.M., Tramontano, J.M. and Cifuentess, L.A. (1984) - The estuarine interaction of nutrients, organics and metals: A case study in the Delaware estuary. In: *The Estuary as a Filter,* (Kennedy, V.S., Ed.) Academic Press, New-York, 241-258.

Sholkovitz, E.R. (1976) - Flocculation of dissolved organic and inorganic matter during the mixing of river water and sea water. *Geochimica et cosmochimia Acta 40 :* 831-845.

Shynamma, C.S., Vijayakumar, K.S. and Balakrishnan, K.P. (1981) - Mortality of fish in the industrial belt around Cochin. *Seminar on Status of Environmental studies in India,* Trivandrum.

Silas, E.G. and Pillai V.K. (1976) - Water Pollution and fish mortality in the Cochin backwaters. *National seminar on Environmental Pollution Souvenir,* Cochin.

Silas, E.G. and Pillai, P.P. (1975) - Dynamics of zooplankton in a tropical estuary (Cochin backwaters) with a review on the plankton fauna of the environment. *Bull. Dept. Mar. Sci. Univ. Cochin., 7 (2):* 329-355.

Sillen, L.G. (1961) - The physical chemistry of seawater In: *Oceanography*, (Sears, M., Ed.), American Association for the Advancement of Science, Washington, D.C., 549-581.

Simons, T.J. and Schertzer, W.M. (1987) - Stratification, Currents, and upwelling in Lake Ontario, Summer 1982. *Can. J. Fish.Aquat. Sci. 44:* 2047-2058.

Simpson, H.J., Hammond, D.E., Deck, B.L. and Williams, S.C. (1975) - Nutrient budgets in the Hudson river estuary. In: *Marine chemistry in the coastal Environment,* (Church, T.M., Ed.) Ame.chem. Soc., 618-635.

Sivadasan, K.K. (1996) - Studies on Benthic Microalgae in Cochin estuary. Ph.D. Cochin University of Science and Technology, Cochin, India. p 61.

Sivenkutty Nair, G. (1972) - Some observations on the hydrography of Kayamkulam estuary. *Bull. Dept. Mar. Biol. Oceanogr. Univ. Cochin,* 5: 87-96.

Snoeyink, V.L. and Jenkins, D. (1980) - Precipitation and dissolution. In ; *Water Chemistry*, John Wiley & Sons, New York., 243-315.

Solorzano, L. and Ehrlich, B. (1977) - Chemical investigation at Loch Etire, Scotland. 1. Inorganic nutrient and pigments. *J. Exp. Mar. Biol. Ecol., 29:* 45-64.

Sreedharan Manikoth and Mohammed Salih, K.Y. (1974) - Distribution characteristics of nutrients in the estuarine complex of Cochin. *Indian J. Mar. Sci., 3:* 125-130.

Stirling, H.P. and Wormald, A.P. (1977) - Phosphate - sediment interaction in Tolo and Long Harbours, Hong Kong and its role in estuarine Phosphorus availability. *Estuarine Coastal Mar. Sci., 5:* 631-642.

Stoner, J.D. (1978) - Water Quality Indices for specific water uses. U.S.Geol. Survey, Circular 770, p 12 .

Strickland, J.D.H. and Parsons, T.R. (1972) - A practical handbook of seawater analysis. *Fish.Res. Bd. Can. Bull.* (2nd Edn.), Ottawa, 167: p419.

Stumm, W. and Morgan, J.J. (1970) - An introduction emphasizing chemical equilibria in natural waters. In: *Aquatic Chemistry,* John Wiley - Interscience, New York, 515-525.

Syanamma, C.S. and Balakrishnan, K.P. (1973) - Diurnal variation of some physico - chemical factors in Cochin backwater during south west monsoon. *J. Mar. Biol. Asso. India., 15 (1):* 391-398.

U.S. Environmental Protection Agency, (1973) - Water Quality Criteria, (9172) - EPA-R3-73-33, Washinton, D.C.

Van Bennekom, A.J., Berger, G.W., Helder, W. and De Vries, R.T.P. (1978) - Nutrient distribution in the Zaire estuary and river Plume. *Netherland J.Sea. Res., 12 (384):* 296-323.

Vijayan, M., Ramani, K.N. and Unnithan, R.V. (1976) - Effect of organic pollution on some hydrographical features of Cochin backwaters. *Indian J. Mar. Sci., 5:* 190-200.

Wafar, M.V.M. (1981) - Nutrients, primary production and dissolved and particulate organic matter in well mixed coastal waters (Bay of Morlaix, Western English Channel). Ph.D. Thesis, University of Paris. 226 p.

Wahby, S.D., Kinaway, S.M., Tabbach, T.I. and Abdel Moneim, M.A. (1978) - Chemical characteristics of lake Maryut, a polluted lake south of Alexandria, Egypt. *Estuarine coastal Mar. Sci., 7(1):* 17-28.

Walski, T.M. and Parker, F.L. (1974) - A consumer water quality index. *Amer. Soc. Civil. Engrs. Proc. J.Environ. Engg. Div.* 100, No.EE 3, 593-611.

Webb, A.H. (1982) - Weak acid concentrations and river chemistry in the Tovdal river, Southern Norway. *Water Res., 16 (5):* 641-648.

Wetzel, R.G. (1975) - Phosphorus cycle. In: *Limnology*, W.B. Saunders Company, Philadelphia., p 215.

Wilmost, W., Toll, P. and Kjerfve, B.(1985) - Nutrient transports in a Swedish estuary. Easturine Coastal & Shelf Sci., 21 : 161 - 184.

Wollast, R. (1978) - Modelling of Biological and Chemical processes in the Scheldt estuary. In: *Hydrodynamics of Estuaries and Fjords* (Nihoul, J.C.J., Ed.), Elsevier Oceanographic series No. 23: p 53-77.

Wyatt, T and Qasim, S.Z. (1973) - Application of a model to an estuarine system. *Limnol. Oceanogr., 18(2):* 301-306.

Table 3.1.1.- Distribution of Temperature (oC) in river chitrapuzha during October 1990 to Janauary 1992

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	32.5	30.7	29.9	28.5	30.7	29.9	30.7	28.9	30.8	29.7	31.4	30.4	32.0	31.1	30.3	29.5	29.4	26.7
Nov-90	29.3	29.0	28.7	28.0	29.7	29.6	28.5	28.4	29.7	29.4	29.1	29.2	28.4	28.8	28.0	28.6	26.4	27.1
Dec-90	29.4	29.2	28.5	28.2	29.5	29.2	29.3	29.2	29.3	29.3	29.3	27.8	29.0	28.8	28.4	28.8	27.7	28.1
Jan-91	29.5	27.5	28.1	28.0	29.6	29.9	30.2	29.8	29.1	29.6	29.2	29.7	29.2	29.6	29.2	29.2	28.6	28.6
Feb-91	30.6	29.3	29.6	28.8	30.2	30.1	29.8	29.2	28.6	29.8	29.2	30.0	29.4	29.0	27.9	29.2	27.4	28.1
Mar-91	33.4	31.2	31.8	31.3	31.3	31.0	33.2	32.6	31.6	31.8	30.9	31.4	31.5	31.5	31.4	31.4	29.4	30.1
Apr-91	32.6	31.5	32.2	31.4	32.7	32.2	32.6	31.8	31.6	31.6	31.7	31.6	31.4	31.2	31.4	31.4	28.0	28.6
May-91	31.0	30.6	30.6	29.8	30.6	30.1	31.2	30.6	30.6	30.2	30.6	30.6	30.8	32.2	30.6	31.0	28.4	28.8
Jun-91	31.1	30.8	30.4	29.8	30.4	30.2	31.9	30.3	30.4	30.2	30.3	30.4	30.9	31.6	30.5	30.8	27.8	27.9
Jul -91	31.1	30.9	30.2	29.0	30.2	29.8	30.6	30.0	30.2	30.2	30.1	30.2	31.0	31.0	30.5	30.6	27.2	27.3
Aug-91	31.1	30.9	29.9	28.7	30.1	29.7	30.4	29.7	30.1	30.3	29.8	30.3	31.1	30.3	30.6	30.3	26.9	26.5
Sep-91	31.2	31.0	29.8	28.3	29.8	29.8	30.1	29.4	30.1	30.4	29.6	30.2	31.2	29.7	30.8	30.1	26.4	25.8
Oct-91	30.2	29.9	29.1	28.7	30.0	29.4	29.3	28.8	30.2	29.7	29.9	29.9	30.5	29.7	29.9	29.3	27.5	26.4
Nov-91	29.3	28.9	28.5	27.6	28.8	28.5	28.5	28.3	29.0	29.1	28.8	28.9	28.6	28.9	28.4	28.2	26.3	26.5
Dec-91	28.7	28.5	27.8	27.6	28.8	28.4	28.4	28.3	28.6	28.6	28.6	28.5	28.2	28.0	27.9	28.0	27.1	27.1
Jan-92	27.2	26.6	26.8	26.4	27.6	26.8	26.4	26.8	26.8	27.2	27.6	27.2	26.4	26.4	26.8	26.3	26.4	26.0

S - Surface B - Bottom

Table 3.2.1.- Distribution of salinity(x10-3) in river Chitrapuzha during October 1990 to January 1992.

