

**ECOLOGICAL STUDIES ON
THE MANGROVES OF
VALAPATTANAM AND THALASSERY
RIVER BASINS**

Thesis submitted to
University of Calicut
in part fulfilment of
Doctor of Philosophy in Botany

Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

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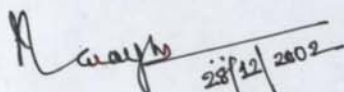
Dr P Narayanan Unni
Scientist E 1

CERTIFICATE

Ref. No. LIWAMP/04/2002

28 December 2002

This is to certify that the thesis entitled "**Ecological Studies on the Mangroves of Valapattanam and Thalassery River Basins**" submitted by Ms K Lakshmi, Research Fellow, for the degree of **Doctor of Philosophy in Botany** of the University of Calicut, is a *bona fide* record of the research work done by her during the period from July 1999 to December 2002 in this institution under my guidance. This work has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title or recognition.


28/12/2002

P Narayanan Unni

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DECLARATION

This is to declare that the thesis entitled **“Ecological Studies on the Mangroves of Valapattanam and Thalassery River Basins”**, submitted by me for the degree of Doctor of Philosophy in Botany of the University of Calicut, has not formed the basis for the award of any degree or diploma.

CWRDM Campus,
28 December 2002

Lak
K. LAKSHMI

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ACKNOWLEDGEMENTS

I express my heartfelt gratitude to Dr P N Unni, Scientist E1, Centre for Water Resources Development and Management (CWRDM), Kunnamangalam, Kozhikode, Kerala for evincing keen interest in the topic and invaluable guidance throughout the course of this work, without whose constant encouragement and supervision, this work would not have been materialized.

I am grateful to Prof (Dr) N Neelakantan, Head of the Department of Botany, University of Calicut for providing initial guidance, library facilities, suggestions and encouragement.

I am immensely grateful to Dr E J James, Executive Director, CWRDM and Dr P Basak, Former Executive Director, CWRDM for facilities and encouragement.

I am grateful to Major (Rtd) V K Premnath, Registrar, CWRDM and former Registrar Mr K Unneenkutty, for administrative sanction to proceed with the work and for providing accommodation in the CWRDM Campus.

I am thankful to the State Committee on Science, Technology & Environment Committee (STEC), Government of Kerala, for the award of a Junior Research Fellowship for the period from June 1998 to February 2002 for undertaking this study.

I am deeply indebted to Mr Sasidharan Pallikkudian, Technical Officer, LIWAMP Cell for the valuable and timely help rendered by him in preparing the sampling site maps. I am also grateful to Dr P K Pradeepkumar,

Scientist E1, Mr E Abdul Hameed, Technical Officer, Ms K P Shijila, Vocational Apprentice Trainee, LIWAMP Cell for their wholehearted cooperation during the course of this work.

I gratefully acknowledge the encouragement and help of Dr K N Remani, Head, Environmental Studies Division & In Charge, Central Water Analysis Laboratory, CWRDM, for providing laboratory facilities. My heartfelt thanks are also due to Dr P S Harikumar, Scientist C, and Mr Madhavan Komath, Technical Officer of the Central Water Analysis Laboratory, CWRDM, for helping in standardization of laboratory techniques and analysis of samples, which has helped a lot in the completion of this work.

I am gratefully indebted to Dr (Mrs) E Nirmala, Scientist E1, Dr (Mrs) T K Jalaja, Mrs Nirmala Stephen, and Mr M Beeran, Technical Officers of Environmental Studies Division, CWRDM, for the valuable help rendered for the timely completion of field and laboratory work.

I am grateful to Dr A Shahul Hameed, Scientist C, Nuclear Hydrology Division, CWRDM, for his timely advice and suggestions.

I express my indebtedness to Er C M Sushanth, Scientist C, LIWAMP Cell, CWRDM without whose encouragement, this work would not have been completed.

I am extremely thankful to my friend Ms K J Shiny, Research Scholar, Environmental Studies Division, CWRDM, for the immense help rendered during the course of this work, especially during the final compilation of the thesis, without which it would not have been possible to complete the task in time.

My heartfelt gratitude is due to Mr B Sivakumar, B. Tech (Engg) Office Secretary (Technical), LIWAMP Cell, CWRDM for the help rendered by him in computer graphics.

My thanks are due to Mr K Jayarajan, Statistical Assistant, Indian Institute of Spices Research, Kozhikode for the help in statistical analysis of data.

I take this opportunity to express my sincere gratitude to all other technical and administrative staff of CWRDM, who has offered their valuable service, wholehearted cooperation and encouragement to me during the entire period of this work.

Finally, I appreciate the patience, support and constant encouragement from the members of my family.

K LAKSHMI

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Doctor of Philosophy in Botany

Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

92/278

ABBREVIATIONS USED

General:

EC	Electrical Conductivity
DO	Dissolved Oxygen
BOD	Biological Oxygen Demand
GPP	Gross Primary Productivity
MPN	Most Probable Number

Units (Measurements):

μ mhos/cm	Micro mhos per centimeter
M mhos/cm	Milli mhos per centimeter
mg/100g	Milligram per 100 grams
ml	Millilitre
l	Litre
mg/l	Milligram per litre
kg	Kilogram
$\text{gC/m}^3/\text{d}$	Gram carbon per cubic meter per day
mg/m^3	Milligram per cubic meter
ppt	Parts per thousand
$^{\circ}\text{C}$	Degree Celsius
μ	Micron
mm	Millimeter
cm	Centimeter
m	Meter
%	Percentage
NTU	Nephelo Turbidity Unit

**ECOLOGICAL STUDIES ON
THE MANGROVES OF
VALAPATTANAM AND THALASSERY
RIVER BASINS**

Thesis submitted to
University of Calicut
in part fulfilment of
Doctor of Philosophy in Botany

Ms K LAKSHMI

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Kunnamangalam Kozhikode Kerala

DECEMBER 2002

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1.0 INTRODUCTION

1.1 WETLANDS

Wetlands, ranked the third among the most productive ecosystems of the world, are considered 'kidneys of the landscape', for the functions they perform in the hydrologic and biogeochemical cycles and as the downstream sinks and transformers of pollutants, both from natural and human sources. Wetlands are transitional zones that occupy an intermediate position between dryland and open water, which embraces an assemblage of habitats ranging from rivers, floodplains, rain fed lakes to mangrove swamps, estuaries and salt marshes. Ramsar Convention, the Convention on Wetlands of International Importance, especially the waterfowl habitat, an international intergovernmental cooperation for the conservation of wetland habitats defines wetlands as **"areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which at low tides does not exceed six meters"**. Wetlands are designated as Ramsar Sites on account of their international importance, which is established on the basis of ecological, botanical, zoological, limnological, or hydrological criteria.

1.2 MANGROVE WETLANDS

Mangroves are the coastal forested wetlands of tropical and subtropical regions forming essential components of intertidal ecosystems and are self-maintaining coastal estuarine components of the biosphere. They have been variously described as 'tidal forest' 'mangrove forest', 'oceans rainforest', 'coastal woodland', etc. The word

mangrove is of doubtful origin as there is no authentic record as to when it first came into use. It is considered to be a combination of the Portuguese word 'mangue' or the Spanish word 'mangle', and the English word 'grove' (MacNae, 1968; Dagar *et al.* 1991). The term 'mangrove' is being used in the broad sense either to refer to the highly adapted plants found in tropical intertidal forest communities or the ecosystem itself. MacNae (1968) suggested 'mangal' as a term to refer to the 'habitat' or the forest community and 'mangroves' to the plant species. The term 'mangrove' might have been derived from a combination of the Malay word 'manggi-manggi' (MacNae, 1968), for a type of mangrove tree (*Avicennia*) and the Arabic 'el gurm', for the same, as 'mang-gurm'. According to Vannucci (1989), the word mangrove may be of African origin and was learned by the Portuguese in the West African coast in the early 15th century and spread throughout the world. The word 'mangue' is commonly used for mangrove in Senegal, Gambia, Casamance and Guinea with the same pronunciation as in Portuguese. Mangroves appear to have evolved in South East Asian region as early as the Tertiary. As a word, it has been used to refer to a species, plant, forest or community or an ecosystem. The mangrove ecosystem is dynamic; the plant species inhabiting it adapt to these frequent changes and it is this adaptability, which enables them to withstand a variety of environmental changes, particularly salinity stress ranging from extreme saline to almost freshwater conditions. Recently, the mangrove wetlands have received much scientific attention and curiosity compared to other plant communities.

1.2.1 HABITAT

There are three mangrove habitats, *viz.*, coastal mangroves, mangroves along the creeks and mangroves along the estuaries. These environments create different physical and chemical structures of the substratum. Mangrove swamps develop only where

coastal physiography and energy conditions are favourable. The natural habitat of mangroves is an environment of high salinity, warm climate, occasional harsh weather, anoxic and waterlogged soil conditions, protected shores and tidal action. Well-developed mangal formations are on muddy coastal plains where adequate nutrient rich fresh water supplies from river discharge are available, followed by periodic seawater inundation. Hence, the mangals are best developed along coasts such as inlets, lagoons and creeks where the environment is protected from strong currents and waves, which would otherwise hinder the establishment of their seedlings.

Mangroves develop well in places where the salt concentration is between 20 and 35%. Too high salt concentration (40-80‰) diminishes the number of species and their size. They are facultative halophytes, *i. e.*, they cannot flourish in salt-free environments that are not subjected to periodic tidal inundation. Freshwater from rivers, channels and rain dilutes the salinity of seawater, creating brackish water congenial for many mangrove species during specific stages of their growth. Extensive mangroves occur generally where the average temperature of the coldest month is higher than 20°C and the seasonal range does not exceed 5°C (Dawes, 1981; Chapman, 1975).

Mangroves grow on sand, mud, peat and coral rock. Most extensive mangal is invariably associated with fine grained, often semi fluid, poorly consolidated soil with abundant humus, high salinity, water, low oxygen and high H₂S content. The mangrove sediments, which are clayey and sandy – clay mud, is suitable for colonization by animals, which grow on a variety of soils with different textural and chemical composition, each species having its own preferences (Shanmukhappa, 1987). The silt brought out by the high tides contains a substantial quantity of calcareous material from the foraminiferan shells and debris from molluscan and other shells. This acted upon by

sulphur bacteria make the calcareous material available to other organisms, the breakdown of which increases the soil alkalinity. The black colour of the soil is due to the presence of H_2S , which reduces the ferric compounds to various hydrated ferrous sulphides (Ananthkrishnan, 1982). The low pH due to the reduction of sulphides to sulphates with the consequent formation of sulphuric acid, and the anoxic soil, influences the distribution and zonation of mangrove species at each site (Dagar, *et al.* 1991). The conditions within the substrate are determined by interaction between a multiplicity of factors including moisture retention, texture, grain size, organic content, oxygenation, salinity, redox potential and other chemical parameters. Abundance of particulate organic matter is typical of mangrove waters (Shanmukhappa, 1987).

Chapman (1975) describes 7 basic requirements, *viz.*, air temperature, ocean currents, protection, shallow shores, salt water, tidal range and mud substrate for the healthy existence of mangrove formations. Shallow shores provide an opportunity for extensive development of the mangroves, whereas on steeply shelving shores, they are seen only on the fringes (Rao, 1987). In the humid tropics, the mangroves give way to some forms of fresh water swamp/riverine forests (Chapman, 1975; 1976; 1977). The plants, which grow in the intertidal belt, have to encounter adverse conditions such as higher salinity, tidal extremes, wind velocity, high temperature and muddy anaerobic soil, where no terrestrial plants can survive (Kathiresan, 1991). Tides and related phenomena appear to control the vertical zonation of some mangrove species (Chapman, 1975). The tides are important for mangrove swamps for importing nutrients, aerating the soil water, stabilizing soil salinity, dispersal of seeds and removing the build up of toxicity which is important for mangroves in eliminating competition from fresh water species.

The substratum of mangroves consists of shifting, changing and muddy saline

environment. They have evolved certain morphological, anatomical and physiological mechanisms to overcome these adverse conditions and flourish well.

1. 2. 2 MORPHOLOGICAL, ANATOMICAL AND PHYSIOLOGICAL ADAPTATIONS

Studies on mangrove leaves and their structure points to the fact that they do not possess any features that are exclusively associated with them, but have xeromorphic features such as thick cuticle, thick walled epidermis, sunken stomata, water storage tissues, palisade like mesophyll, vascular bundles terminating in trachieds and mucus cells, salt glands etc., which may provide protection against water loss, because of the difficulty in water absorption from highly saline water where the osmotic concentration is very high. (Dagar *et al.* 1991; Chapman, 1976).

The mangroves do not have persistent taproots and the root system of mangroves is extensively branched, but not deep due to the poor aeration of the substratum. As the surrounding soil is anoxic, they have additional roots/root adaptations to facilitate the exchange of gases. As soon as the seedling becomes established in the mud, the radicle develops little further (MacNae, 1968; Dagar *et al.* 1991). The common adaptations of the mangroves to remain anchored firmly in these soils are the peg like aerial roots or pneumatophores, which stick out of the soil around the trees. Another type of aerial root is the stilt roots, which support the trees in the constantly shifting substrate. In highly specialized mangroves, the aerial roots are exposed to atmosphere at least during the low tide levels (Tomlinson, 1986).

Species of *Rhizophora*, *Bruguiera* and *Avicennia* are capable of survival under great oxygen tension (Chapman, 1962). Stilt roots of *Rhizophora* are equipped with large lenticels, which have contact with the aerenchyma. If the pneumatophores are covered with water at high tide, the oxygen stored inside is used up due to respiration of the root

cells, while the carbon dioxide, which is soluble in water, escapes through the openings, resulting in a negative pressure in the prop and respiratory roots. Oxygen is sucked into the root system at low tide through special pneumatophores as in *Avicennia*, *Laguncularia*, *Sonneratia* or knee roots as in *Bruguiera* (Dagar, *et al.* 1991).

Vivipary, the common feature of mangroves, is the condition whereby, the embryo grows out of the seed coat and the fruit wall, still attached to the parent plant as in *Bruguiera*, *Ceriops*, *Kandelia*, *Rhizophora*, *Avicennia* and *Aegiceras* of the family Rhizophoraceae (Dagar *et al.* 1991). Vivipary represents only a short, temporary stage of embryonic development prior to the protrusion of the hypocotyle, during which the embryo draws the nutrients necessary from the reserves in the endosperm for its growth. Once this becomes exhausted a shunt to a nearly heterotrophic 'parasitic' stage, in which the embryo utilizes assimilation products supplied by the parent plant (Pannier & Pannier, 1975).

In 'true vivipary' the embryo that results from normal sexual reproduction has no dormancy but grows first out of the seed coat and then out of the fruit while still attached to the parent plant, thus the propagating organ is the seedling and not the seed. Under normal conditions, only one seedling emerges out still attached to the fruit stock and protrudes down to varied lengths. Multiple vivipary is observed in species of *Bruguiera*, *Rhizophora*, and *Kandelia candel* (Dagar, 1987; Dagar & Sharma, 1989, Rao *et al.* 1986).

Mangroves are 'physiologically dry' because, most plants have more water content than seawater. For osmosis to occur, water must move from a region of its higher concentration to a region of its lower concentration. The mangroves have the inherent ability to tolerate levels of salinity of tidal seawater. The three mechanisms of salt regulation in mangroves *viz.*, salt exclusion (*e.g.* members of Rhizophoraceae), salt

excretion (*e.g.*, species of *Avicennia*, *Aegiceras* and *Acanthus*) and salt accumulation (*e.g.* species of *Sonneratia*, *Lumnitzera* and *Excoecaria*) (Dagar, *et al.* 1991). Salt accumulating mangroves are least dominant while, the salt excreting species are the most dominant. Mangroves accumulate sodium and chloride ions when they grow in salt-rich environment. Sodium: Potassium ratio, which is nearly 38 in the seawater, 9 in soil, and much less in tissues, suggests that mangroves have a mechanism for uptake of potassium. Development of salt resistance in non-viviparous species takes place from the beginning of the germination stage, whereas it is gradual in viviparous species (Dagar, *et al.* 1991).

1. 2. 3 MANGROVE FAUNA AND FLORA

Mangroves support rich faunal and floral resources (Rao, 1987). A mangrove, like any other intertidal area, is a zone of transition from the sea to the land and from the land to the sea and has its fauna be derived from either (MacNae, 1986). Among invertebrates, more than 500 species of insects and arachnids, 229 species of crustaceans, 212 species of mollusks, 50 species of nematodes and 150 species of planktonic and benthic organisms are known from Indian mangroves. Vertebrate fauna represented by 300 species of fish, 177 species of birds, 36 species of mammals and 22 species of reptiles (Gopal & Krishnamurthy, 1993).

Marine animals are associated with mangals, largely because they share the same substrate requirements. *e.g.*, mud skippers, crabs, oysters & snails. Mud skippers are characteristics of mangal and related areas; some of them can even climb trees. The benthic community in mangroves is often dominated by crabs (Brachyura) especially crabs of the following families are to be found in mangrove forests all over the world: Grapsidae (Imp. Genera: *Goniopsis*, *Sarmatium*, *Metaplax*, *Metapograpsus* and *Aratus*), Sesarmidae (*Sesarma*, *Parasesarma* and *Metasesarma*), Gecarcinidae (*Cardisoma*) and

Ocypodidae (*Uca*, *Macrothalmus*, *Ilyoplax*, *Tylodiplax* and *Ocypode*). They live on mud banks where these foliage and detritus feeders usually build burrows. Characteristically these crabs have special morphological and physiological means of adapting to life in the mangrove, such as partial respiration of air and the production of cellulase (Malley, 1977). Shrimps (Paenaeidae, Palaemonidae and Alpinidae) and predatory crabs (*e.g.*, *Callinectes* and *Scylla* – Family: Portunidae) are important part of the epibenthos. The dominance of crabs is also shown by the fact that decapod larvae are often found in great abundance in the plankton and kinon of mangrove areas, and that they usually dominate the meroplankton. Benthic fauna includes juvenile fish, crustaceans, crabs and bivalves. Apart from Decapoda, Amphipoda, Isopoda and Gastropoda form important parts of the benthic community. Sessile filter feeders are usually found frequently such as the mangrove oysters (*Crassostrea* sp.) as well as various *Cirripedia*, Crocodiles, poisonous snakes, deer, raccoons, bats etc are also present in mangals. Bats play an important role in the reproduction of *Sonneratia* species. Insects are the main predators of mangrove leaves; mosquitoes and midges are notable and offensive insects (Tomlinson, 1986). Recently, 41 species of invertebrates and 52 species of fishes of Indian mangroves have been assessed and 4 species of the invertebrates and only one species of fish have been categorized as endangered (Anonymous, 1997).

The major groups of benthic organisms found in mangrove ecosystem are molluscs, annelids, crustaceans, hydroids, actinarians, planarians, nematodes, polyzoms & larval forms of several other organisms (Parulekar *et al.* 1973). They are divided into the Macrobenthos (> 1mm) and the Meiobenthos (<1mm). Macrobenthos consists of polychaetes, sipunculids, crustaceans, molluscs, nematodes, gobiids and actinarians.

Polychaetes dominate the benthic taxa in creek environment, where as in the mangroves, sipunculids are the most abundant group (Patra *et al.* 1988, 1990). High populations of meiofauna like nematodes; turbellarians and herpacticoids characterize the reducing environment of mangroves. The meiofaunal taxa are significantly correlated with interstitial water of the sediment and the microbial density in mangrove mudflats (Ansari *et al.* 1993). The meiofaunal densities are positively correlated to standing amounts of mangrove derived detrital mud and in subtropical / tropical mangrove dominated estuaries, available data indicate that the juvenile fish utilize meiofauna for food (Coull *et al.* 1995). Indian mangroves have a rich soil dwelling biodiversity resources which include micro, meio and macro invertebrates and the various regions of both the east and the west coast of India need to be thoroughly investigated for their rich biodiversity (Sunil Kumar, 2000). All the soil biodiversity resources of mangroves do a pivotal role in recycling of nutrients and also enter in the trophic cycle operating in the ecosystem.

Mangroves provide a unique ecological niche to a variety of microorganisms (Agate, 1991). The mangrove has rich microbial diversity due to high organic dumped in to the system. *Desulfovibrio*, was reported from the mangrove environment of Singapore (Kathiresan & Sivasothi, 2000). The bacteria help in the breakdown of sulphides bonds and produces hydrogen sulphides. The important nitrogen-fixing bacteria reported in the mangrove sediments comprise *Azotobacter sp.*, *Rhizobium sp.*, *Aphanocapsa sp.*, *Nodularia sp.* & *Trichodesmium sp.* Several types of microorganisms do exist on mangrove biota like sulphate reducing bacteria (Saxena *et al.* 1988; Lokabharathi *et al.* 1991), iron reducing bacteria (Panchanadikar, 1993) and the methanogenic bacteria (Ramamurthy *et al.* 1990). Human pathogenic bacteria do exist in mangrove waters. Total coliforms, fecal coliforms, fecal streptococci, *Salmonella* & vibrios have been

enumerated by Venketesan & Natarajan (1987). Epiphytic bacteria like *Chaetomorpha crassa*, *C. linum*, *Flavobacterium*, *Vibrio* sp. etc., have been reported from mangrove plants (Padmakumar & Ayyakkannu, 1986; Abhaykumar & Dube, 1991; Kathiresan & Ravikumar, 1995).

The zooplankton constituting the mangrove fauna is represented by almost all aquatic groups of animals from protozoa to fish eggs and fingerlings as well as larvae of most zoological groups. The plants in a mangal will always show a tendency towards, and under optimal conditions, always demonstrate a very distinct and characteristic zonation among animals.

Of the land animals that invade the mangals remain terrestrial. Birds characterize of their food in the creeks and channels and nesting in the trees. Only a few such as 'mangrove kingfishers' are restricted to mangals. This is even true of the mammals, amphibians and reptiles. Insects fall into 2 groups, some are visitors, bees drawn to seek honey from *Aegiceras* and *Rhizophora*; some are parasites, the beetles which bore into the living trees, and the coccids which often cover the leaves and young twigs of members of *Rhizophoraceae*. Some insects such as the 'tailor ants', come after the coccids and some beetles come to bore into dead branches and trunks. All these are still terrestrial. Other insects have larvae which live in the uppermost layers of the soil and only there; these are dependent on the soils at this level for their existence but not on the mangal, and persist even when the mangal has been cleared.

The amphibians include crocodiles, water monitors, water snakes, tadpoles and frogs. Wolf, macaques, fish cat, wild pigs, mouse deer, flying foxes, and monkeys mainly represent mammals. Insects include bees, weaver ant/tailor ant, coccids, mosquitoes, etc.

A large number of obligate marine fungi thrive in the mangrove pneumatophores and submerged mangrove leaf litter. Majority of them belongs to Ascomycotina, Basidiomycotina and Oomycotina. The Asco and Basidiomycotina are lignolytic, while the Oomycotina are 'sugar fungi' and are among the first to colonize the freshly fallen leaves with their residual sugars.

The important mangrove floral resource comprises plankton, mangroves and associated higher plants. Mangrove ecosystem possesses high phytoplankton diversity. The predominant phytoplankton species belongs to Chlorophyceae, Cyanophyceae, Bacillariophyceae, Rhodophyceae, Dinophyceae and Xanthophyceae. The diatoms dominate the phytoplankton, the predominant genera being *Coscinodiscus*, *Rhizosolenia*, *Chaetoceros*, *Biddulphia*, *Pleurosigma*, *Ceratium* & *Protopteridium*, *Nitzschia*, etc.

1. 2. 4 FOOD CHAIN AND PRODUCTIVITY IN THE MANGROVE ECOSYSTEM

A variety of animals are associated with mangroves and make a complete food web and play a major role in energy flow where mangrove trees form the base of the food pyramid. The principal energy flow is as follows:

Mangrove leaf detritus ► bacteria & fungi ► detritus consumers (herbivores & omnivores) ► lower carnivores ► higher carnivores

The food chain begins with the production of carbohydrates and carbon by plants through photosynthesis. Mangroves harbor wide varieties of phytoplankton, which becomes the partner in adding to the nutrition for small fish and other organisms, which in turn become the food for large fishes and prawns. Mangroves act as a dynamic benthic environment with its detrital system. In the mangrove ecosystem, in addition to biological productivity by phytoplankton, the accumulation of primary productive elements of mangrove flora itself in the form of leaf detritus is an additional major

support to the biological production. Therefore, the formation of detritus and release of nutrients in the mangrove areas directly increase the benthic primary production in a large scale (Sunil Kumar, 2001). Litter fall and litter decomposition of Indian mangroves have been studied by many investigators (Wafar *et al.* 1997; Rajendran, 1997). The initial stages of mangrove leaf decomposition generally commence before leaf fall through grazing insects, amphipodes and crabs which remove little of the total leaf area and the holes created on leaves by them being exposed to secondary infection by micro organisms (Sasekumar, 1984). The fallen leaves are subjected to decomposition process by the sedimentary bacteria, fungi and yeasts. The bacterial biomass predominate through out the decomposition of mangrove litter followed by fungi (Blum *et al.* 1988) and reuse of detrital particles by a variety of detritivores (Odum & Heald, 1975) beginning with very small sized invertebrates and ending with species such as worms, molluscs, prawns and crabs, which in turn are preyed upon by lower carnivores. The food chain ends with higher carnivores such as large fish, birds of prey, wild cats or man himself. The plants lose a part of their net primary production in the form of litter fall (Karmarkar, 1985). This is in part due to the fact that many mangrove plants accumulate surplus minerals (primarily sodium) in the withering leaves.

In regions in which the mangroves primarily occur in emerged form, and where a small transfer of energy and matter from the supra littoral to the aquatic milieu takes place, the contribution of mangroves to the net primary production is considerably higher (Lee, 1990). Regions in which the mangroves are completely separated from the aquatic milieu, the mud banks function as a closed system in which nutrients are recirculated. Here, the production of phytoplankton and benthic macroalgae comprised less than 10% of the net primary production and were dependent upon the allochthonous nutrients.

Mangrove waters are more productive than the backwaters and estuaries (Bhattathiri, 1992). In Kakinada, productivity is four times greater in mangroves than that in the adjacent marine environment (Selvam *et al.* 1992). This is attributed to the high production of plankton in the mangrove waters, as the phytoplankton is one of the initial biological components from which energy is transferred into higher organisms through the food web. Biomass and production of phytoplankton of various sizes are important factors, which regulate the availability and diversity of organisms at higher trophic levels. In Pichavaram waters, the phytoplankton of 5-10 μm size is important contributors to the primary production (Kawabata *et al.* 1993).

Quality, location and quantity of water are essential to primary production. Epiphytes attached to the roots can add significantly to this production. Estuarine mangrove systems are second only to the tropics in primary productivity. Estimates of 8.8 dry tons/ha/year of organic material have been recorded. Factors affecting productivity are species composition, age, competition, substrate, wave action, bird activity, hurricanes, etc.

1.3 SIGNIFICANCE OF MANGROVE ECOSYSTEM

The components of mangrove wetlands include those aspects of the system, which describe them through their shape, size, soils, flora and fauna, geography, geomorphology, biomass generation, water quality etc. The mangrove wetland components like flora and fauna provide sustenance to the local population, especially through fishery resources. Apart from fish, a myriad of wild life, both macro and micro invertebrates, herbivores, and birds depend on mangrove wetlands. The floral components satisfy the vital needs of timber, fuel wood, and other raw materials such as root-pith for cork making and various raw materials for medicines. Detritus from the

wetland vegetation together with the silt and humus brought down by the rivers that flow into wetlands provide a fertile ground for agriculture.

In the tropics, mangroves play a significant role in environment populated by animal species which are of economic importance, function as nursery grounds for numerous fish and crustaceans, provide a natural form of protection against the surf, supply wood and presumably serve as an important CO₂ sink.

Mangroves are one of the most productive ecosystems, which can efficiently fertilize the sea, serve as part of a naturally existing ecosystem, and play an important role in the protection of coastal and estuarine regions. With wise management, rich resources that the mangrove ecosystem offers could be of great assistance to the development of livelihoods of local communities. The mangrove ecosystem is particularly vulnerable to human interference and to environmental changes, because of its fragile nature. The mangroves are extremely important in maintaining the health of coastal waters. Their prop roots provide a home and nursery for many marine organisms. When the materials are trapped in the mangrove root system, they allow the decomposition of the waste products through microbial action. The release of carbon from those decaying materials gets trapped in the seawater and is then diffused into bacteria. The bacteria formed are then eaten by filter feeding organisms including plankton, which is consumed by many marine critters including some whales. There is also an increasing release of N₂ from the decaying material.

Mangroves being an intertidal, halophilous ecosystem have the ability to grow where no other trees can, thereby making significant contribution that benefits the environment. Their coverage of coastal shorelines and wetlands provide many diverse species of birds, mammals, and crustaceans and fish a unique irreplaceable habitat.

Mangroves preserve water quality and reduce pollution by filtering suspended material and assimilating dissolved nutrients. They also serve as barriers of shoreline erosion and stabilize sediments.

The mangroves are the foundation in a complex marine food chain and the detrital cycle. The decomposed mangrove leaves become food for the smallest animals such as worms, snails, shrimp, mollusks, mussels, barnacles, clams, oysters and the larger commercially important striped mullet. These detritus eaters are food for carnivores including crabs and fish, subsequently birds and game fish follow the food chain, culminating with the man.

The beneficial effects of mangroves on the marine ecology are (i) Basis of a complex marine food chain; (ii) Creation of breeding habitat; (iii) Establishment of restrictive impounds that offer protection for the maturing offspring; (iv) Filtering and assimilating pollutants from upland runoff; (v) Stabilization of bottom sediments; (vi) Water quality improvements; (vii) Protection of shorelines from erosion. Use of mangrove ecosystem has been studied by many workers (Dagar *et al.* 1991; Snedaker, 1987; Kathiresan, 1991).

Destruction of mangrove wetland habitats by water front development endangers the natural ecosystems of coastal zone. Even activities in nearby uplands may cause changes in water runoff patterns, which eventually alter the plant composition of the community. This in turn, affects human beings through coastal erosion and reduction of food at the base of the chain supporting commercial fisheries. Contribution of mangroves to fishery resources in inshore water has been described by many authors (Blaber & Milton, 1990; Sasekumar *et al.* 1992). Information is available on the extent to which the aquatic consumer organisms utilize mangrove food resources (Odum & Heald, 1975).

Mangroves form an important ecological asset and economic resource of the coastal marine environment.

1.4 SIGNIFICANCE OF THE PRESENT STUDY

Coastal ecosystems have gained importance in view of the resources they support and its usefulness in the international trade scenario. Early studies on mangroves were mostly taxonomical in nature, involving the identification and classification of plants and animals. Floristic studies on Indian mangroves done by botanists Roxburgh (1814), Clarke (1869) and Prain (1903) and on the flora of the Ganges delta is noteworthy. As early as middle of the nineteenth century, Griffith (1836, 1851) investigated the complex biology of halophytes of India. Blatter (1905) and Cooke (1906) started investigations on the West Coast and Schimper (1903) initiated the well known ecological and plant sociological studies. The unique growth characters and adaptability of mangrove organisms were recognized a long time back, but details on their structural and functional relationships were worked out only during the last three decades. The present knowledge on the ecophysiology of mangroves is fragmentary and not yet fully understood.

The mangroves constitute an important ecosystem of the State, which serve as sources, sinks and transformers of a multitude of chemical, biological and genetic material. They provide a unique habitat for a wide variety of animals and plants associated with them and serve in controlling pH, leaching of metals, and regulate the biogeochemical cycles. From fisheries point of view, mangroves have attained great significance because this ecosystem acts as a feeding and breeding and nursery ground of economically important organisms. Fin and shellfish resources of Indian mangroves have been well documented by many authors (Jayseelan *et al.* 1991; Chandrasekharan, 1987; Rajendran, 1997; Sunil Kumar, 2001; MacNae, 1974; Martosubroto & Naamin, 1977;

Chong, 1987). The mangroves also clean polluted waters, prevent floods and recharge ground water. Growing awareness of the protective, productive and social functions and values of tropical mangrove ecosystems has highlighted the need for their conservation/sustainable management. Considering their multiple use potential, it is imperative that mangrove based terrestrial as well as aquatic resources have to be managed in an integrated manner. The depletion of mangroves is a cause of serious environmental concern at present. This stems from the fact that at the inter-tidal zone, the mangroves play a pivotal role in moderating monsoon tidal floods and consequent coastal erosion. At the same time, their primary production supports numerous forms of wildlife, avifauna as well as estuarine and near shore fishery. Consequently, the continuing degradation/depletion of this vital resource will not only retard the terrestrial and aquatic productivity and wildlife, but also seriously impair the environmental stability of coastal forests that impart protection to inland agricultural crops and villages.

The changes in water and sediment quality can increase or decrease the capacity of these aquatic ecosystems to produce living/non-living resources of interest. The production capacity of these ecosystems does not remain constant, but vary from season to season or even from month to month. The changes in water and sediment quality occur primarily because of the rapid industrialization and urbanization phenomena. Hence, there is a need to protect and conserve these coastal ecosystems from such effects. Ramachandran and Mohanan (1987), has already pointed out the importance of analysis of the distribution of major, minor or trace elements in the mangrove waters of Kerala. A detailed scientific study of mangrove ecosystem in relation to water and sediment quality needs top priority, before any conservation programs are implemented. The mangrove, which significantly influences the coastal environment, faces serious threat of destruction

in Northern Kerala. A good percentage of mangroves of Thalassery and Valapattanam estuaries and associated wetlands in Kannur district have already been destroyed. The remaining mangrove forests in Kannur district are on the verge of destruction due to various anthropogenic activities. Extensive agriculture and aquaculture, especially prawn culture in the coastline, coir retting and industries, clay collection and plywood industries have all wrought havoc on this fragile ecosystem. Out of the 26 mangrove species, 15 species are present in Northern Malabar. In this context, an analysis is essential on the distribution of the nutrients and trace elements in the mangrove waters, and sediments, which supports the mangrove flora and fauna, of Kannur, mainly on account of its present degrading status. So far, no comprehensive, systematic studies have been done on the ecology of the mangrove ecosystem of Thalassery and Valapattanam river basins of Kannur district and their relationship with the associated flora, fauna and aquatic productivity, hence, the present study was undertaken.

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Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

92/278

2.0 REVIEW OF LITERATURE

2.1 HISTORICAL PERSPECTIVES OF MANGROVES

The earliest observation on mangrove vegetation was by Nearchus in (325 BC), during his voyage from the Indus delta to the Persian Gulf, when he referred to some trees of the genus *Rhizophora*. Theophrastus (305 BC) also described some plants at the entrance to the Persian Gulf and around Tyros (Baharein), as well as in the Red Sea when he wrote, 'the trees are all washed by the sea up to their middle and are held up by their roots like a polyp' (Gerlach, 1958).

Mangroves were certainly known to the ancients (MacNae, 1968), but significant study began with European colonization in the sixteenth and seventeenth centuries. Mangroves being the common coastal plants that were readily observed and collected, especially in the East Indies, were familiar to the earliest European naturalists. The earliest published account of mangroves is available in the **Hortus Indicus Malabaricus** of H. Van Rheedee (1678 – 1703). The Rumphian accounts are mainly of plants that grew on the Dutch-occupied island of Ambonia, which would have included a rich mangrove flora.

Scientists theorize that the earliest mangrove species originated in the Indo-Malayan region due to the fact that more mangrove species are present in this region than anywhere else in the world. Due to the unique floating propagules and seeds, early mangroves spread westward by ocean currents to India, East Africa and eastward to the Central and South America during the upper Cretaceous period and lower Miocene epoch (66 & 23 million years ago). This may explain why fewer and similar colonizing species, while those of Asia, India and East Africa contain a full range of mangrove

species. Geological history and evidences show that mangroves appeared between Eocene and Oligocene period (30-40 million years ago). Plant remains or fossils of major mangrove genera like *Rhizophora*, *Nypa* and others provide important clues in this matter (Subramonian, 2002).

Mangroves and its products had a significant place in the overseas trade between Mediterranean countries and India since the days of Magasthenese (312–231 BC) (Vannucci, 1989). The Greeks, Romans, Venetians, Portugese and Omanis, also had direct trade with the west coast of India. Travelogues of ancient merchants and voyagers contain descriptions of Indian mangrove forests ‘growing in the sea’ as marvelous, incredible segments along the coast.

The first scientific account of the mangroves of Kerala by Van Rhee (1678 – 1703) in his epochal work ‘**Hortus Indicus Malabaricus**’, described the plants of the Malabar Coast, with the help of local experts during the later half of the 17th century. Blasco (1975), while dealing with the ‘Mangroves of India’, stated that there are only vestiges of mangroves in Kerala. Many floras, district Gazetteers and publications contained references to mangroves of Kerala (Ramachandran & Mohanan, 1990) and that of Kollam in particular (Mohanan, 1984).

2.2 DISTRIBUTION AND DIVERSITY OF MANGROVES: WORLD

Globally, mangroves are distributed in two groups: the New World Group and the Old World Group. The New World Group includes the North, Central and South America and West Africa. This group is dominated by 10 mangrove species, which are not found in the Old World Group. The Old World Group consists of three subgroups viz., the Persian, Gulf-Madagascar and the Indo-Malaysian group (represents mangroves of Pakistan, Bangladesh, India, Burma, Indonesia, North Australia, Celebes and Papua

New Guinea). This group is dominated by 65 species, which are not found in the New World Group.

Considering the distribution of mangrove forests all over the world, two zones are distinguished, *viz.*, the eastern zone consisting of East African coast as well as Pakistan, India, Burma, Malaysia, Thailand, Philippines, Southern Japan, Australia, New Zealand, the Southern Pacific Archipelago, and the western zone comprising the Atlantic Coast of Africa and the Americas including the Galapagos Islands (Chapman, 1970, 1975; Davis, 1940).

The global extent of mangroves has been only roughly estimated due to insufficient data, and loss due to constant natural anthropogenic interferences. In many developing countries, the area covered by mangroves is decreasing rapidly due to human intervention and reclamation of mangrove wetlands for other purposes. In some countries there has been intensive afforestation of mangroves for the purpose of coastal protection. World over, the mangroves cover 14 million ha., distributed in 80 countries with tropical and subtropical forests (Chapman, 1976). According to Silas (1987), worldwide mangroves occupy about 171,000 km². Reliable estimates range from 10 million ha (Bunt, 1992) to 14.2 million ha. (Lacerda *et al.* 1993) and 17 million ha (Hamilton *et al.* 1989) to as much as 24 million ha (Twilley *et al.* 1992), between 15 and 30 million ha. (Lacerda *et al.* 1993). The largest mangrove areas occur in Indonesia, Brazil, Australia and Nigeria. The species richness of the Asian mangrove forests is also greater. Two of the world's largest mangroves are the famous Sunderbans of India and the Niger delta in Africa. Till date, the extent of mangroves in the world have not been surveyed thoroughly, hence, the estimated area under world mangrove zones varies remarkably from one publication to another. The available area under mangrove swamps in the Indo-

Pacific region has been estimated about 102,631 km², and of the adjoining flat lands and the back mangroves are included, this figure may exceed a little more.

Geographically, there are two groups of mangroves, viz., the Indo-West Pacific and the New World-West African (Chapman, 1976). Countries with extensive mangrove resources include the east and west coasts of Africa, Atlantic and Pacific coasts of America and the nations of South East Asia and the Pacific. Brazil, Indonesia, Australia, India, Bangladesh, Vietnam, Malaysia, Myanmar, Thailand, Nigeria, USA and Philippines, are countries with vast stretches of this unique ecosystem.

Mangrove swamps are found along tropical and sub tropical coastlines throughout the world, usually between 25⁰N and 25⁰S. Their limit in the northern hemisphere generally ranges from 24⁰N and 32⁰N, depending upon the local climate and the southern limits of freezing weather (Mitch & Gosselink, 1986). They reach their maximum development and luxuriance in parts of South East Asia, Malaya, Sumatra and parts of Borneo. One or more tolerant species have penetrated into the warm temperate zones of both the hemispheres and even on desert shores as scrub thickets. Even in a continuously humid climate, the number of mangrove species decreases with distance from the equator. The maximum number of species is found on the coasts of Malaya, Indonesia and New Guinea (Rao, 1987). There is only one species in Japan, in Southern Australia and in Northern New Zealand (Chapman, 1977). Mangroves are more extensive along the Indo-Pacific shores and the most extensive mangroves of the world are associated with the river deltas entering the Bay of Bengal, straits of Malacca, Southern Borneo, New Guinea, Thailand and adjoining territories of the east (Anonymous, 1978).

The world mangrove zones are mainly restricted to the Indo-West Pacific region of the Old World. The mangrove vegetation requires fine alluvial mud-flat soils

composed of fine silt and clay particles, high seasonal rainfall, and lowest temperature up to 20°C. The most important mangroves are distributed in South East Asia, South-East Africa and Australia; they are extended within the tropics and subtropics, latitude 32°N to 33° S and the extreme southern limit is Corner Inlet (38° 45') on the Victorian Coast of Australia. In the New World, the mangroves are distributed in Louisiana (North America), Pacific Coast (N. W Mexico), Bermuda Islands and Pacific Coast of South America (Macintosh, 1984).

World over, the mangrove flora that comprises arborescent species of forestry importance is confined to few families, viz., Rhizophoraceae, Combretaceae, Avicenniaceae, Verbenaceae, Meliaceae, Sonneratiaceae, Sterculiaceae, Euphorbiaceae, Theaceae and Pelliceraceae. In the supra-littoral and inter-terrestrial zones, where brackish water conditions prevail, there are species that occur in the mangrove habitat proper, but which are not restricted to it. e. g., *Acrostichum aureum*, *A. speciosum* and *A. danaefolium*.

Compared to tropical forests, sixty nine species, which constitute the mangrove forests is very small. This is attributed to the extreme physical conditions in the littoral area, which require special physiological and morphological adaptations. Mangroves do not form a homogenous taxonomic group, but rather are to be viewed as an ecological convergence of various groups. They belong to different families, which may not be closely related in a phylogenetic sense, but may have in common, a number of special characteristics such as pneumatophores, stilt roots and viviparous seedlings (Dagar *et al.* 1991). Accordingly, in tidal forests twenty families from 14 orders are found (Duke, 1992). Most of the species belong to Combretaceae (order: Myrtales; genera: *Conocarpus*, *Laguncularia*, *Lumnitzera*, *Pemphis*, *Osbornia* & *Sonneratia*),

Rhizophoraceae (order: Rhizophorales; genera: *Rhizophora*, *Bruguiera*, *Ceriops* & *Kandelia*) and Avicenniaceae (order: Lamiales; genus: *Avicennia*). Mangrove vegetation also includes some ferns (genus: *Acrostichum*) and palms (only one species viz., *Nypa fruticans*). Semi-mangroves/mangrove-associates belong to families like Fabaceae, Apocyanaceae, Bignoniaceae, Lecythidaceae, Malvaceae, Verbenaceae, Rubiaceae, Cluciaceae, Pandanaceae, etc.

Tomlinson (1986) listed 34 species belonging to 9 genera and 4 families as a major component of the mangals worldwide and 20 species from 11 genera and 10 families as minor components. Maximum species diversity is found on the coasts of Malaysia, Indonesia and New Guinea. Although extensive mangals are only found in tropical and subtropical regions, some mangroves also occur as far north as Kijushu Island, Japan (35⁰N) and as far south as Auckland, New Zealand (37⁰S). Geographically, their distribution is centered on the tropical regions of S. America, Africa, India, Asia, Australia and the Pacific, but they also extend to more temperate regions. Moving away from the equator, the diversity of mangrove communities decreases; for example, up to 30 different species of trees occur in mangrove forests in tropical Australia, but only 2 occur in Southern New South Wales and further south, there is only one species in Victoria and S. Australia.

2. 3 DISTRIBUTION AND DIVERSITY OF MANGROVES: INDIA

The area covered by mangroves in India has been estimated approximately 7000 km², which is about 7% of the world's mangroves (Sidhu, 1963). Blasco (1977) indicated the total area of mangroves in India to be 3,565 km², the largest areas being in West Bengal (Gangetic Delta) with 2000 km² and the Andaman Nicobar Islands with 1000km². The Ganga-Brahmaputra delta in India and Bangladesh supports one of the largest areas

of mangroves viz., the Sunderbans while the Mahanadi, Godavari and Krishna deltas also have good mangrove forests (Ananthakrishnan, 1982). According to the status report of Govt. of India, (Anonymous, 1987), the total area of mangroves in India has been reported to be 6,740 km². Both these reports do not include several areas like Goa, Karnataka, Konkan and Kerala of South West coast of India. This 6,470 km² of Indian mangroves constitutes only 7% of the world mangroves (Krishnamurthy *et al.* 1987), and 80% of the total Indian coastline (Untawale, 1987). The area wise mangrove forest distribution in India has been thoroughly reviewed (Deshmukh, 1991).

Of the country's total area under mangrove vegetation, 70% was recorded on the east coast, and 12% on the west coast. The extent of mangroves along the east coast of India is larger than that of the west coast because the terrain in the former has a gradual slope along the west coast (Untawale, 1987). The Andaman & Nicobar Islands account for 18% of the country's total mangrove area (Krishnamurthy *et al.* 1987; Kathiresan, 1995a). The mangroves have a vast existence on the east coast of India, due to the nutrient-rich alluvial soil formed by Ganga, Brahmaputra, Mahanadi, Godavari, Krishna and Cauvery rivers and a perennial supply of fresh water along the deltaic coast.

Detailed study of the state wise distribution and species composition along the Indian coastline has been done by RSAM (1992). The Department of Space, Govt. of India has mapped the area under mangroves using satellite data with 83-90 % accuracy, though the extent does not match with earlier data. According to the satellite data, total mangrove areas of the country have been estimated to be 4,474 km², against 6,740 km² as reported earlier (Krishnamurthy *et al.* 1987). The low values of mangrove area reported from satellite data may be due to (a) reduction in the mangrove area; (b) mangrove area smaller than 25 ha. were not mapped; and (c) mixing of mangroves with adjoining forest

areas, especially in the Andaman Nicobar islands (RSAM, 1992) (Table. 2. 1).

Investigations conducted by Blatter (1905), Ferrington (1906), Cooke (1906), Venkateshwaralu (1944), Navalkar (1973), Navalkar & Bharucha (1948-1950), Rajagopalan (1952), Mathauda (1957), Qureshi (1957), Waheed Khan (1957), Rao (1959), Kulkarni & Junagad (1959), Khan (1960, 1964), Sidhu (1961, 1963, 1975 a, b), Rao *et al.* (1966), Venkateshan & Natarajan (1987), Rao & Sastri (1972, 1974), Mehr-Homji (1973), Blasco and Caratini (1973), Blasco *et al.* (1975), Dwivedi *et al.* (1975), Joshi *et al.* (1975), Chapman (1970, 1976), Untawale (1984 a, b, 1987),

Table 2. 1 Mangrove Forest Areas in India Reported by Various Authors

Name of States/Union Territories	Location	Area in Sq. km	Area in Sq. km	Area in Sq. km
Andaman and Nicobar Islands	-	1,190	1190	770
West Bengal	Sunderbans, South 24- Paraganas	4200	4200	1619
Orissa	Mahanadi Delta, Bhitarkanika & Manipura estuary	215	150	187
Andhra Pradesh	Coringa, Godavari & Krishna Estuarine Delta	251	200	480
Tamilnadu	Pichavaram, Thanjaore	150	150	90
Gujarat	Narmada, Tapi Estuaries, Gulf of Cambay, Saurashtra and Kutch	260	260	1166
Maharashtra	Bombay, Ratnagiri, Malvan, Devgad & Vijayadurg	350	330	138
Goa	Mandovi-Zuari Estuary	38	200	5
Karnataka	Kalinadi, Coodapur, Harnover, Malpe	90	60	19
Kerala	Cochin, Vembanad, Quilon, Trivandrum, Cannanore, Kozhikode, Kotayam	16	Sparse	Sparse
Total		6740	6,740	4,474

Source : Krishnamoorthy *et al.*(1987); Nayak, (1993); Banerjee & Gosh, (1998)

Untawale and Parulekar (1976, 1978), Untawale and Wafar (1984-1985), Untawale *et al.* (1980), Bandyopadhyay (1984, 1985, 1986, 1987), Rao (1987 a, b), Vannucci (1989, 1991), Badarudeen and Sakkir (1998), Badarudeen *et al.* (1996, 1997) include morphological, ecological, physiological, phytogeographical and geochemical studies of Indian mangroves.

Sunderbans in West Bengal (taken together with Bangladesh) has the largest area of 4,200 km² (Krishnamurthy *et al.* 1987), which forms the largest single block of mangroves in the world. It is the only mangrove forest in the world, having among its denizens, the famous Royal Bengal Tiger (*Panthera tigris*), and is famous for its richness and diversity of mangrove vegetation. The forest is now largely confined to a number of islands situated on the east of the Maltah River (Scott, 1989). Bagla and Menon (1989) have reported an area of 66, 261 ha. of mangroves in the Andaman-Nicobar islands through remote sensing. Gujarat has the second largest area under mangroves (1,166 km²) according to the remote sensing data (IRSD). Mangroves of Karnataka cover an area of 6,000 ha. The remaining mangroves are scattered in Orissa (150 km²), Andhra Pradesh (200 km²), Goa (200 km²), Karnataka (60 km²), Maharashtra (330 km²) Gujarat (260 km²) and isolated patches along the estuaries of Kerala (Mohanani, 2000).

Geographically, mangroves of the Indian subcontinent extend from southern tip of Sri Lanka and Nicobar Islands in South to 24° N latitude in the Indus delta. In India, mangrove diversity is found in the Andaman and Nicobar Islands, Sunderbans in the Gangetic delta of West Bengal, Mahanadi deltaic complex of Orissa coast, Coringa, Godavari and Krishna delta of Andhra Pradesh, Cauvery delta and Thanjavur in Tamil Nadu, Narmada and Tapi estuaries, Gulf of Cambay, Saurashtra and Kutch in Gujarat,

Bombay, Ratnagiri, Malvan, Devgad and Vijayadurg in Maharashtra, Mandovi-Zuari estuary of Goa, Coondapur, Hannover and Malpe in Karnataka, and Trivandrum, Quilon, Vembanad, Kochi, Kozhikode, Kannur and Kasaragod in Kerala State.

According to a recent study by the Department of Space, Govt. of India, the mangrove forest areas of coastal states/Union Territories/Islands are as follows: Gujarat (1051.5 km²-26.48%); Maharashtra and Goa (148.4 km² - 3.73%); Karnataka (12.5 km² - 0.31%); Tamil Nadu (30.0 km² - 0.75%); Andra Pradesh (329.7 km² - 8.3%); Orissa (192.9 km² - 4.85%); West Bengal (1434.4 km² - 36.13%) and the Andaman and Nicobar Group of Islands (770.5 km² - 19.4%) etc., is 4,474 km² (Table. 2. 1).

About 6,740 km² littoral region including deltas, estuaries, bay islands and lagoons in India is protected by extensive cover of mangals (mangrove communities), being the third largest formation in the world after Indonesia and Australia. Earlier studies (Bordillon, 1908; Troup, 1921; Qureshi, 1957; Mathauda, 1957; Waheed Khan, 1957; Navalkar, 1959; Lugo and Snedaker, 1974; Blasco, 1975, 1977; Blasco *et al.* 1975; Untawale, 1984 a, b, 1987,1991,1992; Untawale and Jagtap, 1991; Untawale and Wafar, 1984-85; Jagtap *et al.* 1993; Untawale and Parulekar, 1976; Untawale *et al.* 1973, 1980, 1992; MOEF, 1987; Nayak, 1993) have provided valuable information on the distribution of mangroves in India and the need for their conservation.

The species diversity is very low in the Indian mangrove ecosystem due to dominance of large physical forces of saline tidewater and lack of stable substrate. About 116 species of higher plants including a number of economically important species have so far been recorded from Indian mangrove forests (Banerjee *et al.* 1989). Kathiresan (2002) recently reported 13 species of mangroves from Pichavaram mangrove with *Avicennia* and *Rhizophora* being dominant. The most abundant mangrove species are

Avicennia marina (Forsk.) Vierh. *A. alba* Bl., *A. officinalis* L., *Rhizophora apiculata* Bl., *R. mucronata* Lamk., *Bruguiera gymnorrhiza* (L.) Lamk., *B. parviflora* Wt. & Arn. ex Griff., *B. cylindrica* (L.) Bl., *Excoecaria agallocha* L., *Ceriops decandra* (Griff.) Ding Hou, *C. tagal* (Perr.) Rob. *Xylocarpus granatum* Konig., *X. mekongensis* Pierre., *Heritiera fomes* Buch. –Ham. *Sonneratia apetala* Buch. –Ham., *S. alba* J. Sm., *S. caceolaris* (L.) Engl., *S. griffithii* Kurz., *Lumnitzera racemosa* Willd., *Aglaia cucullata* (Roxb.) Pellegrin, *Xylocarpus moluccensis* (Lamk.) Roem. *Aegiceras corniculatum* (L.) Blanco, *Aegialitis rotundifolia* Roxb., *Acrostichum aureum* L., *Kandelia candel* (L.) Druce and *Brownlowia tersa* (L.) Kosterm. The most extensively occurring palms and grasses are *Phoenix paludosa* Roxb., *Nypa fruticans* (Thunb.) Wurumb. *Porteratia coarctata* (Roxb.) Tateoka and *Myriostachya wightiana* (Nees ex Steud.) Hook. f. Seven species of orchids and 3 species of ferns have also been recorded in the mangrove forests. There are also a number of climbers, creepers and shrubs, in addition to the numerous algal and fungal species that occur in the wet forest floor and tree trunks (Banerjee & Gosh, 1998).

The Indian mangroves comprise approximately 59 species of higher plants from 41 genera belonging to 29 families (Deshmukh, 1991; Untawale, 1998). Of these, 32 species belonging to 29 families are present along the West Coast. *Sonneratia caceolaris*, *Suaeda fruticosa* and *Urochondra setulosa* have been reported from the west coast. Species like *Ceriops decandra*, *Xylocarpus*, *Lumnitzera littoria*, *Nypa fruticans*, *Phoenix paludosa* and *Cerbera manghas* are limited to the east coast. Of the 60 species existing in Indian mangrove habitats, 12 are critically endangered, 42 endangered and 3 vulnerable, which deserve immediate attention (Anonymous, 1997). Sunderbans mangrove ecosystem had been studied for its biodiversity (Kalyan Chakraborti, 1993). The common

species in Indian coastline are *Rhizophora apiculata*, *Ceriops tagal*, *Bruguiera gymnorhiza*, *Lumnitzera racemosa*, *Sonneratia apetala*, *Acanthus ilicifolius*, *Avicennia marina*, *A. officinalis*, *Excoecaria agallocha* and *Acrostichum aureum*. Thirty-nine species of true mangroves and about 25 mangrove associates occur in the coastal and inland regions. *Scyphyphora hydrophyllaceae* is a rare mangrove reported from India.

2.4 DISTRIBUTION AND DIVERSITY OF MANGROVES: KERALA STATE

Kerala state, with a coastline of 590 km, is endowed with a long stretch of backwaters and a series of lagoons running parallel to the sea, separated by a strip of land varying in width from a few hundred meters to several kilometers. The mixing of tidal waters from the sea and freshwater inflow from 41 west flowing rivers, create a congenial environment for the development of mangroves along the fringes of these backwaters and estuaries. It is estimated that Kerala once supported about 70,000 ha of mangroves along its coast (Ramachandran *et al.* 1986; Ramachandran & Mohanan, 1987; Chand Basha 1991, 1992; James *et al.* 1997), which has dwindled at present to an area of about 1700 ha. as relics of the past. An earlier account of the mangroves of Kerala coast is available in the works of Troup (1921) and Gamble (1915-1936). Detailed comparative study on the hydrography and species composition in three mangrove ecosystems of Kerala has been done earlier (Thomas & Fernandez, 1993). A review of data on the district wise distribution of mangroves of Kerala (Chand Basha 1991, 1992) shows that more area under mangroves still exist in the northern districts, particularly Kozhikode and Kannur (Table. 2. 2). Of the total area under mangroves, 88 % (approximately 15 km²) is under private ownership, which has started dwindling due to developmental activities in this

Table. 2. 2 Distribution of Mangrove Vegetation in Kerala Coast

Name of District	Undisturbed Area (ha) *	Degraded/ Developing Area (ha)**	Potential Area (ha)***	Total Area (ha)
Thiruvananthapuram	-	8	15	23
Kollam	10	20	28	58
Kottayam	5	12	63	80
Alappuzha	-	60	30	90
Ernakulam	53	57	150	260
Kozhikode	20	120	153	293
Malappuram	-	2	10	12
Kannur	55	302	398	755
Kasaragode	5	24	50	79
Total	148	605	897	1650

* **Undisturbed areas:** Areas with pure well developed mangrove vegetation

** **Degraded/Developing areas:** Areas with sparse growth of mangroves due to anthropogenic activities, and areas with very poor mangrove vegetation

*** **Potential areas:** Land/shallow water bodies adjoining mangroves with very few mangrove species and pioneer mangrove species under succession

sector. Only 12% of the total area (approximately 2 km²) is under the control of various Central/State Government agencies, which lies scattered in various districts in isolated patches. Though the existing mangroves of Kerala are highly localized, species diversity of these mangroves and their associates is comparatively rich. They are confined to upper reaches of the estuaries; lagoons, backwaters and creeks in isolated patches in Veli (Thiruvananthapuram), Ashromom of Ashtamudi estuary (Kollam), Pathiramanal (Alappuzha). Kumarakom (Kottayam), Willington Island, Mangalavanam,

Chellanam, Kannamali, Puthuvypu (Vypeen island) (Ernakulam), and Chettuva (Thrissur) as relics of the past in southern Kerala. In northern Kerala, isolated stretches of thick mangroves are distributed in Tirur, Kadalundi (Malappuram), Beypore, Kallai, Eranhipalam, Korappuzha (Kozhikode), Mahe (Union Territory, GOI), Dharmadam, Eranholi, Anjarakkandy, Thalassery, Valapattanam, Payyannur, Ezhimala, (Kannur), Keeryad island Chittari and Shiriya (Kasaragod). Mangroves are sparsely distributed in eight coastal districts of Kerala, of which Kannur has the largest area (755 ha) followed by Kozhikode (293 ha.), Ernakulam (260 ha.), Alappuzha (90 ha.), and Kottayam (80 ha.).

Studies conducted during the last two decades (Ramachandran *et al.* 1986; Ramachandran & Mohanan, 1987; Chand Basha, 1991, 1992; Mohandas *et al.* 1994; Unni & Jayakumar, 1997; Unni 2002, 2003; James *et al.* 1997) shows that the 14 dominant species of true mangroves of Kerala are *Avicennia officinalis*, *A. marina*, *Bruguiera cylindrica*, *B. parviflora*, *B. sexangula*, *Rhizophora apiculata*, *R. mucronata*, *Kandelia candel*, *Sonneratia caseolaris*, *Acanthus ilicifolius*, *Acrostichum aureum*, *Derris trifoliata*, *Aegiceras corniculatum*, *Excoecaria agallocha* and *Ceriops tagal* out of the 17 species listed, with their nature of distribution in south and north Kerala. *Avicennia officinalis*, *A. marina* and *Sonneratia caseolaris* are dominant in the polyhaline regions while *Bruguiera parviflora*, *Kandelia candel*, *Acanthus ilicifolius*, *Avicennia officinalis* and *A. marina* are common in the mesohaline regions. In the oligohaline regions (with low salinities from 0.5–5‰), *Kandelia candel*, *Sonneratia caseolaris* and *Acrostichum aureum* are the only mangrove species available. Twenty-three semi-mangroves/mangrove associates including 7 herbs, 4 shrubs, 2 climbers, 5 small, 2 medium sized trees and 3 large trees have also been found distributed in southern and northern Kerala. The important mangrove species are

Acanthus ilicifolius, *Acrostichum aureum*, *Aegiceras corniculatum*, *Avicennia marina*, *A. officinalis*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *B. parviflora*, *B. sexangula*, *Ceriops tagal*, *Derris trifoliata*, *Excoecaria agallocha*, *E. indica*, *Kandelia candel*, *Lumnitzera racemosa*, *Rhizophora apiculata*, *R. mucronata* and *Sonneratia alba*, *S. apetala*, *S. caseolaris*. Blasco (1975) recorded *Acanthus ilicifolius* from Quilon backwaters. Thomas (1962) and Rao and Sastri (1974) recorded *Rhizophora mucronata*, *R. apiculata*, *Bruguiera gymnorrhiza*, *Avicennia officinalis*, *Derris trifoliata*, *Acrostichum aureum* and *Acanthus ilicifolius* from the Veli backwaters in Thiruvananthapuram. Kurian (1980) reported the occurrence of *Acanthus ilicifolius*, *Avicennia alba*, *Rhizophora* sp. and *Bruguiera* sp. from the Cochin estuary. Detailed comparative study of the hydrography and species composition in three mangrove ecosystems of Kerala has been done earlier (Thomas & Fernandez, 1993), so also, the geochemistry of sediments (Badarudeen & Sakkir, 1998; Badarudeen *et al.* 1996, 1997). Preliminary survey carried out earlier (Ramachandran *et al.* 1986; James *et al.* 1995, 1997; Unni & Jayakumar, 1997; Unni, 1998, 2002, 2003; Mohanan, 1999) shows that the dominant mangrove species of Kerala are *Avicennia officinalis*, *A. marina*, *Bruguiera parviflora*, *Rhizophora mucronata*, *Kandelia candel*, *Sonneratia caseolaris*, *Acanthus ilicifolius*, and *Acrostichum aureum*; other dominant species associated with the mangroves are *Derris trifoliata*, *Clerodendron inerme*, *Excoecaria agallocha* and *Barringtonia racemosa*.

2.5 ECOLOGY OF THE MANGROVE ECOSYSTEM

It is well known that sediment characteristics limit normal growth and development of different mangrove species and so regarded as a major factor in their spatial distribution, extension and abundance (Ramachandran *et al.* 1986). There is link between physical, chemical and biological processes in the mangrove swamp (Mazda *et*

al. 1990). Studies initiated earlier have been centered on the physicochemical characteristics of major abiotic components such as water and sediments of the mangrove ecosystems (Delacered, 1983; Lafond, 1984; Badarudheen *et al.* 1996). Several workers have reported mangrove sediment characteristics earlier. Davis (1940) gave detailed accounts of soil types in the swamps of southern Florida. The role of different forms of carbon, nitrogen, phosphorus and their seasonal variations on productivity have been investigated by many workers (Aston & Hewitt, 1977; Bowmann, 1977; Brenzonik, 1972; Dugdale, 1977; Rhods *et al.* 1975; Roman & Tanore, 1978; Sankaranarayanan & Panampunnayil, 1979; Shanmukhappa, 1981, 1987; Sivakumar *et al.* 1983; Wagmode, 1987). Water chemistry of mangroves has gathered much scientific attention as it contributes much to the nutrient pool of the adjoining coastal waters. Joshi and Jamale (1975), who studied major inorganic constituents, such as sodium, potassium, calcium and chloride content in mangroves of Terekhol and Chiplum rivers reported that potassium and calcium ions are responsible for developing salt tolerance in mangroves. Physicochemical and biological characteristics of backwater and estuarine sediments have been investigated (Hossain *et al.* 1988; Mishra *et al.* 1993; Murugan & Ayyakannu, 1991; Ramakrishna *et al.* 1987; Reddy *et al.* 1994; Saraladevi *et al.* 1991; Upadhyay, 1988; Vaithyanathan *et al.* 1993; Giridhar *et al.* 2001; Valarmathi *et al.* 2002; Mahapatro *et al.* 2001; Das & Sahoo, 1997; Gouda & Panigrahy, 1992 & 1995; Padmavathi & Satyanarayanan, 1999; Prabhadevi *et al.* 1996; Mondal *et al.* 2001; Balakrishnan Nair *et al.* 1983; Krupadam & Anjaneyulu, 2000). Diurnal variations in physical-chemical properties and primary productivity in Kakinada mangroves were recorded (Selvam, *et al.* 1992).

High fertility of mangrove waters could be attributed to the high quality of water. Concentration of different elements in mangrove waters is regulated by freshwater discharge, seawater intrusion, rainfall and tidal range (Walsh, 1974). The physicochemical conditions of mangrove waters and sediments have also been studied in detail (Ananthkrishnan, 1982; Narayanan *et al.* 2002; Sundararaj & Krishnamurthy, 1975; Karmarkar, 1985; Joshi & Sagar Kumar, 1985; Sahoo *et al.* 1985; Kotmire & Bhosale, 1979; Venugopalan & Rajendran, 1975; Blasco *et al.* 1975; Parulekar, 1985; Selvam *et al.* 1992; Balakrishnan Nair *et al.* 1983, 1984; Joshi & Jamale, 1975; Vareethiah, 2001; Janat Augustine Rosily *et al.* 2002; Quardros *et al.* 2001; Dagar *et al.* 1991; Naskar & Guha Bhaskhi, 1987; Garg *et al.* 1985). Distribution of nutrients in the mangrove sediments has been studied by Venketaswamy Reddy and Hariharan (1986). Sengupta and Choudhuri, (1993) studied the physicochemical properties of soils of Sunderban mangroves. Study of the organic carbon in the sediments is of potential significance for a proper understanding of its flow regime in an aquatic ecosystem. Distribution and seasonal variation of organic carbon in the sediments of Ashtamudi estuary has been reported by Balakrishnan Nair *et al.* 1983. Studies on edaphic factors of mangrove ecosystem have been studied by Suresh Kumar *et al.* (1997) in Pudukkottai mangroves, Kerala. Distribution of mangroves in relation to the soil chemical characteristics of Muthupet, Tamil Nadu has been reported by Gunasekharan *et al.* (1992). Sedimentology and geochemistry of some mangrove ecosystems of Kerala has been reported by Badarudheen and Sakkir (1998), Badarudheen *et al.* (1997), Bhaskara Rao *et al.* (1992).

The species composition of the flora and fauna varies from place to place with

climate (Pannier & Pannier, 1975; Blasco, 1984 a, b), tidal amplitude and current (Dwivedi *et al.* 1975; Lugo *et al.* 1973; Chapman, 1976; Rabinowitz, 1978; Clough, 1984, 1992), nature of the soil (Rao, 1987), drainage (Gopal & Krishnamurthy, 1993), land profile, degree and quality of fresh water input, salinity (Thom, 1982; Walsh, 1974; Chapman, 1976; Mukherjee & Mukherjee, 1978; Lugo, 1980; Cintron & Schaeffer-Novelli, 1983; Frodin, 1985), time of exposure between tides, temperature (Duke, 1992), cloud cover, and wind and wave action.

Lalithambika Devi *et al.* (1992) carried out studies on the zooplankton of southwest coast of India. 95 species of zooplanktons were reported recently in the Pichavaram mangrove by Kathiresan (2002). Qualitative and quantitative distribution of benthic organisms in relation to the physical and chemical properties of the mangrove sediments has been studied in detail (Sunil Kumar & Antony, 1994; Saraladevi & Venugopal, 1989; Bijoy Nandan, 1991; Murugan *et al.* 1980). Kurian (1980) reported the seasonal fluctuations in the faunal biomass. Indian mangroves have a rich soil dwelling biodiversity resources which include micro, meio and macro invertebrates and the various regions of both east and west coast of India need to be thoroughly investigated for their rich biodiversity (Sunil Kumar, 2001). Studies on meiobenthos by Quadros *et al.* (1996) revealed a dominance of nematodes in west coast of India. Kathiresan (2002), reported 40 species of meiobenthos and 52 species of macrobenthos from Pichavaram mangrove.

Investigations on phytoplankton from tropical brackish water estuaries have been carried out by Thressiamma Mathew and Balakrishnan Nair (1980) and Francis and Sunil Kumar (2002). Various marine algae belonging to Cyanophyceae, Rhodophyceae & Xanthophyceae have also been reported (Santra & Pal, 1988; Ramachandran, 1982; Asha *et al.* 2002). Kathiresan (2002), reported 82 species of phytoplankton from Pichavaram

mangrove. Distribution of phytoplankton with respect to various inorganic nutrients has been carried out by Yazdandoost and Katdare (2000).

Marine phytoplankton of the mangrove delta of West Bengal has been investigated by Santra *et al.* (1991), which showed a taxonomic account of 46 taxa of bacillariophyceae, dinophyceae and cyanophyceae. The predominant genera found almost round the year are *Coscinodiscus*, *Rhizosolenia*, *Chaetoceros*, *Biddulphia*, *Pleurosigma*, *Ceratium* and *Protopridinium*. Eighty two species, which constitute 67 species of diatoms, 12 species of dinoflagellates and 3 species of blue green algae, have been reported from the Pichavaram mangroves. The diatoms constitute 72% followed by the dinoflagellates with 15% (Kannan & Vasantha 1992). The phytoplankton has also been studied in relation nutrients of mangrove waters. Natural communities of Pichavaram have been documented with predominance of *Nitzschia*, *Closterium*, *Pleurosigma* spp., *Thalassionema nitzschioides* and *Thalassiothrix frauenfeldii* (Mani 1989,1992). Several species of *Thalassiothrix*, *Chaetoceros*, *Biddulphia*, *Asterionella*, *Melosira*, *Stephanopyxis*, *Hemidiscus*, *Eucampia* and *Coscinodiscus* reported from the mangrove environment of Pichavaram (Sundararaj & Krishnamurthy 1975). In Pichavaram mangroves, the dominant phytoplankton especially diatoms were *Coscinodiscus*, *Biddulphia*, *Chaetoceros*, *Pleurosigma*, *Rhizosolenia* and *Thalassiothrix*. The density of diatoms was also found to be high (Krishnmurthy *et al.* 1987).

Nitrogen fixation by microorganisms has also been investigated in the mangrove ecosystem (Ravikumar, 1995; Lakshmanperumalswamy, 1987; Sengupta & Chaudhuri, 1991; Sengupta & Chaudhuri, 1990, Ramachandran & Venugopalan, 1987; Ramachandra Rao, 1994). Seasonal variations in microflora of mangrove swamps have been reported by Matondkar *et al.* (1980). It was reported that various physiological

groups of bacteria responsible for the degradation of organic matter occur abundantly in association with the detritus (Santha Nair, 1979).

Mangrove ecosystem serves as prime breeding and nursery grounds for many animal species especially for prawns (MacNae, 1968). They serve as custodians of their juvenile stock and as material wealth (Kathiresan, 1995 a; Kapetsky, 1985, FAO, 1988). Importance of mangrove ecosystem in fisheries has been discussed (Hamilton & Snedaker, 1984; Parulekar, 1985; Silas, 1987; Purushan, 1991, Jayaseelan *et al.* 1991; Rajendran & Kathiresan, 1999). Krishnamurthy (1983) has estimated the yield of mangrove cum estuarine dependent fisheries of India. Roughly about 60% of India's coastal marine fish species are dependent on the mangrove estuarine complex. Some of the most common fish of mangroves are species of *Liza*, *Mugil*, *Lates*, *Polynemus*, *Sciaena*, *Setipianna*, *Etroplus*. Kathiresan and Sivasothi (2000) reported 36 sp. of crabs, 33 species of molluscs, 29 species of fishes, 6 species of prawns and 6 species of other crustaceans from the Singapore mangrove environment. Recently Kathiresan (2002) reported 177 species of fishes from the Pichavaram mangrove. Prawns are represented by species of *Penaeus* and *Metapenaeus* while crab resource is mainly *Scylla serrata*. The molluscan fishery of water is mainly *Crassostrea* sp. and *Mytilus* sp. (Dagar *et al.* 1991). Mangrove productivity studies are conducted by many workers (Untwale *et al.* 1977; Pant *et al.* 1980; Krishnamurthy & Sundararaj, 1973; Kathiresan 2002; Das 2002; Purvaja & Ramesh, 2002). The productivity through leaf addition contributes to 25 gC/m²/day. The main contribution by mangroves to the environments is due to the litter fall and the consequent contribution as detritus (Pant *et al.* 1980). In Pichavaram mangroves the GPP was 113 g C/m²/Yr exhibiting natural variability with the environmental forcing factors. In Ennore Creek mangrove primary productivity have elevated to 157 gC/m²/yr due to

anthropogenic activities, primarily thorough the direct discharge of fertilizer effluents. By contrast, a combination of domestic and industrial effluent discharges in the Adayar Estuary mangrove has considerably reduced phytoplankton productivity to 83 gC/m²/yr (Purvaja & Ramesh, 2002).

Distribution of heavy metals in the mangrove environment at Veli, Kerala has been studied earlier by Badarudeen *et al.* (1997). Distribution of heavy metals and organic carbon in the sediments of Madras and Visakhapatnam coasts has been reported earlier by Pragatheeswaran *et al.* (1986). Distribution of trace metals in mangrove sediments of Cochin was reported by Janat Augustine Rosily *et al.* (2002). Heavy metal concentration in water and sediments of Sunderbans has been studied by Kawser *et al.* (2002). Distribution of trace metals in the mangrove flora and fauna of Sunderbans was reported earlier (Chakraborti *et al.* 1993); among the metals zinc showed higher values followed by copper and lead. Ouseph (1987) and Venugopalan *et al.* (1981) reported heavy metal pollution in the sediments of the Cochin estuarine system. The distribution of heavy metal in the Vembanad Lake has been extensively studied by Murthy and Veereyya (1981). Some benthic organisms such as mussels and oysters have accumulation of Zn, higher the permissible limits (Remani, 1979) in specimens collected from the Cochin backwaters.

**ECOLOGICAL STUDIES ON
THE MANGROVES OF
VALAPATTANAM AND THALASSERY
RIVER BASINS**

Thesis submitted to
University of Calicut
in part fulfilment of
Doctor of Philosophy in Botany

Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

92/278

3. 0 MATERIAL AND METHODS

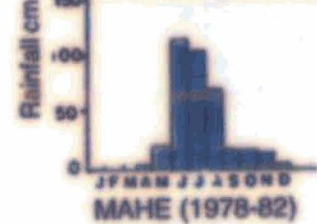
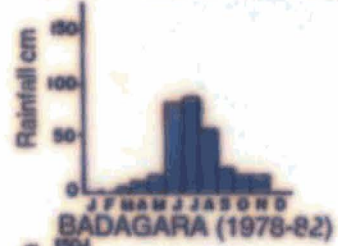
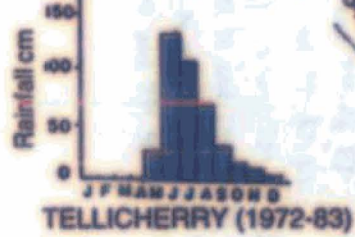
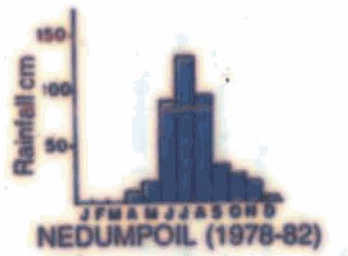
3. 1 SAMPLING

3. 1. 1 STUDY AREA

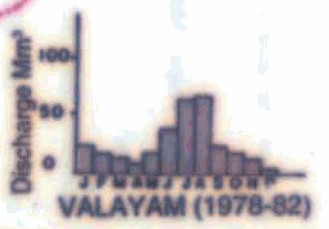
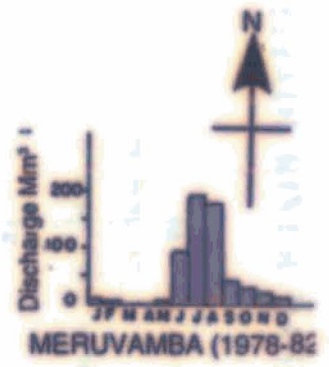
The Thalassery and Valapattanam river basins have been selected for the present study. Both the Thalassery and Valapattanam river basins are located in Kannur district of Kerala State. The Thalassery River basin lying between $75^{\circ} 18'$ - $75^{\circ} 33'$ E longitude and between $11^{\circ} 45'$ and $11^{\circ} 46'$ N latitude has a basin area of 132 km^2 and a length of 28 km (Fig. 3. 1). The Valapattanam river basin lying between $75^{\circ} 18'$ - $75^{\circ} 30'$ E longitude and between $11^{\circ} 57'$ and $12^{\circ} 0'$ N latitude has a basin area of 1867 km^2 and a length of 110 km (Fig. 3. 2). Both of them originate from the Kannothe elevation of the Western Ghats and drains into the Arabian Sea.

3. 1. 2 SAMPLING SITES

Detailed survey was conducted along the Thalassery and Valapattanam river basins, right from the upstream freshwater zone down to the estuary. Based on variations in salinity, tidal action, sources of pollution, diversity and distribution of mangroves, six sampling sites were selected in Valapattanam River and four in Thalassery River. The different sites were selected in such a manner that at each sampling station, both mangrove as well as non-mangrove areas were located, in order to have a clear comparison of the impact of mangroves on the ecosystem and *vice-versa*. As there is no tidal action and salinity upstream, such a separation was not made in the upstream region. The details of the sampling sites in the Thalassery and Valapattanam river basins are given in Figures 3. 3 & 3. 4 respectively. The descriptions of the sampling sites are as follows:



MEAN MONTHLY RAINFALL



MEAN MONTHLY DISCHARGE

Fig. 3. 1 Thalassery River Basin

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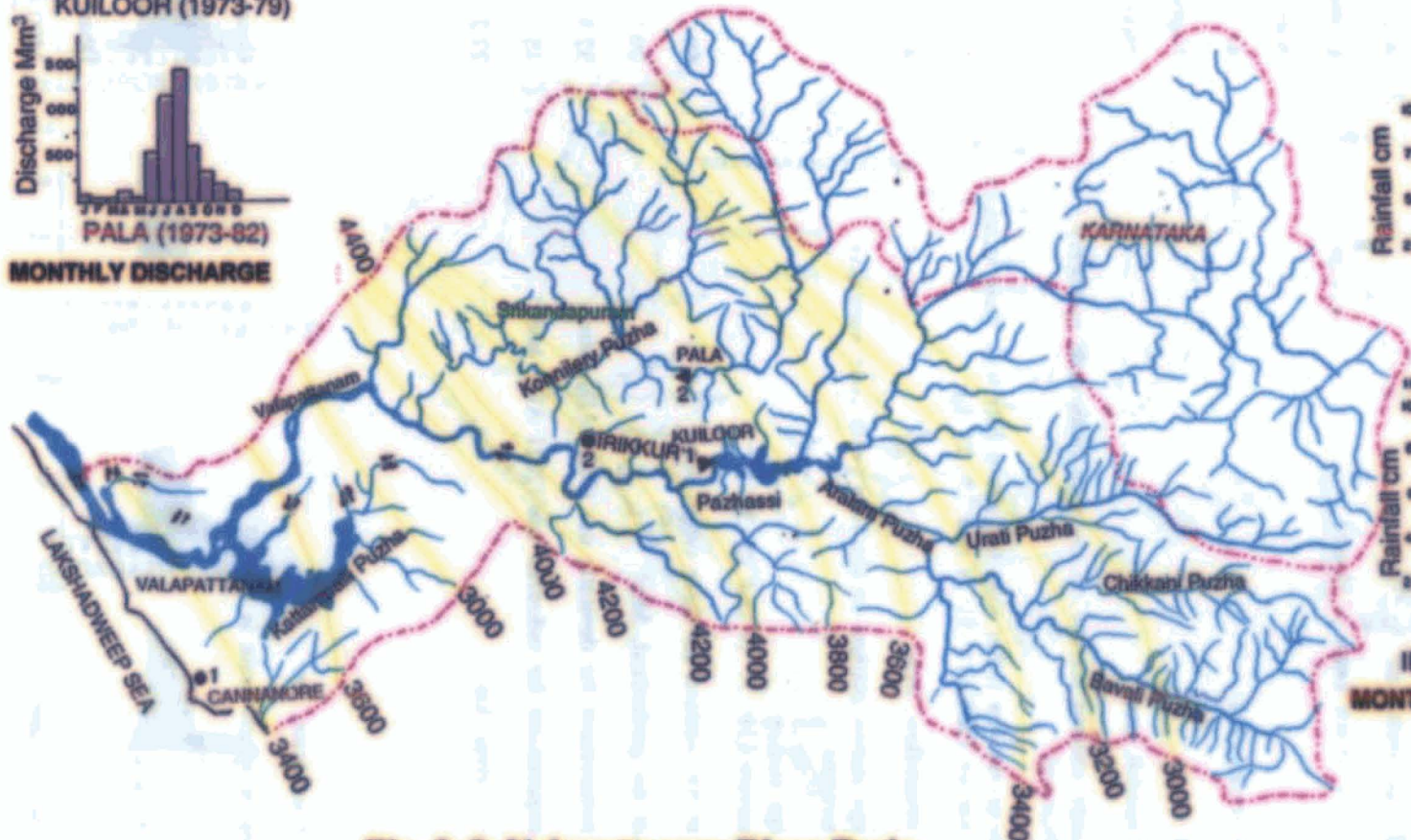
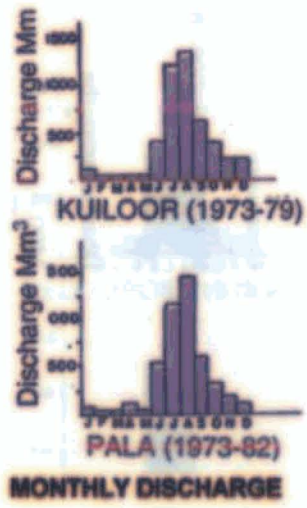


Fig. 3.2 Valapattanam River Basin

40. B. 21

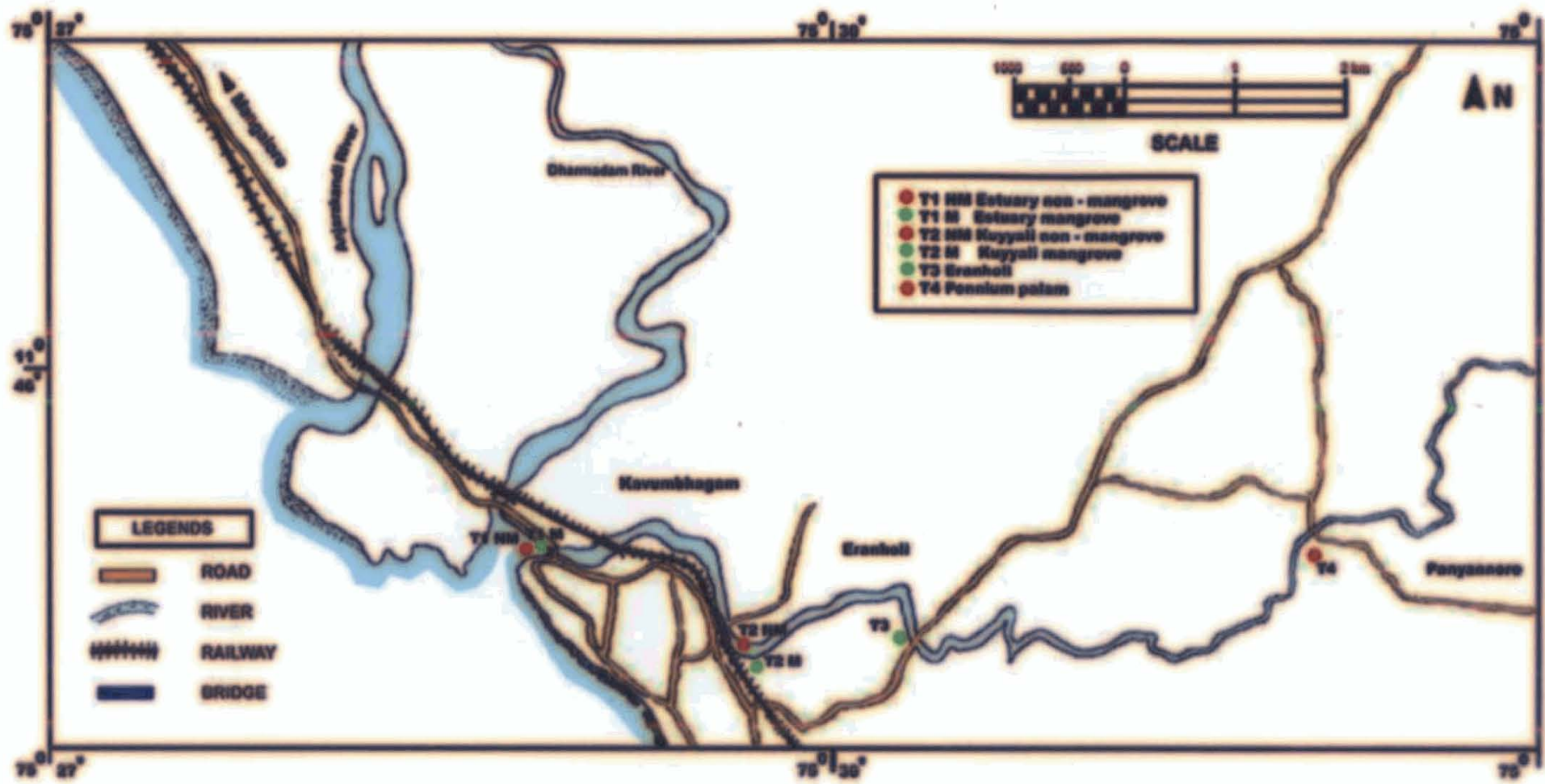


Fig. 3. 3 Sampling Sites in the Thalassery River Basin

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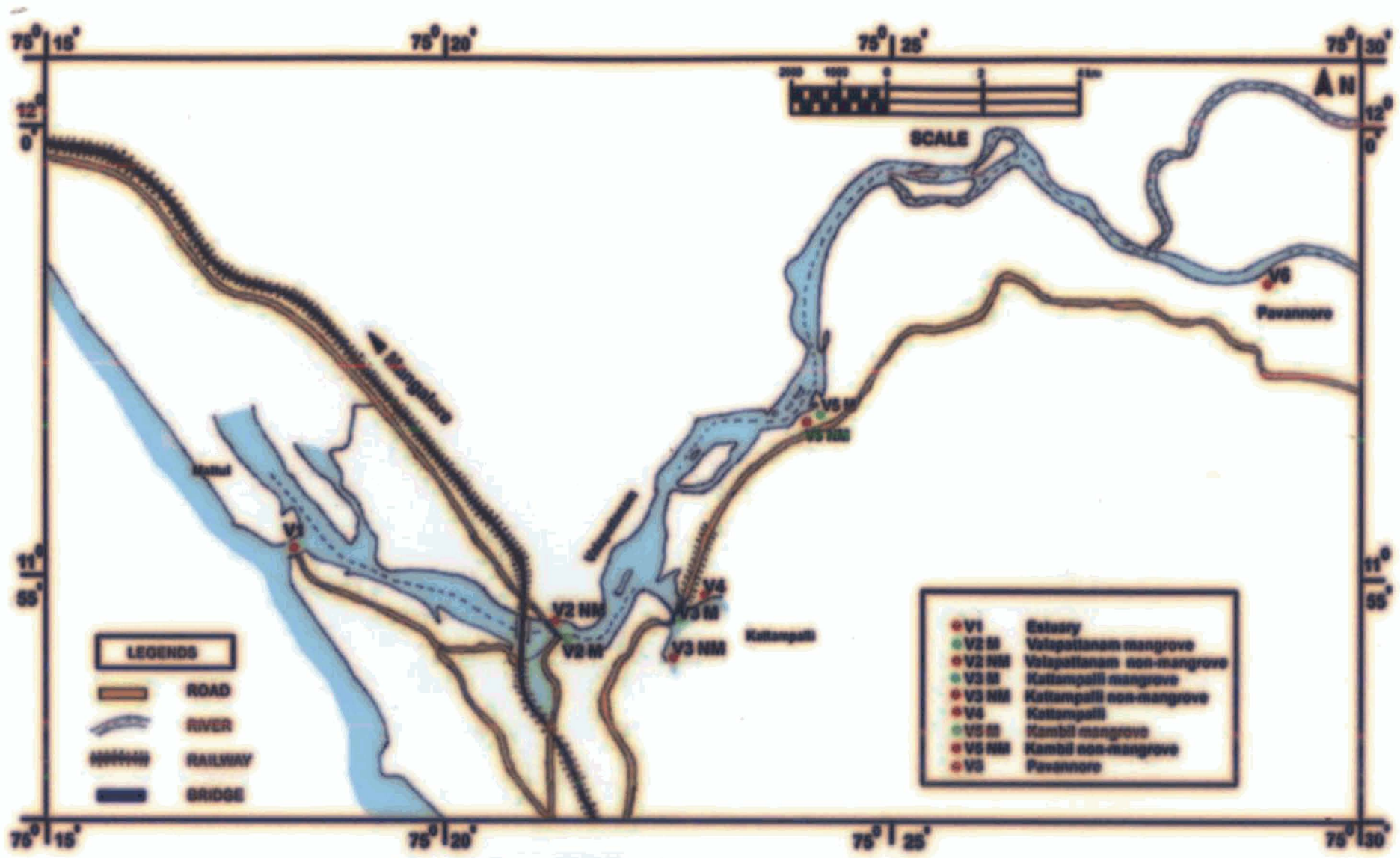


Fig. 3.4 Sampling Sites in the Valapattanam River Basin

40.12

83

3. 1. 2. 1 Thalassery River

Site – I (T1M &T1NM) (Plate 3. 1)

This is the downstream estuarine area of Thalassery River. The bar mouth is common for both the Thalassery and Dharmadam rivers. This site is well influenced by the tidal rhythms. Dense mangrove vegetation was noticed in this site. Fishing is intensively carried out in this region. Another important feature noticed in the site was the culture and capture of the bivalve, *Meretrix meretrix*. A portion of the mangrove area was partly destroyed and reclaimed for the construction of a hospital. Department of Forests and Wildlife, Govt. of Kerala has done mangrove afforestation trials at this site. A non-mangrove area was also selected at the site (T1 NM).

