INTRODUCTION

Introduction

An estuary popularly known as 'Kayal' is a body of water in which river water mixes with and dilutes sea water. The term estuary has a Latin root ‘estuarium’ which can generally be applied to the lower reaches of the tidal mouth of a river. Emery and Stevenson (1957) stated that “ an estuary is the wide mouth of a river or arm of the sea where the tide meets the river currents or flows and ebbs”. According to Pritchard(1955) “an estuary is a semi-enclosed coastal body of water which has free connection with the open sea and within which the sea water is measurably diluted with freshwater derived from land drainage”. Ketchum (1951) described it, "as a body of water in which river water mixes with and measurably dilutes sea water".

Estuaries are geologically very young, less than 3000 years old, their study is only about 100 years old. The study of estuaries has received increasingly greater attention during the past few decades. This interest is reflected in the new journal, such as "Estuarine and Coastal Marine Science" renamed "Estuarine, Coastal and Shelf Science" in January, 1981, devoted particularly to the publication of estuarine work. A part of this work stems from the realization that estuaries have considerable importance in human affairs. Estuarine systems are used as ports and harbours, receivers of domestic and industrial wastes, sites for agriculture, grounds for commercial fishing and for a myriad of recreational purposes (Ketchum, 1951).

An estuary is an ecotone which is characterised by an extremely variable set of environmental conditions which impose unusual stresses on the populations that inhabit it. From an oceanographic point of view, the estuary is an unstable environment. Eventhough estuaries constitute a small area and a small part of the total volume of marine hydrosphere, they play a vital role in the life and development of many aquatic populations. Estuaries are turbid from the fine sediments brought down by the rivers and the bottoms are soft and anoxic and they have been described as 'mixing bowls'. Actually they are way stations for sediments and salts on their way to the bottom of deep sea. Ecological studies of estuarine ecosystem provide useful information for exploitation and conservation of its potential resources.

Among the various ecosystems, estuaries are known to be highly productive and they form natural buffer zones between marine and freshwater regions. They are potential resources for mankind because of their high fertility, sheltered anchorage and the navigational accesses.

The peninsular India is traversed by a network of river systems. The rivers and rivulets give rise to a number of estuaries, backwaters, mangrove swamps, lagoons, deltaic marshes and inlets along the east and west coast of India. The estuaries of India cover an area of about two million hectares (Kurian, 1975).

Estuaries have become recognised through biological studies as nursery grounds for a variety of commercial fish species of the ocean. The importance of the estuaries as nursery grounds has been recognised during the past 50 years. They are not only nursery grounds but also possess indigenous species because of the rich nutrient salts brought in by the rivers.

Estuaries have always been very useful to people. Their usefulness depends partly on the abundance of natural resources they possess and partly on the vital role they play as a means of marine transportation. Again, estuary is an easily accessible place for dumping the waste materials. This accounts for the earliest people settling down on the shores of estuaries and rivers. It is therefore no wonder that most of the major modern cities have been built on the shores of estuaries and rivers.

Estuaries are famous for their rich fishery and the fish production in estuaries depends on the lower trophic levels, namely phytoplankton and zooplankton, the occurrence and abundance of which are greatly influenced by various ecological parameters. The ecological parameters constantly fluctuate in an estuarine ecosystem. This fluctuation is reflected in the occurrence of phytoplankton and zooplankton, which in turn affect the estuarine fishery. In order to improve the estuarine fishery, and to have a continuous fish harvest, it is imperative to have the basic knowledge of the fluctuating parameters of the estuarine ecosystem.

Regarding the study of the ecology of the estuaries, some investigators have confined their study to only one item, some others have limited their study to a few items and still some others have restricted their study to short term observations. A few investigators have focused their study on the community structure, while some others have concentrated their study on the hydrological parameters. And several others have carried out research on the inter dependance of abiotic and biotic factors. It is therefore the need of the hour is to identify estuaries which have not been studied in detail and to provide sufficient scientific information on the ecology of such estuaries by making regular environmental investigations. It is in this respect the Manakkudy estuary along the south west coast of India assumes exceptional significance and hence the present study.

It is certain that the results obtained from the present investigation would enable the Scientists and the Government to arrive at a correct assessment of the natural resources of this estuary and pave the way for similar studies in other estuaries and render the Government to frame the policies necessary for the proper management of this valuable ecosystem.

The various objectives contemplated to investigation include the seasonal fluctuations of environmental parameters, the dissolved nutrients, the primary production,plant pigments, the pelagic and benthic communities.

Chapter 1 deals with the physico - chemical parameters such as rainfall, depth , visibility, temperature, salinity, dissolved oxygen, P^H and hydrogen sulphide.

Chapter 2 deals with the dissolved nutrients such as silicate, total phosphorus, inorganic phosphate, nitrate, nitrite and N : P ratio and correlation of nutrients with physico-chemical parameters and biotic factors.

Chapter 3 describes gross primary production, net primary production, chlorophyll 'a','b' and 'c' and c/a ratio. The association of primary production and chlorophyll with physico-chemical parameters and biological factors is also elucidated.

Chapter 4 is pertaining to plankton- studies, population density, species composition, species diversity, species richness, species evenness of both phytoplankton and zooplankton. The correlation between plankton and physico- chemical parameters, dissolved nutrients, primary productivity and plant pigments is established.

Chapter 5 deals with benthic ecology. Detailed studies are carried out on organic carbon, sediment composition, benthos, population density, species composition, species diversity, species richness and species evenness. The inter-relationship between benthos and organic carbon, sediment composition and physico-chemical parameters is also discussed.

Chapter 6 summarises the findings of physico-chemical parameters, dissolved nutrients, primary productivity, plant pigments, phytoplankton, zooplankton, organic carbon, sediment composition and benthos.

Chapter 7 presents a concise bibliography on various aspects of estuaries.

Review of Literature

In recent years estuaries attracted the attention of ecologists around the world because of the enormous wealth of the aquatic resources hidden in the highly fertile estuarine environment. Several investigations have been conducted on the hydrobiological features of the estuaries at the global level. The basic concept of estuarine circulation was introduced by Ketchum (1951). Day in (1951) reviewed the estuarine conditions in general. Rochford (1951) conducted studies on Australian estuarine hydrology. Pritchard (1955) proposed a scheme for the classification of the estuaries based on the distribution of salinity. Putnam (1966) observed phosphorus and silica as limiting factors of phytoplankton population in a west coast Florida estuary. Barrett (1972) analysed the effects of pollution in Thames estuary. Bousfield and Filteau (1975) studied the population dynamics of zooplankton in the middle St.Lawrence estuary. Sinclair *et al.* (1976) and Sinclair (1977) observed nutrient transport and phytoplankton distribution in St. Lawrence estuary. Alvarez Leon (1980) studied the hydrology and zooplankton of three estuaries adjacent to Mazatlan, Sinaloa, Mexico. Ferrier and Anderson (1997) made a multi-disciplinary study of frontal systems in Tay estuary, Scotland. Grabemann *et al.* (1997) investigated the behaviour of turbidity maximum in the Tamar (U.K.) and Weser (F.R.G.) estuaries. Tremblay *et al.* (1997) observed the size-differential effects of vertical stability on the biomass and production of phytoplankton in St. Lawrence estuary, Canada. Grey *et al.* (1997) determined the temporal patterns of zooplankton abundance and their food in Ellis Fjord, Princess Elizabeth Land, Eastern Antarctica. Blaber *et al.* (1997) observed the ichthyoplankton of 23 estuaries in Sarawak and Sabah. Froneman and McQuaid (1997) made a preliminary investigation of the ecological role of micro-zooplankton in Kariega estuary, South Africa. Valdes and Real (1998) analysed variations and relationships of salinity, nutrients and suspended solids in Chelem coastal lagoon at Yucatan, Mexico. Tamigneaux *et al* . (1999) determined seasonal dynamics and potential fate of size fractionated phytoplankton in a temperate nearshore environment, western Gulf of St. Lawrence, Canada. Howland *et al* . (1999) studied the hydrography of Chupa estuary, White Sea, Russia. Mohammed and Saif (1999) studied the environmental characteristics of the United Arab Emirates waters along the Arabian Gulf.

Many studies have also been undertaken to elucidate the hydrobiology of Indian estuaries. Panikkar and Aiyer (1937) studied the brackishwater fauna of Madras. Chandramohan (1963) carried out studies on the zooplankton of the Godavari estuary. Desai and Krishnankutty (1967) studied the benthic fauna of Cochin backwaters.

Wellershaus (1973) studied the hydrography of the Cochin backwater. Bhargava and Dwivedi (1973, 1974) studied diurnal variation in phytoplankton pigments in Mandovi and Zuari estuaries. Ansari (1974) investigated the macrobenthic production in Vembanad lake. Dwivedi *et al.* (1974) studied the ecology and environmental monitoring of Mandovi, Zuari and Camburzua canal complex during monsoon months. Ajmal Khan *et al.* (1975) studied the bottom fauna in two regions in the Vellar estuary. Parulekar and Dwivedi (1975) investigated the ecology of benthic production during south west monsoon in an estuarine complex of Goa. Sundararaj (1978) made hydrobiological studies in the Vellar - Coleroon estuarine system. Abdul Azis (1978) studied the ecology of retting grounds in the backwater systems of Kerala. Parulekar *et al.* (1980) undertook benthic studies in Goa estuaries. Murugan *et al.* (1980) studied the distribution and seasonal variation of benthic fauna of the Veli lake. Bayly (1980) gave a preliminary report on the zooplankton of the Purari estuary. Abdul Azis and Nair (1983) studied the meiofauna of the Edava Nadayara Paravur backwater system. Nair *et al.* (1983a) studied the ecology of Indian estuaries. Prabha Devi (1986) undertook environmental inventory of tidal and gradient zones of Coleroon estuary, south east coast of India. Jegadeesan (1986) made an environmental inventory of the marine zone of Coleroon estuary and inshore waters of Pazhayaru, south east coast of India. Asokan (1987) studied the plankton of Manakkudy estuary, south west coast of India. Balusamy *et al.* (1987) studied the primary productivity of Muthupet estuary, Thanjavur District. Bhat and Neelakantan (1988) studied the distribution of macrobenthos in relation to environmental parameters in the Kali estuary, Karwar. Rajagopal *et al.* (1990) obtained detailed information on the ecology of fouling organisms in Edaiyur backwater, Kalpakkam. Ramaraju *et al.* (1990) studied mixing in Visakhapatnam harbour and nutrient inputs to the nearshore waters. Murugan and Ayyakkannu (1991) studied the ecology of Uppanar backwater, Cuddalore. Govindasamy and Kannan (1991) studied the hydrobiological aspects of Pitchavaram mangroves. Bijoy Nandan (1991) studied the effect of coconut husk retting on the water quality and biota of Kadinamkulam estuary in Kerala. Shibu (1991) studied the ecology of Paravur lake in Kerala. Ram and Goswami (1993) made observations on phytoplankton pigments, zooplankton and physico-chemical parameters in surface waters from southern Indian Ocean and Antarctic region. De *et al.* (1994) investigated the phytoplankton community organization and species diversity in the Hooghli estuary, north east coast of India. Gopinathan *et al.* (1994) investigated the phytoplankton pigments in relation to primary production and nutrients in the inshore waters of Tuticorin, south east coast of India. Sunil Kumar and Antony (1994) observed the impact of environmental parameters on polychaetous annelids in the mangrove swamps of Cochin, south west coast of

India. Reddy and Reddeppa Reddi (1994) carried out studies on seasonal distribution of Foraminifera in the Araniar river estuary of Pulicat, south east coast of India. Ansari *et al.* (1994) surveyed the macrobenthic assemblage in the soft sediment of the Marmugao harbour, Goa, central west coast of India. Sunil Kumar (1995) studied macrobenthos in the mangrove ecosystem of Cochin backwaters. Madhukumar and Anirudhan (1995) analysed the phosphorus distribution in sediments of Edava Nadayara and Paravur lake systems.