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	0.07	0.07	0.03	0.04	0.42	0.49	0.39	0.49	0.44	0.60	0.55	0.91	2.64	2.90	3.23	4.04	4.84	4.93
Nov-90	0.04	0.01	0.01	0.01	0.09	0.08	0.08	0.08	0.44	0.88	2.17	2.46	2.43	2.38	4.90	5.84	11.03	12.10
Dec-90	0.04	0.04	0.04	0.02	0.16	0.42	0.31	0.33	0.57	0.91	2.32	4.34	3.11	4.72	5.81	6.75	11.30	12.23
Jan-91	0.04	0.10	0.04	0.01	0.16	0.78	0.47	1.01	0.70	2.26	2.41	5.87	5.87	6.16	6.92	8.21	15.04	15.71
Feb-91	0.33	0.83	0.33	0.48	5.13	5.87	4.17	5.57	5.84	9.03	7.04	8.80	11.03	11.16	9.97	10.15	18.05	19.72
Mar-91	0.57	0.88	0.34	0.31	3.17	3.99	4.52	5.40	4.52	5.46	7.48	8.77	11.36	12.03	10.27	12.91	22.07	23.18
Apr-91	0.91	1.01	0.09	0.04	4.52	5.05	5.22	5.43	5.43	8.03	6.16	7.33	11.70	13.70	11.15	14.67	24.30	25.79
May-91	0.03	0.02	0.01	0.01	0.08	0.08	0.07	0.07	0.13	0.25	0.15	0.14	3.11	6.58	3.90	3.99	5.87	6.04
Jun-91	0.03	0.02	0.01	0.01	0.05	0.06	0.06	0.05	0.07	0.14	0.12	0.13	2.17	2.64	2.90	3.55	4.84	4.90
Jul-91	0.03	0.01	0.01	0.07	0.03	0.03	0.04	0.04	0.04	0.04	0.10	0.11	1.07	1.04	1.41	1.44	3.05	3.17
Aug-91	0.03	0.01	0.04	0.07	0.05	0.06	0.07	0.10	0.13	0.14	0.42	0.47	1.85	2.17	2.35	2.38	5.57	6.13
Sep-91	0.02	0.01	0.01	0.01	0.09	0.11	0.14	0.17	0.22	0.19	0.62	0.70	2.35	2.85	3.70	3.73	6.45	7.04
Oct-91	0.01	0.01	0.07	0.32	0.23	0.35	0.10	0.13	0.31	0.42	1.01	1.14	2.38	2.64	3.55	3.90	6.77	7.04
Nov-91	0.01	0.01	0.01	0.07	0.09	0.09	0.07	0.07	0.44	1.09	2.11	2.41	2.38	3.11	4.84	5.54	9.09	9.39
Dec-91	0.03	0.11	0.03	0.02	0.23	0.31	0.24	0.44	0.55	1.56	2.11	2.43	3.11	3.52	5.51	5.57	9.56	9.68
Jan-92	0.04	0.18	0.04	0.01	0.49	0.57	0.60	1.22	0.69	3.05	2.32	3.55	5.46	5.57	6.16	6.48	11.15	12.91

S - Surface B - Bottom

Table 3.3.1- Distribution of dissolved Oxygen (mg l) in the river Chitrapuzha during October 1990 to January 1992

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	7.79	7.08	6.78	5.44	2.90	6.45	6.44	6.10	7.10	6.78	6.45	1.94	5.48	1.97	4.52	3.55	5.16	2.58
Nov-90	7.74	7.05	4.52	4.50	7.42	6.13	2.90	2.58	2.59	1.94	2.59	3.23	4.20	3.42	4.30	3.55	3.55	3.51
Dec-90	7.58	7.27	5.32	5.12	6.14	4.34	4.56	3.44	4.58	3.27	4.25	3.08	5.02	3.38	4.02	3.23	4.01	4.15
Jan-91	7.42	5.49	5.81	5.81	4.84	2.26	6.13	3.23	6.45	4.52	5.81	2.58	5.81	3.55	3.87	2.90	4.52	4.84
Feb-91	7.82	5.76	7.50	7.17	4.41	2.03	6.78	5.42	5.42	2.37	4.40	6.10	5.08	4.07	3.73	3.05	4.76	4.41
Mar-91	7.91	4.74	5.42	7.82	7.82	7.50	7.86	6.10	7.54	2.03	6.76	3.39	4.39	3.38	2.37	3.65	4.40	4.74
Apr-91	6.44	3.22	5.42	3.73	1.36	0.63	7.17	5.23	7.17	3.39	6.78	4.07	4.06	4.04	3.85	3.05	3.39	3.73
May-91	5.42	5.08	3.73	2.37	1.69	0.79	3.39	3.29	3.39	1.02	1.69	1.36	3.73	1.02	3.45	3.25	5.42	5.40
Jun-91	6.61	6.44	5.08	4.40	3.91	2.98	4.58	4.36	4.11	2.94	3.75	3.55	4.57	3.42	4.64	4.36	6.04	6.01
Jul-91	7.79	7.78	6.44	6.41	5.08	5.09	5.76	5.42	4.74	4.70	5.76	5.70	5.42	4.74	5.42	5.40	6.40	6.10
Aug-91	7.81	7.76	6.84	6.05	6.64	6.14	6.12	6.11	5.58	5.42	5.82	5.64	6.49	4.46	6.27	6.16	6.19	6.04
Sep-91	7.74	7.70	7.12	7.17	7.17	7.17	7.12	6.78	6.44	6.10	5.42	4.74	7.48	4.74	7.12	7.12	5.08	5.08
Oct-91	7.84	7.79	6.79	5.78	6.59	6.28	6.12	5.64	6.32	5.98	5.58	5.15	6.44	5.66	5.45	4.88	4.93	4.63
Nov-91	7.79	7.70	6.52	6.52	7.42	6.78	3.76	3.46	4.56	3.96	4.01	3.99	6.33	3.98	5.66	5.33	4.32	4.30
Dec-91	7.22	7.16	6.71	6.04	5.74	6.18	6.68	4.41	6.20	5.88	5.41	4.73	5.59	3.66	4.82	4.13	4.76	4.46
Jan-92	7.51	7.43	6.78	6.71	5.76	5.08	6.10	2.03	6.44	2.03	4.74	3.05	5.08	4.74	4.41	4.08	4.40	4.39

S - Surface B - Bottom

Table 3.4.1 - Distribution of pH in river Chitrapuzha during October 1990 to January 1992.

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	8.68	8.62	8.26	8.24	8.78	8.68	8.71	8.54	8.60	8.64	7.22	6.99	7.11	7.10	7.12	7.21	7.65	7.41
Nov-90	6.88	6.76	6.46	6.48	7.10	7.22	5.91	6.08	6.34	6.16	6.56	6.64	6.92	6.85	6.94	7.00	7.34	7.34
Dec-90	6.93	6.82	6.69	6.80	8.33	8.45	6.22	6.28	6.37	6.11	6.54	6.47	6.88	6.83	6.92	6.90	7.50	7.56
Jan-91	7.04	6.81	6.90	7.40	8.34	8.44	6.78	6.69	7.04	6.62	6.66	6.43	6.74	6.58	7.04	6.86	7.91	8.11
Feb-91	7.15	6.90	7.12	6.73	4.70	4.46	5.30	4.89	3.96	5.03	4.32	5.72	7.00	6.54	7.26	6.60	7.62	8.04
Mar-91	7.23	7.34	7.74	8.10	3.07	3.06	3.43	3.43	3.75	3.99	4.88	4.68	7.49	7.84	7.30	7.18	7.84	7.84
Apr-91	6.80	6.80	7.04	6.88	8.02	7.57	7.22	7.07	6.90	6.92	6.88	6.78	6.78	6.78	6.58	6.54	7.20	7.12
May-91	6.14	6.10	6.22	5.91	6.37	6.24	5.94	5.55	6.16	6.41	6.29	6.22	6.28	6.38	6.04	5.86	6.90	6.79
Jun-91	6.76	6.84	6.54	6.34	5.62	5.26	5.25	5.37	5.28	5.44	6.41	6.40	6.68	6.72	6.64	6.46	7.04	7.02
Jul-91	7.34	7.63	6.82	6.80	4.88	4.27	4.56	4.19	4.40	4.39	6.50	6.58	7.00	7.00	7.03	7.10	7.20	7.22
Aug-91	7.06	7.07	6.94	6.86	5.82	5.45	5.48	4.98	5.04	4.98	5.98	6.32	6.80	6.92	6.90	6.76	7.12	7.08
Sep-91	6.84	7.04	7.04	7.00	6.86	6.71	6.37	5.56	5.66	5.50	5.40	6.07	6.58	6.80	6.88	6.16	6.99	6.90
Oct-91	6.78	7.10	7.26	7.20	7.20	7.16	7.40	6.74	6.86	6.78	6.38	6.56	6.86	6.92	6.94	6.77	7.33	7.24
Nov-91	6.92	6.84	6.50	6.48	7.04	7.18	6.21	6.12	6.32	6.14	6.52	6.60	6.88	6.86	6.90	6.94	7.32	7.32
Dec-91	6.92	6.86	6.70	6.71	7.72	7.66	6.14	6.20	6.16	6.20	6.48	6.42	6.90	6.88	6.88	6.92	7.43	7.45
Jan-92	6.96	6.90	6.88	6.85	7.81	7.35	6.00	6.22	5.77	5.53	6.44	6.20	6.94	6.93	6.83	6.88	7.47	7.47

S - Surface B - Bottom

Table 3.5.1- Distribution of Acidity (mg Ca co3 L-1) in the river Chitrapuzha during October 1990 to January 1992.