Site – II (T2M &T2NM) (Plate 3. 2)

This is the second downstream point located approximately 2.5 km off the estuary with dense mangrove vegetation, which is near to the Kuyyali Bridge (T2M). A non-mangrove area (T2 NM) at a distance of 0.5 km from T2M was also selected on the opposite side of the bridge. Even though dense mangrove vegetation was present at this site, a major portion of this has been destroyed for the doubling of the Shoranur-Mangalore railway line. The non-mangrove area is also under the stress of reclamation and construction activities. This site is famous for the culture and capture of the edible bivalve *Crassostrea madrasensis*. The local people use this area for waste disposal.

Site – III (T3)

This site is located 4.5 km off the estuary, having tidal action and salinity ingress. Only sparse mangrove vegetation occurs here (T3). Slackening of lime was practiced long in this site. Coconut husk retting was also practiced till 2001 at this site. Timber industry is situated along the bank of this river at this site.

41.A

24



Plate 3.1 A Mangrove Area in Thalassery Estuary (T1 M)



Plate 3.2 Reclaimed Mangrove Area in Kuyyali (T2 M)

Site – IV (T4)

This is the last site selected for study in the Thalassery River (T4), which lies 8 km off the estuary, where there is no tidal action and salinity ingress. This is a freshwater site predominating with typical freshwater vegetation. Domestic sewage and detergents used for washing, contributes to the pollution in this part of the river.

3. 1. 2. 2 Valapattanam River

Site – I (V 1)

This site known as Azhikkal, represents the bar mouth, showing typical estuarine habit. This is an estuarine non-mangrove area. In this region, there is circulation and mixing of saline and fresh water due to tidal action. There is a plywood industry located on the bank of the river. Intensive fishing is practiced in this site. This site is located 2 km away from Western India Plywood Factory.

Site – II (V2M & V2NM) (Plate 3. 3)

This site is located 5 km upstream off from the estuary, which is also susceptible to tidal action. This site is located near the Valapattanam Bridge. This area is well known for its luxuriant mangrove vegetation. The saline water of this area is utilized for wood seasoning. The major pollutants of this site are slaughterhouse wastes, domestic sewage and waste from restaurants. Coconut husk retting and separation of coir fibre from retted husk is practiced here (Plate 3. 4). The non-mangrove area (V2 NM) was also fixed opposite to this bridge at a distance of 0.5 km from V2M. Sand mining is a major activity noticed in this site.

Site - III (V3M & V3NM) (Plate 3. 5)

The site is located 9 km upstream off the estuary. This portion of the river is known as Kattampally. Both mangrove and non-mangrove areas were selected on either

421A

35



Plate 3.3 Dense Mangrove Area Near Valapattanam Bridge (V2 M)



Plate 3.4 Coconut Husk Processing in the Mangrove Site Near Valapattanam Bridge (V2 M)

side of the Kattampally Bridge cum regulator. The V3 NM site is fixed 0.5 km from the V3M. This area is also influenced by tidal action and consequent salinity ingress. Moderately dense mangrove vegetation was noticed here.

Site – IV (V4) (Plate 3. 6)

This site is also located in Kattampally at a distance of half kilometer away from the third site (*i.e.*, 9.5 kilometer off estuary). Due to the presence of a regulator in Kattampally Bridge, this site is less influenced by tidal action and salinity ingress. This area is polluted due to deposition of slaughterhouse wastes. Fishing is also practiced in this site. Till the end of 2001, the shutter had a leakage, which contributed to the inflow of saline water from the other side of the regulator. This shutter was repaired in 2002 and the problem of salinity intrusion is solved. A small mixing of saline water occurs through the channel created for the service of boats. Only semi-mangroves were noticed here.

Site – V (V5 M & V5 NM)

The site known as Kambil is located 13.5 km off the estuary having tidal action and salinity intrusion. Both mangrove and non-mangrove areas were selected. V5NM site is fixed at a distance of 0.5 km from V5M. Dense mangrove vegetation is noted in this site. The area is also polluted due to the deposition of slaughter wastes and domestic sewage. In the non-mangrove area, intense sand mining is practiced.

Site – VI (V6)

This upstream freshwater site with no noticeable tidal action located 28.25 km off the estuary is known as Pavannur, the last location of study. Sand mining is the major activity in this area.

3. 1. 3 SAMPLING SEASONS

Sampling was carried out seasonally *i. e.*, the pre-monsoon (April- May), the



Plate 3. 5 A Mangrove Area in Kattampally (V3 M)



Plate 3. 6 A Semi -Mangrove Area in Kattampally (V4)

monsoon (July-August) and the post-monsoon (November- December) seasons during 1999 – 2001. Since the work was initiated only during April 1999, only pre-monsoon and monsoon samples were taken for study during the year.

3. 1. 4 SAMPLE COLLECTION AND PRESERVATION

Water and sediment samples were collected during the high tide. Water samples for physicochemical and biological analysis were collected in acid washed, dried, polyethylene bottles. The samples for bacteriological analysis were collected in pre-sterilized (aseptic) bottles and preserved by freezing *in situ* in an icebox at 4⁰C. Temperature and dissolved oxygen were measured *in situ*. The samples were preserved as per APHA (1995) (Table3. 2). For dissolved oxygen measurements, water was collected directly in 300 ml BOD bottles. The samples for testing ammonia were acidified with 0.8 ml conc. sulphuric acid/litre. For the analysis of sodium, potassium, iron and sulphate, the samples were acidified with 1 ml of conc. nitric acid/litre. The samples for phosphate analysis were freezeed and preserved. Filtered raw samples were collected in 100 ml acid washed polyethylene bottles and preserved by acidifying with 0.5 ml conc. HNO₃, for heavy metal analysis. Sediment samples for physicochemical and biological analysis were collected in acid washed polyethylene bottles using the Van Veen Grab. A portion of the sediment was sieved through metal sieves of 0.5-0.6 mm and 0.2 mm mesh size and preserved as given in Table 3. 1 and stored separately for analysis of benthos, after preservation in 10% formalin. (Trivedy & Goel, 1986). Fish specimens for identification were collected and preserved in 5% formalin. A small portion of the wet sediment sample was used for the estimation of moisture content. The remaining samples were air-dried, pulverized and sieved through 2 mm and 0.5 mm sieves and stored separately. The soil sieved through the 2 mm sieve was analyzed for

monsoon (July-August) and the post-monsoon (November- December) seasons during 1999 – 2001. Since the work was initiated only during April 1999, only pre-monsoon and monsoon samples were taken for study during the year.

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soil texture and other chemical parameters. Soil sieved through 0.5 mm sieve was analyzed for organic carbon and metals.

Table 3. 1 Methods of Preservation of Sediment Samples

Sl. No	Parameters	Preservation
1	Moisture content	Analyzed immediately
2	Mechanical analysis, organic carbon	Drying at 105 ⁰ C in a hot air oven
3	pH	Analyzed immediately
4	Nitrate	Analyzed fresh samples immediately
5	Extractable sodium, potassium, calcium, magnesium, iron, manganese, copper & zinc	Air drying (<40 ⁰ C)

Table. 3. 2 Methods of Preservation of Water Samples

No	Parameters	Preservation Methods	Maximum Storage Time
1	Temperature	-	Measured immediately
2	Colour	Refrigeration	48 hours
3	Turbidity	Immediately /In dark, refrigeration	24 hours
4	pH	-	2 hours
5	Electrical Conductivity (EC)	Refrigeration	28 days
6	Salinity	Immediately/use wax seal	6 months
7	Dissolved Oxygen (DO)	Titration can be delayed, after acidification for a maximum of 8 hours	Immediately titrated
8	Biological Oxygen Demand (BOD)	Refrigeration at 4 ⁰ C	6 hours
9	Hardness	Add HNO ₃ to pH <2	6 months
10	Fluoride (F ⁻)	No preservation required	28 days
11	Ammonia-Nitrogen (NH ₄ - N)	Immediately/add H ₂ SO ₄ to pH < 2, refrigeration	7 days
12	Nitrite-Nitrogen (NO ₂ - N)	Refrigeration	None

13	Nitrate - Nitrogen (NO ₃ - N)	Refrigeration	As soon as possible
14	Phosphate – Phosphorus (PO ₄ - P)	Refrigeration	48 hours
15	Silica	Refrigeration	28 days
16	Sulphate (SO ₄)	Refrigeration	28 days
17	Calcium (Ca ⁺⁺)	Add HNO ₃ to pH <2	28 days
18	Magnesium (Mg ⁺⁺)	Add HNO ₃ to pH <2	28 days
19	Metals	For dissolved metals, filter immediately, add HNO ₃ to pH <2	6 months
20	Total coliforms, Fecal coliforms and <i>E. coli</i>	Refrigeration	Maximum 6 hours

3. 2 ANALYTICAL METHODS

Physicochemical, biological and bacteriological parameters of the collected samples were analyzed following Standard Methods for Analysis of Water and Wastewater (APHA, 1995), Trivedy and Goel (1986), Manivasakam (1996), Abbassi (1998), Trivedy *et al.* (1987), and Pitchai and Govindan (1988).

Sediment analysis was done following the methods given by Hesse (1971), Jackson (1969), Trivedy *et al.* (1987), Chopra and Kanwar, (1976), Van Loon (1985), and Tandon (1993). Sediment texture was determined as per the method of Chopra and Kanwar (1976). Organic carbon was analyzed following the method of Walkely and Black (1934). The interferences were removed and dilutions were done wherever necessary as per standard procedures.

Identification of plankton and benthos were done according to Kotpal (1972), Biswas (1980), Presscott (1982), Desikachary (1959), Diertrich Uhlmann (1975), Charles Davis (1955), Pierre Fauvel (1953) and APHA (1995). Fishes were identified following the methods of Day (1977-1978), Jhingran (1982) and Munro (1955). Parameters and methods of analysis followed are given in Tables 3. 3 and 3. 4.

For studying mangroves and associated flora, plant samples were collected periodically during the flowering season and identified referring to Gamble (1921-25), Tomlinson (1986), Ramachandran and Nair (1988) and also by comparing with the specimens in the Calicut University Herbarium.

Table 3. 3 Instruments and Analytical Methods Followed for Water Analysis

No	Parameters	Methods	Instrument and Model	Unit
Physical:				
1	Temperature	Thermometry	Mercury filled Thermometer	°C
2	Colour	Photometry	Photometer (Merck SQ 118)	Hazen
3	Turbidity	Photometry	Photometer (Merck SQ 118)	NTU
Chemical:				
4	pH	Electrometry	pH Meter (Systronics 335)	-
5	Electrical Conductivity (EC)	Electrometry	Conductivity Meter (Elico 180)	μ mhos/cm
6	Salinity	Electrometry	Oxygen, Conductivity, Salinity and Temperature Meter (YSI 85)	mg/l
7	Dissolved Oxygen (DO)	Winkler's Azide Modification	-	mg/l
8	Biological Oxygen Demand (BOD)	Winkler's Azide Modification	-	mg/l
9	Total Hardness	EDTA Titrmetry	Titration	mg/l
10	Chloride (Cl ⁻)	Argentometry	Titration	mg/l
11	Fluoride (F ⁻)	Electrometry	Ion Meter (Jenway 3345)	mg/l
12	Ammonia – Nitrogen (NH ₄ - N)	Photometry	Photometer (Merck SQ 118)	mg/l
13	Nitrite-Nitrogen (NO ₂ - N)	Photometry	Photometer (Merck SQ 118)	mg/l
14	Nitrate –Nitrogen (NO ₃ - N)	Photometry	Photometer (Merck SQ 118)	mg/l
15	Phosphate (PO ₄ ⁻ - P)	Stannous Chloride Method	UV-Visible Spectrophotometer (Hitachi 220)	mg/l

16	Silica	Photometry	Photometer (Merck SQ 118)	mg/l
17	Sulphate (SO ₄)	Turbidimetry	Digital Nepheloturbidity meter (Systronics 132)	mg/l
18	Iron (Fe)	Phenanthroline Method	UV-Visible Spectrophotometer (Hitachi 220)	mg/l
19	Sodium (Na)	Flame Photometry	Digital Flame Photometer (Systronics 125)	mg/l
20	Potassium (K)	Flame Photometry	Digital Flame Photometer (Systronics 125)	mg/l
21	Calcium (Ca ⁺⁺)	EDTA Titrimetry	-	mg/l
22	Magnesium (Mg ⁺⁺)	EDTA Titrimetry (Mg by calculation)	-	mg/l
23	Metals	Atomic Absorption	Atomic Absorption Spectrophotometer (Elico 173)	mg/l
Biological:				
24	Chlorophyll	Trichromatic Method	UV- Visible Spectrophotometer (Hitachi 220)	mg/l
25	Productivity	Light and Dark Method	-	gC/m ³ /h
26	Total coliforms	Multiple Tube Fermentation Technique	-	MPN/100 ml
27	<i>E. coli</i>	Indole Test	-	-

Table 3. 4 Methods and Instruments Used for Soil Analysis

No	Parameters & abbreviations	Methods	Instrument and Model	Unit
1	pH	Electrometry	Digital pH Meter (Systronics 335)	-
2	Conductivity (EC)	Electrometry	Conductivity Meter (Elico-180)	mmhos/cm
3	Moisture Content	Gravimetry	-	Percentage
4	Organic Carbon (OC)	Black & Walkley Method	-	Percentage
5	Sulphate (SO ₄)	Turbidimetry	UV- Visible Spectrophotometer (Hitachi 220)	mg/100g

6	Available Phosphorus (A.P)	Stannous Chloride Method	UV- Visible Spectro - photometer (Hitachi 220)	mg/100g
7	Chloride (Cl)	Argentometry	Titration	mg/100g
8	Salinity	Electrometry	Oxygen, Conductivity, Salinity and Temperature Meter (YSI 85)	ppt
9	Exchangeable Sodium (Na)	Flame Photometry	Digital Flame Photometer (Systronics 132)	mg/100g
10	Exchangeable Potassium (K)	Flame Photometry	Flame Photometer (Systronics Digital Flame Photometer 132)	mg/100g
11	Exchangeable Calcium (Ca ⁺⁺)	EDTA Titrimetry	Titration	mg/100g
12	Exchangeable Magnesium (Mg ⁺⁺)	EDTA Titrimetry	Titration	mg/100g
13	Nitrate	Phenol Disulphonic Acid Method	UV- Visible Spectrophotometer (Hitachi 220)	mg/100g
14	Soil Texture	Hydrometry	Hydrometer	Percentage
15	Metal Analysis	Atomic Absorption Spectrophotometry	Atomic Absorption Spectrophotometer (Elico 173)	mg/kg

3. 3 WATER QUALITY

3. 3. 1 PHYSICAL PARAMETERS

The physical parameters studied include temperature, colour, and turbidity.

3. 3. 1. 1 Temperature

Apparatus

Temperature measurements were done *in situ* with mercury-filled thermometer graduated at 0.1 °C increments, and expressed in degree Celsius.

Procedure

The temperature was recorded by dipping the thermometer for sufficient time to obtain a constant value, which was expressed in degree Celsius.

3. 3. 1. 2 Colour

Method

Colourimetry, using Photometer.

Procedure

After the selection of the appropriate mode, the sample was taken in the cuvette of the Spectroquant 118 and the readings were expressed in Hazen Units in whole numbers.

3. 3. 1. 3 Turbidity

Method

Colorimetry, using Photometer.

Procedure

After the selection of the appropriate mode, the samples were taken in the cuvette of the Spectroquant 118 and the readings were recorded in NTU (Nephelo Turbidity Unit).

3. 3. 2 CHEMICAL PARAMETRS

The important chemical parameters analyzed for water include pH, EC, TDS, salinity, hardness, calcium, magnesium, sodium, potassium, iron, sulphate, phosphate, nitrate, nitrite, ammonia, fluoride, silicate, dissolved oxygen and the biological oxygen demand.

3. 3. 2. 1 pH

Method

Potentiometry, using digital pH meter.

Procedure

pH meter was standardized using standard buffer solution of pH 4 and 9.8. pH value of the sample were then measured directly by immersing the electrode in the sample.

3. 3. 2. 2 Electrical Conductivity

Method

Conductometry, using digital conductivity meter.

Procedure

After proper washing of the conductivity cell with distilled water, the conductivity cell was dipped into the samples and readings were expressed in $\mu\text{mhos/cm}$.

3. 3. 2. 3 Salinity

Method

Electrometric method using salinity meter

Procedure

After proper washing of the electrode with distilled water, the electrode was dipped into the sample and reading was recorded. Salinity is expressed in parts per trillion (ppt).

3. 3. 2. 4 Dissolved Oxygen

Method

Winkler's Azide modification method

Principle

Oxygen in the sample rapidly oxidizes the Mn^{2+} to a higher state of valance under alkaline conditions and manganese in higher states of valance is capable of oxidizing iodide ions to free iodine under acidic conditions. The free iodine thus released is equivalent to the dissolved oxygen originally present in the sample, which is measured by titrating against standard sodium thiosulphate solution using of starch as indicator.

Reagents

MnSO_4

Alkali-iodide azide

Conc. H₂SO₄

Starch indicator

Sodium thiosulphate (0.025N)

Procedure

Samples were collected in BOD bottles without air bubbles. Two ml of MnSO₄, followed by 2 ml of azide, was added well below the surface through the walls. The brown precipitate obtained was allowed to settle and 2 ml of conc. H₂SO₄ was added and shaken well to dissolve the precipitate. The sample was then immediately titrated against standard sodium thiosulphate using starch as indicator. Disappearance of the initial dark blue colour indicates the end point.

Calculation

$$\text{DO, mg/l} = \frac{(\text{ml} \times \text{Normality}) \text{ of Sodium thiosulphate}}{\text{Volume of sample taken}} \times 8 \times 1000$$

3. 3. 2. 5 Biological Oxygen Demand (BOD)

Principle

The basic principle underlying BOD determination is the measurement of the DO content of the sample before and after 5 days of incubation at 20^o C. BOD is a measure of great value in the analysis of sewage, industrial effluents and grossly polluted water.

Reagents

Same as for determination of dissolved oxygen

Procedure

Samples in duplicate were taken and one set was fixed immediately with Winkler's reagent and the initial DO is measured titrimetrically. The other set of samples were kept in BOD incubator at 20^oC for 5 days and then analyzed for final DO.

Calculation

$$\text{BOD mg/l} = D_1 - D_2$$

Where, D_1 = Initial DO of the sample

D_2 = DO of the sample after 5 days

3. 3. 2. 6 Total Hardness

Method

EDTA titrimetry

Principle

In alkaline solution, EDTA reacts with calcium and magnesium to form a soluble chelated complex. Calcium and magnesium ions develop wine red colour with Eriochrome Black T under alkaline condition. The pH has to be maintained at 10 during the titration. When EDTA is added as a titrant, calcium and magnesium divalent ions get complexed resulting in a sharp change from wine red to blue, which indicate the end point of the reaction.

Reagents

Standard calcium solution (100 mg/l)

Standard EDTA solution (0.01 M)

Ammonium chloride-ammonium hydroxide buffer (pH 7.0)

Eriochrome Black T indicator

Procedure

50 ml of the water sample was taken and 1-2 ml of ammonia buffer and a pinch of Eriochrome Black T indicator was added to it and titrated against standard EDTA solution until the wine red colour changed to blue.

Calculation

$$\text{Total Hardness, (mg/l) as CaCO}_3 = \frac{V \times M \times \text{Equivalent weight of CaCO}_3}{\text{Volume (ml) of sample taken}} \times 1000$$

V = Volume of EDTA (ml); M = Molarity of EDTA

3. 3. 2. 7 Chloride

Method

Argentometry

Principle

Silver nitrate reacts with chloride to form very slightly soluble white precipitate of AgCl. At the end point when all the chlorides get precipitated, free silver ions react with chromate to form silver chromate of reddish brown colour.

Reagents

Silver nitrate solution (0.028 N)

Potassium chromate (5%)

Procedure

50 ml of the sample was taken to which 2 ml of potassium chromate solution was added. The contents were titrated against 0.028 N silver nitrate solution until a persistent reddish brown tinge marked the end point.

Calculation

$$\text{Chloride (mg/l)} = \frac{\text{ml} \times \text{Normality of silver nitrate}}{\text{Volume of sample taken (ml)}} \times 1000 \times 35.5$$

3. 3. 2. 8 Fluoride

Method

Electrometric method.

Reagents

Standard Fluoride solution (0 - 1 mg/l)

Procedure

After calibrating the instrument with standard fluoride solutions, electrode was dipped into the sample and reading was recorded.

3. 3. 2. 9 Ammonia- Nitrogen

Photometric Method

Procedure

As per the instructions given in the manual, the instrument was set as zero with blank, necessary reagents were added to the samples and the colour formed was measured.

3. 3. 2. 10 Nitrite-Nitrogen

Method

Photometric Method

Procedure

As per the instructions given in the manual, the instrument was set as zero with blank, necessary reagents were added to the samples and the colour formed was measured.

3. 3. 2. 11 Nitrate-Nitrogen

Method

Photometric Method

Procedure

As per the instructions given in the manual, the instrument was set as zero with blank, necessary reagents were added to the samples and the colour formed was measured.

3. 3. 2. 12 Phosphate

Method

Stannous chloride method.

Principle

Ammonium molybdate reacts with orthophosphates to form molybdophosphoric acid in acidic medium, which is reduced to blue coloured complex 'molybdenum blue' by the addition of stannous chloride.

Reagents

Ammonium molybdate

Stannous chloride

Standard phosphate solution (0- 10 mg/l)

Procedure

50 ml of the sample was taken, to which 2 ml of ammonium molybdate solution and 5 drops of stannous chloride reagent were added. After 10 minutes, but before 12 minutes the intensity of the colour was measured at 690 nm wavelength in a UV-Visible Spectrophotometer.

3. 3. 2. 13 Silica

Photometric Method

Procedure

As per the instructions given in the manual, the instrument was set as zero with blank, necessary reagents were added to the samples and the colour formed was measured.

3. 3. 2. 14 Sulphate

Method

Turbidimetry

Principle

Sulphate ions are precipitated as barium sulphate crystals in acid medium by addition of barium chloride. The absorption of light by this precipitated suspension was measured by the Nephelo-turbidity meter.

Reagents

Conditioning reagent

Barium chloride

Standard sulphate solution (0 - 40 mg/l)

Procedure

25 ml of the sample was taken to which 1.5 ml conditioning reagent was added and mixed well. A spoonful of barium sulphate crystals were added and stirred for one minute until all the barium chloride got fully dissolved. The solution was taken in the absorption cell of Nephelo Turbidity meter, which was already calibrated using the blank and 40 mg/l standard sulphate solution. The reading was expressed in mg/l.

3. 3. 2. 15 Iron

Method

Phenanthroline method

Principle

When iron is brought into solution, reduced to the ferrous state by boiling with acid and hydroxylamine, and treated with 1,10-phenanthroline at pH 3.2 to 3.3, three molecules of phenanthroline chelate each atom of ferrous ion to form an orange-red complex which obeys Beer's law. The intensity is independent of pH from 3 to 9. A pH between 2.9 and 3.5 ensures rapid colour development in the presence of excess phenanthroline.

Reagents

Hydrochloric acid (<5%)

Hydroxylamine hydrochloride

Ammonium acetate buffer

Phenanthroline solution

Stock Iron solution (0-1 mg/l)

Procedure

50 ml of the sample was acidified and concentrated to 10 ml by boiling. On cooling, the required reagents were added and diluted to 100 ml. The intensity of the colour developed after 10 minutes was read at 510 nm using the UV-VIS Spectrophotometer. The concentration was noted from the standard graph.

3. 3. 2. 16 Sodium

Principle

A characteristic golden yellow colour is produced due to the excitation of electrons when the sample with sodium is sprayed into the flame. The intensity of this characteristic radiation is proportional to the concentration of sodium, which can be read using suitable filter.

Method

Flame photometry

Reagents

Standard sodium solution (0-40 mg/l)

Deionized distilled water.

Procedure

After the selection of sodium filter, the sample was aspirated and the galvanometric reading was recorded.

3. 3. 2. 17 Potassium

Method

Flame photometry

Principle

A characteristic lilac colour is produced due to the excitation of electrons, when the sample with potassium is sprayed into a flame. The intensity of this characteristic radiation is proportional to the concentration of potassium, which can be read using suitable filter.

Reagents

Standard potassium solution (0-10 mg/l)

Deionized distilled water.

Procedure

After the selection of potassium filter, the sample was aspirated and the galvanometric reading was recorded.

3. 3. 2. 18 Calcium

Method

EDTA titrimetry

Principle

At a pH 12, magnesium ions precipitate and finally calcium ions remain in the solution and Murexide indicator forms a pink colour with calcium ions. When EDTA



is added, calcium ions get complexed, resulting in a change from pink to purple colour, which indicates the end point of the reaction.

Reagents

Sodium hydroxide (1N)

Murexide indicator

Standard EDTA titrant (0.01 M)

Procedure

50 ml of the sample was taken and 2 ml of sodium hydroxide and 0.1 – 0.2 g of indicator was added and titrated immediately with 0.01 M EDTA solution to proper end point.

Calculation

$$\text{CaH (mg/l) as CaCO}_3 = \frac{V \times M \times \text{Equivalent weight of CaCO}_3}{\text{Volume (ml) of sample taken}} \times 1000$$

V = Volume of EDTA (ml); M = Molarity of EDTA

$$\text{Calcium as Ca}^{++} \text{ mg/l} = \text{CaH (mg/l)} \times 0.4$$

3. 3. 2. 19 Magnesium

Procedure

Magnesium may be calculated as the difference between the total hardness and calcium hardness.

Calculation

$$\text{Magnesium mg/l as MgH} = (\text{mg/l total hardness} - \text{mg/l calcium hardness})$$

$$\text{Magnesium as Mg}^{++} = \text{Magnesium hardness} \times 0.243$$

3. 3. 3 BIOLOGICAL PARAMETERS

The important biological parameters studied include plankton, nekton, benthos, chlorophyll content, algal biomass, productivity and bacteriological quality of water. Collection and preservation of sample specimens of mangrove and mangrove associates were also done for taxonomic identification.

3.3.3.1 Plankton

Procedure

Subsurface samples were collected for plankton analysis. About 20 – 25 litres of water was collected and sieved through an organdy cloth of 60 µm mesh size to separate the micro and macro plankton. One litre of the filtered sample was collected for micro plankton analysis. The cloth containing the residue after sieving was dipped and washed in 500 ml water and stored for macro plankton analysis. The plankton samples were preserved in 4% formalin solution immediately after collection.

The micro plankton sample was centrifuged at 1500 rpm for 20 minutes and the specimens were identified using a compound microscope. 0.1ml of the centrifuged sample was placed on to a glass slide with the help of a dropper and covered with a cover slip. The slide thus prepared was put under the microscope and the organisms were identified following.

3.3.3.2 Chlorophyll

The characteristic algal pigments are chlorophylls, xanthophylls and carotenes. The three chlorophylls commonly found in planktonic algae are chlorophyll **a**, **b** and **c**. Chlorophyll **a** is the most commonly occurring natural pigment in photosynthetic cells. Green algae contain, in addition to chlorophyll **a**, the blue green chlorophyll **b**. Diatoms and brown algae contain chlorophyll **c**, which is a partially oxidized derivative of chlorophyll **a**.

Estimation of chlorophyll is useful in limnology and water quality management. Chlorophyll constitutes 1-2% of the dry matter in planktonic algae. Estimation of chlorophyll **a** therefore provides an estimation of algal biomass in a water body. In general, chlorophyll content in a given area correlates with primary productivity in that

area, and also a useful indicator of eutrophication.

Collection and preservation

500 ml of the sample was collected in a polyethylene bottle and kept in icebox and brought to the laboratory. The sample was preserved by freezing in the dark.

Reagents

Acetone (90%)

Magnesium carbonate

Procedure

0.2 ml of magnesium carbonate suspension was added to the sample and filtered through filter paper of 0.4 – 0.45 μ size, by using a membrane filter. The filter paper with concentrate was placed in a tissue grinder and covered with 2-3 ml 90% acetone solution. It was macerated with a tissue grinder. The samples were then transferred to a screw-cap centrifuge tube and the volume was made up to 5 ml with 90% acetone solution. The samples were kept over night at 4⁰C in the dark. The next day samples in the closed tubes were centrifuged for 20 minutes at 1500 r p m. The clear extract was transferred to 1 cm cuvette and determined the absorbance (optical density) at 630, 645, 663 nm.

Calculations

Chlorophyll a be calculated using following equations

$$\text{Mg pigment}/\text{m}^3 = \frac{C \times V_e}{V_s \times L}$$

Where, V_e = Volume of acetone extract, ml

L = Light path of cell, cm (in spectrophotometer)

V_s = Volume of water centrifuged, l

C = C_a , obtained from

$$C_a \text{ (for chlorophyll a)} = 11.64 E_{663} - 2.16 E_{645} + 0.10 E_{630}$$

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E663, E645 & E630 are optical density values of the extract at these respective wavelengths.

3. 3. 3. 3 Algal Biomass

A rough estimation of biomass of phytoplankton can be obtained from chlorophyll **a** and is considered as an algal biomass indicator. By assuming that chlorophyll **a** constitutes, on the average, 1.5% of the dry weight organic matter of the algae, the algal biomass can be estimated by multiplying the chlorophyll **a** content by a factor of 67 (APHA, 1995).

3. 3. 3. 4 Productivity

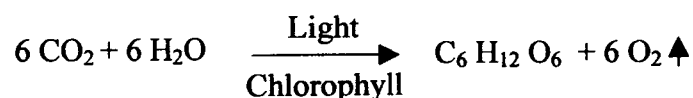
Primary productivity is the rate at which the solar radiant energy is stored by the photosynthetic activity of producer organisms (various forms of algae and higher plants in water) in the form of organic substances, which can be used as food material. The primary productivity is thus the basis of whole metabolic cycle in natural aquatic ecosystems; the remainder is the consumption and decay. The consumers inhabiting the systems utilize the organic matter synthesized by primary producers.

Gross Primary Productivity (GPP) - It is the rate of photosynthesis, and includes the organic matter used up in the respiration during the measurement period.

Primary productivity studies are of paramount importance in understanding the effect of pollution on system's efficiency. High rates of production, both in natural and cultural ecosystems occur, when physicochemical factors are favorable.

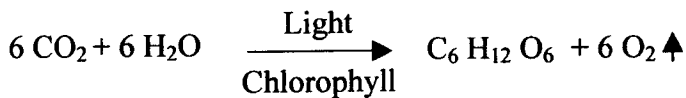
Measurement of productivity

The basic equation of photosynthesis is:



Hence, to estimate primary productivity, one can measure the carbon uptake as well as the oxygen production, or the formation of organic compounds or the gain of chemical energy of the system. In the aquatic ecosystems, the primary production is mainly due to phytoplankton and aquatic macrophytes.

Principle



According to the equation, the amount of CO_2 consumed in carbon assimilation is proportional to the oxygen liberated by plants so that the amount of carbon assimilated can be calculated from the amount of oxygen provided *i.e* it is the rate at which new organic matter is added to the existing standing crop of phytoplankton. Six molecules of oxygen are formed when one molecule of glucose is synthesized.

Reagents

BOD bottles of (300 ml capacity)

Water sampler

Secchi disc

Dark painted and wax coated BOD bottles

Floats

All reagents required for as for dissolved oxygen analysis

Procedure

The depth of the euphotic zone was determined by using Secchi disc and the depth intervals for suspension of bottles were fixed. Water was collected using the sampler and transferred gently to a bucket. Three sets of bottles – initial, light and dark were filled avoiding agitation. The bottles were suspended at desired depths and the oxygen

concentration in the initial bottle was determined the standard procedure for the determination of dissolved oxygen. Light and dark bottles were incubated for selected hours by attachment to a line or wire, which was held in position by an anchored float, so that the bottles are suspended in a horizontal position. After the completion of the incubation period, the bottles were removed carefully and the dissolved oxygen content in them was determined.

Calculation

$$\text{GPP, O}_2 \text{ mg/l/hr} = \frac{Dl - Dd}{H}$$

Dl - dissolved oxygen in the light bottle in mg/l; Dd - dissolved oxygen in the dark bottle in mg/l; h - duration of exposure in hours.

The values can be converted to carbon by using the following formula

$\text{GPP, gC/m}^3/\text{hr} = \text{GPP in mg O}_2/\text{l/hr} \times 0.375$. Daily rates are calculated by multiplying the. The average hourly rates ($\text{gC/m}^3/\text{hr}$) are multiplied by 9 to get the daily rates ($\text{gC/m}^3/\text{d}$).

3. 3. 3. 5 Microbiological Parameters

Sample collection

The grab samples were collected in presterilized bottles. The pre-sterilized sampling bottle was lowered in the water column. The bottle was opened under water, filled up to $\frac{3}{4}$ th of its capacity and closed under water. The samples were preserved immediately at 4⁰C in an icebox, transported to the laboratory and analyzed within 24 hours.

Principle

Multiple tube fermentation technique was used for the enumeration of microorganisms and biochemical tests were used to detect the various groups such as

coliforms, fecal coliforms and *E coli*.

Reagents

Buffered dilution water

Mac Conkey Broth

Brilliant Green Lactose Bile Broth (BGLB)

Peptone water

Kovac's (Indole) Reagent

Phosphate buffer

Procedure

A. Test for total coliforms

Presumptive Test

Mac Conkey Broth of single and double strength were prepared in tubes containing inverted Durham's tubes, sterilized in an autoclave at 15 lb. pressure for 15 minutes without any air bubbles. If the water was highly contaminated, the sample was serially diluted 1000 times (up to 0.001 ml dilution) using phosphate buffer solution. 10 ml and above volume of sample was inoculated in double strength and 1 ml and its below was inoculated into single strength medium and incubated at 37°C for 48 hours. The colour change and gas formation indicates the positive presumptive test.

Confirmatory Test

The medium used for confirmed test was BGLB Broth. The required broth was distributed in tubes containing Durham's tubes and sterilized. One or two loop full of positive cultures from positive presumptive tube was inoculated into the BGLB tubes and incubated at 37 °C for 48 hours. The formation of gas in the Durham's tubes of BGLB tube at any time within 48 ± 2 hours indicated a positive confirmation.

B. Test for fecal coliforms

This procedure was adopted to differentiate coliforms of fecal origin from those of non-fecal origin. Fecal coliforms are those coliforms which can ferment lactose at 44.5°C within 24± 2 hours with the production of acid and gas in Brilliant Green Lactose Bile Broth cultures.

All the presumptive positive tubes of the coliform test were sub-cultured at the end of 24 – 48 hours into BGLB Broth and incubated at 44.5°C for 24 hours in an incubator. Gas formation within 24 hours indicated a positive reaction for fecal coliforms.

C. Rapid test for *E.coli*

The positive tubes of BGLB Broth (fecal coliforms) were sub-cultured in tubes of peptone water. The required peptone water medium was prepared and distributed in test tubes and sterilized. The inoculated tubes were incubated at 44.5 °C for 24± 2 hours. After incubation, the test for indole production was conducted by adding few drops of Kovac's Reagent.

A pinkish red coloured ring indicated a positive test, while yellow colour indicated a negative reaction.

Based on the number of positive tubes at each dilution, the most probable number (MPN) *i. e.*, coliform bacteria per 100 ml of the sample were calculated referring to the standard probability table. In case of unlikely combinations, the following formula was used to calculate MPN/100ml.

$$\text{MPN/100ml} = \frac{\text{No. of positive tubes} \times 100}{\text{Total sample (ml) in negative tubes} \times \text{total sample in test}} \times 100$$

3. 3. 3. 6 Nekton

Procedure

Among the nektons, fishes are the largest animals that influence the structure of the ecosystem by their voracious predation. The fishes collected from the sampling points were preserved in 5% formalin and identified following Jhingran (1982), Day (1977-78), and Munro (1955), Talwar and Jhingran (1991).

3. 4 SEDIMENT QUALITY

3. 4. 1 PHYSICAL PARAMETERS

The physical parameters studied for sediments were moisture content and sediment texture.

3. 4. 1. 1 Moisture Content

Method

Gravimerty

Procedure

Initial weight of fresh homogenized of sediment sample was recorded and kept in a hot air oven at 105 °C, until a constant weight was attained. After cooling the sample in a dessicator, the final weight was recorded. The moisture was calculated using the formula,

$$\text{Moisture \%} = \frac{I - F}{I} \times 100$$

Where, I = Initial weight of the sediment (g): and F = Final weight of the sediment (g).

3. 4. 1. 2 Sediment Texture

Principle

The velocity of setting is proportional to the square of the diameter of the particle.

Method

Hydrometer method

Reagents

Hydrogen peroxide (30 %)

Calgon (5%)

Procedure

Forty grams of oven dried (105 °C) sediment was taken in a 500 ml beaker to which 30 ml of water and 5 ml of H₂O₂ were added, mixed thoroughly and covered with a watch glass and kept to oxidize the organic matter in the sample, with the continuous addition of H₂O₂ until the frothing stopped. The sample was mixed with the help of an electric mixer for 5 minutes after adding 100 ml of Calgon solution. The suspension was transferred into a graduated sedimentation cylinder and the volume was made up to 1 litre. After 4 minutes, a hydrometer was lowered and reading was taken. The temperature was noted in °C. Hydrometer and temperature readings were taken after 120 minutes. A blank was also done similarly using 100 ml Calgon solution. For each °C above or below, 0.0004 graduation (g/CC) on the hydrometer was added or subtracted.

Calculation

$$\frac{\text{Corrected hydrometer reading of the sample at 4 minutes} - \text{Corrected reading of the blank at 4 minutes}}{\text{Weight of the sample}} \times 1000 \times 100$$

$$\% \text{ sand} = 100 - \% \text{ suspension at 4 minutes}$$

$$\% \text{ clay} = \frac{\text{Corrected hydrometer reading of the sample at 120 minutes} - \text{Corrected reading of the blank at 120 minutes}}{\text{Weight of the sample}} \times 1000 \times 100$$

$$\% \text{ silt} = 100 - \% \text{ sand} + \% \text{ clay}$$

Using the textural diagram, the textural class was determined as suggested by Chopra & Kanwar 1976).

3. 4. 2 CHEMICAL PARAMETERS

The sediment samples were analyzed for pH, electrical conductivity, salinity, available phosphorus, sulphate, chloride, nitrate nitrogen, organic carbon, exchangeable sodium, potassium, calcium and magnesium and heavy metals.

3. 4. 2. 1 pH

Apparatus

pH meter

Procedure

To determine pH at the moisture saturation level, 20 gram of sediment was dissolved in 100 ml of distilled water (1:5) and stirred with a glass rod for an hour at regular intervals. The pH was determined with a pH meter and expressed directly in pH units associated with the specific dilution of the sediment suspension.

3. 4. 2. 2 Electrical Conductivity

Apparatus

Conductivity meter

Procedure

A 1:5 sediment suspension was prepared after shaking a mixture of 20 grams of soil in 100 ml deionised water for about an hour. The conductivity of the suspension was measured within an hour by directly dipping the conductivity cell into the suspension. The values were expressed in mmhos/cm at specific dilution of the soil suspension.

3. 4. 2. 3 Salinity

Apparatus

Electrometric method using salinity meter.

Procedure

A 1:5 sediment suspension was prepared and shaken for about an hour. The salinity of the suspension was measured by directly dipping the electrode into the

suspension. The results were expressed in ppt at specific dilution of the sediment suspension.

3. 4. 2. 4 Organic Carbon

Reagents

Potassium dichromate (1 N)

Silver sulphate-sulphuric acid reagent

Ferriin indicator

Ferrous sulphate (0.5 N)

Procedure

Ten ml of 1N potassium dichromate solution was added to 1 gram of 0.5 mm mesh sieved, air- dried sediment and swirled gently to disperse the soil. 20 ml of silver sulphate- sulphuric acid reagent was added rapidly to the suspension with constant swirling and allowed to stand on an asbestos sheet for 30 minutes. After 30 minutes, 100 ml distilled water was added followed by 3–4 drops of Ferriin indicator. The solution was titrated against 0.5 N ferrous sulphate solution. At the end point, solution changes from blue to red.

Calculation

$$\text{Organic carbon, \%} = \frac{(\text{me K}_2\text{Cr}_2\text{O}_7 - \text{me FeSO}_4)}{\text{g of air dried soil}} \times 0.003 \times 100 \times f$$

Correction factor, $f = 1.33$

Me = Normality of solution x ml of the solution used; % of organic matter in soil = % organic carbon x 1.729

3. 4. 2. 5 Chloride

Reagents

Silver nitrate solution (0.028 N)

Potassium chromate (5%)

Procedure

A 1:5 soil suspension was prepared by shaking 20 gram soil in 100 ml of distilled water for one hour. The suspension was filtered through Whatman No 50 filter paper. 2-3 drops of potassium chromate indicator was added to 50 ml of this soil suspension and titrated against 0.028N silver nitrate, until the colour changed to reddish orange, indicating the end point.

Calculation

$$\text{Mg/100 g Cl}^- = \frac{(\text{ml} \times \text{Normality}) \text{ of silver nitrate}}{(\text{ml}) \text{ of soil solution} \times 2} \times 35.5 \times 1000$$

3. 4. 2. 6 Sulphate

Apparatus

Nephelo Turbidity Meter

Reagents

Standard sulphate solution (40mg/l)

Conditioning reagent

Barium chloride

Procedure

A 1: 5 soil suspension was prepared, filtered through Whatman No. 50 filter paper and centrifuged. To 25 ml of this solution, 1.5 ml conditioning reagent and a pinch of Barium chloride was added. The resulting turbidity was measured in Nephelo Turbidity Meter.

Calculation

$$\text{Mg/100g SO}_4^- = \frac{\text{mg SO}_4^- / \text{l}}{2000} \times 1000$$

3. 4. 2. 7 Available Phosphorus

Apparatus

UV-Visible Spectrophotometer.

Method

Stannous chloride method

Reagents

Sulphuric acid (0.02 N)

Stannous chloride

Ammonium molybdate solution

Standard phosphate solution (0 -10 mg/l)

Procedure

1 gram of air-dried sediment sieved through a 2 mm sieve was taken, to which 200 ml of 0.002 N sulphuric acid was added. The suspension was shaken for half an hour and filtered through Whatman No. 50 filter paper to get a clear solution. The concentration of phosphorous was determined following the method used for the determination of phosphate ion in water.

Calculation

$$\% \text{ Available phosphorus} = \frac{\text{mg P/l in sediment solution}}{50}$$

$$\text{P mg/100g} = \frac{\text{mg P/l in sediment solution}}{50} \times 1000$$

3. 4. 2. 8 Nitrate

Reagents

Standard nitrate solution (0 – 1 mg/l)

Phenol disulphonic acid

Liquid ammonia (30%)

Nitrate extraction reagent

Calcium hydroxide

Magnesium carbonate

Procedure

250 ml of nitrate extracting reagent was added to 50 gram of dried sediment and shaken for 15 minutes. To this 0.4 gram of dried calcium hydroxide powder was added and shakes for 5 minutes. To this added 1 gram of dried magnesium carbonate powder. The suspension was filtered through Whatman No. 50 filter paper and the total volume of the filtrate was measured. 50 ml of the filtrate was evaporated in a porcelain basin to dryness, cooled and dissolved the residue in 2 ml phenol disulphonic acid. The contents were diluted to 50 ml and 6 ml of liquid ammonia was added to develop a yellow colour, which was measured at 410 nm in a spectrophotometer.

Calculation

$$\text{Mg / 100g NO}_3 - \text{N} = \frac{V1 \times V2}{1000 \times W} \times 100$$

V1 = NO₃ – N in the filtrate (mg/l)

V2 = Total volume of filtrate (ml)

W = Weight of the dried sediment

3. 4. 2. 9 Exchangeable Sodium and Potassium

Apparatus

Flame Photometer

Reagents

Standard sodium solution (0-40 mg/l)

Standard potassium solution (0-10 mg/l)

Procedure

The remaining ammonium acetate leachate of soil left after calcium and magnesium determination was used for the estimation of sodium and potassium. Using a Flame Photometer, concentration of sodium and potassium was found out as per the procedure adopted for water analysis.

Calculation

$$\text{Na mg/100 g} = \frac{A \times V \times 100}{W \times 10,000}$$

Where, A = Sodium/ Potassium content of soil extract (mg/l)

V = Total volume of the soil extract (ml)

W = Weight of the air dried soil taken for extraction (g)

3. 4. 2. 10 Exchangeable Calcium and Magnesium

Reagents

Ethyl alcohol (40%)

Absolute alcohol

Ammonium acetate solution (pH 7.0); and

All the reagents used in the determination of calcium and magnesium in water

Procedure

Preparation of soil extract:

50 grams of air-dried soil was taken in a conical flask to which 100 ml of 40% ethyl alcohol was added and shaken well. After 10 minutes, the suspension was filtered through Whatman No.50 filter paper. The soil residue on the filter paper was eluted with 40% ethyl alcohol and finally absolute alcohol. The residue was then transferred to a beaker, 100 ml of ammonium acetate solution was added, stirred and allowed to stand overnight. The supernatant was filtered through Whatman No.42 filter paper and

collected filtrate was measured to note the volume.

Calcium and magnesium in soil the extract was determined following the same method used for the determination of calcium and magnesium in water.

Calculation

$$\text{Ca mg/100g} = \frac{T \times 400.4 \times V_1}{V_2 \times W \times 10,000} \times 100$$

Where, T = Volume of EDTA titrant used (ml)

V₁ = Total volume of soil extract (ml)

V₂ = Volume of soil extract titrated (ml)

W = Weight of the air dried soil taken for extraction (g)

$$\text{Mg mg/100g} = \frac{T_2 - T_1 \times 400.4 \times V_1}{V_2 \times 1.645 \times W \times 10,000} \times 100$$

Where, T₁ = Volume of EDTA titrant used for determination of Ca (ml)

T₂ = Volume of EDTA titrant used for the determination of Ca & Mg (ml)

V₁ = Total volume of soil extract (ml)

V₂ = Volume of soil extract titrated (ml)

W = Weight of the air dried soil taken for extraction (g)

3. 4. 2. 11 Metals

The water samples for metal analysis were collected in acid washed polyethylene bottles and preserved immediately by acidifying with conc. HNO₃ to pH <2. The acidified water samples were refrigerated at 4⁰C to prevent change in volume due to evaporation and analyzed using Atomic Absorption Spectrophotometer.

Water and sediment samples were analyzed for heavy metals such as Cu, Fe, Mn & Zn following the method of APHA (1995) and Van Loon (1985). The sediment samples were air dried, pulverized and sieved through a 0.5 mm sieve. From this sample,

0.5 g was taken in a Teflon vessel, 3 ml concentrated HClO_4 was added and kept for two hours at room temperature. After heating in an oven at 100°C for one hour, the samples were evaporated to dryness on a hot plate. After cooling, the samples were diluted with a mixture of 10 ml of 6% 1:1 HNO_3 and HClO_4 and heated on a hot plate for ten minutes. The samples filtered with (Whatman No. 540 filter paper) were made up to 25 ml with the same acid mixture and analyzed using an Atomic Absorption Spectrophotometer.

3. 4. 3 BIOLOGICAL PARAMETERS

3. 4. 3. 1 Benthos

Procedure

Benthic samples were collected using Van Veen Grab (0.048 m^2). The sediment samples collected were sieved through a mesh of 0.5 – 0.6 mm and organisms were collected in polyethylene bottles and preserved in 4% formalin. The macro benthos was visually examined and meiobenthos were identified with the help of compound microscope.

3. 5 STATISTICAL ANALYSIS

The results of the physicochemical and biological analysis were subjected to the statistical analysis for Analysis of Variance (ANOVA) and Multiple Correlation using SPSS Package.

**ECOLOGICAL STUDIES ON
THE MANGROVES OF
VALAPATTANAM AND THALASSERY
RIVER BASINS**

Thesis submitted to
University of Calicut
in part fulfilment of
Doctor of Philosophy in Botany

Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

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4. 0 RESULTS AND DISCUSSION

4. 1 MANGROVES & MANGROVE ASSOCIATES: TAXONOMY & ECOLOGY

Mangroves belong to many different families, which may not be closely related in a phylogenetic sense, but may have in common on a number of special characteristics such as pnuematophores, stilt roots and viviparous seedling habitat (Chapman, 1975). Different authors have classified mangroves and associated vegetations into different categories. According to Chand Basha (1992), the mangrove vegetation possesses many structural and physiological peculiarities and is composed of species with strongly marked characteristics grouped under true mangroves. There are also plants with less strongly marked characteristics, which were grouped as semi-mangroves by Transley and Fritsch (1905). There is yet another group of plants which grow in saline soils fringing the mangrove areas, but thrive on the land which does not get inundated with brackish water even during the high tides. They can withstand some amount of brackish water stàgnation only for a very short period. These can be grouped as non-mangroves growing near mangrove locations (Chand Basha, 1992). Tomlinson (1986) categorized mangroves into major elements (strict/ true mangroves) and minor elements and mangrove associates. He recorded true mangroves based upon the possession of five features such as: (i) complete fidelity to mangrove environment; (ii) major role in the structure of community and the ability to form pure stands;(iii) morphological specializations like aerial roots and vivipary of embryo which adapts them to their environment;(iv) some physiological mechanism of salt exclusion and (v) the taxonomical isolation from terrestrial relatives at the generic, subfamily or family level.

The minor elements are distinguished by their inability to form a conspicuous element of the vegetation. They may occupy peripheral habitats and only rarely form pure communities. Mangrove associates are never inhabitants of strict mangrove communities and may occur only as transitional vegetation. According to Nalini Nayak *et al.* (2000), the mangrove wetland vegetation is broadly classified into two groups: the true mangroves (eumangroves), and the mangrove associates. True mangroves are the ones which have a high degree of salinity tolerance and habitat specificity (which grow only in the inter-tidal environment) whereas mangrove associates are by and large land plants which are capable of withstanding salinity to an extent less than that of true mangroves. Mangrove associates usually lack any elaborated aerial part to their ecosystem.

The present study was aimed to locate the true mangroves and mangrove associates from the Thalassery and Valapattanam river basins and to find out their ecological status. Vegetation survey was conducted periodically through field visits and mangrove and mangrove associates of both Thalassery and Valapattanam rivers were identified and enumerated. In the present study, a based on simple, easily identifiable characters was followed for differentiating the true mangroves.

4. 1. 1 KEY TO IDENTIFICATION OF MANGROVE GENERA AND SPECIES

Plants with true vivipary:

Stilt roots and prop roots absent

Knee roots present; viviparous seedlings fall with calyx *Bruguiera*

Knee roots absent; viviparous seedlings fall without calyx *Kandelia*

Stilt roots and prop roots present *Rhizophora*

Leaves oblong lanceolate, short mucronate; flowers sessile; petals

glabrous..... 1. *Rhizophora apiculata*

Leaves elliptic, long mucronate; flowers

pedicellate; petals hairy2. *Rhizophora mucronata*

Plants with out true vivipary:

Plants with cryptovivipary

Plants without pneumatophores; fruit surface smooth Aegiceras

Plants with pneumatophores; fruit surface tomentose..... Avicennia

Leaves acute apex; flowers ca. 0.4 cm across..... 1. *Avicennia marina*

Leaves obtuse at apex; flowers ca. 1cm across. 2. *Avicennia officinalis*

Plants without vivipary

Leaves with spiny margins; plants with stilt roots..... Acanthus

Leaves without spiny margins; plants without stilt roots

Plants with milky latex; flowers unisexual; stamen..... 3. *Excoecaria*

Plants without milky latex; flowers bisexual; stamens numerous..... *Sonneratia*

Calyx tube ridged; petals white with pinkish tinge

at the tips; stamens with entirely white filaments 1. *Sonneratia alba*

Calyx tube not ridged; petals red; stamens with

lower half of the filaments red 2. *Sonneratia caceolaris*

4. 1. 2 VEGETATIONAL CHARACTERISTICS OF TRUE MANGROVES

1. *Bruguiera cylindrica* (L.) Bl. (Ver. Name: Kanal Kandal or Karikandal)

(Plate 4. 1)

This is a medium sized, buttressed tree; bark smooth, gray, with few lenticels; knee like roots are frequently formed; leaves 7-10 cm long, oblanceolate, rarely elliptic, acute, cuneate base; petiole often red; Inflorescence usually three flowered; flowers

white; calyx tube very small, smooth, 8-10 lobed, completely reflexed in fruits; fruits are long, cylindrical with enlarged calyx and viviparous; radicle 10-15 cm long.

Flowering season: January – April and July – October.

The plant is used for firewood, fuel, charcoal, poles, house posts, tannin, food etc.

The occurrence of this species has been reported earlier from Malabar Coast by Beddome (1866), Kerala coast (Unni, 2002) and from Kannur district (Khaleel, 2002; Nalini Nayak *et al.* 2000).

2. *Sonneratia alba* J. Smith. (Ver. Name: Appakkad or Chakkara Kandal)

(Plate 4. 2)

This true mangrove is a moderate sized tree, bearing negatively geotropic, stout, conical pneumatophores, which are characteristic of the genus. Bark orange brown; leaves leathery, glabrous, opposite, elliptic with obtuse apex; flowers terminal, usually solitary or in threes, calyx tube angular with six lobes, leathery, reddish inside and whitish outside; petals and stamens caducous; style persistent; fruits globose.

Flowering takes place during November and April (Muhammed Jafar Palot & Radhakrishnan, 2002).

The species is used for paper pulp, fodder, matches, poles, tannin, food and fodder.

Sonneratia alba J. Smith has been reported from the estuaries of Thalassery river and Valapattanam rivers (Muhammed Jafar Palot & Radhakrishnan, 2002) and from Kannur (Nalini Nayak *et al.* 2000; Khaleel, 2002). The species is easily distinguished from the closely related species *Sonneratia caseolaris*, by its ribbed calyx with obconical base and white flower.



Plate 4.1 *Bruguiera cylindrica* (L.) BL - Flower

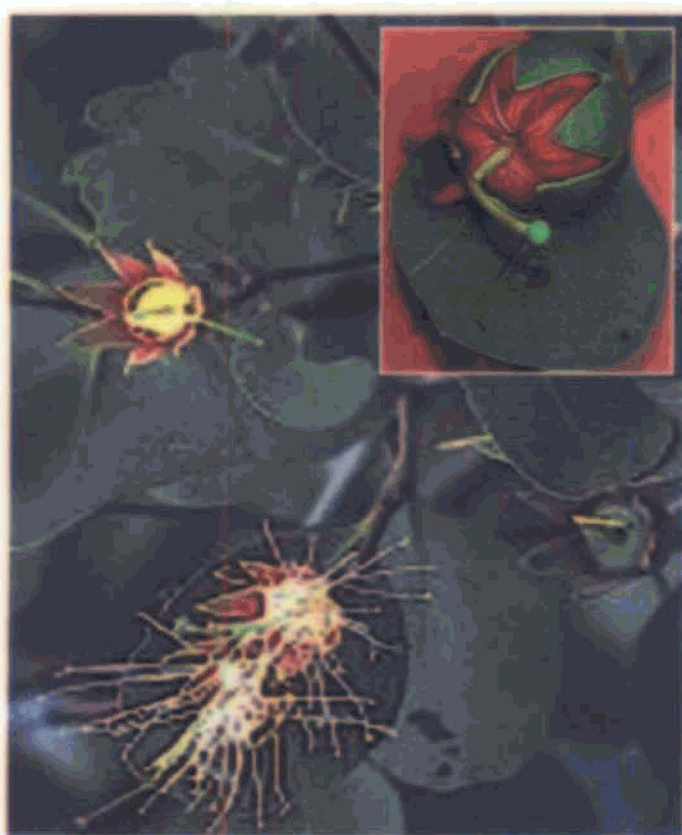


Plate 4.2 *Sonneratia alba* J. Smith

3. *Sonneratia caseolaris* (L.) Engl. (Ver. Name: Thirala, Blathi) (Plate 4. 3)

This is an evergreen true mangrove tree with dark brown rough bark, bearing usually stout, conical pneumatophores on radiating cable roots; leaves broadly ovate, long, with obtuse apex; flowers terminal, solitary, dark rose coloured; calyx six, narrow, oblong, purplish inside; stamens numerous and thread like; fruit large, depressed, globose.

Flowering season: April.

The plant is used as fuel, tannin, fodder and food.

Chand Basha (1992) reported this species to be abundant in the Travancore coast and rare in the Malabar Coast. Ramachandran *et al.* (1986) reported this species to be abundant along the Thalassery River. The present study also supports the earlier observations.

4. *Aegiceras corniculatum* (L.) Blanco. (Ver. Name: Pookandal) (Plate 4. 4)

This is a large evergreen shrub with smooth stem. Leaves alternate, elliptic with rounded tip, obtuse apex, coriaceous and glabrous; flowers in terminal or axillary umbels, white, fragrant; petals five, white, pointed; stamens five opposite to corolla; fruits pinkish, cylindrical, horn shaped with persistent calyx; germination viviparous.

Flowering season: March, May and November.

The flower is used as a source of high quality honey, bees wax and the bark as fish poison.

5. *Avicennia marina* (Forsk.) Vierh. (Ver. Name: Uppetti)

This is a large shrub with small yellow flowers, and shining leaves. It is known as “white mangrove” because of its distinctive smooth white bark. It bears pencil like pnuematophores, which arise from the radial cable roots. Leaves opposite, shortly

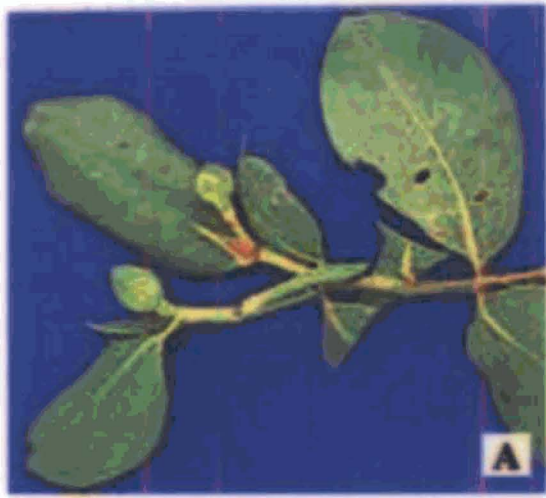


Plate 4.3 *Sonneratia cascolaris* (L.) Engl. - Twig with Flower (A) and Fruit (B)



Plate 4.4 *Aegiceras corniculatum* (L.) Blanco. - Twigs with Flower (A) and Fruit (B)

petiolate, glossy green on the upper side and dull gray or silvery white with very close tomentose hairs; flowers yellow or white; fruit is a compressed capsule with solitary seed; germination viviparous.

Flowering season: June to July.

The species is used for fuel, fodder, fish food, honey, bee wax, and charcoal extraction.

When compared to *Avicennia officinalis* L., this species is not very common along the estuarine areas of both river basins. This species is present in mangrove sites of Eranholi and Kuyyali of Thalassery River and near Valapattanam Bridge and Kambil of Valapattanam River. In these areas, the species occurs in low density when compared to *Avicennia officinalis* L.

6. *Avicennia officinalis* L. (Ver. Name: Oori or Uppetti) (Plate 4. 5)

This is a true mangrove tree branching low, with smooth yellowish-gray bark. Leaves obovate to elliptic, rounded, coriaceous with a very fine silvery- white tomentose beneath; flowers yellow, sessile in small clusters with fetid smell; fruit is a compressed, ovate and pointed capsule.

Flowering season: June-July.

This is the most luxuriant true mangrove species found throughout the areas of both the rivers.

7. *Rhizophora apiculata* Bl. (Ver. Name: Pee Kandal)

This is a moderate sized evergreen tree, with aerial and stilt roots; leaves elliptic to lanceolate, acute, dark green above with tapering base; flowers in strict two-flowered axillary cymes, sessile; petals white; stamens 11-12; fruit conical or obovate with persistent calyx, viviparous.



Plate 4.5 Avicennia officinalis L. - Twig with Flower



Plate 4.6 Rhizophora mucronata Lamk.

Flowering season: March – July and August – December.

This species was less dense in distribution compared to *Rhizophora mucronata* Lamk. in the mangrove areas of both the river basins.

8. *Rhizophora mucronata* Lamk. (Ver. Name: Pranthan Kandal) (Plate 4. 6)

This true mangrove is a moderate sized tree with large number of stilt roots and aerial roots. Leaves simple, elliptic, mucronate, glabrous, pale beneath with black dots; flowers yellowish-white in axillary cymes with four petals; stamens usually eight or more; fruit is conical ovoid and viviparous.

Flowering season: May - August.

It is used for fuel, charcoal extraction, tannin, fodder and food.

This is the most common mangrove species recorded from the study area, as has been reported earlier from Malabar Coast (Chand Basha, 1992).

9. *Kandelia candel* (L.) Druce. (Ver. Name: Cheru Kandal) (Plate 4. 7)

This is a small tree with reddish brown bark; leaves simple, opposite, elliptic oblong, obtuse and glabrous; inflorescence axillary cymes with long peduncles; flowers white, sepals and petals 5-6; stamens numerous, fruits cylindrical and viviparous.

Flowering season: July.

The species is mainly used as fuel, charcoal and tannin.

Chand Basha, (1992) reported this species have a good representation in Malabar Coast. Ramachandran *et al.* (1986) reported this species is at home along the Valapattanam Bridge. This is another most common true mangrove species in the river basins studied with maximum density being in Valapattanam River (Khaleel, 2002). This is always found to grow in association with *Rhizophora mucronata* Lamk. These two

85.1A

30



Plate 4.7 *Kandelia candel* (L.) Druce. - A Twig with Flower (A) with Fruit (B)



Plate 4.8 *Excoecaria agallocha* L.

species are the most abundant true mangroves along the Thalassery and Valapattanam river basins.

10. *Excoecaria agallocha* L. (Ver. Name: Kammatti) (Plate 4. 8)

This is a true mangrove tree with poisonous acrid milky juice. Bark gray; leaves simple, long, elliptic acuminate, margins inconspicuously notched, spirally arranged; inflorescence axillary, in catkin-like spike; flowers dioecious, yellowish-green, trimerous; fruit is three lobed capsule.

Flowering season: July – October. The milky latex is used as fish poison.

In the present study, in estuarine areas from where this species was identified, its density was also found to be very high, though earlier reports (Khaleel, 2002) show rarity of its distribution.

11. *Acanthus ilicifolius* L. (Ver. Name: Chulli) (Plate 4. 9)

This is a true mangrove shrub, up to 2 m tall, with stout, stiff, cylindrical spinescent branches; aerial roots at the base; leaves elliptical to oblong, nearly sessile, glabrous, spinous along the margins and ending in a sharp spine; flowers large, blue in spikes; stamens four; fruit is a capsule.

Flowering season: March – August.

The fruit pulp is medicinal valuable as a blood purifier and leaf paste is used in the treatment of rheumatism.

This plant is gregarious along the tidal swamps in the sheltered mangrove areas in the landward zones. This is one among the most commonly noticed mangrove shrub in all mangrove areas along the two river basins. The species is also seen in the partially degraded mangrove wetlands along with *Acrostichum aureum* L. (Plate 4. 10).

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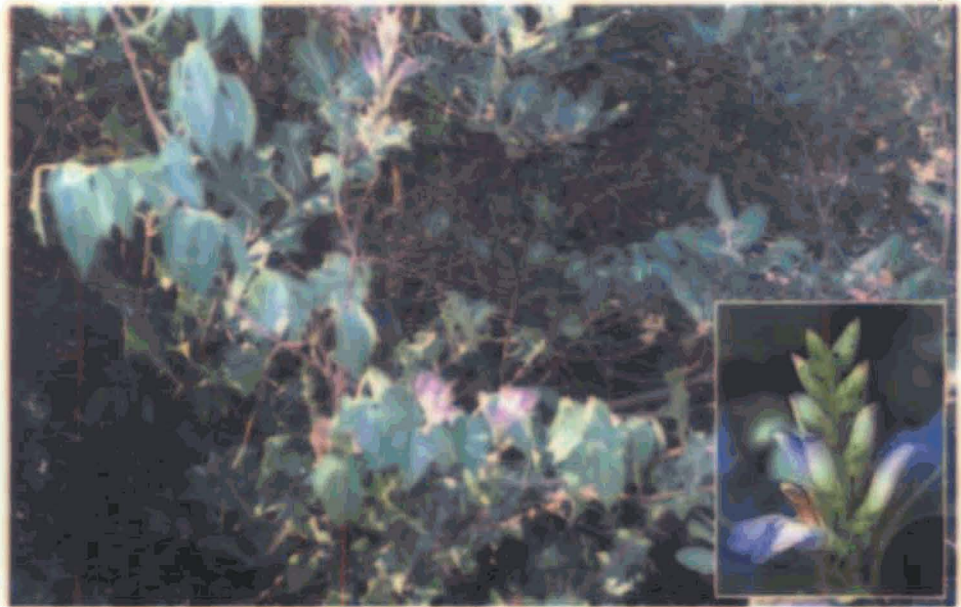


Plate 4.9 Acanthus ilicifolius L.



Plate 4.10 Acrostichum aureum L.

4. 1. 3 ECOLOGICAL STATUS OF MANGROVES

Thalassery Estuary (Site T1M)

Thalassery estuary harbors a rich mangrove community. A diverse group of mangrove vegetation was observed in this site, the principal species being: *Sonneratia caseolaris*, *S. alba*, *Avicennia officinalis*, *A. marina*, *Rhizophora mucronata*, *R. apiculata*, *Kandelia candel* and *Excoecaria agallocha*. This is the only site where few members of *Sonneratia alba* were reported during the present study. The status of occurrence of different species is given in Table 4. 1.

Kuyyali (Site T2M)

During the present study, this was found to be the thickest mangrove area along the Thalassery River. The area was observed to be rich both in density and diversity of mangrove species. Out of the 11 species reported during the present study, 10 species were reported from this site. Pure stand of species of *Avicennia officinalis*, *Rhizophora mucronata* and *Kandelia* was observed along the banks. Kuyyali area was rich both in terms of density and diversity of mangroves, till 1999. *Avicennia officinalis* was recorded to be in higher density compared to *A. marina*. *Sonneratia caseolaris* was also observed in pure stands. Very few members represented *Bruguiera cylindrica*. For the doubling of the railway line (Mangalapuram–Shoranur), a long stretch of this mangrove area has been cleared, which has led to a decline in the density of mangrove species, especially *Brugueira cylindrica*.

Eranholi (Site T3 M)

The area was comparatively poor in terms of density and diversity of mangroves. The area was mainly occupied by true mangroves such as species of *Avicennia officinalis*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Kandelia candel*, *Aegiceras corniculatum*

Table 4.1 Distribution of True Mangroves in the Thalassery and Valapattanam Rivers

Sl. No.	Scientific name	Family	Study Sites						
			T1M	T2M	T3	V2M	V3M	V4	V5M
1	<i>Avicennia officinalis</i> L.	Avicenniaceae	VC	VC	VC	VC	VC	A	VC
2	<i>Avicennia marina</i> (Forsk.) Vierh.		V	VC	C	VC	C	A	C
3	<i>Rhizophora apiculata</i> Bl.	Rhizophoraceae	C	C	R	VC	R	A	R
4	<i>Rhizophora mucronata</i> Poir.		VC	VC	C	VC	VC	A	VC
5	<i>Kandelia candel</i> (L.) Druce.		VC	C	R	VC	VC	A	VC
6	<i>Bruguiera cylindrica</i> (L.) Bl		A	VR	A	VR	A	A	A
7	<i>Aegiceras corniculatum</i> Blanco.	Myrsinaceae	A	VC	R	VC	VC	A	VC
8	<i>Acanthus ilicifolius</i> L.	Acanthaceae	A	VC	VC	VC	VC	VC	VC
9	<i>Excoecaria agallocha</i> L.	Euphorbiaceae	VC	VC	R	VC	VC	A	R
10	<i>Sonneratia alba</i> J. Smith	Sonneratiaceae	VR	A	A	A	A	A	A
11	<i>Sonneratia caseolaris</i> (L.) Engl.		VC	VC	A	VC	C	A	VC

Note: V- Valapattanam; T- Thalassery; 1,2,3,4 & 5 represents the site numbers.

VC – Very Common; C – Common; VR – Very Rare; R – Rare; A – Absent

and *Acanthus ilicifolius*. Among these mangrove species, *Kandelia candel*, *Rhizophora apiculata* and *Aegiceras corniculatum* were found to be very rare in occurrence. The area is under severe anthropogenic pressures like sand mining, waste dumping, land reclamation, etc. This may be the main reason for their decline. Coir retting was also practiced in this area till 2000. A characteristic feature of the fern, *Acrostichum aureum*, is its capacity to grow in the degraded areas (Dagar *et al.* 1991), which was observed to dominate this area.

Valapattanam Bridge (Site V2 M)

This was the rich mangrove area in the Valapattanam river basin. Like Kuyyali, the area was rich in terms of density and diversity of mangrove vegetation. Except *Sonneratia alba*, all the 10 true mangroves were observed at this site. When compared to Kuyyali site of Thalassery River, the density of mangroves was observed to be very high during the present study. Detailed study undertaken earlier (Ramachandran *et al.* 1986), reported the occurrence of *Kandelia candel*, *Rhizophora apiculata*, species of *Avicennia*, *Excoecaria* and *Acanthus*. They have also reported *Kandelia candel* to be the species, which attained maximum development fringing the margins of the vegetation. During the present study, *Bruguiera cylindrica* was found to be very rare in this site. *Avicennia officinalis* was recorded to be abundant in this site. Distribution of *Bruguiera cylindrica* was sparse and this was the only site from where this species was recorded from the Valapattanam River basin. Coconut husk retting, fibre processing and wood seasoning have led to the destruction of this existing pure stands of mangroves. The mangrove associate, *Acrostichum aureum* was reported to be relatively sparse; but the species was reported to invade the mangrove patches (Ramachandran *et al.* 1986). Attempts have been

made by the Kerala Forest and Wildlife Department to afforest the degraded mangrove areas of this site.

Kattampally (Site V3 M)

The site abodes mangrove species of genera such as *Avicennia officinalis*, *Avicennia marina*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Kandelia candel*, *Aegiceras corniculatum*, *Acanthus ilicifolius*, *Excoecaria agallocha*, and *Sonneratia caseolaris*. *Rhizophora apiculata* was found to be rare, while *Sonneratia caseolaris* showed moderate distribution. Among the various sites studied, this site showed highest abundance of *Aegiceras corniculatum*.

Kattampally (Site V4)

Kattampally (Site 4) of Valapattanam river is an intermediate site between mangrove and freshwater. Except *Acanthus ilicifolius* L., no other true mangroves were present in this site. Only the mangrove associates like *Derris trifoliata* Lour., *Acrostichum aureum* L., *Clerodendron inerme* Gaertn. were recorded. This may be due to the presence of a regulator cum bridge at Kattampally, which prevents salinity intrusion and entry of nutrient rich water from the downstream area, making this site uncongenial for the growth of true mangroves. Local enquiry revealed that this area once supported rich mangrove vegetation.

Kambil (Site V5)

This site with moderate salinity harbours a rich mangrove community comprising of 8 species such as *Avicennia officinalis*, *Avicennia marina*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Kandelia candel*, *Aegiceras corniculatum*, *Excoecaria agallocha*, *Acanthus ilicifolius*, and *Sonneratia caseolaris*. Sand mining and waste dumping are the major practices causing destruction of this mangrove site.

In the present study, highest frequency of flowering was observed during the rainy season as has been reported earlier for Veli mangroves (Thomas 1962), except certain species such as *Bruguiera cylindrica*, *Sonneratia caseolaris*, *Sonneratia alba* and *Aegiceras corniculatum*, which flowers during summer months.

The floristic composition showed 11 species belonging to 6 families, and 8 genera in both Thalassery and Valapattanam river basins (Table 4. 1). Out of the 17 species listed on the Kerala coast, including *Derris trifoliata* and *Acrostichum aureum* (Mohanam, 1999, Unni, 2002, 2003), 11 species were recorded during the present study. The three mangrove species, which were not observed during the present study are, *Bruguiera sexangula* (Lour.) Poir., *Ceriops tagal* (Perr.) C.B. Rob. and *Excoecaria indica* (Willd) Muell.- Arg.

Khaleel (2002) reported 12 true mangrove species in Kannur district, excluding *Acanthus ilicifolius* L. and *Acrostichum areum* L. He also recorded *Bruguiera sexangula* (Lour.) Poir., in Koduvally mangrove area of Kannur district. But in the present study, this particular species was not observed along the mangrove sites. Dagar *et al.* (1991) classified *Acanthus ilicifolius* L. as a true mangrove and *Acrostichum areum* L. and *Derris trifoliata* Lour. as mangrove associates. For the present study, the classification of mangroves by Dagar *et al.* (1991) was followed and *Acanthus ilicifolius* L. has been considered as true mangrove species.

Among the various true mangroves listed in Thalassery and Valapattanam rivers, *Avicennia officinalis* L., *Rhizophora mucronata* Lamk., *Acanthus ilicifolius* L., *Excoecaria agallocha* and *Kandelia candel* (L.) Druce. are ubiquitous. According to Khaleel (2002), the species like *Avicennia officinalis*, *Rhizophora mucronata*, *Excoecaria agallocha*, *Aegiceras corniculatum* and *Bruguiera cylindrica* are the common true

mangroves of Kannur. *Bruguiera cylindrica* and *Sonneratia alba* were found sparsely distributed during the present study as has been reported earlier Khaleel (2002).

Littoral flora found growing either in landward side or near the mangrove patches (mangrove associates) comprise 47 species belonging to 24 families (Table 4. 2).

Table 4. 2 Common Mangrove Associates of Thalassery and Valapattanam Rivers

Sl. No	Scientific Name	Family
1	<i>Derris trifoliata</i> Lour.	Papilionaceae
2	<i>Crotalaria striata</i> DC.	Papilionaceae
3	<i>Pongamia pinnata</i> (L.) Pierre.	Papilionaceae
4	<i>Clerodendron inerme</i> (L.) Gaertn.	Verbenaceae
5	<i>Premna serratifolia</i> L.	Verbenaceae
6	<i>Cyperus difformis</i> L.	Cyperaceae
7	<i>Cyperus javanicus</i> Houtt.	Cyperaceae
8	<i>Cyperus malaccensis</i> Lam.	Cyperaceae
9	<i>Cyperus pumilus</i> L.	Cyperaceae
10	<i>Cyperus haspan</i> L.	Cyperaceae
11	<i>Cyperus iria</i> L.	Cyperaceae
12	<i>Cyperus rotundus</i> L.	Cyperaceae
13	<i>Eleocharis geniculata</i> (L.) Roen. & Schult.	Cyperaceae
14	<i>Fimbristylis miliacea</i> (L.) Vahl.	Cyperaceae
15	<i>Fimbristylis aestivalis</i> (Retz.) Vahl.	Cyperaceae
16	<i>Fimbristylis ferruginea</i> (L.) Vahl.	Cyperaceae
17	<i>Fimbristylis dichotoma</i> (L.) Vahl.	Cyperaceae
18	<i>Fimbristylis spathacea</i> Roth.	Cyperaceae

19	<i>Mariscus javanicus</i> (Houtt.) Merr. & Metcalf.	Cyperaceae
20	<i>Pycreus polystachyos</i> (Rottb.) P. Beauv.	Cyperaceae
21	<i>Pycreus pumilus</i> (L.) Ness.	Cyperaceae
22	<i>Phragmites karka</i> (Retz.) Trin. ex. Steud.	Poaceae
23	<i>Paspalum vaginarum</i> S.W	Poaceae
24	<i>Cerbera odollum</i> Gaertn.	Apocyanaceae
25	<i>Pandanus odorattissimus</i> L. f.	Pandanaceae
26	<i>Cyathula prostrata</i> (L.) Blume.	Amaranthaceae
27	<i>Calophyllum inophyllum</i> L.	Guttiferae
28	<i>Thespesia populnea</i> (L.) Corre.	Malvaceae
29	<i>Hibiscus tiliaceus</i> L.	Malvaceae
30	<i>Sphaeranthus indicus</i> L.	Compositae
31	<i>Eupatorium odoratum</i> L.	Compositae
32	<i>Synedrella nodiflora</i> (L.) Gaertn.	Compositae
33	<i>Eclipta alba</i> (L.) Hassk.	Compositae
34	<i>Ipomea biloba</i> Forsk.	Convolvulaceae
35	<i>Crinum defluxum</i> Ker.	Amaryllidaceae
36	<i>Melastoma malabathricum</i> L.	Melastomaceae
37	<i>Morinda citrifolia</i> L.	Rubiaceae
38	<i>Datura metel</i> L.	Solanaceae
39	<i>Boerhavia diffusa</i> L.	Nyctaginaceae
40	<i>Calotropis gigantea</i> (L.) R. Br.	Asclepiadaceae
41	<i>Ziziphus oenoplia</i> (L.) Mill.	Rhamnaceae
42	<i>Alternanthera sessilis</i> (L.) R. Br. ex. D C.	Amaranthaceae
43	<i>Ardisia littoralis</i> Anders.	Myrsinaceae

44	<i>Hygrophila spinosa</i> T. Anders.	Acanthaceae
45	<i>Lippia nodiflora</i> (L.) A. Rich.	Scrophulariaceae
46	<i>Equisetum ramossissimum</i> Desf.	Equisetaceae
47	<i>Acrostichum aureum</i> L.	Pteridaceae

Members of Cyperaceae were found to be highest in density, followed by members of Compositae. *Mariscus javanicus* (Houtt.) Merr. & Metcalf. (Plate 4. 11) and *Pycreus* species were found in higher density associated with mangroves. The two ferns recorded are, *Acrostichum aureum* L. and *Equisetum ramossissimum* Desf. The dominant mangrove associates include, *Acrostichum aureum* L., *Derris trifoliata* Lour. (Plate 4. 12), *Clerodendron inerme* (L.) Gaertn., *Premna serratifolia* L., *Cyperus sp.*, *Cerbera odollum* Gaertn., *Thespesia populnea* (L.) Corre., *Sphaeranthus indicus* L. and *Calotropis gigantea* (L.) R. Br. Khaleel (2002), and Unni, 2002,2003), had already reported these mangrove associates from mangrove wetlands of Kerala. Subromanian (2002) reported about 74 mangrove associates from the mangrove wetlands of Kerala. In the present study, the fern *Equisetum ramossissimum* Desf., was recorded only from the Kattampally mangrove site of Valapattanam River. Even though mangrove associates such as *Premna serratifolia*, *Phragmites karaka*, *Fimbristylis spathacea*, etc. were reported to be rare in the Malabar coast (Chand Basha, 1992), these were observed sparsely distributed in some of the sites in the present study. The mangrove associates such as *Barringtonia racemosa*, *Quassia indica*, *Caesalpinia crista*, *Dolichandrone spathaceae*, etc. were not observed during the present study, though they already have been reported earlier (Chand Basha, 1992; Nalini Nayak *et al.* 2000; Khaleel, 2002).

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Plate 4. 11 Mariscus javanicus (Houtt.) Merr. & Metcalf.



Plate 4. 12 Derris trifoliata Lour.

Most of the mangrove associates are economically important as fodder, fiber or of medicinal value. No specialty, specificity or relationship between the occurrence of mangroves and their associates were observed.

Acrostichum aureum L. is a pan tropical, gregariously growing coastal fern on landward mangrove swamps, or seaward fringes in the absence of mangroves or wetlands, which have been cut off from the sea. It is evident that this fern, with the characteristics of outward mangrove habitat, grows on varied range of habitats including freshwater sources, swampy estuarine areas and elevated sandy areas.

Seaward to landward zonation is a characteristic feature of mangrove vegetation. Different schemes were proposed for the zonation patterns based on the frequency of inundation, soil type, salinity of water and soil, light, temperature, drainage, etc., which are the principal factors that control their zonation (MacNae, 1968; Chapman, 1975; 1976; Balachandra, 1988). Salinity forms the one and only major limiting factor controlling the zonation of mangrove species. In Florida, mangrove species grow in fresh water as well as up to 35 ppt salinities (Davis, 1940). *Avicennia marina*, a pioneer species in colonization on the seaward fringe, has the widest range of salinity tolerance among all mangroves. It can grow in almost freshwater or in soils of water salinity exceeding 90 ppt (MacNae, 1968). This species is categorized under salt excreting kind of mangroves (MOEF, 1987). Moreover, the soil around *A. marina* is sandy and has less water holding capacity than that supporting *A. officinalis*. Soils around both species contain 80-85 ppt sand and are having a pH of 6.8 (*A. marina*) and 7.2 (*A. officinalis*) (MOEF, 1987). In the present study, it was observed that *A. marina* was the most dominant species compared to *A. officinalis* and occurred in high saline sandy regions nearing the estuary and further upstream having a maximum salinity of 33.3 ppt.

Sonneratia alba grows in normal salinity (30-35 ppt), *S. caseolaris* in less than 10 ppt, *Bruguiera* sp. in less than 25 ppt, *Rhizophora mucronata* is less than 55 ppt, and *Lumnitzera* sp. in less than 90 ppt. Among the two species of *Rhizophora*, *R. apiculata* is seen more towards the freshwater region. Till now, no attempt has been made to determine the extent to which individual species are obligate halophytes (Chapman, 1975). According to MOEF (1987), species of *Sonneratia* shows high capacity of salt accumulation. In Thalassery River, *Sonneratia alba* is seen growing sparsely along the estuary. *Avicennia marina*, *A. officinalis* and *Sonneratia caseolaris* are the species, present towards the estuarine area on rocky shores, as has been reported earlier (Dagar *et al.* 1991).

Aegiceras corniculatum is always an indicator of the presence of freshwater (MacNae, 1986). In the present study, this species was found to withstand a salinity range of 14.9 - 33.2 ppt in the Thalassery River and 0.1 - 23.5 ppt in the Valapattanam River. *Acanthus ilicifolius* L. occurred in large populations fringing all along the tidal channels including areas with immense biotic stress. The species was not recorded in the estuarine mangrove area of Thalassery River.

From Table 4.1, the distribution pattern of mangroves can be more or less clearly understood. The distribution was purely discontinuous and in patches of varying extent. Following the classification of Chand Basha (1992), the mangroves in Kannur was classified based up on the type of growth:

1. **Fully mangrove areas:** These are places, which can develop into thick and luxuriant form if not severely disturbed. Mangroves in the Thalassery estuary, Valapattanam Bridge, Kambil areas come under this category.

2. **Potential mangrove locations:** These are lands from where the existing mangrove vegetation has been cleared for alternate land use and still the mangrove vegetation persists escaping all the odds. Kattampally mangrove areas come under this category.

3. **Areas under succession:** Areas under primary or secondary succession where the pioneer species like *Acanthus ilicifolius* and *Acrostichum aureum* with occasional *Avicennia sp.*, *Rhizophora sp.*, *Kandelia sp.*, etc. are available as small patches, where there is regular tidal action coupled with stagnation of brackish water. Eranholi mangroves come under this category.

4. **Threatened mangrove locations:** Vestiges of mangrove vegetation remain in isolated small and narrow patches. Major portion has been converted for various other purposes. Due to change in chemical composition of water owing to the disruption in flow of saline water from the sea by constructing bunds or regulators, due to the addition of effluents, fertilizers, insecticides, decomposition wastes from retting of coconut husk, etc., such patches are under threat. Kuyyali, V4 site of Kattampally come under this category.

4. 2 PHYSICOCHEMICAL PARAMETERS

4. 2. 1 GENERAL

The sampling and analysis was conducted during the period from 1999-2002 for both the Thalassery and Valapattanam rivers. As there was seasonal as well as year wise variations in the parameters, average values have been computed for all the parameters. The data presented here represent the mean values for the three years (1999-2002).

4. 2. 2 WATER QUALITY

4. 2. 2. 1 Physical Parameters

Temperature

Temperature measurements are important in the self-purification studies of water bodies. Water temperature is crucial to aquatic life. Temperature of water bodies generally varies with the source and seasons.

Temperature of water in different sites of Thalassery and Valapattanam river basins are presented in Tables 4. 3 A & 4. 3 B respectively.

Table 4. 3 A Seasonal Variations in Temperature of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	29	31	30	31	31	31.6
Monsoon	27	30	26	29	26	26
Post-monsoon	32	32	31	31	30	29.5

In the Thalassery River, the water temperature varied from 29-31.6 °C, 26-30 °C and 29.5-32 °C during pre-monsoon, monsoon and post-monsoon seasons respectively. The Valapattanam River water recorded a temperature range of 26.3-30 °C, 20-29.5 °C and 20-32 °C during pre-monsoon, monsoon and post-monsoon seasons respectively. Spatial

variation of temperature was not so pronounced. (Figures 4. 1A & 4. 1 B)

Table 4. 3 B Seasonal Variations in Temperature of Valapattanam River

Seasons	Sites								
	V1	V2M	V2NM	V3M	V3NM	V4	V5M	V5NM	V6
Pre-monsoon	27.8	28	30	27.8	26.9	29.3	29.3	29.3	26.3
Monsoon	25.2	27.2	29.5	27	20	27	29.5	20	25.2
Post-monsoon	31	32	31	29.5	20	28.8	30.3	30.8	30.5

The temperature values for the entire period of observation reflected the climatic variations to a certain extent. There was a gradual decrease in temperature during the monsoon season than post-monsoon and pre-monsoon seasons in both the river basins. Fluctuation in temperature during the monsoon season was highly significant. The lower temperature encountered during the monsoon season in the two river basins may be attributed to the combined effects of freshwater run-off, low air and ground temperatures and general atmospheric cooling (Perkins, 1976). Those estuaries that are short and have little development of sand and mud flats, the water temperatures are controlled fundamentally by the temperature of the sea and the run-off water.