Bijoy Nandan and Abdul Azis (1996) evaluated organic matter of sediments from the retting and non-retting areas of Kadinamkulam estuary, south west coast of India. Nasnolkar *et al.* (1996) analysed organic carbon, nitrogen, phosphorus and hydrography of Mandovi estuary, Goa. Goldin *et al.* (1996) carried out studies on the meiobenthos of mangrove mudflats from shallow regions of Thane Creek, central west coast of India. Sunil Kumar (1996) studied the distribution of organic carbon in the sediments of Cochin mangroves, south west coast of India. Sarma and Wilsanand (1996) made a study of the meiofauna of the outer channel of Chilka lagoon, Bay of Bengal. Satpathy (1996) studied the seasonal distribution of nutrients in the coastal waters of Kalpakkam, east coast of India. Gouda and Panigrahy (1996) made a report on the ecology of phytoplankton in coastal waters of Gopalpur, east coast of India. Mishra and Panigrahy (1996) observed copepods of Bahuda estuary, Orissa, east coast of India. Padmavati and Goswami (1996) studied the zooplankton ecology in the Mandovi Zuari estuarine system of Goa, west coast of India. George Abe *et al.* (1996) studied salinity intrusion into Muvattupuzha estuary, south west coast of India, during premonsoon season. Jayaraju and Reddy (1997) studied the water mass parameters of coastal and estuarine environment, south east coast of India. Deepak *et al.* (1997) carried out speciation of Zinc in surface waters of the Rushikulya estuary, Bay of Bengal. Spatial and temporal changes in the qualitative and quantitative composition of zooplankton communities of Rambha Bay located in the southern sector of Chilka lake were studied by Pattanaik and Sarma (1997). The productivity of Cochin estuary and adjacent estuary has been discussed in the light of contribution of periphytic algae by Sreekumar and Joseph (1997). Sivadasan and Joseph (1997) studied the distribution and role of benthic microalgae in Cochin estuary. Karande *et al.* (1997) studied the development of planktonic larvae of unidentified barnacle species from Vellar estuary, south east coast of India. Das *et al.* (1997) studied the semidiurnal variation of some physico-chemical parameters in the Mahanadi estuary, east coast of India. Rao *et al.* (1998) observed circulation and salinity pattern in Hooghly estuary. Ravichandran and Abraham Pylee (1998) investigated mixing and flushing time scales in the Azhikode estuary, south west coast of India. Anilkumar *et al.* (1999) carried out studies on the mixing of waters of different salinity gradients and the suspended sediment distribution in the Beypore estuary, south west coast of India. Mustafa *et al.* (1999) studied the zooplankton community of Bhayandar and Thane salt pans around Bombay. Santhakumari *et al.* (1999) investigated species composition, abundance and distribution of hydromedusae from Dharamtar estuarine system, adjoining Bombay harbour. Goes *et al.* (1999) studied phytoplankton - zooplankton interrelationships in Mandovi estuary. Padmavathi and Satyanarayana (1999) studied the distribution of nutrients and major elements in riverine, estuarine and adjoining coastal waters of Godavari, Bay of Bengal. Mishra and Panigrahy (1999) studied zooplankton ecology of the Bahuda estuary, east coast of India. Padma and Periakali (1999) carried out physico-chemical and geochemical studies in Pulicat lake, east coast of India. Chandra Mohan *et al.* (1999) studied the distribution of zooplankton in relation to water movements in Kakinada bay, east coast of India. Kannapiran *et al.* (1999) investigated magneto bacteria from estuarine, mangrove and coral reef environs in Gulf of Mannar. Perumal *et al.* (1999) carried out studies on the bloom-forming species of phytoplankton in the Vellar estuary, south east coast of India. Goswami *et al.* (2000) analysed diel variations in zooplankton and their biochemical composition from Vengurla to Ratnagiri, west coast of India. Anvar Batcha (2000) observed the sediments of Vambanad lake. Anilakumary *et al.* (2001) studied the sediment characteristics of Poonthura estuary, south west coast of India. Ratna Bharati *et al.* (2001) studied planktonic flagellates in relation to pollution in Visakhapatnam harbour, east coast of India. Sarojini and Sarma (2001) analysed vertical distribution of phytoplankton around Andaman and Nicobar Islands, Bay of Bengal.

From the perusal of wide array of literature on estuaries it is seen that the scientific work on Manakkudy estuary is limited to a simple study on resource and exploitation of juvenile penaeid prawns by Suseelan (1975). However detailed studies are lacking on the hydrobiology of Manakkudy estuary and hence the present study.

Description of the Study Area

Manakkudy estuary has its own uniqueness and specialities. It is the first estuary located on the south west coast of peninsular India (Lat. 8° 05'; Long. 77° 32') from the southern end and is located about 8 km. north of Kanyakumari, the lands end of India where the three great oceans Bay of Bengal, Indian Ocean and Arabian sea meet. (Fig. 1). It receives Pazhayar river which originates from Mahendragiri peak of the Western ghats. It passes through Kanyakumari district in the south east direction and confluences with the Arabian sea through Manakkudy estuary. The river has 11 check dams for irrigational purposes, and the lower most check dam is the Mission dam located near Thamaraikulam about 3.5km. away from the bar mouth. The Pazhayar river has many tributaries and the major tributaries are Thodariyar, Ulakkairiver, Alanthuraiyar, Koyuodai and Poigaiyar.

Manakkudy estuary is a tropical bar-built estuary which remains land-locked on most of the occasions (Fig. 7). It opens during monsoon seasons (June to August and October to December) (Fig. 8). However, it does not remain open throughout the monsoon season. It opens when there is flood in the Pazhayar river and closes when there is no flood. Although the monsoon season exists for a period of six months, the estuary remains open only for a period of 85 to 103 days.

The estuary also establishes connection with the sea when it is cut open by the local people. This happens when the water level of the estuary increases by the inflow of freshwater from the paddy fields and saline water pumped into the estuary from the adjoining salt-pan reservoirs. The sand bar is cut open mainly to prevent the inflow of water into the salt-pans.

When the bar mouth remains closed, the sand bar extending between East Manakkudy and West Manakkudy functions as a way for transportation. When the bar mouth opens the land way is cut off and boats are operated by the local fisherman to transport the passengers and luggages between East Manakkudy and West Manakkudy through the estuary.

The sand bar has a length of 125 metres and the width between the sea and the estuary depends on the water level of the estuary. When the estuary is full, the sand bar has a width of 12 to 15m. and when the water level in the estuary is low, the width increases to about 20 to 30 m. When the sand bar opens, the bar mouth is normally narrow and it has a width of about 10 to 15 m. When there is flood, which occcurs owing to heavy rain, the bar mouth widens to about 25 to 60 m.

On most of the occasions, the bar mouth opens near to the western side of the sand bar. Some times it opens at the middle and very rarely it opens across the eastern side of the sand bar.

The estuary lies perpendicular to the sea. On the eastern side and western sides of the bar mouth are situated two villages, East Manakkudy and West Manakkudy respectively. Both the villages are inhabited by fishermen communities.

The estuary is more or less straight. Near the mouth, the estuary appears to have a bend which is caused by the projection of a coconut grove into the estuary on the western side and by the extension of the estuary on the eastern side. It has an area of 150 ha. It has a length of 2km. and a width of about 500 m. The width is uniform throughout the length but slightly widened in the bend region near the mouth.

On either side of the bend region of the estuary, there are retting pits, each pit has a breadth of 2m. to 4m. and a length of 6m. to 10m. (Fig. 4 and 5). Each pit can accommodate about 5000 coconut husks. There are about 350 retting pits on the western side and about 850 pits on the eastern side.

Beyond retting pits, towards the northern side, the estuary is flanked on either side by the salt pans (Fig. 6). The eastern and western banks of the estuary are constructed with concrete walls to prevent the flow of estuarine water into the salt pans.

The estuary receives two creeks one near the bend region of the estuary and the other called Alankal in the upper reaches of the estuary. They bring in freshwater from the adjoining paddy fields. Another canal opens into the estuary near the first creek and brings in saline water from the salt pan reservoirs.

For the present study three stations of diverse ecological characteristics are selected.

Station I

Station I is situated in the bend region of the estuary and is nearer to the bar mouth (Fig. 1). The width is about 900 m. and the maximum depth recorded is 4.85 m. This station is flanked by retting pits and is under the influence of ret liquor. This station helps to understand the influence of sea water and the influence of retting on the water quality, nutrients and biota.

Station II

Station II is situated about one km. away from the bar mouth (Fig. 2). The width of this station is 500 m. and the depth is 2.8 m. It is a gradient zone and is flanked by salt pans.

Station III

Station III is located about 2.5 km. away from the bar mouth. It is on the upper reaches of the estuary influenced by freshwater. This zone has a width of 35 m. and the maximum depth is 2 m. This station is bordered by coconut groves on either side (Fig. 3).

Fig. 1: Manakkudy estuary showing stationI, the marine zone.

Fig. 2: Manakkudy estuary showing stationII, the estuarine zone.

Fig.3: Manakkudy estuary showing station III, the riverine zone.

Fig.4: Retting pits situated along the western side of station I.

Fig. 5: Retting pits situated along the eastern side of station I.

Fig. 6: Salt pans adjoining Manakkudy estuary.

Fig. 7: Sand bar lying between Manakkudy estuary and Arabian sea.

Fig. 8: Manakkudy estuary connected with the Arabian sea by the opening of sand bar.

1. PHYSICO-CHEMICAL PARAMETERS

1. Physico - Chemical Parameters

1.1. Introduction

Estuaries are fascinating ecosystems revealing the complexity of the operating forces of both marine and freshwaters, induced mainly by the tidal incursion, current patterns and the magnitude of freshwater discharge at different periods and seasons. Being a transient zone, it reflects the balance of forces between marine and freshwater habitats. In such ecosystems, the physico - chemical characters are constantly fluctuating. As the productivity and faunal distribution are dependent on the water quality, a thorough knowledge of the hydrological conditions is vital, when assessing the fertility, productivity and faunal distribution.

1.2. Review of Literature

The hydrography of estuaries has been studied extensively at the global level. The basic concept of estuarine circulation was introduced by Ketchum (1951). Day (1951) reported that a combination of different fluctuating parameters are responsible for the nature and distribution of the flora and fauna in an estuary. Rochford (1951) conducted studies in Australian estuarine hydrology. Pritchard (1955) proposed a scheme for the classification of estuaries based on the distribution of salinity. Seed (1978) studied the seasonal variations of some physico- chemical conditions of Shatt al Arab estuary. Lind (1980) made a report on the chemical and physical characteristics of water in estuaries of Texas. Ferrier and Anderson

(1997) made a multi-disciplinary study of frontal systems in Tay estuary, Scotland. Grabemann *et al.* (1997) investigated the behaviour of turbidity maxima in the Tamar (U.K.) and Weser (F.R.G.) estuaries. Valdes and Real (1998) analysed variations and relationships of salinity, nutrients and suspended solids in Chelem coastal lagoon at Yucatan, Mexico. Howland *et al.* (1999) studied the hydrography of Chupa estuary, White Sea, Russia. Mohammed and Saif (1999) studied the environmental characteristics of the United Arab Emirates waters along the Arabian Gulf.

Hydrobiological studies in the Indian estuaries have been conducted from the beginning of the present century. Annandale (1907) was the pioneer in the field of estuarine studies in India and he observed the fauna of brackishwater ponds of Port Canning, lower Bengal. Sewell (1913) initiated the hydrographical studies of Indian estuaries.