Stations	1		2		3.0		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	0.0	0.0	1.8	1.6	0.0	0.0	0.0	0.0	0.0	0.0	8.8	7.0	4.4	4.5	4.4	4.2	3.5	3.6
Nov-90	12.3	8.8	5.3	7.0	14.0	14.1	22.8	21.0	17.5	15.8	7.2	8.9	5.3	7.0	5.3	6.3	5.3	5.2
Dec-90	2.5	3.2	3.2	4.3	0.0	0.0	7.2	8.6	13.3	11.1	7.2	6.6	3.4	4.5	3.7	3.8	4.3	4.0
Jan-91	1.8	1.8	1.9	1.5	0.0	0.0	1.8	1.8	3.5	3.6	3.5	1.8	1.8	1.9	1.8	1.9	1.8	1.5
Feb-91	1.8	2.6	1.6	2.2	42.0	49.8	3.5	4.4	16.0	4.5	5.5	3.6	1.6	2.4	1.5	2.4	1.9	1.4
Mar-91	1.9	1.9	0.8	0.3	49.8	49.9	46.2	46.2	43.3	42.0	32.6	34.5	7.7	4.4	9.5	10.7	4.4	4.4
Apr-91	3.5	3.5	2.3	2.0	2.7	6.9	10.4	11.9	13.3	13.1	13.5	14.5	14.5	14.4	16.4	16.8	10.4	10.5
May-91	3.6	3.6	2.9	3.3	18.4	19.6	22.5	26.7	20.4	18.0	19.1	19.8	19.2	18.3	21.5	23.8	13.7	13.3
Jun-91	2.8	2.7	2.1	2.3	27.5	29.1	23.4	27.2	28.8	18.8	17.7	18.5	14.6	16.3	16.4	17.6	10.5	11.3
Jul-91	1.8	1.8	2.0	2.2	32.6	38.4	35.0	29.6	37.1	32.2	17.1	16.4	12.4	12.2	12.1	20.0	10.4	10.5
Aug-91	2.3	2.1	1.6	1.6	23.2	22.8	22.4	27.1	29.7	27.4	21.3	17.2	14.4	12.3	14.2	15.1	12.3	11.6
Sep-91	2.6	1.8	1.7	1.8	13.7	15.1	19.0	26.3	25.1	26.2	27.6	21.2	16.4	14.3	14.3	14.0	12.9	12.4
Oct-91	2.5	2.3	1.5	1.7	9.3	10.8	6.8	12.8	12.6	14.0	18.1	17.0	14.0	13.0	14.6	13.6	9.2	10.4
Nov-91	2.6	2.6	2.8	2.9	12.0	10.7	23.3	20.2	18.9	20.6	17.2	16.2	13.5	13.7	13.3	12.8	9.5	9.7
Dec-91	2.4	2.3	2.6	2.7	4.9	5.5	20.1	18.1	19.8	19.7	17.8	17.5	12.3	12.4	12.7	11.3	7.9	8.0
Jan-92	2.7	2.6	2.1	2.3	4.7	9.0	21.6	19.8	24.1	26.4	17.7	20.0	13.0	12.7	13.6	13.5	7.8	7.9

S - Surface B - Bottom

Table 3.6.1- Distribution of Alkalinity (mg Ca co3 L-1) in the river Chitrapuzha during October 1990 to January 1992.

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	95.0	101.3	100.0	142.1	331.3	170.0	102.5	60.0	93.8	50.0	112.5	125.0	162.5	137.5	137.3	75.0	26.3	22.5
Nov-90	75.0	87.5	87.5	100.9	87.5	112.5	62.5	75.0	50.9	62.5	137.5	162.5	163.5	162.3	187.5	225.0	33.8	35.8
Dec-90	105.2	102.4	75.2	77.5	232.3	139.2	63.7	63.2	45.1	55.0	99.8	100.8	126.8	134.7	144.0	158.6	38.7	40.2
Jan-91	137.5	112.5	62.5	75.0	237.5	100.0	62.5	37.5	50.0	62.5	137.5	75.0	75.0	137.2	135.5	222.0	47.5	51.3
Feb-91	65.8	59.4	65.2	57.8	19.1	25.9	31.3	22.5	8.9	45.4	21.2	69.0	63.0	54.2	66.8	56.3	74.8	87.5
Mar-91	67.5	68.8	77.0	83.9	0.0	0.0	0.0	0.0	1.9	9.9	40.3	33.5	129.4	141.3	122.9	108.2	143.8	143.8
Apr-91	59.4	59.4	63.7	60.6	147.5	132.1	98.8	95.1	109.3	108.6	108.6	105.2	105.2	105.0	98.3	97.0	118.9	118.8
May-91	46.3	45.8	48.1	42.1	91.2	86.7	76.3	62.3	84.0	93.2	88.4	86.0	88.1	91.5	79.9	71.7	112.5	112.5
Jun-91	39.2	42.6	50.2	54.5	62.7	56.6	54.3	37.4	57.4	66.1	92.2	92.5	93.3	98.8	92.5	88.4	112.9	113.5
Jul-91	34.4	37.5	59.5	59.1	40.3	19.5	29.4	16.9	23.9	23.6	95.6	98.3	98.3	112.7	113.7	116.1	118.6	118.7
Aug-91	52.5	51.3	62.6	65.0	77.7	67.9	44.7	35.6	39.4	37.6	73.8	74.1	101.7	106.4	102.7	105.7	114.2	117.8
Sep-91	59.4	65.0	63.7	62.9	107.9	102.8	91.3	63.8	66.9	63.2	58.0	46.8	98.5	105.8	105.8	84.0	112.5	112.6
Oct-91	58.4	61.4	70.5	67.5	115.8	110.9	98.4	84.6	99.5	113.5	85.6	84.7	110.5	114.0	104.4	106.3	126.4	123.4
Nov-91	61.2	59.9	53.4	53.0	114.0	118.8	85.6	82.5	89.5	83.3	96.3	99.0	108.6	107.9	109.2	108.9	123.8	123.0
Dec-91	61.0	60.7	57.2	57.0	135.2	139.2	77.6	78.4	81.0	91.0	94.9	90.8	116.9	116.4	106.5	103.2	122.4	125.2
Jan-92	62.5	61.3	60.6	60.1	140.3	124.6	78.8	86.3	70.7	62.5	93.5	85.4	110.6	110.3	106.9	105.8	125.0	125.9

S - Surface B - Bottom

Table 3.7.1- Distribution of Redox Potential(MV) in river Chitrapuzha during October 1990 to January 1992.

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	-76	-73	-55	-54	-81	-76	-78	-71	-76	-78	-3	6	0	0	0	-3	-25	-13
Nov-90	8	15	31	30	-5	-11	62	52	38	48	25	21	5	10	4	1	-18	-18
Dec-90	7	13	20	14	-68	-86	48	45	37	52	24	31	10	12	8	9	-28	-30
Jan-91	-2	10	6	-20	-73	-80	13	23	-1	22	21	32	15	24	-2	9	-50	-61
Feb-91	0	14	0	12	220	197	105	190	178	122	155	68	-30	-38	-40	-45	-59	-68
Mar-91	-11	-17	-42	-63	235	237	214	214	195	182	128	140	-26	-48	-16	-9	-49	-49
Apr-91	23	12	7	20	-63	-32	-8	-8	16	14	17	24	24	24	37	42	-8	-8
May-91	50	54	48	62	37	46	61	86	50	36	42	46	44	36	55	68	8	8
Jun-91	15	11	29	36	84	103	104	102	102	92	34	36	20	17	22	32	1	0
Jul-91	-19	-37	12	11	128	164	147	156	156	157	30	26	0	0	-1	-4	-9	-9
Aug-91	-9	-7	6	8	68	92	96	118	116	118	62	40	13	6	6	22	-3	-2
Sep-91	34	-2	2	4	11	19	46	88	80	87	95	56	26	14	14	51	2	2
Oct-91	21	-2	-12	-11	-11	-9	-12	22	16	20	40	28	13	9	8	22	10	7
Nov-91	12	16	33	34	6	9	47	54	42	51	29	24	14	15	13	12	-8	-8
Dec-91	12	13	21	20	-38	-33	53	53	50	48	30	36	10	14	14	10	-23	-24
Jan-92	4	10	10	12	-52	-21	73	53	84	88	36	52	6	7	14	13	-33	-33

S - Surface B - Bottom

Table 3.8.1- Distribution of Transparency (cm) in river Chitrapuzha during October 1990 to January 1992.