As reported by Sankaranarayanan and Qasim (1969), the influx of fresh water into the estuarine system is not the sole factor in bringing down the water temperature in an estuary, but the inflow of cold water from sea may also be a significant factor. The decrease of temperature in freshwater site is due to intense rain and run off from the catchment during the monsoon season. The peak temperature occurs during dry months when evapotranspiration losses are very high. The higher temperature during the post and

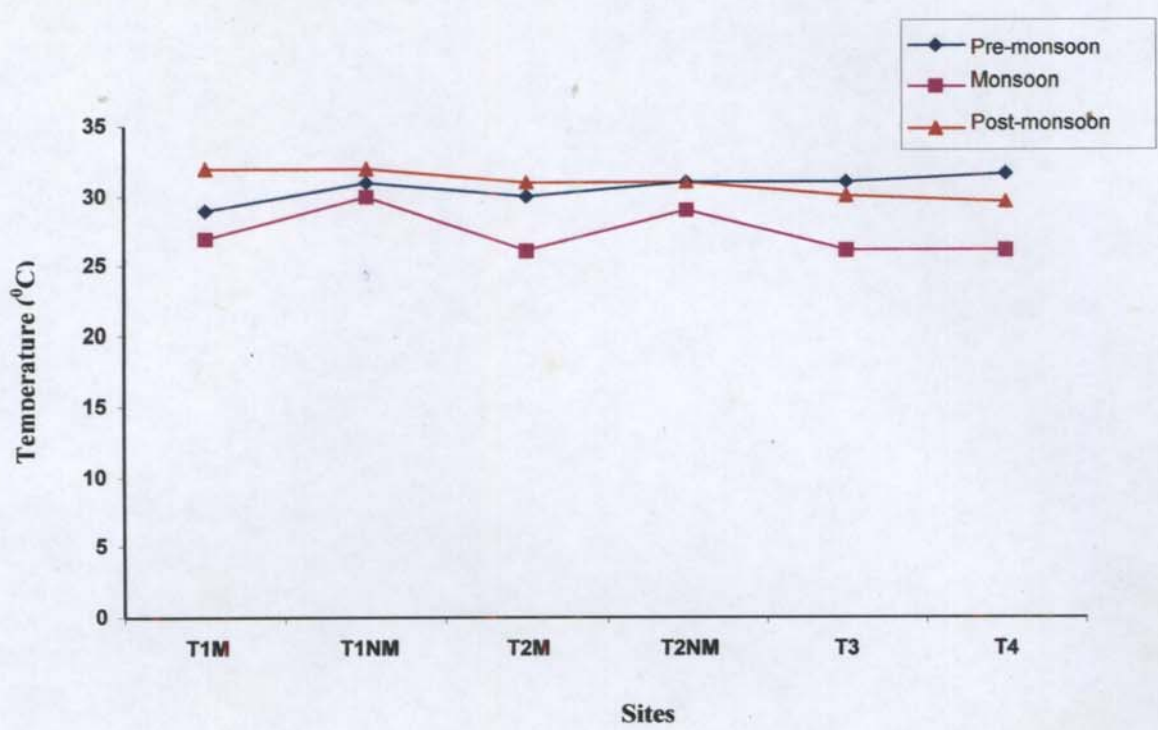


Fig. 4. 1 A Seasonal Variations in Temperature of Thalassery River

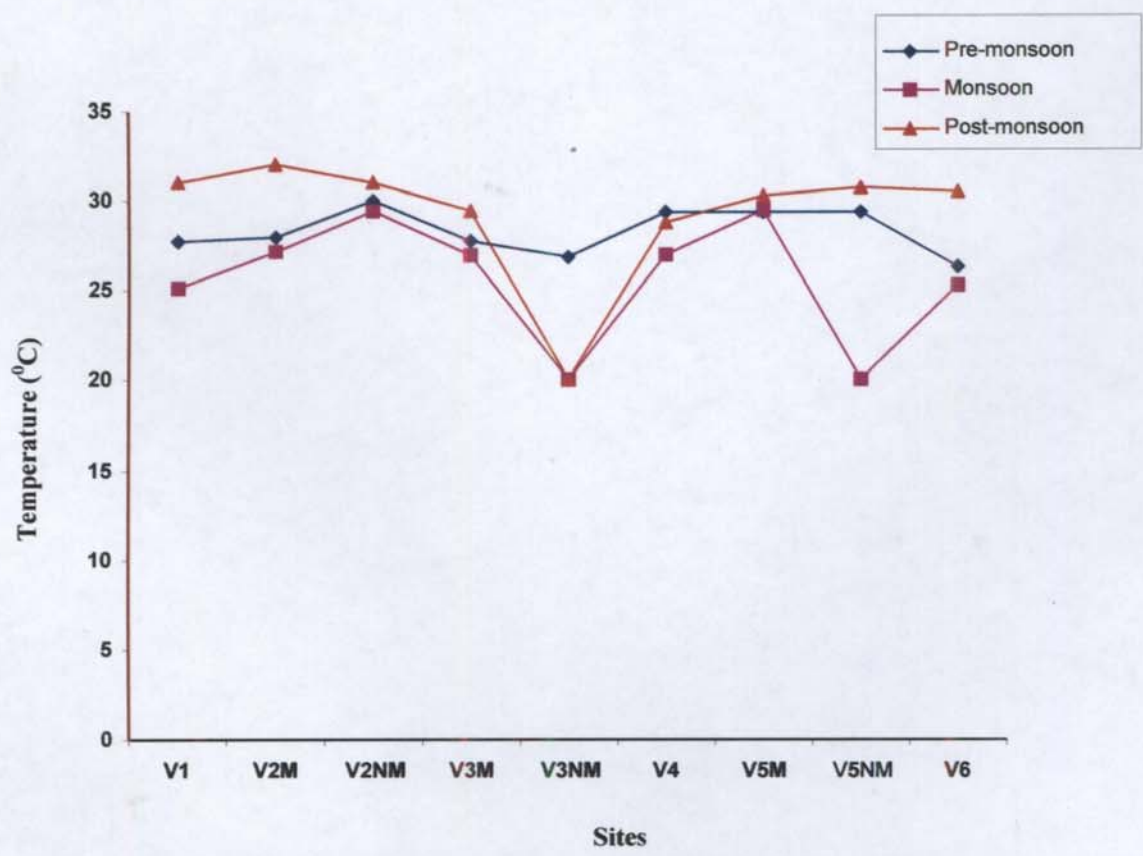


Fig. 4. 1 B Seasonal Variations in Temperature of Valapattanam River

pre-monsoon seasons may be attributed to the high atmospheric temperature and lean flow of water.

Temperature is an important factor in the growth and distribution of mangroves (Chapman, 1977). They require warm, tropical climate to flourish and the average temperature of the coldest month should be above 20°C, and seasonal temperature range should not exceed 5°C (Dawes, 1981). Accordingly, in the mangrove areas of the present study sites, the temperature remained at a range of 20 – 32°C, which is highly congenial for the luxuriant growth of mangroves. Since the mangroves grow in a habitat where it receives water, both from the river and estuary/sea, the water temperature is maintained at an optimum throughout the year, supporting a rich diversity of fauna including fishes.

Statistical analysis revealed that in the Thalassery River, there was a significant difference in temperature and seasons at 5% level. Temperature was found to be significantly correlated with parameters like chloride, pH, sodium and sulphate at 1% level. In the Valapattanam River, there was a significant difference in temperature and seasons at 5% level.

Colour

The colour of water may be due to the presence of substances such as iron, manganous compounds, humus material, peat, tannin, algae, weeds, protozoa, industrial effluents, etc. (Manivasakam, 1996). The average seasonal variations of colour in the Thalassery and Valapattanam river basins are presented in Tables 4.4 A & 4.4 B respectively.

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Table 4. 4 A Seasonal Variations in Colour of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	9	10	15	8	7	8
Monsoon	5	8	9	6	6	7
Post-monsoon	6	5	6	4	7	5

Table 4. 4 B Seasonal Variations in Colour of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	4	7	7	6	5	6	4	4	5
Monsoon	3	4	2	3	2	4	2	2	5
Post-monsoon	3	7	5	6	4	6	5	4	6

The colour ranged from 7-15 Hazen, 5-9 Hazen and 4-7 Hazen units during the pre-monsoon, monsoon and post-monsoon seasons respectively in the Thalassery River samples, while in Valapattanam River samples, it ranged from 4-7 Hazen, 2-5 Hazen and 3-7 Hazen units during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 2 A & 4. 2 B)

The values for colour in all the sites studied showed no well marked seasonal variations. However, in both the river basins, the pre-monsoon season samples recorded a slightly higher colour than the post-monsoon and monsoon seasons. The comparatively lower values in the monsoon season may be attributed to high dilution by the rainwater.

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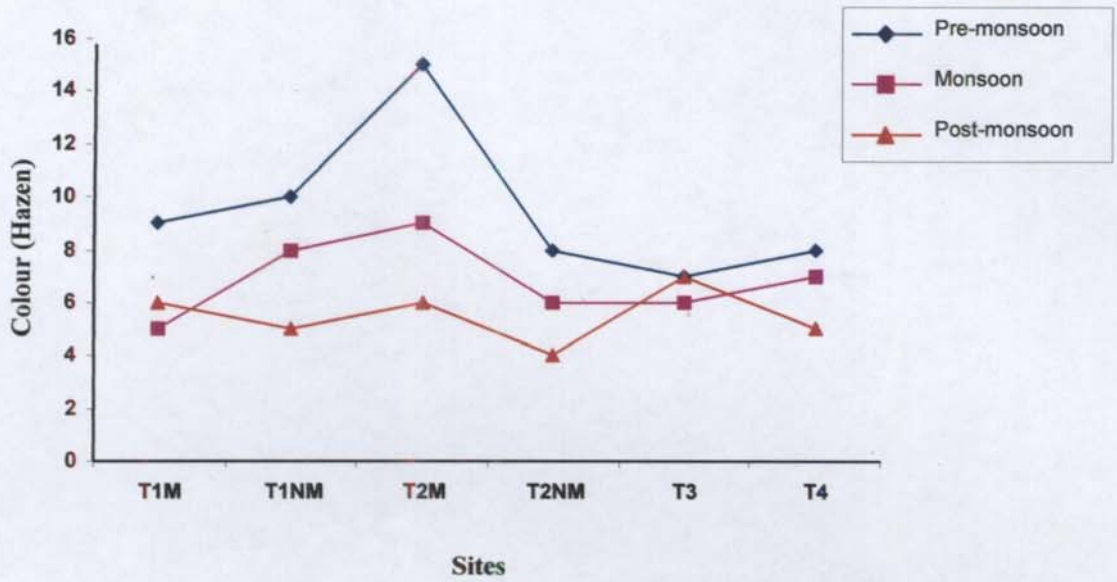


Fig. 4.2 A Seasonal Variations in Colour of Thalassery River

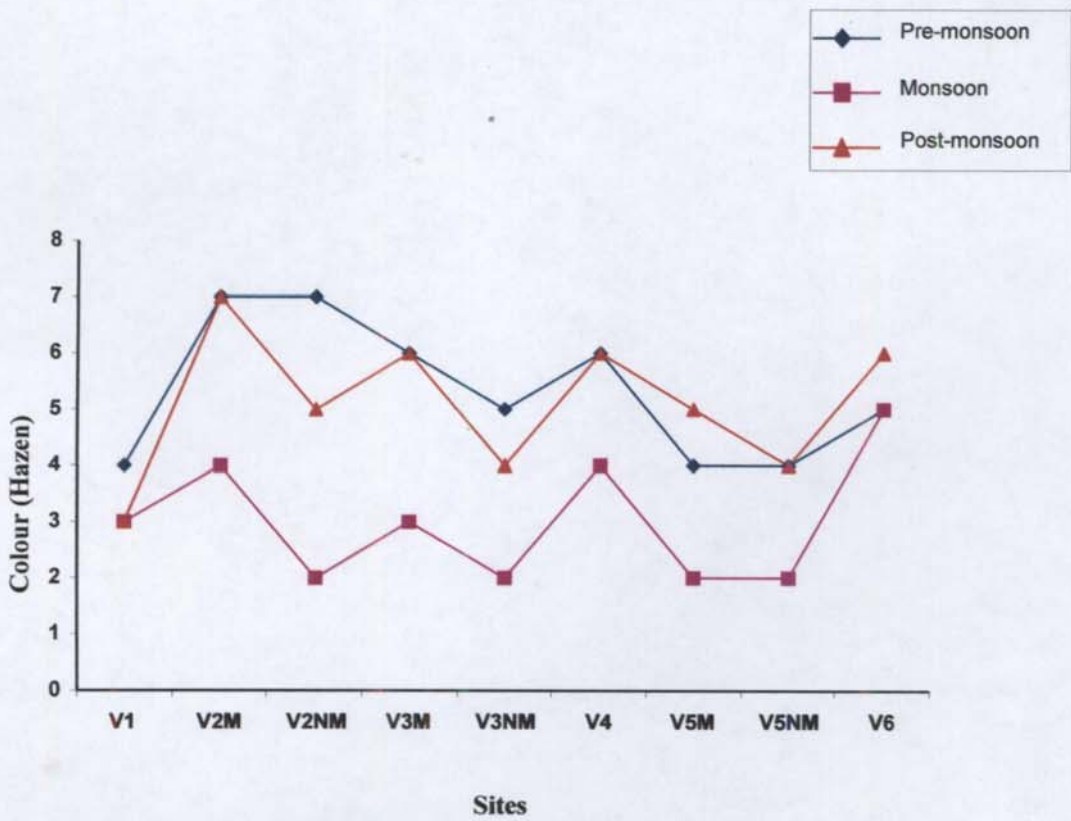


Fig. 4.2 B Seasonal Variations in Colour of Valapattanam River

But during post and pre-monsoon seasons, the inflow and outflow of water from the mangroves is low. Hence, the substances causing colour may have a long residence time at these sites, recording to high values.

The mangrove sites showed higher concentration of colour than the non-mangrove sites in both the river basins studied. This may be due to the tannin content leaching out of the fallen litter and barks of mangroves, which is a good source of the same. The high iron and humus content in the mangrove sites can be correlated with the high values for colour recorded from these sites.

In the mangrove sites, various mechanisms of organic substrate decomposition result in a variety of soluble organic compounds, which are soluble and carried downstream and into the estuaries by tidal action and run-off. Some of them are refractory compounds, which are stable in natural waters, imparting a dark brown to black colour to water (Ananthakrishnan, 1982). Since the water that flow out of the mangroves have characteristics peculiar to it, acquired during its long residence time in the swamps, they contain a large amount of dissolved organic matter in the form of nutrient salts (nitrates, nitrites, phosphates, silicates and trace metals) and also contain noxious chemicals such as flavanoids, tannic acids and their derivatives, which imparts a typical brownish colour (Vannucci, 1989). Results of the present study also confirm the earlier reports.

Retting is brought about by the pectinolytic activity of microorganisms especially bacteria, fungi and yeasts, degrading the fibre material of the husk and liberating large quantities of organics and chemicals to the environment including pectin, pectosan, tannins, polyphenoles into the ambient water (Remani *et al.* 1989). High colour in the T3 site of Thalassery River may be due to coir retting activity in the area by the local people.

Statistical analysis revealed that in the Thalassery River, there are significant differences in colour and seasons at 5% level. Colour was found to be significantly correlated with parameters like fluoride and nitrite at 1% level.

In the Valapattanam River, there were significant differences in colour and seasons and colour and locations at 5% level.

Turbidity

Turbidity of water is mainly due to the colloidal and extremely fine dispersions. Turbidity is an important parameter for characterizing water quality. Turbid water prevents light penetration and inhibits aquatic life, with a consequent loss of plant and animal diversity. Turbidity decreases light penetration into water, which in turn reduces the photosynthetic activity of plants (Manivasakam, 1996).

The seasonal variation in turbidity in the study areas of Thalassery and Valapattanam rivers are presented in Tables 4. 5 A & 4. 5 B respectively.

The turbidity values ranged from 5-18 NTU, 6-13 NTU and 4-12 NTU during pre-monsoon, monsoon and post-monsoon seasons respectively in the Thalassery River. In

Table 4. 5 A Seasonal Variations in Turbidity of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	16	11	13	18	7	5
Monsoon	13	7	6	6	6	6
Post-monsoon	6	7	6	5	12	4

the Valapattanam River, turbidity values varied from 2-10 NTU, 2-5 NTU and 1-10 NTU during pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 3

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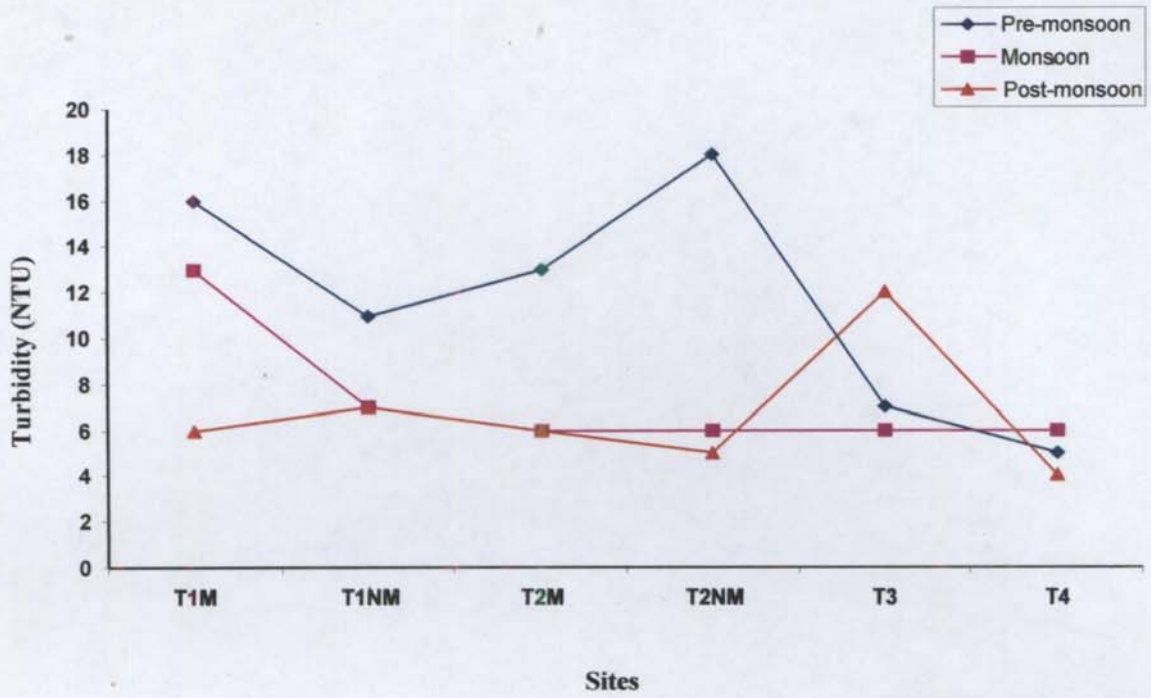


Fig. 4. 3 A Seasonal Variations in Turbidity of Thalassery River

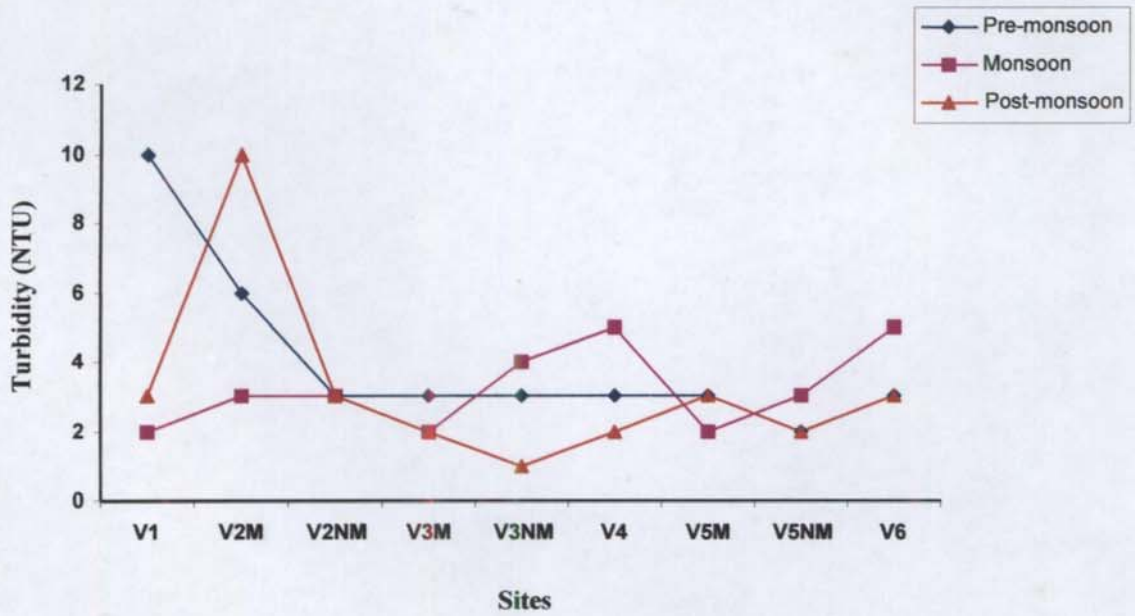


Fig. 4. 3 B Seasonal Variations in Turbidity of Valapattanam River

A & 4. 3 B).

Table 4. 5 B Seasonal Variations in Turbidity of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	10	6	3	3	3	3	3	2	3
Monsoon	2	3	3	2	4	5	2	3	5
Post- monsoon	3	10	3	2	1	2	3	2	3

When the sampling sites were taken into consideration, in general, the mangrove areas recorded a slightly higher turbidity compared to non-mangrove areas. This may be due to the suspended matter such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms. The high turbidity in the estuarine sites is due to the intense wave action. The finely divided organic and inorganic matter, which was high during the pre-monsoon season, might have contributed to high turbidity during the season. Higher values of turbidity were recorded during the monsoon season in the fresh water sites in the river basins studied which may be due to heavy monsoon run-off, which carried large quantities of wastes as well as suspended particles (Hossain, *et al.* 1988).

Statistical analysis revealed that in the Thalassery River, turbidity was found to be significantly correlated with parameters like fluoride, potassium and total hardness at 1% level. In the Valapattanam River, turbidity was significantly correlated with iron at 1% level.

4. 2. 2. 2 Chemical Parameters

pH

pH is a measure of hydrogen ion concentration, or more precisely hydrogen ion activity. pH measurement provides a very quick and easy-to-obtain appraisal of the acid-base equilibrium in an ecological system (Manivasakam, 1996).

Seasonal variation of pH in the Thalassery and Valapattanam rivers are presented in Tables 4. 6 A & 4. 6 B respectively. The pH values do not show much variation between the sites or with reference to change in seasons, in both the river basins.

Table 4. 6 A Seasonal Variations in pH of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	7.6	7.7	7.5	7.7	7.4	7.2
Monsoon	7.4	7.3	7.2	7	6.8	6.7
Post-monsoon	7.7	7.8	7.7	7.6	7.4	7.4

Table 4. 6 B Seasonal Variations in pH of Valapattanam River

Seasons	Sites								
	V1	V2M	V2N M	V3M	V3N M	V4	V5M	V5N M	V6
Pre-monsoon	7.72	7.45	7.27	7.32	7.42	7.24	7.21	7.18	7.35
Monsoon	6.96	6.93	6.97	6.71	6.84	6.63	6.88	6.89	6.84
Post-monsoon	7.82	7.45	7.45	7.50	7.64	7.42	7.21	7.17	7.65

The pH of Thalassery River ranged from 7.2 - 7.7, 6.7 – 7.4 and 7.4 – 7.8 during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam

River, it varied from 7.18 – 7.72 during pre-monsoon, 6.63 – 6.97 during monsoon and 7.17 – 7.82 during post-monsoon seasons respectively (Figures 4. 4 A & 4. 4 B).

Fluctuations in DO, CO₂, salinity etc., also influence the buffering capacity of the inland and saline water bodies. Extensive buffering capacity of the sea water allow only little pH changes to be pronounced normally, while in enclosed portions, the biological activities can cause sizeable variations. The pH values vary considerably with time of the day, especially in highly productive water where high values of pH occur during highly productive hours of the day (Balakrishnan Nair *et al.* 1984).

During the post-monsoon season, the pH was slightly high, due to the influence of the seawater intrusion and biological activity. During floods in peak monsoon season, pH was quite low which may be due to the influx of fresh water and decomposition of organic matter carried by floodwaters into the riverine system, as has been reported earlier in the Gautami- Godavari estuarine system (Krupadam & Anjaneyulu, 2000).

In the present study, the pH values fluctuated from nearly neutral to slightly alkaline. Only minor changes in pH were recorded in the sites studied. Spatial variations revealed that estuarine sites recorded a slightly alkaline pH in both the rivers. Under normal unpolluted conditions, the pH values of estuaries range from 6.8 – 9.25 (Perkins, 1976). The changes in pH arise from the effects of photosynthesis and respiration upon the amount of carbon dioxide dissolved in water. The release of acid and alkaline effluents to the aquatic environment may be expected to disrupt the balance of pH. But in the present study, no such extreme values were recorded for pH, indicating little pollution in the two riverine systems.

When mangrove and non-mangrove areas were compared, the pH was slightly low in the mangrove sites, which may be attributed to the presence of sulphuric acid produced

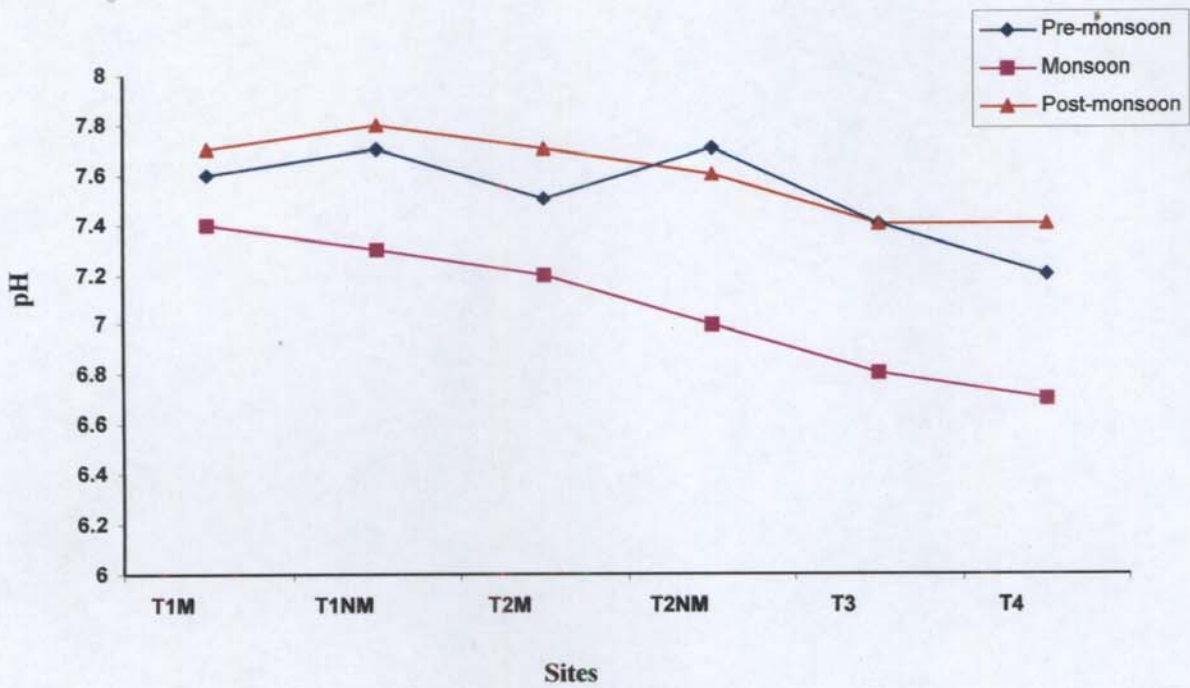


Fig. 4. 4 A Seasonal Variations in pH of Thalassery River

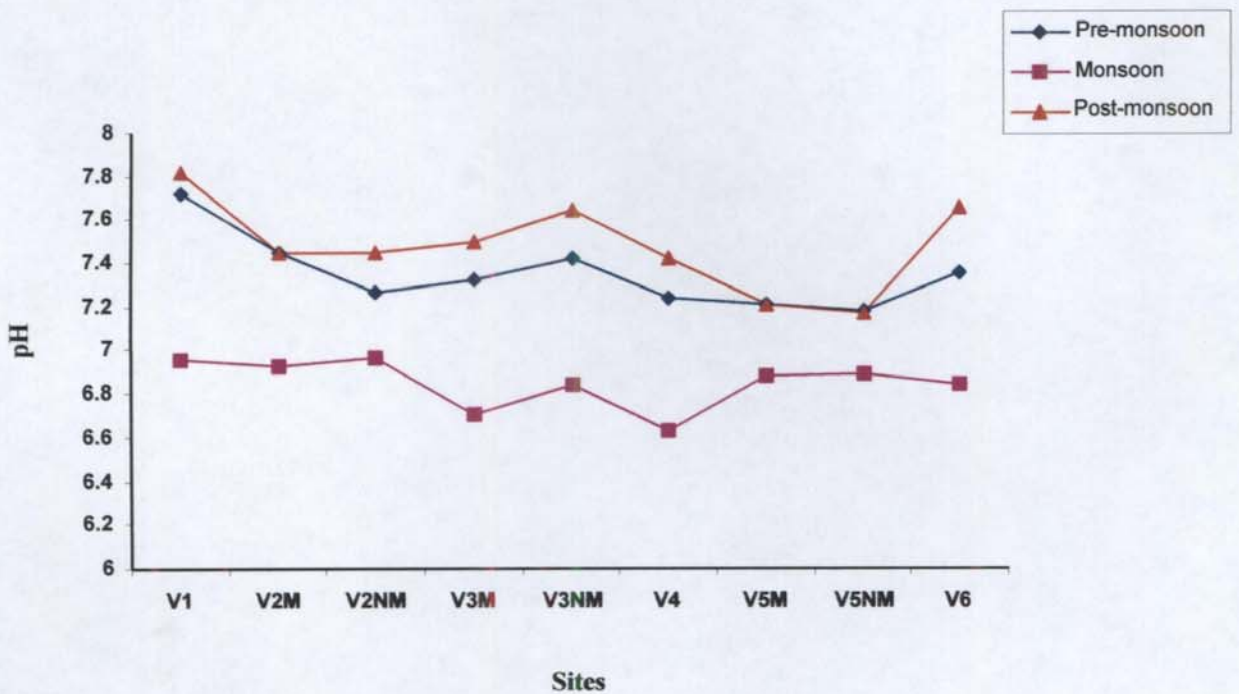


Fig. 4. 4 B Seasonal Variations in pH of Valapattanam River

during the reduction of sulphate, by the activity of sulphur reducing bacteria as has been reported earlier (Ananthakrishnan, 1982). The pH of surface water samples of mangroves of Veli, Quilon and Kumarakam were reported to be 7.4, 8.1 and 7.9 respectively (Ramachandran *et al.* 1986). A pH range of 6.8 – 7.8, 7.2 – 7.8 and 7.2 – 7.8 has been reported from Pazhayangadi, Kunhimangalam and Edat Thuruthummal mangrove waters respectively during the monsoon and summer months (Nalini Nayak *et al.* 2000). In the present study, pH values have never exceeded 7.82.

A pH range of 6.5 – 9.0 has been reported to be most ideal for fish culture (Jhingran, 1982). The pH range of the river basins is congenial for the growth of fishes, especially in the mangrove sites, where high fish populations were noticed.

Statistical analysis revealed that there in the Thalassery River, there are significant differences in pH and seasons and pH and locations at 5% level. pH was found to be significantly correlated with parameters like temperature, EC, total hardness, salinity, chloride, sulphate, calcium, potassium and sodium at 1% level.

In the Valapattanam River, there are significant differences in pH and seasons at 5% level. pH was found to be significantly correlated with parameters like EC, salinity, total hardness, Ca, potassium, sodium and sulphate at 1% level.

Electrical Conductivity (EC)

Electrical conductivity of water sample is a measure of ability of the sample to conduct electric current, which is the reciprocal of resistance. Measurement of conductivity provides a very rapid means of obtaining fairly good estimate of the total dissolved solid concentration and salinity of water samples. Most of the dissolved inorganic substances in water are in an ionized form, which contributes to conductance. A number of salts are usually found dissolved in natural waters, the common ones being

carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates of calcium, magnesium, sodium, potassium, iron and manganese which contribute to the electrical conductivity in water (Trivedy *et al.* 1987).

The seasonal changes in electrical conductivity in the Thalassery and Valapattanam river basins are presented in Table 4. 7 A & 4. 7 B respectively.

Table 4. 7 A Seasonal Variations in EC of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	38400	34000	37800	33850	36333	126
Monsoon	22997	17930	16471	8567	1580	61.4
Post-monsoon	23703	35350	34950	34950	30750	148

Table 4. 7 B Seasonal Variations in EC of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	33533	29300	30800	24933	23900	21896	21550	23750	203
Monsoon	13343	2953	2900	2657	4990	2426	263	158	51
Post-monsoon	31700	26300	28250	24350	25150	16180	14090	13615	66

The electrical conductivity in the Thalassery River ranged from 126-38,400 $\mu\text{mhos/cm}$, 61.4-22,997 $\mu\text{mhos/cm}$ and 148-3,350 $\mu\text{mhos/cm}$ during pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, it ranged from 203-33,533 $\mu\text{mhos/cm}$, 51-13,343 $\mu\text{mhos/cm}$ and 66-31,700 $\mu\text{mhos/cm}$ during pre-

monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 5 A & 4. 5 B). There was a sharp variation in the electrical conductivity of different sites and seasons in the two river basins.

Temporal variations revealed higher concentration during the pre-monsoon season, which was followed by the post-monsoon season. The monsoon season recorded the lowest values in both the river basins. The low values observed during the monsoon season may be attributed to dilution by the run-off.

Spatial variation was very sharp in both the river basins. The approximate conductance of seawater may reach up to 50,000 $\mu\text{mhos/cm}$ (Hem, 1985). In the present study, the bar mouth (estuary) recorded the highest conductivity values and fresh water recorded the lowest, in all the seasons. When mangrove and non-mangrove areas were compared, the former recorded higher concentration than the latter. A mixing of salt rich seawater and fresh water in the mangrove site, which may contribute to higher soluble salts ultimately contributing to high electrical conductivity. In the present study, lower conductivity values were recorded from the mangrove waters when compared to earlier reports (Nalini Nayak *et al.* 2000) where EC values ranged from 220 - 40,900 $\mu\text{mhos/cm}$, 2,600 – 50,500 $\mu\text{mhos/cm}$ and 12,000 $\mu\text{mhos/cm}$ in Pazhayangadi, Kunhimangalam and Edat Thuruthummal mangrove waters respectively during the monsoon and summer months.

Statistical analysis revealed that in the Thalassery River, there are significant differences in EC and seasons and EC and locations at 5% level. EC was found to be significantly correlated with parameters like pH, salinity, total hardness, calcium, chloride, sulphate, fluoride, potassium and sodium at 1% level.

In the Valapattanam River, there are significant differences in EC and seasons and

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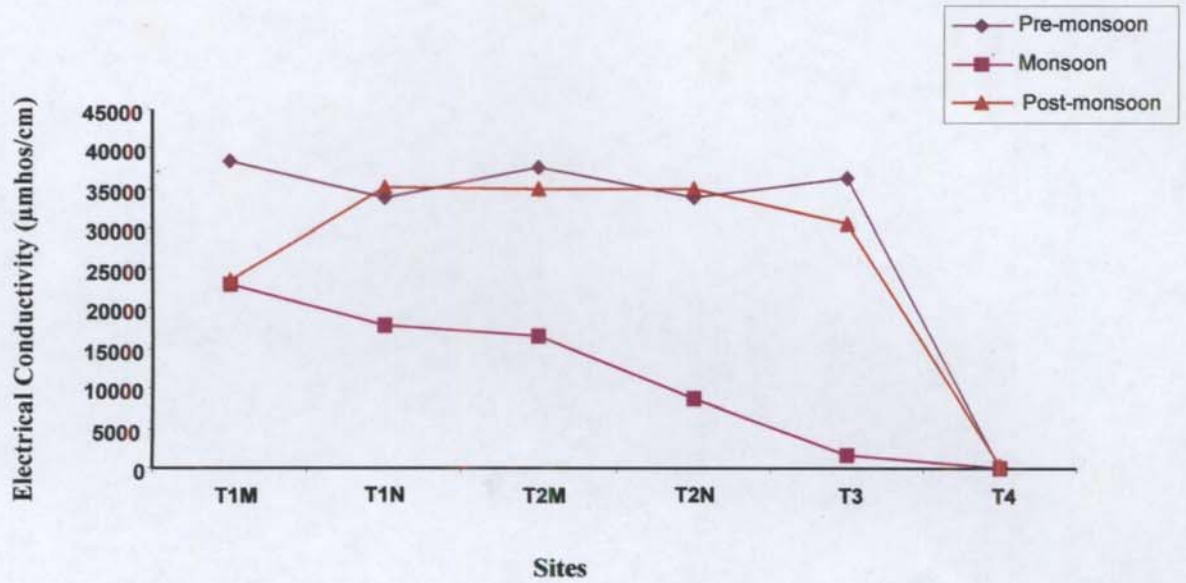


Fig. 4. 5 A Seasonal Variations in Electrical Conductivity of Thalassery River

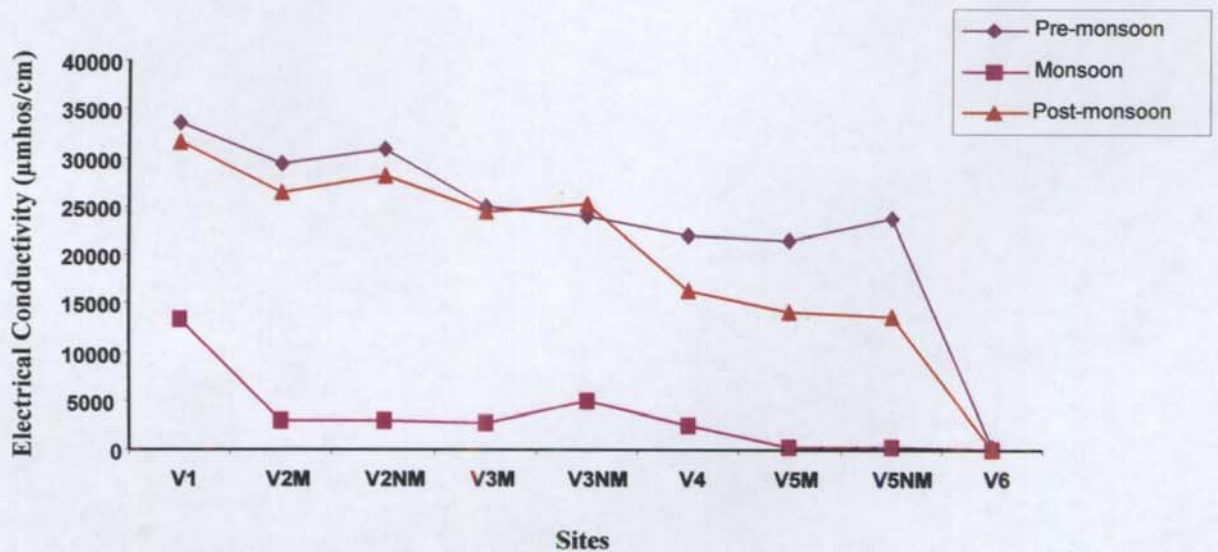


Fig. 4. 5 B Seasonal Variations in Electrical Conductivity of Valapattanam River

EC and locations at 5% level. EC was found to be significantly correlated with parameters like pH, salinity, total hardness, ammonia, chloride, sulphate, fluoride, nitrite, calcium and potassium at 1% level.

Salinity

Salinity refers to the degree of saltiness of water, or more specifically, the concentration of dissolved solids in waters. Seawater has an average salinity of 34.5 ppt and the relative concentration of the major constituents such as chloride (55%) and sodium (31%) remains constant (Nambudiripad & James, 1987).

The salinity of water at different study sites in the Thalassery and Valapattanam river basins are presented in Table 4. 8 A & 4. 8 B respectively.

Table 4. 8 A Seasonal Variations in Salinity of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	33.3	32.9	33.2	32.6	31	0.1
Monsoon	20.5	17.4	14.9	7.5	1	0
Post-monsoon	32.5	29.6	32.1	32.5	27.1	0.1

Table 4. 8 B Seasonal Variations in Salinity of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	32.6	27.1	29.5	22	21	18.5	17.8	20	1.1
Monsoon	8.03	1.9	1.9	1.8	3.6	2.45	0.1	0.1	0
Post-monsoon	30.5	23.5	26.2	21.75	22.5	13	3.6	10.7	0

In the Thalassery River, salinity ranged from 0.1-33.3 ppt, 0-20.5 ppt and 0.1-32.5 ppt during pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, the salinity ranged from 1.1-32.6 ppt during pre-monsoon, 0-8.03 ppt during monsoon and 0-30.5 during post-monsoon seasons (Figures 4.6 A & 4.6 B).

A sharp seasonal and spatial variation of salinity was observed in the river basins studied

Temporal variations in salinity revealed that pre-monsoon recorded highest salinity which was followed post-monsoon season. The lowest salinity was recorded during the monsoon season. The high values during the pre-monsoon and post monsoon period were found to be related to the lean summer flows and increase in evaporation as has been reported earlier (Prabhadevi *et al.* 1996; Govindaswamy & Kannan, 1991). The salinity values reveal an increasing trend both during post and pre-monsoon seasons as has been reported earlier (Krupadam & Anjaneyulu, 2000).

The lowest salinity values recorded during the monsoon season may be attributed to the high dilution by rainwater. With the onset of monsoon, salinity declined drastically due to dilution by rainwater (Prabhadevi *et al.* 1996) and also to direct precipitation (Valarmathi *et al.* 2002; Balakrishnan Nair & Abdul Aziz, 1987).

Among the various sites studied, highest salinity was recorded at the bar mouth in all the seasons studied. Salinity as high as 33.3 ppt and 32.6 ppt respectively were recorded in the lower reaches of Thalassery and Valapattanam river basins respectively. This may be due to salinity intrusion from the sea.

Salinity is considered the most remarkable parameter controlling the distribution of mangroves all over the world, though mangroves are found growing in a wide range of salinities. Salinity of mangrove areas is greatly affected by seasonal rainfall and

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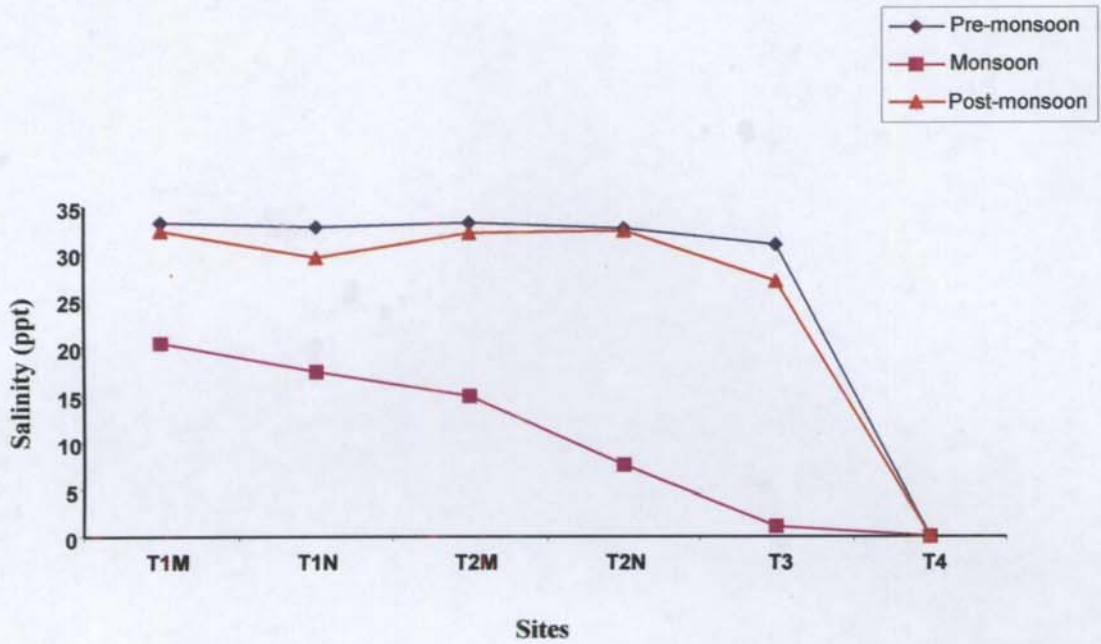


Fig. 4. 6 A Seasonal Variations in Salinity of Thalassery River

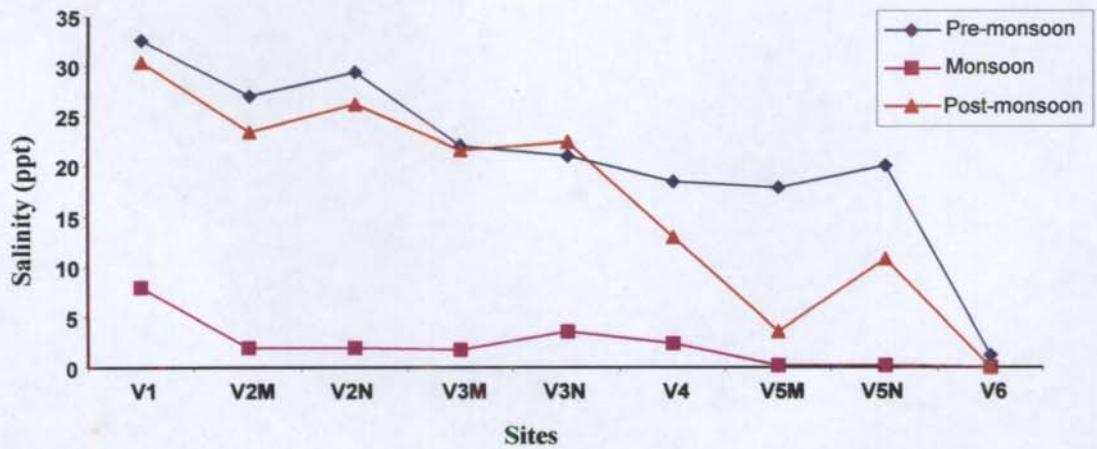


Fig. 4. 6 B Seasonal Variations in Salinity of Valapattanam River

evaporation. The salinity of mangroves of coastal waters range from 25-33 ppt (Dagar *et al.* 1991). The daily variation and annual mean of salinity affects mangrove growth and distribution (Soegiarto, 1984). Each species has a characteristic salinity tolerance range (Dagar *et al.* 1991). Ramchandran *et al.* (1986) reported the surface water salinity of mangroves of Veli, Quilon and Kumarakom to be 3.8, 2.2 and 1.4 ppt respectively, which was observed to be very low compared to the present study. Valarmathi *et al.* (2002) reported a salinity range of 1.4 – 35.7 ppt along the Madras coast and discussed its seasonal variation. Influence of salinity in the distribution, zonation, growth, tolerance limit and development of mangroves have been studied earlier (MacNae, 1968; Chapman 1976; Semesi, 1986; Banyikwa, 1986; Dagar *et al.* 1991 & Ananthkrishnan 1982). Each mangrove species occupies a salinity zone best suited for it and dynamic adaptation of salinity regimes has been described as the ‘metabolic basis of zonation’ (Snedaker, 1978). Therefore, productivity of mangroves is related to the periodicity and frequency of flushing, especially with water having moderate salinity enriched with nutrients. In many mangroves of the world, complete flushing of excess salts occurs during the rainy season (Snedaker, 1978). The range of salinity in the mangrove areas of Valapattanam and Thalassery river basins showed that the salinity was favorable for the growth of mangroves.

Statistical analysis revealed that in the Thalassery River, there are significant differences in salinity and seasons and salinity and locations at 5% level. Salinity was found to be significantly correlated with parameters like calcium, chloride, EC, fluoride, pH, potassium, sodium, sulphate and total hardness at 1% level.

In the Valapattanam River, there are significant differences in salinity and seasons and salinity and locations at 5% level. Salinity was found to be significantly correlated

with parameters like pH, EC, fluoride, nitrite, chloride, sulphate, ammonia, calcium, potassium, sodium, and total hardness at 1% level.

Dissolved Oxygen (DO)

Dissolved oxygen in water is a very important parameter of water quality, which is an index of physical and biological processes taking place in water. DO in water maintain the higher forms of life and keep the proper balance of various populations, thus making the water body healthy. The amount of DO in water varies with its solubility which depends on temperature, pressure and salinity of water and the chemical and biochemical processes undergoing in a water body are largely dependent upon the presence of oxygen (Trivedy *et al.* 1987; Trivedy & Goel, 1986).

Dissolved oxygen is one of the most important limiting factor in aquatic ecosystems, because most organisms other than anaerobic microbes perish rapidly when the oxygen levels in water falls down to zero. The source of oxygen in water is atmospheric aeration and photosynthesis, while the rates of oxygen removal 'or CO₂ sinks' are respiration, decomposition of organic matter and losses to atmosphere.

Seasonal variation of DO in the Thalassery and Valapattanam river basins are presented in Tables 4.9 A & 4.9 B respectively.

Table 4.9 A Seasonal Variations in DO of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	4.16	5.27	5.1	4.9	4.6	3.33
Monsoon	5.43	6.66	5.3	4.72	5.53	6.51
Post-monsoon	5.4	5.37	4.49	4.49	4.17	3.59

Table 4.9 B Seasonal Variations in DO of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	6.09	5.33	4.97	5.82	6.43	6.88	5.03	5.56	6.42
Monsoon	6.5	7.79	7.19	6.52	6.41	6.48	6.45	7.63	7.45
Post- monsoon	5.34	4.52	5.39	5.8	5.58	7.16	5.77	5.97	6.78

In Thalassery River, the DO values ranged from 3.33-5.27 mg/l, 4.72-6.66 mg/l and 3.59-5.4 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively. In Valapattanam River, the DO values ranged between 4.97-6.88 mg/l, 6.41-7.79 mg/l and 4.52-7.16 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4.7 A & 4.7 B).

DO was found to be high during the monsoon season in comparison with pre-monsoon and post-monsoon seasons in both the river basins studied. This may be due to the intrusion of fresh DO rich water from the river into coastal waters and the resultant mixing and circulation (Madhusoodana Kurup & Samuel, 1987; Neelakantan *et al.* 1987). Annual mean DO varied between 3.29-4.40 mg/l in Kali estuary (Neelakantan *et al.* 1987). Low dissolved oxygen content during pre-monsoon has also been reported by Balakrishnan and Abdul Aziz (1987); Madhusoodana Kurup and Samuel (1987).

The temporal variations in DO were not sharp, especially between the mangrove and non-mangrove sites. The mangrove area in general showed less DO contents compared to the non-mangrove area. This may be due to the consumption of oxygen by

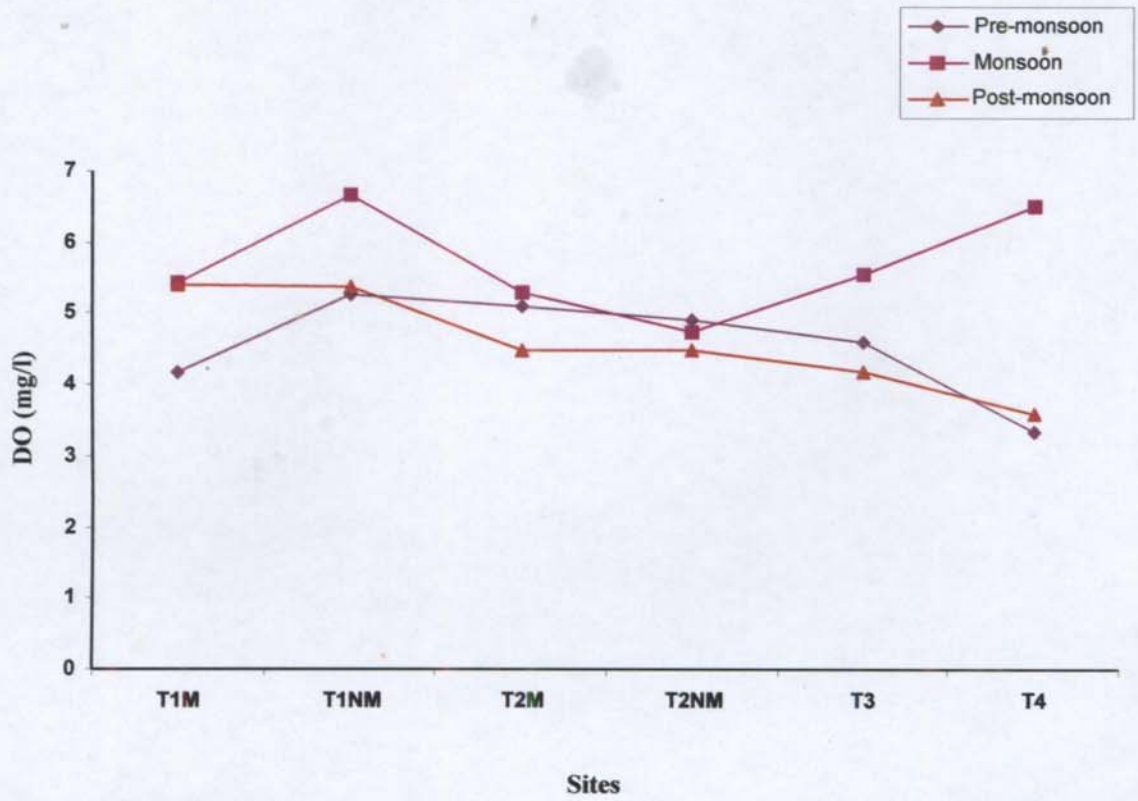


Fig. 4. 7 A Seasonal Variations in Dissolved Oxygen of Thalassery River

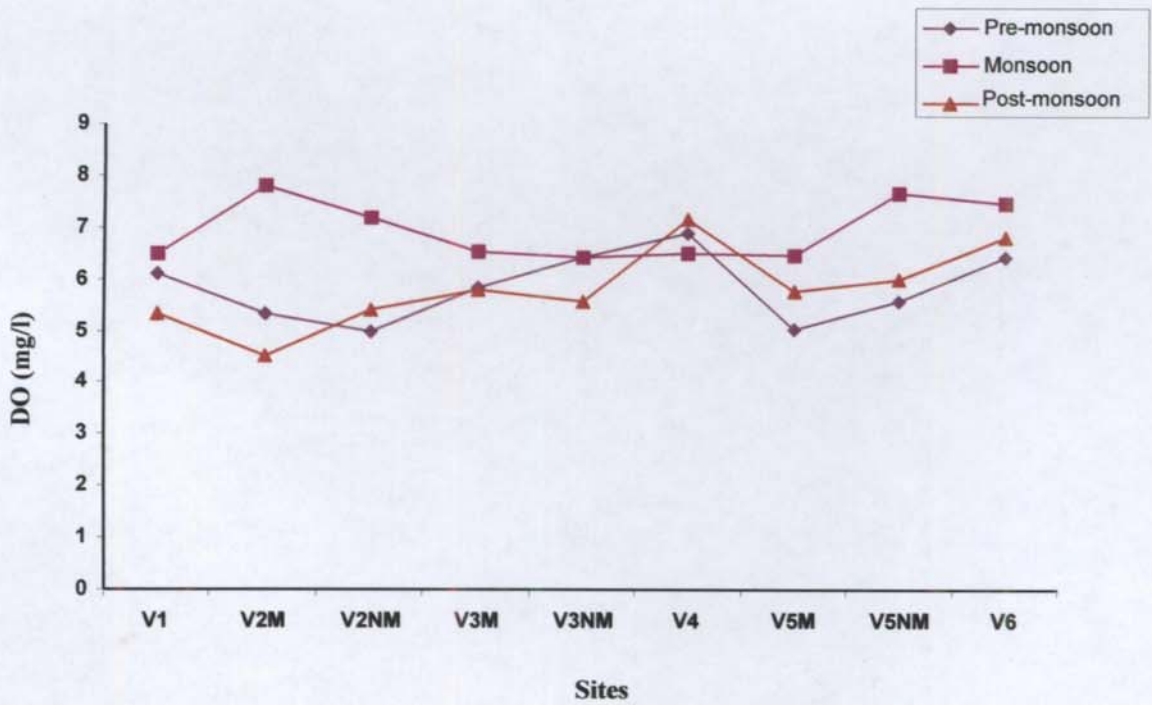


Fig. 4. 7 B Seasonal Variations in Dissolved Oxygen of Valapattanam River

the microbial fauna for decomposition of organic matter content in mangrove sites. Organic wastes (oxygen demanding pollutants) cause rapid depletion of DO in water. Oxidizable inorganic substances like hydrogen sulphide, ammonia, nitrate and ferrous ions also cause decrease in DO (Trivedy *et al.* 1987). Low DO contents noted in the T3 and V2 mangrove sites may be attributed to the effect coir retting, wherein a lot of hydrogen sulphide is released into water. Similar depletion in DO contents has been reported earlier by Remani *et al.* (1989). Low DO is an indication of the anoxic condition that is typical of water bodies heavily loaded with organic discharge.

In a healthy aquatic ecosystem, the level of dissolved oxygen is generally close to saturation (7-9 mg/l). However a minimum concentration of 5 mg/l is considered essential to maintain fish fauna of the water body. In the present study, the DO concentration nearing to 5 mg/l and above was recorded in both the river basins, which is congenial for the sustenance of flora and fauna.

Statistical analysis revealed that in the Thalassery River, there are significant differences in DO and seasons at 5% level.

In the Valapattanam River, there are significant differences in DO and seasons at 5% level. DO was found to be significantly correlated with parameters like phosphate and silica at 1% level.

Biological Oxygen Demand (BOD)

The rate of removal (*i.e.*, consumption) of oxygen by microorganisms through the anaerobic degradation of dissolved or even particulate organic matter is reflected as BOD, which is an index of organic pollution in water. More the oxidizable matter present in water, more the amount of oxygen required for its biodegradation and hence more BOD (Trivedy & Goel, 1986).

Variations in the BOD values in the sampling sites in Thalassery and Valapattanam rivers are presented in Tables 4. 10 A & 4. 10 B respectively.

Table 4. 10 A Seasonal Variations in BOD of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	2.8	1.13	0.74	1.1	3.5	2
Monsoon	0.66	0.33	1.05	1.51	0.52	0.79
Post-monsoon	2.4	2.64	3.27	3.66	2.86	2.17

Table 4. 10 B Seasonal Variations in BOD of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	1.14	20.8	0.4	1.26	0.94	1.11	1.33	0.9	1.24
Monsoon	1.91	2.42	1.09	3.68	1.08	2.64	2.58	1.13	2.01
Post-monsoon	1.12	2.61	1.36	1.71	1.33	2.18	1.15	0.99	0.64

The BOD values of Thalassery River ranged from 2-2.8 mg/l, 0.33-1.51 mg/l and 2.17-3.66 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, it ranged from 0.4-2.08 mg/l in pre-monsoon, 1.08-3.68 mg/l in monsoon and 4.52-7.16 mg/l is post-monsoon seasons respectively (Figures 4. 8 A & 4. 8 B).

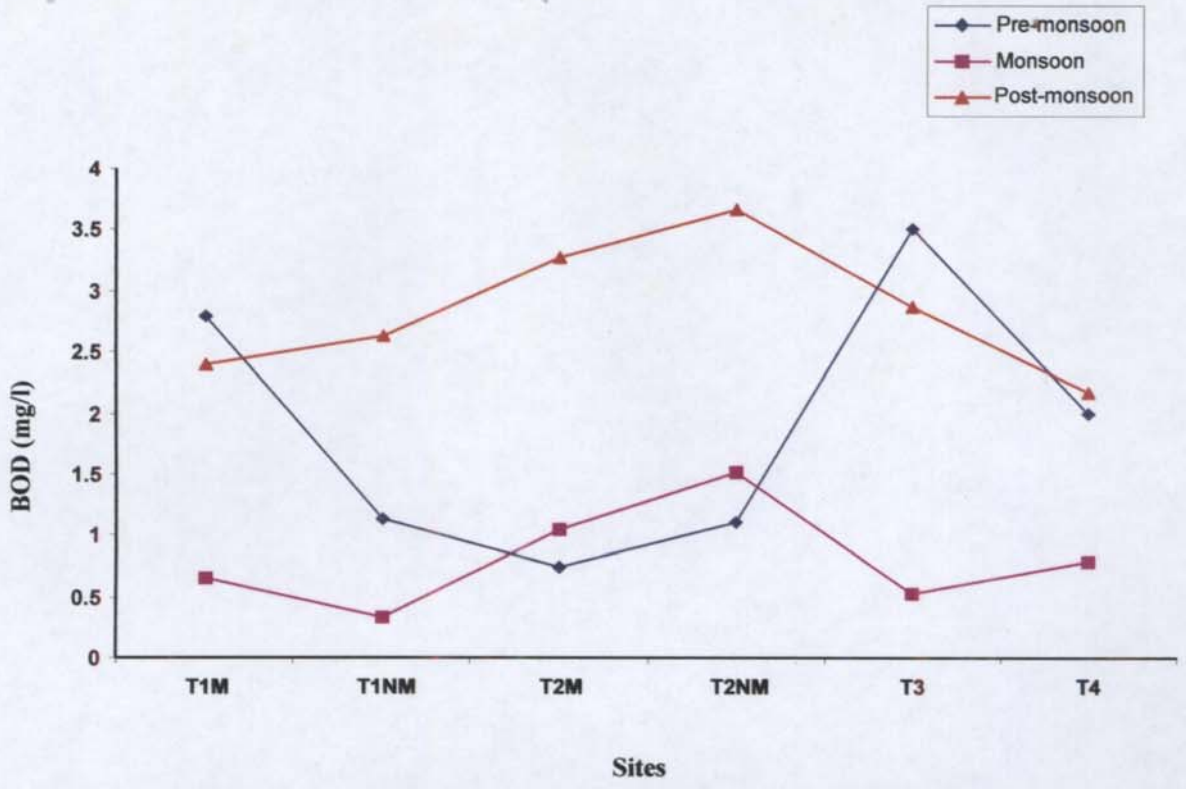


Fig. 4. 8 A Seasonal Variations in BOD of Thalassery River

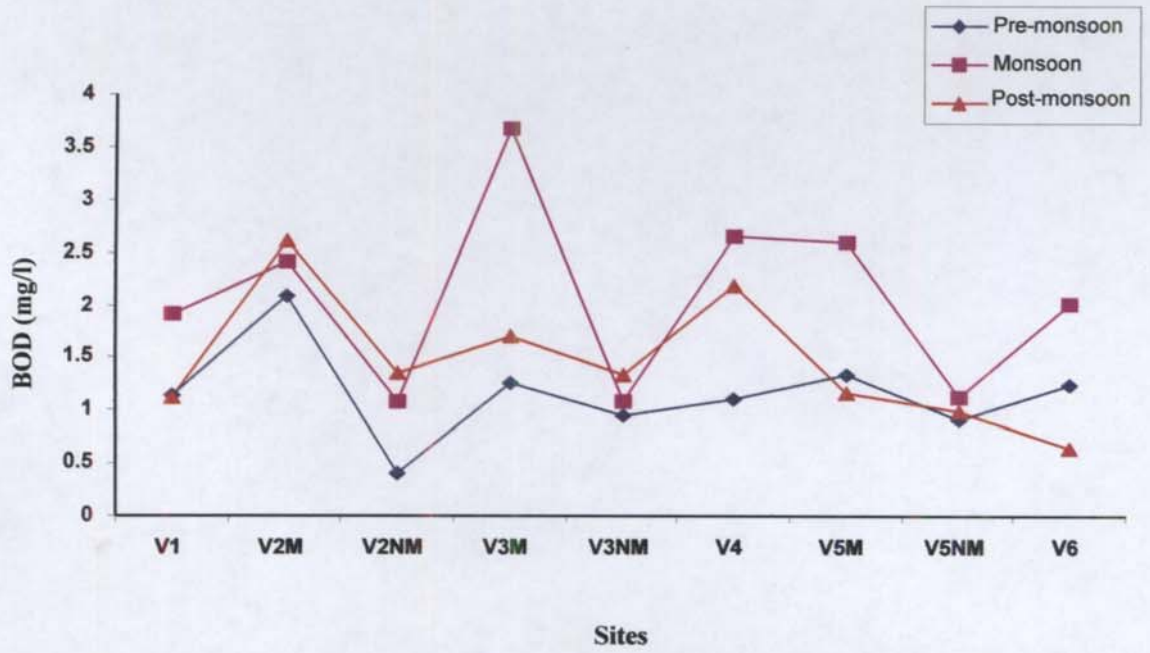


Fig. 4. 8 B Seasonal Variations in BOD of Valapattanam River

The BOD values recorded seasonal and spatial variation in both the rivers. Temporal variation revealed, the BOD to be higher in the post-monsoon season in the Valapattanam River, while in the Thalassery River, higher values were recorded in the monsoon season, which is followed by post-monsoon season. The higher BOD during the post and pre-monsoon may be attributed to the lean flow of DO rich freshwater. The high BOD values recorded in the Valapattanam River, during the monsoon may be attributed to the land runoff carrying high amount of organic matter and consequent decomposition leading to high BOD. This may also be considered as the main reason for the increase in BOD content in freshwater sites.

Spatial variations in BOD recorded higher values in mangrove sites compared to non-mangrove sites. The higher BOD content in mangrove sites may be due to the decomposition of high organic matter characteristic of the ecosystem. Bijoy Nandan and Abdul Aziz (1990), reported high BOD due to coconut husk retting in Kadinamkulam estuary. The T3 and V2M sites recorded high BOD, which may be attributed to the coconut husk retting activities in these sites. The higher BOD in the V4 site may be due to the animal wastes dumped in the area, which consumed high oxygen for decomposition, resulting in high BOD. The BOD of tidal waters and estuaries is affected by salinity and only very low values are obtained. In the present study also, the estuarine sites recorded lower BOD values.

According to Martin (1970), a water body with a BOD₅ of 8 mg/l is considered to be moderately polluted. In the present study, BOD has never exceeded more than 4 mg/l in the river basins studied, showing the good health of both the rivers.

Statistical analysis revealed that in the Thalassery River, there are significant differences in BOD and seasons at 5% level.

In the Valapattanam River, there are significant differences in BOD and seasons and BOD and locations at 5% level.

Total Hardness

Hardness is deemed to be the capacity of water for reducing and destroying the lather of soap and increases the boiling point of waters. Hardness in water is due to the natural accumulation of salts from the soil and geological formations or from pollution by industrial effluents. Total hardness in water is due to bicarbonates of Ca, Mg, sulphate and chloride. Iron, aluminum, manganese, strontium and zinc also cause hardness to a negligible amount. The 'total hardness' indicates the concentrations of calcium and magnesium ions, because these are present in higher concentration over other cations (Trivedy & Goel, 1986).

The total hardness values for different seasons in the study areas in Thalassery and Valapattanam river basins are presented in the Tables 4. 11 A & 4. 11 B respectively.

Table 4. 11 A Seasonal Variations in Total Hardness of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	7170	6800	6770	6700	6227	22
Monsoon	5977	6300	4713	4400	2385	18
Post-monsoon	4536	5860	5222	4424	3212	16

In the Thalassery River basin, total hardness ranged from 22 - 7170 mg/l, 18 - 6300 mg/l and 16 - 5860 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively. While in the Valapattanam River, it ranged from 219 - 5,640 mg/l, 19 - 2,248 mg/l and 21 - 6,080 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 9 A & 4. 9 B).

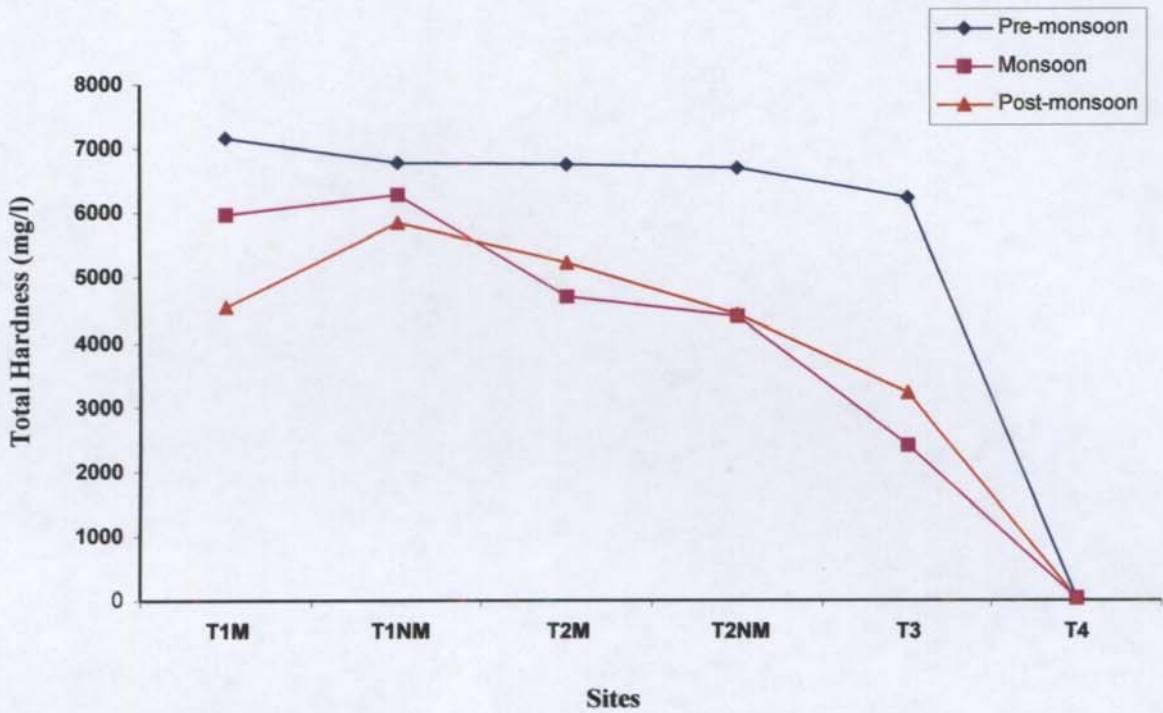


Fig. 4. 9 A Seasonal Variations in Total Hardness of Thalassery River

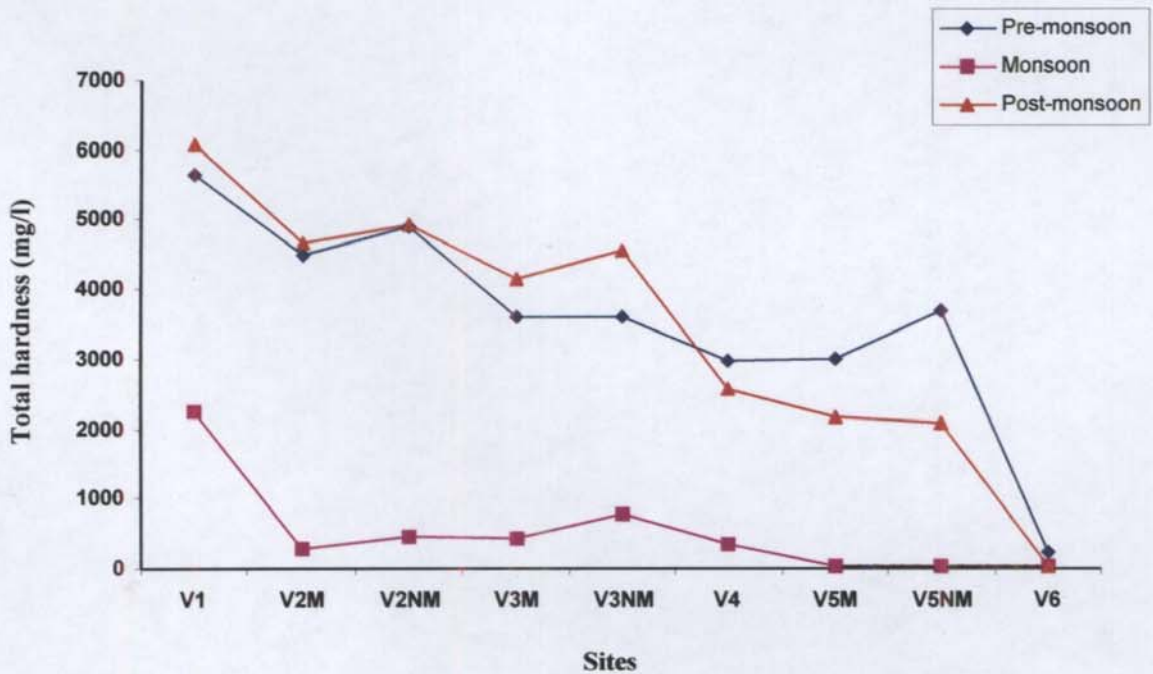


Fig. 4. 9 B Seasonal Variations in Total Hardness of Valapattanam River

Table 4. 11 B Seasonal Variations in Total Hardness of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	5460	4487	4900	3590	3600	2980	3000	3700	219
Monsoon	2248	293	460	419	766	348	40	29	19
Post- monsoon	6080	4660	4940	4160	4560	2550	2160	2060	21

Seasonal and spatial variations in total hardness were recorded in both the rivers studied. In the Thalassery River, higher values were recorded for hardness during the pre-monsoon season, while in the Valapattanam River, higher values were recorded during the post-monsoon season. In both the rivers, hardness recorded the lowest values during the monsoon season. The sudden decrease of hardness with the onset of monsoon may be due to the influx of freshwater resulting in dilution of high order (Ramakrishna *et al.* 1987; Godfery, 1983 & Das, 2002).

Among the different sites studied, in the Thalassery and Valapattanam river basins, maximum were reported at the bar mouth and minimum in fresh water sites. The high hardness recorded in the estuary might have been contributed from the seawater. In the present study, when compared to mangrove areas, the non-mangrove sites showed a higher value for hardness than the mangrove sites. But, in the T2NM site of Thalassery River, comparatively lower values were recorded. This may be either due to the direct uptake of calcium by the mollusc, *Crassostrea madrasensis* or due to its precipitation as calcium carbonate and locked into the sediments. Nalini Nayak *et al.* (2000) reported that total hardness ranged from 32 – 7,100 mg/l in Pazhayangadi, 272 – 7,400 mg/l in

Kunhimangalam and 548 – 7,400 mg/l in the Edat Thuruthummal mangrove waters during the monsoon and summer months respectively. Total hardness values recorded from Thalassery mangrove waters were in agreement with the above observation. In the Valapattanam mangrove water, lower hardness values were observed.

Statistical analysis revealed that in the Thalassery River, there are significant differences in total hardness and seasons and total hardness and locations at 5% level. Total hardness was found to be significantly correlated with parameters like turbidity, calcium, chloride, EC, sulphate, fluoride, magnesium, nitrite and sodium at 1% level.

In the Valapattanam River, there are significant differences in total hardness and seasons and total hardness and locations at 5% level. Total hardness was found to be significantly correlated with parameters like ammonia, calcium, chloride, EC, fluoride, iron, nitrite, pH, potassium, salinity, sodium and sulphate at 1% level.

Chloride

Chloride is the common anion found in water and sewage. The concentration of this major inorganic constituent in natural waters varies from a few milligrams to several thousand milligrams/litre. Higher concentration may be due to the contamination by seawater, sewage or industrial effluents. It may also result from the leaching of chloride containing rocks and soils with which the water comes in contact. In coastal region salt water intrusion may contribute to the chloride content of inland waters (Manivasakam, 1996; Trivedy & Goel, 1986). Discharge of agricultural, industrial and domestic wastes could also be a source of chloride in natural waters. Chloride is a major constituent in seawater. The most common type of water in which chloride is the dominant anion is one in which sodium is the predominant cation.

Seasonal variation of chloride in the Thalassery and Valapattanam River basins

are presented in Tables 4. 12 A & 4. 12 B respectively.

Table 4. 12 A Seasonal Variations in Chloride of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	21819	24114	20200	20938	20784	19.62
Monsoon	12101	10608	4565	4565	716	12
Post-monsoon	25103	25453	23109	23109	14069	26.35

Table 4. 12 B Seasonal Variations in Chloride of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	19568	16312	17890	12383	12793	11015	10953	12395	19.73
Monsoon	6162	183	131	199	61	134	265	201	10
Post-monsoon	19421	13801	15420	12964	13322	5321	6933	6589	11

In the Thalassery River the concentration of chloride ranged from 19.62-24,114 mg/l, 12-12101 mg/l and 26.35-25453 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively. The concentration of chloride reported in the study area of Valapattanam River during pre-monsoon, monsoon and post-monsoon seasons are 19.73-19,568 mg/l, 10-6,162 mg/l and monsoon 11-19,421 mg/l respectively (Figures 4. 10 A & 4. 10 B).

121A

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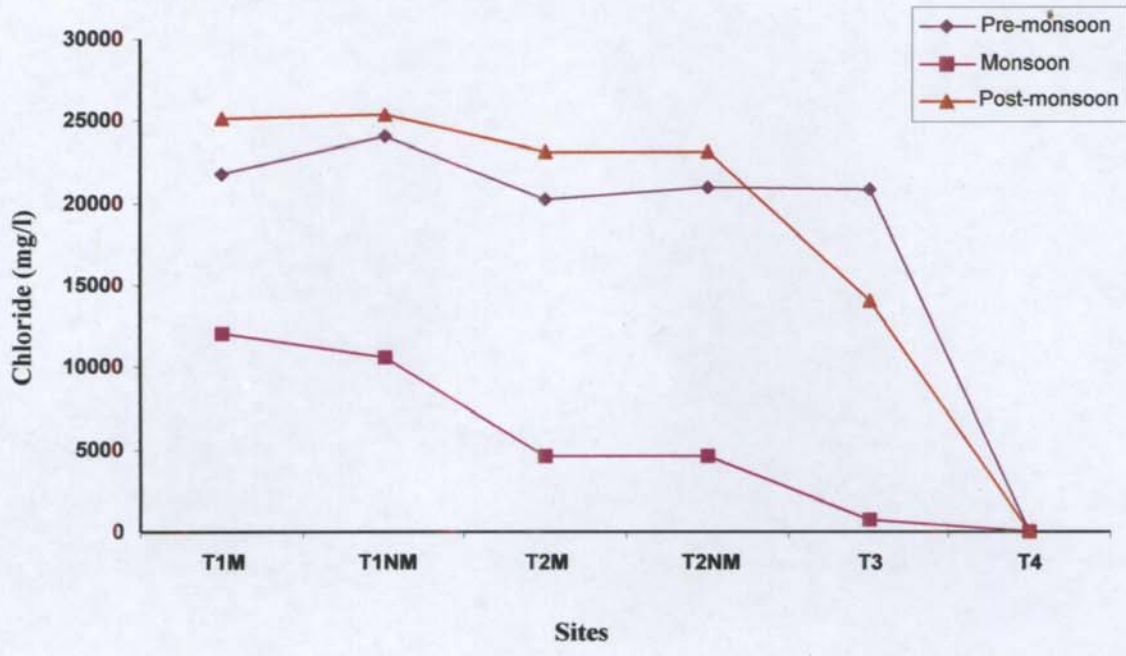


Fig. 4. 10 A Seasonal Variations in Chloride of Thalassery River

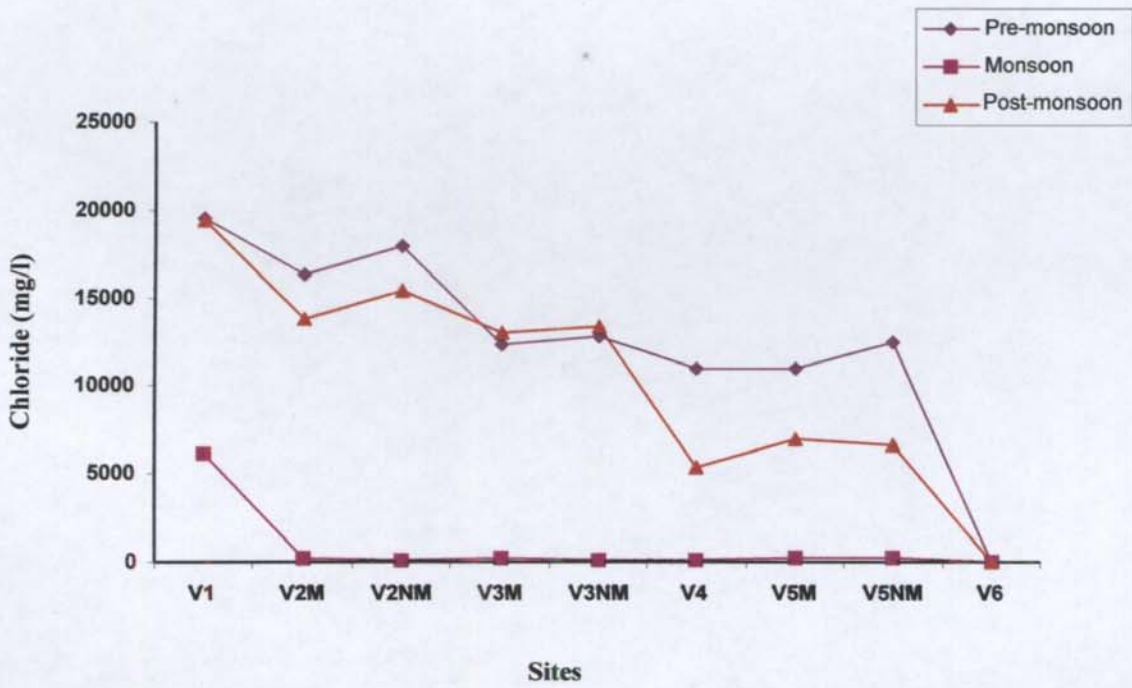


Fig. 4. 10 B Seasonal Variations in Chloride of Valapattanam River

In the present study, a sharp spatial and temporal variation was noticed in chloride content. Among the seasons studied, the pre-monsoon season recorded highest chloride concentration in Valapattanam River, while higher concentration was recorded in the post-monsoon season in the Thalassery River. Monsoon season recorded the least concentration of chloride in both the river basins. A sharp decline in chloride content was recorded with the onset of monsoon due to influx of fresh water resulting in dilution of higher order (Ramakrishna *et al.* 1987; Godfery, 1983; Das, 2002).

Among the various sites studied the estuary showed maximum chloride concentration, while the freshwater recorded the least. Sodium and chloride being the major constituents of sea water imparting salinity, their high concentrations were recorded at the bar mouth. The chloride concentration in seawater is approximately 19,000 mg/l (Goldberg, 1976). When mangrove and non-mangrove areas were compared, non-mangrove area showed higher chloride concentration than the mangrove sites. Comparatively low chloride values in the mangrove site compared to the non-mangrove site may be attributed to the special salt tolerance mechanism, shown by mangroves. They have the unique capacity for salt accumulation, which may probably reduce the chloride content in water. The fine-grained sediments in the mangrove may bind chloride ions from the overlying waters. Nalini Nayak *et al.* (2000), reported chloride concentration ranging from 64 – 18,400 mg/l in Pazhayangadi, 940 – 18,800 mg/l in Kunhimangalam and 3,900 – 21,300 mg/l in the Edat Thuruthummal mangrove waters during monsoon and summer months respectively. In the present study also the mangrove waters recorded chloride values, which is almost in agreement with the above report.

Statistical analysis revealed that in the Thalassery River, there are significant differences in chloride and seasons and chloride and locations at 5% level. Chloride was

found to be significantly correlated with parameters like calcium, EC, pH, salinity, sodium, sulphate, temperature and total hardness at 1% level.

In the Valapattanam River, there are significant differences in chloride and seasons and chloride and locations at 5% level. Chloride was found to be significantly correlated with parameters like ammonia, calcium, chloride, EC, fluoride, nitrite, pH, potassium, salinity, sodium, sulphate and total hardness at 1% level.

Fluoride

The major source of fluoride in water is fluorspar, rock phosphates, theropepitite, triplite and phosphorita. Phosphate rocks are the source of phosphate fertilizers, which contains approximately 3.5-4% fluorides. The fluoride naturally found in water is CaF. The natural fluoride content of water is different and varies according to the sources of water, the geological formation of the area, and the amount of rainfall and quantity of water lost by evaporation. The other sources of fluoride in water resources are phosphatic fertilizers, fluorinated plastics, fluorinated hydrocarbons, etc (Manivasakam, 1996).

The seasonal variation of fluoride in the Thalassery and Valapattanam river basins is presented in Tables 4. 13 A & 4. 13 B respectively. The concentration of fluoride ranged from 0.97-1.61 mg/l, 0.17-0. 68 mg/l and 0.17-0.72 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively. While in the Valapattanam River, it ranged from 0.69-2.29 mg/l, 0.25-0.94 mg/l and 0.16-0.89 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 11 A & 4. 11 B).

The temporal variations recorded a high concentration during the pre-monsoon season in both the river basins. Monsoon season recorded the lowest values for fluoride, which may be due to the mixing and dilution with rainwater.

Table 4. 13 A Seasonal Variations in Fluoride of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	1.61	1.3	1.6	1.5	1.33	0.97
Monsoon	0.57	0.68	0.39	0.33	0.24	0.17
Post-monsoon	0.59	0.72	0.47	0.45	0.34	0.17

Table 4. 13 B Seasonal Variations in Fluoride of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	1.07	2.29	0.78	1.08	1.32	0.67	1.21	1.1	0.69
Monsoon	0.94	0.49	0.38	0.38	0.37	0.29	0.25	0.31	0.39
Post-monsoon	0.52	0.56	0.57	0.55	0.89	0.62	0.62	0.52	0.16

Among the various sites studied, the mangrove sites showed high fluoride content compared to the respective non-mangrove sites. Important source of fluoride in the mangrove areas may be fresh water runoff from the land containing phosphatic fertilizers, which contains about 3.5-4% of fluoride. Low values were encountered in the freshwater sites of both the river basins. Fluoride in seawater approximates a concentration of 1.3 mg/l (Goldberg, 1976). The high fluoride content in the bar mouth in these river basins may be attributed to the contribution from fresh water and seawater.

Statistical analysis revealed that in the Thalassery River, there are significant differences in fluoride and seasons and fluoride and locations at 5% level. Fluoride was found to be significantly correlated with parameters like colour, calcium, EC, potassium,

124-19 63

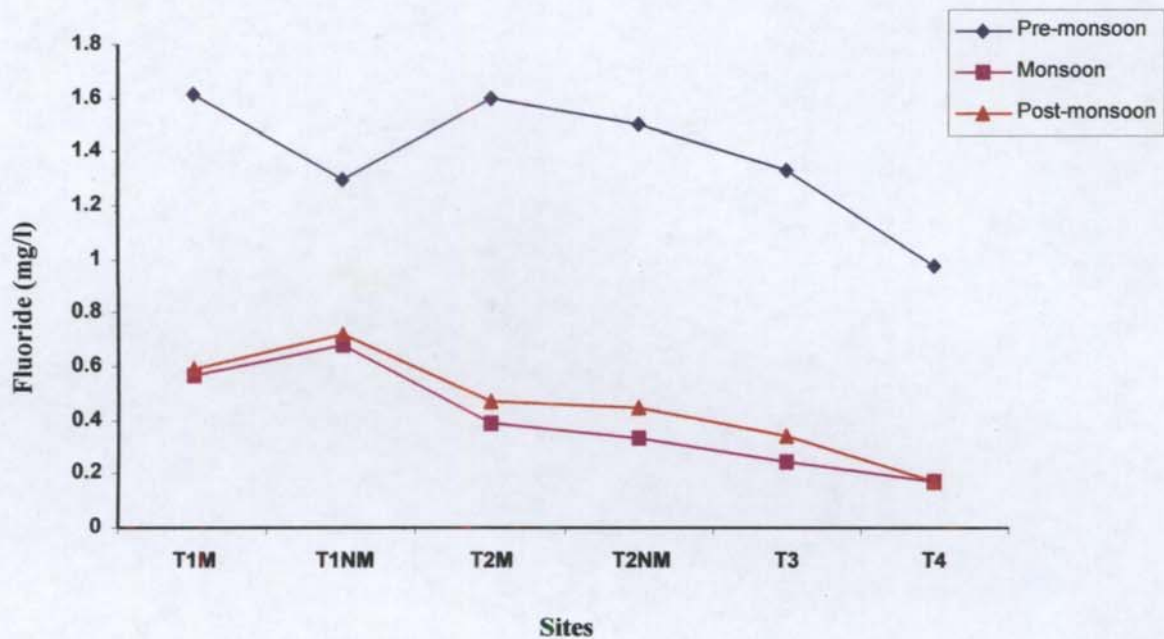


Fig. 4. 11 A Seasonal Variations in Fluoride of Thalassery River

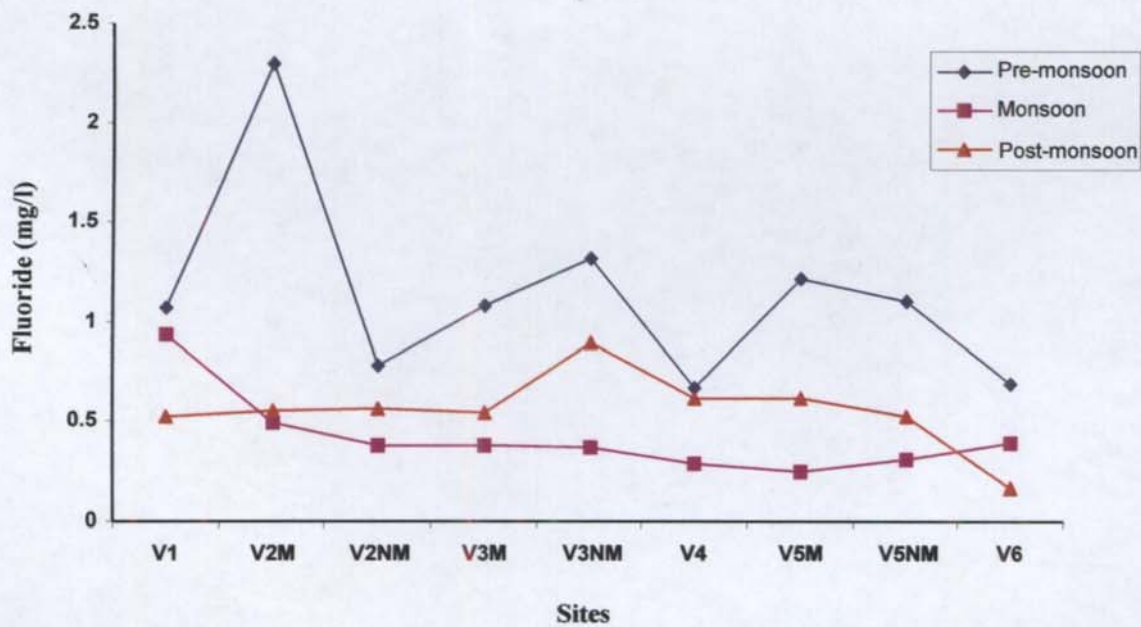


Fig. 4. 11 B Seasonal Variations in Fluoride of Valapattanam River

salinity, total hardness and salinity at 1% level.