Hydrobiological studies along the west coast of India are extensive when compared to those of the east coast. Rao and George (1959) studied the Korapuzha estuary, Malabar. Ramamirtham and Jayaraman (1963) studied some aspects of the hydrographical conditions of the backwaters around Willington Island, Cochin. Dehadrai (1970, 1972) and Dehadrai and Bhargava (1972) studied the environmental features of Mandovi and Zuari estuaries, Goa. Wellershaus (1973) observed the hydrography of the Cochin backwaters. Singbal (1973) studied the diurnal variations of some physico-chemical factors in the Zuari estuary. Dwivedi *et al.* (1974) studied the ecology and environmental monitoring of Mandovi, Zuari and Cambarzua canal complex. Cherian *et al.* (1975) observed the physical characteristics of the Zuari estuary. Josanto (1975) studied the bottom salinity characteristics of Cochin backwaters. The inter-relationship between environmental parameters and foraminiferan species in Mandovi and Zuari estuaries was studied by Dalal (1976). Suseelan (1975) studied the environmental characters, resources and exploitation of juvenile penaeid prawns of Manakkudy estuary. De Souza (1977) studied the monitoring of some environmental parameters at the mouth of Zuari River, Goa. Abdul Azis (1978) studied the ecology of retting grounds in the backwater systems of Kerala. Hydrographical characteristics of the estuarine and inshore waters of Goa have been studied by Sankaranarayanan *et al.* (1978). Reddy *et al.* (1979) studied the seasonal variations in hydrographic conditions of estuarine and oceanic water adjoining the old Mangalore port. Qasim and Sengupta (1981) studied the environmental characteristics of Mandovi - Zuari estuarine system in Goa. Nagarajaiah and Gupta (1983) observed the physico - chemical characteristics of brackishwater ponds along Nethravati estuary. Nair *et al.* (1983 a, 1983 b and 1984) studied the physico-chemical features in Ashtamudi estuary and Akathumuri - Anchuthengu - Kadinamkulam backwater systems. Gopinathan (1985) studied the ecology of certain inland water bodies in Kerala. Shibu (1991) studied the ecology of Paravur lake. Bijoy Nandan(1991) studied the water quality and biota of Kadinamkulam Kayal. George Abe *et al.* (1996) studied salinity intrusion into Muvattupuzha estuary, south west coast of India. Rao *et al.* (1998) observed circulation and salinity in Hooghly estuary. Ravichandran and Abraham Pylee (1998) investigated mixing and flushing time scales in the Azhikode estuary, south west coast of India. Anilkumar *et al.* (1999) carried out studies on mixing of the waters of different salinity gradients and the suspended sediment distribution in the Beypore estuary, south west coast of India.

With respect to the east coast of India Annandale and Kemp (1915) studied the ecology of Chilka lake. Ganapati and Rao (1959) made some preliminary observations on the hydrography and inshore plankton in the Bay of Bengal of Visahapatnam coast. Banerjee and Roychoudhury (1966), Jhingran and Natarajan (1966 and 1969) and Mohanty (1975) observed the hydrography of Chilka lake. Sreenivasan *et al.* (1969) observed physico-chemical features of Adyar estuary. The hydrology of Pulicate lake had been analysed by Chacko *et al.* (1953), Michael (1970), Sreenivasan and Pillai (1972), Raman *et al.* (1975) and Kaliyamurthy (1976). Ramasarma (1970) studied the physico-chemical features of Gourami- Godavari estuarine system. Ramanathan and Varadarajalu (1975) analysed the hydrology and hydrography of the Kistna estuary. Physico-chemical parameters of Vellar estuary have been well documented by Dyer and Ramamoorthi (1969), Vijayalakshmi and Venugopalan (1973), Santhanam and Krishnamurthy (1975), Sundararaj (1978), Thangaraj *et al.* (1979), Sivakumar (1982), Rajendran (1984), Thangaraj (1984) and Chandran and Ramamoorthi (1984 a). Prabha Devi (1986) and Jegadeesan (1986) had analysed the physico- chemical parameters of Coleroon estuary. Balusamy (1988) made a detailed hydrobiological study of the Muthupet estuary. Murugan and Ayyakkannu (1991) studied the ecology of Uppanar backwater, Cuddalore. Govindasamy and Kannan (1991) studied the hydrobiological aspects of Pitchavaram mangroves. Das *et.al.* (1997) studied the semi-diurnal variation of some physico-chemical parameters in the Mahanadi estuary, east coast of India. Long term observations on hydrobiological factors of Manakkudy estuary have not yet been made. So the present study was carried out to assess environmental parameters in relation to biotic factors.

1.3. Materials and Methods

The samples for the present investigation were collected monthly for a period of two years from February 1990 to January 1992. All collections were made in the morning hours between 7.00 a.m. and 10.00 a.m. Rainfall data was obtained from the Public Works Department (PWD), Nagercoil.

The depth of the estuary was measured with a lead weight attached to a nylon rope. Light penetration was measured with the help of a Secchi disc. The depth of disappearance and appearance was recorded from the markings of the rope. The extinction co-efficient was not calculated because the light penetration depth was less than one metre throughout the periods of study.

Surface water samples were collected using a clean plastic bucket where as the bottom samples were collected by means of Mayer's water sampler. Temperature was measured by a celsius thermometer.

Salinity was determined by silver nitrate titration method using potassium chromate as indicator following the description given by Strickland and Parsons (1972).

The water samples collected for the estimation of dissolved oxygen were fixed in the field and analysed in the laboratory by modified Winkler's method as described by Strickland and Parsons (1972).

The pH of the water samples was measured with the help of a Elico model L1-10T pH meter.

Hydrogen sulphide was analysed by titrimetric method using sodium thio-sulphate and starch as indicator as suggested by American Public Health Association (1980). Water samples were preserved using zinc acetate and the sulphide was fixed as zinc sulphide. From the precipitated sample, hydrogen sulphide was generated using concentrated hydrochloric acid in an inert atmosphere of carbon-dioxide. The evolved hydrogen sulphide was dissolved in distilled water and titrated against sodium thio-sulphate solution using starch as indicator after adding a known volume of standard iodine solution. The value of hydrogen sulphide was expressed in mg/ℓ.

1.4. Results

1.4.1. Rainfall

The rainfall recorded during 1990-'91 and 1991-'92 is given in Table 1.1 and is graphically presented in Fig.1.1. There was no rain at all in February 1990, in September 1991 and in January 1992. The monthly rainfall varied from 7 mm (March) to 392 mm (November) during 1990-'91 and from 1mm (December) to 627mm (June) during 1991-'92. The total annual rainfall was higher (1329mm) during 1991-'92 and lower (1114mm) during 1990-'91.

The Manakkudy estuary is situated almost at the tip along the south west coast of India. It is also situated close to the east coast and hence it is influenced by both the south west and north-east monsoons. The pattern of rainfall prevailing in this area facilitated the division of the year into three main seasons, namely premonsoon (February to May), monsoon (June to September) and postmonsoon (October to January).

In 1990-'91 the seasonal total rainfall was maximum in postmonsoon (719.7mm) and minimum in monsoon (153.6mm) whereas in 1991-'92 it was maximum in monsoon (845.9mm) and minimum in premonsoon (107.8mm).

Table 1.1 Rainfall (mm) data collected from Public Works Department(PWD), Nagercoil for the periods of 1990-'91 and 1991-'92

Months	Rainfall (1990-'91)	Rainfall (1991-'92)	Seasons	Seasonal total (1990-'91)	Seasonal total (1991-'92)
February	–	15			
March	7.0	34	Premon-soon	241.6	107.8
April	36.0	27.8			
May	198.6	31.0			
June	68.4	627.02			
July	54.0	189.1	Monsoon	153.6	845.92
August	16.1	29.8			
September	15.1	–			
October	237.5	257.8			
November	392.0	117.2	Postmon-soon	719.7	376
December	7.2	1.0			
January	83.0	–			
Total	**1114.9**	**1329.72**		**1114.9**	**1329.72**

1.4.2. Opening and closing of bar mouth

The opening and closing of bar mouth along with rainfall during 1990-'91 and 1991-'92 are presented in Fig.1.1. The estuary

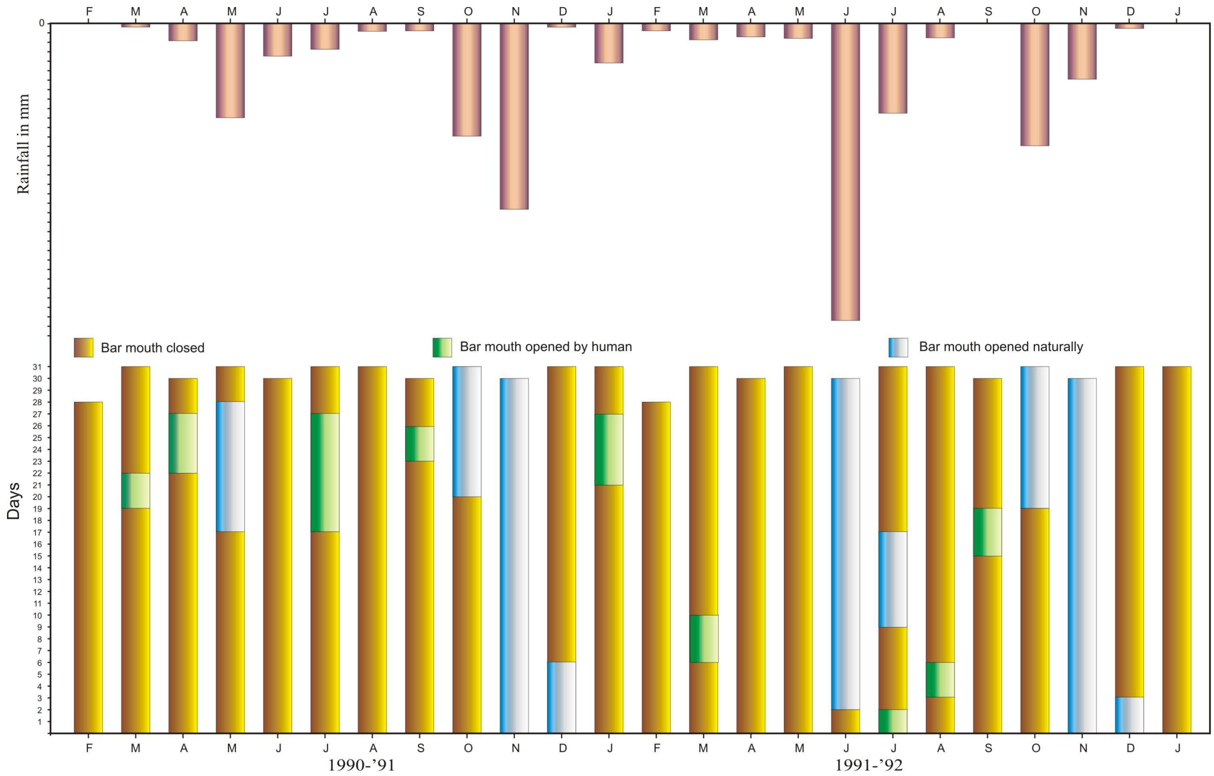

Fig. 1.2. Nature of the sand bar at Manakkudy estuary and rainfall during 1990-'91 and 1991-'92.

remained open for 85 days during 1990-'91 and for 103 days during 1991-'92. On other days the estuary remained land-locked. The estuary established connections with the sea due to cut opening of sand bar on five occasions during 1990-'91 and on four occasions during 1991-'92. In the postmonsoon seasons the estuary remained connected to the sea for more number of days during both the years.