Stations	1	2	3	4	5	6	7	8	9
Period									
Oct-90	106	100	55	56	44	87	90	115	100
Nov-90	140	102	102	60	78	106	80	87	98
Dec-90	114	104	100	62	77	104	61	106	97
Jan-91	68	104	87	62	71	90	29	107	95
Feb-91	64	77	65	22	42	67	69	108	112
Mar-91	62	70	42	42	28	64	61	93	110
Apr-91	66	58	36	25	50	78	60	120	116
May-91	82	78	40	66	48	56	84	66	94
Jun-91	78	72	46	64	50	74	76	60	76
Jul-91	76	65	50	62	54	83	70	54	72
Aug-91	77	61	52	60	56	95	74	54	79
Sep-91	80	55	54	60	60	102	82	48	81
Oct-91	82	62	60	66	67	103	80	51	88
Nov-91	83	68	66	74	73	105	81	57	72
Dec-91	78	76	74	82	76	109	78	68	58
Jan-92	76	96	78	96	80	112	76	86	44

Table 4.1.1.- Concentration of nitrate - nitrogen(mg No3 - L-1) in river Chitrapuzha

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	360	280	560	380	9960	10390	9920	9540	9620	9220	1240	1210	980	940	890	560	800	470
Nov-90	380	450	380	340	2700	2680	590	680	680	740	860	900	760	670	1240	1360	2180	1820
Dec-90	300	340	350	320	4140	3960	1210	1410	1610	1430	1240	1280	1480	1150	1370	1720	2750	2860
Jan-91	240	290	340	320	5620	5280	1880	2160	2540	2140	1640	1680	2200	1660	1910	2090	3300	3900
Feb-91	320	380	310	350	2480	2260	1260	2020	1620	1800	1890	2090	1820	1860	2120	2220	3320	3780
Mar-91	270	290	580	590	4700	4170	2810	2290	3090	2410	2170	2160	1340	1400	1720	1710	2000	2450
Apr-91	270	280	520	340	3460	3560	2390	1560	3420	3100	2850	2880	2540	2660	3340	3040	3350	3520
May-91	840	840	700	840	8820	8640	4780	4820	4960	5880	5040	3080	10500	8820	6720	7560	3540	3520
Jun-91	960	820	910	890	6140	6090	3260	3320	3540	3610	3510	2930	6560	6030	5410	5320	2660	2470
Jul-91	1120	840	1120	980	3500	3500	1540	1860	1680	1820	2380	2380	3220	2380	4900	3080	1820	1820
Aug-91	1010	830	890	870	5190	5120	4450	4620	4010	4020	5020	5120	3860	3720	5110	5140	1270	1230
Sep-91	700	420	700	560	7280	7700	7560	7700	7140	5180	8120	8260	4900	5040	6720	7280	1120	1040
Oct-91	310	280	550	470	6380	6510	5540	5710	5310	4920	5420	5550	3020	3040	4330	4280	1470	1510
Nov-91	320	340	420	360	6080	6120	4130	4120	4280	4220	3280	3260	1310	1120	2340	2320	2220	2060
Dec-91	290	350	360	320	4650	4560	3160	3220	3240	3170	2650	2680	1220	1130	1930	1970	1860	1920
Jan-92	310	440	340	330	3620	3440	2240	2680	2620	2560	2260	2350	1590	1390	1760	1820	1940	2160

S - Surface B - Bottom

Table 4.2.1.- Concentration of nitrate - nitrogen(mg No3 - L-1) in river Chitrapuzha

stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	3	4	220	240	1820	2320	1740	2120	1780	1190	390	330	60	50	200	204	10	4
Nov-90	2	3	260	250	1740	1960	1720	2040	1440	1560	760	720	520	480	640	660	560	540
Dec-90	25	24	230	220	1610	1820	1750	2030	1330	1420	680	630	480	450	610	620	520	510
Jan-91	40	60	240	250	1520	1700	1800	2060	1260	1320	640	580	460	440	590	580	510	480
Feb-91	4	3	220	180	1300	1420	1860	1980	560	480	540	520	420	380	520	480	480	440
Mar-91	3	2	230	190	1460	1440	1920	1940	1160	1220	660	620	240	220	580	560	240	210
Apr-91	3	4	4	3	1610	1500	1620	1580	1020	760	670	680	220	250	240	250	5	6
May-91	170	220	270	250	1240	1246	1220	1220	1090	1100	1120	1090	1100	1120	1000	1070	560	460
Jun-91	82	113	660	630	1160	1150	1190	1180	1060	980	850	860	610	670	910	850	270	230
Jul-91	5	4	1070	1040	1120	1100	1160	1150	1070	920	620	680	140	610	850	650	4	7
Aug-91	3	4	820	810	1380	1360	1110	1120	1080	1020	860	850	550	810	950	870	540	530
Sep-91	5	5	570	570	1660	1620	1070	1070	1120	1120	1100	1090	1070	1070	1080	1090	1120	1120
Oct-91	9	12	450	460	1180	1860	1290	1400	1260	1160	910	900	810	800	860	850	840	820
Nov-91	40	20	350	360	1740	1960	1510	1740	1400	1220	750	710	550	530	640	650	560	550
Dec-91	24	18	310	280	1610	1820	1630	1850	1450	1340	840	750	480	470	610	590	530	510
Jan-92	10	20	250	230	1520	1680	1780	2030	1480	1420	950	810	460	440	620	570	520	500

S - Surface B - Bottom

Table 4.3.1.- Concentration of Ammonia nitrogen(mg Nh3 NL-1) in river Chitrapuzha

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	6	5	5	4	1815	2320	1750	1988	1784	837	390	330	52	26	198	156	124	100
Nov-90	37	34	25	23	108	116	47	44	144	176	176	182	163	110	412	283	803	603
Dec-90	19	17	14	16	325	283	104	92	271	246	251	243	382	242	465	444	507	449
Jan-91	7	2	6	6	458	634	137	163	698	676	326	304	121	155	674	846	496	526
Feb-91	6	3	9	2	761	492	221	571	698	414	690	412	482	407	528	571	846	888
Mar-91	6	5	2	2	665	550	760	655	676	528	782	740	655	613	634	676	635	554
Apr-91	21	24	8	11	239	761	740	748	803	740	951	846	740	676	803	678	613	603
May-91	7	5	6	4	324	307	551	478	237	197	167	80	514	489	294	180	422	402
Jun-91	12	7	5	3	205	184	322	275	186	155	155	106	325	265	153	148	231	202
Jul-91	17	9	4	2	87	61	93	80	175	82	111	33	137	123	124	151	51	31
Aug-91	18	8	6	3	240	206	796	685	162	78	139	122	150	113	124	130	200	199
Sep-91	5	4	7	4	1390	1346	1326	1588	1466	1567	1396	1146	288	180	253	245	395	390
Oct-91	7	5	5	3	1563	1436	1692	1622	1397	1088	869	717	153	147	243	164	260	252
Nov-91	8	7	4	2	1184	1032	2002	1592	942	862	822	674	120	124	262	291	262	262
Dec-91	11	10	10	10	703	579	1482	830	594	465	441	373	182	112	323	300	299	279
Jan-92	6	5	7	5	978	721	372	140	420	159	250	240	44	69	73	136	129	128

S - Surface B - Bottom

Table 4.4.1.- Concentration of total soluble inorganic nitrogen(mg N L-1) in river Chitrapuzha