In the Valapattanam River, there are significant differences in fluoride and seasons at 5% level. Fluoride was found to be significantly correlated with parameters like ammonia, calcium, chloride, EC, magnesium, nitrite, potassium, salinity, sodium, sulphate and total hardness at 1% level.

Ammonia-Nitrogen

Ammonia occurs naturally in water bodies due to the breakdown of nitrogenous organic and inorganic matter in soil and water, extraction by biota, reduction of nitrogen in water by microorganisms and from gas exchange with the atmosphere. It may also occur in water due to the discharge of industrial and municipal effluents. High concentration of ammonia is toxic to aquatic life and therefore detrimental to the ecological balance of water bodies (Trivedy & Goel, 1986).

Ammonia in natural water is the ammonification of organic matter. Occurrence of ammonia is the consequence of organic pollution. Ammonia of mineral origin is rare in natural waters (Trivedy *et al.* 1987).

The seasonal variation of nitrite content in Thalassery and Valapattanam river basins are presented in Tables 4. 14 A & 4. 14 B respectively.

Table 4. 14 A Seasonal Variations in Ammonia – Nitrogen of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.05	0.042	0.261	0.026	0.289	0.011
Monsoon	0.011	0.011	0.01	0.015	0.005	0.004
Post-monsoon	0.021	0.021	0.005	0.014	0.007	0.001

Table 4. 14 B Seasonal Variations in Ammonia - Nitrogen of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	0.007	0.028	0.022	0.016	0.01	0.01	0.012	0.004	0.007
Monsoon	0	0	0	0.002	0	0	0	0	0
Post- monsoon	0.002	0.008	0.013	0.014	0.011	0.023	0.014	0.007	0.015

In the Thalassery river basin, ammonia concentration ranged from 0.011 – 0.289 mg/l, 0.004 – 0.015 mg/l and 0.001 – 0.021 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam river basin, it ranged from 0.004 – 0.028 mg/l, 0.0 – 0.002 mg/l and 0.002 – 0.023 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 12 A & 4. 12 B).

Seasonal variation in ammonia was not clearly recorded during the present study. Comparatively higher concentration was observed during the pre-monsoon season. Low concentration of this nutrient was observed during the monsoon season in both the river basins.

When compared to earlier studies (Saraladevi *et al.* 1991) very low concentration of ammonia was recorded in the present study. The low concentration may be attributed to its rapid conversion to nitrite and to nitrate. Nixon *et al.* (1976) reported that, microbial decomposition of bottom detritus causes extensive transfer of nitrogen in the form of ammonia with the overlying water. This may be the reason for the presence of comparatively high ammonia in the mangrove sites of both the river basins especially

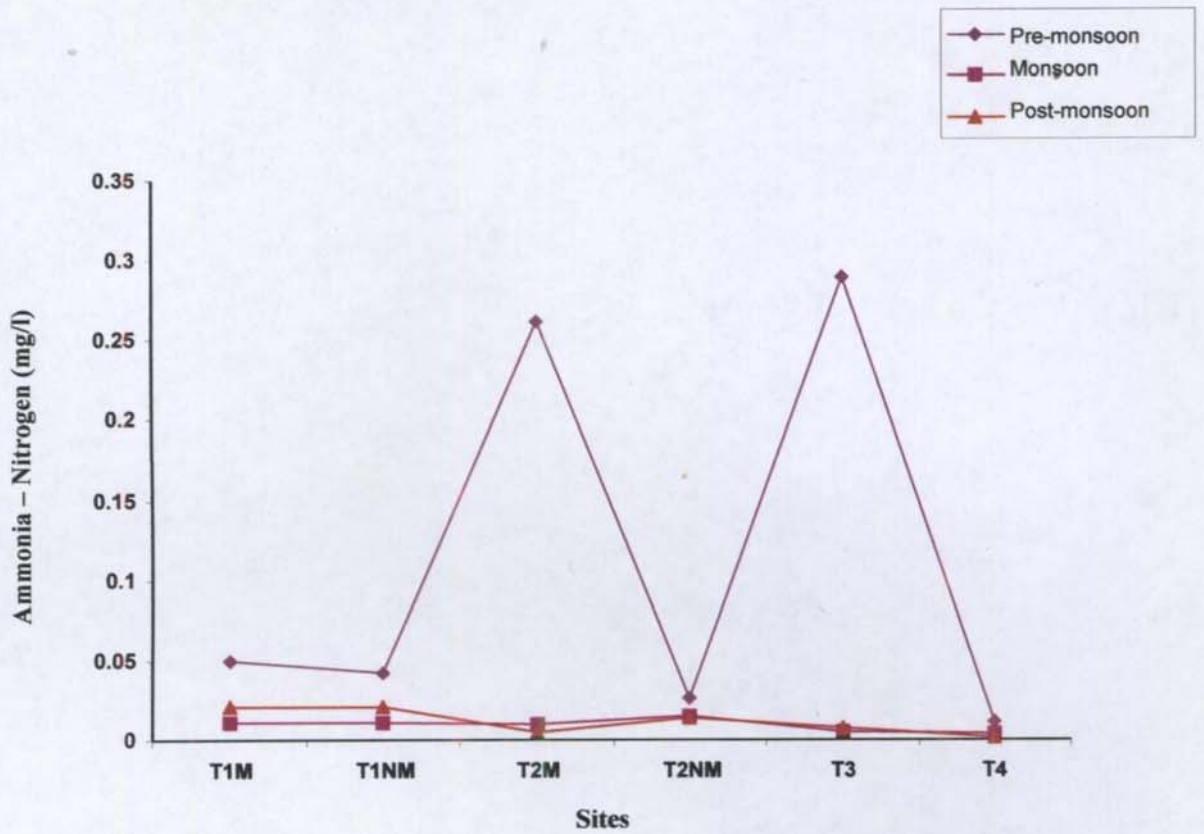


Fig. 4. 12 A Seasonal Variations in Ammonia – Nitrogen of Thalassery River

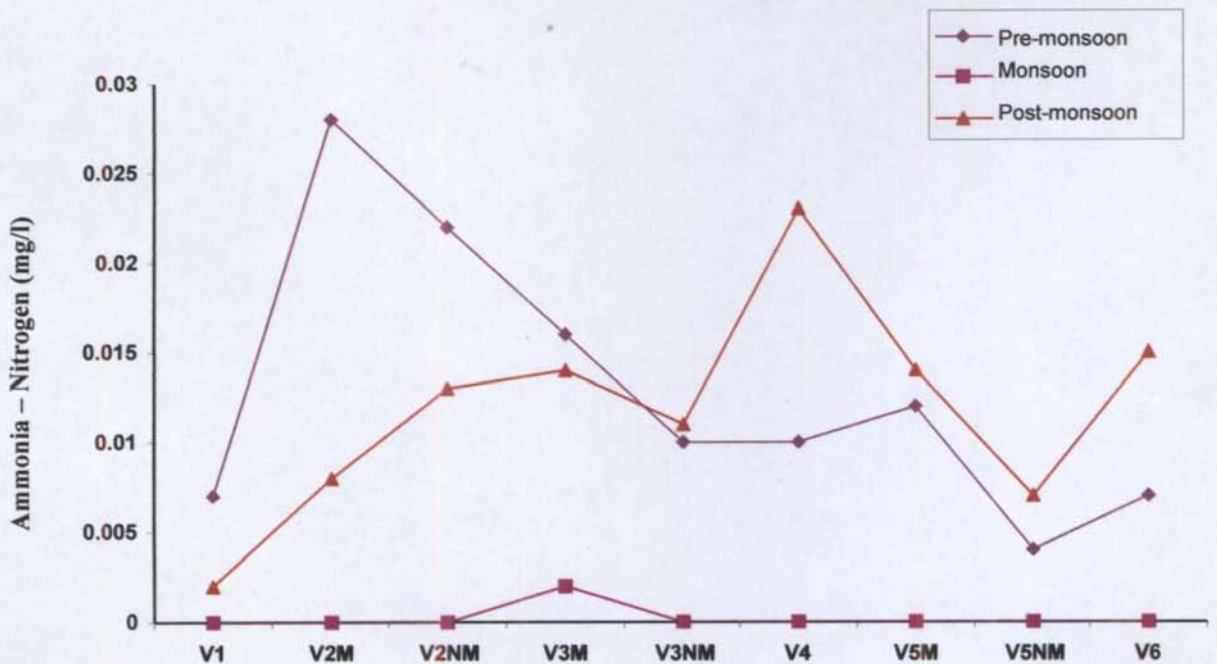


Fig. 4. 12 B Seasonal Variations in Ammonia – Nitrogen of Valapattanam River

during the summer seasons. The fluctuations noticed in different seasons and sites may be attributed to its unstable nature.

Statistical analysis revealed that in the Thalassery River, ammonia was found to be significantly correlated with parameters like algal biomass, chlorophyll a and colour at 1% level.

In the Valapattanam River, there are significant differences in ammonia and seasons at 5% level. Ammonia was found to be significantly correlated with parameters like calcium, chloride, colour, EC, fluoride, magnesium, nitrite, potassium, salinity, sodium and total hardness at 1% level.

Nitrite-Nitrogen

Biological decomposition of nitrogenous organic matter such as sewage and animal wastes contributes to nitrite. Presence of this reduced form of nitrogen in water is generally indicative of industrial pollution and is often associated with poor microbial quality of water. So the determination of nitrate and nitrite in water gives a general indication of the nutrient status and level of organic pollution. Nitrite ion is however rapidly oxidized to nitrate under aerobic conditions (Manivasakam, 1996).

Nitrite production was generally more which may be due to the excretion of nitrogenous compounds by plankton and decay of mangrove litter. Nitrite is recycled many times than other compounds. Nitrite is an intermediate product in the regeneration of nitrogenous compounds by bacterial action. It may be possible that some organisms prefer nitrite as the source of nitrogen and use it, which on their death and decay is liberated to water (Sundararaj & Krishnamurthy, 1975).

The seasonal variation in nitrite of the Thalassery and Valapattanam river basins are presented in Tables 4. 15 A & 4. 15 B respectively.

Table 4. 15 A Seasonal Variations in Nitrite - Nitrogen of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.13	0.11	0.14	0.14	0.11	0.01
Monsoon	0.14	0.15	0.24	0.24	0.13	0.01
Post-monsoon	0.17	0.14	0.09	0.1	0.13	0.01

Table 4. 15 B Seasonal Variations in Nitrite - Nitrogen of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.2	0.58	0.17	0.15	0.13	0.13	0.14	0.15	0.16
Monsoon	0.14	0.07	0.08	0.07	0.1	0.1	0.05	0.04	0.01
Post-monsoon	0.24	0.29	0.25	0.2	0.16	0.15	0.17	0.14	0.01

In the Thalassery river basin, nitrite concentration ranged from 0.01-0.14 mg/l, 0.01-0.24 mg/l and 0.01-0.17 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam river basin, it ranged from 0.13-0.58 mg/l, 0.01-0.14 mg/l and 0.01-0.29 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 13 A & 4. 13 B).

In the Valapattanam River, highest concentration of NO₂-N was observed in the post-monsoon season, while in the Thalassery River, monsoon recorded higher concentration. Lower values of nitrite-nitrogen were recorded during the pre-monsoon season in both the river basins. Nitrite-nitrogen concentration varied from 0.04-0.81 µg/l

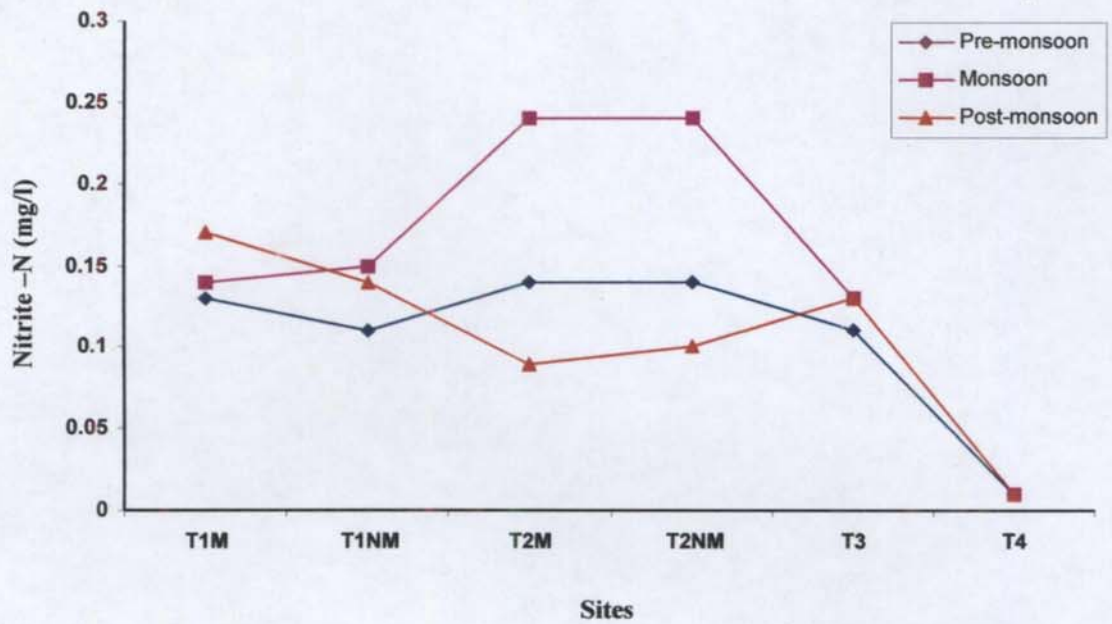


Fig. 4.13 A Seasonal Variations in Nitrite - Nitrogen of Thalassery River

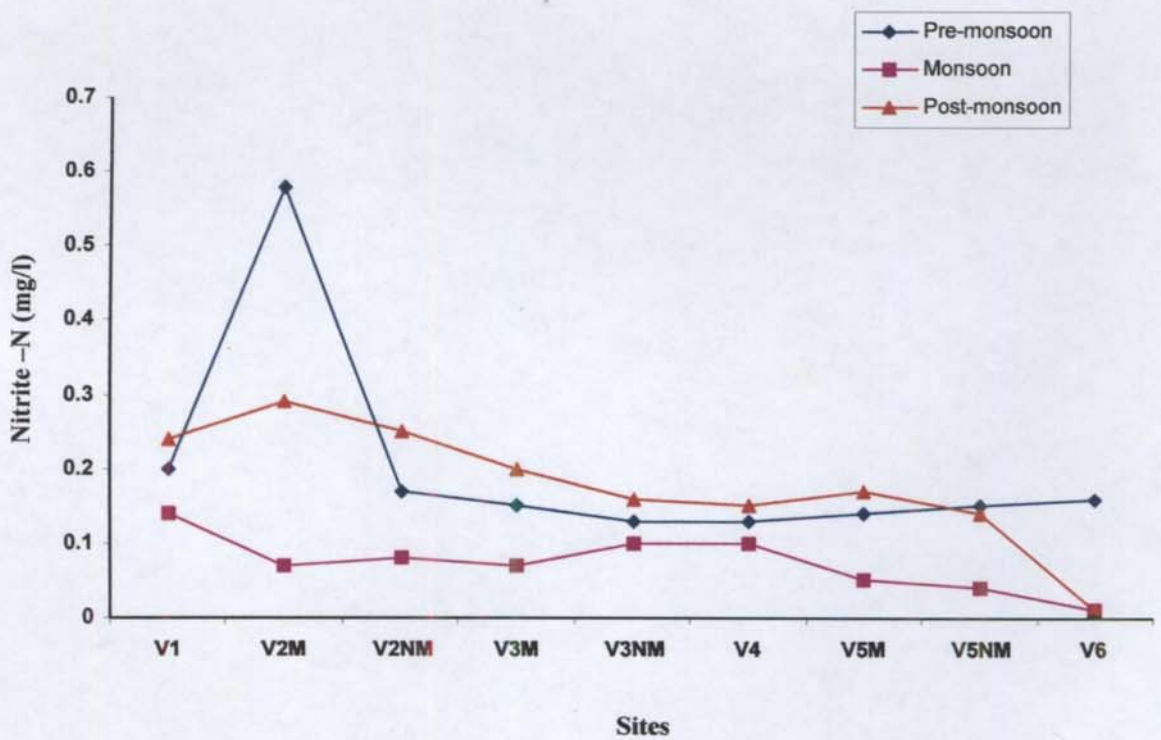


Fig. 4.13 B Seasonal Variations in Nitrite - Nitrogen of Valapattanam River

in Ashtamudy estuary, which was low during pre-monsoon period (Shoba & Ignatius Miranda, 1987). In the monsoon season a sharp rise in concentration of $\text{NO}_2\text{-N}$ was evident, which may presumably be due to heavy rainfall and consequent river discharge (Shoba & Ignatius Miranda, 1987). It is possible that excretion by phytoplankton, oxidation of ammonia and reduction of nitrate could contribute to the accumulation of nitrite in the aquatic environment. Studies of Rajendran *et al* (1973), who reported that oxidation of ammonia and reduction of nitrate could be the chief source of nitrite in Vellar estuary. The monsoonal peak of nitrite-nitrogen in Thalassery River is in good agreement with the earlier studies. In the present study the observed range of nitrite values were high when compared with the results of Valarmathi *et al.* (2002); Angelina (1994) and Chandra (1993).

Higher values encountered at the marine and nearby zones suggest the possibilities of intrusion of seawater containing higher concentrations of nitrite-nitrogen. This higher $\text{NO}_2\text{-N}$ content in the downstream areas suggests that nitrite input does not entirely depend on the freshwater discharge, indicating local replenishment (Balakrishnan Nair *et al.* 1983). Voccaro & Ryther (1960) and Valarmathi *et al.* (2002) suggested that the assimilation of nitrate by phytoplankton was often accompanied by the production of considerable amounts of extracellular nitrite, which might be the reason for the increase in nitrite content in the estuary. The comparatively higher concentration of nitrite observed in the mangroves sites might be due to the above mentioned phenomena coupled with the oxidation of ammonia to nitrite or reduction of nitrate to nitrite.

No traces of nitrite were reported from the Pazhayangadi and Kunhimangalam mangrove waters (Nalini Nayak, *et al.* 2000). Nitrite concentrations of 0.07 – 12.2 $\mu\text{g/l}$ were recorded by Valarmathi *et al.* (2002) along the Madras coast. In the backwater and

mangrove environment 0.09 – 1.04 $\mu\text{g/l}$ of nitrite-nitrogen has been recorded (Sundararaj & Krishnamurthy, 1975). When compared to earlier reports, nitrite concentration was recorded slightly higher during the present study.

The fresh water sites recorded the least concentration. This may be attributed to oxidation of nitrite-nitrogen to nitrate-nitrogen, in the aerobic condition.

Nitrite being an intermediate product produced both during nitrification and denitrification process, its unstable nature might be the major factor for the low and varying values encountered (Balakrishnan Nair *et al.* 1983 & Nair *et al.* 1983). The presence of this reduced form of nitrogen is associated with poor microbial quality of water.

Statistical analysis revealed that in the Thalassery River, there are significant differences in nitrite and locations at 5% level. Nitrite was found to be significantly correlated with total hardness at 1% level.

In the Valapattanam River, there are significant differences in nitrite and seasons at 5% level. Nitrite was found to be significantly correlated with parameters like ammonia, calcium, chloride, EC, fluoride, magnesium, potassium, salinity, sodium, sulphate and total hardness at 1% level.

Nitrate-Nitrogen

Like phosphate, nitrate is one of the critical nutrients for the growth of algae and is the highest oxidized form of nitrogen accelerating the process of eutrophication. The most important source of nitrate is the biological oxidation of organic nitrogenous substances from sewage and industrial wastes or produced indigenously in water. Domestic sewage, natural runoff and agricultural wastes are important sources of $\text{NO}_3\text{-N}$ in water (Trivedy *et al.* 1987). Nitrate is the end product of aerobic stabilization of organic nitrogen and occurs generally in traces in surface water. Application of fertilizer

to agricultural lands and leaching from cesspools contribute to nitrate content in ground water.

The concentration of nitrate-nitrogen in the sampling sites of both Thalassery and Valapattanam river basins are represented in Tables 4. 16 A & 4. 16 B respectively.

Table 4. 16 A Seasonal Variations in Nitrate - Nitrogen of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.58	0.81	0.87	0.2	0.57	0.2
Monsoon	0.53	0.91	0.48	0.3	0.22	0.21
Post-monsoon	0.07	0.07	0.08	0.07	0.06	0.06

Table 4. 16 B Seasonal Variations in Nitrate - Nitrogen of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.25	0.38	0.5	0.25	0.52	0.49	0.5	1.02	0.81
Monsoon	1.13	0.76	2.07	0.69	0.35	0.95	3	1.43	0.95
Post-monsoon	1.7	3.05	3.05	2.11	1.56	4.3	2.01	2.2	2.3

In the Thalassery river basin, nitrate concentration ranged from 0.2 – 0.87 mg/l, 0.21 – 0.91 mg/l and 0.06 – 0.08 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam river basin, it ranged from 0.25 – 1.02 mg/l,

0.35 – 2.07 mg/l and 1.56 – 4.3 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 14 A & 4. 14 B).

In Cochin backwaters (Qasim *et al.* 1969), surface water nitrate ranged from 0.3-39.97 µg/l. No trace of nitrite has been reported from the Pazhayangadi and Kunhimangalam mangrove waters (Nalini Nayak *et al.* 2000).

In Valapattanam river basin, higher concentration of NO₃-N was reported in post-monsoon and least in pre-monsoon as has been reported by Balakrishnan Nair and Abdul Aziz, (1987) and Balakrishnan Nair *et al.* (1983). The post-monsoon and monsoon peak might be due to the cumulative impact of rainfall, runoff from the land and river discharge. Such high concentration of nitrate associated with monsoon rain has been reported from Ashtamudi estuary (Balakrishnan Nair *et al.* 1983 & Nair *et al.* 1984). In most of the Indian estuaries, nitrate-nitrogen varied from 0-1.96 mg/l (Saraladevi *et al.* 1991). According to Varshney (1985), more than 1.26 mg/l of nitrate-nitrogen indicates polluted condition of the water body. The concentration of nitrate was always high in a polluted river tract indicating the influence of river water and the decomposition of organic matter in the enrichment of the nutrient (Balakrishnan Nair & Abdul Aziz, 1987).

In the Thalassery river basin a reverse situation was observed, NO₃-N concentration being highest in pre-monsoon and least in post-monsoon period. The peak period of nitrate in the pre-monsoon, following the monsoon has been reported earlier by Gopinathan (1975). This may be due to the sequential regeneration process, especially the oxidation of ammonia. Lower concentration of nitrate-nitrogen observed during post-monsoon may be attributed to the rapid utilization of nitrate by phytoplankton and the consequent reduction of nitrate to nitrite in an atmosphere with low DO as has been reported earlier (Krupadam & Anjaneyulu, 2000).

132. A

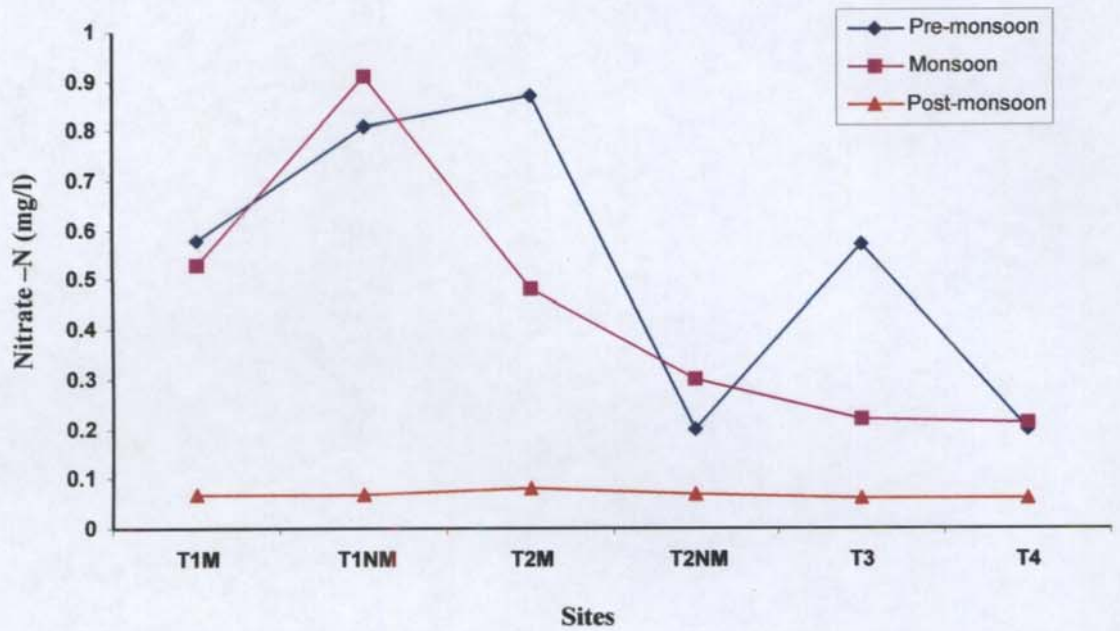


Fig. 4. 14 A Seasonal Variations in Nitrate - Nitrogen of Thalassery River

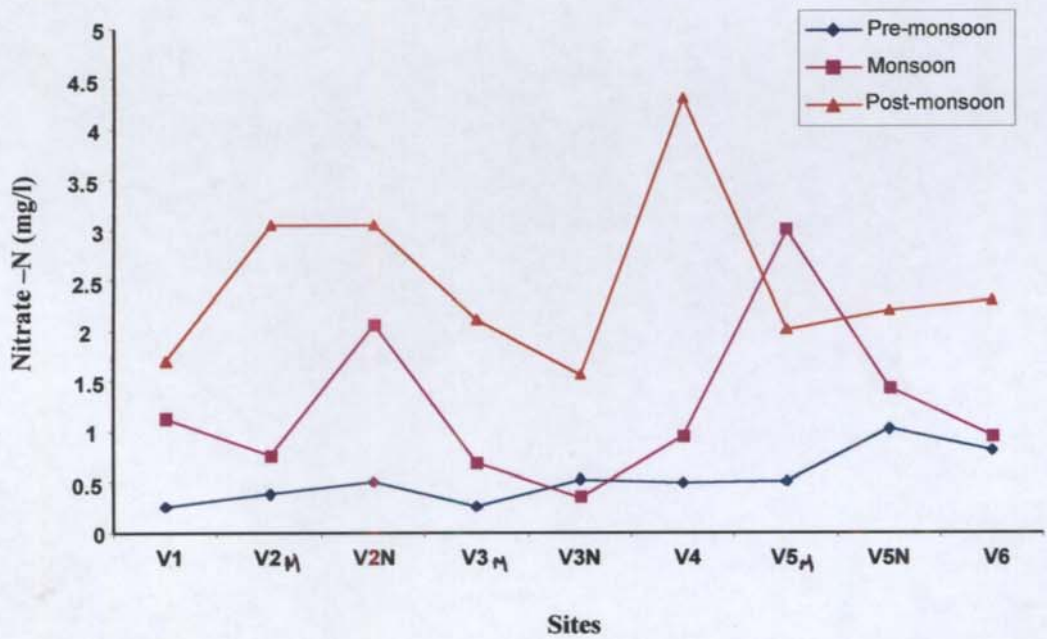


Fig. 4. 14 B Seasonal Variations in Nitrate - Nitrogen of Valapattanam River

In Valapattanam river basin, the non-mangrove areas recorded higher nitrate content than the corresponding mangrove areas. The reason for the reduction of nitrate in the mangrove site may be attributed to the biological utilization of $\text{NO}_3\text{-N}$ or denitrification process by the anaerobic bacteria to form gaseous nitrogen or nitrous oxide, due to the prevailing reducing conditions in mangrove sites, as has been reported by Clough *et al.* 1983. A reverse trend was recorded in Thalassery River basin, with higher concentration of $\text{NO}_3\text{-N}$ in the mangrove compared to the non-mangrove site. This may be due to the oxidation of organic matter and ammonia contributing to nitrate maxima. The oxidation of ammonia may be mediated bacterially, photochemically or even by phytoplankton.

The comparatively higher concentration of nitrate in the V4 site may be attributed to the dumping of slaughter wastes. The decomposition of wastes might have contributed to the high concentration of nitrate in this site showing the unhealthy condition. The higher concentration of $\text{NO}_3\text{-N}$ may be related to the heavy input of fertilizers in agriculture during this season (Johny Thomas & Ragothaman, 1987). The higher concentration of nitrate in the fresh water site (V6) is due to the run off from agricultural lands in the catchment of the river basin during the monsoon season, mainly due to leaching of nitrate rich fertilizer applied to the agricultural lands as has been reported earlier (Sooraj *et al.* 2000).

Statistical analysis revealed that in the Thalassery River, there are significant differences in nitrate and locations at 5% level. Nitrate was found to be significantly correlated with colour and total hardness at 1% level.

In the Valapattanam River, there are significant differences in nitrate and seasons at 5% level.

Phosphate-Phosphorus

Phosphate is one of the most important nutrients limiting the growth of autotrophs and controls the biological productivity of the system. Phosphate is generally considered the critical nutrient for the growth of algae in water, the enrichment of which leads to eutrophication. The important sources of phosphate are the discharge of domestic sewage, detergents, agricultural wastes, fertilizers, minerals or ores and industrial effluents (Trivedy *et al.* 1987). It is also present in animal metabolic wastes. High concentration of phosphorus is indicative of pollution (Trivedy & Goel, 1986). The various forms of phosphates that occur in natural and wastewaters include orthophosphates, condensed phosphates (pyro, meta, and polyphosphates) and organically bound phosphates. These may be present in the soluble form in particles of detritus, or in the bodies of aquatic organisms. Being an important constituent of biological systems, it may also be present in the organic forms (Manivasakam, 1996). Organic phosphates are formed primarily by biological processes, but may also be contributed by domestic sewage. Phosphates may also occur in bottom sediments and biological sludge, both in precipitated inorganic forms and incorporated into organic compounds.

Phosphorus occurs in natural waters solely as phosphate, as the fallen phosphate - rich detritus decomposed by the bacteria (Mahapatro & Pandhy, 2002). Organic phosphates species synthesized by plants and animals constitute a significant fraction of the dissolved and particulate form in many natural waters (Hem, 1985). The phosphorus bound to the rocks are generally insoluble in water and hence, the phosphorus content in natural fresh water is low and biological growth is limited due to this fact.

The seasonal variations in phosphate concentration in the Thalassery and Valapattanam river basins are presented in Tables 4. 17 A & 4. 17 B respectively.

Table 4. 17 A Seasonal Variations in Phosphate - Phosphorus of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.15	0.22	0.04	0.09	0.22	0.04
Monsoon	0.17	0.06	0.1	0.06	0.19	0.08
Post-monsoon	0.02	0.03	0.02	0.03	0.01	0.01

Table 4. 17 B Seasonal Variations in Phosphate - Phosphorus of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.03
Monsoon	0.01	0.08	0.12	0.07	0.11	0.07	0.18	0.09	0.32
Post-monsoon	0.03	0.03	0.02	0.03	0.02	0.03	0.02	0.01	0.03

The phosphate concentration in Thalassery River ranged from 0.04-0.22 mg/l, 0.06-0.19 mg/l and 0.01-0.03 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River basin, it ranged from 0.02-0.03 mg/l, 0.01-0.32 mg/l and 0.01-0.03 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 15 A & 4. 15 B).

Phosphate concentration in monsoon season recorded slightly higher values in the river basins, as has been reported earlier Narayanan *et al.* (2002); Quadros *et al.* (2001)

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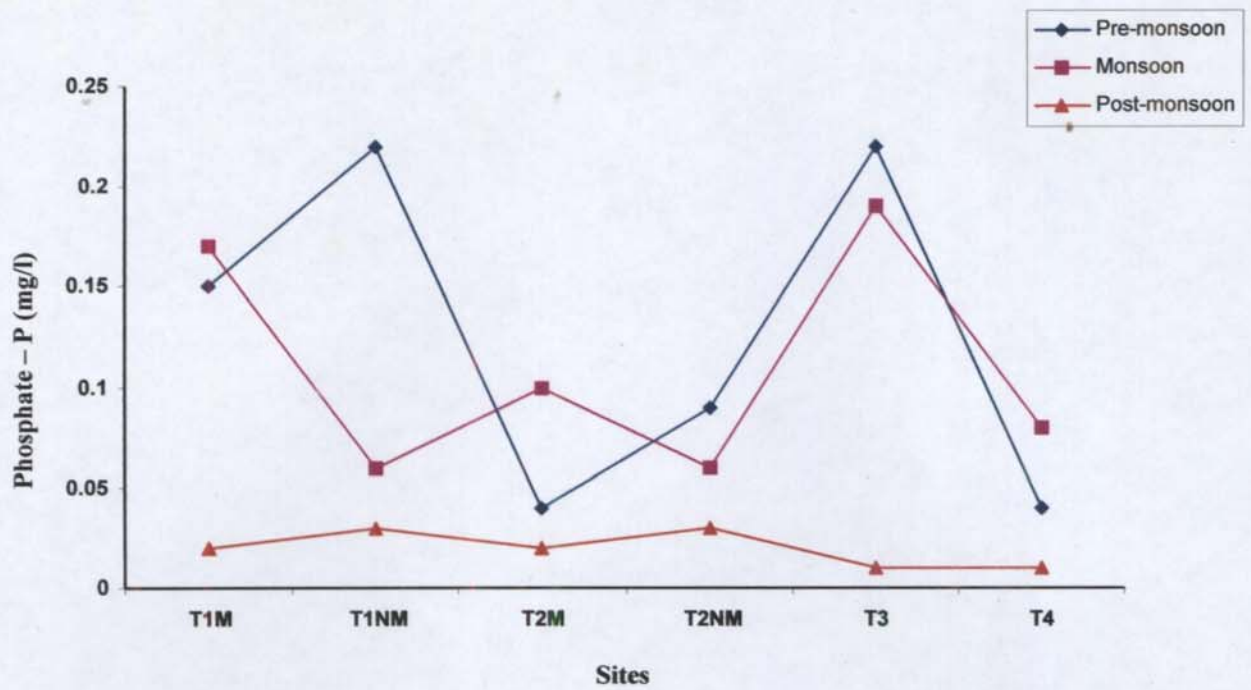


Fig. 4. 15 A Seasonal Variations in Phosphate- Phosphorus of Thalassery River

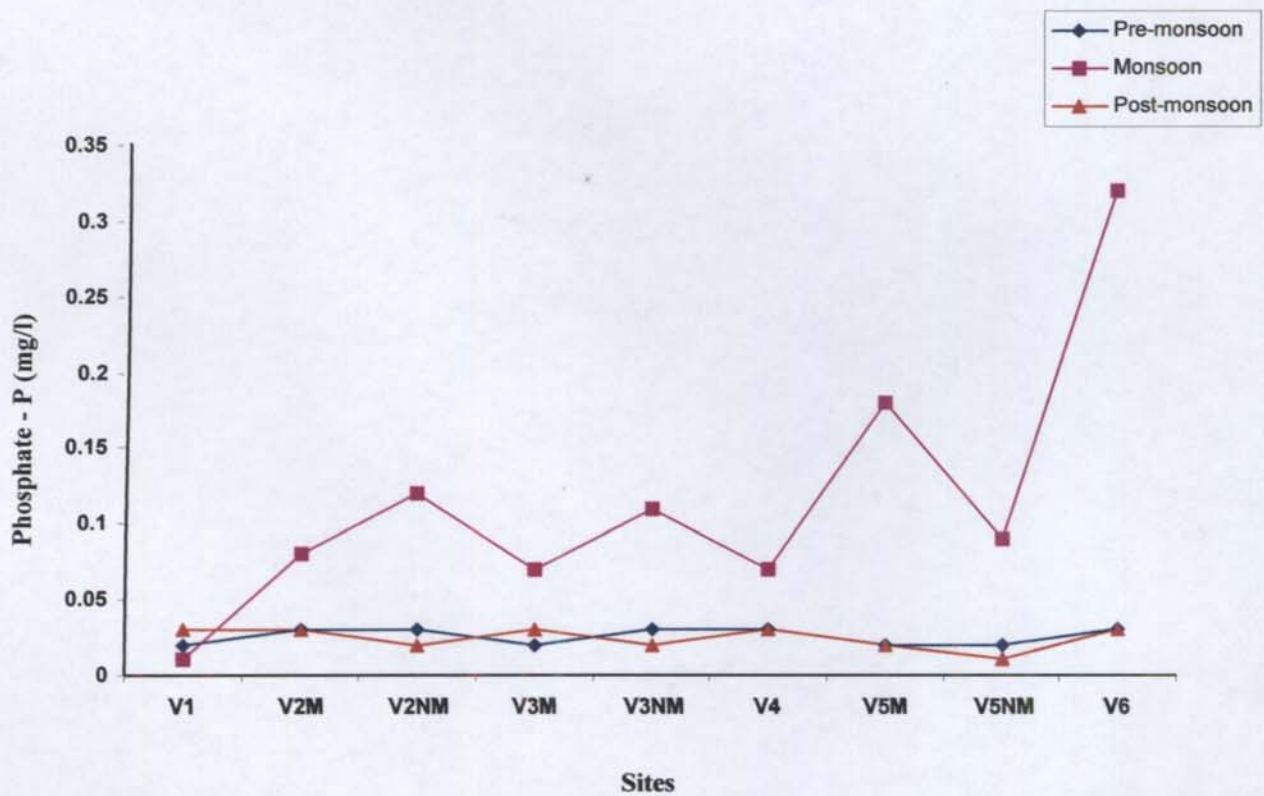


Fig. 4. 15 B Seasonal Variations in Phosphate - Phosphorus of Valapattanam River

and Mahapatro and Pandhy (2002). The significant seasonal variation in phosphate content may be due to the impact of rainfall and river discharge on the phosphate. According to Nair *et al.* (1983), rainfall leading to heavy river discharge results in transportation of sediments in a big way. Input of phosphate fertilizers in elas and alkali phosphates used in detergents may be the other sources of inorganic phosphate, as has been reported earlier by Das and Sahoo (1997). Irregular fluctuations in phosphate content are a common phenomena (Fox *et al.* 1986). This difference in the phosphate concentration may be attributed to differential uptake by the phytoplankton. The lower concentration of phosphate in freshwater site of the Thalassery River may be due to the fact that the iron and iron oxy-hydroxides transported through fresh water have a strong affinity for phosphates (Vaithyanathan *et al.* 1993). Further the acidic pH of fresh water favours the adsorption of phosphate (Upadhyay, 1988). The concentration of this nutrient was observed to be less compared to nitrate and nitrite concentrations in both the rivers, which is in agreement with the finding of Das (2002) in the Upper Ganga Complex, where the reported value for phosphate was much lesser than the present study. Phosphate concentration of surface waters of the estuary during the monsoon season may be attributed to high precipitation (Krupadam & Anjaneyulu, 2000). Another important factor contributing to high phosphate content in the estuary and mangrove sites is the intrusion of seawater, containing higher concentration of phosphorus than freshwater (Garcia-soto *et al.* 1990). A slight increase in phosphate content in T3 and V2 mangrove sites may be attributed to the impact of coconut husk retting practice there as has been reported earlier (Remani *et al.* 1989).

Statistical analysis revealed that in the Thalassery River, there are significant differences in phosphate and seasons at 5% level.

In the Valapattanam River, there are significant differences in phosphate and seasons at 5% level. Phosphate was found to be significantly correlated with parameters like DO and silica at 1% level.

Silica

The range of silica most commonly observed in natural water may vary from 1-30 mg/l or up to 100 mg/l (Hem, 1985). Seawater near the surface is very low in silica (commonly less than 1 mg/l) apparently because marine organisms, mostly diatoms, extract and use silica for building up of their shells and skeletons.

The seasonal variations in silica content in the Thalassery and Valapattanam river basins are presented in Tables 4. 18 A & 4. 18 B.

Table 4. 18 A Seasonal Variations in Silica of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.47	0.44	0.45	0.43	0.55	4.6
Monsoon	3.7	3.4	5.9	6	6.9	7.7
Post-monsoon	2.7	0.48	0.55	0.69	0.98	7.4

Table 4. 18 B Seasonal Variations in Silica of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.39	0.63	0.49	0.57	0.54	0.54	0.87	0.72	3.8
Monsoon	4.9	7.6	7.5	5.5	5.9	5.4	8.2	9.1	7.5
Post-monsoon	0.14	0.4	0.27	0.45	0.34	0.63	0.88	0.74	5.1

The silica concentration in the Thalassery River varied from 0.43-4.6 mg/l, 3.4-7.7 mg/l and 7.4-2.7 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, it ranged from 0.39-3.8 mg/l, 4.9-7.5 mg/l and 0.14-5.1 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 16 A & 4. 16 B).

In the present study, there was spatial and temporal variation in silica concentration. Silica content in water showed a significant peak during the monsoon season. Das (2002) reported a range of silica from 4 -12.2 mg/l in monsoon, 0.02-2.2 mg/l in pre-monsoon and 4.6-7.0 mg/l in post-monsoon seasons and a low amount of silica in the river water during summer seasons, with subsequent recovery during the monsoon season, which is favorable for the growth of diatoms. Similarly, higher concentration of silica during monsoon has also been reported by others (Gopinathan, 1975; Quadros *et al.* 2001; Valarmathi *et al.* 2002; Balakrishnan & Abdul Aziz, 1987 & Murugan & Ayyakkannu, 1991). The increase in silica following the onset of monsoon may be presumably due to enrichment with silicates from the land drainage, as has been reported by Ramakrishna *et al.* (1987). In Ashtamudi estuary, a silica concentration of 14.73 $\mu\text{g/l}$ has been reported (Shoba & Ignatius Miranda, 1987).

Lower values for silica were reported during the summer season in both the river basins. In the Valapattanam River, lower values were recorded for silica content during the post-monsoon season, which may be attributed either to the removal of it by biological processes (Murugan & Ayyakkannu, 1991), or to removal of silica by flocculation and precipitation due to increased salinity (Sengupta & Upadhyay, 1987; Quadros *et al.* 2001). Low concentration of silica in surface water samples during the pre- monsoon season in the Thalassery River may presumably be due to the river water

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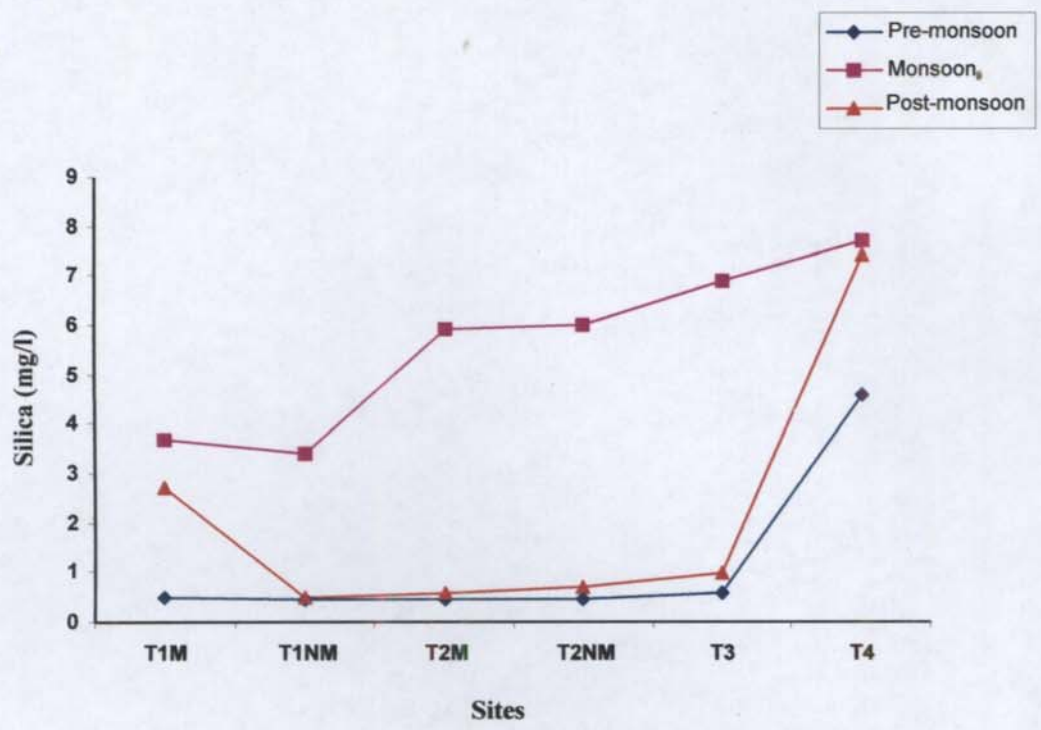


Fig. 4. 16 A Seasonal Variations in Silica of Thalassery River

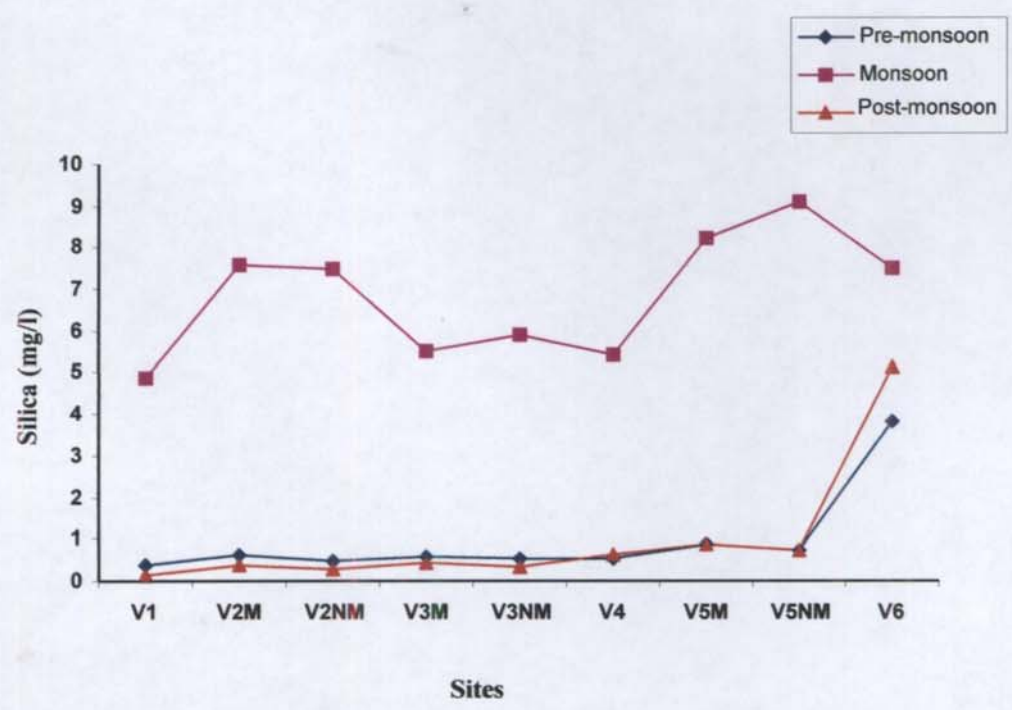


Fig. 4. 16 B Seasonal Variations in Silica of Valapattanam River

bringing in additional quantities of this nutrient, which is in agreement with the earlier results (Mahapatro & Pandhy, 2002; Nair *et al.* 1983).

Distribution of reactive silicon showed a regular pattern *i.e.*, high concentrations were observed at the fresh water region which gradually decreased towards the estuary as has been reported earlier in Cochin backwaters (Anirudhan *et al.* 1987; Krupadam & Anjaneyulu, 2000). When river water mixes with seawater in estuaries, up to 20% of dissolved silicon may be removed by non-biological processes (Perkins, 1976). In the present study, silica concentration was reported high at station V6 in Valapaṭṭanam and T4 in Thalassery river basins, where salinity was reported to be minimum. Exceptionally high silica content observed in the V5 site may be attributed to intense sand mining activity in the site (Quadros *et al.* 2001). In the pre and post-monsoon seasons, there was an increasing trend in silica concentration from the estuarine to riverine zone, as has been reported earlier (Mahapatro & Pandhy, 2002; Padmavati & Satyanarayanan, 1999). This may be due to the dominance of fresh river water over seawater, which carries a wide spectrum of finely divided siliceous material transported to the sea by rivers or by wind (Riley & Chester, 1971). River, which is the main source of silicon, carries water from land washout, land runoff, sewage and agricultural waste during the monsoon season. Hence, highest peak for silica was recorded at fresh water sites.

In Ashtamudy estuary, mean silicate values varied between 15.47 and 42.56 $\mu\text{g/l}$. Maximum concentration of this nutrient was encountered in the river site (Nair *et al.* 1983). In Cochin backwaters (Qasim & Gopinathan, 1969) reported a silicate concentration of 5-59.71 $\mu\text{g/l}$ and 3.25-16.10 $\mu\text{g/l}$. In the present study, silicate concentration was recorded higher than the earlier reports.

Silicon content in river water was usually higher than in seawater and the inverse relationship between the salinity and concentration of reactive silicate is apparent. Low values at the estuary are in conformity with the pattern found in most estuaries. The dilution effect due to river runoff may have considerable influence on the silica content, thus limiting the build-up of reactive silicate in the water column (Krupadam & Anjaneyulu, 2000). In the present study, silica concentration showed a strong negative correlation with salinity, being higher in the river and lower in the estuary.

Statistical analysis revealed that in the Thalassery River, there are significant differences in silica and seasons and silica and locations at 5% level.

In the Valapattanam River, there are significant differences in silica and seasons and silica and locations at 5% level. Silica was found to be significantly correlated with parameters like DO and phosphate at 1% level.

Sulphate

Sulphates are found in appreciable quantities in all natural waters, particularly where there is high salt content. Sulphates occur naturally in water as a result of leaching off from gypsum and other common minerals and input from biological or biochemical processes (Manivasakam, 1996). Sulphates contribute to the total solid content and play a key role in the sulphur cycle. It is the principal available source of sulphur, which is reduced by autotrophs and incorporated into amino acids such as methionine and proteins. Rainwater has high concentration of sulphates particularly, in areas with high industrial pollution. Most of the sulphate salts are soluble in water and undergoes transformation to sulphur and hydrogen sulphide depending on the redox potential of water. The most important forms of sulphate in natural waters are sodium and calcium sulphates.

Variation in sulphate concentration in the sampling sites of Thalassery and Valapattanam river basins are presented in Table 4. 19 A & 4. 19 B respectively.

Table 4. 19 A Seasonal Variations in Sulphate of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	1923	2150	1745	2163	1200	1.75
Monsoon	606	683	407	153	64	3.8
Post-monsoon	1850	2210	2058	2208	1705	4

Table 4. 19 B Seasonal Variations in Sulphate of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	1750	1533	1975	1097	1375	1047	1275	1450	171
Monsoon	788	100	76.2	95	219	106	3.5	2.2	1.4
Post-monsoon	1918	1004	1457	886	1146	477	342	512	0.8

The sulphate concentration in the Thalassery River ranged from 1.75 – 2,150 mg/l, 3.8 – 683 mg/l and 4 – 2,210 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively. While in the Valapattanam River, it ranged from 171 – 1975 mg/l, 1.4 – 788 mg/l and 0.8 – 1918 mg/l during the pre-monsoon, monsoon and post-monsoons seasons respectively (Figures 4. 17 A & 4. 17 B).

Among the various seasons studied, pre and post -monsoon seasons recorded the higher concentration. The monsoon season recorded the lowest sulphate content in both

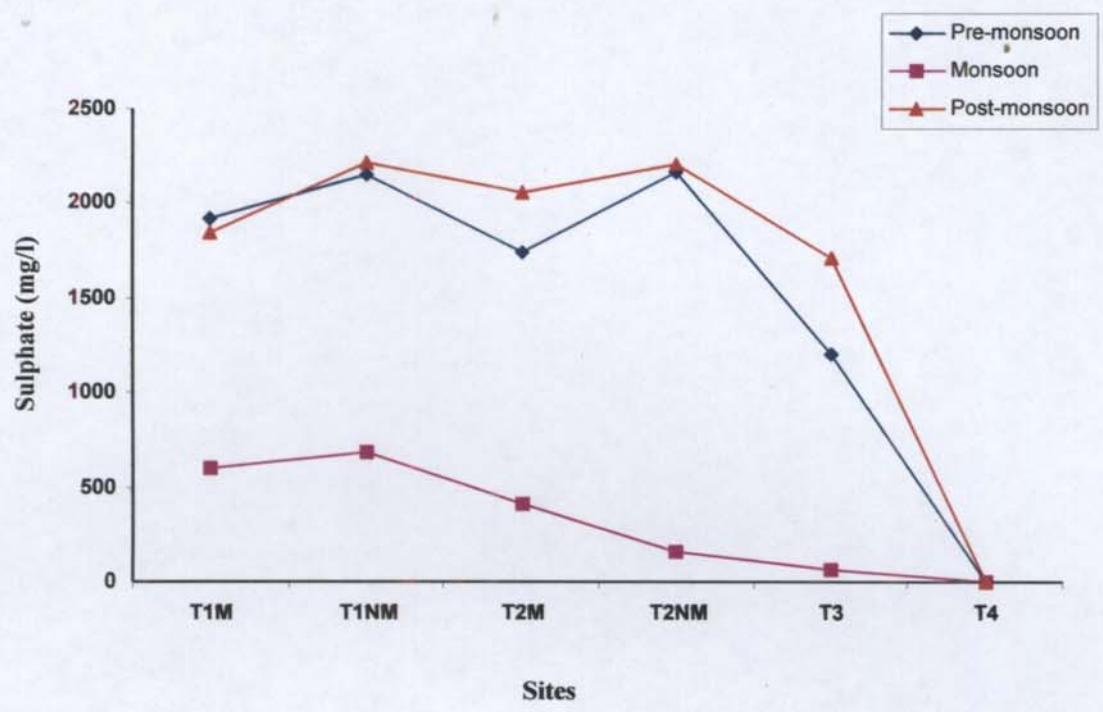


Fig. 4. 17 A Seasonal Variations in Sulphate of Thalassery River

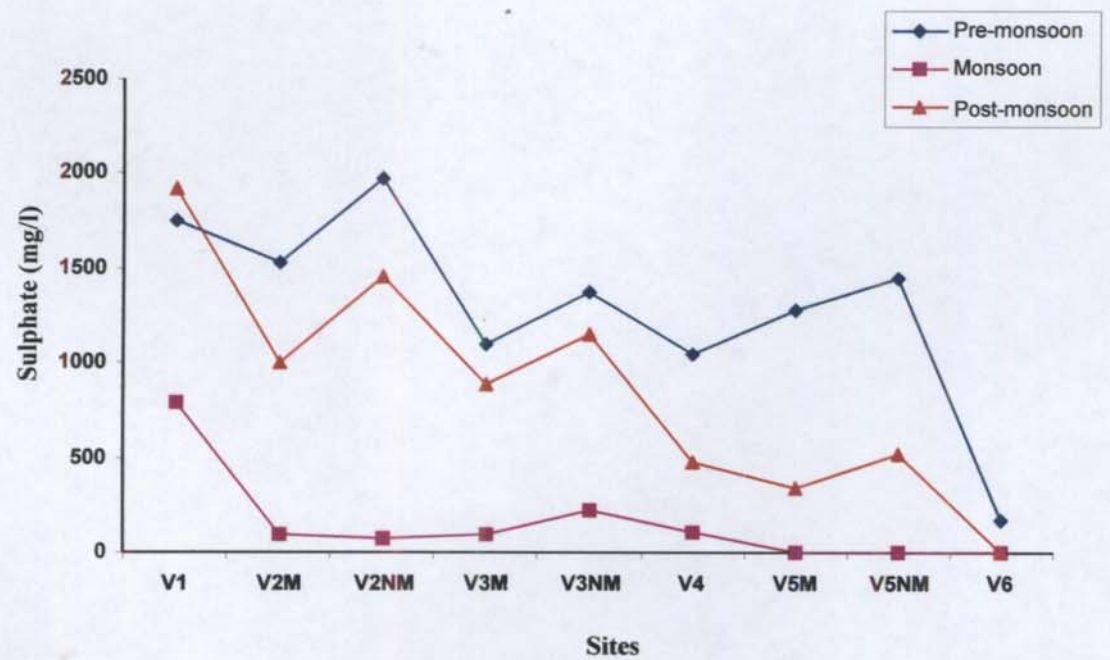


Fig. 4. 17 B Seasonal Variations in Sulphate of Valapattanam River

the rivers. The lower concentration during monsoon season may be attributed to high dilution of its soluble forms by rainwater.

Spatial variations showed a high concentration of sulphate in the estuary in all the seasons studied. When the mangrove and non-mangrove sites were compared, the non-mangrove sites registered high values for sulphates. Nalini Nayak *et al.* (2000), reported sulphate concentration of 10 – 2,509.9 mg/l in Pazhayangadi, 100 – 4,850 mg/l in Kunhimangalam and 500 – 3,119.6 mg/l from mangrove waters during the monsoon and summer months respectively. On the contrary, in the present study, mangrove water recorded lower sulphate values in both river basins, may be attributed to the transformation of sulphate to hydrogen sulphide in the anaerobic conditions prevailing in these sites, which produces a pungent odour in mangrove swamps as reported earlier (Saxena *et al.* 1988 & Lokabharati *et al.* 1991).

Statistical analysis revealed that in the Thalassery River, there are significant differences in sulphate and seasons and sulphate and locations at 5% level. Sulphate was found to be significantly correlated with parameters like calcium, chloride, EC, pH, potassium, salinity, sodium, temperature and total hardness at 1% level.

In the Valapattanam River, there are significant differences in sulphate and seasons and sulphate and locations at 5% level. Sulphate was found to be significantly correlated with parameters like calcium, chloride, EC, fluoride, nitrite, pH, potassium, salinity, sodium and total hardness at 1% level.

Iron

Iron is one of the most abundant elements present in rocks and soil, ranking the 4th by weight. It is also an essential element in the metabolism of animals and plants. All kinds of waters have appreciable quantities of iron (Trivedy & Goel, 1986). Water in a

flowing, fully aerated surface stream should not contain more than a few grams per litre of uncomplexed dissolved iron at equilibrium in the pH range of 6.5-8.5 (Hem, 1985). Iron occurs in two states viz., ferrous and ferric. In waters lacking dissolved oxygen, iron mainly remains in the ferrous state. In acidic pH, iron becomes more soluble, hence present in high concentration in water.

Seasonal variations in iron in the sampling sites of Thalassery and Valapattanam river basins are presented in Tables 4. 20 A & 4. 20 B respectively.

Table 4. 20 A Seasonal Variations in Iron of Thalassery River .

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.21	0.08	0.1	0.08	0.06	0.09
Monsoon	0.06	0.04	0.04	0.06	0.04	0.05
Post-monsoon	0.06	0.06	0.03	0.1	0.11	0.06

In the Thalassery River, iron concentration ranged from 0.06-0.21 mg/l, 0.04-0.06 mg/l and 0.03-0.11 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, it ranged from 0.02-0.28 mg/l, 0.01-0.12 mg/l and 0.04-0.27 mg/l during the pre-monsoon, monsoon seasons respectively (Figures 4. 18 A & 4. 18 B).

Nalini Nayak *et al.* (2000), reported that iron concentration ranged from 0.2 – 0.2 mg/l in Pazhayangadi mangrove waters without any seasonal variations, while in Kunhimangalam mangrove waters, iron concentration ranged from 0.2 – 0.3 mg/l with higher concentration during the monsoon season. Iron concentration recorded during the present study is in agreement with the earlier report (Nalini Nayak *et al.* 2000). But in

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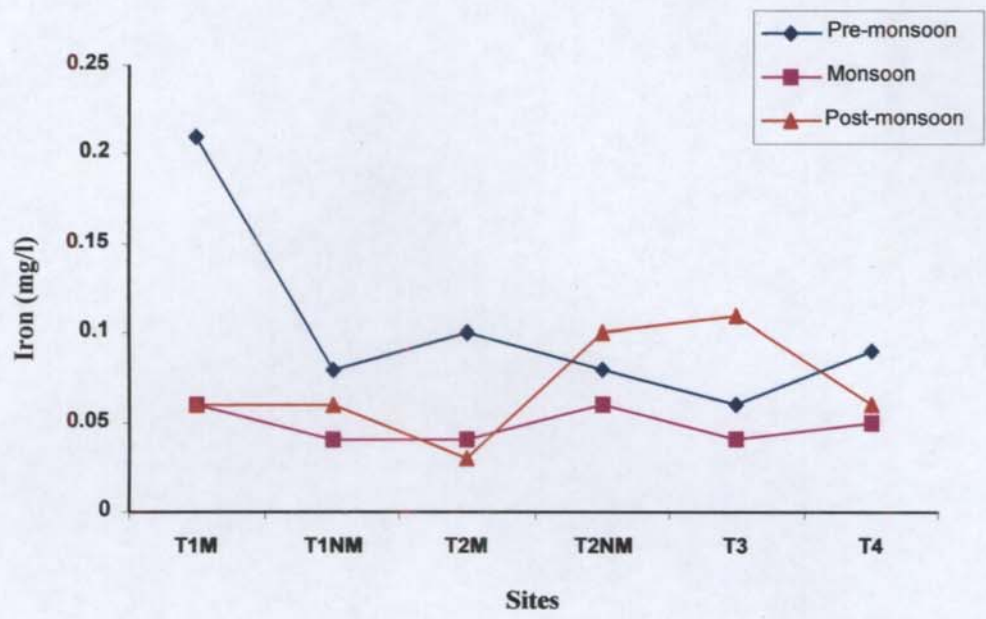


Fig. 4. 18 A Seasonal Variations in Iron of Thalassery River

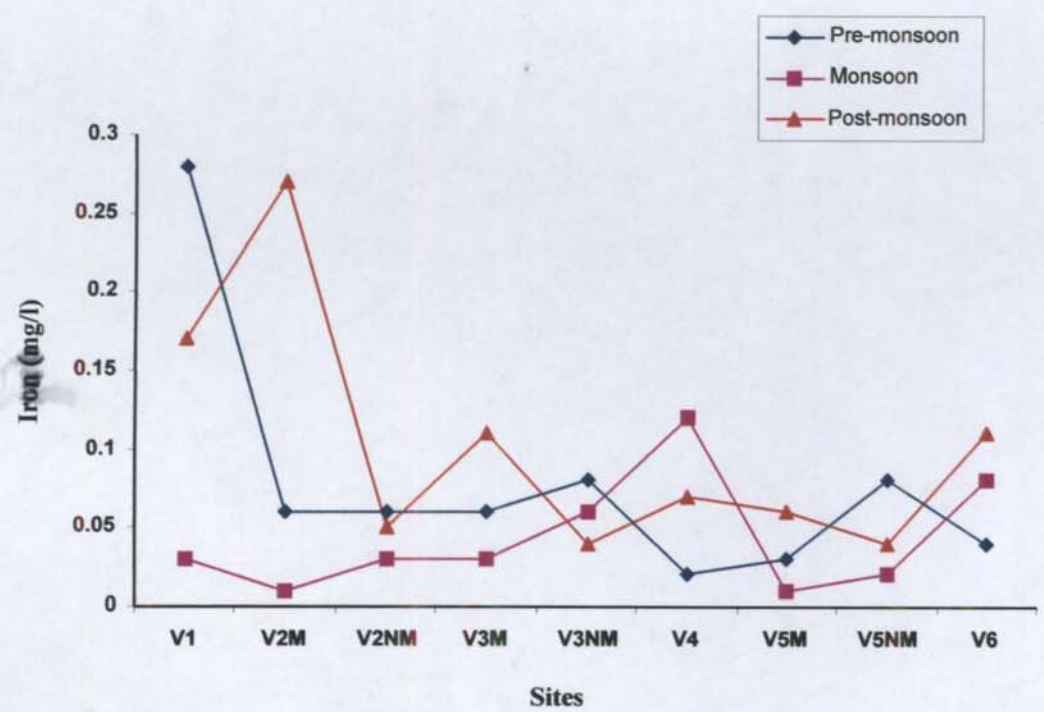


Fig. 4. 18 B Seasonal Variations in Iron of Valapattanam River

Table 4. 20 B Seasonal Variations in Iron of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	0.28	0.06	0.06	0.06	0.08	0.02	0.03	0.08	0.04
Monsoon	0.03	0.01	0.03	0.03	0.06	0.12	0.01	0.02	0.08
Post- monsoon	0.17	0.27	0.05	0.11	0.04	0.07	0.06	0.04	0.11

the monsoon season, comparatively lower iron concentration was recorded, which may be attributed to the oxidation of Fe^{2+} to Fe^{3+} form in the presence of dissolved oxygen, which was higher during this season.

Normal elemental composition of iron in seawater is 0.01 mg/l (Goldberg, 1976). The high concentration of iron in the estuary may be due to the fact that it receives water containing iron from sea and fresh water or may be due to the presence trace elements such as iron and manganese may occur in much greater concentration in estuaries than the open sea (Perkins, 1976).

Statistical analysis revealed that in the Thalassery River, there are significant differences in iron and seasons at 5% level.

In the Valapattanam River, iron was found to be significantly correlated with parameters like turbidity and total hardness at 1% level.

Sodium

This is one of the important, abundant, naturally occurring alkali metal, whose concentration is remarkably high in saline and brackish waters. Sodium limits biological diversity due to osmotic stress. Many industrial wastes and domestic sewage are rich in

sodium and hence its concentration is higher in polluted waters. Salts of sodium are highly soluble in water. Human activities can have a significant influence on the concentration of sodium in surface water and ground water (Trivedy *et al.* 1987).

Seasonal variations in sodium content of different sites in Thalassery and Valapattanam river basins are presented in Tables 4. 21 A & 4. 21 B respectively.

Table 4. 21 A Seasonal Variations in Sodium of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	10750	12325	10783	12350	8867	12
Monsoon	7267	15300	2687	2963	404	9.5
Post-monsoon	16550	16900	16100	9020	9200	18

Table 4. 21 B Seasonal Variations in Sodium of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	10260	8320	10335	6553	7655	4797	6165	6965	421
Monsoon	3567	785	909	833	1596	753	98.4	61	10.3
Post-monsoon	11500	8700	9250	8375	8025	6200	4350	4900	21

In the Thalassery river basin the sodium concentration ranged from 12-12,350 mg/l, 9.5 –15,300 mg/l & 18-16,900 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively. The sodium concentration in Valapattanam river basins

ranged from 421-10,335 mg/l, 10.3 – 3,567 mg/l & 21 – 11,500 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 19 A & 4. 19 B).

In the present study, well marked variations in sodium concentration were documented in all the seasons studied. Maximum concentration was observed during the post monsoon seasons in all the sites followed by the pre-monsoon season in both the river basins. Sodium concentration has direct correlation with salinity and chloride because salinity is due to the presence of sodium chloride and salinity increases with the amount of sodium chloride. During monsoon season low values were observed which is attributed to dilution by rainwater.

The spatial variation revealed highest concentration in the estuary in both the river basins, which is due to the seawater intrusion in the estuary. Another important reason for the abundance of this element is its high solubility, hence cannot be easily removed from water except by ion exchange or reverse osmosis. In the present study, sharp and gradual decrease in sodium content was observed towards the freshwater site in both the river basins studied. When mangrove and non-mangrove areas were compared, highest concentration was observed in the non-mangrove sites. This may be attributed to the special salt absorption and accumulation capacity of mangroves. Due to salinity intrusion through the shutter in Kattampally Regulator-cum-bridge, V4 site also encountered higher salinity. Ramachandran *et al.* (1986), reported the surface water sodium concentration in Veli, Quilon and Kumarakom mangroves to be 271, 5970 and 896 mg/l respectively, whereas, in the present study, sodium concentration was recorded to be very high.

Statistical analysis revealed that in the Thalassery River, there are significant differences in sodium and seasons and sodium and locations at 5% level. Sodium was found to be significantly correlated with parameters like calcium, chloride, EC,

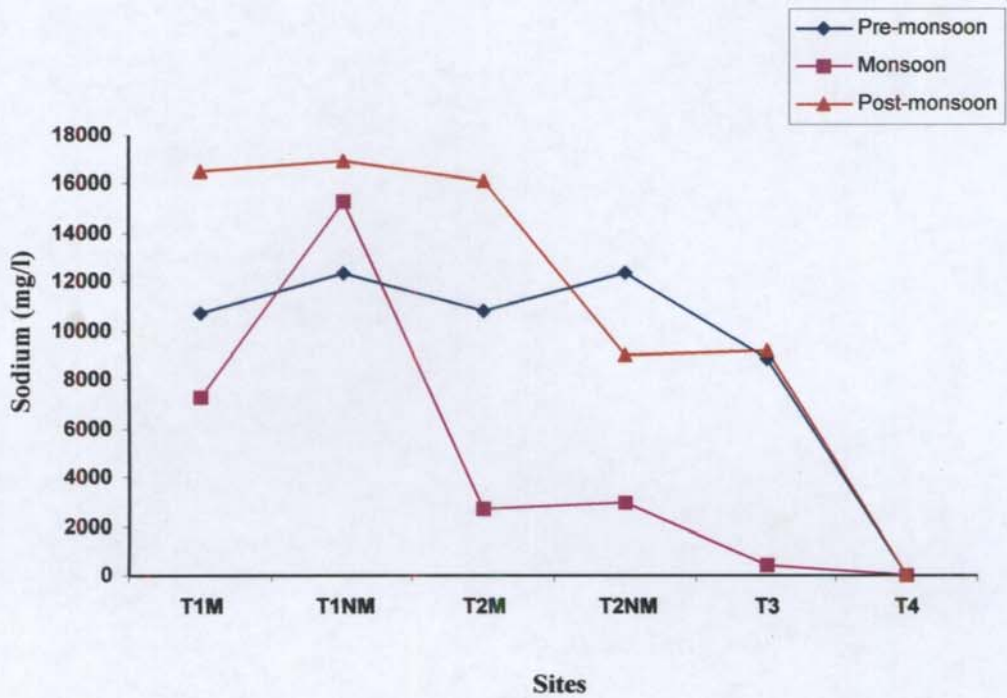


Fig. 4. 19 A Seasonal Variations in Sodium of Thalassery River

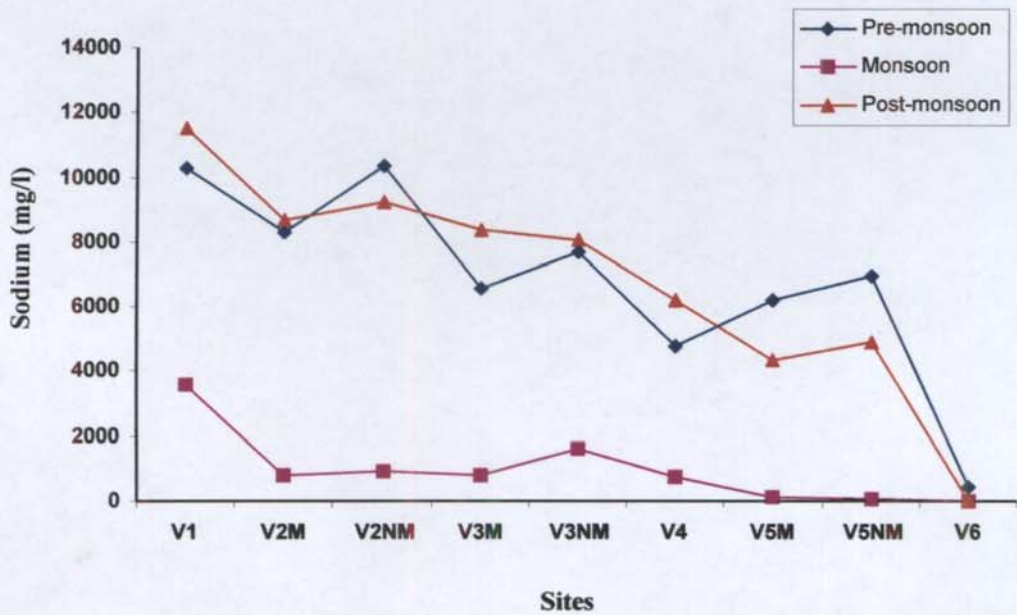


Fig. 4. 19 B Seasonal Variations in Sodium of Valapattanam River

magnesium, pH, potassium, salinity, sodium, sulphate, temperature and total hardness at 1% level.

In the Valapattanam River, there are significant differences in sodium and seasons and sodium and locations at 5% level. Sodium was found to be significantly correlated with parameters like ammonia, calcium, chloride, EC, fluoride, nitrite, pH, potassium, salinity, sulphate and total hardness at 1% level.

Potassium

Potassium ranks seventh among the elements in the order of abundance. It is a naturally occurring element whose concentration remains quite lower than sodium, calcium and magnesium, but it has a more or less similar chemistry like sodium and remains in solution without undergoing precipitation. The major source of potassium in natural waters is weathering of rocks. Potassium is an essential element for both plants and animals (Trivedy *et al.* 1987).

Seasonal variations in potassium concentration in the sampling sites of Thalassery and Valapattanam river basins are presented in Tables 4. 22 A & 4. 22 B respectively.

Table 4. 22 A Seasonal Variations in Potassium of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	717	925	579	750	560	3.6
Monsoon	223	198	142	77	12	0.6
Post-monsoon	610	530	470	460	340	1.6

In the Thalassery river basin, potassium ranged from 3.6 - 925 mg/l, 0.6 - 223 mg/l and 1.6 - 610 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam river basin, it ranged from 15 - 665 mg/l, 0.33 - 86

mg/l and 8.5 - 415 mg/l in the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 20 A & 4. 20 B).

Table 4. 22 B Seasonal Variations in Potassium of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	547	473	665	334	413	308	365	435	15
Monsoon	86	21	15.2	17.4	41	17.4	1.7	1.2	0.33
Post-monsoon	415	335	345	300	285	98	120	105	8.5

Clear seasonal variations in potassium concentration were noticed in both the river basins studied. Higher concentration was reported during the pre-monsoon season, was followed by post-monsoon season, and the lowest in the monsoon season. The lower values for potassium may be attributed to dilution of this element by rainwater.

Spatial variations in potassium were recorded in both the river basins. Highest concentration of potassium was reported in the estuary. The elemental composition of potassium in the seawater accounts for 380 mg/l (Goldberg, 1976). Highest concentration of potassium was reported in the estuary and lowest in freshwater in both the river basins.

Among the mangrove and non-mangrove sites studied, higher concentration was recorded in the non-mangrove sites in both the rivers. The lower concentration in the mangrove sites may be attributed to the high uptake of this element by the mangrove flora. Potassium ions assimilated by plants get dissolved in water again when the plants mature, shed their litter and die. The decay of plant litter makes available this ion for natural recycling.

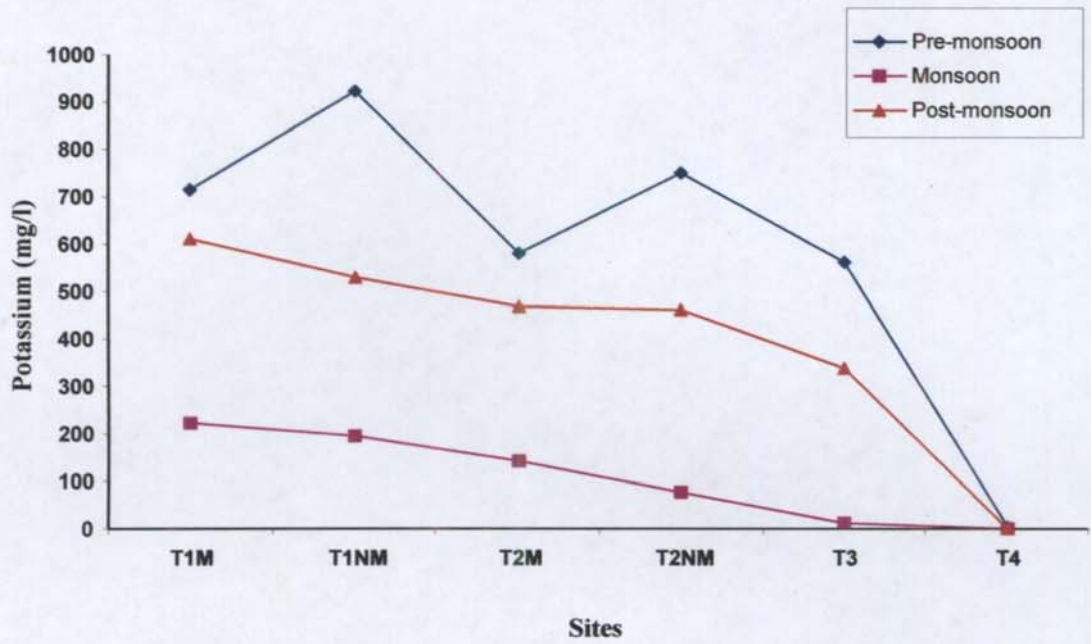


Fig. 4. 20 A Seasonal Variations in Potassium of Thalassery River

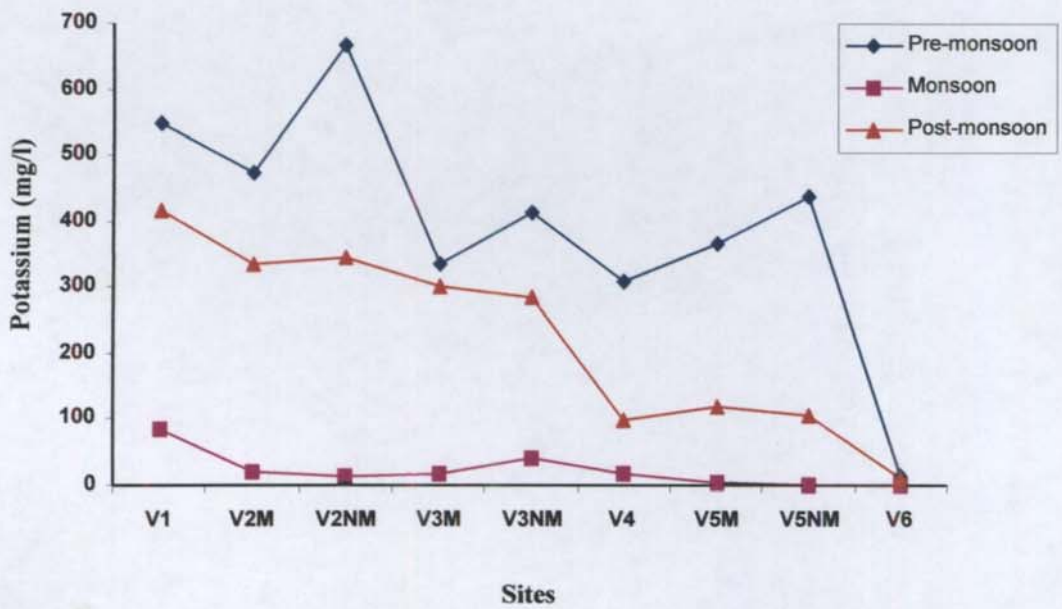


Fig. 4. 20 B Seasonal Variations in Potassium of Valapattanam River

Statistical analysis revealed that in the Thalassery River, there are significant differences in potassium and seasons and potassium and locations at 5% level. Potassium was found to be significantly correlated with parameters like calcium, chloride, EC, fluoride, pH, salinity, sodium, sulphate, turbidity and total hardness at 1% level.

In the Valapattanam River, there are significant differences in potassium and seasons and potassium and locations at 5% level. Potassium was found to be significantly correlated with parameters like ammonia, calcium, chloride, EC, fluoride, nitrite, pH, salinity, sodium, sulphate and total hardness at 1% level.

Calcium

Calcium, the fifth element in the order of abundance, is an important macronutrient in the aquatic environment and is essential in large quantities by the molluscs and vertebrates. Generally calcium is predominant cation in river water (Hem, 1985). Its concentration varies greatly in natural waters depending on the nature of river basin. The presence of Ca in water is mainly due to its passage through or over deposits of limestone, dolomite, gypsum and other gypsiferous materials. Being present in high quantities, it may get leached from there to the overlying waters (Manivasakam, 1996).

Calcium content in different sampling sites of Thalassery and Valapattanam river basins are presented in Tables 4. 23 A & 4. 23 B.

Table 4. 23 A Seasonal Variations in Calcium of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	520	490	437	360	413	3.7
Monsoon	192	235	145	102	14.4	2.9
Post-monsoon	380	460	300	300	240	6.4

Table 4. 23 B Seasonal Variations in Calcium of Valapattanam River

Seasons	Sites								
	V1	V2M	V2N M	V3M	V3N M	V4	V5M	V5N M	V6
Pre- monsoon	600	667	640	303	480	313	320	520	53
Monsoon	101	32	26.8	24.2	50	21	5.6	4.4	2.4
Post- monsoon	380	340	310	260	250	150	170	130	3.2

In the Thalassery River, the concentration of calcium ranged from 3.7 - 520 mg/l during pre-monsoon, 2.9 - 235 mg/l during monsoon and 6.4 - 380 mg/l during the post-monsoon seasons. In the Valapattanam River, it ranged from 53 - 667 mg/l during pre-monsoon, 2.4 - 101 mg/l during monsoon and 3.2 - 380 mg/l during the post-monsoon seasons (Figures 4. 21 A & 4. 21 B).

In Harija coast, maximum calcium content of 159.51 mg/l during the pre-monsoon and minimum of 140.28 mg/l in monsoon season have been reported earlier (Johny Thomas & Ragothaman, 1987). In the present study too the, pre-monsoon season recorded highest concentration of calcium, followed by the post-monsoon season and the lowest value in the monsoon season in both the rivers. The lower concentration of calcium in monsoon season may be attributed to the heavy monsoon rain causing dilution.

Among the different sites studied in both the river basins, calcium concentration was recorded maximum at the bar mouth and lowest in fresh water sites. Depending upon the distance from the bar mouth, calcium concentration was found to be gradually decreasing towards the upstream. Higher concentration of calcium in the bar mouth may be attributed to the precipitation of calcium as calcium carbonate at high pH

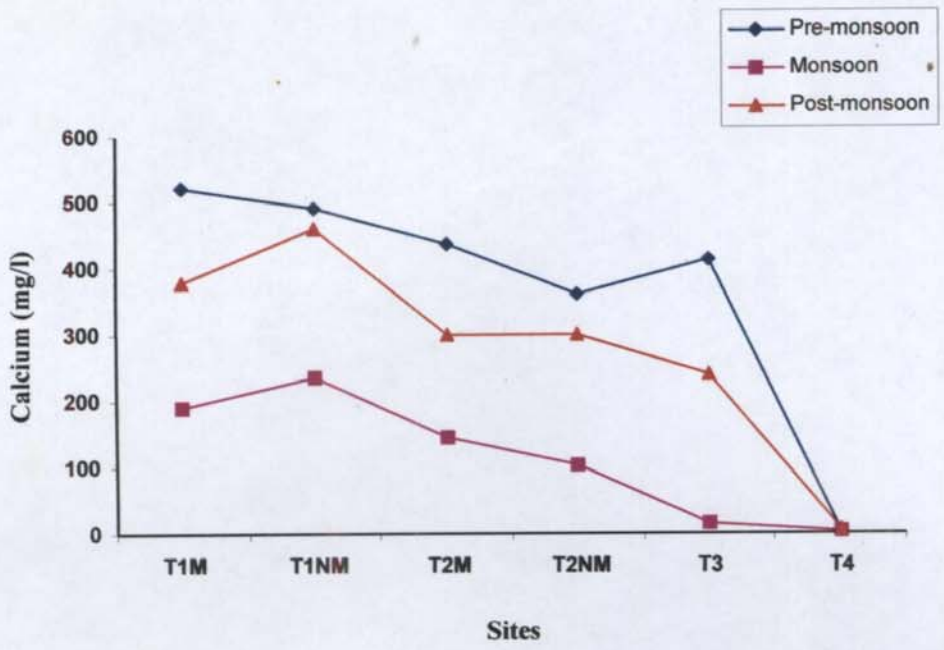


Fig. 4. 21 A Seasonal Variations in Calcium of Thalassery River

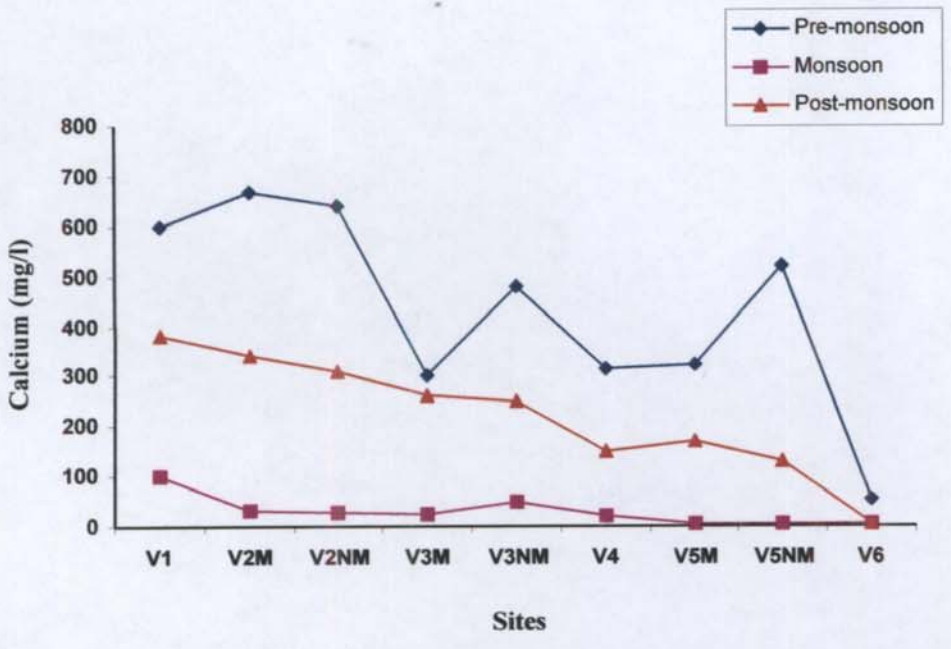


Fig. 4. 21 B Seasonal Variations in Calcium of Valapattanam River

(Trivedy *et al.* 1987). In a solution containing 2,500 mg/l of chloride and about 1,500 mg/l of sodium, the equilibrium concentration of calcium would be around 700 mg/l (Hem, 1985). Similar situation has been recorded during the present study also.

The silt brought about by the high tides from the sea contains a substantial quantity of calcareous material from foraminiferan shells and debris from molluscan and other shells and the mangrove sediments comprise these (Ananthakrishnan, 1982). The sulphur bacteria, abundant in the mangrove site act upon the calcareous material and make it available to other organisms. This may be the possible reason for the lower calcium content in mangrove sites during different seasons (Ananthakrishnan, 1982). When this calcium-rich seawater mixes with the freshwater in the estuary, contributing to the higher calcium concentration in estuaries.

Another reason for the lower concentration in mangrove sites may be attributed to the uptake of this element by the diatoms, molluscs and foraminifera, which are abundant in the mangrove areas. These organisms can take up calcium directly from the water (Perkins, 1976). The low concentration of calcium in the T2 NM site may be attributed to the uptake of this element by the *Crassostrea madrasensis*. Fluctuations in the calcium content were observed in different seasons in the mangrove and non-mangrove sites in both the river basins. This may be attributed to the differential uptake of calcium by the diatom and molluscs in the mangrove sites during different periods in both the river basins.

The higher concentration observed in the T3 site may be attributed to the calcium deposits from the practice of lime slackening near the site because lime is chemically calcium carbonate.

Compared to the calcium content reported for the Veli, Quilon and Kumarakom mangrove waters (Ramachandran *et al.* 1986), the present study recorded higher values.

Statistical analysis revealed that in the Thalassery River, there are significant differences in calcium and seasons and calcium and locations at 5% level. Calcium was found to be significantly correlated with parameters like chloride, EC, fluoride, pH, potassium, salinity, sodium, sulphate and total hardness at 1% level.

In the Valapattanam River, there are significant differences in calcium and seasons and calcium and locations at 5% level. Calcium was found to be significantly correlated with parameters like ammonia, chloride, colour, EC, fluoride, nitrite, pH, potassium, salinity, sodium, sulphate and total hardness at 1% level.