1.4.3. Depth

The depth of the estuary at station I, II and III during 1990-'91 and 1991-'92 is given in Fig. 1.2. At station I the depth was minimum (2.1m) in May and maximum (4.9m) in September during 1990-'91 and it was minimum (1.2m) in May and maximum (4.8m) in June during 1991-'92. At station II the depth was low (0.8m) in May and high (1.7m) in September during 1990-'91 and it was low (0.5m) in May and high (1.7m) in September during 1991-'92. At station III the depth fluctuated between 1.0m (May) and 2.3m (September) during 1990-'91 and between 0.8m (May) and 2.2m (September) during 1991-'92.

Throughout the study period station I recorded the maximum depth and station II recorded the minimum depth. In both years the minimum depth was observed during the premonsoon season and maximum depth was recorded during monsoon season throughout the study period.

1.4.4. Light Penetration

Light penetration obtained from Secchi disc readings for the years 1990-'91 and 1991-'92 is given in Fig. 1.2. At station I the light penetration ranged between 0.2m (November) and 0.8m (April) during 1990-'91 and between 0.1m (July) and 0.9m (December) during 1991-'92.

At station II the light penetration varied from 0.2m (November) to 0.9m (March) during 1990-'91 and from 0.1m (July) to 0.8m (December) during 1991-'92.

At station III the light penetration was minimum (0.2m) in October and maximum (0.8m) in April during 1990-'91 and was minimum (0.1m) in July and maximum (1.0m) in December during 1991-'92.

The variation of light penetration between the three stations was not much. The seasonal average light penetration was low in the postmonsoon seasons and high in the premonsoon season in both the years. This was due to heavy influx of turbid water from the river caused by heavy rains.

1.4.5. Temperature

The variations in the atmospheric, surface and bottom water temperature recorded for the three different stations are presented in Fig. 1.3. During 1990-'91 the atmospheric temperature was low

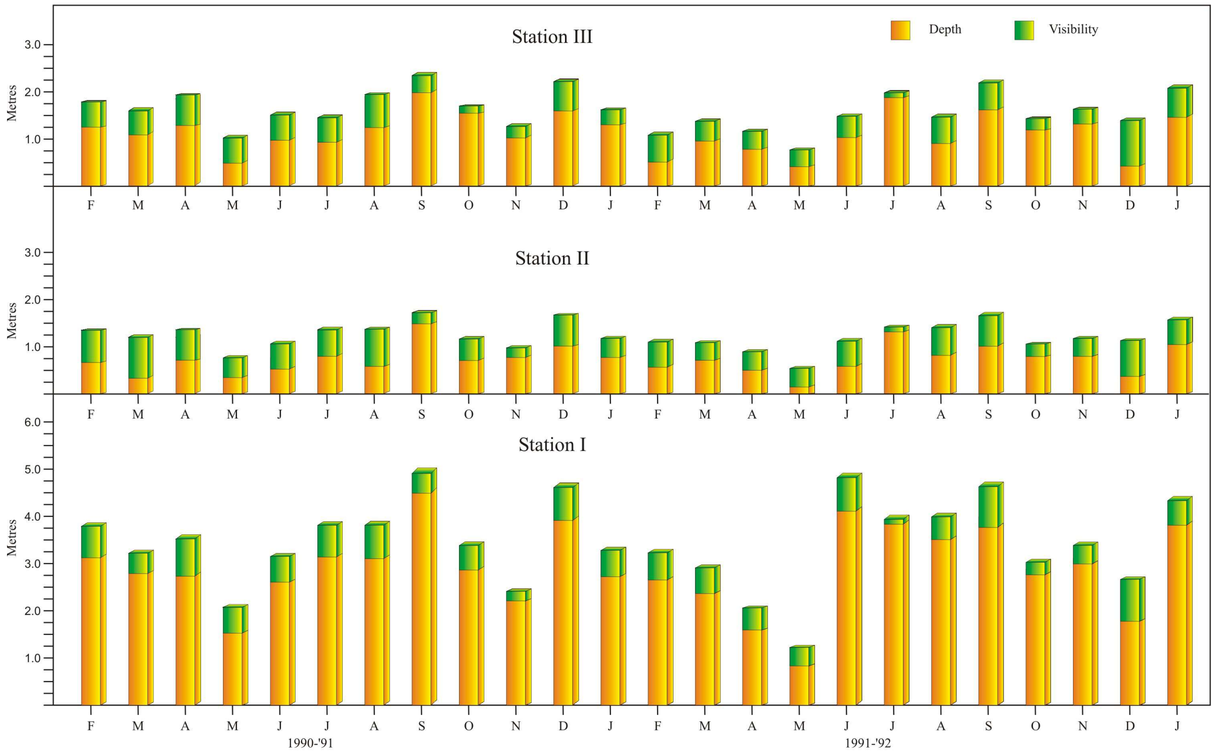

Fig. 1.3: Depth and visibility at station I, II and III in Manakkudy estuary during 1990-'91 and 1991-'92.

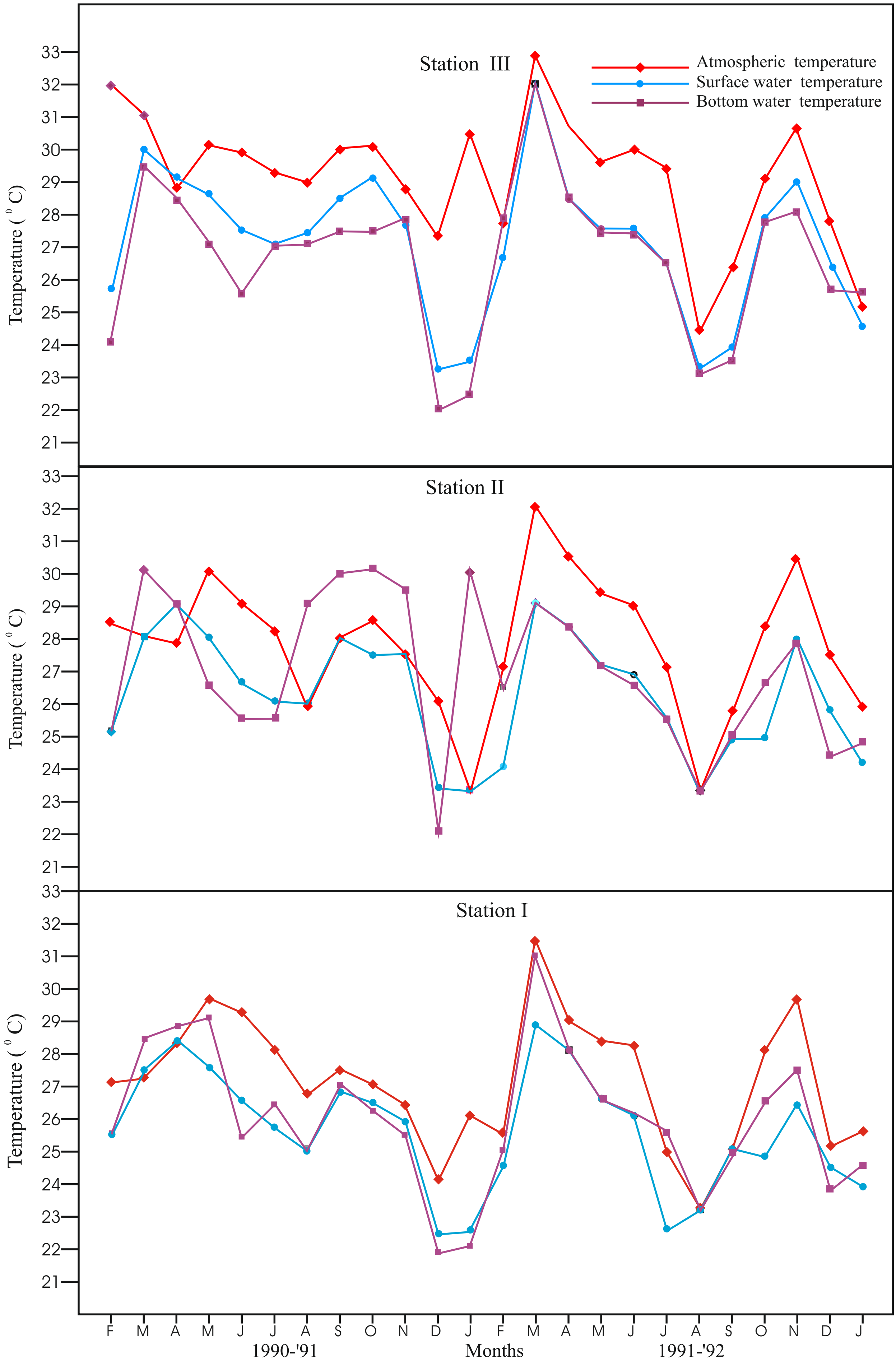

Fig. 1.3: The variations in temperature of atmosphere, surface and bottom water at station I, II and III during 1990-'91 and 1991-'92.

(24.1˚C) in December, (23.3ºC) in January and (27.3˚C) in December at station I, II and III respectively. It was high (29.2˚C and 30.2˚C) at station I and II respectively in May and at station III it was high (32.1˚C) in March. During 1991-'92 the atmospheric temperature was low (23.1˚C, 23.2˚C and 24.3˚C) in August at station I, II and III respectively. It was high (31.5˚C, 32.1˚C and 32.9˚C) in March at station I, II and III respectively.

The atmospheric temperature remained higher than that of the estuarine water temperature throughout the study period except in the premonsoon season. At station III during 1991-'92 the temperature of the estuarine water was either higher than or similar to that of atmospheric temperature. Throughout the study period the temperature recorded at station I was low, at station II it was higher and at station III it was the highest. Maximum atmospheric temperature was recorded in the premonsoon season in both the years at all the stations throughout the study period. Throughout the period of study, minimum temperature was recorded in the postmonsoon season during both the years.

The surface water temperature ranged between 22.3˚C (December) and 28.5˚C (April) at station I, between 23.2˚C (January) and 29.2˚C (April) at station II and between 23.2˚ C (December) and 30.0˚C (March) at station III during 1990-'91. During 1991-'92 it

ranged between 23.1˚C (August) and 28.9°C (March) at station I, between 23.2˚C (August) and 29.1˚C (March) at station II and between 23.2˚C (August) and 32.1˚C (March) at station III.

The surface water temperature showed minimum values in monsoon season and maximum values in the premonsoon season during both the years.

The bottom water temperature varied from 21.8°C (December) to 29.1°C (May) at station I, from 22.2°C (December) to 30.3°C (January) at station II and from 22.0°C (December) to 29.5°C (March) at station III during 1990-'91. During 1991-'92, it varied from 23.1°C (August) to 31.1°C (March) at station I, from 23.2°C (August) to 29.1°C (March) at station II and from 23.1°C (August) to 32.1°C (March) at station III.

The bottom water temperature was minimum in the postmonsoon season and maximum in the premonsoon season during both the years at all the stations.

The bottom water temperature was always lower than that of surface water temperature except in the premonsoon season, where at times, the bottom water temperature was slightly higher than that of surface water. However, the range of variation between surface water temperature and bottom water temperature was small when compared to that of atmospheric temperature and surface water temperature.

Atmospheric and surface water temperature at station I had negative correlation, during 1990-’91.

1.4.6. Salinity

The seasonal variation of salinity during 1990-'91 and 1991-'92 at stations I, II and III are presented in Fig. 1.4. The minimum surface water salinity recorded was 0.2%o. It was recorded at all the three stations in November during both the years and in June during 1991-'92. The maximum surface water salinity recorded in station I ranged between 23.5%o (April) during 1990-'91 and 24.1%o (May) during 1991-'92 and in station II it fluctuated between 16.5%o (April) during 1990-’91 and 19.3%o (May) during 1991-’92 and in station III it varied between 13.2%o in April during 1990-'91 and 15.0%o in May during 1991-'92. Thus the surface water salinity ranged between 0.2%o and 24.1%o throughout the period of study.