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	369.3	289.2	784.6	623.8	13595.0	15030.0	13410.0	13648.0	13184.0	11247.0	2020.4	1870.2	1091.8	1016.2	1288.4	920.4	1334.0	574.0
Nov-90	418.8	486.8	665.4	613.3	4547.8	4756.3	2356.5	2764.4	2264.4	2475.5	1795.5	1801.8	1442.8	1259.8	2292.3	2303.4	3543.0	2963.0
Dec-90	343.7	381.3	594.4	556.3	6075.1	6062.9	3063.6	3531.9	3211.2	3095.7	2170.6	2152.6	2342.4	1841.6	2444.7	2784.1	3777.0	3819.0
Jan-91	286.8	352.1	586.3	575.5	7598.0	7614.0	3817.4	4382.8	4498.0	4136.0	2605.8	2563.5	2780.5	2255.0	3174.0	3516.0	4306.0	4906.0
Feb-91	330.3	586.1	538.5	532.1	4541.0	4172.0	3340.9	4571.0	2878.0	2694.2	3120.0	3022.3	2721.7	2646.9	3168.0	3271.0	4646.0	5108.0
Mar-91	279.0	296.8	812.1	1382.1	6825.0	6160.0	5490.0	4885.0	4926.0	4158.0	3612.0	3520.0	2235.0	2233.0	2934.0	2946.0	2875.0	3214.0
Apr-91	693.6	308.3	532.3	353.6	5308.8	5821.0	4750.0	3888.0	5243.0	4600.0	4471.0	4406.0	3500.0	3586.0	4383.0	3968.0	3968.0	4129.0
May-91	1017.0	1065.2	975.7	1093.8	10384.0	10193.0	6551.0	6518.0	6287.0	7177.0	6327.0	4249.7	12113.5	10429.1	8014.1	8810.4	4521.5	4381.5
Jun-91	1053.8	940.0	1574.7	1523.0	7505.2	7424.0	4772.0	4775.0	4785.9	4744.6	4514.8	3896.4	7495.2	6965.4	6473.2	6318.2	3161.1	2902.0
Jul-91	1141.7	852.8	2193.8	2022.1	4706.5	4661.0	2792.6	3090.4	2924.8	2822.3	3110.5	3093.0	3497.0	3113.1	5874.0	3881.0	1875.0	1858.0
Aug-91	1031.0	841.5	1715.6	1682.6	6810.0	6686.0	6356.0	6425.0	5252.3	5118.2	6018.7	6091.5	4560.3	4642.6	6183.6	6140.1	2010.1	1958.9
Sep-91	710.0	428.9	1277.3	1133.8	10330.0	10666.0	9956.0	10358.0	9726.0	7867.0	10616.0	10496.0	6258.3	6289.5	8052.9	8615.2	2635.1	2550.1
Oct-91	325.5	297.3	1005.3	933.2	9123.0	9806.0	8522.0	8732.0	7967.0	7168.0	7199.4	7166.7	3983.3	3986.5	5433.3	5294.1	2570.4	2582.2
Nov-91	368.1	366.8	774.2	722.1	9004.0	9112.0	7642.0	7452.0	6622.0	6302.0	4852.0	4644.0	1980.0	1774.0	3242.0	3260.6	3042.1	2871.5
Dec-91	324.9	377.7	679.9	609.6	6963.0	6959.0	6272.0	5900.0	5284.0	4975.0	3931.0	3803.0	1882.0	1712.0	2863.0	2860.0	2689.0	2709.0
Jan-92	326.0	465.1	596.6	565.1	6118.4	5841.2	4391.8	4850.2	4520.4	4139.1	3459.7	3400.4	2094.4	1898.6	2452.8	2526.0	2589.1	2788.0

S - Surface B - Bottom

Table 5.2.1.- Concentration of Phosphate - Phosporus (mg po4 3 P L - 1) in river Chitrapuzha

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	2	3	4	5	2764	2560	1934	1640	1645	1254	934	743	191	130	860	542	7	7
Nov-90	8	9	1	1	1313	1373	2460	2099	1520	1174	500	1124	483	334	322	217	6	5
Dec-90	6	5	3	2	1123	1496	1758	1338	1524	1494	760	734	626	434	360	372	4	4
Jan-91	4	3	4	3	1132	2018	1254	779	1932	2012	1425	1543	1174	536	798	545	4	3
Feb-91	3	2	8	7	2344	1815	2724	2146	1825	1430	1768	1121	512	491	372	466	3	2
Mar-91	4	4	4	5	2998	3049	1306	1861	1584	1598	1651	1891	197	196	648	799	5	6
Apr-91	10	3	109	159	2935	2728	1768	1803	1817	1598	1871	1811	373	228	119	798	8	7
May-91	66	74	63	67	2218	2163	2107	1962	1805	1789	1707	1602	403	399	1472	1103	8	7
Jun-91	64	70	65	74	1714	1746	1563	1514	1162	1406	1080	1198	692	708	1104	1026	10	6
Jul-91	100	87	85	89	1206	1367	1020	1264	522	1227	473	1195	979	1416	985	953	8	8
Aug-91	86	88	88	86	1560	1584	1256	1212	1238	1414	952	1098	488	662	744	582	7	8
Sep-91	92	96	97	92	2313	2198	1690	1364	2152	2008	1730	1202	206	307	704	210	9	9
Oct-91	88	89	98	88	1982	1960	1720	1642	1838	1792	1328	1266	270	246	542	480	22	18
Nov-91	86	84	85	88	1876	1929	1954	1923	1723	1587	1128	1136	338	382	777	552	34	27
Dec-91	34	32	72	60	1668	1878	1842	1680	1582	1556	1194	1252	531	442	812	717	49	37
Jan-92	11	9	126	21	2002	2211	1817	1777	1497	1577	1694	1682	631	504	1306	1228	111	82

S - Surface B - Bottom

Table 5.2.2.- Nitrogen Phosphate ratio in river Chitrapuzha

Stations	1		2		3		4		5		6		7		8		9	
Period	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
Oct-90	408.37	213.20	433.80	275.92	10.88	12.98	15.33	18.40	17.73	19.84	4.78	5.57	12.64	17.29	3.31	3.76	421.47	181.35
Nov-90	115.78	119.62	1471.59	1356.37	7.66	7.66	2.12	2.91	3.29	4.66	7.94	3.55	6.61	8.34	15.74	23.48	1305.95	1310.59
Dec-90	126.69	168.66	438.19	615.15	11.96	8.96	3.85	5.84	4.66	4.58	6.32	6.49	8.28	9.38	15.02	16.55	2088.30	2111.52
Jan-91	158.57	259.57	324.16	424.26	14.84	8.34	6.73	12.44	5.15	4.55	4.04	3.67	5.24	9.30	8.80	14.27	2380.78	3616.69
Feb-91	243.50	648.11	148.87	168.11	4.28	5.08	2.71	4.71	3.49	4.17	3.90	5.96	11.76	11.92	18.83	15.52	3425.02	5648.41
Mar-91	154.26	164.10	449.01	611.33	5.03	4.47	9.30	5.81	6.88	5.75	4.84	4.12	25.09	25.20	10.01	8.15	1271.67	1184.68
Apr-91	153.40	227.28	10.80	4.92	4.00	4.72	5.94	4.77	6.38	6.37	5.28	5.38	20.75	34.78	81.46	11.00	1096.95	1304.52
May-91	34.08	31.83	34.25	36.11	10.35	10.42	6.88	7.35	7.70	8.87	8.20	5.87	66.48	57.81	12.04	17.67	1249.96	1384.30
Jun-91	36.42	29.70	53.58	45.52	9.68	9.40	6.75	6.98	9.11	7.46	9.25	7.19	23.95	21.76	12.97	13.62	699.11	1069.67
Jul-91	25.25	21.68	57.08	50.25	8.63	7.54	6.05	5.41	12.39	5.09	14.54	5.72	7.90	4.86	13.19	9.01	518.34	513.64
Aug-91	26.51	21.15	43.12	43.27	9.65	9.34	11.19	11.72	9.38	8.01	13.98	12.27	20.67	15.51	18.38	23.33	635.07	541.54
Sep-91	17.07	9.88	29.12	27.26	9.88	10.73	13.03	16.79	10.00	8.66	13.57	19.31	67.19	45.31	25.30	90.73	647.53	626.64
Oct-91	8.18	7.39	24.98	23.45	10.18	11.06	10.96	11.76	9.59	8.85	11.99	12.52	32.63	35.84	22.17	24.39	258.39	317.27
Nov-91	9.47	9.66	20.14	18.15	10.61	10.45	8.65	8.57	8.50	8.78	9.51	9.04	12.96	10.27	9.23	13.06	197.88	235.21
Dec-91	21.13	26.10	20.88	22.47	9.23	8.20	7.53	7.77	7.39	7.07	7.28	6.72	7.84	8.57	7.80	8.82	121.37	161.92
Jan-92	65.54	114.29	10.47	59.51	6.76	5.84	5.35	6.04	6.68	5.80	4.52	4.47	7.34	8.33	4.15	4.55	51.59	75.19

S - Surface B - Bottom

Means of variables for each period (Surface water)

Period	Temperature	Salinity	D.O	pH	Acidity	Alkalinity	Transparency	Redox potential
1	30.856	1.401	5.847	8.014	2.544	129.022	83.667	-43.778
2	28.644	2.354	4.423	6.717	10.556	98.411	94.778	16.667
3	28.933	2.629	5.053	6.931	4.978	103.422	91.667	6.444
4	29.189	3.517	5.629	7.161	1.989	105.056	79.222	-8.111
5	29.189	6.877	5.544	6.048	8.378	46.233	69.556	58.778
6	31.611	7.144	6.052	5.859	21.800	64.756	63.556	69.778
7	31.578	7.720	5.071	7.047	9.667	101.078	67.667	5.000
8	30.489	1.483	3.546	6.260	15.700	79.422	68.222	43.889
9	30.411	1.139	4.810	6.247	15.978	72.744	66.222	45.667
10	30.122	0.642	5.868	6.192	17.833	68.189	65.111	49.333
11	30.000	1.168	6.418	6.349	15.711	74.367	67.556	39.444
12	29.889	1.511	6.743	6.513	14.811	84.889	69.111	34.444
13	29.622	1.603	6.229	7.001	9.844	96.611	73.222	8.111
14	28.467	2.116	5.597	6.734	12.567	93.511	75.444	20.889
15	28.233	2.374	5.903	6.814	11.167	94.744	77.667	14.333
16	26.889	2.994	5.691	6.789	11.922	94.322	82.667	15.778