Magnesium

Magnesium salts occur in significant concentrations in natural water in the oxidized state of Mg^{++} . Seawater and estuarine water contain high amounts of magnesium. Magnesium, being an essential constituent of chlorophyll molecule without which no ecosystem could operate (Manivasakam, 1996). The industrial and commercial uses of magnesium salts are numerous and the occurrence of magnesium in industrial wastewater is common.

Seasonal variations in magnesium concentration in the sampling sites in Thalassery and Valapattanam river basins are presented in Tables 4. 24 A & 4. 24 B respectively.

In the Thalassery river basin, the magnesium concentration ranged from 3.2- 14.7 mg/l, 0.96 -31.7 mg/l and 1.4-18.8 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam river basin, magnesium concentration

ranged between 0.89 - 34.5 mg/l, 0.33 - 2.77 mg/l & 0.44 - 5.6 mg/l during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 22 A & 4. 22 B).

Table 4. 24 A Seasonal Variations in Magnesium of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	10.6	13.12	14.7	13.9	12.8	3.2
Monsoon	31.7	24.5	6.5	7.17	7.4	0.96
Post-monsoon	15.9	18.8	18.6	16.16	13.85	1.4

Table 4. 24 B Seasonal Variations in Magnesium of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	2.4	34.5	3.4	20.03	2.7	3.85	3.6	2.4	0.89
Monsoon	2.7	2.77	1.4	2.18	0.86	1.1	1.7	0.9	0.33
Post-monsoon	1.2	5.6	3.1	3.8	2.3	3.2	4.4	2.5	0.44

Among the three seasons, maximum concentration was recorded during the summer seasons and minimum during the monsoon season, which may be attributed to dilution by rainwater. The seasonal differences in concentration of this element in the two river basins may be attributed to the differential uptake by the flora in the different seasons.

A comparison of mangrove and non-mangrove sites of both the river basins showed higher concentration in the former, which may be attributed to the contribution of

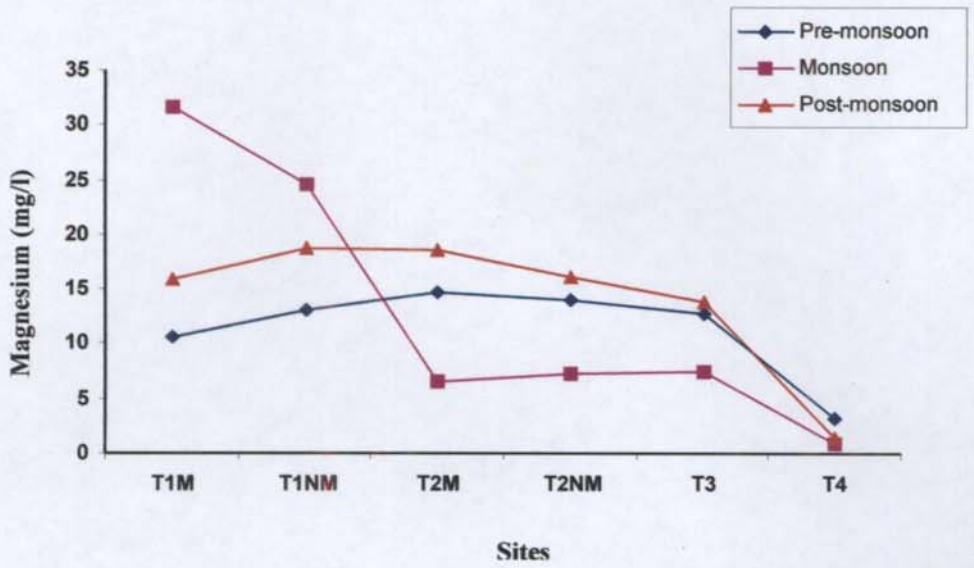


Fig. 4. 22 A Seasonal Variations in Magnesium of Thalassery River

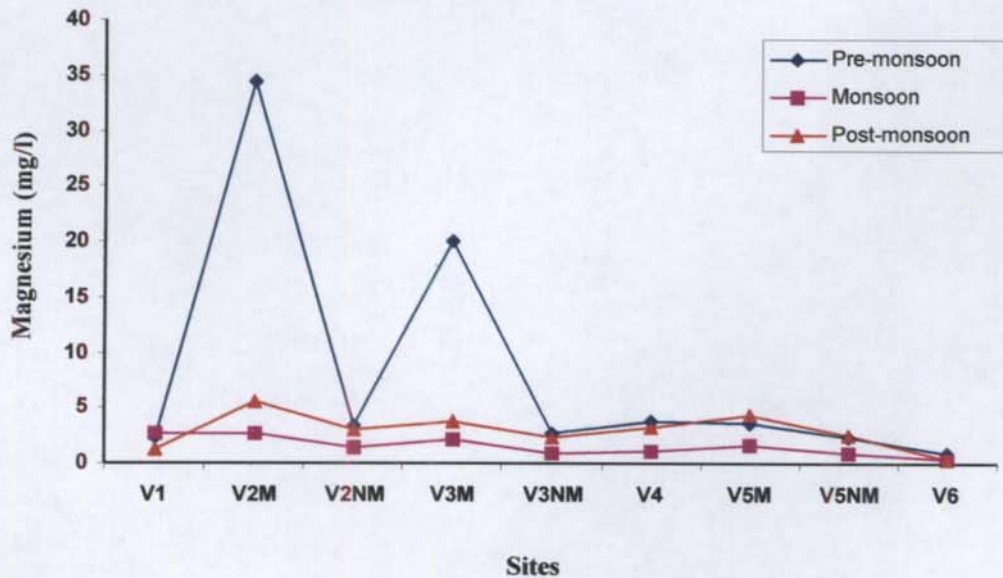


Fig. 4. 22 B Seasonal Variations in Magnesium of Valapattanam River

magnesium by the decomposed mangrove litter. The freshwater sites recorded lower values for magnesium. Magnesium concentration remained generally lower than calcium as reported earlier (Trivedy *et al.* 1987).

Statistical analysis revealed that in the Thalassery River, there are significant differences in magnesium and locations at 5% level. Magnesium was found to be significantly correlated with parameters like sodium and total hardness at 1% level.

In the Valapattanam River, there are significant differences in magnesium and seasons and magnesium and locations at 5% level. Magnesium was found to be significantly correlated with parameters like ammonia, fluoride, GPP and nitrite at 1% level.

Metals

In the present study manganese, zinc, iron and copper were analyzed. Contrary to sediments, in the water all the analyzed metals were below detectable limit. This might be due to the control of surface water in changing the concentration of dissolved metals in the interstitial water of sediments rather than *insitu* diagenetic processes as has been reported earlier (Badarudheen *et al.* 1997).

4. 2. 2. 3 Biological Parameters

Biological environment of the Thalassery and Valapattanam river basins were evaluated by conducting plankton analysis (micro and macro), productivity, chlorophyll estimation, biomass estimation, bacteriological quality of water and analysis of benthos of the sediment samples.

Plankton

The term plankton refers to those microscopic aquatic forms having little or no resistance to water currents and living free-floating and suspended in open or pelagic

waters. The plankton above 60 μm in size are referred to as the macroplankton and those below 10 μm as microplankton. The planktonic plants are referred to as phytoplankton and the animals as zooplankton. The phytoplankton occurring as unicellular, colonial or filamentous forms are the primary producers that indicate the productivity status of a water body. The zooplankton and other aquatic organisms consume them. The zooplankton belong to the four main taxonomic groups, Rotifera, Cladocera, Cyclopod and Copepoda of which only few species are abundant in open water. They occupy an intermediate position in the food webs, feeding mainly on algae and bacteria, which in turn are consumed by numerous invertebrates and fish.

Phytoplankton

Phytoplankton are floating microscopic autotrophs, which form the basic components of aquatic productivity. Their qualitative and quantitative estimates provide good indices of water quality and the capacity of water to sustain heterotrophic communities. They play an important role in the biosynthesis of organic matter in aquatic ecosystem, which directly or indirectly serves as food of prawns, crabs and estuarine fish. In Kakinada coast, productivity has been reported to be four times higher in mangroves than that of adjacent marine waters (Selvam *et al.* 1992). This has been attributed to be due to the high production of plankton in the mangrove environment, transferring energy into higher organisms through the food web. Biomass and production of phytoplankton of various sizes are important factors, which regulate the availability and diversity of organisms at higher trophic levels.

Seasonal variations of phytoplankton in the Thalassery and Valapattanam river basins are presented in Tables 4. 25 A & 4. 25 B.

Table 4. 25 A. Seasonal Variations in Phytoplankton of Thalassery River

Sites	Pre-monsoon	Monsoon	Post-monsoon
T1M	Class- Bacillariophyceae <i>Rhizosolenia</i> <i>Coscinodiscus</i> <i>Pleurosigma</i> <i>Surirella</i> <i>Navicula</i> <i>Diatoma</i> <i>Thalassiothrix</i> Class - Chlorophyceae <i>Ankistrodesmus</i> Class - Cyanophyceae <i>Anacystis</i> <i>Anabaena</i> <i>Nodularia</i> <i>Lyngbya</i>	Class - Bacillariophyceae <i>Rhizosolenia</i> <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Diatoma</i> <i>Surirella</i> <i>Synedra</i> <i>Cylindrotheca</i> <i>Navicula</i> Class - Chlorophyceae <i>Ankistrodesmus</i> Class - Cyanophyceae <i>Microcystis</i> <i>Anabaena</i> <i>Gleocapsa</i> <i>Oscillatoria</i>	Class- Bacillariophyceae <i>Cyclotella</i> <i>Rhizosolenia</i> <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Surirella</i> <i>Synedra</i> Class- Chlorophyceae <i>Ankistrodesmus</i> Class - Cyanophyceae <i>Anacystis</i> <i>Anabaena</i> <i>Gleocapsa</i> <i>Nodularia</i>
T1 NM	Class- Bacillariophyceae <i>Rhizosolenia</i> <i>Coscinodiscus</i> <i>Pleurosigma</i> <i>Surirella</i> Class - Cyanophyceae <i>Nodularia</i> <i>Lyngbya</i>	Class - Bacillariophyceae <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Diatoma</i> Class - Chlorophyceae <i>Ankistrodesmus</i> Class - Cyanophyceae <i>Gleocapsa</i> <i>Oscillatoria</i>	Class- Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> Class- Chlorophyceae <i>Ankistrodesmus</i> Class - Cyanophyceae <i>Anacystis</i> <i>Anabaena</i>

T2M	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Diatoma</i></p> <p><i>Pinnularia</i></p> <p><i>Coscinodiscus</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Eudorina</i></p> <p><i>Coelastrum</i></p> <p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabaena</i></p> <p><i>Gleocapsa</i></p> <p><i>Gleotrichia</i></p> <p><i>Lyngbya</i></p> <p><i>Nodularia</i></p>	<p>Class - Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Chaetoceros</i></p> <p><i>Pinnularia</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p> <p><i>Campylodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Stephanodiscus</i></p> <p><i>Surirella</i></p> <p><i>Ceratium</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Pediastrum</i></p> <p><i>Coelastrum</i></p> <p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabaena</i></p> <p><i>Gleocapsa</i></p> <p><i>Gleotrichia</i></p> <p><i>Oscillatoria</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Cheat ceros</i></p> <p><i>Pinnularia</i></p> <p><i>Campylodiscus</i></p> <p><i>Coscinodiscus</i></p> <p><i>Skeletonema</i></p> <p><i>Diatoma</i></p> <p><i>Biddulphia</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Pediastrum</i></p> <p><i>Closterium</i></p> <p><i>Eudorina</i></p> <p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabena</i></p> <p><i>Gleocapsa</i></p> <p><i>Microcystis</i></p> <p><i>Gleotrichia</i></p> <p><i>Lyngbya</i></p> <p><i>Nodularia</i></p>
T2N M	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Diatoma</i></p> <p><i>Pinnularia</i></p> <p><i>Coscinodiscus</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Eudorina</i></p> <p><i>Coelastrum</i></p>	<p>Class - Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Chaetoceros</i></p> <p><i>Pinnularia</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p> <p><i>Campylodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Stephanodiscus</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Chaetoceros</i></p> <p><i>Pinnularia</i></p> <p><i>Campylodiscus</i></p> <p><i>Coscinodiscus</i></p> <p><i>Skeletonema</i></p> <p><i>Diatoma</i></p> <p><i>Biddulphia</i></p>

	<p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabena</i></p> <p><i>Gleocapsa</i></p> <p><i>Gloetrichia</i></p> <p><i>Lyngbya</i></p> <p><i>Nodularia</i></p>	<p><i>Surirella</i></p> <p><i>Ceratium</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Pediastrum</i></p> <p><i>Celeastrum</i></p> <p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabena</i></p> <p><i>Gleocapsa</i></p> <p><i>Gloetrichia</i></p> <p><i>Oscillatoria</i></p>	<p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Pediastrum</i></p> <p><i>Closterium</i></p> <p><i>Eudorina</i></p> <p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabena</i></p> <p><i>Gleocapsa</i></p> <p><i>Microcystis</i></p> <p><i>Gloetrichia</i></p> <p><i>Lyngbya</i></p> <p><i>Nodularia</i></p>
T3	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Chaetoceros</i></p> <p><i>Pinnularia</i></p> <p><i>Coscinodiscus</i></p> <p><i>Campylodiscus</i></p> <p><i>Stephanodiscus</i></p> <p><i>Navicula</i></p> <p><i>Surirella</i></p> <p><i>Biddulphia</i></p> <p><i>Pleurosigma</i></p> <p><i>Skeletonema</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Pediastrum</i></p> <p><i>Coelastrum</i></p> <p><i>Eudorina</i></p> <p><i>Closterium</i></p>	<p>Class - Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Chaetoceros</i></p> <p><i>Pinnularia</i></p> <p><i>Coscinodiscus</i></p> <p><i>Campylodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Surirella</i></p> <p><i>Pleurosigma</i></p> <p><i>Skeletonema</i></p> <p><i>Gyrosigma</i></p> <p><i>Bacillaria</i></p> <p><i>Ceratium</i></p> <p><i>Chaetoceros</i></p> <p><i>Navicula</i></p> <p><i>Closterium</i></p> <p><i>Stephanodiscus</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Pinnularia</i></p> <p><i>Coscinodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Pleurosigma</i></p> <p><i>Gyrosigma</i></p> <p><i>Campylodiscus</i></p> <p><i>Navicula</i></p> <p><i>Stephanodiscus</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Scenedesmus</i></p> <p><i>Clasteriopsis</i></p> <p><i>Selenastrum</i></p> <p><i>Closterium</i></p> <p><i>Ulothrix</i></p>

	<p><i>Ulothrix</i></p> <p>Class - Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Gleocapsa</i></p> <p><i>Microcystis</i></p> <p><i>Gleotrichia</i></p>	<p><i>Pediastrum</i></p> <p><i>Eudorina</i></p> <p><i>Ulothrix</i></p> <p><i>Closterium</i></p> <p><i>Scenedesmus</i></p> <p>Class - Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Oscillatoria</i></p> <p><i>Lyngbya</i></p> <p><i>Nodularia</i></p>	<p>Class - Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Oscillatoria</i></p> <p><i>Gleotrichia</i></p> <p><i>Nostoc</i></p>
T4	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Pleurosigma</i></p> <p><i>Synedra</i></p> <p><i>Pinnularia</i></p> <p><i>Nitzschia</i></p> <p><i>Diatoma</i></p> <p><i>Skeletonema</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Ulothrix</i></p> <p><i>Scenedesmus</i></p> <p><i>Euastrum</i></p> <p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabena</i></p> <p><i>Gleocapsa</i></p> <p><i>Oscillatoria</i></p>	<p>Class - Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Rhizosolenia</i></p> <p><i>Pleurosigma</i></p> <p><i>Synedra</i></p> <p><i>Chaetoceros</i></p> <p><i>Pinnularia</i></p> <p><i>Coscinodiscus</i></p> <p><i>Campylodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Ceratium</i></p> <p><i>Diatoma</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Scenedesmus</i></p> <p><i>Selenastrum</i></p> <p><i>Pediastrum</i></p> <p><i>Ulothrix</i></p> <p><i>Chlorella</i></p> <p>Class - Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Anabena</i></p> <p><i>Gleocapsa</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Cyclotella</i></p> <p><i>Pinnularia</i></p> <p><i>Campylodiscus</i></p> <p><i>Navicula</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p> <p><i>Diatoma</i></p> <p><i>Synedra</i></p> <p><i>Nitzschia</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Pediastrum</i></p> <p><i>Scenedesmus</i></p> <p><i>Eudorina</i></p> <p><i>Ulothrix</i></p> <p>Class - Cyanophyceae</p> <p><i>Oscillatoria</i></p> <p><i>Anabena</i></p> <p><i>Nostoc</i></p>

Table 4. 25 B Seasonal Variations in Phytoplankton of Valapattanam River

Sites	Pre-monsoon	Monsoon	Post-monsoon
V1	Class- Bacillariophyceae <i>Rhizosolena</i> <i>Coscinodiscus</i> <i>Pleurosigma</i> <i>Navicula</i> <i>Cyclotella</i> <i>Diatoma</i> Class- Chlorophyceae <i>Ankistrodesmus</i> Class- Cyanophyceae <i>Anacystis</i> <i>Microcystis</i> <i>Anacystis</i>	Class- Bacillariophyceae <i>Rhizosolena</i> <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Surirella</i> <i>Biddulphia</i> <i>Diatoma</i> <i>Stephanodiscus</i> <i>Cyclotella</i> <i>Nitzchia</i> <i>Navicula</i> <i>Synedra</i> Class- Chlorophyceae <i>Ankistrodesmus</i> Class- Cyanophyceae <i>Anabena</i> <i>Oscillatoria</i>	Class- Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Cyclotella</i> <i>Campylodiscus</i> <i>Stephanodiscus</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Gyrosigma</i> <i>Pinnularia</i> <i>Synedra</i> Class- Chlorophyceae <i>Ankistrodesmus</i> Class- Cyanophyceae <i>Anacystis</i> <i>Anabena</i> <i>Nostoc</i>
V2M	Class- Bacillariophyceae <i>Rhizosolena</i> <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Diatoma</i> <i>Cyclotella</i> <i>Nitzchia</i> <i>Melosira</i> <i>Navicula</i> <i>Cymbella</i> <i>Stephanodiscus</i> <i>Bacillaria</i>	Class- Bacillariophyceae <i>Rhizosolena</i> <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Diatoma</i> <i>Stephanodiscus</i> <i>Cyclotella</i> <i>Cymbella</i> <i>Nitzchia</i> <i>Navicula</i> <i>Melosira</i>	Class- Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Gyrosigma</i> <i>Biddulphia</i> <i>Stephanodiscus</i> <i>Cyclotella</i> <i>Navicula</i> <i>Synedra</i> <i>Bacillaria</i>

	<p>Class- Chlorophyceae <i>Ankistrodesmus</i> <i>Celeastrum</i> <i>Eudorina</i> <i>Closterium</i></p> <p>Class- Cyanophyceae <i>Anabena</i> <i>Oscillatoria</i> <i>Microcystis</i> <i>Nostoc</i> <i>Lyngbya</i></p>	<p><i>Surirella</i> <i>Bacillaria</i></p> <p>Class- Chlorophyceae <i>Ankistrodesmus</i> <i>Celeastrum</i> <i>Selenastrum</i> <i>Closterium</i> <i>Pediastrum</i> <i>Scenedesmus</i> <i>Hydrodictyon</i></p> <p>Class- Cyanophyceae <i>Anabena</i> <i>Oscillatoria</i> <i>Microcystis</i></p>	<p>Class- Chlorophyceae <i>Ankistrodesmus</i> <i>Closterium</i> <i>Scenedesmus</i></p> <p>Class- Cyanophyceae <i>Anacystis</i> <i>Oscillatoria</i> <i>Lyngbya</i> <i>Nodularia</i></p>
V2 NM	<p>Class- Bacillariophyceae <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Navicula</i> <i>Cymbella</i> <i>Surirella</i> <i>Synedra</i> <i>Stephanodiscus</i></p> <p>Class- Chlorophyceae <i>Ankistrodesmus</i> <i>Celeastrum</i></p> <p>Class- Cyanophyceae <i>Anabena</i> <i>Oscillatoria</i> <i>Nostoc</i> <i>Coelosphaerium</i></p>	<p>Class- Bacillariophyceae <i>Pinnularia</i> <i>Coscinodiscus</i> <i>Diatoma</i> <i>Navicula</i> <i>Surirella</i> <i>Nitzchia</i></p> <p>Class- Chlorophyceae <i>Ankistrodesmus</i> <i>Claseriopsis</i> <i>Celeastrum</i> <i>Selenastrum</i> <i>Scenedesmus</i> <i>Pediastrum</i></p> <p>Class- Cyanophyceae <i>Anabena</i> <i>Oscillatoria</i> <i>Nostoc</i> <i>Coelosphaerium</i></p>	<p>Class- Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Gyrosigma</i> <i>Biddulphia</i> <i>Navicula</i> <i>Synedra</i></p> <p>Class- Chlorophyceae <i>Ankistrodesmus</i> <i>Scenedesmus</i> <i>Pediastrum</i></p> <p>Class- Cyanophyceae <i>Anacystis</i> <i>Anabena</i></p>

	<p>Class- Bacillariophyceae</p> <p><i>Pinnularia</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Cyclotella</i></p> <p><i>Nitzchia</i></p> <p><i>Stephanodiscus</i></p> <p><i>Navicula</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Celeastrum</i></p> <p><i>Pediastrum</i></p> <p><i>Closterium</i></p> <p>Class- Cyanophyceae</p> <p><i>Anacystis</i></p> <p><i>Oscillatoria</i></p> <p><i>Nostoc</i></p> <p><i>Nodularia</i></p> <p><i>Lyngbya</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Rhizosolena</i></p> <p><i>Pinnularia</i></p> <p><i>Bacillaria</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Diatoma</i></p> <p><i>Stephanodiscus</i></p> <p><i>Cyclotella</i></p> <p><i>Nitzchia</i></p> <p><i>Navicula</i></p> <p><i>Cylindrotheca</i></p> <p><i>Synedra</i></p> <p><i>Surirella</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Celeastrum</i></p> <p><i>Eudorina</i></p> <p><i>Closterium</i></p> <p><i>Pediastrum</i></p> <p><i>Scenedesmus</i></p> <p><i>Chlorella</i></p> <p>Class- Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Oscillatoria</i></p> <p><i>Microcystis</i></p> <p><i>Nostoc</i></p> <p><i>Anacystis</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Pinnularia</i></p> <p><i>Rhizosolena</i></p> <p><i>Biddulphia</i></p> <p><i>Cymbella</i></p> <p><i>Cyclotella</i></p> <p><i>Nitzchia</i></p> <p><i>Campylodiscus</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Coelastrum</i></p> <p><i>Scenedesmus</i></p> <p>Class- Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Oscillatoria</i></p> <p><i>Gleocapsa</i></p> <p><i>Anacystis</i></p>
<p>V3N</p> <p>M</p>	<p>Class- Bacillariophyceae</p> <p><i>Pinnularia</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Pinnularia</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Pinnularia</i></p> <p><i>Rhizosolena</i></p>

	<p><i>Diatoma</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Celeastrum</i></p> <p><i>Closterium</i></p> <p>Class- Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Oscillatoria</i></p> <p><i>Nostoc</i></p>	<p><i>Biddulphia</i></p> <p><i>Diatoma</i></p> <p><i>Cyclotella</i></p> <p><i>Navicula</i></p> <p><i>Synedra</i></p> <p><i>Surirella</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Celeastrum</i></p> <p><i>Scenedesmus</i></p> <p><i>Hydrodictyon</i></p> <p>Class- Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Oscillatoria</i></p> <p><i>Anacystis</i></p>	<p><i>Biddulphia</i></p> <p><i>Cyclotella</i></p> <p><i>Nitzchia</i></p> <p><i>Campylodiscus</i></p> <p>Class- Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Coelastrum</i></p> <p><i>Scenedesmus</i></p> <p><i>Closterium</i></p> <p>Class- Cyanophyceae</p> <p><i>Anabena</i></p> <p><i>Oscillatoria</i></p> <p><i>Nostoc</i></p> <p><i>Nodularia</i></p>
V4	<p>Class- Bacillariophyceae</p> <p><i>Coscinodiscus</i></p> <p><i>Diatoma</i></p> <p><i>Nitzchia</i></p> <p><i>Melosira</i></p> <p><i>Navicula</i></p> <p><i>Cymbella</i></p> <p><i>Pleurosigma</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Closterium</i></p> <p><i>Ulothrix</i></p> <p><i>Triploceras</i></p> <p>Class - Cyanophyceae</p> <p><i>Oscillatoria</i></p> <p><i>Nostoc</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Pinnularia</i></p> <p><i>Pleurosigma</i></p> <p><i>Coscinodiscus</i></p> <p><i>Biddulphia</i></p> <p><i>Diatoma</i></p> <p><i>Cyclotella</i></p> <p><i>Nitzchia</i></p> <p><i>Navicula</i></p> <p><i>Synedra</i></p> <p><i>Surirella</i></p> <p><i>Cylindrotheca</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Celeastrum</i></p> <p><i>Eudorina</i></p> <p><i>Pediastrum</i></p> <p><i>Scenedesmus</i></p>	<p>Class- Bacillariophyceae</p> <p><i>Pinnularia</i></p> <p><i>Rhizosolena</i></p> <p><i>Biddulphia</i></p> <p><i>Cyclotella</i></p> <p><i>Nitzchia</i></p> <p><i>Campylodiscus</i></p> <p><i>Coscinodiscus</i></p> <p><i>Gyrosigma</i></p> <p><i>Cymbella</i></p> <p>Class - Chlorophyceae</p> <p><i>Ankistrodesmus</i></p> <p><i>Coelastrum</i></p> <p><i>Scenedesmus</i></p> <p><i>Hydrodictyon</i></p> <p>Class - Cyanophyceae</p> <p><i>Anabena</i></p>

		<i>Cosmarium</i> Class - Cyanophyceae <i>Anabena</i> <i>Oscillatoria</i> <i>Nostoc</i> <i>Anacystis</i>	<i>Oscillatoria</i> <i>Nodularia</i> <i>Lyngbya</i>
V5M	Class - Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Cyclotella</i> <i>Nitzschia</i> <i>Stephanodiscus</i> <i>Navicula</i> Class - Chlorophyceae <i>Ankistrodesmus</i> <i>Celeastrum</i> <i>Pediastrum</i> <i>Closterium</i> Class - Cyanophyceae <i>Anacystis</i> <i>Oscillatoria</i> <i>Nostoc</i> <i>Lyngbya</i> <i>Anabena</i>	Class- Bacillariophyceae <i>Cyclotella</i> <i>Rhizosolena</i> <i>Cheat ceros</i> <i>Pinnularia</i> <i>Coscinodiscus</i> <i>Campylodiscus</i> <i>Biddulphia</i> <i>Ceratium</i> <i>Diatoma</i> <i>Melosira</i> <i>Pleurosigma</i> <i>Cymbella</i> <i>Synedra</i> <i>Nitzschia</i> <i>Stephanodiscus</i> <i>Bacillaria</i> <i>Surirella</i> Class - Chlorophyceae <i>Ankistrodesmus</i> <i>Scenedesmus</i> <i>Pediastrum</i> <i>Ulothrix</i> <i>Hydrodictyon</i> Class - Cyanophyceae <i>Anacystis</i> <i>Anabena</i>	Class- Bacillariophyceae <i>Pinnularia</i> <i>Cyclotella</i> <i>Amphora</i> <i>Melosira</i> <i>Biddulphia</i> <i>Navicula</i> <i>Cyclotella</i> <i>Surirella</i> <i>Synedra</i> <i>Campylodiscus</i> <i>Pleurosigma</i> <i>Cymbella</i> <i>Nitzschia</i> Class - Chlorophyceae <i>Ankistrodesmus</i> <i>Pediastrum</i> <i>Scenedesmus</i> <i>Hydrodictyon</i> Class - Cyanophyceae <i>Anacystis</i> <i>Anabena</i> <i>Nostoc</i> <i>Nodularia</i>

		<i>Gleocapsa</i> <i>Nostoc</i>	
V5 NM	Class - Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Diatoma</i> <i>Nitzschia</i> <i>Navicula</i> Class - Chlorophyceae <i>Ankistrodesmus</i> <i>Celeastrum</i> <i>Closterium</i> <i>Hydrodictyon</i> Class - Cyanophyceae <i>Oscillatoria</i> <i>Nostoc</i> <i>Anabena</i>	Class- Bacillariophyceae <i>Cyclotella</i> <i>Chaetoceros</i> <i>Pinnularia</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Ceratium</i> <i>Diatoma</i> <i>Melosira</i> <i>Pleurosigma</i> <i>Synedra</i> <i>Nitzschia</i> <i>Surirella</i> Class - Chlorophyceae <i>Ankistrodesmus</i> <i>Scenedesmus</i> <i>Ulothrix</i> Class - Cyanophyceae <i>Anacystis</i> <i>Anabena</i> <i>Gleocapsa</i>	Class- Bacillariophyceae <i>Pinnularia</i> <i>Cyclotella</i> <i>Melosira</i> <i>Biddulphia</i> <i>Navicula</i> <i>Cyclotella</i> <i>Surirella</i> <i>Synedra</i> <i>Pleurosigma</i> <i>Cymbella</i> <i>Nitzschia</i> Class - Chlorophyceae <i>Ankistrodesmus</i> <i>Pediastrum</i> <i>Scenedesmus</i> Class - Cyanophyceae <i>Anacystis</i> <i>Anabena</i>
	Class - Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Cyclotella</i> <i>Nitzschia</i> <i>Stephanodiscus</i> <i>Navicula</i>	Class-Bacillariophyceae <i>Pinnularia</i> <i>Bacillaria</i> <i>Pleurosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Diatoma</i> <i>Cyclotella</i> <i>Nitzschia</i> <i>Navicula</i>	Class- Bacillariophyceae <i>Gyrosigma</i> <i>Coscinodiscus</i> <i>Biddulphia</i> <i>Cymbella</i> <i>Synedra</i> <i>Diatoma</i> <i>Pleurosigma</i> <i>Pinnularia</i>

V6	Class - Chlorophyceae	<i>Stephanodiscus</i>	<i>Cyclotella</i>
	<i>Ankistrodesmus</i>	<i>Synedra</i>	<i>Nitzschia</i>
	<i>Celeastrum</i>	<i>Melosira</i>	Class - Chlorophyceae
	<i>Pediastrum</i>	<i>Surirella</i>	<i>Ankistrodesmus</i>
	<i>Closterium</i>	Class - Chlorophyceae	<i>Coelastrum</i>
	<i>Hydrodictyon</i>	<i>Ankistrodesmus</i>	<i>Scenedesmus</i>
	Class - Cyanophyceae	<i>Euastrum</i>	<i>Pediastrum</i>
	<i>Anacystis</i>	<i>Eudorina</i>	<i>Ulothrix</i>
	<i>Oscillatoria</i>	<i>Pediastrum</i>	<i>Staurastrum</i>
	<i>Nostoc</i>	<i>Scenedesmus</i>	Class - Cyanophyceae
		<i>Chlorella</i>	<i>Oscillatoria</i>
		<i>Hydrodictyon</i>	<i>Gleocapsa</i>
		Class - Cyanophyceae	
		<i>Anabena</i>	
		<i>Oscillatoria</i>	
		<i>Microcystis</i>	
		<i>Nostoc</i>	
		<i>Anacystis</i>	
		<i>Gleotrichia</i>	
		<i>Dictyosphaerium</i>	
	<i>Gleocapsa</i>		

Phytoplankton belonging to Chlorophyceae, Cyanophyceae and Bacillariophyceae were noticed in the rivers. Phytoplankton community included 46 genera and the dominant group was Bacillariophyceae followed by Chlorophyceae and Cyanophyceae. Twenty genera of Bacillariophyceae, 12 genera belonging to Chlorophyceae and 9 genera belonging to Cyanophyceae were recorded from the Thalassery River, while in Valapattanam River, 21 genera belonging to Bacillariophyceae, 14 genera belonging to Chlorophyceae and 10 genera belonging to Cyanophyceae were recorded.

In Thalassery and Valapattanam rivers, pronounced seasonal variations in phytoplankton were noticed. Among the different seasons studied, the monsoon season recorded the highest diversity of plankton in both the river basins. Similar observations have been made in marine environment off Cochin (Asha *et al.* 2002). Thressiamma Mathew and Balakrishnan Nair, (1980) reported high density and diversity of phytoplankton during the monsoon months characterized by low salinity. A direct relation of phytoplankton production with low salinity and temperature seems to be an adaptation by phytoplankton to utilize the enrichment to the maximum degree (Qasim *et al.* 1972). Compared to earlier reports, in the present study, a reverse condition was observed wherein high diversity and low density of phytoplankton was observed during the monsoon season. The salinity may be considered as a limiting factor determining the diversity of phytoplankton in both the river basins studied. In the present study, there was an inverse relation ship between the salinity and the diversity of phytoplankton and direct relation ship with its density. An inverse relationship between phytoplankton density and salinity was noted by Ramachandran Nair *et al.* (1975) in the Vembanad Lake. These features clearly indicate that lowering of salinity and enrichment of nutrients during the SW monsoon are mainly responsible for the rich diversity of phytoplankton as has been reported by Thressiamma Mathew and Balakrishnan Nair (1980). The common diatoms identified from the mangrove water are *Navicula*, *Pleurosigma*, *Coscinodiscus*, *Cyclotella*, *Pinnularia*, *Biddulphia* etc. In Sunderban mangroves the common diatoms identified were *Navicula*, *Pleurosigma*, *Coscinodiscus*, *Cyclotella*, *Cymbella*, *Fragilaria* sps.

Among the various sites studied, mangrove and freshwater sites recorded maximum diversity, which may be attributed high rate of nutrient uptake by the plankton

in this congenial environment. Following the changes in environment, well marked changes occur in the plankton populations in different seasons of the year (Battish, 1968). The phytoplankton composition and density in mangrove areas are highly variable, but specific to the location in question and manifests temporal and spatial variability (Dittel & Epifanio, 1990). Mangrove swamps are considered to be rich in phytoplankton, dominated mainly by the diatoms (Vannucci, 1989). Marine phytoplankton of West Bengal has been investigated by Santra *et al.* (1991), which showed a taxonomic account of 46 taxa of Bacillariophyceae, Dinophyceae and Cyanophyceae. The predominant genera found almost round the year are *Coscinodiscus*, *Rhizosolenia*, *Chaetoceros*, *Biddulphia*, *Pleurosigma*, *Ceratium* and *Protoperidinium*. Eighty-two species, which constitute 67 species of diatoms, 12 species of dinoflagellates and 3 species of blue green algae, have been reported from the Pichavaram mangroves. The diatoms constitute 72% followed by the dinoflagellates with 15% (Kannan & Vasantha 1992). The phytoplankton has also been studied in relation nutrients of mangrove waters. Natural communities of Pichavaram mangroves have been reported to be with predominant with *Nitzschia*, *Closterium*, *Pleurosigma* sp., *Thalassionema nitzschioides* and *Thalassiothrix frauenfeldii* (Mani 1989,1992). Thirtyone species have been identified as bloom formers with a predominance of *Rhizosolenia alata* f. *gracillima* in Pichavaram mangroves (Mani, 1994). Micro-algal diversity in the mangroves around Kochi has been studied by Francis & Sunil (2002). Several species of *Thalassiothrix*, *Chaetoceros*, *Biddulphia*, *Asterionella*, *Melosira*, *Stephanopyxis*, *Hemidiscus*, *Eucampia* and *Coscinodiscus* reported from the mangrove environment of Pichavaram (Sundararaj & Krishnamurthy 1975). In the present study, low diversity was recorded in the estuarine zone, which may be due to the higher salinity contributing to lower nutrient availability in these sites. The important

genera of Bacillariophyceae observed throughout the year in both the river basins are *Pleurosigma*, *Navicula*, *Coscinodiscus*, *Biddulphia*, *Diatoma*, *Nitzschia*, *Cyclotella*, and *Rhizosolenia* etc. The common Chlorophycean members recorded were *Ankistrodesmus*, *Celeastrum*, *Eudorina*, *Closterium*, *Selenastrum*, *Pediastrum*, *Scenedesmus*, *Chlorella*, *Ulothrix* and *Euastrum*. The important Cyanophycean members observed were *Oscillatoria*, *Anacystis*, *Anabena*, *Nostoc*, *Microcystis*, *Lyngbya*, *Nodularia*, *Gleocapsa* and *Gelotrichia*. The qualitative composition of phytoplankton in both the river basins were observed to be homogenous.

Zooplanktons

The zooplankton in water mainly belong to five taxonomic groups viz., the protozoa, rotifera, cladocera, the cyclopid and calanoid copepoda. Zooplankton, unlike phytoplankton, are distributed horizontally and vertically in an ecosystem. They undergo diurnal and vertical migration. They are important, as they occupy an intermediate position in the food web; many of them feed on algae and bacteria which in turn are fed by numerous invertebrates, fish. They are also highly sensitive to pollution and many species are recognized indicators of pollution.

In the present study, zooplankton comprising the micro and macro plankton showed distinct seasonal variations. Pre-monsoon and post-monsoon seasons recorded higher diversity in both the river basins, compared to the monsoon season. This increased diversity and density during summer season may be attributed to high salinity and stable hydrographical features as has been reported earlier (Karuppasamy & Perumal, 2002). They reported that out of 55 species of zooplanktons recorded, the copepods were the dominant group in Pichavaram mangroves during summer. The microzooplanktons included tintinnids, rotifers, larvae of molluscs, with tintinnids predominating in the

Pichavaram mangrove, the macrozooplankton consisted of 95% copepods (Kathiresan, 2002). In the present study, the zooplankton were represented by members of Aschelminthes, Arthropoda and Protozoa, distributed among six classes viz., Crustacea, Rotifera, Ciliata, Rhizopoda, Sarcodina and Nematoda (Tables 4. 26 A & 4. 26 B).

Table. 4. 26 A Seasonal Variation of Zooplankton (Micro and Macro) in the Thalassery River

Sites	Pre-monsoon	Monsoon	Post-monsoon
T1 M	Phylum - Protozoa Class – Rhizopoda <i>Foraminifera</i> <i>Arcella</i> Class - Ciliata <i>Euplotes</i> <i>Colpoda</i> <i>Diffugia</i> Phylum-Aschelminthes Class- Rotifera <i>Keratella</i>	Phylum - Protozoa Class - Ciliata <i>Prorodon</i> Class - Sarcodina <i>Glaborotallidae</i> <i>Radiolarian</i> Phylum - Aschelminthes Class - Rotifera <i>Keratella</i>	Phylum - Protozoa Class – Ciliata <i>Euplotes</i> <i>Paramecium</i> Phylum- Arthropoda Class – Crustacea <i>Cyclops</i> Prawn larvae
T1 NM	Phylum - Protozoa Class – Ciliata <i>Euplotes</i> <i>Colpoda</i> <i>Paramecium</i> <i>Diffugia</i> Phylum - Arthropoda Class – Crustacea <i>Cyclops</i> Prawn larvae Phylum – Aschelminthes Class- Rotifera <i>Brachionus</i>	Phylum - Protozoa Class - Ciliata <i>Stylonychia</i> Phylum –Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Philodina</i>	Phylum - Protozoa Class – Ciliata <i>Paramecium</i> Phylum - Arthropoda Class - Crustacea <i>Cyclops</i>

T2M	<p>Phylum - Protozoa Class - Ciliata <i>Euplotes</i> <i>Peridinium</i></p> <p>Phylum - Arthropoda Class - Crustacea <i>Cyclops</i> <i>Cypris</i></p> <p>Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Pedalia</i></p>	<p>Phylum - Protozoa Class - Ciliata <i>Stylonychia</i></p> <p>Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Pedalia</i></p> <p>Phylum – Arthropoda Class - Crustacea <i>Cyclops</i> Prawn larvae</p>	<p>Phylum – Annelida Class – Nematoda <i>Strongyloides</i></p> <p>Phylum - Protozoa Class - Ciliata <i>Paramecium</i></p> <p>Phylum – Arthropoda Class - Crustacea <i>Cyclops</i> Prawn larvae</p>
T2 NM	<p>Phylum - Protozoa Class - Ciliata <i>Euplotes</i> <i>Paramecium</i> <i>Peridinium</i></p>	<p>Phylum - Protozoa Class - Ciliata <i>Stylonychia</i></p> <p>Phylum – Aschelminthes Class - Rotifera <i>Keratella</i> <i>Brachionus</i></p> <p>Phylum – Arthropoda Class - Crustacea <i>Cyclops</i> Prawn larvae</p>	<p>Phylum - Protozoa Class – Ciliata <i>Paramecium</i> <i>Stylonychia</i> <i>Colpoda</i></p>
T3	<p>Phylum - Aschelminthes Class – Nematoda <i>Strongyloides</i></p> <p>Class - Rotifera <i>Keratella</i></p> <p>Phylum-Protozoa Class - Ciliata <i>Stylonychia</i> <i>Paramecium</i></p> <p>Phylum- Arthropoda Class - Crustacea <i>Cyclops</i></p>	<p>Phylum - Aschelminthes Class - Rotifera <i>Keratella</i> <i>Brachionus</i></p> <p>Phylum-Protozoa Class - Ciliata <i>Chilodonella</i> <i>Paramecium</i></p>	<p>Phylum - Aschelminthes Class - Rotifera <i>Keratella</i> <i>Brachionus</i></p> <p>Phylum- Arthropoda Class - Crustacea <i>Daphnia</i> Prawn larvae</p> <p>Phylum - Protozoa Class – Ciliata <i>Chilodonella</i> <i>Paramecium</i></p>

T4	Phylum - Protozoa	Phylum- Protozoa	Phylum – Aschelminthes
	Class - Rhizopoda	Class - Rhizopoda	Class - Rotifera
	<i>Euglypha</i>	<i>Euglypha</i>	<i>Brachionus</i>
	Phylum – Aschelminthes	Phylum –Aschelminthes	<i>Philodina</i>
	Class - Rotifera	Class - Rotifera	Phylum- Protozoa
	<i>Brachionus</i>	<i>Keratella</i>	Class – Rhizopoda
	<i>Philodina</i>	Phylum- Arthropoda	<i>Foraminifera</i>
	<i>Keratella</i>	Class - Crustacea	Class – Ciliata
	Phylum- Arthropoda	<i>Cyclops sp.</i>	<i>Colpoda</i>
	Class - Crustacea	<i>Cypris sp.</i>	Phylum- Arthropoda
<i>Cyclops</i>	<i>Daphnia sp.</i>	Class - Crustacea	
<i>Daphnia</i>		<i>Cyclops</i>	

The important zooplankton recorded from the Thalassery River basin was *Foraminifera*, *Euglypha*, *Euplotes*, *Colpoda*, *Diffugia*, *Prorodon*, *Paramecium*, *Stylonchia*, *Peridinium*, *Chilodonella*, *Glaborotallidae*, *Radiolarian*, *Strongyloides*, *Brachionus*, *Keratella*, *Philodina*, *Pedalia*, *Cyclops*, *Daphnia*, *Prawn larvae* and *Cypris*. Among the different classes, Ciliata recorded maximum genera, which is followed by Rotifera. In the Valapattanam river basin, the zooplankton noticed were *Foraminifera*, *Euglypha*, *Amoeba*, *Actinophrys*, *Euplotes*, *Diffugia*, *Paramecium*, *Stylonchia*, *Vorticella*, *Strongyloides*, *Brachionus*, *Keratella*, *Philodina*, *Pedalia*, *Chaetonatus*, *Cyclops*, *Prawn larvae*, *Chydorus* *Bosmina*, *Cypris* and prawn larvae. Except Nematoda, all the other classes represented high diversity.

Spatial distribution showed a higher diversity of zooplankton in the mangrove sites of both the river basins, compared to non-mangrove sites. High zooplankton diversity in mangrove sites may be due to prevalence of high saline waters through out the year and high percentage of sediment organic matter; contributed by decomposing mangrove leaves.

Table 4. 26 B Seasonal Variation of Zooplankton in the Valapattanam River

Sites	Pre-monsoon	Monsoon	Post-monsoon
V1	Phylum – Protozoa Class - Ciliata <i>Euplotes</i> Phylum- Annelida Class- Nematoda <i>Strongyloides</i>	Phylum - Aschelminthes Class - Rotifera <i>Keratella</i> Phylum-Protozoa Class - Ciliata <i>Euplotes</i> <i>Paramecium</i>	Phylum – Protozoa Class - Rhizopoda <i>Foraminifera</i>
V2M	Phylum - Protozoa Class - Ciliata <i>Euplotes</i> <i>Paramecium</i> <i>Diffflugia</i> Phylum – Arthropoda Class – Crustacea Prawn larvae Phylum - Aschelminthes Class – Rotifera <i>Brachionus</i> <i>Philodina</i> Phylum – Arthropoda Class - Crustacea <i>Cyclops</i> <i>Cypris</i> <i>Bosmina</i> Prawn larvae	Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i> Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Philodina</i> Class – Nematoda <i>Strongyloides</i>	Phylum - Protozoa Class – Rhizopoda <i>Amoeba</i> <i>Euglypha</i> Class - Ciliata <i>Euplotes</i> <i>Paramecium</i> <i>Diffflugia</i> Phylum – Arthropoda Class - Crustacea <i>Cyclops</i> <i>Cypris</i> <i>Chydorus.</i> <i>Bosmina.</i> Prawn larvae
V2 NM	Phylum - Protozoa Class – Rhizopoda <i>Foraminifera</i> Phylum -Aschelminthes Class- Rotifera <i>Brachionus</i> <i>Philodina</i>	Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i>	Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i> <i>Amoeba</i> Class – Ciliata <i>Euplotes.</i> <i>Paramecium</i> <i>Vorticella</i>

V3M	<p>Phylum - Protozoa Class - Rhizopoda <i>Euglypha</i> <i>Amoeba</i></p> <p>Class - Ciliata <i>Euplotes.</i> <i>Diffflugia</i></p> <p>Phylum – Aschelminthes Class- Rotifera <i>Brachionus</i> <i>Philodina</i></p> <p>Phylum - Arthropoda Class - Crustacea <i>Cyclops</i> <i>Cypris</i> Prawn larvae</p>	<p>Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i></p> <p>Phylum - Arthropoda Class - <i>Crustacea</i> <i>Cyclops</i> <i>Cypris</i></p>	<p>Phylum- Protozoa Class – Rhizopoda <i>Amoeba</i> <i>Euglypha</i> <i>Actinophrys</i></p> <p>Class – Ciliata <i>Euplotes</i></p> <p>Phylum – Arthropoda Class - Crustacea <i>Cyclops</i> <i>Cypris</i> <i>Bosmina</i> <i>Chydorus</i> Prawn larvae</p>
V 3 NM	<p>Phylum - Protozoa Class - Rhizopoda <i>Euglypha</i> <i>Amoeba</i></p> <p>Class - Ciliata <i>Euplotes</i> <i>Stylonychia</i> <i>Diffflugia</i></p> <p>Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Philodina</i></p>	<p>Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i> <i>Amoeba</i></p> <p>Class – <i>Ciliata</i> <i>Euplotes</i></p> <p>Phylum- Aschelminthes Class - Nematoda <i>Strongyloides</i></p>	<p>Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i> <i>Amoeba</i> <i>Actinophrys</i></p> <p>Class – Ciliata <i>Euplotes</i> <i>Paramecium</i></p> <p>Phylum – Arthropoda Class - Crustacea <i>Cyclops</i> <i>Cypris</i></p>
V4	<p>Phylum Aschelminthes Class – Rotifera <i>Keratella</i> <i>Brachionus</i> <i>Philodina</i> <i>Chaetonatus</i></p> <p>Phylum- Protozoa Class – Ciliata <i>Euplotes</i></p>	<p>Phylum- Protozoa Class – Rhizopoda <i>Amoeba</i></p> <p>Class – Ciliata <i>Euplotes</i></p> <p>Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Philodina</i></p>	<p>Phylum- Protozoa Class – Rhizopoda <i>Amoeba</i> <i>Euglypha</i></p> <p>Class – <i>Ciliata</i> <i>Euplotes</i> <i>Diffflugia</i></p>

	<i>Stylonychia</i> Phylum – Arthropoda Class - Crustacea <i>Cyclops</i>		Phylum-Arthropoda Class - Crustacea <i>Cyclops</i> <i>Chydorus</i> <i>Bosmina</i>
V5M	Phylum – Aschelminthes Class- Rotifera <i>Brachionus</i> <i>Philodina</i> <i>Chaetonatus</i> Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i> <i>Amoeba</i> <i>Actinophrys</i> Phylum-Arthropoda Class – Crustacea <i>Cyclops</i> <i>Chydorus</i> Prawn larva	Phylum - Protozoa Class – Rhizopoda <i>Euglypha</i> Phylum – Aschelminthes Class- Rotifera <i>Brachionus</i>	Phylum - Protozoa Class – Rhizopoda <i>Amoeba</i> Class – Ciliata <i>Euplotes</i> <i>Paramecium</i> Phylum Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Pedalia</i> Phylum-Arthropoda Class - Crustacea <i>Cyclops</i> <i>Chydorus</i> <i>Chaetonatus</i>
V5 NM	Phylum- Protozoa Class – Ciliata <i>Euplotes</i> <i>Paramecium</i> <i>Vorticella</i> Phylum - Arthropoda Class - Crustacea <i>Cyclops</i> Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i>	Phylum- Protozoa Class – Rhizopoda <i>Euglypha</i> Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i>	Phylum - Protozoa Class – Ciliata <i>Paramecium</i> <i>Euplotes</i> Phylum - Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Philodina</i>
V6	Phylum- Arthropoda Class – Crustacea <i>Prawn larva</i> Phylum - Protozoa Class - Ciliata <i>Stylonychia</i>	Phylum - Aschelminthes Class - Rotifera <i>Brachionus</i> Phylum - Protozoa Class - Ciliata <i>Stylonychia</i>	Phylum- Protozoa Class – Ciliata <i>Euplotes</i> <i>Paramecium</i>

Phylum – Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Philodina</i>	<i>Vorticella</i> <i>Paramecium</i>	Phylum - Aschelminthes Class - Rotifera <i>Brachionus</i> <i>Philodina</i>
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It was also observed that sites V2 NM, V5 NM and V6 of the Valapattanam River have less diversity and density of zooplankton. This may be attributed to the disturbances caused by the sand mining practiced in these sites as has been reported earlier (Robin *et al.* 2002).

Chlorophyll

The seasonal variations in chlorophyll **a** of the Thalassery and Valapattanam river basins are presented in Table 4. 27 A & 4. 27 B respectively.

The Chlorophyll **a** values ranged from 0.007 – 0.08 mg/m³ during the pre-monsoon, 0.002 – 0.046 mg/m³ during the monsoon and 0.001–0.01 mg/m³ during the post-monsoon seasons in the Thalassery River. In the Valapattanam River, it ranged from

Table 4. 27 A Seasonal Variations in Chlorophyll a of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.04	0.011	0.08	0.007	0.07	0.04
Monsoon	0.004	0.009	0.005	0.002	0.046	0.046
Post-monsoon	0.003	0.01	0.001	0.001	0.003	0.002

0.001 – 0.053 mg/m³ during the pre-monsoon, 0.005 – 0.04 mg/m³ during the monsoon and 0.002- 0.01mg/m³ during the post-monsoon season (Figures 4. 23 A & 4. 23 B).

Table 4. 27 B Seasonal Variations in Chlorophyll a of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	0.001	0.053	0.031	0.046	0.02	0.008	0.007	0.044	0.013
Monsoon	0.007	0.042	0.039	0.03	0.016	0.025	0.035	0.009	0.005
Post- monsoon	0.002	0.006	0.008	0.017	0.003	0.002	0.004	0.004	0.002

In the present study, seasonal variation was observed in both the river basins studied. The pre-monsoon season recorded higher chlorophyll **a** values, which was followed by the monsoon and the post-monsoon seasons. Asha *et al.* (2002) Sarupriya and Bhargava (1998) also reported high chlorophyll **a** during pre-monsoon season.

It was also observed that primary productivity was closely related to chlorophyll **a** as has been reported earlier (Ramachandran Nair *et al.* 1975). It has been observed that wherever there is a decline in the surface productivity, the values of chlorophyll **a** and related hydrography was found to be changed (Ramachandran Nair *et al.* 1975).

Among the various sites studied, the mangrove sites recorded higher chlorophyll **a** than the corresponding non-mangrove site. The estuarine sites recorded comparatively low chlorophyll **a** values. The freshwater sites in both the rivers recorded higher chlorophyll **a** values, where high diversity and density of phytoplankton were also recorded. The maximum chlorophyll **a** content recorded was 0.08 mg/m³ in the Thalassery River and 0.05 mg/m³ in the Valapattanam River. In Pichavaram mangroves, chlorophyll **a** recorded a value of 30 mg/m³. Changes in percentage of living chlorophyll **a** of water (in total chlorophyll) would indicate the relative species composition (MOEF, 1987). A maximum average chlorophyll **a** concentration of 18 mg/m³ was recorded in

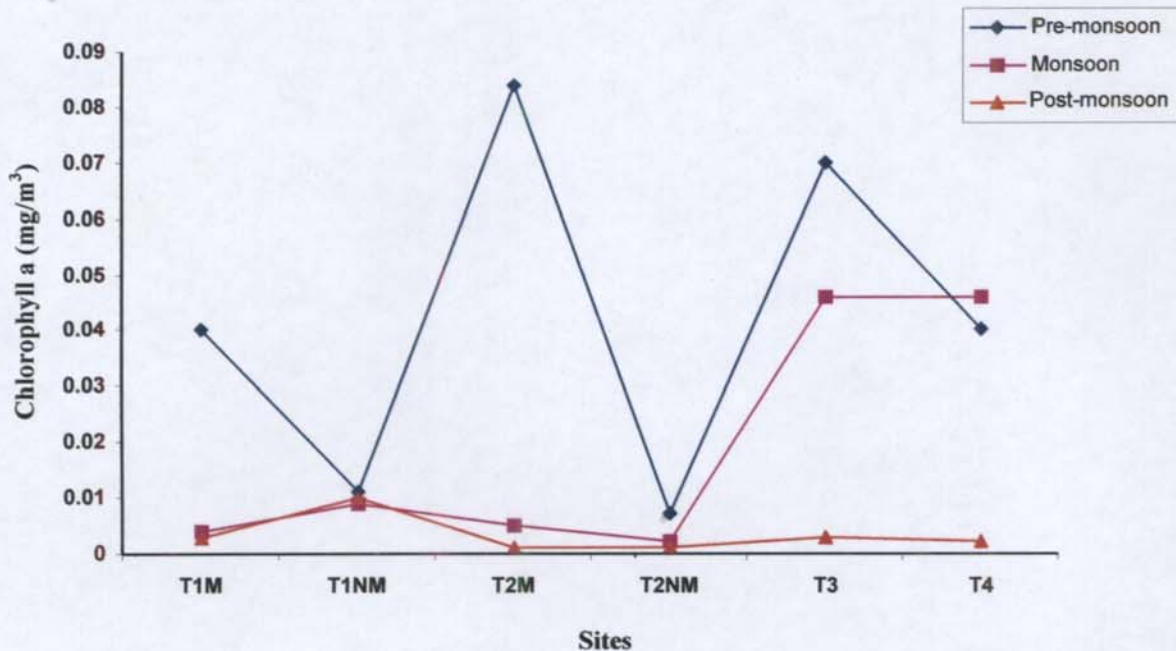


Fig. 4.23 A Seasonal Variations in Chlorophyll a of Thalassery River

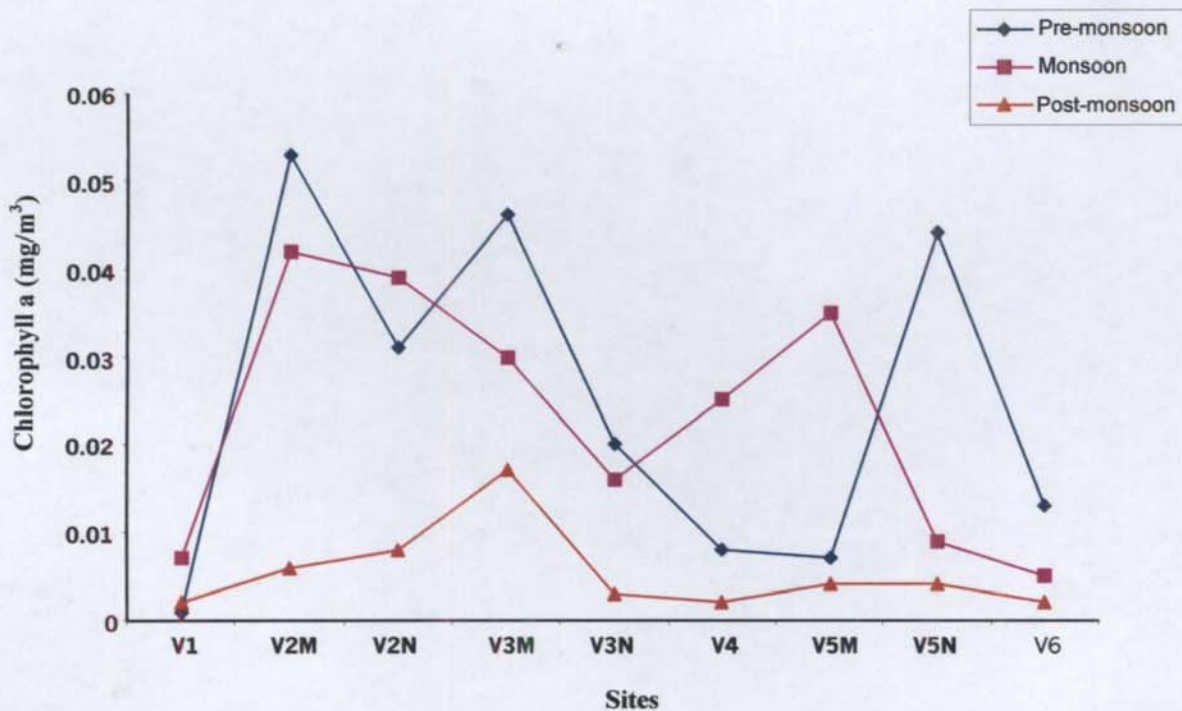


Fig.4.23 B Seasonal Variations in Chlorophyll a of Valapattanam River

Lakshadweep Sea (Sarupriya & Bhargava, 1998). Compared to earlier report relatively lower chlorophyll **a** concentration was recorded during the present study.

In the T3 and V2 mangrove sites in Thalassery and Valapattanam river basins, higher chlorophyll **a** values were recorded. In the present study, higher phytoplankton density and diversity was noticed in T3 and V2 mangrove sites, where coir retting was practiced, contrary to earlier reports, where the phytoplankton density and diversity was low (Remani *et al.* 1989). This higher phytoplankton density and diversity in these sites might be contributing to high chlorophyll **a** content. This may be due to the fact that higher density of some pollution tolerant species of phytoplankton might have contributed to high chlorophyll **a**. The important phytoplankton observed in the retting sites was *Closterium*, *Ulothrix*, *Scenedesmus*, *Cyclotella*, *Stephanodiscus*, *Navicula*, *Pinnularia*, *Surirella* and *Oscillatoria sp.* which were high in density. These species have also been reported earlier in the retting sites (Remani *et al.* 1989). According to Trivedy *et al.* (1987), these species were reported to be the most tolerant genera of algae.

Statistical analysis revealed that in the Thalassery River, there are significant differences in chlorophyll **a** and seasons at 5% level. Chlorophyll **a** was found to be significantly correlated with parameters like algal biomass, ammonia and GPP hardness at 1% level.

In the Valapattanam River, there are significant differences in chlorophyll **a** and seasons at 5% level. Chlorophyll **a** was found to be significantly correlated with parameters like algal biomass and GPP at 1% level.

Algal Biomass

Biomass is the amount of organic material present in phytoplankton at any time. It is extremely difficult to estimate the biomass of phytoplankton accurately from natural

waters, as it is difficult to separate the phytoplankton and zooplankton due to their similarity in size. Therefore, one has to resort to indirect methods of estimation of biomass. The standing crop of plankton can be expressed as numbers of organisms per unit volume. However, as the plankton population vary greatly in their size, distribution and cell numbers, alone do not give an adequate picture of the population dynamics and the diversity and structure of the ecosystem. The spatial and temporal distribution of biomass varied in the same pattern as chlorophyll a.

The seasonal variations in algal biomass of the Thalassery and Valapattanam river basins are presented in Tables 4. 28 A & 4. 28 B respectively.

The algal biomass ranged from 0.47 - 5.63 during pre-monsoon, 0.13 - 3.15 mg/m³ during the monsoon and 0.07 - 0.67 mg/m³ during the post-monsoon in the Thalassery River. In the Valapattanam River, it ranged from 0.06 - 3.55 mg/m³ during pre-monsoon, 0.34 - 2.81 mg/m³ during the monsoon and 0.13 - 1.14 mg/m³ during the post-monsoon season (Figures 4. 24 A & 4. 24 B).

In both the river basins, the algal biomass varied in accordance with the chlorophyll a values during different seasons and in sites studied. Among the three seasons, the pre-monsoon season recorded higher algal biomass, followed by the monsoon and the post-monsoon seasons.

Table 4. 28 A Seasonal Variations in Algal Biomass of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	2.69	0.74	5.63	0.47	4.82	2.71
Monsoon	0.29	0.6	0.37	0.13	3.05	3.15
Post-monsoon	0.13	0.4	0.54	1.14	0.02	0.13

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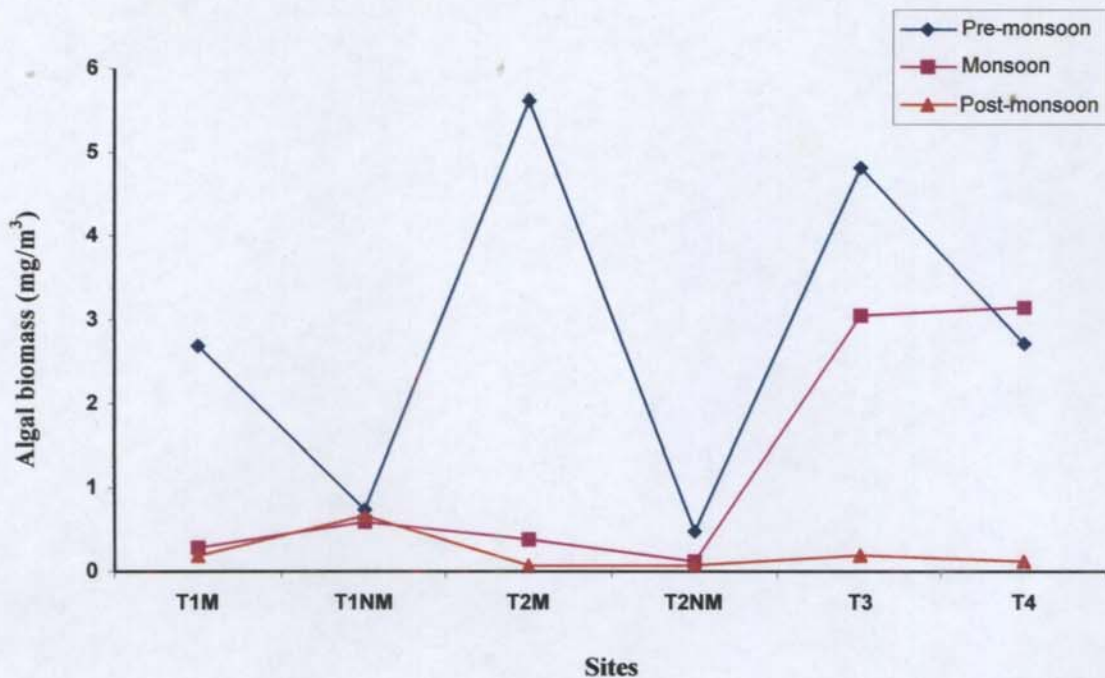


Fig. 4. 24 A Seasonal Variations in Algal biomass of Thalassery River

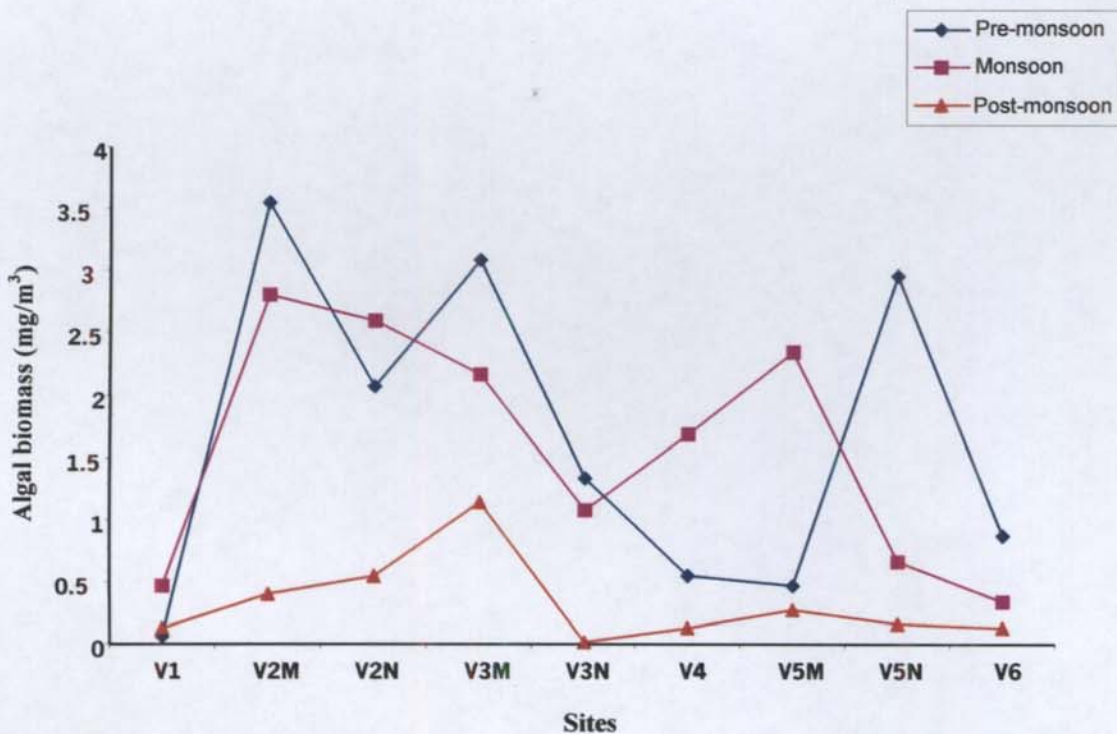


Fig.4. 24 B Seasonal Variations in Algal biomass of Valapattanam River

Table 4. 28 B Seasonal Variations in Algal Biomass of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	0.06	3.55	2.08	3.08	1.34	0.54	0.47	2.95	0.87
Monsoon	0.47	2.81	2.61	2.17	1.07	1.68	2.35	0.66	0.34
Post- monsoon	0.13	0.4	0.54	1.14	0.02	0.13	0.27	0.16	0.13

Among the various sites studied, the mangrove sites recorded higher biomass compared to the non-mangrove sites. The freshwater sites in the two river basins also recorded high algal biomass. The lowest algal biomass was observed in the estuarine sites of both the river basins, where correspondingly lower chlorophyll a and productivity were observed.

Statistical analysis revealed that in the Thalassery River, there are significant differences in algal biomass and seasons at 5% level. Algal biomass was found to be significantly correlated with parameters like ammonia, chlorophyll a, and GPP at 1% level.

In the Valapattanam River, there are significant differences in algal biomass and seasons and algal biomass and locations at 5% level. Algal biomass was found to be significantly correlated with parameters like chlorophyll a and GPP at 1% level.

Productivity

Measurement of primary productivity is of great importance in view of the healthy existence of an ecosystem.

The seasonal changes in the productivity in the Thalassery and Valapattanam river basins are presented in Tables 4. 29A & 4. 29 B respectively.

In the present study gross primary productivity varied from 0.47 - 8.42 gC/m³/d during the pre-monsoon season, 0.28 - 8.1 gC/m³/d during the monsoon season and 0.3 - 3.98 gC/m³/d during the post-monsoon season in the Thalassery River. While in the Valapattanam River, it ranged from 0.27 - 9.67 gC/m³/d during the pre-monsoon season, 0.38 - 7.2 gC/m³/d during the monsoon season and 0.2 - 2.1gC/m³/d during the post-monsoon season (Figures 4. 25 A & 4. 25 B).

Gross primary productivity recorded seasonal and spatial variations in both the river basins. Among the various seasons studied, the pre-monsoon season recorded higher GPP, which is followed by the monsoon and the post-monsoon seasons. Comparatively higher

Table 4. 29 A Seasonal Variations in GPP of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	7.79	0.47	8.42	3.96	5.73	4.78
Monsoon	3.48	0.28	3	3	3.81	8.1
Post-monsoon	3.15	0.3	3.98	1.17	2.8	1.08

Table 4. 29 B Seasonal Variations in GPP of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.27	9.67	3.1	8.5	2.9	0.7	1.2	2	2.7
Monsoon	1.26	7.2	3.8	4.7	2.1	2.7	4.75	0.38	2.1
Post-monsoon	0.96	1.42	0.82	2.1	0.89	0.51	0.48	0.2	0.5

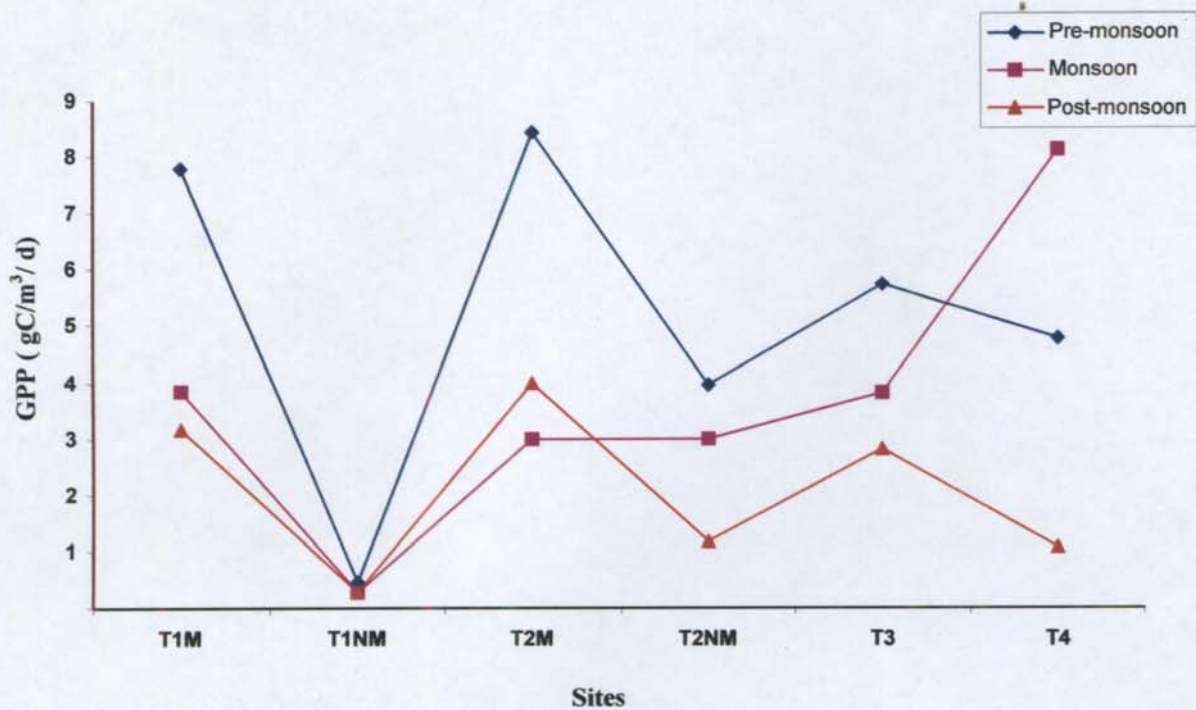


Fig. 4. 25 A Seasonal Variations in GPP of Thalassery River

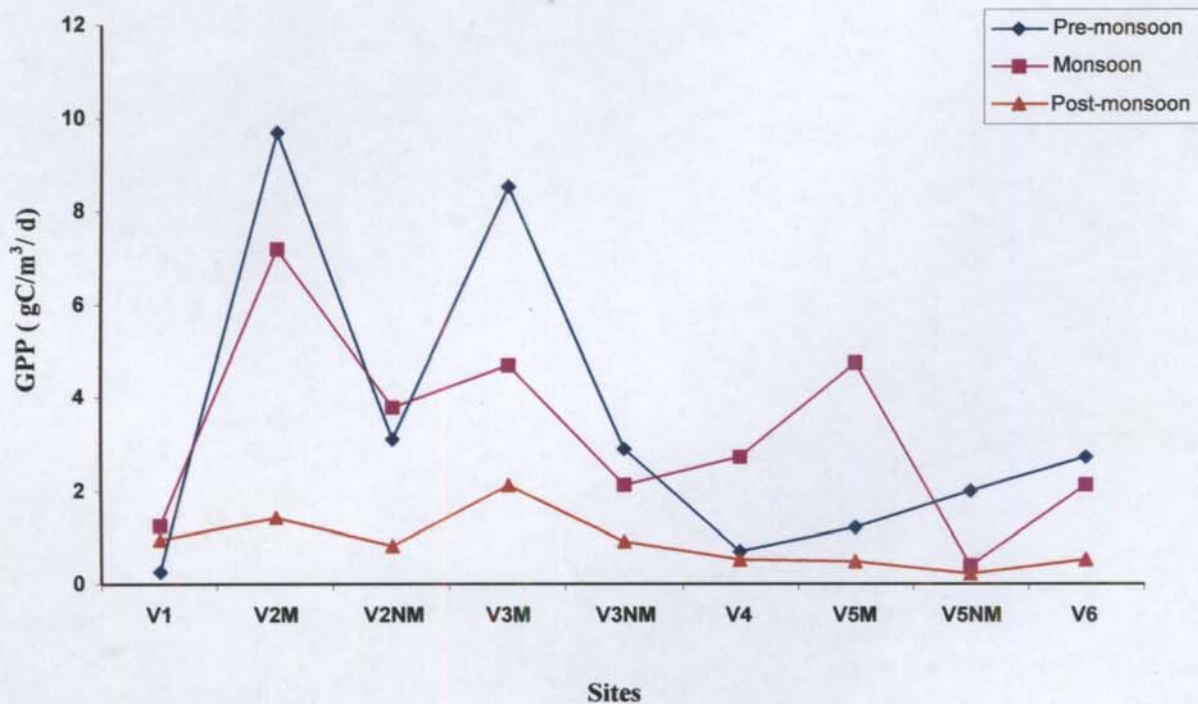


Fig. 4. 25 B Seasonal Variations in GPP of Valapattanam River

primary productivity during pre-monsoon season with high chlorophyll **a** was reported during pre-monsoon season as has been reported earlier (Asha *et al.* 2002). Sarupriya and Bhargava (1998) reported maximum average chlorophyll **a** concentration in Lakshadweep Sea during the pre-monsoon. A noticeable spatio-temporal variation was observed in gross primary production in pre-monsoon by Das (2002). The low monsoonal productivity may be attributed to low light intensity, transparency and low density of phytoplankton during the season as has been reported earlier (Mishra & Tripathi, 2000). The primary productivity was observed to be directly related with the chlorophyll **a** and biomass values. Changes in the percentage of living chlorophyll **a** of water indirectly indicate the relative species composition. This relationship between species composition and chlorophyll **a** was inverse. Higher the species diversity, a lower the percentage of chlorophyll **a** (MOEF, 1987). In the present study also, eventhough high diversity of plankton was observed during the monsoon season, their high density might have contributed to the high productivity during the pre-monsoon season.

Spatial variation revealed a higher primary productivity in the mangrove sites compared to non-mangrove sites in both the river basins. The maximum GPP noted was 8.42 gC/m³/d and 9.67 gC/m³/d in the T2M site of the Thalassery River and V2M site of Valapattanam River. The phytoplankton productivity in the mangroves was quite high and the GPP was recorded 8.00 gC/m³/day (MOEF, 1987). Krishnamurthy and Sundararaj (1973) reported an average production of 0.52 gC/m³/day from Pichavaram mangroves. In Pichavaram mangroves, Kathiresan (2002) reported that the water was fertile and productive, having several fold-higher levels of nutrients, microbes, plankton and other biological resources than the adjoining estuarine, brackish water and neritic environments, where the GPP was 8 gC/m³/ d. Pant *et al.* (1980) found that the

phytoplankton production was 1 - 2 g C/m²/day, the overall range of gross primary production (GPP) was 0.045 – 2.4, 0.25 – 2.1 and 0.38 – 2.25 gC/m³/d during the pre-monsoon, post-monsoon and monsoon seasons respectively in the entire stretch in the Upper Ganga Complex (Das, 2002). The productivity of phytoplankton has been studied from the mangrove swamps of Bay Islands in areas dominated by *Rhizophora*, *Bruguiera*, *Sonneratia* and *Avicennia* (Gopinathan & Rajagopalan, 1983; Rajagopalan, 1987). Productivity of mangrove ecosystems depends on the interrelationship of the frequency of tidal flooding, salinity of soil water, water logging of the soil, and exposure to high concentration of nutrient consequent of periodic flooding by seawater. The phytoplankton in the mangrove environment represents the values as generally found in the nearshore and estuarine waters (Bhattathiri, 1992). Untawale *et al.* (1977) found GPP of phytoplankton in the mangrove environment of Goa was 2.24 gC/m²/day. Pant *et al.* (1980) observed that the phytoplankton production varied from 0.8 – 2.06 gC/m²/day. The productivity values reported from the mangroves sites in the river basins were found to be in agreement with the earlier observations.

The correlations between the DO and GPP increased and decreased along with the fluctuations in the oxygen concentrations (Balakrishnan Nair & Abdul Aziz, 1987; Ramachandran *et al.* 1975). In the present study no significant relationship was recorded between DO and GPP. This may be due to the fact that the oxygen liberated during photosynthesis might have been utilized by the fauna for their respiration and by microorganisms for decomposition process.

A high GPP was also observed in the freshwater sites in both the river basins, which may be attributed to the higher plankton diversity and density in these sites. But

comparatively low GPP was observed in the estuarine sites, which may be due to low density of phytoplankton though out the year.

Statistical analysis revealed that in the Thalassery River, there are significant differences in GPP and seasons at 5% level. GPP was found to be significantly correlated with parameters like algal biomass and chlorophyll **a** at 1% level.

In the Valapattanam River, there are significant differences in GPP and seasons and GPP and locations at 5% level. GPP was found to be significantly correlated with parameters like algal biomass and chlorophyll **a** at 1% level.

Bacteriological Quality

Microbiological enumeration of water is an important step in pollution studies, as it is a direct indicator of the deleterious effects of pollution on human health. Water receives microbes from soil, sewage, wastewaters, plants, animals and air. As the number of pathogenic organisms present in polluted waters are few and difficult to isolate, the coliform group which are more numerous and easily detectable, are used as indicator organisms. The presence of coliforms is considered as an indicator of the presence of pathogenic organisms. The coliform group includes all the aerobic and facultative anaerobic, gram negative, non-spore forming, rod-shaped bacteria, which ferment lactose, with gas formation within 48 hours at 37⁰C. The coliform bacteria such as *E coli*, *Klebsiella* and *Enterobacter* are most frequently used as indicators of fecal contamination. In routine bacteriological tests, the actual number of coliforms are not reported, but their Most Probable Number (MPN) is enumerated. In the present study, the total coliforms and *E. coli* counts were recorded to know the extent of anthropogenic activities in the Thalassery and Valapattanam mangrove ecosystems. The seasonal

variations in the MPN of total coliforms in the Thalassery and Valapattanam rivers are presented in Tables 4. 30 A & 4. 30 B respectively.

Table 4. 30 A Seasonal Variations in MPN of Thalassery River

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	460	1100	460	24000	4600	46000
Monsoon	40	4600	24000	90	930	1500
Post-monsoon	4600	1500	4600	24000	4600	11000

Table 4. 30 B Seasonal Variations in MPN of Valapattanam River

Seasons	Sites								
	V1	V2M	V2 NM	V3 M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	2400	1500	240	4300	7500	240	4300	2400	2400
Monsoon	46000	240000	110000	7500	4300	2400	7500	2300	7500
Post-monsoon	21000	900	2300	7000	9300	700	400	700	93000

The total coliform counts ranged from 460 – 46,000/100 ml, 40 – 24,000/100 ml and 1,500 – 24,000/100 ml during the pre-monsoon, monsoon and post-monsoon seasons respectively in the Thalassery River basin. In the Valapattanam River, it ranged from 240 – 7,500 /100 ml, 2,300 – 2,40,000 /100 ml and 400 – 93,000 /100 ml during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 26 A & 4. 26 B).

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185-1A

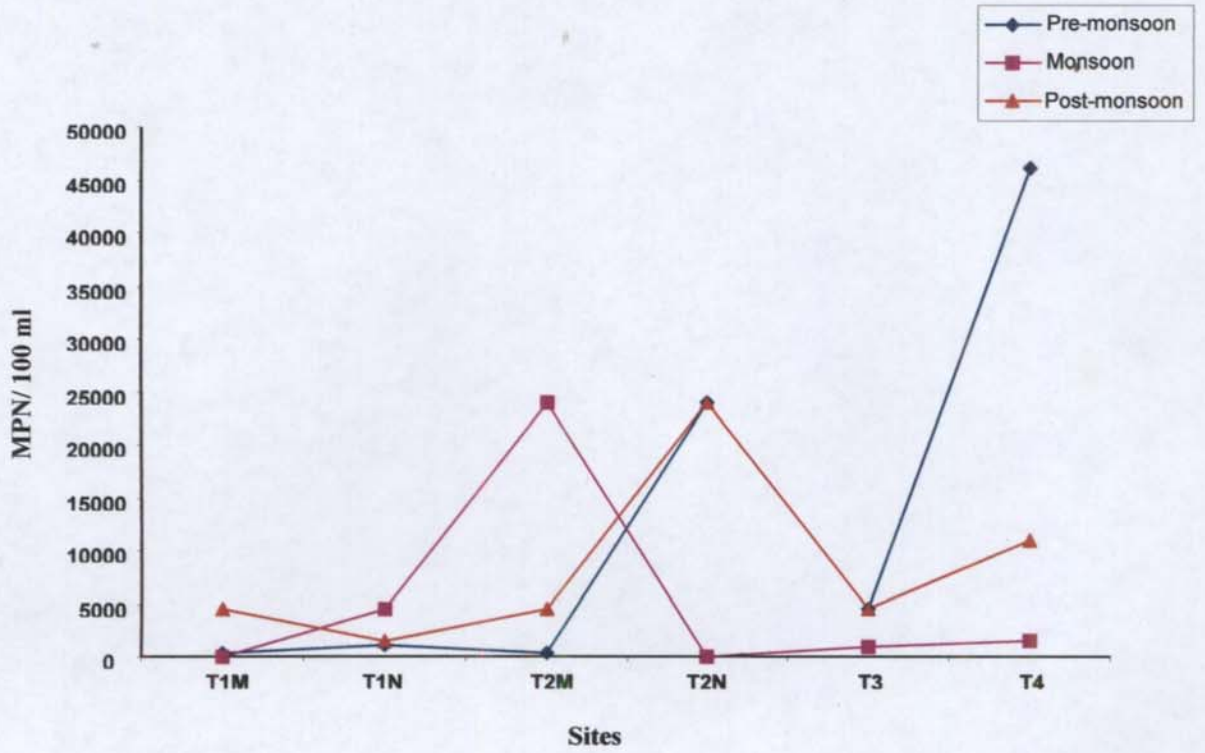


Fig. 4. 26 A Seasonal Variations in MPN of Thalassery River

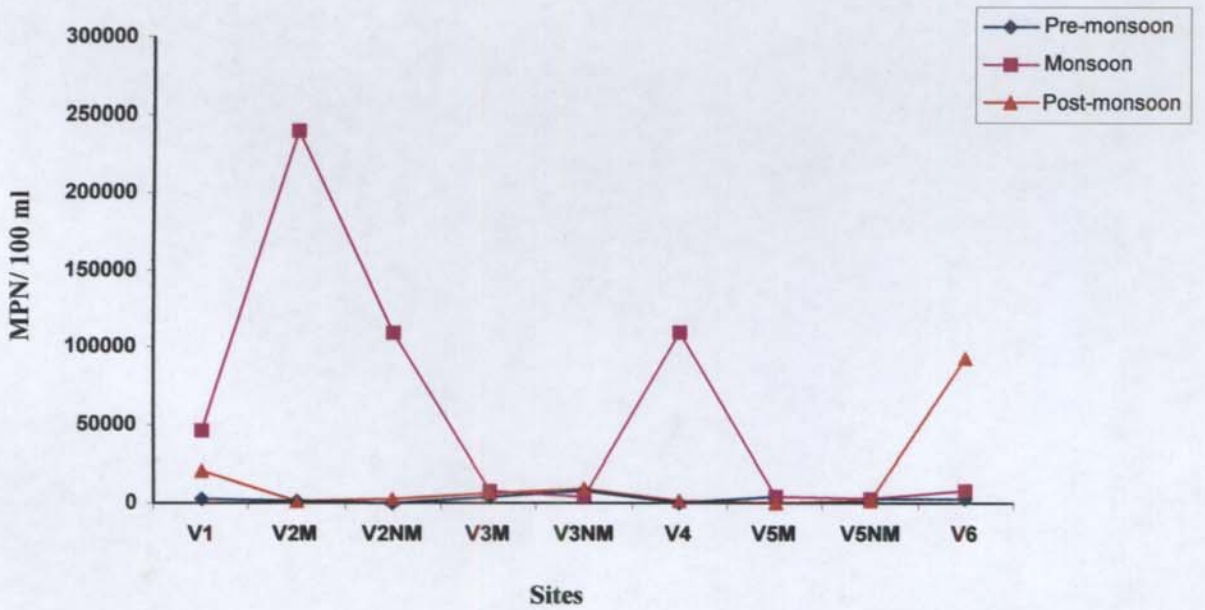


Fig. 4. 26 B Seasonal Variations in MPN of Valapattanam River

Ecological changes in the environment reflect the seasonal variations in the microflora and cycling of nutrients (Matondkar *et al.* 1980). According to him, during the monsoon season, heavy rainfall leads to considerable reduction in salinity and nutrients due to continuous flushing and dilution of the estuarine waters, leading to low bacterial counts. But, in the present study, the total coliforms counts during the monsoon season recorded maximum values except some sites in the Thalassery River. This increase in the total coliforms during the monsoon season may be attributed to the heavy run off from the catchments along with the low salinity favoring the rapid multiplication of bacteria. After the monsoons, salinity normalizes and the accumulation of degraded mangrove foliage and particulate matter utilizable by the heterotrophic bacteria leads to increase in bacterial counts during the pre-monsoon season (Matondkar *et al.* 1980). But, in the present study, during the pre-monsoon and post-monsoon seasons, the salinity was maximum and land drainage was minimum, leading to the low counts of total coliforms.

The spatial variations showed higher coliforms counts at the mangrove areas near Valapattanam Bridge and Kattampally. The fresh water sites in both the river basins were severely microbially polluted. The estuary of Valapattanam River was also found to be intensely polluted indicated by high coliforms counts, which can be attributed to the practice of open defecation by local people in the mangrove areas. The presence of *E. coli* in all the sites confirms the contamination by human activities.

Fishes

Kerala is endowed with a vast expanse of open inland waters in the form of rivers, canals, estuaries, backwaters and mangrove wetlands. Potentially, the inland fish resources of Kerala are the richest (Balakrishnan Nair *et al.* 1983). The fauna of brackish water system is generally composed of marine and freshwater organisms, which can adapt

to waters of different and varying salinities and truly resident estuarine species. The brackish water environment has certain advantages like rich supply of nutrient salts, little variation in pH (7.5 –8.3).