The minimum salinity of bottom water remained 0.2%o in all the three stations throughout the period of study in both the years. The maximum salinity of bottom water at station I ranged between 27.1%o (April) during 1990-'91 and 28.5%o (May) during 1991-'92; at station II it varied from 20.9%o (March) during 1990-'91 to 21.3%o (May) during 1991-'92 and in station III it fluctuated between 18.5%o (April) during 1990-'91 and 20.5%o (May) during 1991-'92. Thus the bottom salinity ranged between 0.2%o to 28.5%o.

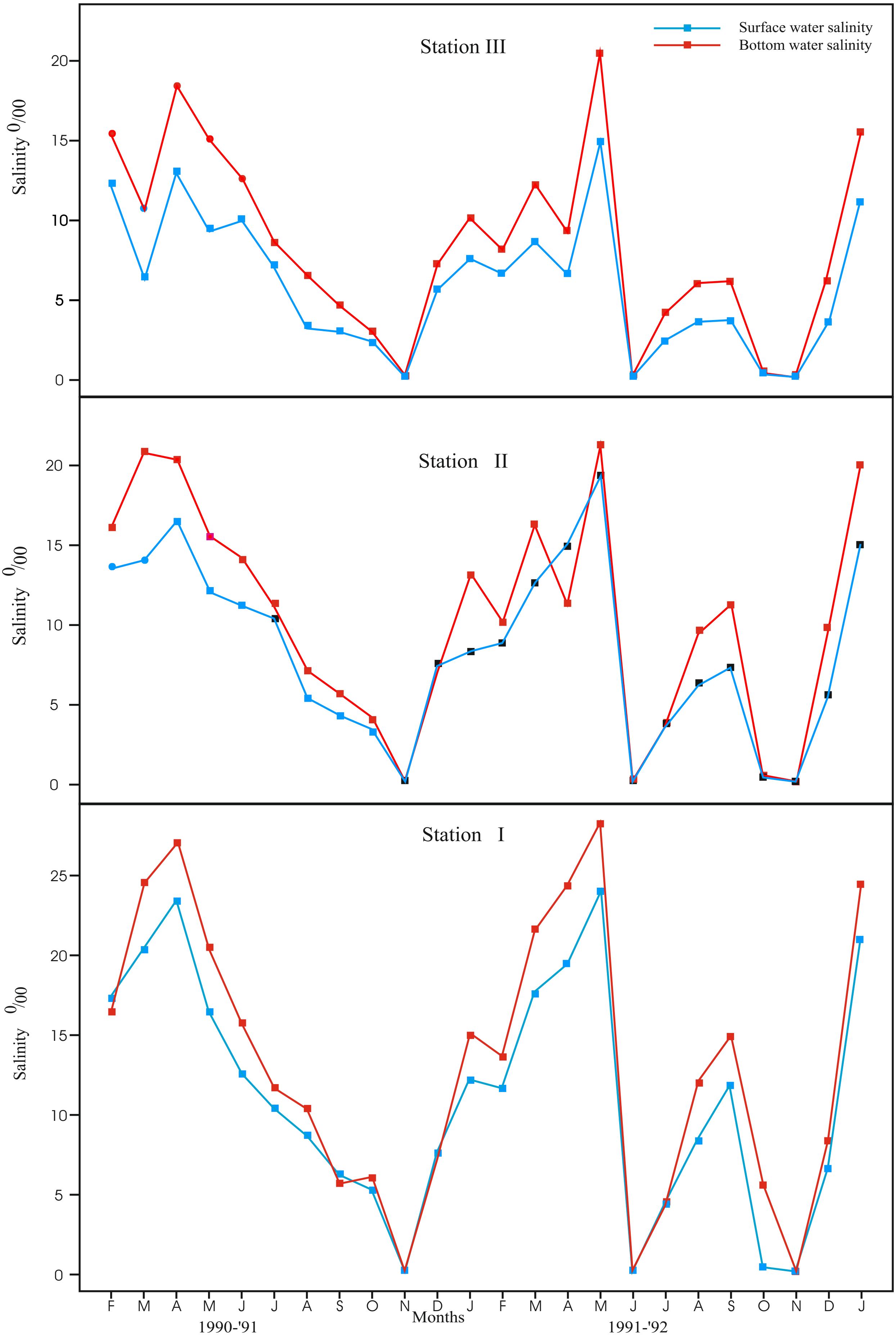

Fig. 1.4: The variations in salinity of surface and bottom water at station I, II and III during 1990-'91 and 1991-'92.

The monsoon and postmonsoon seasons registered minimum salinity (0.2‰) and maximum salinity (28.5‰) was observed during premonsoon season. The salinity distribution observed was typical to an estuary. It was high at station I (near the mouth of the estuary) and gradually decreased towards station III (upstream) except in November during both years and in June during 1991-'92 when the salinity remained the same from the mouth to the head of the estuary.

The vertical distribution of salinity was also similar to that of other estuaries. It was low on the surface and high in the bottom except in November during both the years and June during 1991-'92 when the salinity of surface water and bottom water remained the same.

1.4.7. Dissolved Oxygen

The data obtained for dissolved oxygen at stations I, II and III during the years 1990-'91 and 1991-'92 are given in Fig. 1.5. The dissolved oxygen concentration of surface water recorded at station I was low (2.71 ml/ℓ) in March and high (6.66 ml/ℓ) in November during 1990-'91 and low (2.57 ml/ℓ) in May and high (6.58 ml/ℓ) in July during 1991-'92. At station II it was minimum (2.14 ml/ℓ) in March and maximum (6.96 ml/ℓ) in November during 1990-'91 and minimum (4.12 ml/ℓ) in May and maximum (6.93 ml/ℓ) in July during 1991-'92. At station III it varied from 2.85 ml/ℓ(March) to 7.11ml/ℓ(November) during 1990-'91 and from 4.12 ml/ℓ(May) to 7.06 ml/ℓ(July) during 1991-'92.

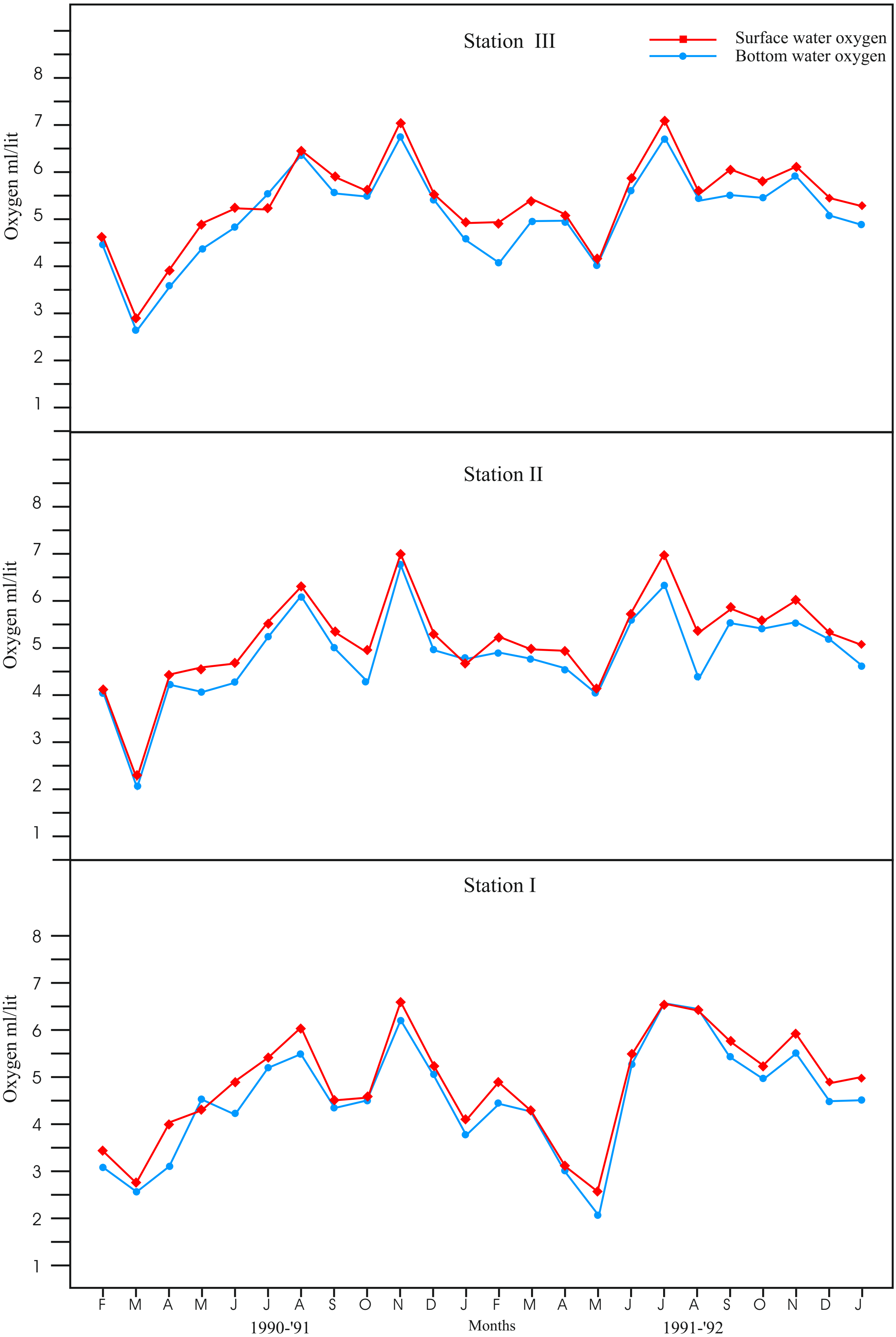

Fig. 1.5: The variations in dissolved oxygen of surface and bottom water at station I, II and III during 1990-'91 and 1991-'92.

The dissolved oxygen concentration of bottom water at station I varied from 2.65ml/ℓ (March) to 6.25ml/ℓ (November), at station II it varied from 2.04 ml/ℓ (March) to 6.73 ml/ℓ (November) and at station III from 2.65 ml/ℓ (March) to 6.72 ml/ℓ (November) during 1990-'91. During 1991-'92 at station I it ranged from 2.13ml/ℓ (May) to 6.56 ml/ℓ (July), at station II from 4.04 ml/ℓ (May) to 6.03ml/ℓ (July) and at station III from 4.03 ml/ℓ (May) to 6.71 ml/ℓ (July).

The average concentration of dissolved oxygen in the surface water was high in the monsoon season during both the years. Minimum values were recorded in the premonsoon season during both the years. The average value was maximum (5.57ml/ℓ) in station III and minimum (4.66ml/ℓ) in station I.

The concentration of dissolved oxygen in bottom water was low in premonsoon season throughout the study period. The concentration was high at all stations in the postmonsoon season during 1990-'91. But during 1991-'92 it was high in the monsoon season.

The range of variation between surface and bottom water was not very high. In general, the surface water showed slightly higher values and at times, the surface and bottom water recorded similar values. Oxygen had shown positive correlation with rainfall during 1991-’92 at all stations and only in station I during 1990-’91.

1.4.8. Hydrogen ion concentration (pH)

The results obtained for hydrogen ion concentration (pH) for a period of two years at station I, II and III are given in Fig. 1.6.