Means of variables for each station (Surface water)

ation	Temperature	Salinity	D.O	pH	Acidity	Alkalinity	Transparency	Redox potential
1	30.513	0.139	7.402	7.027	2.944	67.519	83.250	4.313
2	29.494	0.069	6.049	6.944	2.262	66.056	78.000	7.250
3	30.000	0.937	5.306	6.729	15.925	121.269	62.938	24.875
4	30.069	1.034	5.717	6.057	17.875	66.106	59.938	60.688
5	29.794	1.282	5.539	5.913	20.212	60.763	59.625	67.688
6	29.756	2.318	4.951	6.216	15.744	89.731	89.688	47.813
7	29.975	4.501	5.323	6.865	10.531	109.494	71.938	9.000
8	29.537	5.411	4.619	6.888	10.956	113.369	80.000	8.500
9	27.556	10.561	4.833	7.366	7.862	97.006	87.000	-18.250

Means of variables for each period (Surface water)

Period				Total					
	Ammonia	Nitrite	Nitrate	Nitrogen	NH _N/TN	NO _N/TN	NO3_N/TN	Phosphate	NP Ratio
1	48.580	49.360	272.306	373.418	0.101	0.122	0.776	29.917	147.590
2	15.186	60.616	77.496	153.299	0.094	0.373	0.532	23.717	326.298
3	18.542	57.388	114.618	190.547	0.092	0.290	0.613	22.108	300.363
4	23.186	56.001	156.021	235.203	0.088	0.248	0.667	27.714	323.146
5	33.636	46.831	120.090	200.556	0.141	0.227	0.633	34.286	429.151
6	38.193	51.501	148.169	237.864	0.150	0.184	0.667	30.117	215.121
7	39.007	42.770	175.614	260.562	0.128	0.122	0.747	32.314	153.884
8	19.996	61.631	364.077	445.703	0.041	0.160	0.801	35.322	158.882
9	12.644	53.873	261.357	327.874	0.034	0.180	0.786	26.736	95.647
10	6.321	47.900	168.792	223.013	0.028	0.211	0.760	19.288	73.708
11	14.550	57.848	244.384	316.783	0.043	0.193	0.762	23.023	87.550
12	51.769	69.760	350.910	472.442	0.088	0.187	0.726	32.252	92.521
13	49.100	60.353	256.440	365.898	0.098	0.193	0.711	28.260	43.230
14	44.470	59.808	193.381	297.660	0.107	0.219	0.674	28.697	31.883
15	32.083	59.363	153.563	245.008	0.102	0.241	0.653	27.918	23.383
16	18.080	60.203	132.306	210.587	0.059	0.264	0.676	32.979	18.044

Means of variables for each station (Surface water)

Station				Total					
	Ammonia	Nitrite	Nitrate	Nitrogen	NH _N/TN	NO _N/TN	NO3_N/TN	Phosphate	NP Ratio
1	0.854	1.909	35.692	40.242	0.025	0.046	0.928	1.341	100.264
2	0.548	27.458	40.289	68.293	0.011	0.379	0.612	1.821	223.127
3	49.281	105.608	377.998	532.887	0.086	0.216	0.696	62.839	8.976
4	55.298	108.732	253.071	417.101	0.113	0.332	0.555	56.838	7.648
5	47.536	87.271	264.848	399.655	0.113	0.259	0.627	51.174	8.020
6	35.313	55.057	221.168	311.537	0.119	0.203	0.677	40.742	8.121
7	20.115	36.452	211.039	267.608	0.091	0.160	0.749	16.331	21.083
8	24.821	48.633	231.164	304.617	0.106	0.174	0.718	24.058	17.400
9	27.989	32.433	158.838	221.046	0.119	0.152	0.729	0.596	1023.086

Means of variables for each period (Bottom water)

Period	Temperature	Salinity	D.O	pH	Acidity	Alkalinity	Redox potentia
1	29.489	1.608	4.654	7.937	2.322	98.156	-40.222
2	28.678	2.649	3.990	6.726	10.456	113.778	16.444
3	28.733	3.307	4.142	6.913	5.122	96.844	6.667
4	29.100	4.457	3.909	7.104	1.756	97.000	-4.556
5	29.278	7.957	4.487	6.101	8.144	53.111	50.222
6	31.367	8.103	4.817	5.940	21.589	65.489	65.222
7	31.256	9.006	3.454	6.940	10.400	97.978	9.778
8	30.433	1.909	2.620	6.162	16.267	76.867	49.111
9	30.222	1.278	4.273	6.206	15.978	72.267	47.667
10	29.889	0.661	5.704	6.131	18.144	66.933	51.556
11	29.633	1.281	5.976	6.269	15.244	73.489	43.889
12	29.411	1.646	6.289	6.416	14.789	78.544	35.444
13	29.089	1.772	5.754	6.941	10.622	96.256	9.556
14	28.322	2.420	5.113	6.720	12.156	92.922	23.000
15	28.111	2.627	5.183	6.811	10.833	95.967	15.222
16	26.633	3.727	5.393	6.703	12.689	91.356	20.111

Means of variables for each station (Bottom water)

Station	Temperature	Salinity	D.O	pH	Acidity	Alkalinity	Redox potentia
1	29.781	0.207	6.591	7.027	2.725	67.300	1.875
2	28.756	0.094	5.690	6.924	2.481	69.938	7.188
3	29.663	1.146	4.739	6.572	17.606	94.169	32.438
4	29.506	1.288	4.600	5.869	18.856	56.319	73.563
5	29.819	2.128	3.896	5.928	18.338	64.244	66.188
6	29.769	3.098	3.894	6.317	15.044	89.288	41.625
7	29.863	5.198	3.764	6.871	10.269	114.750	6.375
8	29.544	6.197	4.231	6.759	11.737	114.513	14.375
9	27.475	11.248	4.648	7.369	7.856	98.281	-19.125

Means of variables for each period (Bottom water)

Period	Ammonia	Nitrite	Nitrate	Total Nitrogen	NH _N/TN	NO _N/TN	NO3_N/TN	Phosphate	NP Ratio
1	45.742	51.257	261.677	358.676	0.106	0.141	0.756	24.691	60.923
2	12.463	65.146	76.464	154.071	0.081	0.383	0.534	22.723	315.242
3	16.113	61.267	114.777	192.156	0.084	0.297	0.618	21.084	327.459
4	26.262	59.251	154.831	240.347	0.093	0.256	0.651	26.693	483.677
5	29.828	46.664	132.941	211.020	0.114	0.206	0.679	26.827	723.554
6	34.289	50.780	138.571	228.401	0.139	0.179	0.683	33.746	223.734
7	40.350	39.921	166.094	246.367	0.143	0.127	0.729	32.764	178.193
8	16.988	61.679	349.007	427.674	0.034	0.166	0.800	32.874	173.359
9	10.674	52.851	249.700	313.222	0.031	0.186	0.782	27.788	134.589
10	4.543	48.870	148.011	201.423	0.021	0.227	0.750	27.280	69.244
11	12.236	58.491	243.274	313.999	0.037	0.197	0.767	24.152	76.238
12	51.134	69.442	342.502	463.263	0.090	0.193	0.716	26.850	95.034
13	43.101	65.534	255.964	364.601	0.087	0.206	0.707	27.189	50.281
14	38.432	61.393	189.732	289.558	0.098	0.226	0.676	27.646	35.910
15	23.459	60.506	153.246	237.209	0.081	0.247	0.673	27.451	28.627
16	12.720	61.076	136.192	209.990	0.047	0.264	0.689	32.606	31.558

Means of variables for each station (Bottom water)

Station	Ammonia	Nitrite	Nitrate	Total Nitrogen	NH _N/TN	NO _N/TN	No3_N/TN	Phosphate	NP Ratio
1	0.669	2.303	33.329	37.192	0.024	0.050	0.928	1.327	117.014
2	0.441	26.605	36.854	66.578	0.009	0.381	0.607	1.709	236.378
3	49.206	115.810	374.698	539.712	0.082	0.233	0.682	64.711	8.449
4	51.540	118.280	257.487	427.307	0.104	0.336	0.559	52.461	8.579
5	36.897	81.337	250.839	369.074	0.097	0.259	0.644	50.267	7.407
6	29.212	52.736	213.316	295.265	0.104	0.204	0.692	41.554	7.366
7	17.176	39.219	191.898	248.293	0.083	0.183	0.734	14.960	20.279
8	24.096	47.044	229.645	300.786	0.104	0.174	0.722	21.364	18.619
9	26.178	30.862	162.987	220.028	0.116	0.147	0.736	0.476	1267.696

ANALYSIS OF VARIANCE TABLE FOR TEMPERATURE - SURFACE WATER

```
               Degrees of   Sum of
Source           Freedom    Squares       Mean Square    F-value   Prob
------------------------------------------------------------------------
PERIOD             15         213.10         14.207       41.77    0.0000
STATION             8          89.56         11.195       32.92    0.0000
Error             120          40.81          0.340
------------------------------------------------------------------------
Total             143         343.48
------------------------------------------------------------------------

   Grand Mean=     29.633   Grand Sum=  4267.100  Total Count= 144

   Coefficient of Variation=    1.97%
```