The mangrove harbors a large number of juvenile fishes, especially during summer and post-monsoon. The seasonal variation in the fish composition showed that mangroves harbour the highest diversity of fishes during the pre and post-monsoon seasons as has been reported earlier (Kathiresan, 2002). Most of the recorded species were transient forms inhabiting estuarine and riverine, and estuarine and marine, marine, estuarine and riverine habitats (Talwar & Jhingran, 1991). Only few members were fresh water species. In the present study, majority of the fishes were estuarine in nature inhabiting in the mangrove areas. Only few freshwater species were recorded. High fish diversity was recorded from the mangrove environments of Thalassery and Valapattanam river basins (Tables 4. 31 A & 4. 31 B). In the present study, 44 species of fishes from Thalassery River basin and 42 species of fishes from the Valapattanam River were recorded. The work carried out by Nalini Nayak *et al.* (2000), reported 36 fish species from the backwaters of Kannur. In the mangroves, *Mugil cephalus*, *Liza parsia*, *Etroplus suratensis*, *Plotosus canius* and *Ambassis gymnocephalus* have been reported to be the dominant species (Rajendran & Kathiresan, 1999). In the present study also *Etroplus suratensis*, *E. maculatus*, *Mugil cephalus*, *Ambassis dayi*, *Tilapia mossambica*, *Liza parsia*, *L. tade*, *Chanos chanos*, *Lates calcarifer*, *Megalopes cyprinoides*, *Lutjanus argentimaculatus*, *Eleotris fusca*, *Leognathus argenteus*, *Cynoglossus lingua*, *Anchoviella commorsoni*, *Secutor insidiator* and *Sillago sihama* were recorded to be the dominant species in the mangrove areas of both the river basins.

Table 4. 31 A Fishes of Thalassery River

Sl No	Scientific name	Family	Habitat*
1	<i>Etroplus suratensis</i> (Bloch.)	Cichlidae	M,E, R
2	<i>Etroplus maculatus</i> (Bloch.)	Cichlidae	E, R
3	<i>Tilapia mossambica</i> Peters	Cichlidae	E,R
4	<i>Mugil cephalus</i> Linnaeus	Mugilidae	M,E,R
5	<i>Liza parsia</i> (Ham. Buch.)	Mugilidae	M,E
6	<i>Liza tade</i> (Forsskal)	Mugilidae	M,E
7	<i>Chanos chanos</i> (Forsskal)	Chanidae	E,R
8	<i>Lates calcarifer</i> (Bloch.)	Centropomidae	E
9	<i>Megalopes cyprinoides</i> (Broussonet)	Megalopidae	E,R
10	<i>Lutjanus argentimaculatus</i> (Forsskal)	Lutjanidae	E
11	<i>Glossogobius giurus</i> (Hamilton)	Gobiidae	E,R
12	<i>Stenogobius malabaricus</i> Day	Gobiidae	E,R
13	<i>Eleotris fusca</i> (Bloch. & Schneider)	Eleotridae	E
14	<i>Leiognathus argenteus</i> Lacepede	Leiognathidae	M, E, R
15	<i>Scatophagus argus</i> (Linnaeus)	Scatophagidae	E,R
16	<i>Lepturacanthus savala</i> (Cuvier)	Trichiuridae	E
17	<i>Cynoglossus lingua</i> Ham. Buch.	Cynoglossidae	E
18	<i>Mastacembelus armatus</i> (Lacepede)	Mastacembelidae	E,R
19	<i>Anchoviella commorsoni</i> Misra	Engraulidae	M,E
20	<i>Carangoides praeustus</i> (Bennet)	Carangidae	M
21	<i>Hyporhamphus limbatus</i> Valenciennes	Hemirhamphidae	M,E,R
22	<i>Xenentodon cancila</i> (Ham. Buch.)	Belonidae	R
23	<i>Secutor insidiator</i> (Bloch.)	Leiognathidae	M,E
24	<i>Sillago sihama</i> (Forsskal)	Sillaginidae	M,E
25	<i>Lactarias lactarias</i> (Schneider)	Lactariidae	R
26	<i>Sphyreana jello</i> Cuvier	Sphyraenidae	E
27	<i>Chirocentrus dorab</i> (Forsskal)	Chirocentridae	M
28	<i>Pampus argenteus</i> (Euphrasen)	Stromteidae	M
29	<i>Pampus chinensis</i> (Euphrasen)	Stromteidae	M
30	<i>Channa marulius</i> (Hamilton)	Channidae	R
31	<i>Daysciaena albida</i> Cuvier	Sciaenidae	M,E
32	<i>Thysariophrys indicus</i> (Linnaeus)	Platycephalidae	M,R
33	<i>Rasbora daniconius</i> (Hamilton)	Cyprinidae	R
34	<i>Aplocheilus lineatus</i> (Val.)	Cyprinodontidae	R
35	<i>Synaptura commorsonii</i> (Swainson)	Soleidae	M
36	<i>Lutianus argentimaculatus</i> (Forsskal)	Lutjanidae	M
37	<i>Anabas testudineus</i> (Bloch.)	Anabantidae	E,R
38	<i>Ambassis dayi</i> (Bleeker)	Ambassidae	E,R
39	<i>Rastrelliger kanagurt</i> Cuvier	Scomberidae	M
40	<i>Puntius amphibious</i> (Val.)	Cyprinidae	R
41	<i>Sardinella longiceps</i> Valenciennes	Clupeidae	M,E
42	<i>Nemipterus japonicus</i> (Bloch.)	Nemipteridae	M
43	<i>Nuria danrica</i> Day	Rasborinae	R
44	<i>Clarius batrachus</i> (Lin.)	Claridae	R

* E - Estuarine M - Marine R - Riverine

Table 4. 31 B Fishes of Valapattanam River

Sl No	Scientific name	Family	Habitat*
1	<i>Etroplus suratensis</i> (Bloch.)	Cichlidae	M,E, R
2	<i>Etroplus maculatus</i> (Bloch.)	Cichlidae	E, R
3	<i>Tilapia mossambica</i> Peters	Cichlidae	E,R
4	<i>Mugil cephalus</i> Linnaeus	Mugilidae	M,E,R
5	<i>Liza parsia</i> (Ham. Buch.)	Mugilidae	M,E
6	<i>Liza tade</i> (Forsskal)	Mugilidae	M,E
7	<i>Chanos chanos</i> (Forsskal)	Chanidae	E,R
8	<i>Lates calcarifer</i> (Bloch.)	Centropomidae	E
9	<i>Megalopes cyprinoides</i> (Broussonet)	Megalopidae	E,R
10	<i>Lutjanus argentimaculatus</i> (Forsskal)	Lutjanidae	E
11	<i>Glossogobius giurus</i> (Hamilton)	Gobiidae	E,R
12	<i>Stenogobius malabaricus</i> Day	Gobiidae	E,R
13	<i>Eleotris fusca</i> (Bloch. & Schneider)	Eleotridae	E
14	<i>Leiognathus argenteus</i> Lacepede	Leiognathidae	M, E, R
15	<i>Scatophagus argus</i> (Linnaeus)	Scatophagidae	E,R
16	<i>Lepturacanthus savala</i> Cuvier	Trichiuridae	E
17	<i>Cynoglossus lingua</i> Ham. Buch.	Cynoglossidae	E
18	<i>Mastacembelus armatus</i> (Lacepede)	Mastacembilidae	E,R
19	<i>Anchoviella commorsoni</i> Misra	Engraulidae	M,E
20	<i>Carangoides praeustus</i> (Bennet)	Carangidae	M
21	<i>Hyporhamphus limbatus</i> Valenciennes	Hemirhamphidae	M,E,R
22	<i>Xenentodon cancila</i> (Ham.Buch.)	Belonidae	R
23	<i>Secutor insidiator</i> (Bloch.)	Leiognathidae	M,E
24	<i>Sillago sihama</i> (Forsskal)	Sillaginidae	M,E
25	<i>Lactarias lactarias</i> (Schneider)	Lactariidae	R
26	<i>Sphyreana jello</i> Cuvier	Sphyraenidae	E
27	<i>Chirocentrus dorab</i> (Forsskal)	Chirocentridae	M
28	<i>Pampus argenteus</i> (Euphrasen)	Stromteidae	M
29	<i>Pampus chinensis</i> (Euphrasen)	Stromteidae	M
30	<i>Channa marulius</i> (Hamilton)	Channidae	R
31	<i>Daysciaena albida</i> Cuvier	Sciaenidae	M,E
32	<i>Thysariophrys indicus</i> (Linnaeus)	Platycephalidae	M,R
33	<i>Rasbora daniconius</i> (Hamilton)	Cyprinidae	R
34	<i>Aplocheilus lineatus</i> (Val.)	Cyprinodontidae	R
35	<i>Synaptura commorsonii</i> (Swainson)	Soleidae	M
36	<i>Lutianus argentimaculatus</i> (Forsskal)	Lutjanidae	M
37	<i>Anabas testudineus</i> (Bloch.)	Anabantidae	E,R
38	<i>Ambassis dayi</i> (Bleeker)	Ambassidae	E,R
39	<i>Rastrelliger kanagurta</i> Cuvier	Scomberidae	M
40	<i>Puntius amphibious</i> (Val.)	Cyprinidae	R
41	<i>Sardinella longiceps</i> Valenciennes	Clupeidae	M,E
42	<i>Nemipterus japonicus</i> (Bloch.)	Nemipteridae	M

* E - Estuarine M - Marine R - Riverine

4.2.3 SEDIMENT QUALITY

4.2.3.1 Physical Parameters

Moisture Content

Water in the soil is not only important as a solvent and transporting agent, but also it maintains the texture and compactness of soil and makes it habitable for microbes, plants and animals. The moisture content in soil is mainly from infiltration of the precipitated water, which always depends on the water holding capacity and drains through percolation, evaporation and uptake by plants depending upon climatic factors, soil texture, porosity, etc.

The percentage of moisture content in the sediments collected from the sampling sites of Thalassery and Valapattanam rivers are documented in Tables 4.32 A & 4.32 B.

Table 4.32 A Seasonal Variations in Moisture content (%) of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	12.7	8.01	17.52	12.4	15	12.15
Monsoon	15.9	11.6	17.9	12.3	18.8	12.6
Post-monsoon	12.8	8.7	13.7	8.9	12.4	14.7

In the Thalassery River sediments, the moisture content ranged from 8.01 – 17.52 %, 11.6 - 18.8 % and 8.7 – 14.7 % during the pre-monsoon, monsoon and post-monsoon seasons respectively. The moisture content in the Valapattanam river sediments ranged from 9.6 – 19.01 %, 7.88 – 25.5 % and 4.9 – 20.6 % during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4.27 A & 4.27 B).

Table 4. 32 B Seasonal Variations in Moisture content (%) of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	9.6	20	13.9	14.4	10.7	16.6	19.01	15.9	10.9
Monsoon	10.3	25.5	7.88	21.4	10.9	17.5	15.7	17	10.5
Post- monsoon	4.9	17	11.4	13.8	6.6	10.3	20.6	12.7	12.4

Among the various seasons studied, the monsoon season recorded higher moisture content than pre/post monsoon seasons in the both sediments of the river basins. The monsoon season leading to flooding together with the loamy sediment contributes to higher moisture content in sediments during this season.

A clear spatial variation was observed for moisture content in both the river basins during the present study. Among the various sites studied, the mangrove sites recorded high moisture content than the non-mangrove sites in both the river basins. This is attributed to the sandy-loam/loamy-sand texture of the sediments of these sites, which have the highest moisture holding capacity. Fine-grained sediments generally retain higher moisture content. The moisture retention capacity increases due to the incorporation of organic matter as has been documented in the present study, wherein, higher percentage of moisture was observed in the mangrove sites containing high organic matter. Frequent inundation by water, together with clayey/silty sediment contributes to higher moisture content of mangrove sediments. The percentage moisture in the mangrove soils of Deogad and Mumbra creek was found to be 5.68% and 5.86%

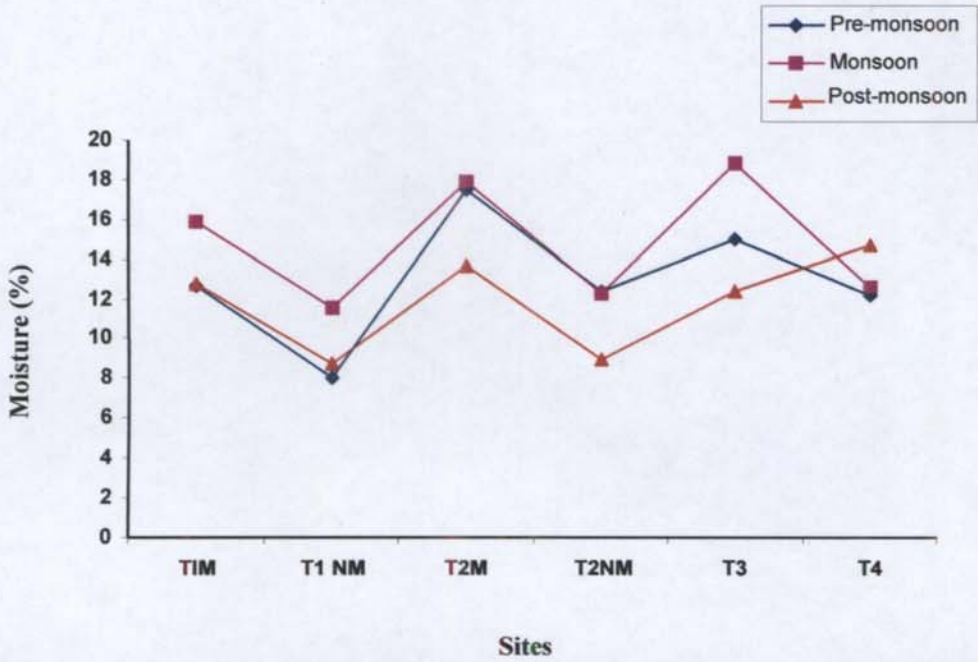


Fig. 4. 27 A Seasonal Variations in Moisture of Thalassery River Sediments

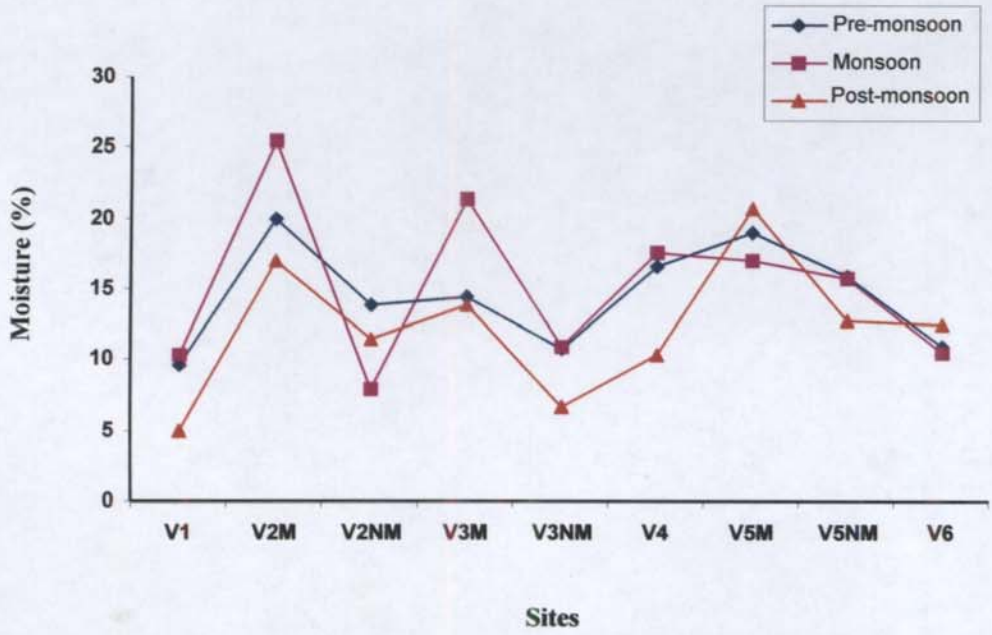


Fig. 4. 27 B Seasonal Variations in Moisture of Valapattanam River Sediments

respectively (Kotmire & Bhosale, 1979). Water holding capacity of 32.74% and 29.7% has been reported in the mangrove soils (Karmarkar, 1985). The moisture content of the soil varies because the concentration of the soil solution depends both on the amount of soluble salts and water present (Karmarkar, 1985). Results of the present study, wherein higher moisture content was observed in mangrove sites where concentration of soluble salts was high is in agreement with the above findings. The mangrove sediments contain high organic matter and humus material, which may be another reason for the increased moisture content in these sites. The clayey soil causes reduction in infiltration rate with corresponding increase in water holding capacity (Kotmire & Bhosale, 1979). The estuary as well as the fresh water sites of both the Thalassery and Valapattanam river basins recorded lower moisture content, which can be attributed to the sandy sediment present in these sites which have the least water holding capacity.

Statistical analysis revealed that in the Thalassery River, there are significant differences in moisture content and seasons and moisture content and locations at 5% level. Moisture content was found to be significantly correlated with parameters like silt, clay, manganese and potassium at 1% level.

In the Valapattanam River, there are significant differences in moisture content and locations at 5% level. Moisture content was found to be significantly correlated with parameters like clay, iron, organic carbon and sulphate at 1% level.

Sediment Texture

The term soil texture refers to the relative percentage of coarse and fine-grained soil particles. The coarse fraction includes particles larger than 0.05 mm in diameter (stones, gavel and sand), which provides physical support to plants, and plays only a minor role in the water retention and in plant nutrition. The fine sediment is made up of

silt and clay particles smaller than 0.05 mm in diameter, which determines, to a large extent, the water holding capacity of soil aeration and supply of available nutrients (Chopra & Kanwar, 1976).

The seasonal and spatial distribution of sediment texture in the two river basins are presented in Tables 4. 33 A & 4. 33 B.

Table 4. 33 B Seasonal Variations in the Sediment Texture of Thalassery River Basin

Seasons		T1 M	T 1 NM	T2 M	T2 NM	T3	T4
Pre- monsoon	Sand (%)	89.25	99.75	81.25	98.6	82.25	97.98
	Silt (%)	2.5	0.25	7.25	0.525	6.25	0.525
	Clay (%)	8.25	0	11.5	0.875	11.5	1.5
	Textural Class	Sandy loam	Sandy	Sandy loam	Sandy	Sandy loam	Sandy
Monsoon	Sand (%)	96	99.5	76	98.5	77.5	92.5
	Silt (%)	0.75	0.5	6.5	0	8.75	1.25
	Clay (%)	3.75	0	17.5	1.5	13.75	6.25
	Textural Class	Sandy	Sandy	Sandy loam	Sandy	Sandy loam	Sandy
Post- monsoon	Sand (%)	90.75	98	89.25	94.25	88	86.5
	Silt (%)	3.75	2	2.25	4.75	3.75	7.25
	Clay (%)	9	0	8.15	1	8.25	6.25
	Textural Class	Sandy loam	Sandy	Sandy loam	Sandy	Sandy loam	Loamy sand

A wide range of variation in sand, silt and clay components is seen in mangrove soils of Kerala coast. Reports of the definite sediment textural class in the mangrove ecosystem are limited and fragmentary. The Veli (Trivandrum) and Nadakkavu

(Kozhikode) mangrove areas have been reported to be composed of silty-clay textural substratum (Ramachandran *et al.* 1986; Badarudheen *et al.* 1997). Silty-sand particles are reported to dominate in Kumarakom and Quilon mangrove areas. Edakkad, Pappinissery and Kunghimangalam mangrove areas are characterized by clayey- sand textured sediments.

Table 4. 33 B Seasonal Variations in the Sediment Texture of Valapattanam River Basin

Seasons		V1	V2M	V2 NM	V3 M	V3 NM	V4	V5M	V5 NM	V6
Pre - monsoon	Sand (%)	92.75	78	89.25	80.25	90.25	97.5	79.75	98.83	95.5
	Silt (%)	6.23	8	3	11	2.75	1.25	2.5	0.3	0
	Clay (%)	1.02	14	7.75	8.75	7	1.25	17.75	0.875	0.5
	Textural Class	Sandy	Loamy sand	Sandy loam	Loamy sand	Sandy	Sandy	Sand-clay-loam	Sand	Sand
Monsoon	Sand (%)	78.75	65	97.5	87.5	86.25	94.5	80	92	94.5
	Silt (%)	12	15	0	0	9.25	2.25	10.25	2.5	4
	Clay (%)	8	20	3.75	12.5	4.5	3.25	9.75	5.5	1.5
	Textural Class	Loamy sand	Loam	Sandy	Sandy loam	Sandy loam	Sandy	Sandy loam	Sand	Sand
Post- monsoon	Sand (%)	95.25	74	87.75	87.75	89.25	93.75	82	91.25	98
	Silt (%)	4.75	8	12.75	12.75	8.75	1.5	9.5	4	0
	Clay (%)	0	18	0.5	0.5	2	4.75	8.5	4.75	2
	Textural Class	Sandy	Loamy sand	Loamy sand	Loamy sand	Loamy sand	Sandy	Loamy sand	Sand	Sand

Different admixtures of sand, silt, and clay components formed the mangrove substratum in Kannamali, Chetuwai and Chittari. In all these sediments, sand and silt dominated the sediment (Ramachandran *et al.* 1986). Navalkar (1941) who analyzed surface sediments of some Indian mangrove swamps dominated by indicated abundance of sand than silt and clay. In the present study, loamy-sand was observed in the Valapattanam mangrove

sediment. The soils supporting the mangroves are broadly distinguished into sandy loams and silty loams, with great variability from one region to other was reported by Karmarkar, (1985). Results of the present analysis of mangrove sediments indicate a wide range of variation in sand, silt and clay components. From the sediment distribution pattern in the Thalassery and Valapattanam rivers, a definite textural class was found suggested in the mangrove localities *i.e.*, either loamy-sand or sandy-loam. It was interesting to note that, among the mangrove and non-mangrove areas of the same site, significant differences could be observed in the texture of the sediments. The non-mangrove areas were mostly sandy in nature while the corresponding mangrove areas loamy – sand texture. This clearly indicates the capacity of mangroves for sediment accretion. Textural analysis revealed that the estuarine and freshwater sediments were sandy in nature. The mangrove areas, in general, fall under the loamy sand and sandy loam with only some seasonal differences. Loam is a soil between sandy and clay soil in texture. Loams are chiefly admixtures of sand, clay and silt. The V4, V5 NM, V6, T1NM, T2N M and T4 sites were found to be sandy in nature. Among these sites V5 NM, V6, T4 sites were sand mining spots. The V2 NM site was sandy loam in nature and sand mining was being practiced here. In the Thalassery River, the sediment falls under the sandy loam category. Seasonal differences in sediment texture may be attributed either to the fresh water runoff or to tidal action and the consequent deposition.

Coarse textures or sandy soils usually have a low supply of moisture and nutrients. Fine textures or loam and clay soils on the other hand have sufficient water-holding capacity and often a high supply of nutrients.

Karmarkar (1985) reported that the soils of mangroves belong to sandy loams and silty loams, with great variability from one region to another. In a study conducted by

Balakrishnan Nair and Abdul Aziz (1987), in Ashtamudi estuary, the pre-monsoon period showed the peak percentage of clay (26.04) and silt (11.46%). Spatial variation was also observed in the sediments of both the river basins studied. At the mangrove sites the sediments was mainly sandy loam or loamy sand, whereas at the estuary sand was the main constituent. The monsoonal months however, were marked by sand, silt and clay at all station. The clay content in the sediment generally decreased towards the estuary, in both Thalassery and Valapattanam rivers, as has been reported earlier (Vareethaih, 2001). The inorganic phase of estuarine sediments, which include rock fragments and minerals, constitutes the second largest component. This component assumes significance as it controls the availability of many divalent metals; minerals and inorganic matter of biogenic origin are held in this phase. The sediment texture determines its ability to hold organic and inorganic matter (Vareethiah, 2001). The sediment texture may show wide variations depending upon the disturbance caused due to human interventions (Ramachandran *et al.* 1986). This may be one of the reasons for the degradation of mangroves of Eranholi, Kuyyali and Kattampally, although from the point of view of sediment or soil substratum, these localities have been congenial for mangroves.

4. 2. 3. 2 Chemical Parameters

pH

pH of the soil is the measure of 'hydrogen ion activity' which depends largely on the **relative** amounts of the adsorbed hydrogen and metallic ions. It is a good measure of the indication of acidity or alkalinity of a soil-water suspension and provides good identification of the soil's chemical properties (Trivedy & Goel, 1986). The pH values of the sampling sites of both the river basins in different seasons are presented in Tables 4. 34 A & 4. 34 B.

Table 4. 34 A Seasonal Variations in pH of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	8.2	7.9	7.1	7.6	5.5	6.5
Monsoon	7.9	8.5	6.4	7.3	5.3	5.2
Post-monsoon	7.9	8.1	7.3	7.6	6.3	6.1

Table 4. 34 B Seasonal Variations in pH of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	8.0	6.2	7.6	5.1	6.6	6.3	5.6	6.1	6.4
Monsoon	8.3	5.1	6.7	3.7	5.1	5.0	4.5	6.0	6.1
Post-monsoon	7.7	6.6	7.7	5.2	6.3	6.2	4.7	6.5	5.6

In the Thalassery River, the pH of sediments ranged from 5.5 – 8.24, 5.2 – 8.5 and 6.1 – 8.1 during pre-monsoon, monsoon and post-monsoon seasons respectively. The pH ranged from 5.1 – 8.02 in pre -monsoon, 4.5 – 8.3 in monsoon and 4.7 – 7.7 in post-monsoon seasons in the Valapattanam River basin (Figures 4. 28 A & 4. 28 B).

Among the various seasons studied, no sharp variation in the pH was noticed in the sediments of various sites of both the river basins. In general, the pH was found to be low during the monsoon season than the pre/post monsoon seasons in both the river basins. This could be due to the effect of water logging and consequent anoxic conditions.

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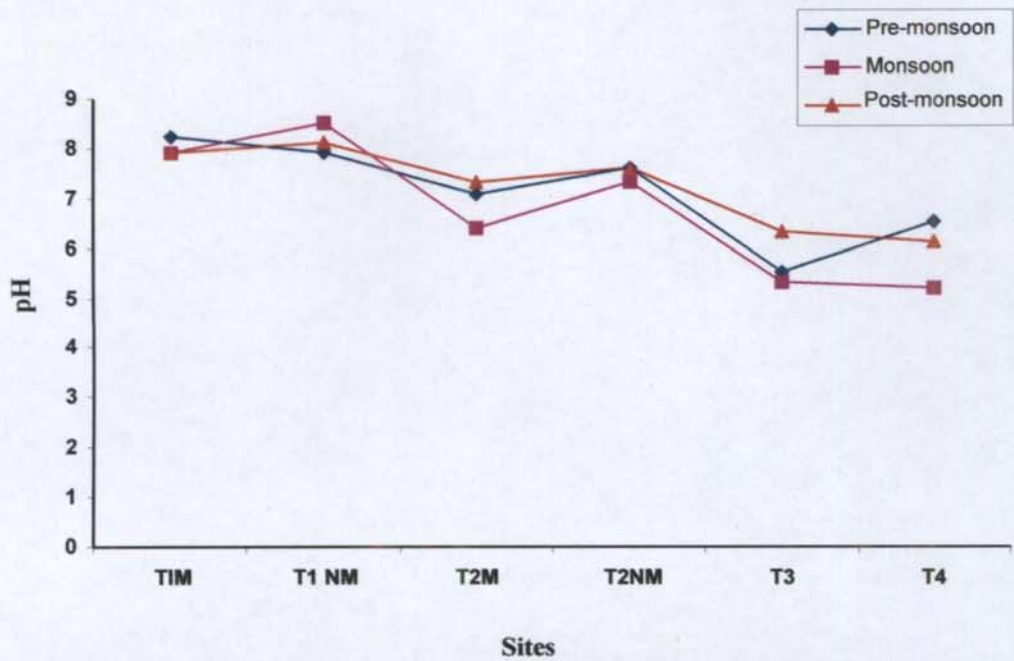


Fig. 4. 28 A Seasonal Variations in pH of Thalassery River Sediments

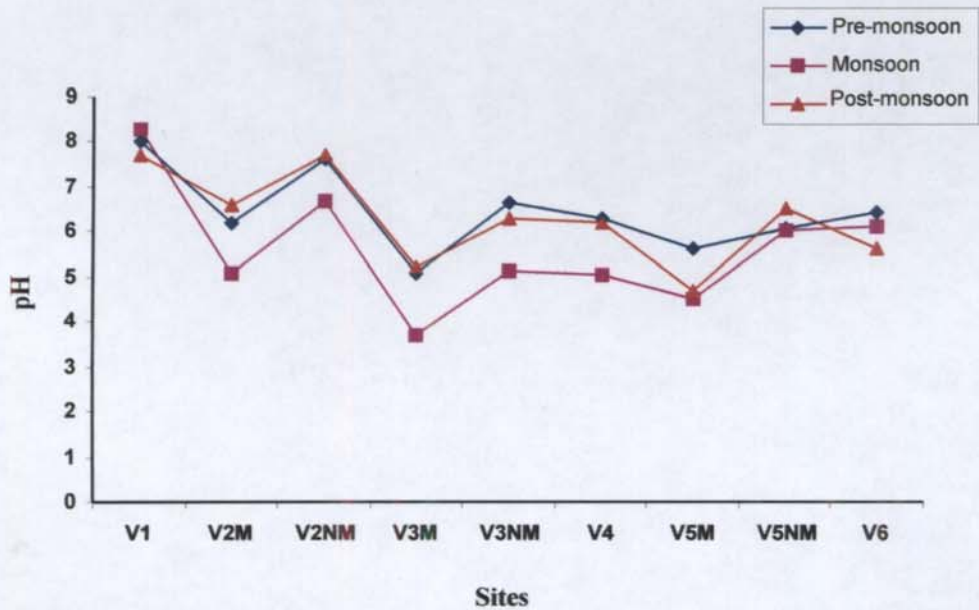


Fig. 4. 28 B Seasonal Variations in pH of Valapattanam River Sediments

A sharp spatial variation in pH of sediments in both the river basins were recorded. In both the river basins the mangrove sediments recorded a low pH, indicating the acidity of the soil. The pH is low due to the reduction of sulphides to sulphate with consequent formation of sulphuric acid in anaerobic conditions arising due to compaction of materials deposited by tidal waters. In Kaveri delta region, *Avicennia marina* occurs in acidic soils having pH 3.4 – 4.5 (Blasco, 1975). An acidic pH in the sediments of *Acrostichum*, *Avicennia*, *Rhizophora*, *Bruguiera* have been earlier reported (Dagar *et al.* 1991) as has been observed in the present study. The acidity of the mangrove soils also occurs due to the oxidation of FeSO_4 in the soil. Carbon dioxide released from the decomposition of organic matter and from annual respiration may also lower the pH values of the soils (Sasekumar, 1984). The pH normally falls with increasing depth in sediment and especially in the presence of the black sulphide (Perkins, 1976). According to Donahue *et al.* (1977) & Kotmire & Bhosale (1979), the soil becomes acidic when basic cations are leached out of the least disturbed mangroves soils irrespective of the locality because of the submerged, marshy conditions prevailing in these areas.

Blasco (1975) reported that the pH of the coastline soils ranges from 6.5-7.0. An acidic pH was noted in the mangrove sites studied, which is in conformity with earlier reports (Susumu Kuracshi *et al.* 1985; Dagar *et al.* 1991; Kotmire & Bhosale 1979), wherein a pH of 5.8 – 6.6 was reported in the mangrove sediments.

The sediments of the mangrove areas contain potential acid sulphate material upto 50 cm below from the surface. Except for sediment layers rich in shells of bivalves and coral reefs, all soils become strongly acidic on drying. A low pH was observed where the sites are moderately/highly disturbed, the decrease being more in soils which were dominant with *Acrostichum* species and were inundated daily record lowest pH value

(4.2), which may be due to the highly oxidized condition created during the drying cycle (Dagar *et al.* 1991). Similar situation was also noticed during the present study.

In the present study, the estuarine sediment recorded a high pH in both the river basins. This alkaline pH was due to dominance of seawater. The pH profoundly increases hydroxide, carbonate, sulphide, phosphate and silicate equilibria in sediments, which in turn regulates the precipitation and dissociation of solids, the sorption and desorption of ions and concentration of such nutrients/ substances such as P, Fe, Al, Cu, Zn, H₂S, carbonic acid and organic acids. Hence fluctuations in the equilibria of estuarine sediments will have a definite influence on the distribution of aquatic flora and fauna (Aiyer & Rajendran, 1987). In the Thalassery River, the sediments of Eranholi site was found to be highly acidic, which may be attributed to the coconut husk retting practiced there. Hydrogen sulphide produced during the retting process gets further oxidized to sulphuric acid may be the reason for the increase in the acidity of the sediment.

Statistical analysis revealed that in the Thalassery River, there are significant differences in pH and locations at 5% level. pH was found to be significantly correlated with silt at 1% level.

In the Valapattanam River, there are significant differences in pH and locations and pH and seasons at 5% level.

Electrical Conductivity (EC)

Conductivity is the current carrying capacity, which gives a clear idea of the soluble salts present in soil. Conductivity of the sediment is usually lower when compared to that of the water from the same sampling sites Trivedy & Goel, (1986). Conductivity recorded at 25⁰ C in a 1:5 soil suspension from different sites of the two river basins are presented in Tables 4. 35 A & 4. 35 B.

Table 4. 35 A Seasonal Variations in Electrical Conductivity of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	2.357	1.330	7.387	2.475	5.347	0.083
Monsoon	1.420	0.767	1.487	0.499	1.866	0.030
Post-monsoon	3.940	1.437	8.865	3.710	5.465	0.102

Table 4. 35 B Seasonal Variations in Electrical Conductivity of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	2.011	5.523	1.390	3.043	1.230	1.957	2.325	2.020	0.124
Monsoon	0.254	1.250	0.611	1.764	0.661	0.921	0.681	0.130	0.081
Post-monsoon	1.069	4.945	2.960	3.541	1.209	1.043	3.090	1.485	0.143

The conductivity values ranged from 0.083 – 7.387 mmhos/cm during pre-monsoon, 0.030 – 1.866 mmhos/cm during monsoon and 0.102 – 8.865 mmhos/cm during post-monsoon seasons in the Thalassery River. While in the Valapattanam River, conductivity values varied from 0.124 – 5.523 mmhos/cm during pre-monsoon, 0.081 – 1.764 mmhos/cm during monsoon and 0.143 – 4.945 mhos/cm during the post-monsoon season (Figures 4. 29 A & 4. 29 B).

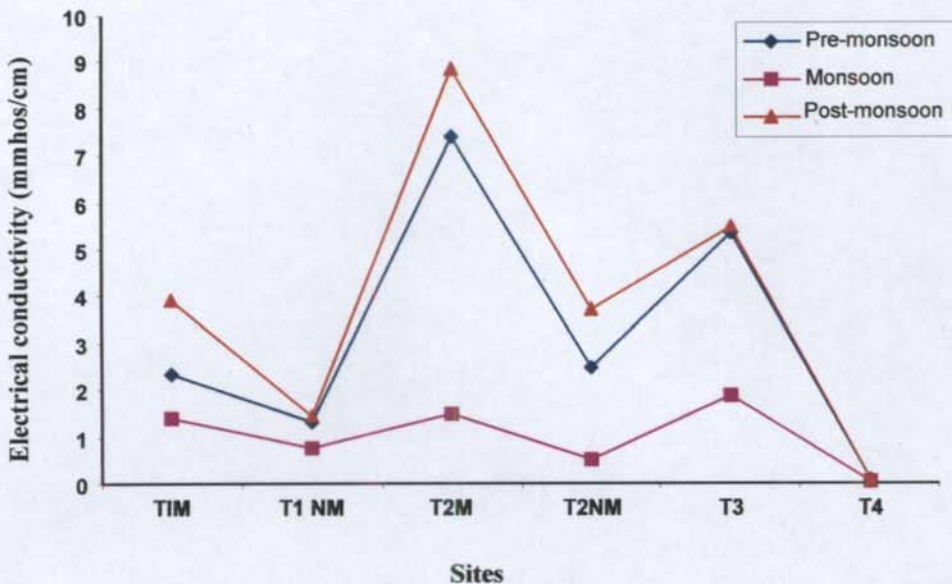


Fig. 4. 29 A Seasonal Variations in Electrical Conductivity of Thalassery River Sediments

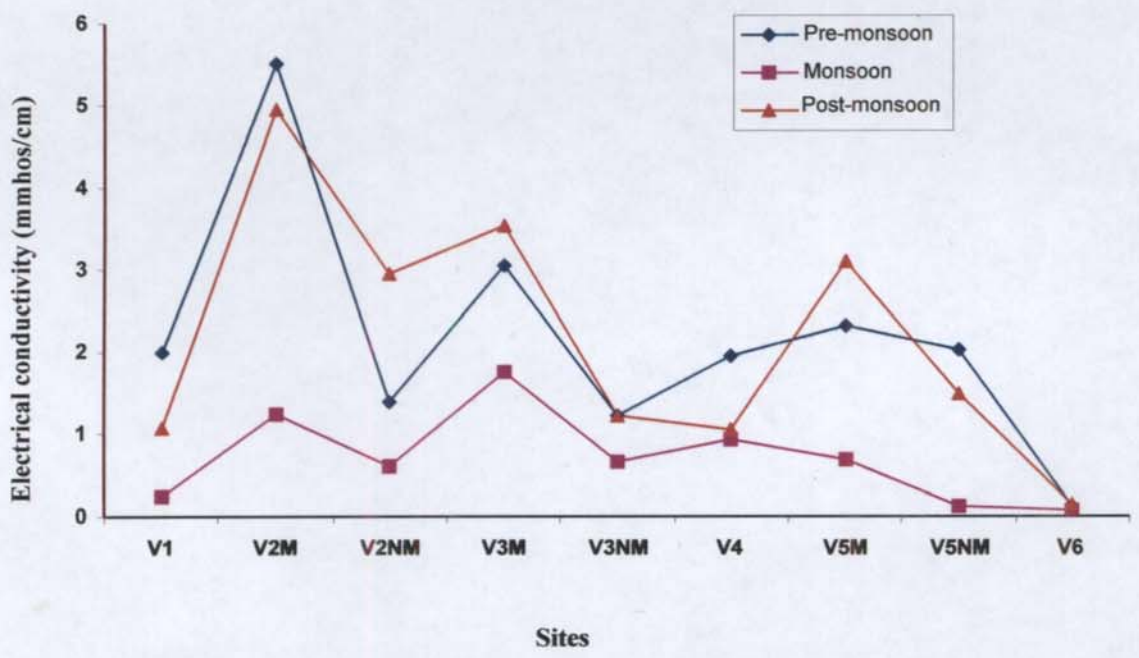


Fig. 4. 29 B Seasonal Variations in Electrical Conductivity of Valapattanam River Sediment

Distinct temporal and spatial variations were observed in electrical conductivity of both the river basins. Among the seasons studied, higher conductivity values were reported during pre & post – monsoon seasons. The monsoon season recorded the lowest EC values, which may be due to dilution by rainwater.

High EC was observed in the mangrove sites when compared to non-mangrove sites of both the river basins. Since the mangrove sediments of these two rivers were loamy in nature, the number of soluble salts adsorbed on to these particles may be high, contributing to high conductivity values in these sites. Moreover, the increase in conductivity in flooded soils may be due to the release of Fe^{2+} and Mn^{2+} from the insoluble Fe (III) and Mn (IV) oxide hydrates, the accumulation of NH_3 , HCO_3^- and R-COOH , and the dissolution of CaCO_3 by CO_2 and organic acids. An additional factor is the displacement of ions, especially cations from the soil colloids by exchange reactions (Aiyer & Rajendran, 1987). Even though high conductivity values were recorded for estuarine water, comparatively low conductivity values were registered for the estuarine sediments. Conductivity of the freshwater sediments was low, which recorded an increasing trend towards the downstream up to the mangrove sites. But further downstream, the estuarine sediments recorded lower EC values. This may be attributed to the sandy texture of the sediment, which retains only low salt content. Conversely, the silty/clayey sediments containing high organic matter and acidic pH, attains specific conductivity values exceeding 4 m mhos/cm (Aiyer & Rajendran, 1987). This is in agreement with the results of the present study, wherein a high EC was recorded in the mangrove sites compared to the non-mangrove sites. Another main reason, which can be attributed to, the high EC in the mangrove sites may be due to flooding with soluble, salt-rich estuarine water, which ultimately get adsorbed to the fine-grained sediments in this

site. The corresponding non-mangrove areas recorded lower values. From these observations, it can be concluded that the major contributors for increase in salt content in the mangrove sediments may be the estuarine water and the decaying mangrove litter along with the fine-grained texture of the soil. The high EC in the T3 site of Thalassery River was due to coconut husk retting activity supplemented with high organic matter contributed to high EC.

Statistical analysis revealed that in the Thalassery River, there are significant differences in EC and locations and EC and seasons at 5% level. EC was found to be significantly correlated with chloride, copper, exchangeable magnesium, organic carbon, salinity, sulphate and sodium at 1% level.

In the Valapattanam River, there are significant differences in EC and locations and EC and seasons at 5% level. EC was found to be significantly correlated with available phosphorus, copper, exchangeable magnesium, organic carbon, salinity, sulphate and sodium at 1% level.

Salinity

The seasonal and spatial distribution of salinity in the sediments of Thalassery and Valapattanam river basins are represented in Tables 4. 36 A & 4. 36 B.

Table 4. 36 A Seasonal Variations in Salinity of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	1.9	0.6	6.2	1.8	2.9	0.1
Monsoon	0.9	0.2	1.7	0.6	0.8	0.1
Post-monsoon	2.2	0.6	3.6	1.1	2.6	0.1

Table 4. 36 B Seasonal Variations in Salinity of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	0.5	3.4	1.1	2.8	1.1	0.9	0.1	3.1	1.7
Monsoon	0.3	1.2	0.2	0.9	0.3	0.3	0.1	0.5	0.2
Post- monsoon	0.3	2.5	0.3	1.1	0.7	0.5	0.1	2.1	1.9

In the Thalassery River, the salinity ranged from 0.1 – 6.2, 0.1 – 1.7 ppt and 0.1 – 3.6 ppt during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, the salinity varied from 0.1 – 3.4 ppt, 0.1 – 1.2 ppt and 0.1 – 2.5 ppt during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 30 A & 4. 30 B).

Sharp seasonal and spatial variations in salinity were recorded for sediments in the two river basins. The monsoon season recorded the lowest salinity, which may be attributed to dilution by the fresh water run-off. The pre-monsoon season recorded the highest salinity, followed by the post-monsoon season.

Spatial variations revealed higher salinity in mangrove sediments compared to the non-mangrove sediments, which may be attributed to the adsorption capacity of fine-grained sediments for sodium and chloride ions. The estuarine and freshwater sites where sandy substratum predominate, correspondingly lower salinity was recorded.

Statistical analysis revealed that in the Thalassery River, there are significant differences in salinity and locations and salinity and seasons at 5% level. Salinity was

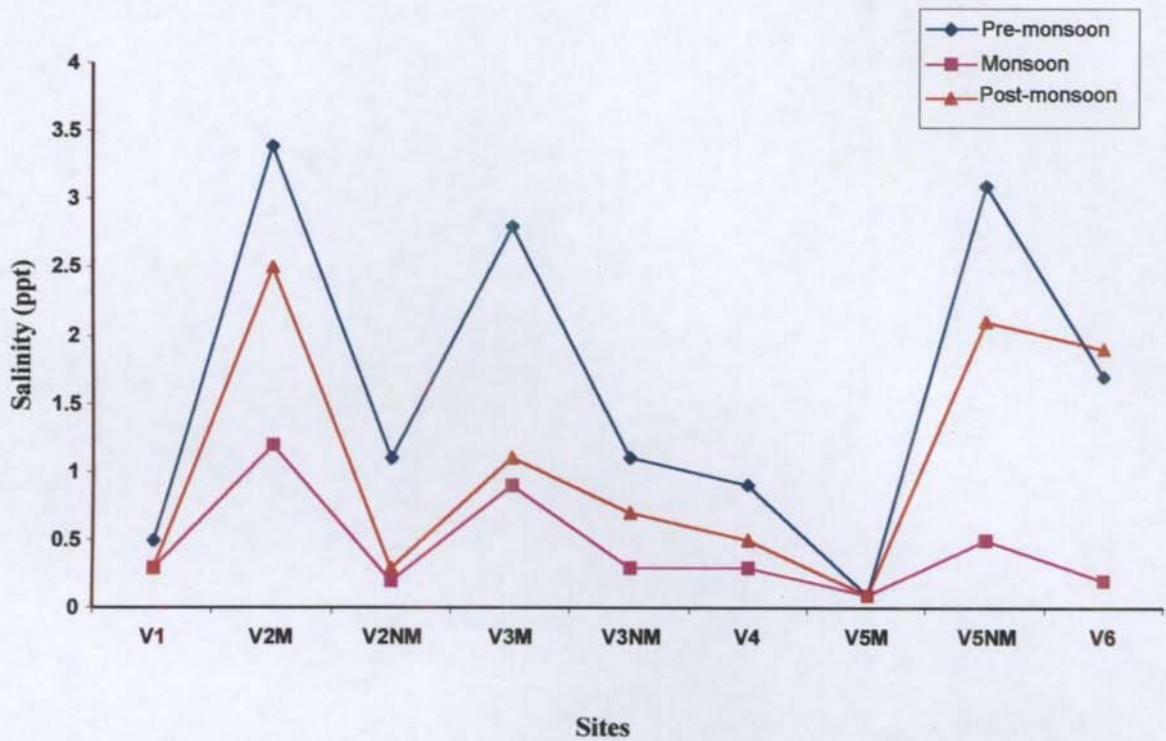


Fig. 4.30 A Seasonal Variations in Salinity of Thalassery River Sediments

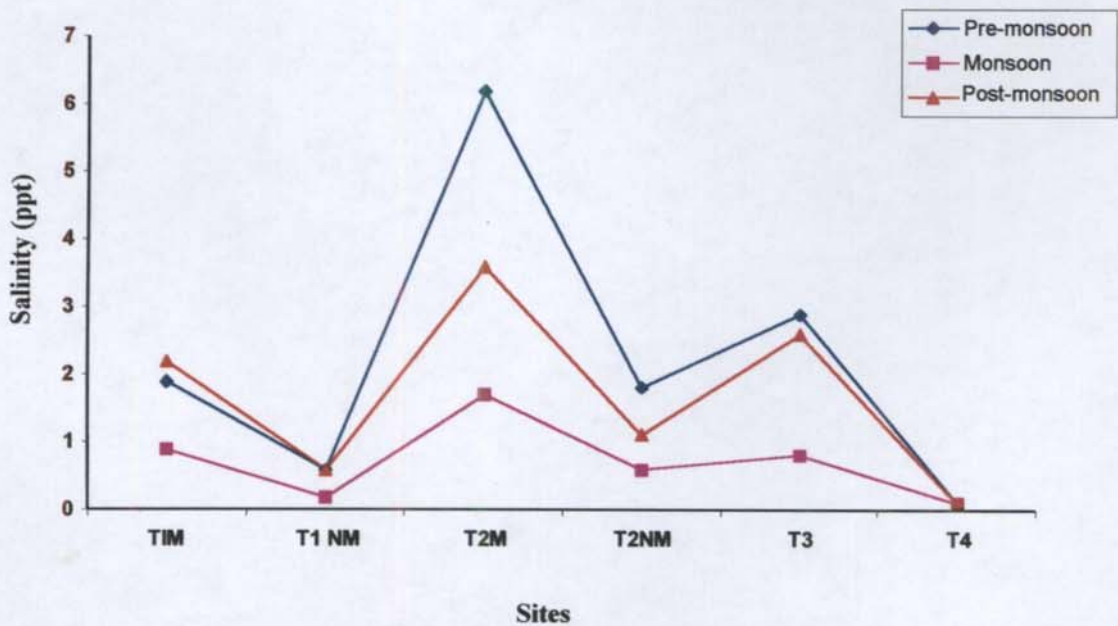


Fig. 4.30 B Seasonal Variations in Salinity of Valapattanam River Sediments

found to be significantly correlated with EC, exchangeable magnesium and exchangeable sodium at 1% level.

In the Valapattanam River, there are significant differences in salinity and locations and salinity and seasons at 5% level. Salinity was found to be significantly correlated with chloride and EC at 1% level.

Organic Carbon

The decay of plant material ultimately gives rise to humic substances, which are part of the organic matter in aquatic systems. In coastal waters, humic acid in water and sediments predominate (Shanmukhappa *et al.* 1987). Shanmukhappa *et al.* (1986) reported that *Avicennia*, *Bruguiera*, *Sonneratia* and *Rhizophora* are the most abundant and common species found on the east and west coast of India, which contribute significantly to the formation of humic acid.

The seasonal variations in organic carbon in the Thalassery and Valapattanam rivers are documented in Tables 4. 37 A & 4. 37 B respectively.

Organic carbon in the sediments ranged from 2.47- 0.43 % during pre-monsoon, 0.09 –2.91 % during monsoon and 0.29 – 2.37 % during post-monsoon seasons in the

Table 4. 37 A Seasonal Variations in Organic Carbon (%) of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.43	0.62	2.47	0.73	1.83	1.73
Monsoon	0.62	0.09	1.96	0.51	2.91	0.74
Post-monsoon	0.74	0.29	2.37	1.66	2.13	0.55

Thalassery River. While in the Valapattanam River, organic carbon values ranged from 0.72- 2.99 %, 0.08 – 3.2 % and 0.19 – 3.5 % during pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 31 A & 4. 31 B).

Table 4. 37 B Seasonal Variations in Organic Carbon (%) of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.81	2.9	2.1	2.2	0.88	0.72	2.3	2.01	0.83
Monsoon	0.08	3.2	1	2.99	1.4	1.3	2	1.1	0.72
Post-monsoon	0.19	3.5	2.4	2.5	0.5	0.9	3.1	2.4	1.9

No well-marked seasonal variations were noticed in the river basins studied. But, in downstream estuarine sites of both the rivers, a much higher *insitu* organic productivity in the relatively more saline waters during the pre-monsoon season and a considerable influx of organic matter from extraneous sources during that season are presumed to be instrumental in making the pre-flood sediments of tidal channels rich in organic matter than those of the post-flooded period, as has been reported by Dora and Borreswara Rao (1975). Relatively lower values in the sediments of two rivers during the monsoon season, except in some mangrove sites, may be attributed to high dilution, circulation and mixing process taking place in the estuarine systems. The monsoonal increase organic carbon suggests that bulk of the organic matter is derived from freshwater run off or through seepage from land.

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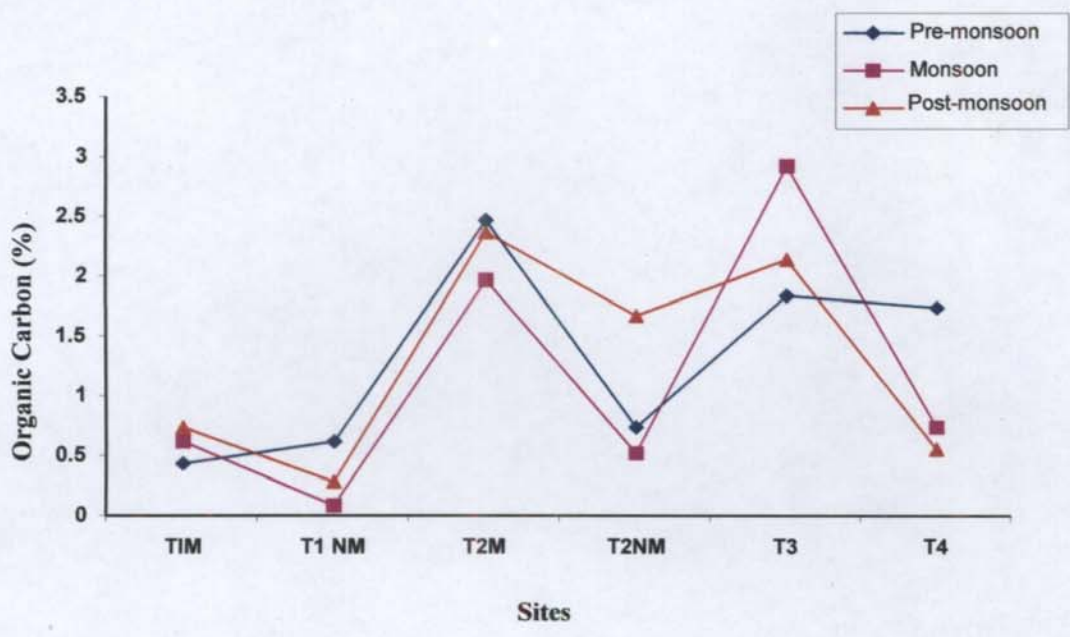


Fig. 4. 31 A Seasonal Variations in Organic carbon of Thalassery River sediments

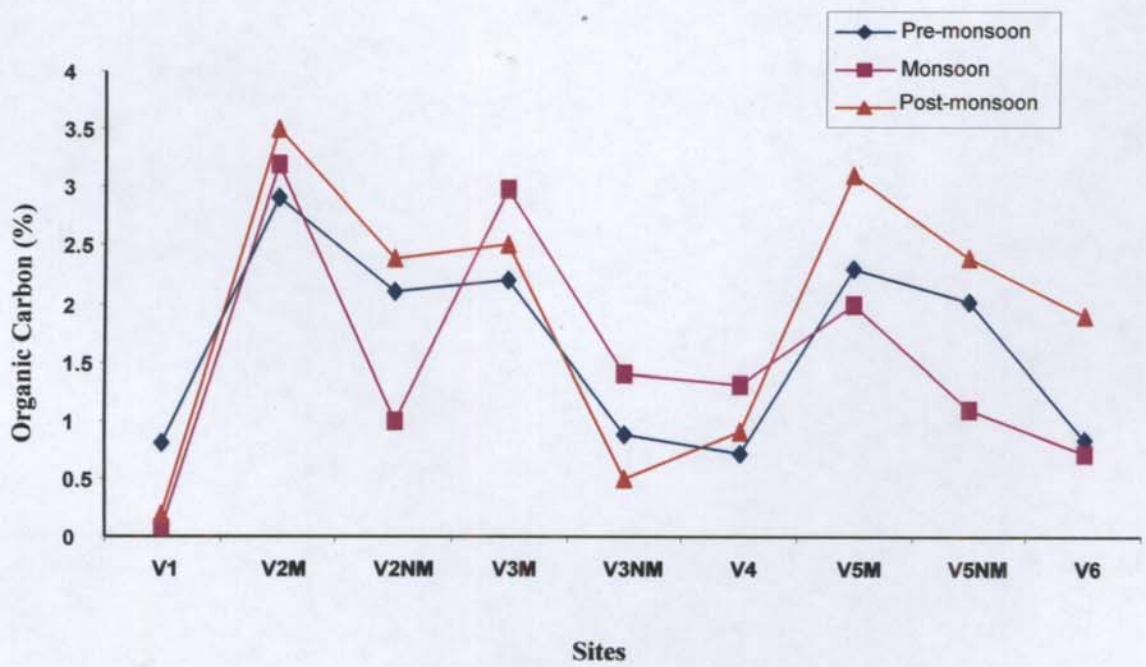


Fig. 4. 31 B Seasonal Variations in Organic carbon of Valapattanam River sediments

Organic carbon content in the sediments showed clear spatial variations. Among the various sites studied in both the river basins, the mangrove sites recorded higher values when compared to other sites. High organic carbon contents have been reported in the mangrove sediments (Dagar *et al.* 1991; Phani Bhushan & Amlesh Chaudury 1987; Shanmukhappa, 1987; Kotmire & Bhosale 1979). The high concentration of organic carbon in the mangrove sediments may be contributed by plant and animal debris. Increased organic carbon in the mangrove sediments may be attributed to microbial biodegradation of mangrove litter and also the contribution from run off from the catchments upstream. Poor circulation and mixing in the mangrove biotope may be another reason for high organic carbon contents in the two river basins studied, as has been reported earlier (Shanmukhappa, 1987).

The nature of sediments and its influence on organic matter has been well understood (Shanmukhappa, 1987). An increase in organic matter with decrease in grain size of the sediments have been reported by Dora & Borreswara Rao (1975). Since the mangrove sites have generally high clay and lower sand content (Shanmukhappa, 1987), besides abundant plant and animal populations, a high percentage of organic matter was noticed. Hence, the incidence of high organic matter compared to other biotopes is imperative. Further, organic carbon contents exhibited an increasing trend from the estuaries to mangrove sites, which can be attributed to the fine texture of sediments, as has been reported earlier (Satyanarayanan *et al.* 1993). The progressive decrease in organic matter in the downstream points in the two river basins may presumably be due to greater turbulence and aeration of waters and hence, faster decomposition of organic matter near the confluence of the river as has been reported earlier (Dora & Borreswara Rao, 1975). The sandy nature of the bottom sediments in this region can also be

considered another factor for the relative decrease in organic carbon of the sediments. Suresh Kumar and Mohan Kumar (1997) reported silty clay texture in the mangroves. The main reason for such a close correlation between organic content and texture of sediment may be attributed to the similar settling velocities of organic matter and fine mineral particles. The above correlation may also depend on the possibility that in place where fine deposits are laid down, the environment is comparatively less turbulent and as well as less aerated and hence is relatively more favorable for the deposition and preservation of organic matter (Dora & Borreswara Rao, 1975). The carbon values increased when the percentage of sand was very low (Prabhadevi *et al.* 1996; Muraleedharan Nair, (1994). Rajamanickam & Setty (1973); Badarudheen *et al.* (1997) had expressed the possibility of greater accumulation of organic carbon in the case of clayey sediments, which offer larger surface area for the adsorption of organic matter. Organic carbon in Veli mangroves varied between 0.32 – 5.64% (Badarudheen *et al.* 1997). Organic carbon in the Kali estuarine sediments varied from 2.05 – 3.15 % (Neelakantan *et al.* 1987) where substratum was found to be sandy but mixed with a considerable portion of silts and clay. In the present study, a direct relation could be drawn between the organic carbon content and the texture of the sediments, the organic carbon content was more at stations where the fine fractions dominate as has been reported earlier.

The higher organic carbon at V2NM, V4 and V5NM sites may also be attributed to the slaughter waste deposition, which ultimately on its decomposition forms organic carbon, which get adsorbed onto the sediment. The T3 and V2M recorded higher organic content, which may be attributed to the coconut husk retting practiced in this area. The retting of coconut husk is one of the principal sources of organic pollution in the estuaries

and backwaters of Kerala. The accumulation of organic compounds like pectin, phenol, tannin and lignin in water due to microbial activity contributes to the high percentage of organic carbon (Remani *et al.* 1989; Bijoy Nandan & Abdul Aziz, 1996. The anoxic condition prevailing at the retting area together with the high proportion of fine-grained sediments is the reason for the enrichment of organic carbon (Remani *et al.* 1981). The increase in organic carbon in the T4 site of Thalassery River may be attributed to the influx of land run off containing considerable amounts of terrigenous organic matter. A similar contribution of organic matter from land was reported in Cochin backwaters (Sankaranarayanan & Pananpunnayil, 1979).

Statistical analysis revealed that in the Thalassery River, there are significant differences in organic carbon and locations at 5% level. Organic carbon was found to be significantly correlated with clay, manganese, potassium and silt at 1% level.

In the Valapattanam River, there are significant differences in organic carbon and locations at 5% level. Organic carbon was found to be significantly correlated with chloride, clay, copper, EC, exchangeable magnesium, iron, moisture content, sulphate and sodium at 1% level.

Chloride

The seasonal and spatial distribution of chloride in the sediments of the two river basins are presented in Tables 4. 38 A & 4. 38 B respectively.

Table 4. 38 A Seasonal Variations in Chloride of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	909	623	1086	714	808	13
Monsoon	180	173	215	121	120	8.2
Post-monsoon	1254	708	1994	1119	1198	17.5

Table 4. 38 B Seasonal Variations in Chloride of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	446	1369	603	896	378	505	679	425	62.2
Monsoon	62.8	119.7	33.4	49.8	49.5	43.2	18.9	14.6	8.73
Post- monsoon	221	1093	486	606	215	200	575	595	20.6

The chloride concentration in the Thalassery River, ranged from 13 –1086 mg/100g, 8.2 – 180 mg/100g and 17.5 - 1198 mg/100g during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, chloride concentration varied from 62.2 - 1369 mg/100g, 8.73 – 120.0 mg/100g and 20.6 – 1,093 mg/100g during the pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 32 A & 4. 32 B).

Among the various seasons studied, the pre-monsoon season recorded the highest concentration of chloride followed by the post-monsoon in Valapattanam River, while in the Thalassery River, higher concentration was observed during the post-monsoon season. In both the river sediments, the monsoon season recorded least concentration of chloride content. Lower chloride concentration during the monsoon season may be attributed to the heavy fresh water discharge, leading to high dilution of chloride content.

Spatial variations in the sediment chloride content showed a higher concentration at the mangrove sites when compared to the non-mangrove sites. The fresh water sites recorded the lowest concentration in both the river basins. Even though the estuarine water contained high chloride content, the estuarine sediments recorded comparatively

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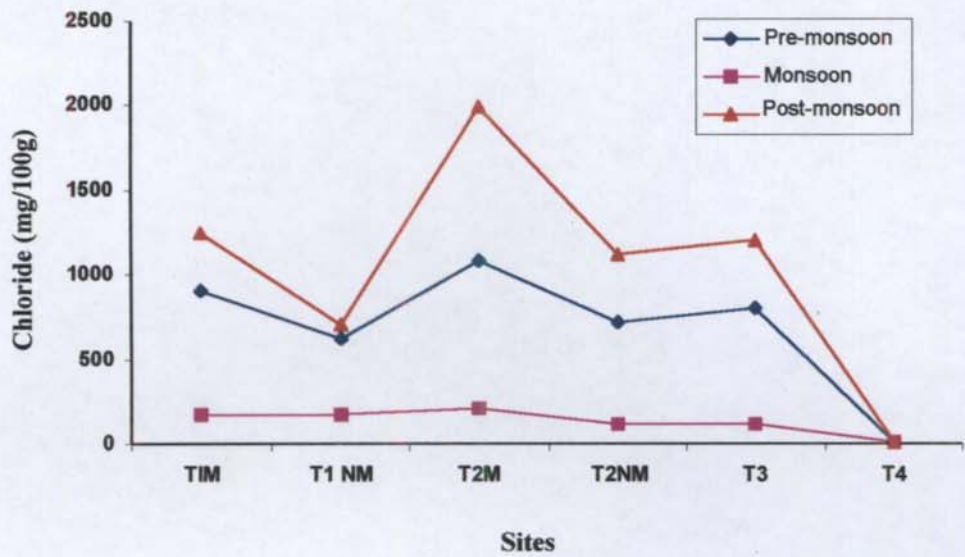


Fig. 4. 32 A Seasonal Variations in Chloride of Thalassery River Sediments

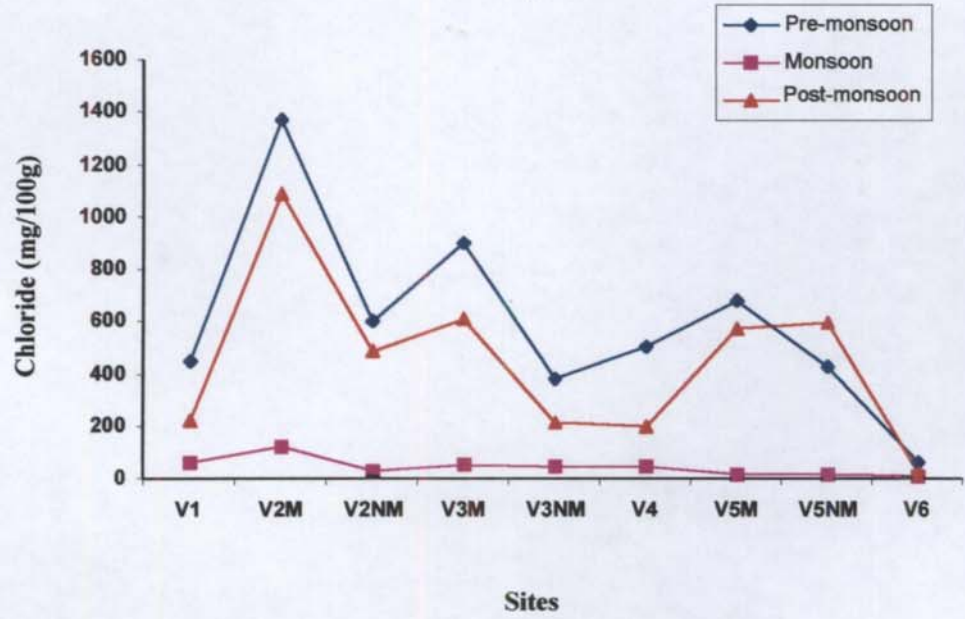


Fig. 4. 32 B Seasonal Variations in Chloride of Valapattanam River Sediments

lower concentration. The sediment texture showed a sharp positive correlation with chloride concentration. The fine sediments in the mangrove sites recorded a higher concentration in both the river basins. The lower concentration in the estuarine and fresh water sites may be attributed to the sandy texture of the sediments. Another important source of chloride in the mangrove sediments may be due to the decomposition of the mangrove litter. This is because certain species such as *Rhizophora*, *Avicennia*, and *Acanthus* etc., are efficient salt accumulators and accumulates salts in the salt glands of the leaves. The fallen leaves contribute to high soil salinity during its decomposition, especially during the pre-monsoon and the post-monsoon seasons, when the circulation and mixing of water is less. Even though, the litter is removed from the ground by the flowing water and receding tide, still a higher concentration of chloride was observed in the mangrove sites, which may be due to the efficient adsorption of these ions to the fine grained sediments. Hence, it can be concluded that the high chloride content in the mangrove soils may be attributed to the combined effect of the soil texture and the contribution from the mangrove leaves.

The sediment chloride content decreased towards the upstream, as evidenced by the lower concentration in the fresh water sites in both the river basins. Maximum chloride content was recorded at the V2 and T2 mangrove sites, with is in close proximity to the estuary.

Statistical analysis revealed that in the Thalassery River, chloride was found to be significantly correlated with EC and sulphate at 1% level.

In the Valapattanam River, there are significant differences in chloride and locations and chloride and seasons at 5% level. Chloride was found to be significantly

correlated with available phosphorus, EC, exchangeable magnesium, organic carbon, salinity and sodium at 1% level.

Sulphate

Sulphate is a major plant nutrient and is a constituent of sulphur containing amino acids like methionine. In the soil under normal aerobic conditions, inorganic sulphur occurs as sulphate, which can easily be taken up by plants. Vegetable or animal material containing organic sulphur compounds decompose to give sulphate-sulphur, which is then taken up by plants and converted into organic forms.

The seasonal distribution of sulphate in Thalassery and Valapattanam river basins are presented in Tables 4. 39 A & 4. 39 B respectively.

Table 4. 39 A Seasonal Variations in Sulphate of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	194	143	240	180	539	9.8
Monsoon	64.5	86.7	382	61	377	11.8
Post-monsoon	340	305	345	318	356	12.6

Table 4. 39 B Seasonal Variations in Sulphate of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	61.5	445	85.5	255	131	151	238	198	28.3
Monsoon	25.4	258	203	1020	110	245	312	5.4	11
Post-monsoon	12.6	366	45	378	64.5	87.5	449	105	44.6

In the Thalassery River, the sulphate concentration ranged from 9.8 - 539 mg/100g in pre-monsoon, 11.8 - 382 mg/100g the monsoon and 12.6 - 356 mg/100g during the post-monsoon seasons. In the Valapattanam river sediments basin varies from 28.3 - 445 mg/100g during the pre-monsoon, 11 - 1,020 mg/100g during monsoon and 12.6 - 449 mg/100g during the post-monsoon season (Figures 4. 33 A & 4. 33 B).

In the present study, temporal variations in sulphate concentration were not clearly noticed. Even though among the seasons studied, there was maximum concentration of sulphate during the post-monsoon season in the mangrove sites in both the river basins.

Among the various sites studied in both the river basins, higher sulphate concentration was recorded in the mangrove sites rather than the non-mangrove sites. The higher concentration of sulphate in the mangrove sites may be attributed to continuous and periodic inundation of the mangrove mud with seawater, having high sulphate content, as well as continuous microbial decomposition and mineralization of organic matter may account for the high amounts of organic and available sulphate in the sediments. Moreover, the fine-grained sediments adsorb more sulphate than the sandy sediment. Organic matter also contributes to sulphate, as sulphur is predominantly a constituent of organic matter, as has been reported earlier (Kamprath *et al.* 1976).

Highest concentration of sulphates reported in the V2 M & T3 sites may be attributed to the coconut husk retting activity in these sites (Remani *et al.* 1981). The lowest sulphate concentration was reported in the fresh water and estuarine sites in both the river basins, which may be attributed to the sandy texture of the sediment in these sites.

Statistical analysis revealed that in the Thalassery River, there are significant differences in sulphate and locations at 5% level. Sulphate was found to be significantly

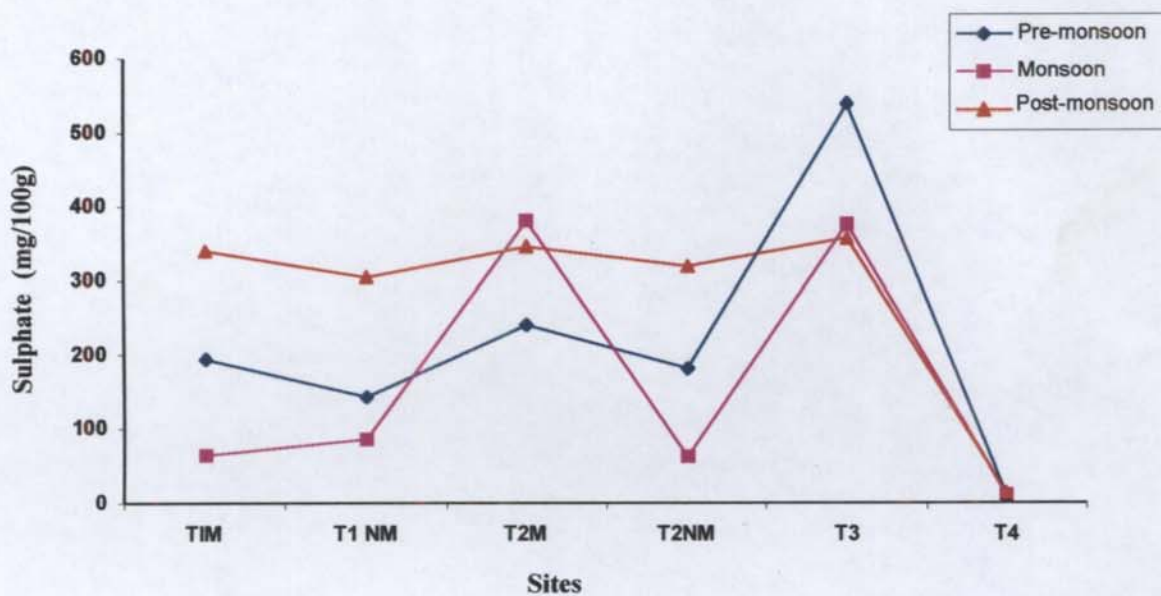


Fig. 4.33 A Seasonal Variations in Sulphate of Thalassery River Sediments

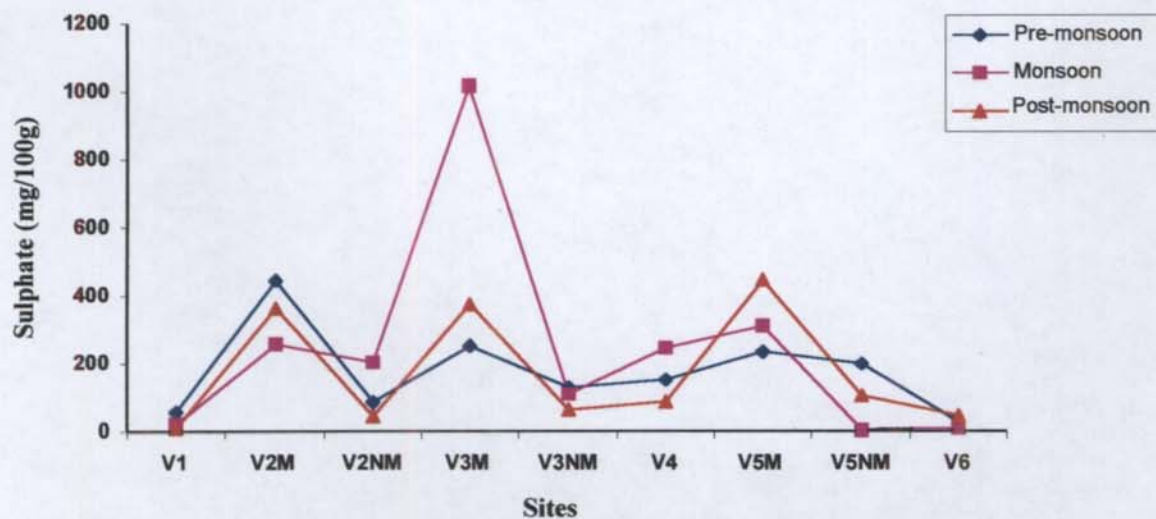


Fig. 4.33 B Seasonal Variations in Sulphate of Valapattanam River Sediments

correlated with chloride and EC at 1% level.

In the Valapattanam River, there are significant differences in sulphate and locations at 5% level. Sulphate was found to be significantly correlated with clay, iron, moisture content and organic carbon at 1% level.

Available Phosphorus

This is an essential nutrient for plant growth, though the phosphorus content in plants is low. At the soil pH, $\text{H}_2\text{PO}_4^{4-}$ and HPO_4^{2-} are the phosphate species utilized by plants (De, 1993).

The seasonal variations in available phosphorus in Thalassery and Valapattanam river sediments are presented in Tables 4. 40 A & 4. 40 B respectively.

Available phosphorus content in the Thalassery River sediments varied from 8 – 16.9 mg/100g, 1.7 – 8.4 mg/100g and 3-9 mg/100g during pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam river, the phosphorous values ranged from 7.2 – 12.9 mg/100g, 0.52 – 4.03 mg/100g and 10.5 – 19.2 mg/100g during pre-monsoon, monsoon and post-monsoon seasons respectively (Figures 4. 34 A & 4. 34 B).

In general, pre/post monsoon seasons recorded higher phosphorus concentration compared to monsoon season, which may be attributed to the deposition of phosphorus from the overlying water due to low turbulence. Peak values reported during summer season were discernable with a fall in the monsoon season as has been reported earlier by Vareethiah (2001). In the Valapattanam River, highest concentration of phosphorous was recorded during the post-monsoon season. Higher phosphate values were observed during the post-monsoon season in mangrove sediments (Venketaswamy Reddy & Hariharan, 1986; Kotmire & Bhosale, 1979). But, in the Thalassery River, higher concentration of

**Table 4. 40 A Seasonal Variations in Available Phosphorus of Thalassery River
Sediments**

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	14.4	8	11	16.9	10	9.9
Monsoon	8.4	5.6	1.7	6.5	2.3	2.5
Post-monsoon	8.5	9	8.1	5.9	3	6.2

**Table 4. 40 B Seasonal Variations in Available Phosphorus of Valapattanam River
Sediments**

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	11.5	9.6	12.9	9	9.5	7.7	9.2	10.3	7.2
Monsoon	4.03	3.7	3.5	1.5	1.2	1.7	0.52	0.9	1.1
Post-monsoon	15.3	18.1	19.2	12.1	11.4	10.5	12.4	17	10.9

phosphorous was reported during the pre-monsoon season. Higher percentage of silt and clay during the pre-monsoon with higher concentration of total phosphorus may be attributed to the retention of autochthonous phosphorus by fine-grained sediments (Mortimer, 1941,1942; Jitts, 1959; Miller, 1952 & Rittenberg *et al.* 1955).

In monsoon season, low values of phosphorus was reported which is due to the leaching of phosphorus to the overlying water because of fresh water influx and severe agitation due to wave action leading to resuspension of sediments in the water column.

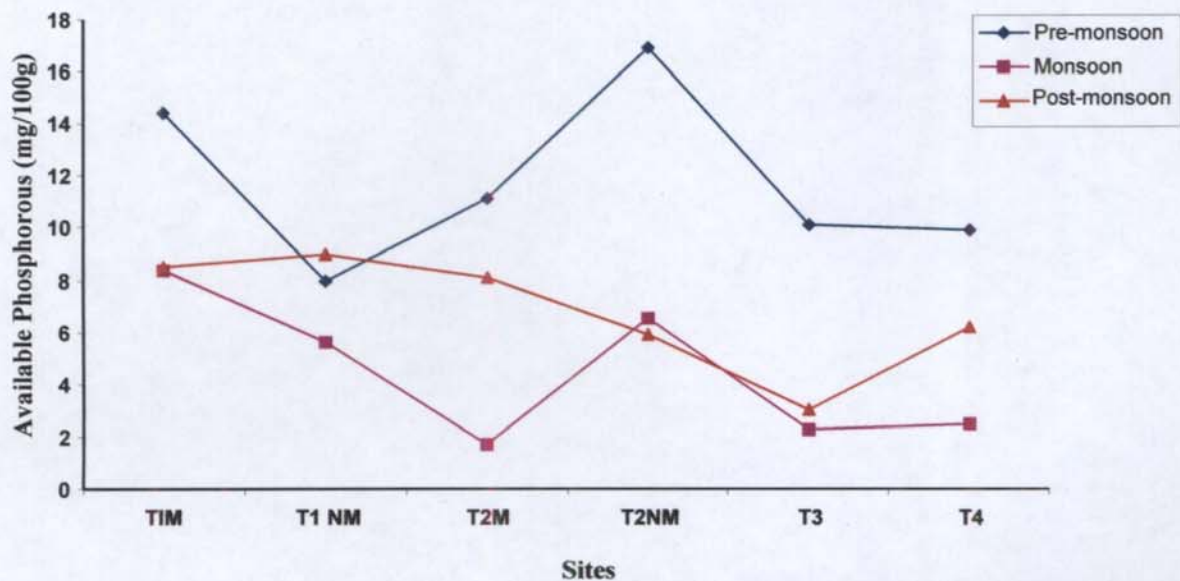


Fig. 4. 34 A Seasonal Variations in Available Phosphorous of Thalassery River Sediments

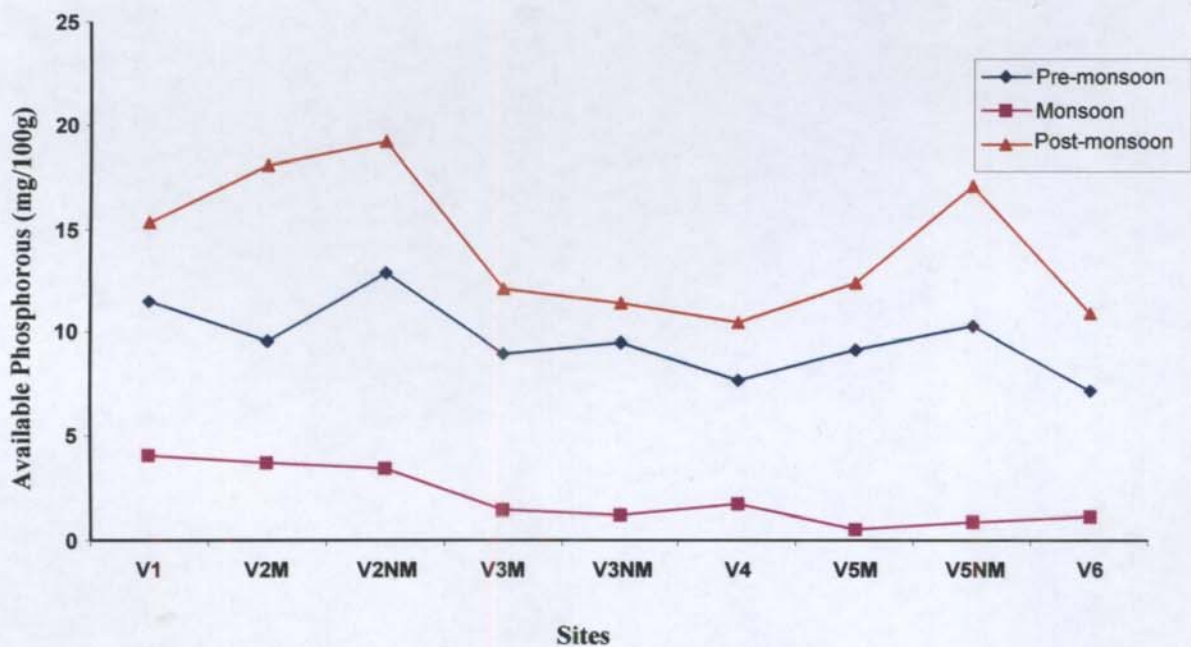


Fig. 4. 34 B Seasonal Variations in Available Phosphorous of Valapattanam River Sediments

Similar trends have been reported earlier in Vellar estuary, Vishakhapattanam shelf, and Cochin backwaters (Sivakumar *et al.* 1983; Satyanarayanan *et al.* 1993; Sankaranarayanan & Panampunnayil, 1979).

Spatial variations revealed that a high concentration of available phosphorus was reported in estuary in the two river basins. The mangrove sites at the downstream areas also recorded higher values for available phosphorous. The phosphorus content in estuaries is due to seawater intrusion, as the concentration of phosphorus in seawater is usually higher than freshwater. Earlier studies revealed that sediments in estuaries trap 80 – 90% of phosphorous and release the same to overlying waters (Mortimer, 1941,1942; Jitts, 1959; Miller, 1952 & Rittenberg *et al.* 1955). The mangrove sites in general recorded lower concentration. This decrease may be due to the high uptake by phytoplankton.

The higher concentration of available phosphorus in the riverine sediments may be due to the deposition of the alluvium brought down by land drainage into the river system as has been observed in both the river basins studied, which is in agreement with the results of Balakrishnan & Abdul Aziz (1987).

Statistical analysis revealed that in the Thalassery River, there are significant differences in available phosphorus and seasons at 5% level.

In the Valapattanam River, there are significant differences in available phosphorus and locations and available phosphorus and seasons at 5% level. Available phosphorus was found to be significantly correlated with chloride, EC, exchangeable magnesium, nitrate and sodium at 1% level.

Nitrate

The seasonal variation of nitrate-nitrogen in the sediments of Thalassery and Valapattanam rivers is given in Tables 4. 41 A & 4. 41 B respectively.

Table 4. 41 A Seasonal Variations in Nitrate - Nitrogen of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	0.59	0.62	0.69	0.26	0.45	0.37
Monsoon	0.09	0.23	0.09	0.09	0.12	0.18
Post-monsoon	1.1	0.6	0.98	0.77	1.34	0.94

Table 4. 41 B Seasonal Variations in Nitrate - Nitrogen of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.64	0.39	0.19	0.52	0.36	0.40	0.25	0.67	0.46
Monsoon	0.33	0.41	0.24	0.63	0.32	0.43	0.15	0.27	0.21
Post-monsoon	0.62	0.62	0.96	1.53	1.01	0.97	3.03	2.3	2.3

In the Thalassery River, nitrate-nitrogen ranged from 0.26 – 0.69 mg/ 100g during the pre-monsoon, 0.09 – 0.23 mg/ 100g during monsoon and 0.6 – 1.34 mg/ 100g during the post-monsoon seasons respectively. The nitrate-nitrogen values ranged from 0.19 – 0.67 mg/ 100g during pre-monsoon, 0.15 – 0.63 mg/ 100g during monsoon and 0.62 – 3.03 mg/ 100g during the post-monsoon seasons respectively in the Valapattanam River (Figures 4. 35 A & 4. 35 B).

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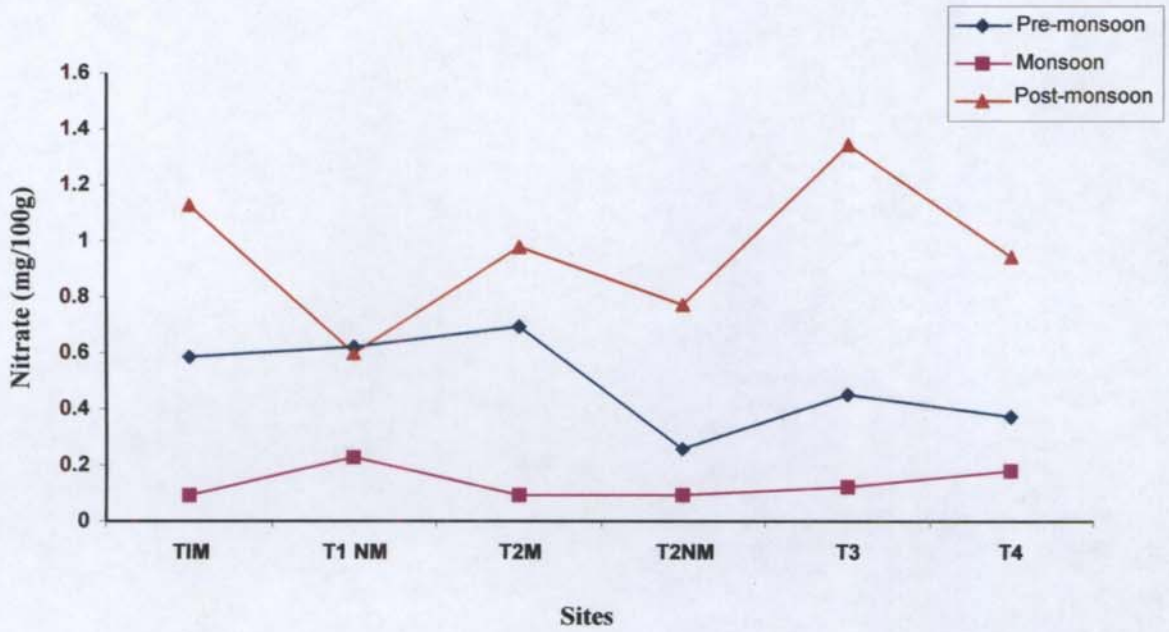


Fig. 4. 35 A Seasonal Variations in Nitrate of Thalassery River Sediments

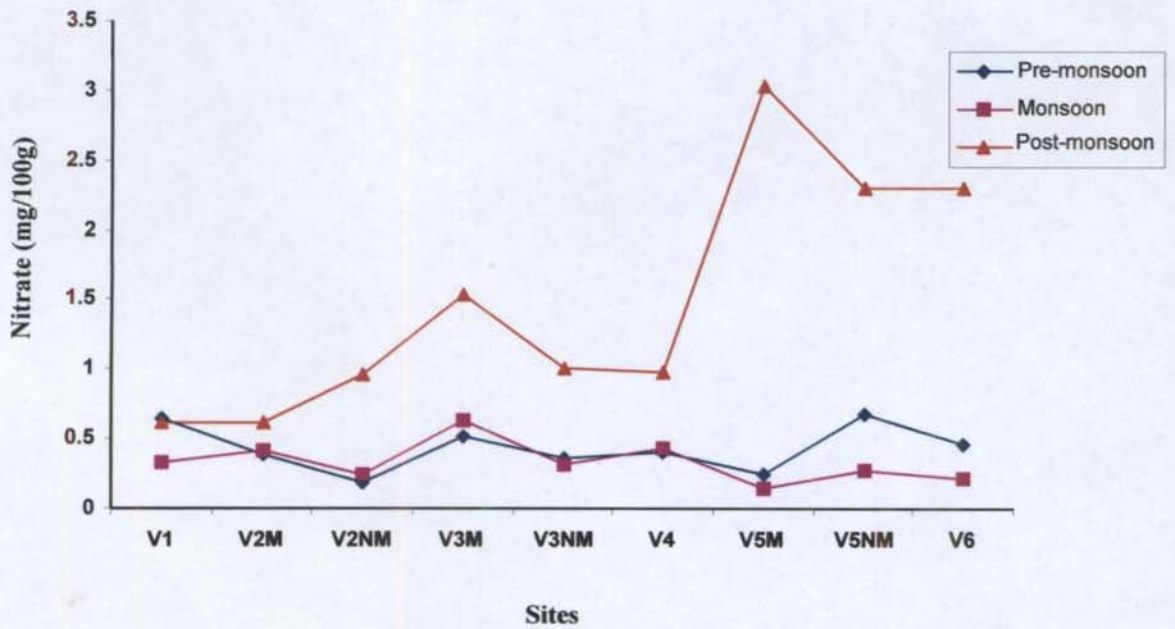


Fig. 4. 35 B Seasonal Variations in Nitrate of Valapattanam River Sediments

Temporal variation in nitrate-nitrogen concentration was noticed in both Thalassery and Valapattanam river basins. Higher concentration was documented in post-monsoon and minimum during monsoon seasons in both the rivers, with minor exceptions in some sites of the Valapattanam River. The release of nitrogen from the sediments is controlled to a large extent by biological processes. The minimum concentration of during the monsoon season may also be attributed to the radical alteration in sediment textural characteristics brought about by river discharge and tidal currents.

There was no pronounced spatial variation noticed in the two river basins studied. Though the total nitrogen content has been studied in many estuaries (Neelakatan *et al.* 1987), the distribution of nitrate-nitrogen in the sediments of the estuary and mangrove areas has not been studied so far in detail.