The pH of the water in all the three stations remained on the alkaline side throughout the study period except for station I where acidic pH was recorded in March during 1990-’91 and in April during 1991-’92. At station I the pH value was low (6.81) in March and high (8.24) in April during 1990-'91 and was low (6.81) in April and high (8.31) in March during 1991-'92. At station II the pH measurement ranged between 7.02 (November) and 7.98 (April) during 1990-'91 and between 7.02 (June and November) and 8.13 (April) during 1991-'92. At station III the pH values fluctuated from 7.02 (November) to 7.73 (February) during 1990-'91 and from 7.02 (November) to 8.01 (May) during 1991-'92. However, the pH of bottom water did not vary much from the surface water and hence that data was not referred here.

Maximum values of pH were observed in premonsoon season during both the years. Minimum value of pH was observed in monsoon season throughout the period of study.The pH had no association with rainfall.

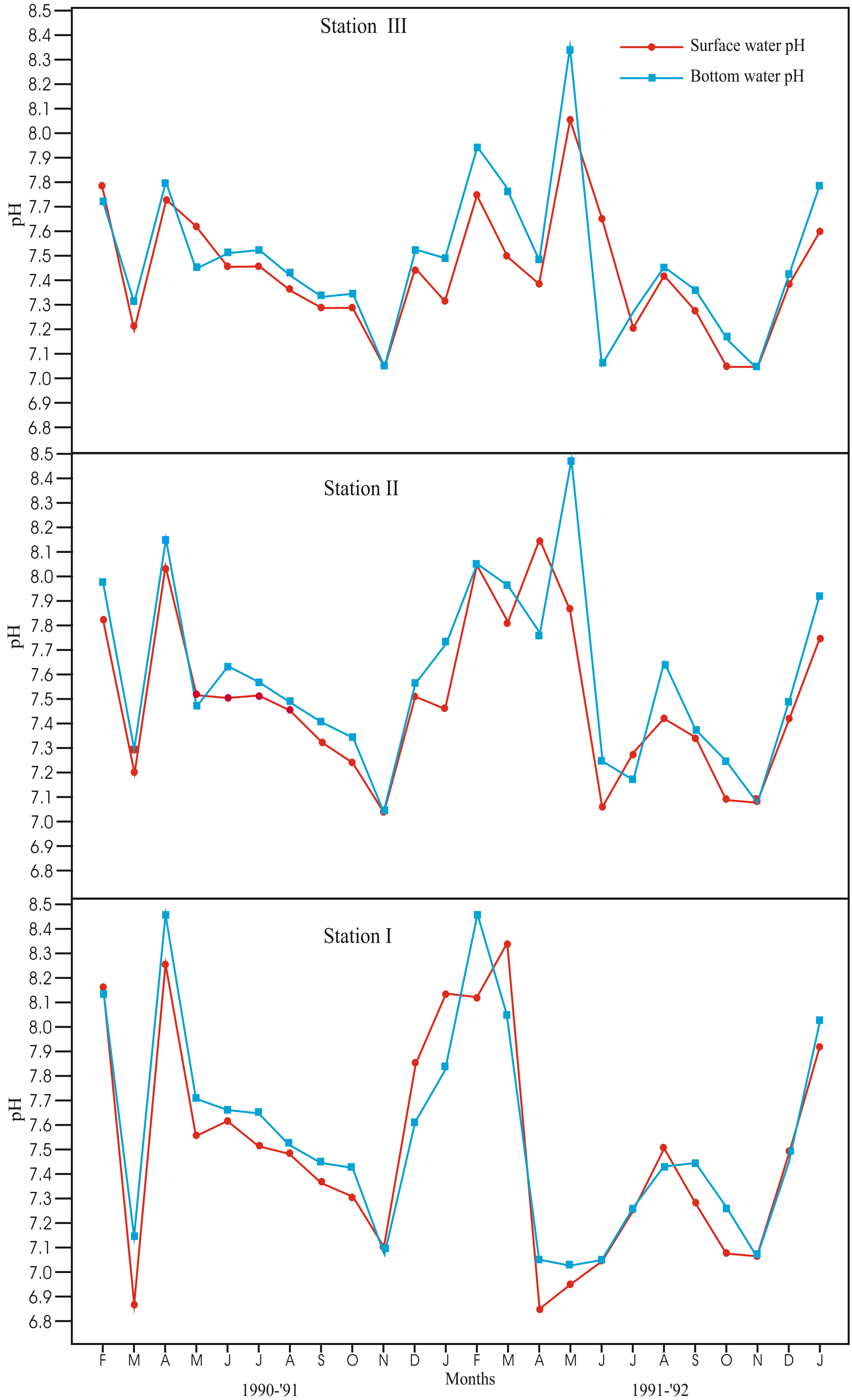

Fig. 1.6: The variations in hydrogen ion concentrations (pH) at station I, II and III during 1990-'91 and 1991-'92.

1.4.9. Hydrogen Sulphide

The monthly data obtained for hydrogen sulphide for station I during 1990-'91 and 1991-'92 are graphically presented in Fig.1.7.

Of the three stations examined, hydrogen sulphide was totally absent in station II and III throughout the study period in both the years. Even in station I it was completely absent in the months of June, July and November during 1990-'91 and in 1991-'92 it was absent in June, July, August, November and December. The concentration of hydrogen sulphide in the surface water ranged from 0.49 mg/ℓ (April) to 4.51 mg/ℓ(March) during 1990-'91 and from 0.41 mg/ℓ(October) to 4.88 mg/ℓ (May) during 1991-'92. Similarly the concentration of hydrogen sulphide in the bottom water at station I varied from 0.14 mg/ℓ(May) to 2.12 mg/ℓ(March) during 1990-'91 and between 0.25 mg/ℓ(September) to 3.82 mg/ℓ (May) during 1991-'92.

The concentration of hydrogen sulphide in the bottom water was always found to be lower than that of the surface water. The concentration steadily increases in the premonsoon season when there was stagnation of water. It decreased during monsoon season and disappeared completely in certain monsoon and postmonsoon months.

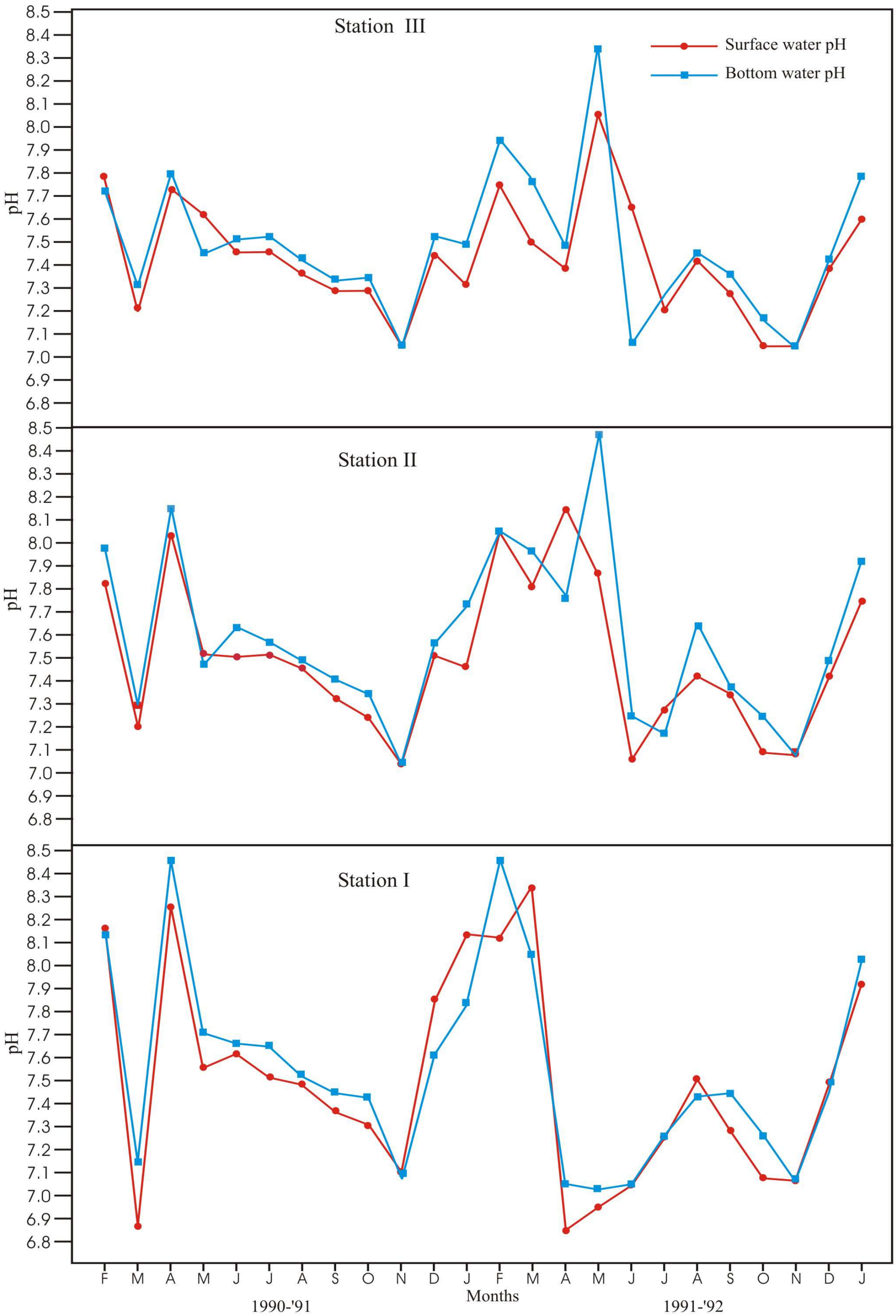

Fig. 1.7: The variations in hydrogen ion concentrations (pH) at station I, II and III during 1990-'91 and 1991-'92.

1.5. Statistical Treatment

The mean and standard error of physico-chemical parameters are given in Table 1.2. The significance of physico-chemical parameters in relation to station I, II and III, rainfall and seasons is given in Table 1.3. Simple correlation of physico-chemical parameters with rainfall at station I, II and III during 1990-'91 and 1991-'92 is given in Table 1.4.

1.5.1. Depth

In both the years the average depth of station I was significantly higher than that of station II and station III. Station II and station III were on par in both the years. At station I the maximum depth was 4.9m in 1990-'91 and 4.8m in 1991-'92 whereas the minimum depth was 2.1m in 1990-'91 and 1.2m in 1991-'92.

1.5.2. Light Penetration

The average light penetration levels did not show any significant difference between the stations in both the years. The maximum value recorded was 0.9m in station III in 1991-'92 and the minimum was 0.1m in station I and II during 1990-'91.

1.5.3. Temperature

In 1990-'91 the atmospheric temperature in station III had registered an average value of 29.8^{0}C which was significantly higher than that in station I and II which were on par with each other. In

1991-'92 the average temperature in the atmosphere did not show any variation in all the three stations. The maximum atmospheric temperature of 32.9^{0}C was recorded in station III in 1991-'92 and the minimum of 23.10^{0}C in station I in 1991-'92.

In the case of surface water temperature there was significant variation among the three stations in both the years. The maximum temperature was observed in station III (32.1^{0}C) in 1991-'92 and the minimum in station I (22.3^{0}C) in 1990-'91.

Regarding the bottom water temperature in both the years station II recorded an average temperature, which was higher than that in station I and III which were on par. The maximum recorded bottom temperature was 32.11^{0}C in station III during 1991-'92 and the minimum was 21.80^{0}C in station I in 1990-'91.

1.5.4. Salinity

The average surface water salinity level had no significant difference in any of the three stations during 1991-'92. In 1990-'91 the average salinity level was highest for station I which was on par with station II. However, it was significantly higher than that in station III. The maximum average surface salinity level in station I was 11.875‰. The maximum was 24.10‰ in station I in 1991-'92 and the minimum was 0.20‰ in all the stations.