ANALYSIS OF VARIANCE TABLE FOR SALINITY - SURFACE WATER

```
               Degrees of   Sum of
Source           Freedom    Squares       Mean Square    F-value   Prob
------------------------------------------------------------------------
PERIOD             15         699.95         46.663       12.00    0.0000
STATION             8        1495.71        186.964       48.09    0.0000
Error             120         466.55          3.888
------------------------------------------------------------------------
Total             143        2662.21
------------------------------------------------------------------------

   Grand Mean=      2.917   Grand Sum=   420.060  Total Count= 144

   Coefficient of Variation=   67.59%
```

ANALYSIS OF VARIANCE TABLE FOR D.O - SURFACE WATER

```
               Degrees of   Sum of
Source           Freedom    Squares       Mean Square    F-value   Prob
------------------------------------------------------------------------
PERIOD             15          85.81          5.721        4.94    0.0000
STATION             8          88.83         11.104        9.58    0.0000
Error             120         139.09          1.159
------------------------------------------------------------------------
Total             143         313.73
------------------------------------------------------------------------

   Grand Mean=      5.527   Grand Sum=   795.820  Total Count= 144

   Coefficient of Variation=   19.48%
```

```
      ANALYSIS OF VARIANCE TABLE FOR pH - SURFACE WATER

              Degrees of   Sum of
Source         Freedom     Squares      Mean Square    F-value   Prob
-----------------------------------------------------------------------
PERIOD            15         37.42            2.495       4.70    0.0000
STATION            8         30.88            3.860       7.28    0.0000
Error            120         63.64            0.530
-----------------------------------------------------------------------
Total            143        131.95
-----------------------------------------------------------------------

   Grand Mean=     6.667   Grand Sum=    960.090  Total Count= 144

   Coefficient of Variation=    10.92%
```

```
    ANALYSIS OF VARIANCE TABLE FOR ACIDITY - SURFACE WATER

              Degrees of   Sum of
Source         Freedom     Squares      Mean Square    F-value   Prob
-----------------------------------------------------------------------
PERIOD            15       3994.47          266.298       5.29    0.0000
STATION            8       5233.14          654.143      12.98    0.0000
Error            120       6045.97           50.383
-----------------------------------------------------------------------
Total            143      15273.59
-----------------------------------------------------------------------

   Grand Mean=    11.590   Grand Sum=   1669.000  Total Count= 144

   Coefficient of Variation=    61.24%
```

```
    ANALYSIS OF VARIANCE TABLE FOR ALKALINITY - SURFACE WATER

              Degrees of   Sum of
Source         Freedom     Squares      Mean Square    F-value   Prob
-----------------------------------------------------------------------
PERIOD            15      52739.67         3515.978       2.68    0.0015
STATION            8      70698.39         8837.298       6.73    0.0000
Error            120     157650.30         1313.753
-----------------------------------------------------------------------
Total            143     281088.36
-----------------------------------------------------------------------

   Grand Mean=    87.924   Grand Sum= 12661.000  Total Count= 144

   Coefficient of Variation=    41.22%
```

```
    ANALYSIS OF VARIANCE TABLE FOR TRANSPARENCY- SURFACE WATER

                 Degrees of   Sum of
Source            Freedom     Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
period               15       12195.31        813.020       2.64   0.0018
station               8       17266.75       2158.344       7.01   0.0000
Error               120       36973.69        308.114
-------------------------------------------------------------------------
Total               143       66435.75
-------------------------------------------------------------------------

   Grand Mean=    74.708   Grand Sum= 10758.000  Total Count= 144

   Coefficient of Variation=   23.50%
```

```
    ANALYSIS OF VARIANCE TABLE FOR REDOX POTENTIAL - SURFACE WATER

                 Degrees of   Sum of
Source            Freedom     Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD               15      107345.31       7156.354       3.43   0.0001
STATION               8      107823.25      13477.906       6.47   0.0000
Error               120      250103.19       2084.193
-------------------------------------------------------------------------
Total               143      465271.75
-------------------------------------------------------------------------

   Grand Mean=    23.542   Grand Sum=  3390.000  Total Count= 144

   Coefficient of Variation=  193.92%
```

```
    ANALYSIS OF VARIANCE TABLE FOR AMMONIA - SURFACE WATER

                 Degrees of   Sum of
Source            Freedom     Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD               15       29570.76       1971.384       3.38   0.0001
STATION               8       50965.77       6370.722      10.91   0.0000
Error               120       70067.28        583.894
-------------------------------------------------------------------------
Total               143      150603.82
-------------------------------------------------------------------------

   Grand Mean=    29.084   Grand Sum=  4188.080  Total Count= 144

   Coefficient of Variation=   83.08%
```

```
    ANALYSIS OF VARIANCE TABLE FOR NITRITE - SURFACE WATER

               Degrees of   Sum of
Source          Freedom     Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD             15        6332.81         422.187       1.38    0.1670
STATION             8      175242.77       21905.347      71.69    0.0000
Error             120       36665.23         305.544
-------------------------------------------------------------------------
Total             143      218240.82
-------------------------------------------------------------------------

   Grand Mean=     55.950   Grand Sum=  8056.860  Total Count= 144

   Coefficient of Variation=   31.24%
```

```
    ANALYSIS OF VARIANCE TABLE FOR NITRATE - SURFACE WATER

               Degrees of   Sum of
Source          Freedom     Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD             15      949421.51       63294.767       5.38    0.0000
STATION             8     1511057.57      188882.196      16.04    0.0000
Error             120     1412721.92       11772.683
-------------------------------------------------------------------------
Total             143     3873201.00
-------------------------------------------------------------------------

   Grand Mean=    199.345   Grand Sum= 28705.710  Total Count= 144

   Coefficient of Variation=   54.43%
```

```
    ANALYSIS OF VARIANCE TABLE FOR TOTAL_N - SURFACE WATER

               Degrees of   Sum of
Source          Freedom     Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD             15     1152048.54       76803.236       4.54    0.0000
STATION             8     3270297.46      408787.182      24.15    0.0000
Error             120     2031272.08       16927.267
-------------------------------------------------------------------------
Total             143     6453618.08
-------------------------------------------------------------------------

   Grand Mean=    284.776   Grand Sum= 41007.760  Total Count= 144

   Coefficient of Variation=   45.69%
```

```
    ANALYSIS OF VARIANCE TABLE FOR NH3-N/TN - SURFACE WATER

               Degrees of   Sum of
Source          Freedom    Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD             15          0.19          0.012       4.86    0.0000
STATION             8          0.21          0.027      10.52    0.0000
Error             120          0.31          0.003
-------------------------------------------------------------------------
Total             143          0.71
-------------------------------------------------------------------------

   Grand Mean=     0.087   Grand Sum=    12.550  Total Count= 144

   Coefficient of Variation=   57.94%


    ANALYSIS OF VARIANCE TABLE FOR NO2-N/TN - SURFACE WATER

               Degrees of   Sum of
Source          Freedom    Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD             15          0.53          0.035       4.13    0.0000
STATION             8          1.28          0.160      18.59    0.0000
Error             120          1.03          0.009
-------------------------------------------------------------------------
Total             143          2.84
-------------------------------------------------------------------------

   Grand Mean=     0.213   Grand Sum=    30.740  Total Count= 144

   Coefficient of Variation=   43.44%


    ANALYSIS OF VARIANCE TABLE FOR NO3-N/TN - SURFACE WATER

               Degrees of   Sum of
Source          Freedom    Squares      Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD             15          0.71          0.048       6.07    0.0000
STATION             8          1.44          0.181      22.99    0.0000
Error             120          0.94          0.008
-------------------------------------------------------------------------
Total             143          3.10
-------------------------------------------------------------------------

   Grand Mean=     0.699   Grand Sum=   100.650  Total Count= 144

   Coefficient of Variation=   12.68%
```

```
    ANALYSIS OF VARIANCE TABLE FOR PHOSPHATE - SURFACE WATER

                Degrees of   Sum of
Source           Freedom     Squares       Mean Square     F-value   Prob
-------------------------------------------------------------------------
PERIOD              15        2843.79         189.586        1.53    0.1066
STATION              8       80671.52       10083.940       81.13    0.0000
Error              120       14916.04         124.300
-------------------------------------------------------------------------
Total              143       98431.35
-------------------------------------------------------------------------

   Grand Mean=     28.415   Grand Sum=  4091.820  Total Count= 144

   Coefficient of Variation=   39.24%
```

```
    ANALYSIS OF VARIANCE TABLE FOR NP RATIO - SURFACE WATER

                Degrees of   Sum of
Source           Freedom     Squares       Mean Square     F-value   Prob
-------------------------------------------------------------------------
PERIOD              15     2158229.82      143881.988        1.32    0.2019
STATION              8    14147732.15     1768466.519       16.20    0.0000
Error              120    13100980.62      109174.839
-------------------------------------------------------------------------
Total              143    29406942.60
-------------------------------------------------------------------------

   Grand Mean=   157.525   Grand Sum= 22683.620  Total Count= 144

   Coefficient of Variation=  209.75%
```

```
            ANALYSIS OF VARIANCE TABLE FOR TEMPERATURE - BOTTOM WATER

                 Degrees of   Sum of
Source            Freedom     Squares       Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD              15          188.69           12.579     36.00    0.0000