In general, the mangrove sediments recorded higher concentration of $\text{NO}_3\text{-N}$ compared to corresponding non-mangrove sediments of both Thalassery and Valapattanam river basins. The excreta of the mangrove fauna is a rich source of nitrate, contributing to surface layers of the sediment. The nitrogen fixing bacteria *viz.*, *Azotobactor* sp. have been isolated from the sediments of mangroves and their counts were high in mangrove habitat than in marine backwaters and estuarine systems (Lakshmanaperumalsamy, 1987). Halotolerant nitrogen fixing *Rhizobium* strains have been isolated from the root nodules of *Derris scandens* and *Sesbania* sp. growing along the mangrove swamps of the Subnderbans (Sengupta & Choudary, 1990). These bacteria in the mangrove sediments may convert nitrogen into nitrates, which get trapped in the fine sediments. The decay of plant and animal material ultimately produce humic substances, which are a part of organic matter in aquatic systems. Higher nitrate-nitrogen

content in the mangrove sites may be due to high concentration of humic acids in the sediments, which is known to have high C/N ratio (Phani Bushan Gosh & Amalesh Chaudhury, 1987). In the present study higher nitrate-nitrogen in the mangrove sites may be contributed by the above mentioned factors.

In the Thalassery River, high nitrate-nitrogen was observed in the T3 site, which may be attributed to the coconut husk retting activity practiced in this area. The same may be applicable to the increase in nitrate-nitrogen in the Valapattanam River site (V2M). The freshwater sediments of both the river basins recorded higher concentration of nitrate-nitrogen, which may be attributed to the practice of defecation by the local people in that area, and also the leaching of nutrients from the fertilizers applied to agricultural fields within the catchment.

Nitrate-nitrogen showed no significant correlation with respect to the particle size as in the case of organic carbon. According to De Sousa *et al.* (1981), nitrates are not well retained in the soil if not utilized quickly by plants, and are lost through drainage. High nitrate and nitrite values are indicative of organic pollution.

The fluctuations in nitrate-nitrogen content of sediments could also be due to a significant factor, which controls the nitrate concentration in sediments in addition to the usual channel of utilization of nitrates by phytoplankton. This may also be due to the fluctuations in the number and activity of the denitrifiers, which is in conformity with the observations of Jayaraman, (1954); Balakrishnan Nair *et al.* (1987). Compared to earlier studies, the nitrate-nitrogen concentration in the sediments of Thalassery and Valapattanam river basins were very low. Statistical analysis revealed that in the Thalassery River, there are significant differences in nitrate and seasons at 5% level. Nitrate was found to be significantly correlated with copper at 1% level.

In the Valapattanam River, there are significant differences in nitrate and seasons at 5% level. Nitrate was found to be significantly correlated with available phosphorus at 1% level.

Exchangeable Sodium

Sodium is the dominant cation in water as well as soil through which seawater percolates. Such soils are usually characterized by a high percentage of exchangeable sodium, which affect the availability of water to plants (Karmarkar, 1985).

Seasonal variations in exchangeable sodium in Thalassery and Valapattanam river basins are represented in Tables 4. 42 A & 4. 42 B respectively.

In the Thalassery River, exchangeable sodium content ranged from 0.63 – 25.4 mg/100g, 0.63 – 6.7 mg/100g and 0.56 - 33 mg/100g in the pre-monsoon, monsoon and post-monsoon seasons respectively. In Valapattanam River, exchangeable sodium ranged from 1.8 – 14.2 mg/100g in pre-monsoon, 0.27 – 2.05 mg/100g in monsoon and 1.13 – 22 mg/100g in post-monsoon season (Figures 4. 36 A & 4. 36 B).

Table 4. 42 A Seasonal Variations in Exchangeable Sodium of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	8.3	3.3	25.4	10.7	12.9	0.63
Monsoon	3.7	1.4	6.7	2.3	1.7	0.63
Post-monsoon	7.9	6.5	33	8.7	18	0.56

Seasonal variations revealed that higher concentration of exchangeable sodium was observed during the pre/post-monsoon seasons in both the river basins, except at the mangrove sites. The lowest concentration was observed during the monsoon season. The

Table 4. 42 B Seasonal Variations in Exchangeable Sodium of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	5.2	13.3	12	12	10	5	14.2	9	1.8
Monsoon	0.73	4	1.02	2.05	1.17	1.24	0.27	0.38	1.1
Post- monsoon	3.12	22	8.5	15	4.15	9	17.7	13.3	1.13

lower concentration observed during the monsoon season may be attributed to dilution by the rainwater.

Spatial variations in exchangeable sodium were observed in both the river basins studied. Like chlorides, exchangeable sodium also showed a similar trend, being higher in the mangrove sediments. The higher concentration of sodium in mangrove sediments may be attributed to the cation exchange capacity of the sediments or adsorption of sodium on to the fine-grained sediments, as has been reported earlier (Badarudheen & Sakkir, 1998). The primary source of sodium in the mangrove environment may be the weathered product of plagioclase feldspar (Badarudheen & Sakkir, 1998). Seawater also contributes to high sodium contents in the mangrove areas. The unprecipitated sodium may be present in aqueous solution, filling the pore spaces of sediment particles. The mangrove litter or plant part, which accumulates salts in the salt glands, also contributes sodium to sediments on their decay and disintegration due to microbial action.

A low adsorption of sodium was found in the sandy sediments as evidenced by the low concentration in the estuary and fresh water sites.

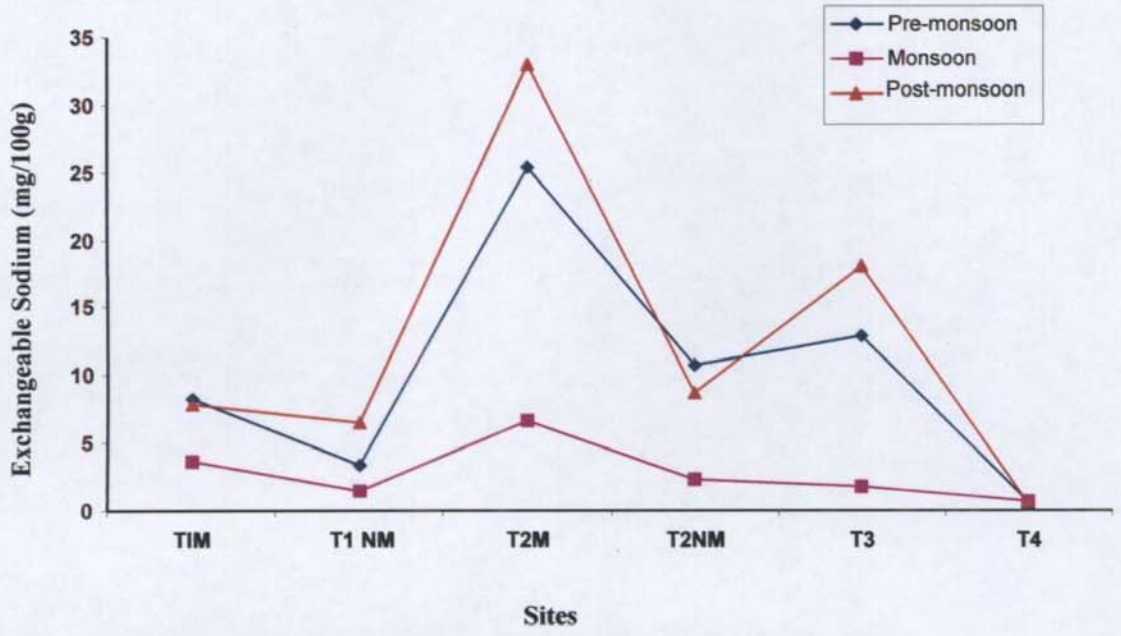


Fig. 4. 36 A Seasonal Variations in Exchangeable Sodium of Thalassery River Sediments

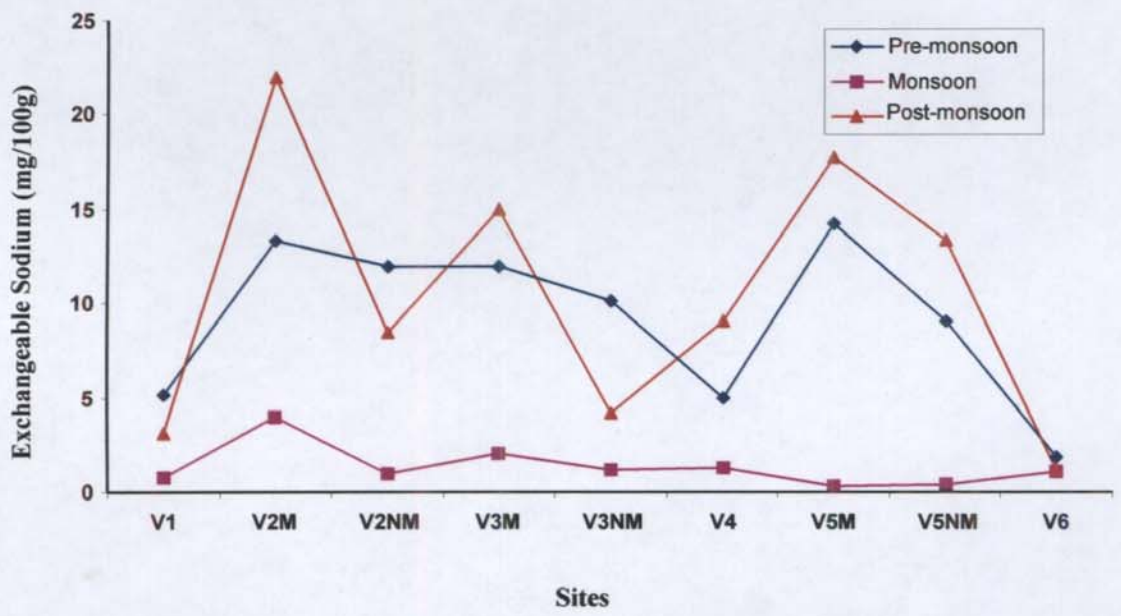


Fig. 4. 36 B Seasonal Variations in Exchangeable Sodium of Valapattanam River Sediments

Kotmire & Bhosale (1979) reported that sodium content were more in less acidic soil. But a reverse situation was observed in the present study, where sodium content was found to be higher under acidic conditions in the T3 site of Thalassery River. This may be because of the fast decomposition of the mangrove litter in the sites by the microbes releasing the element into the environment.

Statistical analysis revealed that in the Thalassery River, there are significant differences in exchangeable sodium and seasons and exchangeable sodium and locations at 5% level. Exchangeable sodium was found to be significantly correlated with copper, EC, exchangeable magnesium and salinity at 1% level.

In the Valapattanam River, there are significant differences in exchangeable sodium and seasons and exchangeable sodium and locations at 5% level. Exchangeable sodium was found to be significantly correlated with available phosphorus, chloride, EC, exchangeable magnesium and organic carbon at 1% level.

Exchangeable Potassium

The source of potassium may be from weathering of rocks rich in orthoclase, microcline and biolite (Badarudheen & Sakkir, 1998). The decomposition of vegetative parts of mangroves may also contribute significant amount of potassium to the sediments.

Seasonal variations in exchangeable potassium in the Thalassery and Valapattanam river basins are presented in Tables 4. 43 A & 4. 43 B respectively.

In the Thalassery River, exchangeable potassium contents ranged from 0.86 – 9.6 mg/100g, 0.68 – 11.2 mg/100g and 0.21 – 6.3 mg/100g in the pre-monsoon, monsoon and post-monsoon seasons respectively. In Valapattanam River, sodium contents ranged from 0.32 – 4.5 mg/100g in pre-monsoon, 0.05 – 11.3 mg/100g in monsoon and 0.39 – 3.22 mg/100g in post-monsoon season (Figures 4. 37 A & 4. 37B).

Table 4. 43 A Seasonal Variations in Exchangeable Potassium of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	2.15	0.97	9.6	2.6	2.7	0.86
Monsoon	1.3	2.9	4.1	0.71	11.2	0.68
Post-monsoon	1.7	2.1	6.3	2.5	2.9	0.21

Table 4. 43 B Seasonal Variations in Exchangeable Potassium of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	0.45	4.5	2.1	3.1	1.6	3.0	1.8	1.9	0.32
Monsoon	0.95	11.3	0.35	0.05	0.47	1.63	0.12	0.19	0.64
Post-monsoon	0.39	3.04	3.22	2.2	0.88	3.14	3	1.86	0.47

The temporal variation observed in sodium contents was not so sharp. In general, increase in potassium concentration was recorded during the summer seasons than the monsoon season.

According to Kotmire & Bhosale (1979), among the inorganic constituents of leaves, potassium forms the major constituent in the leaves of mangrove plants, followed by sodium. Hence, the decay of the leaves liberates potassium, contributing to high values of potassium in the sediments. In the present study, like sodium, potassium also showed similar trend, being higher in mangrove sites than the non-mangrove sites in both

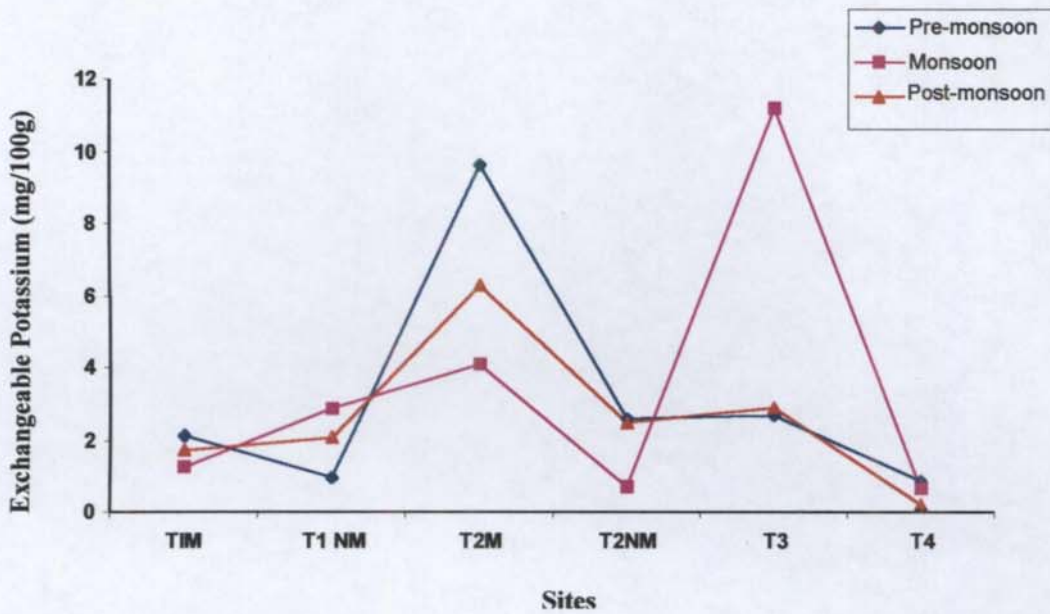


Fig. 4. 37 A Seasonal Variations in Exchangeable Potassium of Thalassery River Sediments

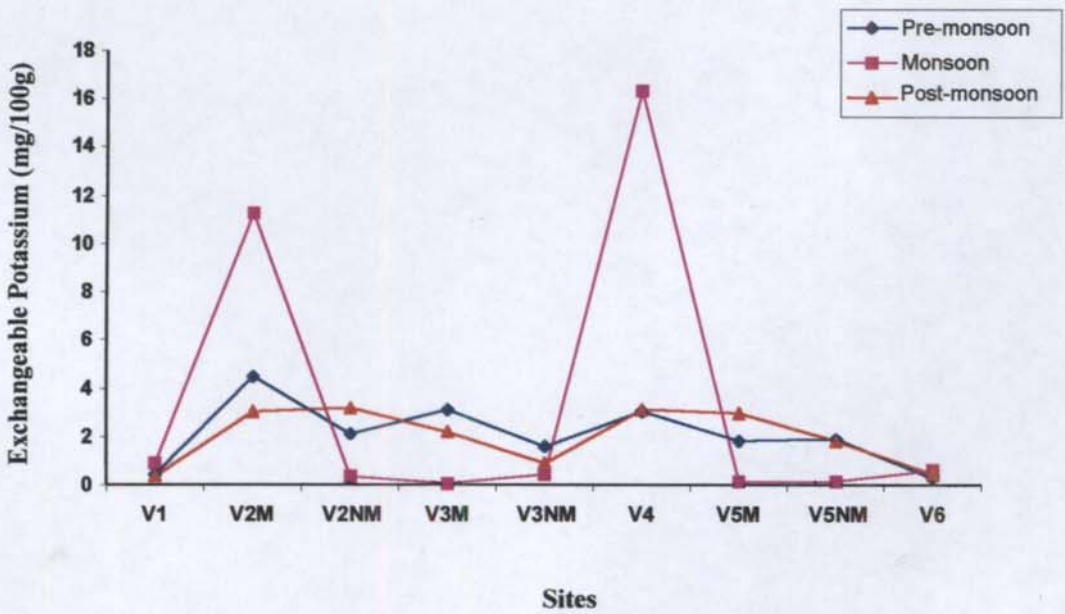


Fig. 4. 37 B Seasonal Variations in Exchangeable Potassium of Valapattanam River Sediments

the river basins, which may be attributed to the decay of mangrove litter releasing potassium, which may get adsorbed to the sediments.

The concentration of potassium in the sediments may also be correlated with the sediment texture. The fresh water as well as estuarine sediments recorded low values of potassium where the sediment is sandy in nature.

Kotmire & Bhosale (1979) recorded more potassium in less acidic soil. On the contrary, in the present study, higher concentration of potassium was found to be associated with acidic soils in the mangroves. This may be due to the fast decomposition of mangrove litter by microbes, releasing the element into the environment.

Statistical analysis revealed that in the Thalassery River, exchangeable potassium was found to be significantly correlated with manganese, moisture content, silt and organic carbon at 1% level.

Exchangeable Calcium

Seasonal variations in exchangeable calcium content in Thalassery and Valapattanam rivers during the pre-monsoon, monsoon and post-monsoon seasons are presented in Tables 4. 44 A & 4. 44 B respectively.

Table 4. 44 A Seasonal Variations in Exchangeable Calcium of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	4.0	6.2	5.5	5.7	2.4	0.8
Monsoon	1.2	1.5	2.9	1.5	2.5	0.06
Post-monsoon	1.9	3.5	3.9	3	2.2	0.04

Table 4. 44 B Seasonal Variations in Exchangeable Calcium of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre- monsoon	5.5	8.5	7.3	3.9	4.0	3.6	4.1	3.1	8.2
Monsoon	0.25	1.14	1.5	1.1	1.4	1.6	1.4	0.73	0.6
Post- monsoon	7.3	4.3	5.5	2.8	1.7	17.8	2.5	1.95	17.9

Exchangeable calcium content in the Thalassery River ranged from 0.8 – 6.2 mg/100g, 0.06 – 2.9 mg/100g and 0.04 – 3.9 mg/100g during the pre-monsoon, monsoon and post-monsoon seasons respectively. In the Valapattanam River, exchangeable calcium varied from 3.1 – 8.5 mg/100g, 0.25 – 1.6 mg/100g and 1.7 - 17.9 mg/100g during the pre-monsoon, monsoon and post-monsoon seasons respectively (4.38 A & 4.38 B).

Exchangeable calcium contents recorded seasonal variations in both the river basins. Highest concentration was recorded during the pre-monsoon season in the mangrove areas followed by the post-monsoon in both the rivers. The lowest calcium concentration was reported during the monsoon season in both the river basins.

In general, site wise distribution of calcium contents revealed a higher concentration in the non-mangrove site compared to the mangrove sites. Low calcium content in the mangrove sediments of Mumbra creek has been reported earlier by Donahue *et al.* (1977) and Kotmire & Bhosale (1979). Lower values of calcium in the mangrove environment recorded in the present study may be attributed to the breakdown

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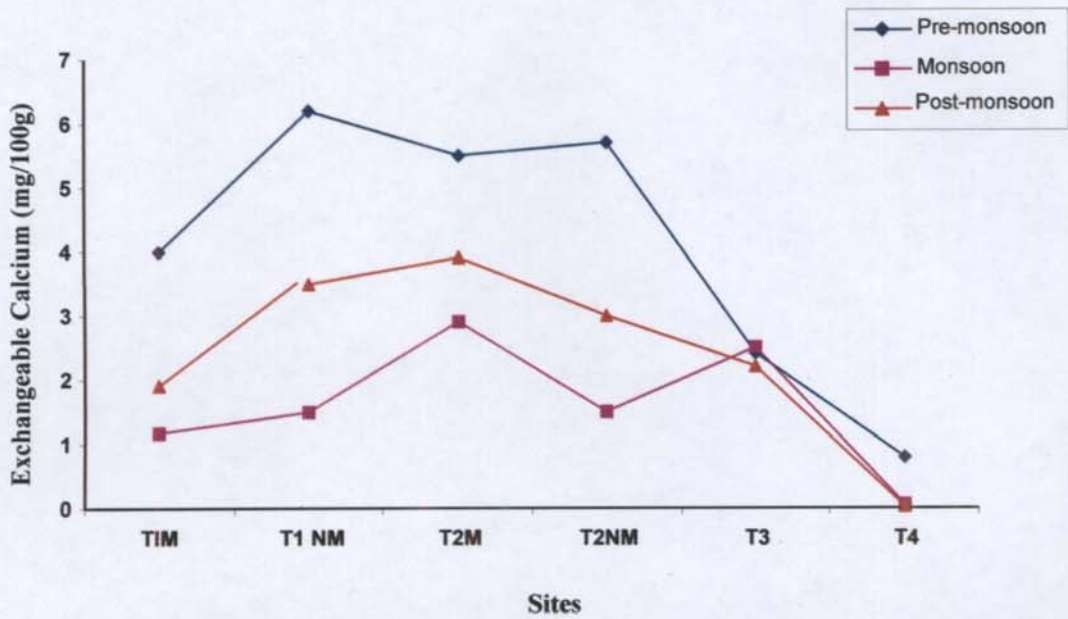


Fig. 4. 38 A Seasonal Variations in Exchangeable Calcium of Thalassery River Sediments

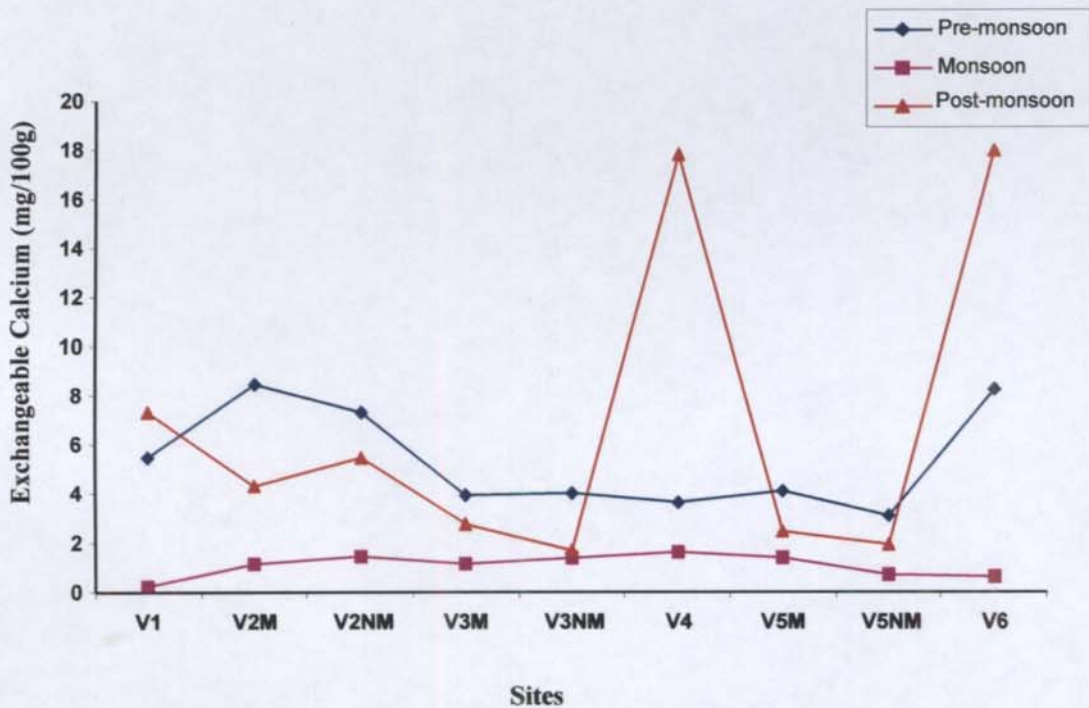


Fig. 4. 38 B Seasonal Variations in Exchangeable Calcium of Valapattanam River Sediments

of this mineral by the sulphur reducing bacteria present in the mangrove sediments, which may ultimately be made available to other organisms. Similarly low concentration of calcium has been reported in the mangrove sediments of Andaman & Nicobar Islands (Dagar *et al.*1991).

The accelerated dissolution as a result of tidal flushing combined with dissolution of calcium carbonate by carbon dioxide produced during the decomposition of mangrove litter and oxidation of pyrite during low tides may be suggested as the reasons for low calcium content in the mangrove sites (Dagar *et al.*1991).

Like sodium and potassium, calcium content in sediments is also correlated with its texture. Higher concentration was found to be associated with the fine sediments, compared to the sandy sediments of estuary and freshwater sites of both the river basins. Kotmire & Bhosale (1979) reported that calcium uptake in the mangroves was efficient, even though the saline soils are known to have low exchangeable calcium. In the T3 site of Thalassery River, the lime slackening and its deposition in near by areas contributed to higher calcium content in these sediments.

Statistical analysis revealed that in the Thalassery River, there are significant differences in exchangeable calcium and seasons and exchangeable calcium and locations at 5% level. Exchangeable calcium was found to be significantly correlated with exchangeable magnesium at 1% level.

In the Valapattanam River, there are significant differences in exchangeable calcium and seasons at 5% level.

Exchangeable Magnesium

The seasonal and spatial distribution of exchangeable magnesium in the two river basins is presented in Tables 4. 45 A & 4. 45 B respectively. Exchangeable magnesium

contents ranged from 0.19 – 9.9, 0.05 – 2.14 and 0.23 – 6.0 mg/100g during the pre-monsoon, monsoon and post-monsoon seasons respectively in the Thalassery River. In the Valapattanam River, exchangeable magnesium content varied from 0.89 – 6.6 mg/100g, 0.33 – 2.76 mg/100g and 0.94 – 5.6 mg/100g during the pre-monsoon, monsoon and post-monsoon seasons respectively (4. 39 A & 4. 39 B).

Table 4. 45 A Seasonal Variations in Exchangeable Magnesium of Thalassery River Sediments

Seasons	Sites					
	T1M	T1NM	T2M	T2NM	T3	T4
Pre-monsoon	3.9	1.5	9.9	4.14	2.4	0.19
Monsoon	1.4	0.74	2.14	0.92	0.75	0.05
Post-monsoon	2.9	2.6	6.0	3.2	2.7	0.23

Table 4. 45 B Seasonal Variations in Exchangeable Magnesium of Valapattanam River Sediments

Seasons	Sites								
	V1	V2M	V2 NM	V3M	V3 NM	V4	V5M	V5 NM	V6
Pre-monsoon	2.5	6.6	3.4	2.0	2.9	3.9	3.6	2.4	0.89
Monsoon	2.69	2.76	1.40	2.18	0.86	1.1	1.7	0.86	0.33
Post-monsoon	1.2	5.6	3.1	3.7	2.3	3.2	4.4	2.5	0.94

The temporal variations in exchangeable magnesium content revealed higher concentration during the pre-monsoon, especially in the mangrove sites in both the rivers.

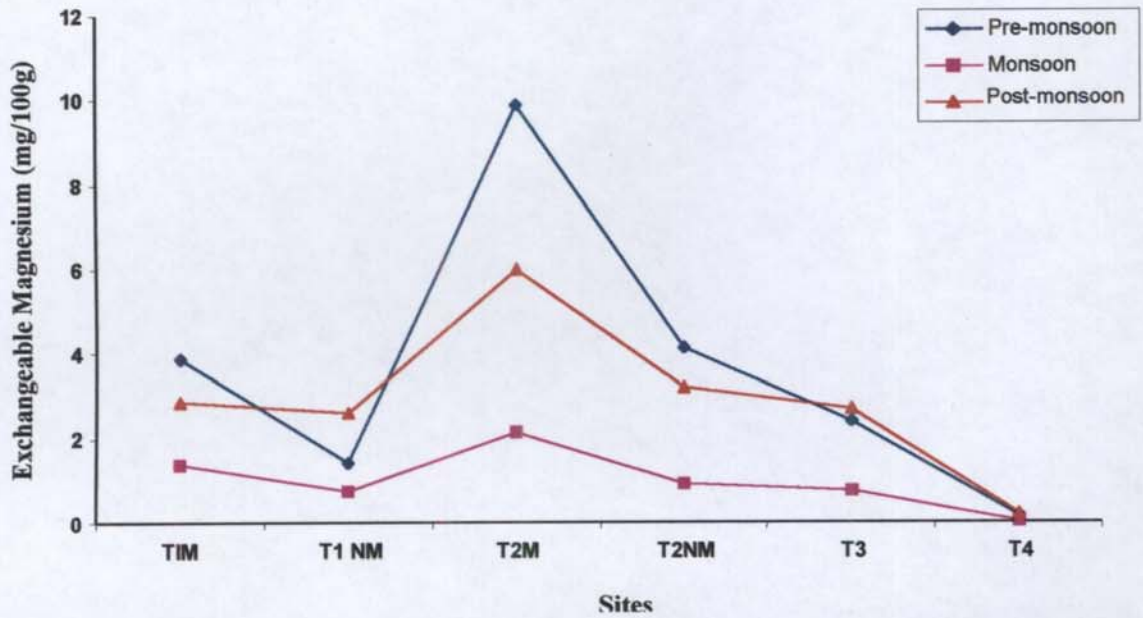


Fig. 4.39 A Seasonal Variations in Exchangeable Magnesium of Thalassery River Sediments

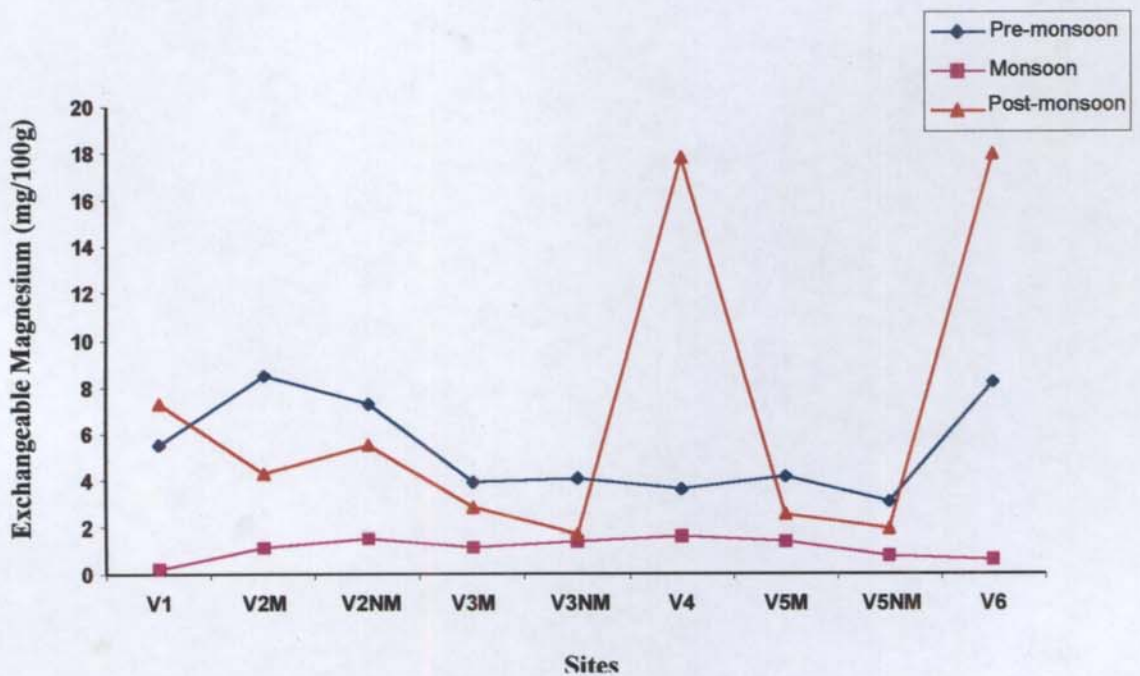


Fig. 4.39 B Seasonal Variations in Exchangeable Magnesium of Valapattanam River Sediments

This variation in the magnesium concentration in different sites may be attributed to the differential uptake by the mangroves of the two river basins. The lower concentration of magnesium during the monsoon season may be attributed to dilution by rainwater. Magnesium being an important constituent of the chlorophyll, increased concentration of magnesium in the mangrove sediments may be attributed to the decomposition of mangrove litter, with little circulation during summer, thereby releasing high amount of this element into the ecosystem.

In the present study, higher concentration of magnesium was observed in the mangrove sites of both the river basins, which is in agreement with the earlier reports of Dagar *et al.* (1991) who reported higher concentration of exchangeable magnesium when compared to calcium and potassium. Kotmire & Bhosale (1979) suggested a range of 0.031-1.66% in the mangrove sediments.

In the river basins studied, T2 & V2 mangrove sites recorded the highest magnesium concentration, which may be attributed to the highly disturbed conditions experienced in the site. Such an increase in the magnesium concentration in the disturbed mangrove sediments has been reported earlier by Dagar *et al.* (1991).

The influence of sediment texture on the distribution of magnesium was also noticed in the river basins. The upstream freshwater sites and downstream estuarine sites recorded the lowest values, which may be due to the sandy texture of the sediments.

Statistical analysis revealed that in the Thalassery River, there are significant differences in exchangeable magnesium and seasons and exchangeable magnesium and locations at 5% level. Exchangeable magnesium was found to be significantly correlated with EC, exchangeable calcium, salinity and sodium at 1% level.

Statistical analysis revealed that in the Valapattanam River, there are significant differences in exchangeable magnesium and seasons and exchangeable magnesium and locations at 5% level. Exchangeable magnesium was found to be significantly correlated with available phosphorus, chloride, clay, EC, organic carbon, and sodium at 1% level.

Metals

Metals are those having density more than five times higher than that of water. They are usually present in trace amounts in natural waters but many of them are toxic even at very low concentration. Their increase in concentration in water may be due to pollution by industrial effluents and sewage. Some of them get biomagnified in water and get accumulated in higher trophic levels such as fish, crabs and other organisms. Agricultural run off from the catchment may also contain organometallic pesticides & insecticides. The effects of metals in aquatic system may range from beneficial to dangerously toxic levels. Some metals are essential while others may adversely affect aquatic and human life. Information on the distribution of metals in the marine environment is important in studying environmental pollution, as they can be toxic even in traces. Metals are biologically non-biodegradable, and through the food chain, may finally get accumulated in human beings.

Seasonal variations in Zinc, Manganese, Copper and Iron in the Thalassery and Valapattanam river sediments are presented in Tables 4. 46 A & 4. 46 B respectively.

In the present study, metal concentration in sediments was recorded in order to assess the level of their accumulation due to various anthropogenic activities and the potential of mangrove plants to withstand metal toxicity. Among the four metals studied, zinc and manganese recorded higher concentration, followed by copper and iron.

Mangrove areas have been immensely overexploited for waste disposal. The pesticides containing metals are brought in through runoff from the catchments during monsoon season ultimately gets accumulated in the estuary. Before draining into estuary, the water has a retention time in the mangrove sites. Mangroves and mangrove sediments are capable of trapping large quantity of metals, without much significant effect on their physiological activities. The various biogeochemical processes that they undergo during their retention in the ecosystem ultimately determine their distribution and fate in the marine environment. Different factors such as sediment characteristics, grain size distribution, mineral composition and organic content may control the extent of metal accumulation in an ecosystem. The organic content in the sediment plays an important role in the accumulation and release of different metals in sediments (Janat Augustine & Chandramohankumar, 2002). The fine-grained particles in mangrove sediment may adsorb metals, thereby contributing to high metal concentration in mangrove sites.

Table 4. 46 A Seasonal Variations in Metals of Thalassery River Sediments

Seasons		T1 M	T 1 NM	T2 M	T2 NM	T3	T4
Pre- monsoon	Zinc	65	43	97	51	88	43
	Manganese	64	73	178	99	127	75
	Copper	35.5	0.5	37	14	30	16
	Iron	0.06	2.1	2.5	3.2	6.6	3
Monsoon	Zinc	284	173	212	186	211	143
	Manganese	77	94	137	124	188	82
	Copper	34	27	37	39	30	20
	Iron	2.7	1.8	3.2	9.4	11	4
Post- monsoon	Zinc	48	21	97	37	93	30
	Manganese	53	88	114	84	105	85
	Copper	67	46	109	54	83	22
	Iron	2.1	1.8	2.4	2.6	2.1	2.3

Table 4. 46 A Seasonal Variations in Metals of Valapattanam River Sediments

Seasons		V1	V2M	V2 NM	V3 M	V3 NM	V4	V5M	V5 NM	V6
Pre - monsoon	Zinc	65	70	62	94	83	94	132	94	56
	Manganese	57	112	113	86	97	108	271	198	221
	Copper	15	24	16	43	19	22	45	42	23
	Iron	1.3	6	2	5	0.9	1.9	4.3	1.5	1
Monsoon	Zinc	207	218	216	180	140	169	165	110	117
	Manganese	48	134	117	108	142	160	245	245	170
	Copper	14	54	22	33	40	28	39	35	39
	Iron	2.3	10	3.4	11	3	6	9	2	3.8
Post- monsoon	Zinc	111	139	103	203	137	56	121	47	22
	Manganese	32	127	174	161	126	69	201	151	72
	Copper	16	67	60	63	47	44	46	41	60
	Iron	1.5	4.4	3	5	3	3	7	2	3.5

The distribution of zinc, manganese and iron showed temporal variations being high during the monsoon season in both the river basins (Figures 4. 40 A & 4. 40 B, 4. 41 B & 4. 41 B and 4. 43 A & 4. 43 B respectively). This may be attributed to heavy monsoonal inflow and consequent accumulation in sediments. This may be attributed to the high adsorbing capacity of fine-grained loamy sediments along with the high organic matter in the mangrove sites (Aiyer & Rajendran, 1987). Salinity ingress and precipitation of particulate matter enriches the sediment with higher content of fine-grained fraction, which accumulates high concentration of metals (Ouseph, 1987; Narendra Babu, 1993;

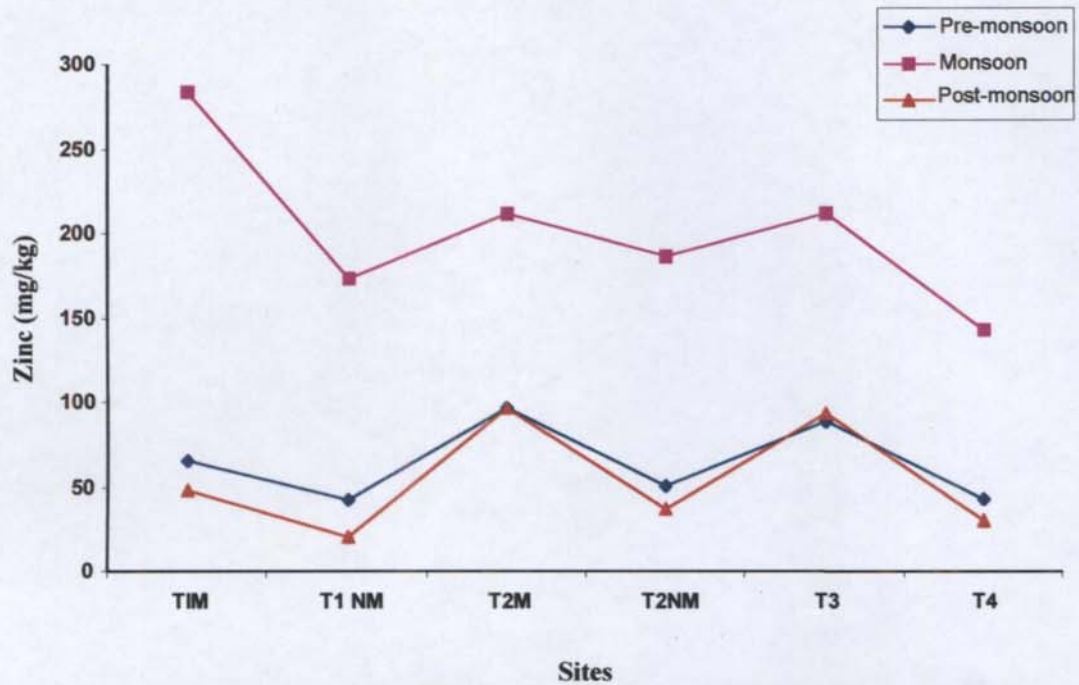


Fig. 4. 40 A Seasonal Variations in Zinc of Thalassery River Sediments

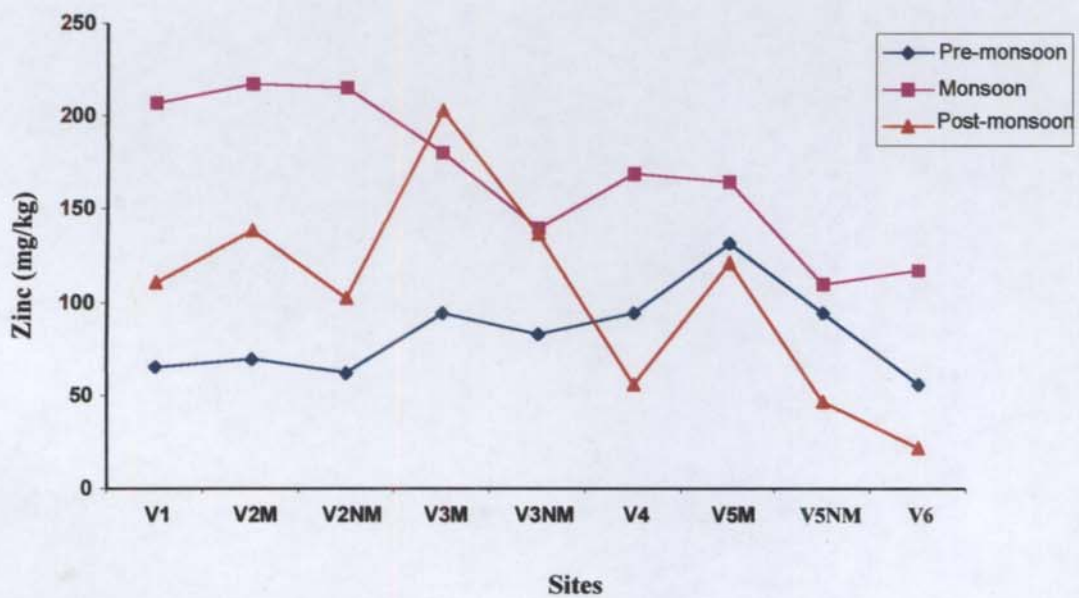


Fig. 4. 40 B Seasonal Variations in Zinc of Valapattanam River Sediments

230.13

72

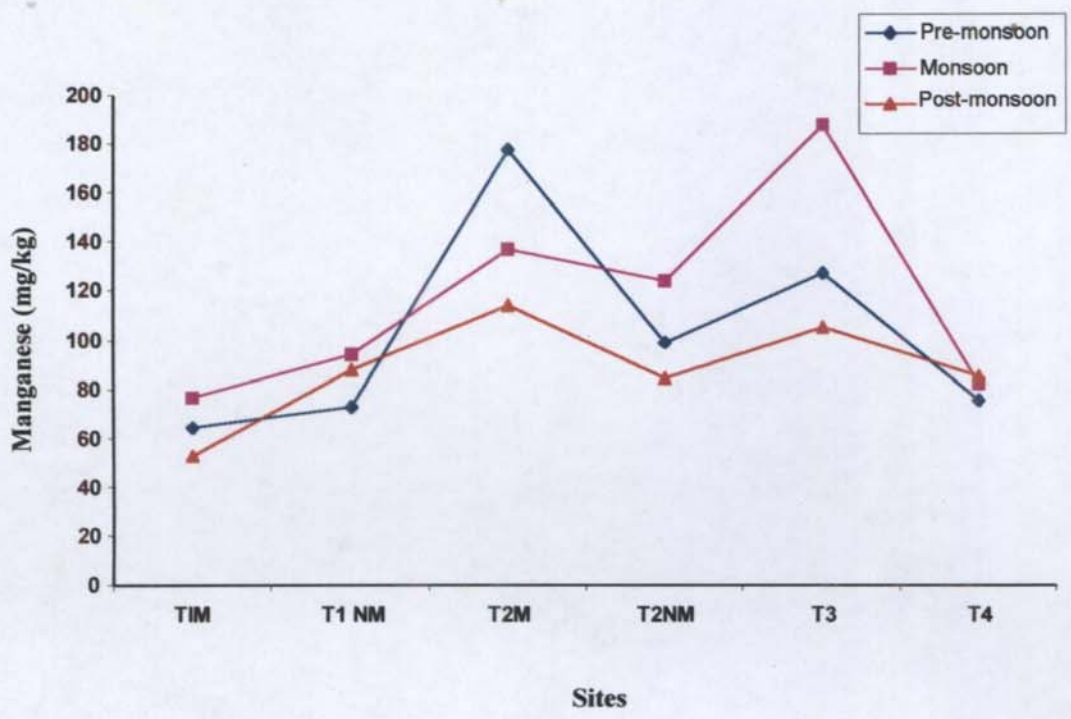


Fig. 4. 41 A Seasonal Variations in Manganese of Thalassery River Sediments

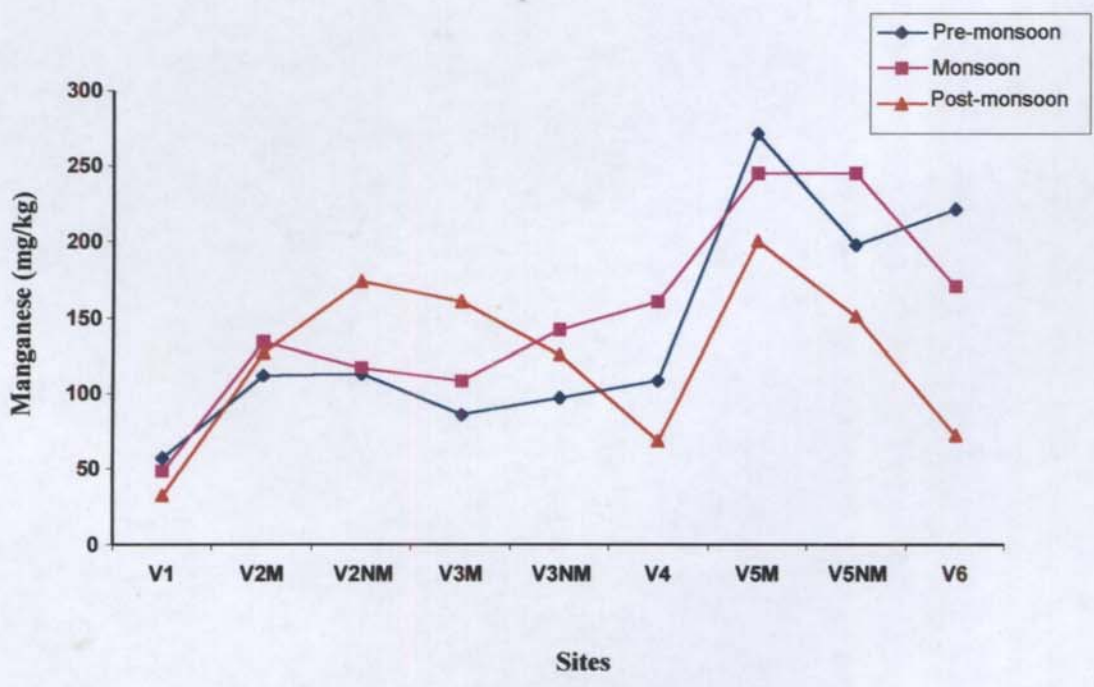


Fig. 4. 41 B Seasonal Variations in Manganese of Valapattanam River Sediments

23010

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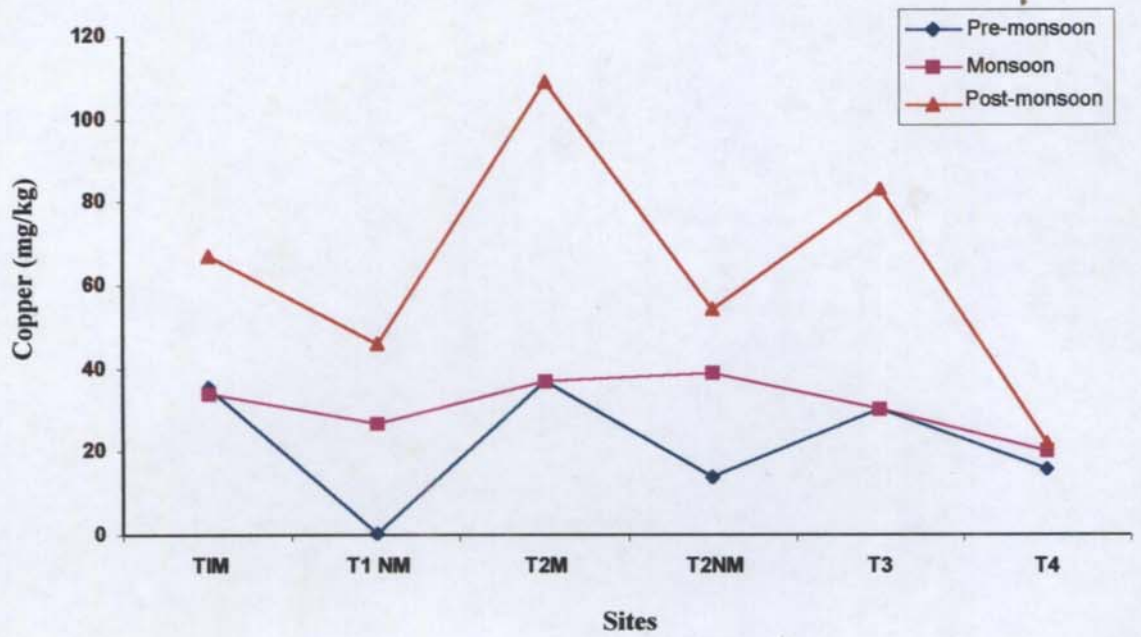


Fig. 4. 42 A Seasonal Variations in Copper of Thalassery River Sediments

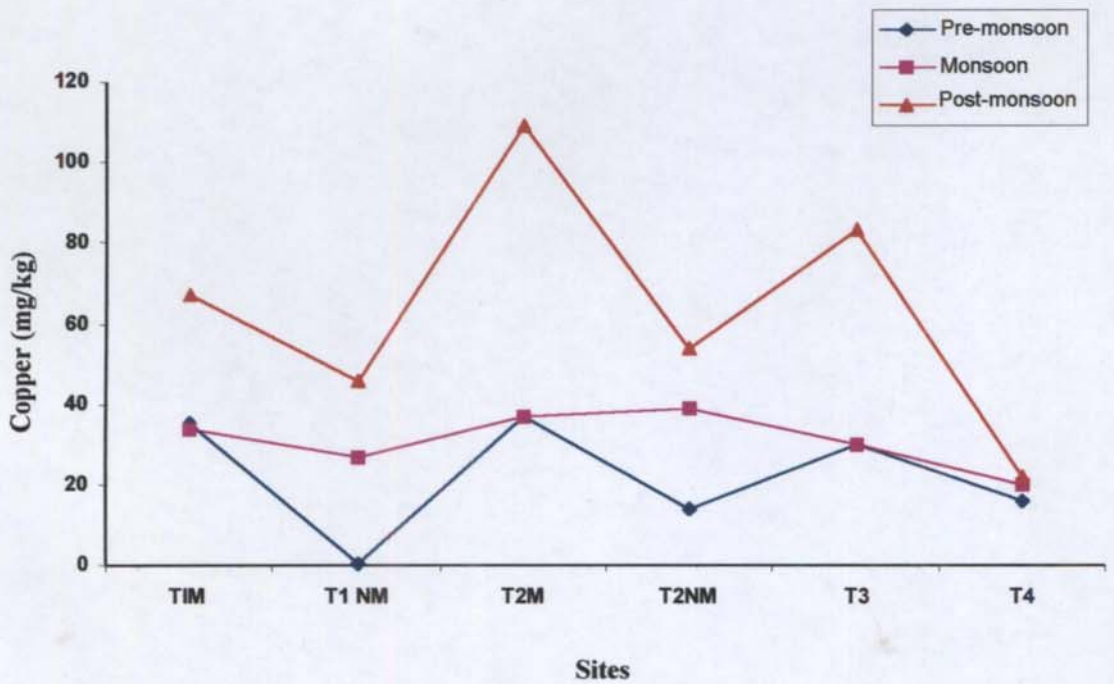


Fig. 4. 42 B Seasonal Variations in Copper of Valapattanam River Sediments

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70

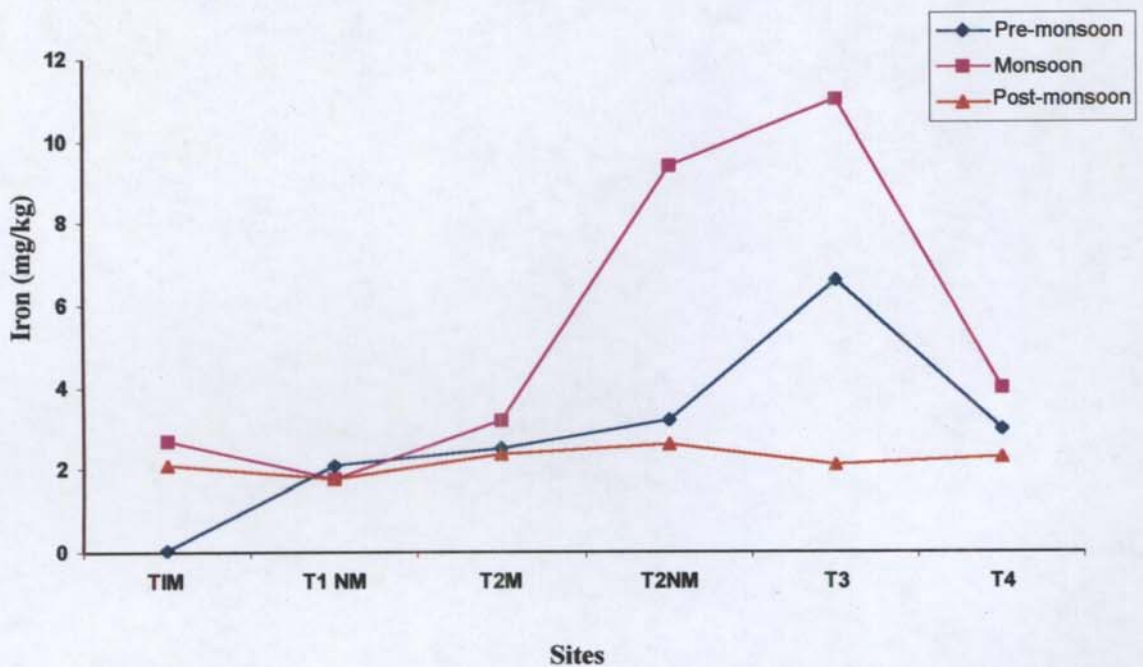


Fig. 4. 43 A Seasonal Variations in Iron of Thalassery River Sediments

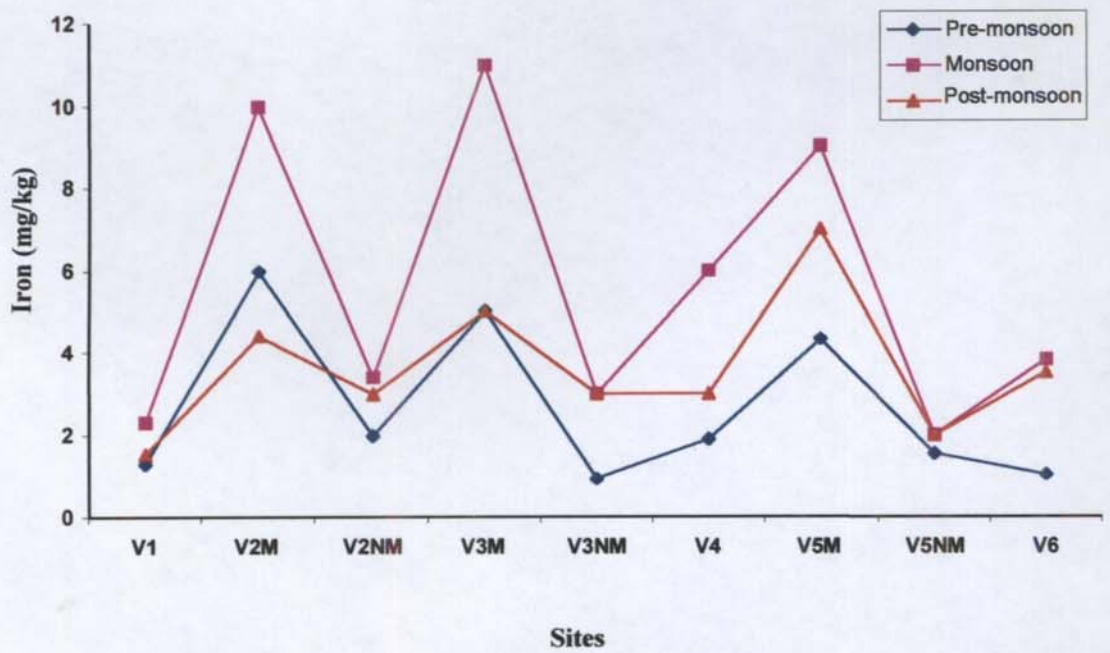


Fig. 4. 43 B Seasonal Variations in Iron of Valapattanam River Sediments

Remani *et al.* 1981).

Higher concentration of iron in the mangrove sites may be attributed to the precipitation of iron as sulphides, which is common in mangrove ecosystem. These sulphides form a major sink for other metals including heavy metals in the mangrove area (Janat Augustine & Chandramohankumar, 2002).

Badarudheen *et al.* (1997) reported that copper exhibited a marked positive correlation with organic carbon as well as mud content in Veli mangrove sediments. He also reported that zinc and manganese does not show much correlation with mud and organic carbon content. On the contrary, results of the present study shows that all the four metals studied manifested a positive correlation with organic carbon and sediment texture, which is was in agreement with the observations of Ouseph (1987), who reported the occurrence of high concentration of metals in the fine-grained sediments.

Estuarine and freshwater sediments recorded lower concentration of zinc, manganese, copper and iron, which may be attributed to the sandy texture of sediments and low organic matter, except for iron, which was high in freshwater sites. This may be attributed to the oxidation of iron in the aerobic environment to ferric hydroxide and its consequent deposition in the sediments.

Statistical analysis revealed that in the Thalassery River, there are significant differences in the metals zinc, copper and iron with seasons and manganese with locations at 5% level. Copper was found to be significantly correlated with EC, nitrate and sodium; manganese with iron, moisture content, organic carbon, potassium and silt and iron with manganese.

Statistical analysis revealed that in the Valapattanam River, there are significant differences in the metals zinc, copper and iron with seasons and manganese with locations

at 5% level. Copper was found to be significantly correlated with organic carbon; iron with clay, moisture content, organic carbon, sulphate, zinc and zinc with iron at 1% level.

4. 2. 3. 3 Biological Parameters

Benthos

Heterogeneous assemblage of organisms attached or resting on the bottom or living in the bottom sediments of a water body are referred to as benthos, which are recognized as a very important group in water quality surveillance as these organisms integrate the effect of pollution unlike other organisms, which move away from the site of pollution. The benthos in the mangrove environment include polychaetes, bivalves, gastropods, tanaids, isopods, amphipods, cirripedes, crabs, hermit crabs and shrimps (Kathiresan, 2002). Molluscs and polychaetes formed the bulk of the macrobenthic fauna in the estuarine sediment of Mulki estuary (Ramachandra *et al.* 1984) where the important bivalves include *Meretrix meretrix*, *Meretrix casta*, *Tellina philippinarum* and *Modiolus undulatus*. Parulekar *et al.* (1973) reported that the major groups of benthic organisms in mangrove ecosystem are Molluscs, Annelids, Crustaceans, Nematodes and larval forms of several other organisms.

In the present study, qualitative composition of benthic organisms was almost homogenous. The benthos identified mainly belonged to the phylum Annelida, Arthropoda and Mollusca. The Annelids were composed of polychaetes and oligochaetes. The Arthropodes were represented by crustaceans and insect larvae such as Chironomous, water beetle and Caddis fly represented the Arthropods. Molluscs mainly comprised gastropods and bivalves (Tables 4. 47 A & 4. 47 B). *Telescopium telescopium*, a gastropod recorded from the mangrove sediments of Thalassery and Valapattanam rivers. The Fiddler crab, *Uca* sp. was found to be the most common crustacean along the

Table 4. 47A Crustaceans and Molluscs in the Thalassery River

Sl. No	Crustaceans		Molluscs
	Prawns	Crabs	
1	<i>Penaeus monodon</i>	<i>Scylla serrata</i>	<i>Meretrix casta</i>
2	<i>Penaeus indicus</i>	<i>Charybdis cruciata</i>	<i>Meretrix meretrix</i>
3	<i>Metapenaeus dobsoni</i>	<i>Portunus pelagicus</i>	<i>Perna indica</i>
4	<i>Metapenaeus affinis</i>	<i>Portunus sanguinolentus</i>	<i>Perna viridis</i>
5	<i>Metapenaeus merguensis</i>	<i>Maluta lunaris</i>	<i>Crassostrea madrasensis</i>
6	<i>Metapenaeus monoceros</i>	<i>Uca sp.</i>	<i>Pinctada fucata</i>
7	<i>Macrobrachium sp.</i>	<i>Eupagurus sp</i>	<i>Cordium sp.</i>
8	<i>Panulirus homarus</i>	<i>Sesarma</i>	<i>Arca sp.</i>
9	-	<i>Gelasimus sp.</i>	<i>Cardite bicolor</i>
10	-	-	<i>Tridacha gigas</i>
11	-	-	<i>Bullia sp.</i>
12	-	-	<i>Telescopium telescopium</i>
13	-	-	<i>Fusinus sp.</i>
14	-	-	<i>Terebra sp.</i>
15	-	-	<i>Murex sp.</i>
16	-	-	<i>Balanus sp.</i>
17	-	-	<i>Villorita cyprinoids</i>
18	-	-	<i>Pila virens</i>
19	-	-	<i>Limnaea sp.</i>
20	-	-	<i>Indoplanorbis sp.</i>
21	-	-	<i>Bellamyia sp.</i>
22	-	-	<i>Paphia malabarica</i>

mangrove areas in burrows along the bank of both the river basins. The other dominant mangrove crabs were *Sesarma sp.* and *Scylla serrata*. in the mangrove sites of both the rivers. Polychaetes represented the most dominant group, followed by crustaceans and molluscs, as has been reported earlier by Harkantra *et al.* (1980). The important benthic

Table 4. 47 B Crustaceans and Molluscs in the Valapattanam River

Sl. No	Crustaceans		Molluscs
	Prawns	Crabs	
1	<i>Penaeus monodon</i>	<i>Scylla serrata</i>	<i>Meretrix casia</i>
2	<i>Penaeus indicus</i>	<i>Charybdis cruciata</i>	<i>Meretrix meretrix</i>
3	<i>Metapenaeus dobsoni</i>	<i>Portunus pelagicus</i>	<i>Perna indica</i>
4	<i>Metapenaeus affinis</i>	<i>Portunus sanguinolentus</i>	<i>Perna viridis</i>
5	<i>Metapenaeus merguensis</i>	<i>Maluta lunaris</i>	<i>Crassostrea madrasensis</i>
6	<i>Metapenaeus monoceros</i>	<i>Uca sp.</i>	<i>Pinctada fucata</i>
7	<i>Macrobrachium sp.</i>	<i>Eupagurus sp</i>	<i>Cordium sp.</i>
8	<i>Panulirus homarus</i>	<i>Sesarma</i>	<i>Arca sp.</i>
9	-	<i>Gelasimus sp.</i>	<i>Cardite bicolor</i>
10	-	-	<i>Tridacha gigas</i>
11	-	-	<i>Bullia sp.</i>
12	-	-	<i>Telescopium telescopium</i>
13	-	-	<i>Fusinus sp.</i>
14	-	-	<i>Terebra sp.</i>
15	-	-	<i>Murex sp.</i>
16	-	-	<i>Balanus sp.</i>
17	-	-	<i>Villorita cyprinoids</i>
18	-	-	<i>Pila virens</i>
19	-	-	<i>Limnaea sp.</i>
20	-	-	<i>Indoplanorbis sp.</i>
21	-	-	<i>Bellamyia sp.</i>
22	-	-	<i>Paphia malabarica</i>
23	-	-	<i>Pholas sp.</i>
24	-	-	<i>Modiolus sp.</i>

crustaceans recorded during the study were crabs, prawns and lobsters. Eight genera of crabs were identified from the mangrove areas of both the river basins, which have been reported earlier from the backwaters of Kannur (Nalini Nayak *et al.* 2000). Most of the

crab species are having high edible value. The prawns belonged to 7 species of the genera *Penaeus*, *Metapenaeus* and *Macrobrachium*. *Panulirus homarus* was the lobster species recorded from the mangrove sites of both the rivers. Rajendran & Kathiresan (1999) reported that among the penaeid prawns, the most abundant species are *Penaeus inidcus*, *Metapenaeus monoceros*, *Metapenaeus dobsoni* and *Metapenaeus brevicornis*. Twenty one genera of molluscs were identified from the Thalassery River and twenty three genera from the Valapattanam River. The two genera of boring molluscs such as *Pholas sp.* and *Modiolus sp.* were observed in the poles and abandoned pieces of wood in the V2M mangrove site of Valapattanam River.

The spatial variations revealed that in those areas having high anthropogenic activities, relatively low density and diversity of benthos were observed. Low density and diversity of polychaetes and oligochaetes were recorded in areas where sand mining was practiced.. Low benthic population in the sand mining areas has already been reported by Balakrishnan Nair *et al.* (1983). In the present study, freshwater and estuarine sediments mainly composed of polychaetes as has been reported earlier by Robin *et al.* (2002), who observed that median particle size sediments harbors more population than the fine particle size sediment. But in the present study, the distribution of benthos in the mangrove and non-mangrove areas studied revealed that mangrove sediments harbored high benthic population. The mangrove sediments were mainly dominated by the crustaceans, which showed a preference to fine particulate sediments. The abundance of detritus feeders, which include most of the crustaceans, seem to be related to the availability of detritus rather than the type of substratum, hence, they were found to dominate in the mangrove sediments, while the seston-feeding bivalves were limited to sandy bottom sediments, as has been reported earlier (Harkantra *et al.* 1980).

Seasonal differences revealed that post and pre-monsoon seasons recorded higher density and diversity of benthos compared to monsoon season. This may be attributed to high salinity and organic matter during these seasons. Many workers have studied the relation ship between the benthic abundance and percentage organic carbon. Above 4% of organic carbon, the number of benthos decreases (Harkantra *et al.* 1980), which was considered anoxic to marine life. This may be considered as one of the limiting factor for the benthic population in the mangrove sites of the Thalassery and Valapattanam river basins.

**ECOLOGICAL STUDIES ON
THE MANGROVES OF
VALAPATTANAM AND THALASSERY
RIVER BASINS**

Thesis submitted to
University of Calicut
in part fulfilment of
Doctor of Philosophy in Botany

Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

92/278

5.0 SUMMARY AND CONCLUSIONS

Mangroves, the unique, halophilous, estuarine, fragile, ecosystem forming essential components of intertidal ecosystem, are considered the most productive, self-maintaining estuarine components of the biosphere. They are open ecosystems coupled with both upstream riverine freshwater and down stream saline estuarine systems. They provide a unique habitat for a wide variety of fauna and flora associated with them and serves in regulating pH, leaching of metals, and biogeochemical cycling of nutrients. Mangroves have attained greater significance due to the fact that this ecosystem serves as feeding, breeding and nursery grounds for a wide variety of economically important organisms, especially prawns, crabs, molluscs and birds and supports numerous forms of wildlife, as well as estuarine and near shore fishery. Growing awareness on the protective, productive and social functions and values of this tropical ecosystem have highlighted the need for their conservation/sustainable management. The depletion of mangroves is a cause of serious environmental concern at present in the country as well as the State due to the fact that at the inter-tidal zone, they play a pivotal role in moderating the monsoon floods and consequent coastal erosion. The continuing degradation/depletion of this vital resource will not only retard the terrestrial and aquatic productivity and wildlife, but also seriously impair the environmental stability of the coastal zone.

Kerala, once endowed with a luxurious mangrove vegetation of 70,000 ha, have now been dwindled considerably to about 1650 ha at present due to anthropogenic activities connected with agricultural and developmental activities. Though, more mangrove area exists at present in Kozhikode and Kannur districts, they are facing serious

threats of destruction due to anthropogenic interferences. Considerable extent of mangroves in Thalassery and Valapattanam estuaries and associated wetlands in Kannur district have already been destroyed, and the remaining mangrove areas are on the verge of destruction due to reclamation for agriculture and aquaculture, coir retting and industrial pollution, clay mining, etc. Out of the 26 mangrove species recorded from Kerala, 15 species are present in North Malabar. In this context, it was felt essential to undertake a detailed scientific study the ecology of water and sediments, which supports the mangroves of Thalassery and Valapattanam River Basins of Kannur District. So far, no comprehensive, systematic studies have been done on the ecology of the mangrove ecosystem of Thalassery and Valapattanam river basins of Kannur district and their relationship with the associated flora, fauna and aquatic productivity, hence, the present study was undertaken.

In the present study, the physicochemical and biological status of water and sediments of the Thalassery and Valapattanam rivers of Kannur district, Kerala have been investigated detail during the pre-monsoon, monsoon and post-monsoon seasons for three consecutive years, with special reference to the mangrove ecosystem.

Among the various mangrove sites studied in the Thalassery and Valapattanam rivers, T1 M, T2 M, V2 M & V5 M supported a rich mangrove density and diversity. Eleven species of true mangroves have been recorded from these sites during the present study, viz., *Sonneratia caceolaris*, *S. alba*, *Avicennia officinalis*, *A. marina*, *Rhizophora mucronata*, *R. apiculata*, *Kandelia candel*, *Aegiceras corniculatum*, *Bruguiera cylindrica* *Excoecaria agallocha* and *Acanthus ilicifolius* which form the eight genera belonging to six families. Among these species, *Sonneratia alba* and *Bruguiera cylindrica* are worth mentioning. The only site where *Sonneratia alba* could be observed was the estuarine

mangrove site of the Thalassery River while few members of *Bruguiera cylindrica* were observed T2M and V2M sites of Thalassery and Valapattanam rivers respectively. *Avicennia officinalis*, *Rhizophora mucronata*, *Kandelia candel* and *Acanthus ilicifolius* were the most abundant species recorded along both the river basins.

Forty-two common mangrove associates belonging to 24 families have been recorded from the study areas, dominated by members of Cyperaceae.

Water quality parameters like salinity, electrical conductivity, sodium, chloride, fluoride, sulphate, total hardness, calcium, potassium, iron, etc., were found to be very high in the estuary due to the contribution from the sea as well as freshwater. The estuarine water was alkaline in nature. The sediment quality in the estuary revealed low nutrients, organic carbon, etc., when compared to the mangrove ecosystem, due to the sandy substratum. Severe anthropogenic pressures were also found to alter the environmental status of the estuaries of both the river basins.

In comparison with the non-mangrove areas, mangrove areas were characterized by optimum temperature, pH, salinity, dissolved salts, high amounts of nutrients, contributing to high electrical conductivity. Nutrients were distributed as inorganic mineral compounds from within and outside the ecosystem by circulation and mixing processes in the estuary consequent to tidal action. Spatial differences could be observed in the physicochemical and biological characteristics between the mangrove and non-mangrove sites studied, even though the sites selected were only half a kilometer apart. The availability of nutrients and the diversity and density of biota showed a lesser degree in the non-mangrove areas when compared to the corresponding mangrove areas. Even though, no sharp variations could be noticed among different water quality parameters of

the mangrove and non-mangrove areas, a clear difference could be recorded in the sediment quality.

Most of the water and sediment quality parameters were found to fluctuate with respect to different seasons, sites and sources. The nutrient contents in mangrove sediments were found to be high compared to non-mangrove sites, which may be attributed to the loamy sand or sandy loam nature of the substratum of Thalassery and Valapattanam rivers. The variation in surface sediment properties at different locations, especially in mangrove areas, may be the result of frequency of seawater inundation, tidal action, current velocity and the fresh water inflow from the land during the monsoon season, which influenced each location. Sediment organic carbon, which forms the important component of the detritus food chain, was considerably high in mangrove areas compared to non-mangrove areas.

Metal concentration in the mangrove sediments were also found to high in both the river basins. High amounts of zinc, followed by manganese, copper and iron were documented in both river sediments, which may be due to the use of pesticides and fertilizers in the watershed, which ultimately got deposited in the mangrove sediments. Results of the present study revealed the capacity of mangroves to withstand high metal pollution, still sustaining higher biotic forms. The molluscs present in abundance in the mangrove ecosystems, have got high capacity of metal accumulation.

The mangrove areas of Thalassery and Valapattanam rivers presented rich plankton diversity. The dominant group belonged to the Bacillariophyceae followed by Chlorophyceae and Cyanophyceae during the monsoon season. The diatoms constituted the bulk of the plankton population. A total of 23 genera of Bacillariophyceae, 16 genera of Chlorophyceae and 10 genera of Cyanophyceae were recorded from the river

basins studied. The important genera of Bacillariophyceae recorded from both the river basins throughout the year were *Pleurosigma*, *Navicula*, *Coscinodiscus*, *Biddulphia*, *Diatoma*, *Nitzschia*, *Cyclotella*, and *Rhizosolenia*. The common Chlorophycean members recorded were *Ankistrodesmus*, *Celeastrum*, *Eudorina*, *Closterium*, *Selenastrum*, *Pediastrum*, *Scenedesmus*, *Chlorella*, *Ulothrix* and *Euastrum*. The important Cyanophycean members observed were *Oscillatoria*, *Anacystis*, *Anabena*, *Nostoc*, *Microcystis*, *Lyngbya*, *Nodularia*, *Gleocapsa* and *Gelotrichia*. The qualitative composition of phytoplankton in both the river basins were found to be homogenous.

The zooplanktons in the mangrove ecosystem belonged to the phyla Protozoa, Aschelminthes and Arthropoda distributed among the six classes, viz., Crustacea, Rotifera, Ciliata, Rhizopoda, Sarcodina and Nematoda. The important zooplanktons recorded from the two river basins were Foraminifera, *Euglypha*, *Euplotes*, *Colpoda*, *Diffugia*, *Paramecium*, *Stylonchia*, *Peridinium*, *Chilodonella*, *Strongyloides*, *Brachionus*, *Keratella*, *Philodina*, *Cyclops*, *Daphnia* and *Cypris*. High zooplankton diversity was recorded in the mangrove sites during the pre-monsoon season. The diversity and density of zooplanktons showed positive correlation with organic matter content.

The benthos recorded from the two river basins belonged to phylum Annelida, Arthropoda and Mollusca. The benthos was mainly represented by polychaetes. The benthic population showed fluctuations in their distribution in different sites depending upon the anthropogenic activities. *Uca* sp. and *Scylla serrata* were the most abundant crab species recorded from the mangrove sites, which form the main detritus feeders in the mangrove ecosystem. *Uca* sp. was not recorded from the estuarine, freshwater and non-mangrove areas of both the river basins. Wood-boring molluscs such as

Pholas and *Modiolus* sp. were also identified from the V2 M site of the Valapattanam River, where wood seasoning was practiced.

The fishery wealth of mangroves of Thalassery and Valapattanam rivers are worth mentioning. Fortyfour species of fishes of value were identified from the mangrove sites. High organic matter and detritus along with rich plankton population supported high population of prawns in the mangrove sites, including juveniles. The 7 species of prawns recorded from the sites were of the genera *Penaeus*, *Metapenaeus* and *Macrobrachium*. *Panulirus homarus*, the lobster species having export value was also recorded from the mangrove sites of both the rivers. The local communities mainly depend on this fishery wealth of mangrove ecosystem.

Highest primary productivity in the mangrove ecosystems of Thalassery and Valapattanam river basins were reflected by the high chlorophyll a content and algal biomass recorded during the study. Productivity was high in the mangrove ecosystem compared to other biota. The mangroves contribute to this mainly by litter fall and the conversion of these to organic carbon by the microorganisms present in this ecosystem.

The differences observed in the abiotic and biotic elements between the mangroves and other biota clearly indicates the importance of the mangrove habitat. The high biotic diversity observed in the mangrove ecosystem contributes to high primary and secondary productivity.

Even though, high anthropogenic activities like coconut husk retting; coir processing and waste dumping was practiced in the V2 mangrove site of the Valapattanam River, physicochemical parameters were not deteriorated much and is still congenial for the luxuriant growth and regeneration of mangroves, hence supports dense mangrove vegetation. Similarly, T2M site of the Thalassery River also supported rich

and diverse mangrove vegetation, though a considerable portion of mangrove areas have been reclaimed for doubling of the railway line.

Dredging and sand mining activities have caused tremendous disturbances in the benthic population, especially in the V5 NM, V2 NM and V6 sites of Valapattanam River, where low zooplankton and benthic population were recorded. The V2 M site of Valapattanam River and T3 site of Thalassery River supported rich species of zooplankton and benthic population, which can tolerate pollution due to coconut husk retting. Anthropogenic activities have resulted in the destruction of considerable mangrove areas in the Kuyyali site of Thalassery River.

Statistical analysis revealed in the Thalassery and Valapattanam river basins, there was significant difference in most of the physicochemical and biological parameters of the water and sediments and seasons and locations at 5% level. Significant correlation was observed among most of the physicochemical and biological parameters of water and sediments at 1% level.

The pH, salinity, tidal action, presence of optimum organic and inorganic nutrients in water and sediments along with the biotic factors provide a congenial environment for the healthy existence and regeneration of mangroves along the Thalassery and Valapattanam rivers.

In a nutshell, coastal waters and sediments are unique environments where spatial and temporal changes and variations in physical and chemical properties are controlling the environmental parameters, which in turn exert a profound influence on the mangrove vegetation, its distribution, abundance, diversity, etc.

**ECOLOGICAL STUDIES ON
THE MANGROVES OF
VALAPATTANAM AND THALASSERY
RIVER BASINS**

Thesis submitted to
University of Calicut
in part fulfilment of
Doctor of Philosophy in Botany

Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

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- Abbassi, S. A., 1998. **Water Quality, Sampling and Analysis**. Discovery Publishing House, New Delhi, 212 pp
- Abhaykumar, V. K. & Dube, H. C., 1991. Epiphytic bacteria of mangrove plants *Avicennia* and *Sesuvium portulacastrum*. *Ind. J. Mar. Sci.* **20**: 275 - 276
- Agate, A. D., 1991. Mangrove microbiology. In: **Pro. Symp. Significance of Mangroves**, Agate, A. D., Bonde, S. D & Kaumaran, K. P. N. (Ed.). Maharashtra Assoc. Cultiv. Sci. Res. Inst., Pune, India, pp 11 - 13
- Aiyer, R. S & Rajendran, P., 1987. Physicochemical aspects of estuarine and lake-bed sediments In: **Proc. Nat. Sem. Estuarine Management**, 4 – 5 June 1987, Trivandrum, pp 117 – 122
- Aksornkoae, S & Papharasit, N., 1996. Effect of sea level rise on the mangrove ecosystem in Thailand. *Natl. Resour. Develop.* **43/44**: 95 -104
- Ananthakrishnan, T. N., 1982. **Bio Resources Ecology**. Oxford & IBH Publishing Co., New Delhi, 131-142 pp
- Angelina, G. P. S., 1994. **An environmental assessment on the coastal zone of Madras and people's attitude towards the coastal pollution**. Ph.D. Thesis, University of Madras, Tamil Nadu, India
- Anirudhan, A. N., Balchand, A. N., Nair, S. M & Nambisan, P. N. K., 1987. Distribution pattern of salinity and silicon and their interrelationship in Cochin backwaters. In: **Proc. Natn. Sem. Estuarine Management**, 4 - 5 June 1987, Trivandrum, pp 26 – 31
- Anonymous, 1978. **Annual Report: 1978**. Central Inland Fisheries Research Institute, Barrackpore, West Bengal

- Anonymous, 1987. *Mangroves in India – Status report*, Govt. of India, United Printing Press, New Delhi
- Anonymous, 1997. Mangrove ecosystem. *CAMP. Zoo's Print* **12**: 12 - 16
- Ansari, Z. A., Sreepada, R. A., Matondkar, S. G. P & Parulekar, A. H., 1993. Meiofaunal stratification in relation to microbial food in a tropical mangrove mud flat. *Trop. Ecol.* **34**: 204 - 216
- APHA, 1995. **Standard Methods for the Examination of Water and Wastewater**. 19th Edn., American Public Health Association, Washington, D. C., USA
- Asha, B. S., Satheesh Kumar, C. S & Ouseph, P. P., 2002. Plankton characteristics in the marine environment off Cochin. *Proc. XIV Kerala Science Congress*, 29 - 31 January 2002, Kochi, pp 435 - 438
- Aston, S. R & Hewitt, C. N., 1977. Phosphorus and carbon distribution in a polluted coastal environment. *Estuar. Coast. Mar. Sci.* **5**: 243 – 254
- Badarudeen, A & Sakkir, S., 1998. Distribution of Na & K in the sediments of Veli, Kochi & Kannur Mangroves, Kerala. *Indian. J. Mar. Sci.* **27**: 253-255
- Badarudeen, A., Damodaran, K. T., Sajan, K & Padmalal, D., 1996. Texture and geochemistry of the sediments of a tropical mangrove ecosystem, Southeast coast of India. *Environ. Geol.* **27**: 164-169
- Badarudeen, A., Maya, K & Sajan, K., 1997. Sediment, organic carbon and trace metal distribution in the mangrove environment at Veli, Kerala. In: *Proc. IX Kerala Science Congress*, 27 – 29 January 1997, Thiruvananthapuram, Kerala, pp 85-87
- Bagla, P & Menon, S., 1989. *Ravaged forests and soiled seas: Ecological issue in the tropics with special reference to Andaman and Nicobar Islands*, Kalpavriksh, New Delhi
- Balachandra, L., 1988. A comprehensive account of the mangrove vegetation of Andaman and Nicobar Islands. *Indian For.* **114**: 741 - 751
- Balakrishnan Nair, N & Abdul Aziz, P. K., 1987. Hydrobiology of the Ashtamudi estuary – a tropical backwater system in Kerala. In: *Proc. Nam. Sem. Estuarine Management*, 4 – 5 June 1987, Trivandrum, pp 268-280

- Balakrishnan Nair, N., Krishna Kumar, K., Abdul Aziz, P. K., Dharmaraj, K & Arunachalam, M., 1983. Ecology of Indian estuaries – IX. A preliminary survey of the fishery resources of the Ashtamudi estuarine system. *Fishery Technology* **20**: 75 – 83
- Balakrishnan Nair, N., Abdul Aziz, P. K., Dharmaraj, K., Arunachalam, M., Krishnakumar, K & Balasubrahmanian, N. K., 1983. Ecology of Indian Estuaries: Part I: Physicochemical features of water and sediment nutrients of Ashtamudi Estuary. *Ind. J. Mar. Sci.* **12**: 143-150
- Balakrishnan Nair, N., Krishna Kumar, K., Abdul Aziz, P. K., Dharmaraj, K., Arunachalam, M & Balasubrahmanian, N. K., 1983. Ecology of Indian estuaries: Part III – Physicochemical features of Akathumuri-Anchuthengu-Kadinamkulam backwater Systems, South West Coast of India. *Ind. J. Mar. Sci.* **12**: 154 – 159
- Balakrishnan Nair, N., Abdul Aziz, P. K., Krishna Kumar, K., Dharmaraj, K. & Arunachalam, M., 1984. Ecology of Indian Estuaries: Part VI – Physicochemical conditions in Kadinamkulam backwater, SW Coast of India. *Ind. J. Mar. Sci.* **13**: 69 – 74
- Balakrishnan Nair, N., Sobha, V., Chandran, R., Rathi Ammal, M., Maya, S & Suryanarayanan, H., 1987. Vertical distribution of certain algae in a brackish water lagoon in Kerala. In: *Proc. Nat. Sem. Estuarine Management*, 4 – 5 June 1987, Trivandrum, pp 296 – 304
- Bandyopadhyay, A. K., 1984. Soil and water characteristics of the mangrove forest of Sunderbans (India). **Report of 2nd Introductory Training Course on Mangrove Ecosystems**. UNDP/UNESCO Regional Project No. **RAS/79/002**
- Bandyopadhyay, A. K., 1985. The Sunderban mangrove experience on reclamation. In: *Proc. Workshop on the conversion of Mangrove Areas to Paddy Cultivation*. Los Banos, Laguna, Philippines, 1-3 April 1985. UNDP/UNESCO Res. & Training Pilot Programs on Mangrove Ecosystem in Asia and the Pacific, pp 65 - 69
- Bandyopadhyay, A. K., 1986. Soil and water characteristics of the mangrove forest of Sunderbans (India). *Indian Forester* **112**: 58 - 65

- Bandyopadhyay, A. K., 1987. A note on the effect of reclamation through marginal embankments on coastal ecosystems of Sunderban (India). *J. Ind. Soc. Coastal Agric. Res.* 5: 39 - 41
- Banerjee, L. K & Gosh, D., 1998. An anthology of Indian mangroves: Species diversity and distribution of mangroves of India. *Seshaiyana* 5: 20-24
- Banerjee, L. K., Sastry, A. R. K & Nayar, M. P., 1989. **Mangroves of India – Identification Manual.** Botanical Survey of India, Calcutta
- Banyikwa, F. F., 1986. The geographical distribution of mangrove forests along the East African coast. In: *Status and Utilization of Mangroves, Proc. of a workshop on Save and the Mangrove Ecosystems in Tanzania*, 21 – 22 February 1986, Dar es Salaam, pp 5 - 13
- Battish, S. K., 1968. **A study on the taxonomy and seasonal variation of rotifers and crustaceans.** M. Sc. (Hons.) Thesis, Punjab University, Chandigarh, 199 pp
- Beddome, R. H., 1866. The flora of Sylvatica of Southern India. Granz Bros., Madras
- Bhaskara Rao, V., Narasimha Rao, Sharma, G. V. S & Krishna Rao, B., 1992. Mangrove environment and its sediment characters in Godavari Estuary, East Coast of India. *Ind. J. Mar. Sci.* 21: 64 – 66
- Bhattathiri, P. M. A., 1992. Primary production of tropical marine ecosystems. In: *Tropical Ecosystems: Ecology and Management.* Wiely Eastern Limited, New Delhi, pp 269 – 276
- Bijoy Nandan, S., 1991. **Effect of coconut husk retting on the water quality and biota of an aquatic biotope in Kerala.** Ph. D Thesis, Kerala University
- Bijoy Nandan, S & Abdul Azis, P. K., 1990. Studies on BOD and dissolved oxygen in the Kadinamkulam Kayal, Southern Kerala. *Mahasagar, Bull. Nat. Inst. Oceanogr.* 2: 95-101
- Bijoy Nandan, S & Abdul Azis, P. K., 1996. Organic matter of sediments from the retting and non-retting areas of Kadinamkulam estuary, Southwest Coast of India. *Ind. J. Mar. Sci.* 25: 25 - 28

- Biswas, 1980. **Common Fresh and Backwater Algal Flora of India and Burma.** Periodical Experts Book Agency, Delhi, 101 pp
- Blaber S. J. M & D.A. Milton., 1990. Species composition, community structure and zoogeography of fishes of mangrove estuaries in the Solomon Islands. *Mar. Biol.* **105**: 259-267
- Blasco, F., 1975. **The Mangroves of India.** Inst. Fr. Pondicherry. *Tran. Sect. Sci. Tech.* **14**: 180
- Blasco, F., 1977. Outline of ecology, botany and forestry of mangals of Indian subcontinent. pp 241-260. In: Chapman, V. J (Ed.). **Wet Coastal Ecosystems: Ecosystems of the World I. West Coastal Ecosystems, India.** Elsevier, Amsterdam
- Blasco, F., 1984 a. Climatic factors and the biology of mangrove plants. pp 18-35. In: Snedaker, S. C & Snedaker, J. G (Eds.). **The Mangrove Ecosystem: Research Methods.** UNESCO, Paris
- Blasco, F., 1984 b. Taxonomic consideration of the mangrove species. pp 81-90. In: Snedakar, S. C & Snedakar, J. G (Ed.). **The Mangrove Ecosystem: Research Methods.** UNESCO, Paris
- Blasco, F & Caratini, C., 1973. Mangrove de Pichavaram (Tamil Nadu), (Indie du sud), Phytogeographie et palynologie. *Trav. Doc. Cent. Etudes Geogr. Trop.* **8**: 164 - 185
- Blasco, F., Chandra, S & Thanikaimoni, G., 1975. Main characteristics of Indian mangroves. pp 71-83. In: Walsh, G., Snedakar, S & Tear, H. J (Ed.). **Proc. Intern. Symp. Biol. Manage. Mangroves.** Vol. I., Inst. Food & Agric. Sci., Univ. Florida
- Blatter, E., 1905. The mangroves of Bombay Presidency and their biology. *J. Bombay Nat. Hist. Soc.* **16**: 644 - 656
- Blum, L.K., Mills, A., L., Zieman, J. C & Zieman, R.I., 1988. Abundance of bacteria and fungi in sea grass and mangroves detritus. *Mar. Ecol. Prog. Ser.* **42**: 73 -78
- Bordillon, T. F., 1908. **The Forests of Travancore.** Govt. Press, Trivandrum, Kerala.