As far as the bottom salinity levels were concerned, in both the years the salinity levels were on par in all the three stations. The maximum was 28.50‰ in station I in 1991-'92 and the minimum was 0.20‰ in all the stations.

1.5.5. Oxygen

The average level of oxygen at the surface and bottom did not change from station to station in both the years. The maximum level at the surface was 7.11ml/ℓ in station III during 1990-'91 and the minimum was 2.14ml/ℓ in station II during 1990-'91. Similarly, in the bottom the maximum was 6.73ml/ℓ in station II in 1990-'91 and the minimum was 2.04ml/ℓ in station II in 1990-'91.

1.5.6. pH

The results of pH indicated that the average pH level was almost the same in all the stations over the two years both at the bottom and surface. The maximum was 8.31 for the surface water in station I in 1991-'92 and the minimum was 6.81 in station I in 1991-'92. Similarly at the bottom water the maximum was 8.23 in station II in 1991-'92 and the minimum was 6.81 in station I in 1991-'92.

1.5.7. H_2S

H_2S was found at the surface and bottom water in both the years in station I only. The average levels indicated that they were higher in the surface waters in both the years. The maximum value registered was 4.88mg/ℓ during 1991-'92. At the bottom, the maximum was 3.05mg/ℓ in 1991-'92.

Table 1.2 : Mean and standard error of the physico-chemical parameters . The mean values are written in the increasing order with the station numbers along with it in the paranthesis, S1 indicating station 1, S2 indicating station 2 and S3 indicating station 3. Bars above the means are used to indicate statistically on par values. The value in the paranthesis below each mean indicates the standard error.

S.No.	PARAMETERS	1990 – '91			1991 – '92		
1	Depth	1.44450 (S2) (.6672)	1.67592 (S3) (.3709)	3.4950 (S1) (.7970)	1.17033 (S2) (.3054)	1.50242 (S3) (.4247)	3.34867 (S1) (1.0640)
2	Light penetration	.50767 (S3) (.1876)	.54942 (S2) (.2107)	.56425 (S1) (.1616)	.46358 (S3) (.2193)	.46633 (S2) (.1781)	.51733 (S1) (.2271)
3	Atmospheric temperature	27.40 (S1) (1.5302)	27.625 (S2) (1.7838)	29.8333 (S3) (1.3472)	27.075 (S1) (2.4647)	28.05 (S2) (2.4751)	28.6417 (S3) (2.4897)
	Surface water temperature	25.855 (S1) (1.9209)	26.6083 (S2) (1.9477)	27.3083 (S3) (2.1798)	25.6333 (S1) (1.6945)	26.1583 (S2) (1.8578)	26.9833 (S3) (2.4135)
	Bottom water temperature	26.25 (S1) (2.0138)	26.35 (S3) (2.3616)	28.1333 (S2) (2.0544)	25.7583 (S1) (2.4366)	26.9583 (S3) (2.3845)	28.6417 (S2) (2.4897)
4	Surface water salinity	6.8333 (S3) (4.0632)	8.8917 (S2) (4.9096)	11.875 (S1) (6.7484)	5.2083 (S3) (4.6872)	7.0083 (S2) (6.1065)	10.6417 (S1) (8.6340)
	Bottom water salinity	9.4917 (S3) (5.4005)	11.425 (S2) (6.6049)	13.5167 (S1) (7.9589)	7.4333 (S3) (6.3201)	10.0 (S2) (7.6904)	13.3917 (S1) (9.9458)

S.No.	PARAMETERS	1990 – '91			1991 – '92		
5	Surface water oxygen	4.6633 (S1) (1.0964)	4.9217 (S2) (1.2010)	5.2058 (S3) (1.0556)	5.0158 (S1) (1.2047)	5.4167 (S2) (.6883)	5.5650 (S3) (.7226)
	Bottom water oxygen	4.3925 (S1) (1.0699)	4.6692 (S2) (1.1925)	4.9483 (S3) (1.1565)	4.77 (S1) (3.4119)	5.0608 (S2) (1.6524)	5.2175 (S3) (.7393)
6	Surface water pH	7.3792 (S3) (.2087)	7.4308 (S2) (.2610)	7.54 (S1) (.4274)	7.3742 (S1) (.4842)	7.4092 (S3) (.2871)	7.4867 (S2) (.3920)
	Bottom water pH	7.42 (S3) (.1948)	7.5258 (S2) (.2930)	7.6008 (S1) (.3809)	7.4283 (S1) (.4685)	7.455 (S3) (.3866)	7.585 (S2) (.4286)
7	Surface water H_2S	1.7842 (1.5335)	-	-	1.4883 (1.7601)	-	-
	Bottom water H_2S	.7992 (.8398)	-	-	.6525 (1.0048)	-	-

Table 1.3 : Mean values of the physico-chemical parameters in the premonsoon, monsoon and postmonsoon seasons in all the stations during 1990-'91 and 1991-'92.

I	Premonsoon						Monsoon						Postmonsoon					
	1990-'91			1991-'92			1990-'91			1991-'92			1990-'91			1991-'92		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Depth	3.1440	1.163	1.5543	2.3553	.8973	1.0895	3.9225	1.3745	1.7915	4.3445	1.3440	1.7835	3.4210	1.7960	1.6820	3.3463	1.2197	1.6343
Light penetration	.6118	.6730	.6368	.4958	.4343	.4310	.5863	.5280	.5283	.5395	.4673	.4253	.4948	.4473	.3580	.5168	.4975	.5345
Atmospheric temperature	28.1250	28.65	30.75	28.6250	29.80	30.25	28.15	27.825	29.575	28.375	26.300	27.525	25.9250	26.4000	29.1750	27.2250	28.0500	28.1500
Surface temperature	27.25	27.775	28.375	27.0250	27.225	28.675	26.025	26.70	27.70	24.975	25.15	25.275	24.2750	25.3500	25.8500	24.9000	26.1000	27.000
Bottom temperature	27.9750	27.70	27.325	26.60	30.25	28.95	26.00	27.525	26.825	25.05	27.525	25.100	24.7750	29.1750	24.9000	25.6250	28.1500	26.8250
Surface salinity	19.525	14.075	10.425	18.55	14.00	9.35	9.675	7.775	6.025	6.25	4.275	2.55	6.4250	4.8250	4.0500	7.1250	2.7500	3.7250
Bottom salinity	22.30	18.525	14.975	22.45	16.275	12.575	10.975	9.625	8.325	7.950	6.075	4.15	7.2750	6.1250	5.1750	9.7750	7.6500	5.5750
Surface oxygen	3.6100	3.8250	4.0925	3.7250	4.7975	4.89	5.2150	5.51	5.74	6.0675	5.925	6.14	5.1650	5.4300	5.7850	5.2550	5.5275	5.6650
Bottom oxygen	3.3875	3.6150	3.755	3.4525	4.5525	4.50	4.8850	5.2125	5.53	5.9575	5.44	5.8375	4.9050	5.1800	5.5575	4.9000	5.1900	5.3150
Surface water pH	7.67	7.6025	7.5425	7.5325	7.9350	7.6325	7.4575	7.4125	7.3550	7.2400	7.2375	7.35	7.4925	7.2775	7.2400	7.3500	7.2875	7.2450
Bottom water pH	7.8225	7.6900	7.5350	7.6075	8.030	7.8050	7.53	7.4450	7.4075	7.26	7.3275	7.2425	7.4500	7.3925	7.3175	7.4175	7.3975	7.3175
H_2S surface	2.7858	-	-	3.6775	-	-	1.20	-	-	.3025	-	-	1.3675	-	-	.4850	-	-
H_2S bottom	1.23	-	-	1.835	-	-	.5050	-	-	.035	-	-	.6625	-	-	.0875	-	-

Table 1.4 : Simple correlation of rainfall with physico-chemical parameters at station I, II and III during 1990-'91 and 1991-'92.

YEAR	1990-'91			1991-'92		
Station	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Depth	-0.319	-0.381	-0.154	0.364	-0.234	0.513
Light penetration	0.017	-0.308	-0.061	0.153	-0.276	0.346
Atmospheric temperature	-0.583*	-0.355	-0.232	0.128	-0.235	0.039
Surface temperature	-0.577*	0.101	0.067	-0.232	-0.373	-0.465
Bottom temperature	0.138	0.001	0.066	0.049	-0.148	0.027
Surface salinity	-0.505	-0.387	-0.298	-0.402	-0.316	-0.355
Bottom salinity	-0.510	-0.480	-0.379	-0.467	-0.411	-0.325
Surface oxygen	0.601*	0.449	0.480	0.562	0.756**	0.709
Bottom oxygen	0.553	0.417	0.441	0.588*	0.593*	0.753**
pH – surface	-0.215	-0.230	-0.258	-0.200	-0.370	-0.420
pH – bottom	-0.301	-0.309	-0286	-0.290	-0.480	-0.342
H_2S surface	-0.440	-	-	0.536	-	-
H_2S bottom	-0.344	-	-	-0.099	-	-

1.6. Discussion

Among the factors that influence the ecological conditions of estuaries, rainfall has a major role. The rainfall prevailing in this area, makes the whole year divisible into three seasons, namely premonsoon (February to May), monsoon (June to September) and postmonsoon (October to January). The same pattern of classification was adopted along the west coast by Nair (1965) in Cochin harbour, Haridas *et al.* (1973) in the backwaters from Cochin to Alleppey, Abdul Azis and Nair (1983) in the retting zones of the backwaters of Kerala, Bijoy Nandan (1991) in Kadinamkulam lake and Shibu (1991) in Paravur lake. However, along the east coast, the whole year was divisible into four seasons, namely postmonsoon season (January to March), summer season (April to June) premonsoon season (July to September) and monsoon season (October to December). This pattern was adopted by Dyer and Ramamoorthy (1969), Vijayalakshmi and Venugopalan (1973), Santhanam and Krishnamurthy (1975), Thangaraj *et al.* (1979), Sivakumar (1982), Rajendran (1984), Chandran and Ramamoorthi (1984 a) in Vellar estuary, Prabha Devi (1986) and Jegadeesan (1986) in Coleroon estuary and Balusamy (1988) in Muthupet estuary.

The depth of the estuary varied from one station to the other. The depth was maximum at station I and minimum at station II. The maximum depth was restricted to a narrow canal like area running along the length of the estuary. The depth was minimum at all stations during premonsoon season. The maximum depth was recorded in the monsoon seasons. Generally maximum depth was attained by the discharge of fresh water from the channels and river when the bar mouth remained closed. When the estuary attained maximum depth, the sand bar was cut open by the local people there. The maximum depth recorded was 4.9m and 4.8m at stations I during 1990-'91 and 1991-'92 respectively. Haridas *et al.* (1973) recorded a depth of 10m to 12m in the backwater system around Cochin harbour channel. Nair *et al.* (1983 b) recorded a depth of 1.86m to 2.06m in Kadinamkulam backwater system, 1.65m to 2.31m in Anchuthengu backwater system and 1.95m to 3.04m in Akathumuri backwater system. Jegadeesan (1986) recorded a depth of 7m at high tide in the mouth of the Coleroon estuary. Balusamy (1988) recorded a maximum depth of 2m in Muthupet estuary.

Light is an important ecological factor for aquatic organisms. The penetration of light depends mainly on the transparency of water. It is influenced by wind, current, turbidity, and also the absorption loss due to suspended colloidal particles created by autochthonous and allochthonous substances. The light penetration showed maximum values in postmonsoon and premonsoon seasons and minimum values in monsoon season throughout the study. Maximum light penetration during postmonsoon and premonsoon was due to clear water and high intensity of light rays. Minimum light penetration was due to turbid water brought into the estuary by the Pazhayar river and adjoining canals owing to monsoon rains.