STATION              8           77.94            9.743     27.89    0.0000
Error              120           41.93            0.349
-------------------------------------------------------------------------
Total              143          308.56
-------------------------------------------------------------------------
 Grand Mean=    29.353   Grand Sum=  4226.800  Total Count= 144
 Coefficient of Variation=    2.01%
```

```
             ANALYSIS OF VARIANCE TABLE FOR SALINITY- BOTTOM WATER

                 Degrees of   Sum of
Source            Freedom     Squares       Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD              15          947.88           63.192     13.59    0.0000
STATION              8         1680.22          210.027     45.16    0.0000
Error              120          558.04            4.650
-------------------------------------------------------------------------
Total              143         3186.14
-------------------------------------------------------------------------

   Grand Mean=     3.400   Grand Sum=   489.650  Total Count= 144

   Coefficient of Variation=   63.42%
```

```
            ANALYSIS OF VARIANCE TABLE FOR D.O - BOTTOM WATER

                 Degrees of   Sum of
Source            Freedom     Squares       Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD              15          128.89            8.593      6.08    0.0000
STATION              8          111.28           13.910      9.85    0.0000
Error              120          169.47            1.412
-------------------------------------------------------------------------
Total              143          409.63
-------------------------------------------------------------------------

   Grand Mean=     4.673   Grand Sum=   672.840  Total Count= 144

   Coefficient of Variation=   25.43%
```

```
      ANALYSIS OF VARIANCE TABLE FOR pH - BOTTOM WATER

               Degrees of   Sum of
Source           Freedom    Squares      Mean Square    F-value   Prob
------------------------------------------------------------------------
PERIOD              15         34.57           2.305       4.24    0.0000
STATION              8         32.61           4.076       7.50    0.0000
Error              120         65.18           0.543
------------------------------------------------------------------------
Total              143        132.35
------------------------------------------------------------------------

   Grand Mean=     6.626   Grand Sum=   954.180  Total Count= 144

   Coefficient of Variation=    11.12%


      ANALYSIS OF VARIANCE TABLE FOR ACIDITY - BOTTOM WATER

               Degrees of   Sum of
Source           Freedom    Squares      Mean Square    F-value   Prob
------------------------------------------------------------------------
PERIOD              15       4046.67         269.778       5.11    0.0000
STATION              8       5178.82         647.353      12.26    0.0000
Error              120       6334.46          52.787
------------------------------------------------------------------------
Total              143      15559.95
------------------------------------------------------------------------

   Grand Mean=    11.657   Grand Sum=  1678.600  Total Count= 144

   Coefficient of Variation=    62.33%


      ANALYSIS OF VARIANCE TABLE FOR ALKALINITY - BOTTOM WATER

               Degrees of   Sum of
Source           Freedom    Squares      Mean Square    F-value   Prob
------------------------------------------------------------------------
PERIOD              15      35309.81        2353.987       2.38    0.0048
STATION              8      61230.25        7653.782       7.75    0.0000
Error              120     118440.17         987.001
------------------------------------------------------------------------
Total              143     214980.23
------------------------------------------------------------------------

   Grand Mean=    85.422   Grand Sum= 12300.800  Total Count= 144

   Coefficient of Variation=    36.78%
```

```
    ANALYSIS OF VARIANCE TABLE FOR REDOX POTENTIAL - BOTTOM WATER

                  Degrees of   Sum of
Source             Freedom     Squares      Mean Square    F-value   Prob
-----------------------------------------------------------------------
PERIOD                15       95856.00       6390.400        2.99   0.0004
STATION                8      122324.06      15290.507        7.16   0.0000
Error                120      256171.50       2134.763
-----------------------------------------------------------------------
Total                143      474351.56
-----------------------------------------------------------------------

   Grand Mean=    24.944   Grand Sum=  3592.000  Total Count= 144

   Coefficient of Variation=  185.23%
```

```
   ANALYSIS OF VARIANCE TABLE FOR AMMONIA - BOTTOM WATER

                  Degrees of   Sum of
Source             Freedom     Squares      Mean Square    F-value   Prob
-----------------------------------------------------------------------
PERIOD                15       28766.54       1917.769        3.68   0.0000
STATION                8       43137.29       5392.161       10.34   0.0000
Error                120       62572.68        521.439
-----------------------------------------------------------------------
Total                143      134476.51
-----------------------------------------------------------------------

   Grand Mean=    26.157   Grand Sum=  3766.640  Total Count= 144

   Coefficient of Variation=   87.30%
```

```
    ANALYSIS OF VARIANCE TABLE FOR NITRITE - BOTTOM WATER

                  Degrees of   Sum of
Source             Freedom     Squares      Mean Square    F-value   Prob
-----------------------------------------------------------------------
PERIOD                15        8485.17        565.678        1.53   0.1036
STATION                8      205411.50      25676.437       69.64   0.0000
Error                120       44247.42        368.729
-----------------------------------------------------------------------
Total                143      258144.10
-----------------------------------------------------------------------

   Grand Mean=    57.133   Grand Sum=  8227.150  Total Count= 144

   Coefficient of Variation=   33.61%
```

```
      ANALYSIS OF VARIANCE TABLE FOR NITRATE - BOTTOM WATER


                Degrees of   Sum of
Source            Freedom    Squares       Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD              15        867288.48      57819.232      5.05    0.0000
STATION              8       1488475.14     186059.392     16.24    0.0000
Error              120       1375080.20      11459.002
-------------------------------------------------------------------------
Total              143       3730843.82
-------------------------------------------------------------------------

   Grand Mean=   194.562   Grand Sum= 28016.860  Total Count= 144

   Coefficient of Variation=    55.02%
```

```
      ANALYSIS OF VARIANCE TABLE FOR TOTAL_N - BOTTOM WATER


                Degrees of   Sum of
Source            Freedom    Squares       Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD              15       1058832.59      70588.839      4.28    0.0000
STATION              8       3309259.11     413657.389     25.11    0.0000
Error              120       1976849.42      16473.745
-------------------------------------------------------------------------
Total              143       6344941.12
-------------------------------------------------------------------------

   Grand Mean=   278.249   Grand Sum= 40067.790  Total Count= 144

   Coefficient of Variation=    46.13%
```

```
      ANALYSIS OF VARIANCE TABLE FOR NH3-N/TN - BOTTOM WATER

                Degrees of   Sum of
Source            Freedom    Squares       Mean Square    F-value   Prob
-------------------------------------------------------------------------
PERIOD              15             0.19          0.013      6.55    0.0000
STATION              8             0.18          0.023     11.99    0.0000
Error              120             0.23          0.002
-------------------------------------------------------------------------
Total              143             0.60
-------------------------------------------------------------------------

   Grand Mean=     0.080   Grand Sum=     11.580  Total Count= 144

   Coefficient of Variation=    54.43%
```

```
        ANALYSIS OF VARIANCE TABLE FOR NO2-N/TNURE - BOTTOM WATER


                Degrees of   Sum of
Source           Freedom     Squares       Mean Square     F-value    Prob
-------------------------------------------------------------------------
PERIOD              15           0.53            0.035        3.86    0.0000
STATION              8           1.27            0.158       17.26    0.0000
Error              120           1.10            0.009
-------------------------------------------------------------------------
Total              143           2.90
-------------------------------------------------------------------------

   Grand Mean=      0.219   Grand Sum=     31.480  Total Count= 144

   Coefficient of Variation=   43.83%


        ANALYSIS OF VARIANCE TABLE FOR NO3-N/TN - BOTTOM WATER

                Degrees of   Sum of
Source           Freedom     Squares       Mean Square     F-value    Prob
-------------------------------------------------------------------------
PERIOD              15           0.60            0.040        4.22    0.0000
STATION              8           1.38            0.173       18.26    0.0000
Error              120           1.14            0.009
-------------------------------------------------------------------------
Total              143           3.12
-------------------------------------------------------------------------

   Grand Mean=      0.701   Grand Sum=    100.880  Total Count= 144

   Coefficient of Variation=   13.89%


        ANALYSIS OF VARIANCE TABLE FOR PHOSPHATE - BOTTOM WATER


                Degrees of   Sum of
Source           Freedom     Squares       Mean Square     F-value    Prob
-------------------------------------------------------------------------
PERIOD              15        1855.57          123.705        1.58    0.0901
STATION              8       79979.57         9997.446      127.44    0.0000
Error              120        9413.78           78.448
-------------------------------------------------------------------------
Total              143       91248.92
-------------------------------------------------------------------------

   Grand Mean=     27.648   Grand Sum=   3981.280  Total Count= 144

   Coefficient of Variation=   32.04%
```

```
      ANALYSIS OF VARIANCE TABLE FOR NP RATIO - BOTTOM WATER

               Degrees of   Sum of
Source           Freedom    Squares     Mean Square    F-value   Prob
------------------------------------------------------------------------
PERIOD             15      5019115.44     334607.696      1.33   0.1946
STATION             8     21753861.75    2719232.718     10.81   0.0000
Error             120     30178415.69     251486.797
------------------------------------------------------------------------
Total             143     56951392.87
------------------------------------------------------------------------

   Grand Mean=   187.976   Grand Sum= 27068.610  Total Count= 144

   Coefficient of Variation=  266.78%
```