This pattern of light penetration was also recorded by Qasim *et al.* (1968) from Cochin backwaters, Bhat and Gupta (1983) from Nethravati-Gurupur estuary, Nair *et al.* (1983 a) from Ashtamudi estuary, Thangaraj (1984) from Vellar estuary, Prabha devi (1986) and Jegadeesan (1986) from Coleroon estuary, Balusamy (1988) from Muthupet estuary, Bijoy Nandan (1991) from Kadinamkulam lake and Shibu (1991) from Paravur lake.

The temperature variations are a function of bathymetry, solar radiation, tidal currents and atmospheric variations (Alvarez Borrego and Borrego, 1982). In the present study, temperature was related with the time of collection, season, rainfall, depth and wind. As Manakkudy estuary is a bar built estuary, the effect of tidal current was less. Throughout the study period, the atmospheric temperature was minimum at station I, maximum at station III and intermediate at station II. This gradual rise of temperature from station I to station III through station II was dependent on the time of observation. Generally the temperature measurements were made between 0700 hrs. and 0800 hrs. at station I, between 0800 hrs. and 0900 hrs. at station II and between 0900 hrs. and 1000 hrs. at station III and this pattern of timing was the reason for the stationwise increase in atmospheric temperature.

The atmospheric temperature and the estuarine water temperature remained minimum in the postmonsoon season during 1990-’91 and in the monsoon season during 1991-’92. It was maximum in the premonsoon months. The minimum temperature in monsoon and postmonsoon seasons was mainly due to rainfall, cloudy sky and cold weather. The maximum temperature during premonsoon was due to high intensity of solar radiation and evaporation.

Day (1951) suggested that in shallow estuaries with wide inter tidal flats, solar radiation and evaporation cause marked temperature changes. High temperature during summer season was observed in Chilka lake by Mohanty (1975). In Pulicat lake, Sreenivasan and Pillai (1972) and Raman *et al.* (1975) observed maximum water temperature during summer and premonsoon months. Santhanam (1976), Ramadhas (1977), Sivakumar (1982), Chandran and Ramamoorthi (1984 a) and Thangaraj (1984) recorded higher values of atmospheric temperature during summer and premonsoon and lower values during monsoon and postmonsoon periods in Vellar estuary. Jegadeesan (1986) observed that water temperature was maximum during summer months and minimum during monsoon months in Coleroon estuary. Balusamy (1988) recorded higher atmospheric and water temperature during summer and premonsoon and lower temperature during monsoon and postmonsoon periods in Muthupet estuary. Minimum temperature in monsoon months was also recorded in Korapuzha estuary by Rao and George (1959), in Cochin backwater by Nair (1965) and Haridas *et al.* (1973), in Veli lake by Krishnan (1974) and Nair *et al.* (1987), in Kadinamkulam backwater by Nair *et al.* (1984), in Ashtamudi estuary by Nair *et al.* (1983 a, 1984), in Poonthura backwater by Kahar (1988), in Paravur lake by Shibu (1991) and in Kadinamkulam kayal by Bijoy Nandan (1991).

The bottom water temperature was slightly lower than that of surface water temperature except in the premonsoon season where, sometimes the bottom water temperature was slightly higher than that of, or equal to, the surface water. Singbal (1973) observed a higher bottom water temperature during February in Zuari estuary. Haridas *et al.*(1973) recorded higher bottom water temperature in the back-waters from Cochin to Alleppey in the premonsoon periods. Nair *et al.* (1984, 1987) and Bijoy Nandan (1991) recorded higher bottom water temperature in Kadinamkulam Kayal. Similarly higher bottom water temperature was observed by Sarala Devi (1987) in Cochin backwater. In Ashtamudi estuary Nair *et al.* (1984) observed higher values in bottom water than that of the surface water and this situation was due to the discharge of cold freshwater and due to the absence of large scale mixing in the locality.

In the present study, the temperature usually decreased with depth. But when the depth was shallow the temperature did not show much difference between the surface and bottom layers. Ellis (1937) has pointed out that silt particles suspended in the shallow areas of the lake quickly absorb the heat and impart it gradually to the waters preventing pronounced thermal stratification.

Salinity plays the key role in the dynamics of an estuarine ecosystem. A slight change in salinity will reflect on other physical, chemical and biological factors (Dehadrai, 1970, Goswami and Singbal 1974). In the present study the annual average salinity was maximum at station I (near mouth) and minimum at station III (near the head of the estuary). The maximum salinity at station I was due to the sea water entry into estuary when the sand bar was open. The minimum salinity at station III was due to the discharge of fresh water through the river. In the present study surface water salinity was lower than that of the bottom water, producing a clear stratification between the surface and bottom layers. This may be due to the penetration of the saline sea water along the bottom of the estuary. Similar type of observations were also made by Rao and George (1959) in Korapuzha estuary, Dehadrai (1970) in Mandovi estuary, Haridas *et al.* (1973) in the backwaters from Cochin to Alleppey, Nair *et al.* (1984) in the Kadinamkulam backwater system, Chandran and Ramamoorthi (1984 a) in Vellar estuary, Jegadeesan (1986) in Coleroon estuary Balusamy (1988) in Muthupet estuary and Bijoy Nandan (1991) in Kadinamkulam Kayal. The low saline nature of the surface water was due to the dilution resulting from the freshwater flow.

Throughout the period of study the salinity was minimum during the monsoon months and maximum during premonsoon months. The low salinity was due to the effect of monsoonal rains and river run off from the upper reaches. The high salinity was due to the high rate of evaporation and the absence of river discharge. The present observation of low salinity in monsoon and high salinity during premonsoon was in conformity with the earlier reports in the estuaries of India (Ramamirtham and Jayaraman, 1963; Sreenivasan and Pillai, 1972; Sarala Devi *et al.,* 1979; Thangaraj *et al.,* 1979; Sivakumar, 1982; Nair *et al.,* 1983 a; Jegadeesan, 1986; Balusamy, 1988 and Shibu, 1991).

Unlike the larger backwaters and estuaries along the west and east coasts of India, a very low average salinity was recorded in Manakkudy estuary. This was because of the occasional opening of the sand bar, the narrow bar mouth, the absence of significant tidal influence, the local precipitation and the inflow of fresh water.

The concentration of dissolved oxygen of surface water was found to be higher than that of the bottom water in the present investigation. This observation is in conformity with the observation made by Devassy and Gopinathan (1970), Haridas *et al.* (1973) from the Cochin backwaters, Dwivedi *et al.* (1974) from the Mandovi-Zuari estuaries and Cambarzua canal, Ramadhas (1977) from the Vellar estuary and Jegadeesan (1986) from the Coleroon estuary. The low values of dissolved oxygen in the estuaries may be due to the shallowness of the estuary, high salinity profile at the bottom, amount of utilization of oxygen by the bottom living organisms and the decomposition of organic matter (Ramasarma 1970, Vijayalakshmi 1973, Santhanam 1976, Sivakumar 1982 and Chandran and Ramamoorthi 1984. Brouardel and Fage (1955) suggested that low oxygen content of the water near bottom was perhaps be due to the very rapid oxidation of the sediment and the slow diffusion of the dissolved gases. The higher concentration of oxygen in the surface water was mainly due to the photosynthetic activity of the phytoplankton and low levels of salinity in the surface water.

In the present study higher concentration of dissolved oxygen was observed in the monsoon season and lower values in the postmonsoon and premonsoon seasons. A similar situation has been observed in Mandovi and Zuari estuaries by Dwivedi *et al.* (1974) and in the backwaters from Cochin to Alleppey by Haridas *et al.* (1973). The higher oxygen concentration during monsoon may be due to the monsoonal flood.

Station I showed lower values of oxygen when compared to station II and III in certain collections in the premonsoon season especially in March during 1990 and May during 1991. This lower level of oxygen may be attributed to retting activity prevailing in this area and the stagnation of water. The small amount of retting going on in the enclosures along the shores of this area might release small quantities of ret liquor. The ret liquor got dissolved in the estuarine water leading to decrease in oxygen content. Depletion of oxygen owing to retting was observed by Abdul Azis and Nair (1983) in Edava- Nadayara backwater, Nair *et al.* (1984) in Kadinamkulam backwater system, Bijoy Nandan (1991) in Kadinamkulam kayal and Shibu (1991) in Paravur lake.

In the present investigation, the pH was low in the postmonsoon season during 1990-'91 and in the monsoon and postmonsoon seasons during 1991-'92. The low pH value may be attributed to fresh water discharge, rainfall and the decomposition of organic matter. Heald (1971) reported that the reduction of pH in monsoon was due to fresh water discharge and decomposition of organic matter. In Vellar estuary Rajendran (1984) noted low values of pH during monsoon season. In Chilka lake Mohanty (1975) observed low pH values.

The pH values were always towards alkaline side in the premonsoon season. A clear decrease in pH from the mouth to the head was evident. A more similar type of observation was reported in Ashtamudi estuary by Nair *et al.* (1983 a).

Station I, the retting zone, recorded acidic pH in March during 1990 and in April and May during 1991. The low pH in the retting zone was due to the release of hydrogen sulphide. A low pH in the retting zones was also recorded by Abdul Azis (1978) in the retting grounds of the backwaters of Kerala, Bijoy Nandan (1991) in Kadinamkulam Kayal and Shibu (1991) in Paravur lake.

Hydrogen sulphide is not a normal constituent of natural water. It is evolved in water due to the protein decomposition and reduction of sulphates (Vamos, 1964). It is produced in water containing large amount of sulphate and organic matter. When the organic compounds of sulphur undergo decomposition, hydrogen sulphide is released as a disintegration product.

Sulphide rich habitats have a world wide distribution. The production of H_2S was associated with the retting of coconut husk (Prabhu 1957, Pandalai *et al.* 1957, Jayasankar 1966, Bhat and Nambudiri 1971, Bhat *et al.* ,1972, 1974, Jayasankar 1985 and Parimala Varadaraj *et al.*, 1985).

In the present investigation station II and III recorded no hydrogen sulphide round the year. But it was found in station I. The presence of hydrogen sulphide at station I was due to the retting activity going on along the banks of the estuary adjoining station I. Hydrogen sulphide was also recorded by Abdul Azis (1978) in the retting zones of the Edava Nadayara backwater, Remani (1979) in the retting zones of the Cochin backwaters, Shibu (1991) in the retting zones of Paravur lake and Bijoy Nandan (1991) in the retting zones of Kadinamkulam Kayal.

In the present study, the maximum concentration of hydrogen sulphide recorded was 4.95 mg/ℓ. Abdul Azis (1978) recorded a maximum concentration of 47.16mg/ℓ in Edava Nadayara Kayal, Remani (1979) recorded 4.97mg/ℓ in Cochin backwater, Shibu (1991) recorded 35.05mg/ℓ in Paravur lake and Bijoy Nandan (1991) recorded 41.1 mg/ℓ in Kadinamkulam Kayal. In the present study the concentration of hydrogen sulphide was comparatively very low. This is because the nature of sampling site which was about 30 to 40 m away from the retting pits.

The concentration of hydrogen sulphide was uniformly high at the surface and low at the bottom. This was in conformity with the previous observations (Abdul Azis, 1978; Remani, 1979; Shibu, 1991; and Bijoy Nandan, 1991).

In the present study, the concentration of hydrogen sulphide was low during monsoon season and high during premonsoon season. This was because during monsoon season the hydrogen sulphide evolved, was washed away by the influx of monsoonal flood. The higher concentration during premonsoon was due to the stagnation of water.