- Bowman, M. J., 1977. Nutrient distributions and transport in Long Island Sound. *Estuar. Coast. Mar. Sci.* **5**: 531 – 548
- Brenzonik, P. L., 1972. Nitrogen, source and transformations in natural waters. In: Allen & Kramer (Ed.). **Nutrients in Natural Waters**. Wiley Interscience, New York.
- Bunt, J. S., 1992 a. Introduction to mangrove ecosystems. pp 1–6. In: Robertson, A. I & D. M. Alongi (Eds.). **Tropical Mangrove Ecosystems**. America Geophysical Union, Washington
- Bunt, J. S., 1992 b. Introduction to mangrove ecosystems. pp 101 – 136. In: Robertson, A. I & D. M. Alongi (Eds.). **Coastal and Estuarine Studies 41**. America Geophysical Union, Washington
- Chakrabarti, C., Kundu, S. K., Ghosh, A. & Choudhury, 1993. A preliminary study on certain trace metals in some plant and animal organisms from mangroves of Sunderbans, India, *Mahasagar, Bull. Nat. Inst. Oceanogr.* **26**: 17 – 20
- Chandra, N., 1993. **Plankton dynamics of sewage and oil polluted coastal water of Tuticorin**. Report submitted to M.S. University, Baroda, India
- Chandrasekharan, V.S., 1987. **Studies on prawn and finfish seed resources of the Pichavaram mangrove region (Southeast Coast of India)**. Ph.D. Thesis, Annamalai University, India, 218 pp
- Chand Basha, S., 1991. Distribution of mangroves in Kerala, *Indian Forester* **117**: 439-448
- Chand Basha, S., 1992. Mangroves of Kerala: A fast disappearing asset. *Indian Forester* **118**: 175-190
- Chapman, V. J., 1962. Respiration studies of mangrove seedlings. *Bull. Mar. Sci. Gulf. Caribb.* **12**: 137 – 167
- Chapman, V. J., 1970. Mangrove physiology. Davis, J. H. 1940. The ecology and geologic role of mangroves in Florida, *Trop. Ecol.* **11**: 1-190
- Chapman, V. J., 1975. **Mangrove vegetation**. Lehre: Cramer, 425 pp
- Chapman, V. J., 1976. **Mangrove Vegetation**. J. Cramer, Vaduz, 447 pp

- Chapman, V. J., 1977. **Wet Coastal Ecosystems. Ecosystems of the World, Vol. I**, Elsevier, New York
- Charles Davis, C. 1955. **The Marine and Freshwater Plankton**, Michigan State Univ. Press, USA, 562 pp
- Chong, P. W., 1987. **Proposed Management and Integrated Utilization of Mangrove Resources in Sierra Leone, Freetown**. UNDP/FAO Project No. SIL/84/00, Field Document No. 6: 123 pp
- Chopra, S. I & Kanwar, J. S., 1976. **Analytical Agricultural Chemistry**. Kalyani Publishers, Ludhiana, New Delhi, 518 pp
- Cintron, G & Schaeffer-Novelli, Y., 1983. Introduction a la ecologia del manglar. ROST-LAC/UNESCO, Monterideo, 109 pp
- Clark, C. B., 1869. Presidential address to the Linnaean Society on the Sunderbans of Bengal. *Proc. Linn. Soc. London*, pp 14 - 29
- Clough, B. F., 1984. Growth and salt balance of the mangroves *Avicennia marina* (Forsk.) Vierh. and *Rhizophora stylosa* Griff. in relation to salinity. *Aust. J. Plant Physiol.* **11**: 419 - 430
- Clough, B. F., 1992. Primary productivity and growth of mangrove forests. In: Robertson, A. I & Alongi, D. M (Eds.). **Tropical Mangrove Ecosystems. Coastal and Estuarine Studies**, **41**: 225-249
- Clough, B. E., Boto, K. G & Attwill, P. M., 1983. Mangroves and sewage: A re-evaluation. In: Teas, H. J (Ed.), **Biology and Ecology of Mangroves**, Dr. W. Junk Publishers, Boston, pp 151 - 161
- Cooke, T., 1906. **The Flora of the Presidency of Bombay**. Botanical Survey of India, Calcutta
- Coull, B. C., Greenwood, J.G., Fielder, D. R & Coull B. A., 1995. Subtropical Australian juvenile fish eat meiofauna: Experiments with winter whiting *Sillago maculata* and observations on other species. *Mar. Ecol. Prog. Ser.* **125**:13-19
- Dagar, J.C., 1987. Mangrove vegetation, its structure, ecology, management and importance with special reference to Andaman and Nicobar Islands. In: *Proc.*

- Symp. Management of Coastal Ecosystems and Oceanic Resources of the Andamans*, 17 – 19 July 1987, Andaman Science Association (CARI), Port Blair, pp 8- 23
- Dagar, J. S., Mongia, A. D & Bandyopadhyay, A. K., 1991. **Mangroves of Andaman and Nicobar Islands**. Oxford & IBH Pub. Co. Pvt. Ltd., India, 166 pp
- Dagar, J. S & Sharma, A. K. 1989. Multiple viviparity in mangroves. *J. Andaman Sci. Assoc.* **5**: 72- 73 pp
- Das, A. K., 2002. Limno-chemistry and productivity of upper Ganga complex. *Pollution Research* **21**: 157 – 168
- Das, J., Nand Sahoo, R. K., 1997. Semi diurnal variation of some physicochemical parameters in the Mahanadi estuary East West of India. *Indian J. Mar. Sci.* **26**:323-326
- Davis, J. H., 1940. The ecology and geologic role of mangroves in Florida (Paper from Tortugas Lab No. 22 Publ. Carneg. Instn. No. 517.) pp 303 – 412
- Dawes, C. J., 1981. **Marine Biology**. John Wiley & Sons, New York
- Day, F., 1977-1978. **The Fishes of India**. 1 & 2 Bernard Quaritch, London
- Delacerd, L. D., 1983. Heavy metal accumulation by mangrove salt marsh intertidal sediments. *Brazilian J. Med.* **16**: 442 - 451
- Deshmukh, S. V., 1991. Mangroves of India: Status report. Deshmukh, S. V. & Mahalingam, R. A. (Eds.). Global Network of Mangrove Genetic Resource Centers Project Formulation Workshop, Madras, India, pp 15 - 25
- Desikachary, T. V., 1959. **Cyanophyta**. Indian Council of Agricultural Research, New Delhi
- De Sousa, S. N. Sen Gupta, R. Sanzgiri, S. & Rajagopal, M. D., 1981. Studies on the nutrients of Mandovi and Zuari river system. *Indian J. Mar. Sci.* **10**: 314-321
- Dietrich Uhlmann., 1975. **Hydrobiology**. Wiley Inter Science, New York

- Dittel, A. I & Epifanio, C. E., 1990. Seasonal and tidal abundance of crab larvae in a tropical mangrove system, Gulf of Nicoya, Costa Rica. *Mar. Ecol. Prog. Ser.* **65**: 25-34
- Donahue, R. L., Miller, R. W & Shickluna, J. C., 1977. **Soils: An Introduction to Soils and Plant Growth**. Prentice – Hall, Inc. New Jersey, 50 pp
- Dora, Y. L & Borreswara Rao, C., 1975. Organic matter content of the Vasishta Godavari river sediments. *Bull. Dept. Mar. Sci. Univ. Cochin* **4**: 945 – 952
- Dugdale, R. C., 1977. Nutrient limitation in the sea; dynamics, identifications and significance. *Limnol. Oceanogr.* **12**: 685 – 695
- Duke, N. C., 1992. Mangrove floristics and biogeography. In: Robertson, A. I & Alongi, D. M (Ed.). **Tropical Mangrove Ecosystems. Coastal and Estuarine Studies, 41**. American Geophysical Union, Washington, USA, pp 63-100
- Dwivedi, S. N., Parulekar, A. H., Goswami, S. C & Untawale A. G., 1975. Ecology of the mangrove swamps on the Mandovi estuary, Goa, India. In: *Proc. Intern. Symp. Biol. Manage. Mangroves*. Inst. Food and Agric. Sci., Univ. Florida, **1**: 115-125
- FAO., 1988. Worldwide compendium of mangrove associated aquatic species of economic importance. **FAO Fish. 814 (FIRI/C 814)**, 236 pp
- Ferrington, H. A., 1906. **Third Working Plan for the Sunderbans Division, Calcutta**. Bengal Secretariat Press, Calcutta
- Fox, L. E., Sagar, S. L & Wolfsy, S. C., 1986. The chemical control of soluble phosphorus in the Amazon estuary. *Geochimica et Cosmochimica, ACTA*, **50**: 783 - 794
- Francis, M. S & Sunil, C. N., 2002. Micro-algal diversity in the mangroves around Kochi. *Proc. XIV Kerala Science Congress*, 29 – 31 January 2002, pp 776
- Frodin, D., 1985. The mangrove ecosystem in Papua New Guinea. pp 58-63 In: Field, C. D & Dartnell, A. J (Eds.). **Mangrove Ecosystems of Asia and the Pacific**. Townsville, Australia

- Gamble, J. S., 1915-1936. **Flora of the Presidency of Madras**, Vols. I-III. Botanical Survey of India, Calcutta, India, Reprint Edition, 1967
- Garcia-soto, C., de Madariaga, I., Villate, F & Orive, E., 1990. Day-to-day variability in phytoplankton community of coastal shallow embayment in response to changes in river run-off and water turbulence. *Estuarine, Coastal and Shell Sci.* **31**: 217-229
- Garg, A., Pathak., S. M., Donderia, M. S., Singh, V. P & Mall, L. P., 1985. Mangrove and chemical characteristics of inundating water in Andaman region. *J. Hydrobiol.* **1**: 91 – 95
- Gerlach, S. A., 1958. Die Mangrove region tropischer Kusten als Lebenaraum. *Z. Morph. U. Okol. Tiere.* **46**: 7-21
- Giridhar, V. V., Kuppusamy, M. R., Srivatsan, S. G., Sodhantaraman, N., Kuppusamy, M., Panchatcharam, K & Ramamurthy, S. 2001. Seasonal variation of water and sediment quality along Pulicat, Chennai Ennore and Mahabalipuram coasts. In: Iyer, C. S. P. (Ed.). **Emerging Trends in Environmental Service**. Asiatech Publishers, New Delhi, 304 pp
- Godfery, J. S., 1983. Tidal flushing and vertical diffusion in Southwest arm Port Hacking: Synthesis and modeling of intermittent estuaries - a case study from planning to evaluation. Cuff, W. R & Tomczak, M. (Eds.). Springer verlag, Berlin, pp 27 – 54
- Goldberg, E. D., 1976. **The Health of the Oceans**. UNESCO, Paris, 172 pp
- Gopal, B & Krishnamurthy, K., 1993. Wetlands of South Asia. pp 345 – 414 In: Whighan, D. F., Dykyjova, D & Hejny, S (Eds.). **Wetlands of the World. Handbook of Vegetation. Science, Inventory, Ecology and Management**, Kluwer Academic Pubs., Dordrecht
- Gopinathan, C. P., 1975. Studies on the estuarine diatoms of India. *Bull. Dept. Mar. Sc. Univ. Cochin* **4**: 995-1004
- Gopinathan, C. P & Rajagopalan, M. S., 1983. Mangrove resources. *Bull. Cent. Mar. Fish. Res. Inst.* **34**: 44 - 46

- Gouda, C & Panigraphy, R.C., 1992. Seasonal Distribution and behavior of silicate in the Rushikulya estuary, East coast of India. *Indian. J. Mar. Sci.* **21**: 111-115
- Gouda, R & Panigraphy, R.C., 1995. Seasonal distribution and behavior of nitrate and phosphate in Rushikulya Estuary, East Coast of India. *Indian J. Mar. Sci.* **24**: 233 - 235
- Govindasamy, C & Kannan, K., 1991. Rotifers of the Pichavaram mangroves (southeast coast of India), Hydrobiological approach, *Mahasagar, Bull. Natl. Inst. Oceanogr.* **24**: 39 - 45
- Grewling, T & Peech, M., 1965. **Chemical Soil Tests.** Cornel Univ. Agric. Exp. Station, Bull., 960 pp
- Griffith, W., 1836. On the family Rhizophoraceae. *Trans. Med. Phys. Soc. Calcutta*, 8 pp
- Griffith, W., 1851. On the development of ovule in *Avicennia*. *Proc. Linn. Soc. London* **20**: 1- 6
- Gunasekaran, S. A., Jayapaul, A & Raju, P. M., 1992. Distribution of mangrove plants in relation to the chemical characteristics of the soil, Muthupet, Tamil Nadu, India. *Asian. Env.* **14**: 59 – 69
- Hamilton, L. S & Snedaker, S. C., 1984. Handbook for mangroves area management, UNESCO-IUCN-East West Centre, Publication: Honolulu 123
- Hamilton, L. S., Dixon, J. A & G. O. Miller., 1989. Mangrove forests: An underestimated source of the land and of the sea. pp 254 - 288. In: Borgese, E. M., Ginsbergh, N. & Morgan J. R (Eds.). **Ocean Yearbook**, No. 8, University of Chicago Press, Chicago, London
- Harkantra, S. N., Ayyappan Nair., Ansari, Z. A & Parulekar, A. H., 1980. Benthos of the shelf region along the west coast of India. *Ind. J. Mar. Sci.* **9**: 106 – 110
- Hesse. P. R., 1971. **Textbook of Soil Chemical Analysis**, John Murray, London, 520 pp
- Hem, J. D., 1985. **Study and Interpretation of the Chemical Characteristics of Natural Water.** U. S. Geological Survey Water - Supply Paper – 2254. U. S. Govt. Printing Office, 264 pp

- Hossain, M. M., Mahmood, N & Bhouyain, A. M., 1988. Some water quality characteristics of the Karnakully river estuary. *Mahasagar, Bull. Nat. Inst. Oceanogr.* **21**: 183 - 188
- Jackson, M. L., 1969. **Soil Chemical Analysis**. Advanced Course. IInd edition, Madison, 895 pp
- Jagtap, T. G., Chavan, V. S & Untawale, A. G., 1993. Mangrove ecosystems of India: A need for protection. *Ambio* **22**: 252-254
- James, E. J., Anitha, A. B., Divakaran Nambudripad, K., Joseph, E. J., Kamalam Joseph., Nandeshwar, M. D., Nirmala, E., Padmini, V., Unni, P. N & Venugopal, M. R., 1995. Vembanad-Kol wetland system in relation to drainage basin management: A case study. In: *AWB/UNEP Workshop*, 14 - 17 October 1995, Selangor, Malaysia, 80 pp
- James, E. J., Anitha, A. B., Divakaran Nambudripad, K., Joseph, E. J., Nandeshwar, M. D., Nirmala, E., Padmini, V., Unni, P. N & Venugopal, M. R., 1997. Vembanad-Kol Wetland system in relation to drainage basin management. In: Anonymous, 1997. **Wetlands and Integrated River Basin Management: Experiences in Asia and the Pacific**. ISBN 983-9663-24-0, 1997. UNEP / Wetland International – Asia Pacific, Kuala Lumpur, Malaysia
- Janat Augustine Rosily, A. V & Chandramohankumar, N., 2002. Distribution of trace metals in relation to sediment organic carbon in the mangrove sediments of Cochin. *Proc. XIV Kerala Science Congress*, 29 – 31 January 2002, 777 pp
- Jayaraman, R. 1954. Seasonal variations in salinity, dissolved oxygen and nutrient salts in the inshore waters of the Gulf of Mannar and Palk Bay near Mandapam (S. India) *Ind. J. Fish.* **1**: 345 - 364
- Jeyseelan, M. J. P., Sundararaj, V & Devaraj, M., 1991. Significance of mangroves in fisheries. In: *Proc. Symp. Significance of Mangroves*, Maharashtra Assoc. Cultiv. Sci. Pune, India, pp 14 – 23
- Jhingran, V. G., 1982. **Fish and Fisheries of India**. Hindustan Publishing Corporation, Delhi, India, 666 pp

- Jhingran, V. G & Gopalakrishnan, V. L., 1973. Estuarine fisheries resources of India in relation to adjacent areas. *J. Mar. Biol. Assn.* **15**: 323 - 334
- Jitts, H. R., 1959. The adsorption of phosphate by estuarine bottom deposits, *Aust. J. Freshwat. Res.* **10**: 7 - 21
- Johny Thomas & Ragothaman., 1987. Studies on the hydrography of Harija coast. In: *Proc. Nat. Sem. Estuarine Management*, 4 - 5 June 1987, Trivandrum, pp 138 – 142
- Joshi, G. V & Jamale, B. B., 1975. Ecological studies in mangroves of Terekhol and Vashisti rivers. *Bull. Dept. Mar. Sci. Univ. Cochin* **7**: 751 – 760
- Joshi. A. J & Sagar Kumar, A., 1985. Chemical characteristics of mangrove soils on Gujarat coast. In: *The Mangroves: Proc. Nat. Symp. Bio. Util. Cons. Mangroves* pp 351-355
- Joshi, G. V., Jamale B. B & Bhosale. L., 1975. Ion regulations in mangroves. In: *Proc. Int. Symp. Biol. & Mang. Mangroves*. Inst. Food and Agri. Sci. Univ. Florida **2**: 595-607
- Jitts, H. R., 1975. The adsorption of potassium by estuarine bottom deposits. *Aust. J. Mari. Fresh. Res.* **10**: 17-21
- Kalyan Chakraborti., 1993. Biodiversity of the mangrove ecosystems of Sunderbans. *Indian Forester* **119**: 891 – 898
- Kamprath, E. J., Nelson, W. L & Fits, J. W., 1976. In: *Proc. Soil. Sci. Soc. Am.* **20**: 463
- Kannan, L & Vasantha, K., 1992. Microphytoplankton of the Pichavaram mangals, Southeast coast of India: Species composition and population density. In: Jaccarini, V & Martens, V. (Eds.). *The Ecology of Mangrove and Related Ecosystems* **247**: 77 - 86
- Kapetsky, J. M., 1985. **Mangroves, Fisheries and Aquaculture**. FAO. Fish Report. 338 (Suppl). pp 17-36
- Karmarkar, S. M., 1985. Mangroves – A review. In: *The mangroves: Proc. Nat. Symp. Biol. Util. Cons. Mangroves*, pp 60-79

- Karuppasamy, P. K & Perumal, P., 2002. Biodiversity of zooplankton at Pichavaram mangroves, South India. *Seshaiyana* **10**: 15
- Kathireshan, K., 1991. Uses of Mangroves. *Yojana* 27 – 29
- Kathireshan, K., 1995 a. Quo vadis, mangroves? *Seshaiyana* **3**: 25 - 28
- Kathireshan, K., 2002. A review studies on Pichavaram mangrove, southeast India, *Seshaiyana* **10**: 15
- Kathiresan, K & Ravikumar, S., 1995. Vegetative propagation through air layering in 20 species of mangroves. *Aquatic Botany* **50**:107 -110
- Kathireshan, K & Sivasothi, N., 2000. Current status of mangrove ecosystem in Singapore. *Seshaiyana* **8**: 9
- Kawabata, Z., Magendran, A., Palanichamy, S., Venugoplan, V. K. V & Tatsukawa, R., 1993. Phytoplankton biomass and productivity of different size fractions in the Vellar estuarine system, southeast coast of India. *Indian J. Mar. Sci.* **22**: 294 - 296
- Kawsar, A., Yousuf Mehedi, Md., Rezaul Haq & Faruq Ahmed., 2002. Heavy metal concentration in water and sediment of the Sunderbans reserved forest, Bangladesh. *Asian. J. Micr. Biot. Eenvt. Sci.* **4**: 171 - 179
- Khaleel, K. M., 2002. Study of the qualitative structure of true mangroves present in three sample sites of Kannur district. pp 74 - 81. In: Madhyastha, M. N., Sridhar, K. R & Ahana Lakshmi (Eds.). **Prospects and Problems of Environment Across the Millennium**. Daya Publishing House, New Delhi
- Khan, A. A., 1960. The mangrove forests of Andhra state. In: *Proc. Silvicult. Conf.* **9**: 182 - 186
- Khan, S. A., 1964. Mangrove forests: Their past and present management in Hyderabad region. *Pakistan J. Sci.* **16**: 329-332
- Kotmire, S. Y & Bhosale, L. J., 1979. Some aspects chemical composition of mangrove leaves and sediments. *Mahasagar, Bull. Nat. Inst. of. Oceanogr.* **12**: 149 – 154
- Kotpal, R. L., 1972. **A Textbook of Protozoa**. Rastogi & Co., Meerut, India, 303 pp

- Krishnamurthy, K., 1966. The cycle of phosphorus in the near shore waters of Porto Novo during 1961. In: *Proc. Second All Ind. Cong. Zool.* 2: 313 - 316
- Krishnamurthy, K., 1983. The conversion of mangroves lands and waters to other uses. UNDP/UNESCO workshop of human population, mangroves resources, human induces stresses & human health, Bogor, Indonesia, pp 1-12
- Krishnamurthy, K & Sundararaj, V., 1973. A survey of the environmental features in a section of Vellar-Coleroon estuarine systems, South India. *Marine Biology* 23: 229 – 237
- Krishnamurthy, K., Choudhury, A & Untawale, A. G., 1987. Status Report, Mangroves in India, Ministry of Environment and Forests, Govt. of India, New Delhi, 150 pp
- Krupadam, R. J & Anjaneyulu, Y., 2000. Cycling of nutrients in Gautami-Godavari estuarine ecosystem, Bay of Bengal - East Coast of India. *Res. J. Chem. Environ* 4: 55-70
- Kulkarni, D. H & Junagad, C. F., 1959. Utilization of mangrove forests in Saurashtra and Kutch. In: *Proc. Mangrove Symp.* Calcutta, pp 30-32
- Kurian, C. V., 1980. Fauna of the mangrove swamps of Cochin estuary. In: *Proc. Asian Symp. Mangrove Environ. Res. Manage.* Aug.1980, Univ. Malaya, Kuala Lumpur, Malaysia, pp5
- Lacerda, L. D., Conde, J. E., Alarcon, C., Alvarez Leon, R., Bacon, P. R., Croz, L. D., Kjerfve, B., Polaina, J & Vannucci, M., 1993. Mangrove ecosystems of Latin America and the Carribean: A summary. International Tropical Timber organization, International Society for mangrove Ecosystems (ITTO/ISME) Project PD 114/90/ (F): Mangrove ecosystems technical reports ITTO TS – 13, 2: 1 - 42
- Lafond, L. R., 1984. Dynamical processes in deltaic sedimentation with special respect to mangrove areas. UNDP/UNESCO, New Delhi, pp 25-26
- Lakshmanaperumalsamy, P., 1987. Nitrogen fixing bacteria *Azotobacter* sp. in aquatic sediments. *Fish. Technol. Soc. Fish. Technol.* Cochin, 24: 126 –128

- Lalithambika Devi, C. V., Meenakshi Kunjamma, P. P & Narayanan, B., 1992. Zooplankton studies on Southwest coast of India. *Proc. IV Kerala Science Congress*, 27 – 29 Feb 1992, Thrissur, pp 264 – 266
- Lee, S.Y., 1990. Primary productivity and particulate organic matter flow in an estuarine mangrove wetland in Hong Kong. *Mar. Biol.* **106**: 453 - 463
- Lokabharathi, P. A., Oak, S & Chandramohan, D., 1991. Sulphate reducing bacteria from mangrove swamps. Their ecology and physiology. *Oceanol. Acta.* **14**: 163 – 171
- Lugo, A. E., 1980. Mangrove ecosystems: Successional or steady state? *Biotropica* **12**: 65-72
- Lugo, A. E & Snedaker, S. C., 1974. The ecology of mangroves. *Ann. Rev. Ecol. Syst.* **5**: 39-64
- Lugo, A. E., Sell, M & Snedaker, S. C., 1973. Mangrove ecosystem analysis. In: **The Role of Mangrove Ecosystems in the Maintenance of Environmental Quality and High Productivity of Desirable Fisheries**. Univ. Florida, Gainesville, Florida, USA E 1- E 59
- Macintosh, D. J., 1984. Ecology and productivity of Malaysian mangrove crab population (Decapoda: Brachyura). In: *Proc. Symp. Mangr. Env. Res. & Manag.* pp 354 - 377
- MacNae, W., 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific region. *Adv. Mar. Biol.* **6**: 73-270
- MacNae, W., 1974. Mangrove forest and fisheries. FAO/UNDP Indian Ocean Programme (Indian Fishery Commission) IOCF/DEV/74/34, Rome
- Madhusoodana Kurup, B & Samuel, C. T., 1987. Ecology and fish distribution pattern of a tropical estuary. In: *Proc. Natl. Sem. Estuarine Management*, 4 –5 June 1987, Trivandrum, pp 339-349
- Mahapatro, T. R. & Pandhy, S. N., 2002. Seasonal variation of micronutrients in Rushikulya Estuary. *Pollution Research* **21**: 1-5
- Mahapatro, T. R., Pandhy, S. N & Patra, S. P., 2001. Assessment of Water Quality in Rushikulya Estuary. *J. Ind. Poll. Cont.* **17**: 107 - 112

- Malley, D. F., 1977. Adaptations of decapod crustaceans to life in mangrove swamps, *Mar. Res. Indonesia* **18**: 63-72
- Mani, P., 1989. **Phytoplankton ecology of the mangrove ecosystem**. Ph. D. Thesis, Annamalai University, Tamil Nadu India, 122 pp
- Mani, P., 1992. Natural phytoplankton communities in Pichavaram mangroves. *Indian J. Mar. Sci.* **21**: 278 –280
- Mani, P., 1994. Phytoplankton in Pichavaram mangroves, east coast of India. *Indian J. Mar. Sci.* **23**: 22 – 26
- Manivasakam, M., 1996. **Physicochemical Examination of Water, Sewage and Industrial Effluents**, Pragati Prakashan, Meerut, 257 pp
- Martin, D. F., 1970. **Marine Chemistry**. Marcel Dekker Inc. New York Vol. I. 271pp
- Martosubroto, P & Naamin, N., 1977. Relationship between tidal forests (mangroves) and commercial shrimp production in Indonesia. *Mar. Res. in Indonesia* **18**: 81-86
- Mathauda, G. S., 1957. The mangrove forests of India. In: *Proc. Mangrove Symp.* Min. Food and Agric., Calcutta, pp 66-87
- Matondkar, S. G. P., Mahtani, S & Mavinkurve, S., 1980. Seasonal variations in the microflora from mangrove swamps of Goa. *Ind. J. Mar. Sci.* **9**: 119 – 120
- Mazda, Y. S., Sawamoo, H., Yakochi, H & Wolanski, E., 1990. Links between physical, chemical and biological process in Bashita-Minato, a mangal mangrove swamp in Japan. *Estuar. Coast. Shelf Sci.* **31**: 817 – 833
- Mehr-Homji, V. M., 1973. Zonation of the mangrove vegetation in the Vellar estuary. In: *Proc. XVI Indian Sci. Cong.* **3**: 338
- Miller, S. M., 1952. Phosphorus exchange in a subtropical marine basin. *Bull. Mar. Sci. Gulf. Carrib.* **14**: 257 - 265
- Mishra, S., Panda, D & Panigrahy, R. C., 1993. Physicochemical characteristics of the Bahuda estuary (Orisssa), East coasts of India. *Ind. J. Mar. Sci.* **22**: 75 - 77

- Mishra, B. P & Tripathi, B. D., 2000. Changes in algal community structure and primary productivity of River Ganga as influenced by sewage discharge. *Ecol. Env. Cons.* **6**: 279 – 287
- Mitch, W. J & Gosselink, J. G., 1986. **Wetlands**. Van Nostrand Reinhold Co., New York, 537 pp
- MOEF., 1987. **Mangroves of India: Status Report**. Ministry of Environment & Forests, Govt. of India, New Delhi, 150 pp
- Mohanam, C.N., 1984. **Studies on the flora of Quilon district, Kerala**. Ph. D. Thesis, University of Madras
- Mohanam, C. N., 1999. Mangroves. In: **The Natural Resources of Kerala**, WWF India, Thiruvananthapuram, Kerala, India, pp 149-158
- Mohanam, C. N. 2000. The mangrove wetlands. **The National Science Magazine**. **3**: 18-23
- Mohandas, A., Ramanujan, N & Sreedevi, P., 1994. The effect of man-made changes in the mangrove ecosystem at Asramom, Kollam, *Proc. VI Kerala Science Congress*, 27 – 29 January 1994, pp 55 - 57
- Mondal, D, Kumar, B., Ganguly, A. K., Naskar, A. K & Bhowmick, B. 2001. Water quality status along the coast of West Bengal during 1994 – 97. pp 33 – 41 Iyer, C. S. P. (Ed.) **In: Emerging Trends in Environmental Science**. Asiatech Publishers, New Delhi
- Mortimer, C, H., 1941. The exchange of dissolved substances between mud and water in lakes, *J. Ecol.* **29**: 280 – 329
- Mortimer, C, H., 1942. The exchange of dissolved substances between mud and water in lakes, *J. Ecol.* **30**: 147 - 201
- Muhamed Jafar Palot & Radhakrishnan, C., 2002. *Sonneratia alba* J. Smith (Sonneratiaceae), and addition to the mangrove flora of Kerala. *Seshaiyana* **10**: 1
- Mukherjee, B. B & Mukherjee, J., 1978. Mangroves of Sunderbans, India. *Phytomorphology* **28**: 177-191

- Munro, I. S. R.1., 1955. **The Marine and Fresh Water Fishes of Ceylon.**
- Muraleedharan Nair, M. N., 1994. Residual Mercury in the sediments of Beypore estuary. *Proc. VI Kerala Science Congress*, 27 – 29 January 1994, Trivandrum, pp 60 – 61
- Muraleedharan Nair, M. N & Ajaykumar Varma, R., 2002. A review of the pollution problems in the wetlands of Kerala and management options. In: **Wetland Conservation and Management in Kerala.** STEC, Govt. of Kerala. A compendium on the focal theme of XIV Kerala Science Congress
- Murthy, P. S. N & Veerayya, M., 1981. Studies on the sediments of Vembanad Lake, Kerala State: Part IV – Distribution of trace elements. *Ind. J. Mar. Sci* **10**: 165 – 172
- Murugan A & Ayyakkanu K., 1991. Ecology of Uppanar backwaters Cuddalore: II Nutrients. *Mahasagar, Bull. Natn. Inst. Oceanogr.* **24**: 103 – 108
- Murugan, T., Divakaran, O., Balakrishnan Nair, N & Padmanabhan, K. G., 1980. Distribution and seasonal variation of benthic fauna of the Veli Lake, South West coast of India. *Ind. J. Mar. Sci.* **9**: 184 – 188
- Nalini Nayak, Nandakumar, D., Amruth, M., Unnikrishnan, P & Padmanabhan, T. P., 2000. **Wetland Resources of Northern Kerala: A Case Study of Pazhayangadi and Kunhimangalam in Kannur District.** Kerala Research Programme on Local Development. 83pp
- Nambudiripad, K. D & James, E. J., 1987. Instrumentation and methods of observation for studies on estuarine dynamics with special reference to Malabar Coast. In: *Proc. Nat. Sem. Estuarine Management*, 4 – 5 June 1987, Trivandrum, pp 49 – 51
- Narayanan, T., Geetha, R & Chandramohankumar, N., 2002. A comparative study on the hydrography of three mangrove ecosystems of Cochin, Kerala. *Proc. XIV Kerala Science Congress*, 29 – 31 January 2002, pp 779 – 780

- Narendra Babu, K., 1993. Distribution of heavy metals and organic carbon in sediments of Ashtamudi Estuary, Kerala. *Proc. V Kerala Science Congress*, 28 – 30 January 1993, pp 62 - 65
- Naskar, K. R & Guha Bakshi, D. N., 1987. **Mangrove Swamps of the Sunderbans: An Ecological Perspective**, Naya Prakash, Calcutta, India, 263 pp
- Navalkar, B. S., 1940. Studies on the ecology of mangroves: Determination of osmotic pressure of *Avicennia alba*. Blume. *J. Univ. Bombay* **8**: 3-19
- Navalkar, B. S., 1941. Studies on the ecology of mangroves- Physical factors of the mangrove soil. *J. Univ. Bombay* **9**: 78-92
- Navalkar, B. S., 1959. Studies on the ecology of the mangroves. Humus content of mangrove soils of Bombay and Satellite Islands. *J. Univ. Bombay* **27**: 6-10
- Navalkar, B. S., 1973. Ecology of mangroves. In: Misra, K., Gopal, B., Singh, K. P & Singh, J.S (Eds.). **Progress of Plant Ecology in India**. Today and Tommorrow Print. & Publs. New Delhi, **1**: 101-109
- Navalkar, B. S & Bharucha, F. R., 1942. Studies on the ecology of mangroves: The chloride content of seawater, soil solution and in the leaf cell sap of the mangroves. *J. Univ. Bombay* **10**: 99 –106
- Navalkar, B. S & Bharucha, F. R., 1948. Studies on the ecology of mangroves. *J. Univ. Bombay* **16**: 36 – 45
- Navalkar, B. S & Bharucha, F. R., 1949. Studies on the ecology of mangroves. *J. Univ. Bombay* **17**: 17 –35
- Navalkar, B. S & Bharucha, F. R., 1950. Studies on the ecology of mangroves. *J. Univ. Bombay* **18**: 7 – 16
- Nayak, S. T., 1993. Remote sensing applications in the management of wetland ecosystem with special emphasis on management of mangrove ecosystem and coastal protection, Visakhapatnam, India. NRSA Report, 21 pp
- Neelakantan, B., Prasad, P. N., Naik, V. G., Gunaga, V. R & Kusuma, M. S., 1987. Culture potentiality of Kali estuary and adjoining brackish water systems. In: *Proc. Nat. Sem. Estuarine Management*, 4 – 5 June 1987, Trivandrum pp 350 - 358

- Nixon, S. W., Oivatt C.W & Hale, S.S., 1976. Nutrient regeneration and the metabolism of the coastal marine communities; *Graduate School of Oceanography, Collected Reprints* 13: 669 - 683
- Odum, W. E & Heald E. J., 1975. Mangrove forests and aquatic productivity. pp 129-136. In: Hasler P.D. (Ed.). **Coupling of Land and Water System**. Springer – Verlag. Berlin
- Ouseph, P. P., 1987. Heavy metal pollution in the sediments of Cochin estuarine system. In: *Proc. Nat. Sem. Estuarine Management*, 4 -5 June 1987, Trivandrum, pp 123 – 127
- Padmakumar, K & Ayyakkannu, K., 1986. Heterotrophic bacteria associated with seaweeds of Porto Novo and adjacent waters. In: *Nat. Sem. Microbial Ecology*, 53 pp
- Padmavathi, D & Satyanarayanan, D., 1999. Distribution of nutrients and major element in riverine, estuarine and adjoining coastal water of Godavari, Bay of Bengal. *Ind. J. Mar. Sci.* 28: 345-354
- Panchanadikar, V. V., 1993. Studies of iron bacteria from a mangrove ecosystem in Goa and Konkan. *Int. J. Environ. Stud. Sect.* 45: 17 – 21
- Panigraphy, P.K., Das, J., Das, S. N & Sahoo, R. K., 1999. Evaluation of the influence of various physicochemical parameters on coastal water quality, around Orissa, by factor analysis. *Ind. J. Mar. Sci.* 28: 360 – 364
- Pannier, F & Pannier, R. F., 1975. Physiology of vivipary in *Rhizophora* mangle. In: *Proc. Int. Symp. Biol. & Managt. Mangroves*. Walsh, G. E., Snedaker S. C & Teas H. J (Ed.). Inst. Food and Agrl. Sci. Univ. of Florida, Gainville, Florida, 2: 632 – 639
- Pant, A., Dhargalkar, V. K., Bhosale, N. B & Unwale, A. G., 1980. Contribution of phytoplankton photosynthesis to a mangrove ecosystem. *Mahasagar, Bull. Nat. Inst. Oceanogr.* 13: 225 – 234

- Parulekar, A., 1985. Aquaculture in mangrove ecosystems of India: State-of-Art and Prospects. In: *The Mangroves: Proc. Nat. Symp. Biol. Util. Cons. Mangroves*, pp 112 – 118
- Parulekar, A. H., Dwivedi, S. N & Dhargalkar., 1973. Ecology of clam beds in Mandovi, Cumarjua canal and Zuari estuarine system of Goa. *Ind. J. Mar. Sci.* 2: 122 – 126
- Patra, K. C., Bhunia, A. B & Mitra, A., 1988. Ecology of macrobenthos from a coastal zone of West Bengal. *CMFRI Spl. Publ.* 40 - 45
- Patra, K. C., Bhunia, A. B & Mitra, A., 1990. Ecology of macrobenthos in a tidal creek and adjoining mangroves in West Bengal, India. *Environ. Ecol.* 8: 539– 547
- Perkins, E. J., 1976. **The Biology of Estuaries and Coastal Waters.** Academic Press, London 25-37
- Phani Bhushan, G & Amallesh Choudhury., 1987. Carbon, nitrogen and phosphorus in the Hooghly estuary. In: *Proc. Nat. Sem. Estuarine Management*, 4 - 5 June 1987, Trivandrum, pp 453 - 454
- Pierre Fauvel, 1953. **The Fauna of India Including Pakistan, Ceylon, Burma and Malaya.** The Indian Press, Ltd, Allahabad, 507 pp
- Pitchai, R & Govindan, V. S., 1988. **Biological Processes in Pollution Control.** Annamalai University, Madras, 310 pp
- Prabhadevi, L., Natarajan, P., Saraswathy Ammal, G & Abdul Aziz, P. K., 1996. Water quality and benthic fauna of the Kayamkulam backwaters and Arattupuzha coast along southwest coast of India. *Indian. J. Mar. Sci.* 25: 264-267
- Pragatheeswaran, B., Loganathan, A., Ramesh & Venugopalan, V. K., 1986. Distribution of heavy metals and organic carbon in sediments off Madras and Visakhapatnam. *Mahasagar, Bull. Nat. Inst. Oceangr.* 19: 39 – 44
- Prain, D., 1903. Flora of Sunderbans. *Rec. Bot. Surv. India*, 2: 231-370
- Presscott, G. W., 1982. **Algae of the Western Great Lakes Area, with an Illustrated Key to the Genera of Desmids and Freshwater Diatoms.** Koenigutein, Otto Koeltz. 977 pp

- Purushan, K.S., 1991. Prospects of fish production from mangroves ecosystems. *Fish. Chemis.* **11**: 24-26
- Purvaja, R & Ramesh, R., 2002. Natural and anthropogenic effects on phytoplankton productivity in mangroves. *Seshaiyana* **10**: 13 pp
- Qasim S. Z., 1965. Fisheries hydrography, *Fish Technology* **22**: 155 – 157
- Qasim, S. Z & Gopinathan, C. K., 1969. Tidal cycle and the environmental features of Cochin backwater (A tropical estuary) In: *Proc. Indian. Acad. Sci.* B **69**
- Qasim, S. Z., Bhattathiri, P. M. A & Devarsy, V. P., 1972. The effect of quality of illumination as the photosynthesis of some tropical phytoplankton. *Mari. Biol.* **12**: 200 – 206
- Quadros, G., Vidya Mishra, Vidya Ullal, K. S., Athalye, & Gokhale, K. S. R. P., 1996. Meiobenthos of mangrove mudflats from shallow region of Thane Creek, Central West coast of India. *Indian. J. Mar. Sci.* **25**: 137 141
- Quadros, G., Vidya Mishra, Vidya Ullal, K. S., Gokhale, K. S & Athalye, R. P., 2001. Status of Water Quality of Thane Creek (India). *Ecol. Env. & Cons.* **7**: 235 – 240
- Qureshi, J. M., 1957. Botanical and silvicultural features of mangrove forests of Bombay State. In: *Proc. Mangrove Symp.* Min. Food and Agric., Calcutta, pp 20-26
- Rabinowitz, D., 1978. Early growth of mangrove seedlings in Panama and a hypothesis concerning the relationship of dispersal and zonation. *J. Biogeogr.* **5**: 113-133
- Rajagopalan, V. R., 1952. Ecological adaptation of the mangrove vegetation of Pichavaram. *J. Annamalai University*, India
- Rajagopalan, M. S., 1987. Mangroves as component of coastal ecosystems of the Andamans In: *Proc. Symp. Management of Coastal Ecosystems and Oceanic Resources of the Andamans*, Singh, N. N., Gangwar, B., Rao, G. C & Soundararajan, R (Ed.). pp 1 – 7
- Rajamanickam, G. V & Setty, M. G. A. P., 1973. Distribution of phosphorus and organic carbon in the near shore sediments of Goa. *Indian J. Mar. Sci.* **2**: 84 89

- Rajendran, N., 1997. **Studies on Mangrove associated prawn in Pichavaram (southeast coast of India)**. Ph. D Thesis, Annamalai University, India, 131pp
- Rajendran, N & Kathiresan, K., 1999. Do decomposing leaves of mangroves attract fishes? *Current Science* 7: 972 – 976
- Rajendran, A., Venugopal, V. K. & Ramdhas, V., 1973. Studies on marine nitrification. *J. Annamalai Univ.* 30
- Ramachandran, S., 1982. **Studies on blue green algae from Porto Novo marine environment**. Ph. D Thesis, Annamalai University, India, 157 pp
- Ramachandran, K. K & Mohanan, C. N., 1987. Perspectives in management of mangroves of Kerala with special reference to Kumarakom mangroves, a bird sanctuary. In: *Proc. Nat. Sem. Estuarine Management*, 4-5 June 1987, Trivandrum, pp 252 – 257
- Ramachandran, K. K & Mohanan C. N., 1990. The Mangrove Ecosystem of Kerala. Final report, CESS, Trivandrum
- Ramachandran, V. S & Nair, V. J., 1988. **Flora of Cannanore**, Botanical Survey of India. 599 pp
- Ramachandran Nair, P. V., Joseph, K. J., Balachandran, V. K & Kujnukrishnapillai, V., 1975. A study on the primary production in the Vembanad Lake. *Bull. Dept. Mar. Sci.* University of Cochin, 1: 161 - 170
- Ramachandra Rao, C. S. V & Krishnamurthy, K., 1994. Chemoheterotrophy in the mangrove environment. *Current Science* 66: 382 – 384
- Ramachandran, S & Venugopalan, V. K., 1987. Nitrogen fixation by blue green algae in Porto Novo marine environments. *J. Mar. Biol. Assoc. India*, 29: 337 – 343
- Ramachandra, V., Gupta, T. R. C & Katti, R. J., 1984. Macrobenthos and sediment characteristics of Mulki Estuary, West Coast of India, *Ind. J. Mar. Sci.* 13:109 – 115

- Ramachandran, K. K., Mohanan, C. N., Balasubramanian, G., Johnson Kurian & Jessy Thomas., 1986. **The mangrove ecosystem of Kerala: Its mapping, inventory and some environmental aspects.** Final Report, Centre for Earth Science Studies, Trivandrum, Kerala, India, 38 pp
- Ramakrishna T., Naidu A.K., Asokanathan N., Dilipkumar T., Haridasan C., Monomani T., Saseendran C.K & Visalakshi T., 1987. A longitudinal study of the physicochemical characteristics of Olipuramkadavu backwaters – Preliminary report. In: *Proc. Nat. Sem. Estuarine Management*, 4 – 5 June 1987, Trivandrum, pp 223 -225
- Ramamurthy, T, Mahan R & Natrajan R., 1990. Distribution and Ecology of methnogenic bacteria in mangroves sediment of Pichavaram, east coast of India. *Ind. J. Mar. Sci.* **19**: 269-273
- Rao, V. S., 1959. Mangrove forests and the problems of reclaiming saline blanks. In: *Proc. Mangrove Symp.* Calcutta, pp 58 – 65
- Rao, A. N. 1987. Mangrove ecosystems of Asia and the Pacific. In: *Mangroves of Asia and the Pacific: Status and Management.* Technical report of the UNDP – UNESCO research and training pilot programme on mangrove ecosystems in Asia and the Pacific (RAS/79/002) Umali, R. M., Zamora, P. M. R., Gotera, R., Jara, R. S & Camacho, A. S. (Eds.). National mangrove committee of Philippines, Quezon City, Manila, Philippines, pp 1- 41
- Rao, G. C., 1987a. Effect of exploitation and pollution on littoral fauna in Bay Islands. In: *Proc. Symp. Manag. Coastal Ecosystems and Oceanic Resources of the Andamans.* Andaman Sci. Assoc., Port Blair, pp 28 – 39
- Rao, G. C., 1987b. Meiofauna of the Marine National Park, South Andaman. *J. Andaman Sci. Assoc.* **3**: 88 – 97
- Rao, T. A & Sastry, A. R. K., 1972. An ecological approach towards classification of coastal vegetation of India. *Indian Forester* **98**: 594-607
- Rao, T. A & Sastry, A. R. K., 1974. Classification and distribution of Indian mangroves. *Indian Forester* **100**: 438-452

- Rao, T. A., Aggrawal, K. R & Mukherjee, A. K., 1966. Ecological studies of Saurashtra coast and neighboring islands. *Bull. Bot. Surv.* **8**: 60 –67
- Rao, T. A., Suresh, P. V & Shereieff, A. N., 1986. Multiple viviparity in a few taxa of mangroves. *Curr. Sci.* **55**: 295 – 261
- Ravikumar, S., 1995. **Nitrogen fixing Azotobacters from the mangrove habitat and their utility as biofertilizers.** Ph. D. Thesis, Annamalai University, India, 202 pp
- Reddy N.P.C., Rao, B. P., Rao, K. M & Rao V. S., 1994. Seasonal changes in suspended sediment load in the Gauthami – Godavari estuary, *Mahasagar, Bull. Nat. Inst. Oceanogr.* **27**: 47-53
- Remani, K. N., 1979. **Studies on the effect of pollution with special reference to benthos in Cochin backwater.** Ph. D Thesis, University of Cochin, Kerala
- Remani, K. N., Venugopal, P., Saraladevi, K & Unnithan, K. V., 1981. Sediment of a retting yard. *Ind. J. Mar. Sci.* **10**: 41 – 44
- Remani, K. N., Nirmala, E & Nair, S. R., 1989. Pollution due to coir retting and its effect on estuarine flora and fauna. *Int. J. Env't. Studies* **32**: 285 – 295
- Rhods, D. C., Tennore, K & Browne, M., 1975. The role of suspended bottom mud in nutrient cycles of shallow embayment. pp 563 – 579 In: Cronine (Ed.). **Estuarine Research**, Academic Press, London
- Riley, J.P & Chester, R., 1971. **Introduction to Marine Chemistry.** Academic Press, Inc.
- Rittenberg, S. C., Emmr, K. C & Orr, W. L., 1955. Regeneration of nutrients in sediments of marine basins. *Deep. Sea. Res.* **3**: 23 - 45
- Robin, R. S., Sunilkumar, S., Ajithkumar, A & Sajith Kumar, A., 2002. Macrobenthos in relation with physicochemical characteristics along the southern sector of Kerala coast. *Proc. XIV Kerala Science Congress*, 29 – 31 January 2002, pp 439 – 441
- Roman, M. R & Tennore, K. R., 1978. Tidal resuspension in Buzzards Bay I. Seasonal changes in resuspension of organic carbon and chlorophyll a. *Estuar. Coast. Mar. Sci.* **2**: 235-240

- Roxburgh, W., 1814. **A Catalogue of Plants in the Honorable East India Company's Botanical Garden at Calcutta.** Mission Press, Serampore, Calcutta, 105 pp
- RSAM (Remote Sensing Application Mission), 1992. Coastal Environment. Space Application Centre (ISRO), Ahamadabad
- Sahoo, J. K., Hariharan, V & Katti, R. J., 1991. Seasonal distribution of C, N & P in the sediments of Talapady lagoon, Dakshina Kannada. *Environ. Ecol.* **9**: 516 –520
- Sahoo, A. K., Sah, K. D & Gupta, S. K., 1985. Studies on Nutrients Status of Some Mangrove Muds of the Sunderbans. In: *Mangroves: Proc. Nat. Symp. Biol. Util. Cons. Mangroves*, pp 375 – 377
- Santha Nair., 1979. Microbial characteristics of the Laccadive Sea. *Ind. J. Mar. Sci.* **8**: 227 – 231
- Santra, S. C. and Pal, U. C. 1988. Marine Algae of Mangrove Delta Region of West Bengal, India, *Pollut. Biol.* **20**: 31 – 41
- Santra, S. C., Pal, U. C & Choudhury, A., 1991. Marine phytoplankton of the mangrove delta region of West Bengal, India. *J. Mar. Biol. Assoc. India* **33**: 292 –307
- Sankaranarayanan, V. N & Qasim, S. Z., 1969. Nutrients of the Cochin backwaters in relation to environmental characteristics. *Mar. Bio.* **2**: 235 – 247
- Sankaranarayanan, V. N & Panampunnayil, S. U., 1979. Studies on organic carbon, nitrogen and phosphorus in sediments of the Cochin backwater, *Ind. J. Mar. Sci.* **8**: 27 - 30
- Sarala Devi, K. S & Venugopal, P., 1989. Benthos of Cochin backwaters receiving industrial effluents. *Ind. J. Mar. Sci.* **18**: 165-169
- Sarala Devi, K & Sankaranarayanan, V. N., 1994. Benthos of Beypore and Korapuzha estuaries of North Kerala. *Proc. VI Kerala Science Congress*, 27 – 29 January 1994, Trivandrum, pp 64 – 67
- Sarala Devi, K., Sankaranarayanan, V. N & Venugopal P., 1991. Distribution of nutrients in the Periyar river estuary. *Indian J. Mar. Sci.* **20**: 49-54

- Sasekumar, A., 1984. Secondary productivity in mangrove forest. In: *Proc. UNESCO Workshop Prod. Mangr. Ecosys. Mange, Implication*, J. E. Ong and W.K.Gong (Ed.). University.Sains Malaya, Penang, Malaysia
- Sasekumar, A., Chong, V.C., Lehand M.U & Cruz, R.D.,1992. Mangroves as habitats for fish and prawns. *Hydrobiologia* **247**:195-207
- Sarupriya, J. S & Bhargava, R. M. S., 1998. Seasonal distribution of chlorophyll a in the EEZ of India. *Ind. J. Mar. Sci.* **27**: 292 – 297
- Satyanarayanan, D., Panigrahy, P. K & Sahu, S. D., 1993. Texture, mineralogy, carbon, nitrogen and phosphorus of Visakhapatnam shelf sediments, east coast of India. *Ind. J. Mar. Sci.* **22**: 235 – 240
- Saxena, D., Lokabharathi, P. A & Chandramohan, D., 1988. Sulfate reducing bacteria from mangrove swamps of Goa, Central West Coast of India. *Ind. J. Mar. Sci.* **17**: 153 – 157
- Schimper, A. F. W., 1903. **Plant Geography upon a Physiological Basis** (Transl.). Fischer, W. R., Groom, P & Balfour, I. B (Ed.). Clarendon Press, Oxford
- Scott, D. A., 1989. A directory of Asian wetlands, IUCN.
- Selvam,V., Azariah, J & Azariah, H., 1992. Diurnal variation in physicochemical properties and primary production in the interconnected marine, mangrove and freshwater biotopes of Kakinada coast, Andhra Pradesh, India. In: Jaccarini, V & Vartens, E (Eds.). **The Ecology of Mangrove and Related Ecosystems.** **247**: 1-3 & 181 –186
- Semesi, A. K., 1986. Zonation and vegetation structure of mangrove communities in Tanzania. In: Status and Utilization of Mangroves, *Proc. of a workshop on Save and The Mangrove Ecosystems in Tanzania*, 21 – 22, February 1986, Dar es salaam, pp 5 - 13
- Sengupta R & Upadhyay S., 1987. Marine Science. Dr. S.Z. Quasim Sastyabdi purti Felicitation. 291 pp
- Sengupta, A & Chaudhury, S., 1990. Halo tolerant *Rhizobium* strains from mangrove swamps of the Ganges River Delta. *Indian J. Microbiol.* **30**: 483 – 484

- Sengupta, A & Chaudhury, S., 1991. Ecology of heterotrophic dinitrogen fixation in the rhizosphere of mangrove plant community at the Ganges River Estuary in India. *Oecologia*, **87**: 560 – 564
- Sengupta, A & Chaudhury, S., 1993. Studies on the physicochemical properties of soils of the eco-successional stages of mangrove sediments in the Sunderbans. *Indian J. Forestry* **16**: 250 - 254
- Shanmukhappa, H., 1981. **Primary productivity by phytoplankton under controlled laboratory conditions.** M. Phil dissertation, Jawaharlal Nehru University, New Delhi
- Shanmukhappa, H. 1987. Organic matter and C, N, P in sediments of Porto Novo. In: *Proc. Nat. Sem. Estuarine Management*, 4 –5 June 1987, Trivandrum pp 128 – 133
- Shanmukhappa. H., Banerjee, D. K & Krishnamurthy, K., 1986. Humic acid, copper and iron in the sediments of Porto Novo, India In: *Pro. Int. Conf. Chemicals in the Environment*, Lester, J. N., Perry, R & Sterritt, R. M. (Eds.). pp 800 – 808
- Shanmukhappa, H., Neelakantan, B & Kusuma Neelakantan., 1987. Ecological and physical investigation into sediments humic acid from two mangrove habitats and an estuary. In: *Proc. Nat. Seminar on Estuarine Management*, 4 – 5 June 1987, Trivandrum, pp 134 – 137
- Shoba, V & Ignatius Miranda, P., 1987. Nature of plankton production in Kadinamkulam and Ashtamudi estuary of Kerala. In: *Proc. Nat. Sem. Estuarine Management*, 4 – 5 June 1987, Trivandrum, pp 307 – 317
- Sidhu, S. S., 1961. Vegetation of east Godavari. *Proc. Indian Sci. Congr.* **3**: 358 – 359
- Sidhu, S. S., 1963. Studies on mangroves. *Proc. Indian Acad. Sci.* **33**: 129 – 13
- Sidhu., S. S., 1975 a. Culture and growth of some mangrove species. In: *Proc. Intern. Symp. Biol. & Manage. Mangroves.* Walsh, G. E., Snedakar, S. C & Teas, H. J (Eds.). Inst. Food & Agric. Sci., Univ. Florida, Vol. I pp 394 – 401

- Sidhu, S. S., 1975 b. Structure of epidermis and stomatal apparatus of some mangrove species. In: *Proc. Intern. Symp. Biol. & Manage. Mangroves*. Walsh, G. E., Snedakar, S. C & Teas, H. J (Eds.). Inst. Food & Agric. Sci., Univ. Florida. Vol II, pp. 569 – 578
- Silas, E. G. 1987. Mangroves and Fisheries – Management Strategies. In: *Proc. Nat. Sem. Estuarine Management*, 4 –5 June 1987, Trivandrum, pp 258-261
- Sivakumar, V., Thangaraj, G. S., Chandran, R & Ramamoorthi, K., 1983. Seasonal variations in C, N & P in sediments of the Vellar estuary, Porto Novo. *Mahasagar, Bull. Natn. Inst. Oceanogr.* **16**: 175–181
- Snedaker, S. C., 1978. Mangroves: Their Value and Perpetuation, Nature and Resources. UNESCO. **14**: 6 – 13
- Snedaker, S.C., 1987. Mangroves forests of South America: some traditional uses. *Backwan* 10-12
- Soegiarto, A., 1984. The mangrove ecosystem in Indonesia, its problems and management. In: *Physiology and Management of Mangroves*. Teas, H. J (Ed.). Dr. W. Junk Publ., Hague, pp 69-78
- Sooraj, S., Preeja, N. B., Baji, S & Sangeetha, P. Viswan., 2000. Spatial variation of nutrient content and water quality parameters in Vembanad Lake, South of Thanneermukkam Bund. *Proc. XII Kerala Science Congress*, January 2000, Kumily, pp 640 - 643
- Subrahmanian K. N., 2002. Wetland Conservation and management in India: Wetland resources with particular reference to the mangroves of Kerala. 119 -130 pp
- Sundararaj, V & Krishnamurthy, K., 1975. Nutrients and plankton: Backwater and mangrove environment. pp 273 – 290 In: *Estuarine Biology*. Hindustan Publishing Corporation, Delhi
- Sunil Kumar, R., 2000. A review of biodiversity studies of soil dwelling organisms in Indian mangroves. *Zoo's Print Journal* **15**: 221 - 227

- Sunil Kumar, R., 2001. Occurrence and distribution of juveniles of *Macrobrachium rosenbergii* (de man) in the mangroves soil from Cochin backwaters. *Indian J. Fish.* **48**
- Sunil Kumar, R., 2001. Mangrove detritus loading, tidal export and its large-scale effect on promoting biodiversity resources. *Seshaiyana* **9**: 6 – 8 pp
- Sunil Kumar, R & Antony, A., 1994. Preliminary studies on the polychaete fauna of the Mangroves areas of Cochin. *Proc. VI Kerala Science Congress*, 27 – 29 January 1994, Trivandrum, pp 74-77
- Suresh Kumar, S & Mohan Kumar, B., 1997. Floristics, biomass production and edaphic attributes of the mangrove forests of Pudukkottai, Kerala, *Ind. J. For.* **20**: 136 - 143
- Susumu Kuraishi., Kiyohide Kojima & Hiroshi Miyauchi., Naoki Sakurai & Hiroyuki Tsubota., 1985. Brackish water and soil components of mangroves forests on Iriomote Island, Japan *Biotropica* **17**: 277 – 286
- Talwar, P. K & Jhingran, A. G., 1991. **Inland Fishes. Vol. I & II.** Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi, 1158 pp
- Tandon, H. L. S., 1993. **Methods of Analysis of Soils, Plants, Waters and Fertilizers.** Fertilizers Development and Consultation Organization, New Delhi, India, 144 pp
- Thom, B. G., 1982. Mangrove ecology - A geomorphological perspective. In: **Mangrove Ecosystems in Australia: Structure, function and management.** Australian National Mangrove Workshop, Canberra, ANU Press, pp 3-17
- Thomas, K. J., 1962. A survey on vegetation of Veli, Trivandrum with special reference to ecological factors. *J. Indian Bot. Soc.* **42**: 104 - 131
- Thomas, G & Fernandez, T. V., 1993. A comparative study on the hydrography and species composition in three mangrove ecosystems of Kerala, South India. *J. Ecobiol* **5**: 181-188
- Thresiamma Mathew & Balakrishnan Nair, N., 1980. Phytoplankton of the Ashtamudi Estuary, Kerala, *Ind. J. Mar. Sci.* **9**: 253 – 257
- Tomlinson, P. B., 1986. **The Botany of Mangroves.** Cambridge Univ. Press, Cambridge, U. K., 419 pp

- Transley, A. G & Fritsch, F. E., 1905. Sketches of vegetation at home and abroad 1. The flora of the Ceylon Littoral. *New Phytol.* 4: 27 – 55
- Trivedy, R. K & Goel, P. K., 1986. **Chemical and biological Methods for Water Pollution.** Environmental Publications. 247 pp
- Trivedy, R. K., Goel, P. K & Trisal, C. L., 1987. **Practical Methods in Ecology and Environmental Science.** Enviro Media Publications, Karad, India, 340 pp
- Troup, R. S., 1921. **The Silviculture of Indian Trees, Vols. I-III.** Clarendon Press, Oxford, London
- Twilley, R. R., Chen, R. H & Hargis, T., 1992. Carbon sink in mangroves and their implications to carbon budget of tropical coastal ecosystems. *Water, Air & Soil Pollution* 64: 265-288
- Unni, P. N., 2002. Biodiversity of mangroves and avifauna in wetlands of Kerala: Need and strategies for conservation. pp 92 – 105. In: **Proc. Internat. Conf. Biodiversity and Environment**, 22-26 January 2002, Kozhikode, Kerala, Oisca South India Chapter
- Unni, P. N., 2003. Conservation of Mangroves in Kerala. pp16 – 27. In: Madhyastha, M. N., Sridhar, K. R & Ahana Lakshmi (Eds.). **Prospects and Problems of Environment Across the Millennium.** Daya Publishing House, New Delhi
- Unni, P. N & Jayakumar, P., 1997. Mangroves of Kerala: Need for conservation and management. In: **Proc. International Seminar on Mangroves**, 25-27 March 1997, Andhra University, Waltair, India, pp 58
- Untawale, A. G., 1984 a. Present status of mangroves along the West coasts of India. In: **Proc. Asian. Symp. Managr. Environ. Res. Manage.** Soepadmo, E., Rao, A. N & Macintosh, D. J (Ed.). Univ. Malaya, Kuala Lumpur, Malaysia, pp 57- 74
- Untawale, A. G., 1984 b. Mangroves of India: Present status and multiple use practices. Status Report, UNDP/UNESCO Regional Mangroves Project for Asia and the Pacific.

- Untawale, A. G., 1987. Country Reports: Asia. pp 51-87. In: **Mangroves of Asia and Pacific: Status and Management**. Tech. Rep., UNDP/UNESCO Research and Training Pilot Programme on Mangrove Ecosystems in Asia and the Pacific.
- Untawale, A. G., 1987. Conservation of Indian Mangroves: A National Perspective. In: Rao, T. S. S., Natarajan, R., Desai, B. N., Narayanaswamy, G & Bhatt, S. R (Eds.). **A Special Collection of Papers to Felicitate Dr. S. Z. Quasim on his Sixtieth Birthday**, pp 85-104
- Untawale, A. G., 1991. Research and management of mangrove ecosystems in India. pp 27-33 In: Deshmukh, S. V., Mahalingam, R (Eds.). **A Global Network of Mangrove Genetic Resource Centres. Proc. Project Formation Workshop**, Centre for Research on Sustainable Agric. & Rural Dev., Madras, India
- Untawale, A. G., 1992. Rehabilitation of coastal wetlands of India. In: Wali, M. K (Ed.). **Ecosystem Analysis and Synthesis**. Acad. Press, The Hague 2: 333-348
- Untawale, A. G., 1998. Management of mangroves for energy needs. *Seshaiyana* 5: 51 - 56
- Untawale, A. G & Jagtap, T. G., 1991. Floristic composition of the deltaic regions of India. In: Vaidyanadhan, R (Ed.). **Quaternary Deltas of India**. Geol. Soc. India, Bangalore, 22: 243-263
- Untawale, A. G & Parulekar, A. H., 1976. Some observations on the ecology of an estuarine mangrove of Goa. *Mahasagar, Bull. Natl. Inst. Oceanogr.* 9: 57-62 pp
- Untawale, A. G & Parulekar, A. H., 1978. Status Report of the Pirotan Islands in the Gulf of Kutch for development of a conservation plan. Report submitted to World Wildlife, Bombay
- Untawale, A. G., Wafar, S., 1984-85. **Karnataka State Environment Report**, pp 1-17
- Untawale, A. G., Balasubrahmanian, T & Wafar, M. V. M., 1977. Structure and production in a detritus-rich estuarine mangrove swamp. *Mahasagar, Bull. Nat. Inst. Oceanogr.* 10: 173 - 177

- Untawale, A. G., Dwivedi, S. N & Singhal, S. Y. S., 1973. Ecology of mangroves in Mandovi and Zuari estuaries and interconnecting Cumbarjua Canal of Goa. *Indian J. Mar. Sci.* 2: 47-63
- Untawale, A. G., Wafar, S & Jagtap, T. G., 1980. Application of remote sensing techniques to study the distribution of mangroves along the estuaries of Goa. pp 51-67 In: **Wetlands: Ecology and Management. Proc. First Intern. Wetland Conference.** Brij Gopal, Turner, R. E., Wetzel, R. G & Whigham, D. F (Eds.). 10-17 Sept. 1980, New Delhi, National Inst. Ecology & Intern. Scientific Publications, Jaipur, India
- Untawale, A. G., Wafar, S & Jagtap, T. G., 1992. Status of mangroves along the countries bordering the Arabian Sea. pp 239-245. In: Desai, B. N (Ed.), **Oceanography of the Indian Ocean.** Oxford & IBH, New Delhi, India
- Upadhyay, S., 1988. Physicochemical characteristics of Mahanadi estuarine ecosystem, east coast of India. *Ind. J. Mar Sci.* 17: 19-23
- Vaithyanathan P., Jha P.K & Subramaniam V., 1993. Phosphorous distribution in the sediments of the Hooghly (Ganges) estuary, India. *Estuarine, Coastal and Shelf Science* 37: 603-614
- Valarmathi,S., Azariah, J & Govindasamy, C. 2002. Seasonal variation of physicochemical parameters in estuarine and coastal waters samples of Madras Coast, Bay of Bengal, India. *Poll. Res.* 21: 177 – 185
- Van Loon C. Jon., 1985. **Selected Methods of Trace Metal Analysis- Biological and Environmental Samples in Monograph on Analytical Chemistry and its Applications.** John Wiley, 357 pp
- Vannucci, M., 1989. **The Mangroves and Us: A Synthesis of Insights.** Indian Association for the Advancement of Science, New Delhi, India
- Vannucci, M., 1991. Saving a crucial ecosystem. **Survey of the Environment.** The Hindu, Madras, pp 157-161
- Vareethiah, K. 2001. Sediment nutrient distribution in a bar-built estuary. *Ecol. Env. & Conserv.* 7: 179 – 183
- Van , H. Rheede., 1678 – 1693. **Hortus Indicus Malabaricus.** 12 Vols. Amsterdam

- Varshney, P. K., 1985. Meiobenthic study off Mahim (Bombay) in relation to prevailing organic pollution. *Mahasagar, Bull. Natn. Inst. Oceanogr.* **1**: 27-35
- Venkatesan, T & Natarajan, R., 1987. Influence of certain hydrographical parameters on the fungal population of Pichavaram mangroves near Porto Nova. In: *Proc. Nat. Sem. Estuarine Management*, 4 – 5 June 1987, Trivandrum, Kerala, pp 455-457
- Venkateswarlu, J., 1944. The estuarine flora of the Godavari. *J. Bombay. Nat. Hist. Soc.* **44**: 431- 435
- Venkataswamy Reddy, H. R & Hariharan, V., 1986. Distribution of total nitrogen, total phosphorus and organic carbon in the sediments of Mangalore. *Mahasagar, Bull. Nat. Inst. Oceanogr.* **19**: 119 - 122
- Venugopalan V.K & Rajendran, A., 1975. Dissolved and particulate Nitrogen in Vellar Estuary. *Bull. Dept. Ma. Sci. Univ. Cochin* **7**: 885-897
- Venugopalan, V. K., Vijayalakshmi, G. S & Rajendran, A., 1981. Nitrate-phosphate relationship in a tropical estuarine environment. *Ind. J. Mar. Sci.* **10**: 379 - 381
- Voccaro, R. F & Ryther, J. H., 1960. Marine phytoplankton and distribution of nitrite in the sea. *J. Cons. Perm. Int. Explor. Mer.* **25**: 260-271
- Wafar, S., Untawale A.G & Wafar, M., 1997. Litter fall and energy flux in mangrove ecosystem, *Estuarine, Coast. Shelf Sci.* **44**: 11-124
- Waghmode, A. P., 1987. Preliminary studies in the Nitrogen dynamics of estuarine ecosystem. *J. Mar. Biol. Assoc. India* **29**: 362 – 364
- Waheed Khan, M. A., 1957. Ecological studies of the mangrove forests in India. In: *Proc. Mangrove Symp.* Min. Food and Agric., Calcutta, pp 97-107
- Walkley, A & Black. I. A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **37**: 29-38
- Walsh, G. E., 1974. Mangroves: A review. In: Peinold, R. J. & Queen, W. H (Eds.). *Ecology of Halophytes*. Acad. Press Inc., London, pp 51-174
- Yazdandoost M. Y & Katdare, M. S., 2000. Study of the population density of plankton with respect to physicochemical characteristics water in Pune rivers-India. *Ecol. Env. & Conserv.* **6**: 127 – 135 pp

**ECOLOGICAL STUDIES ON
THE MANGROVES OF
VALAPATTANAM AND THALASSERY
RIVER BASINS**

Thesis submitted to
University of Calicut
in part fulfilment of
Doctor of Philosophy in Botany

Ms K LAKSHMI

Centre for Water Resources Development & Management
Kunnamangalam Kozhikode Kerala

DECEMBER 2002

92/278

7.0 PUBLICATIONS

1. Lakshmi, K., Unni, P. N., Neelakantan, N & Harikumar, P. S., 2000. Environmental status of the mangrove ecosystem in Valapattanam river basin, Kerala. *Ecol. Environ. & Conserv.* **6**: 363 – 371
2. Lakshmi, K & Unni, P. N., 2000. Biodiversity of mangroves and avifauna in wetlands of Kerala. *10th Swadeshi Science Congress*, 7-9 November 2000, Cochin, Kerala. pp 71(Abstr.)
3. Lakshmi K & Unni, P. N., 2002. Spatial and temporal variations in organic carbon, nitrogen and phosphorous in mangrove sediments of two riverine ecosystems of Kerala. *Asian J. Microbiol. Biotechnol. & Environ. Sci.* **4**: 259 – 263
4. Unni, P. N & Lakshmi, K., 2002. Spatial and temporal variations in organic and inorganic nutrients in mangrove sediments of Valapattanam and Thalassery river basins. *Proc. National Seminar on Current Environmental Problems and Management*, 01 - 03 August 2002, Irinjalakuda, Kerala, pp 151 - 159
5. Lakshmi, K & Unni, P. N., 2003. Distribution of Nutrients and Phytoplankton in Thalassery and Valapattanam Rivers, North Kerala. *Proc. National Seminar on River Conservation and Management*. 02 - 04 January 2003, Thrissur, Kerala (Accepted for publication in Proceedings Volume)
6. Lakshmi, K., Unni, P. N & Neelakantan, N., 2003. Seasonal distribution of exchangeable sodium, potassium calcium and magnesium in the mangrove sediments of Valapattanam and Thalassery rivers, Kerala. *Asian J. Microbiol. Biotechnol. & Environ. Sci.* (Accepted for publication in Vol. 5, 2003)

Environmental Status of the Mangrove Ecosystem in Valapattanam River Basin, Kerala

K. Lakshmi¹, P. N. Unni², N. Neelakandan³ and P.S. Harikumar⁴

^{1,2,4}Central Water Analysis Laboratory,
Centre for Water Resources Development and Management,
Calicut 673 571, Kerala;

³Professor and Head, Department of Botany,
University of Calicut 673 635, Kerala

ABSTRACT

Baseline study of the aquatic environment of the mangrove ecosystem of Valapattanam river basin, Kerala was studied. The physicochemical and biological quality of water and sediments of mangrove and non-mangrove areas were assessed. The presence of high amounts of nutrients especially sodium, potassium and organic carbon was a salient feature of the mangrove sites. Seasonal variations in the nutrient content in water and sediments are presented. Benthic fauna of mangrove sites was dominated by Polychaetes. Bacillaryophyceae and Protozoan dominated the phyto and zooplankton respectively. Estimation of chlorophyll a, b, c and total chlorophyll done during the seasons studied indicated the mangrove sites to be highly productive. Faecal contamination was observed in the sampling sites. The dominant fish species observed were *Mughil cephalus*, *Etroplus suretensis*, *Lutiganus* sp., etc. Prawns and crabs were also abundant in mangrove sites. The dominant mangrove genera are *Rhizophora*, *Avicennia*, *Sonneratia*, *Acanthus* and *Acrostichum*. Medicinally important plants were also recorded among mangrove associates. Very high nutrient content, optimum salinity, pH and tidal action in the mangrove environment favours their development and distribution in the river basin.

Key words : Valapattanam River; Mangroves: *Avicennia officinalis*; *Acanthus illicifolius*; *Kandelia candel*; *Acrostichum aureum*; *Rhizophora apiculata*; Phytoplankton; Zooplankton; Benthic Fauna; Water Quality; Sediment Quality; Chlorophyll; Productivity.

Introduction

Mangrove ecosystem is a complex, intertidal, halophilous, wetland ecosystem, which is a natural reservoir of biodiversity constituting a bridge between the terrestrial and aquatic ecosystem. The mangrove-associated fauna and microorganisms are interdependent ecosystem and would not survive in isolation if any one component of the ecosystem is disturbed. The micro-flora and fauna associated with the system serve in controlling pH, leaching of metals and nutrient cycling (Ananthkrishnan, 1982). The mangroves harbour a rich community of plankton, which form the source of food for crabs, prawns and fishes. They also form the feeding, breeding and nursery

grounds for many marine and freshwater fishes. They clean polluted water, prevent floods and bank erosion, reduce the fury of waves and wind, recharge groundwater and provide unique habitat for a wide variety of fauna and flora associated with them. Mangroves are rated as one of the highly productive ecosystems of the world (Vannucci, 1991; Mohanan, 1999) and play a key role in boosting productivity in coastal aquaculture (Kathiresan, 1991). The withered mangrove litter are colonized by microorganisms which enrich water with particulate organic matter which form the food for several marine organisms like carbs, worms, shrimps and fishes (Kathiresan, 1991). Mangroves adjacent to large cities and habitations receive a considerable amount of industrial and urban

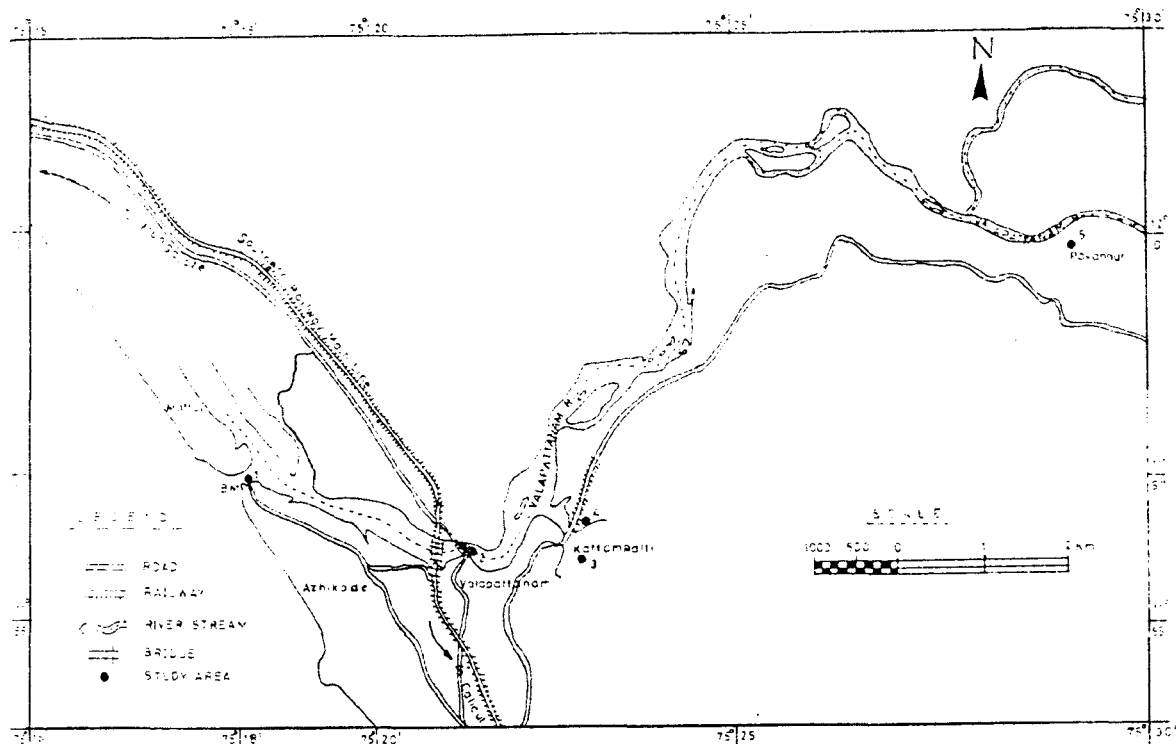


Fig. 1. Sampling Sites in Valapattanam River Basin

pollutants apart from pesticides and fertilizers from surrounding cultivated fields. The mangrove sediments bind toxic contaminants and prevent them from entering into aquatic organisms. They, in fact, act as bioindicators of pollutants and biofilters of toxic chemicals without inflicting much damage to the vegetation (Mohan, 1999).

Kerala, which once had a luxuriant mangrove vegetation occupying 70,000 ha supports only about 1700 ha. of mangroves at present (Chand Basha, 1991, 1992). A review of the data on the distribution of mangroves of Kerala shows that more area under mangroves exist in the northern districts particularly Kozhikode and Kannur (Unni and Jayakumar, 1997; Unni, 1998; Mohan, 1999). So far no detailed systematic studies have been done on the water, sediment and biological quality of Valapattanam river basin. In this paper, environmental status of the mangrove ecosystem of Valapattanam river basin is reported.

Study Area

The Valapattanam river basin of Kannur district, Kerala State (between 75° 18' – 75° 30' latitude and

between 11° 57' and 12° 0' E longitude) (Fig. 1) with a basin area of 1867 km², originate from the Western Ghats and drain into the Arabian sea after traversing a distance of 110 km. Baseline data on the environmental status of the ecosystem was collected from 5 randomly selected sampling sites, depending upon the variation in salinity, sources of pollution, diversity of mangroves, etc. Station I at the bar mouth (BM) is a non-mangrove site, and stations II, III, IV are saline situated at a distance of 6 km, 6.45 km, 9.5 km from the BM respectively, showing dense mangrove vegetation. Station V is a fresh water zone without mangroves. The sampling points are demarcated in Fig. 1. Water and sediment samples were collected for physicochemical and biological analysis from the sampling sites. The sampling was done in pre-monsoon and monsoon seasons.

Materials and Methods

Physicochemical, biological and bacteriological analysis of water samples were done as per the Standard Methods for the Examination of Water

basin was assessed by studying the seasonal variation in temperature, pH, EC, DO, BOD, salinity, total hardness, total dissolved solids, chlorides, nitrate, phosphate, sulphate, sodium, potassium, calcium and magnesium during the pre-monsoon and monsoon seasons of 1999.

Temperature and pH are important parameters controlling fish life. The maximum temperature of 24 °C and minimum of 16.5 °C was recorded during the period of study. pH of the river water varied from 6.4–7.87 which is congenial for the fishes, especially at the mangrove sites, where high fish population was noticed. A pH range of 6.5–9.0 has been reported to be most ideal for fish culture (Jhingran, 1982). Maximum EC and TDS were observed at the bar mouth (46,975 μ S and 30,064 ppm) and minimum at station V (36.7 μ S & 23.48 ppm) where the water is fresh and unpolluted. Dissolved oxygen is an important factor for the aquatic life and reflects the physical and biological processes prevailing in water (Trivedi and Goel, 1984). DO was high during the monsoon when compared to pre-monsoon season. This may be due to the intrusion of fresh DO rich water from the river into the coastal waters and the resultant mixing and circulation of water. DO values varied from 6.53–7.53 ppm during the pre-monsoon and 7.66–8.86 ppm in monsoon

season. DO below 5 ppm may be unfavourable for a productive water body, where as above 7 ppm is optimum for a productive water body (Jhingran, 1982). Mangrove rich sites II, III & IV recorded high DO values which are an indication of productive water body. The BOD of the tidal waters and estuaries is affected by salinity resulting in very low values (Jhingran, 1982). The BOD values were low in Valapattanam river basin. High salinity was noticed near the bar mouth, except during the monsoon season. The high values during the pre-monsoon period were found to be related to the lean summer flows and increase in evaporation (Prabhadevi *et al.*, 1996). Salinity as high as 32.7 ppt was recorded in the lower reaches of Valapattanam river due to salinity intrusion from the estuary. With the onset of monsoon during May, salinity declined to below 2 ppt in all sampling sites. High values were recorded for total hardness was recorded during the pre-monsoon season. Nitrate-nitrogen and phosphate contents were also low in both seasons. Nitrate content varied from 0.07–0.3 ppm in pre-monsoon and 0.22–0.5 ppm during monsoon season. Station IV showed high values for nitrate-nitrogen, which is the most mangrove-rich area. Maximum concentration of phosphate recorded was 0.015 ppm and minimum was 0.003 ppm. Very high sulfate

Table 2. Seasonal Changes in Physicochemical Characteristics of Sediments of Valapattanam River Basin

Parameters	Premonsoon					Monsoon				
	V-1	V-2	V-3	V-4	V-5	V-1	V-2	V-3	V-4	V-5
pH	8.18	6.83	6.62	6.52	6.43	9.29	4.62	3.56	4.52	6.84
EC (μ S/cm ²)	4780	7690	3670	2940	41.8	137.8	1546	2120	1370	19.1
Organic carbon (%)	0.878	4.009	0.798	0.837	0.937	0.169	3.37	3.17	1.75	0.38
Nitrate (mg/100g)	1.3	0.24	0.56	0.92	0.12	0.56	0.25	0.72	0.32	0.2
Sulfate (mg/100g)	125	750	140	125	50	15	410	750	400	3
Chloride (mg/100g)	720	1200	560	440	12	36	32	28	56	12
Exchangeable Na (mg/100g)	96	176	48	48	1	8	68	44	80	8
Exchangeable K (mg/100g)	528	64	48	32	1	2.6	32	2.7	48	0.88
Exchangeable Ca (mg/100g)	93	86	28	25	6	48	80	82	80	36
Exchangeable Mg (mg/100g)	39	93	29	45	8	2.9	144.8	120	137	23
Available P (mg/100g)	11	6	2	1	1	1.1	1.2	1.4	1	1.8

content was also noticed during pre-monsoon with a maximum of 1200 ppm at Station I and minimum of 40 ppm at station V with seasonal variations. Sodium and chlorides being the major constituents of seawater imparting salinity, high concentration of sodium and chloride were recorded at the bar mouth (Site.1) and mangrove sites (II, III, IV) during the pre-monsoon with corresponding reduction during monsoon season. Corresponding to the total hardness, calcium and magnesium concentra-

tions were also found to be high. Stations II and IV showed a slightly high concentration of calcium. This may be due to the collection and deposition of lime shell by the local people. Mangrove sites II, III, IV showed high potassium concentration during pre-monsoon. Like sodium, potassium also does not undergo precipitation. Hence, during monsoon decrease in concentration of sodium and potassium was recorded, probably due to dilution by the monsoon flows.

Table 3. Seasonal variation of Phytoplankton and zooplankton in valapattanam river basin

Sampling Sites	Phytoplankton		Zooplankton	
	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon
V-1	Class - Chlorophyceae <i>Scenedesmus</i>	Class - Chlorophyceae <i>Clasterium</i>	Phylum - Protozoa Class - Ciliata <i>Euplotes</i>	Phylum - Aschelminthes Class - Rotifera <i>Rotifer</i>
	Class - Bacillariophyceae <i>Navicula</i> <i>Eunotia</i>	Class - Bacillariophyceae <i>Coscinodiscus</i> <i>Diatom</i>		Phylum - Protozoa Class - Ciliata <i>Paramecium</i>
V-2	Class - Bacillariophyceae <i>Eunotia</i> <i>Nitzschia</i> <i>Cyclotella</i> <i>Coscinodiscus</i>	Class - Chlorophyceae <i>Netrium</i> Class - Bacillariophyceae <i>Pleurosigma</i> <i>Surirella</i> <i>Coscinodiscus</i> <i>Pinnularia</i>	Phylum - Protozoa Class - Ciliata <i>Euplotes</i>	Phylum - Protozoa Class - Rhizopoda <i>Euglypha</i> Phylum - Aschelminthes Class - Rotifera <i>Rotifer</i> Class - Nematoda <i>Strongyloides</i>
	Class - Chlorophyceae <i>Ankistrodesmus</i> <i>Pediastrum</i> Class - Bacillariophyceae <i>Pinnularia</i> <i>Pleurosigma</i> <i>Diatoms</i> <i>Eunotia</i> <i>Coscinodiscus</i>	Class - Bacillariophyceae <i>Navicula</i>	Phylum - Protozoa Class - Rhizopoda <i>Euglypha</i> <i>Diffugia</i> Class - Ciliata <i>Euplotes</i>	Phylum - Aschelminthes Class - Nematoda Worms
V-4	Class - Chlorophyceae <i>Ulothrix</i> <i>Triploceras</i>	Class - Chlorophyceae <i>Cosmarium</i> <i>Scenedesmus</i> <i>Staurastrum</i> <i>Coelastrum</i>	Phylum - Aschelminthes Class - Rotifera <i>Keratella</i>	—
V-5	Class - Chlorophyceae <i>Ulothrix</i> <i>Pediastrum</i> Class - Bacillariophyceae <i>Diatoms</i>	Class - Bacillariophyceae <i>Synedra</i> <i>Cyclotella</i>		Phylum - Aschelminthes Class - Rotifera <i>Rotifer</i> Phylum - Protozoa Class - Ciliata <i>Stylonchia</i>

Physicochemical and biological status of sediments of Valapattanam river basin during the pre-monsoon and monsoon seasons is presented in Table 2. During the pre-monsoon season, pH of sediments of all sites was almost neutral except at the bar mouth where it was alkaline. During the monsoon season, sediment was acidic except at the bar mouth where alkalinity was noticed. The mangrove sediments were found to be acidic. Mangroves prefer low pH *i.e.*, the sediments may become acidic due to the reduction of sulphides to sulphate with consequent formation of sulfuric acid in anoxic conditions resulting from the compaction of material deposited by tidal waters. (Vannucci, 1989). Organic carbon content in Valapattanam river sediments was found to be high in the mangrove sites during monsoon season, the main source being

the plant and animal matter brought in through the run off. Abundance of particulate organic matter is a characteristic of mangrove sites. (Vanucci, 1989) and the nature of sediments has been reported to influence the abundance of organic matter (Badarudheen *et al.*, 1997). Comparatively low organic carbon was observed at site I (bar-mouth), where the sediment was mainly composed of sand. Generally higher concentrations were observed in all other stations, especially the mangrove sites II, III & IV, where the sediment was clayey silt or silty clay. This may be due to the decay and deposition of mangrove litter and organic matter brought in from land to these sites. A similar situation has been reported from Pitchavaram mangroves. The Valapattanam river sediments recorded organic carbon values ranging from 4.01% - 0.38%, with a maximum of 4.01% at site II. The concentration of organic matter in sediments were of the order Mangroves > Freshwater > Estuary, with highest at the mangrove sites (4.01%). Exchangeable sodium, potassium, calcium and magnesium values were also found to be high during the pre-monsoon season, in sites I, II, III and IV. The enhanced values of sodium and potassium in the mangrove sites may be due to the presence of these ions in aqueous solution which fill the pore spaces of sediments and fixed with lattices of clay minerals, as has been reported for Veli mangroves (Badarudheen and Sakkir, 1998). A major portion of the sodium in mangrove environment is fixed in clay minerals and the higher values of sodium over potassium may be due to this tendency. The potassium content in the mangrove sediments may be from the decayed mangrove litter (Badarudheen and Sakkir 1998). Chloride content in the mangrove sediments was also noticeably high. Nitrate-nitrogen recorded low

Table 4. Benthic Fauna of Valapattanam River Basin

Number	Pre-monsoon	Monsoon
V-1	Nil	Nil
V-2	Nil	Phylum- Arthropoda Crab Phylum- Annelida Leech <i>Stylaria</i>
V-3	Phylum- Mollusca <i>Vellorita sp.</i>	Phylum- Annelida Polychaete
V-4	Phylum- Mollusca Gastropod	Phylum- Annelida Polychaete Phylum- Arthropoda Insect larva
V-5	Phylum- Annelida Polychaete	Nil

Table 5. Seasonal Variation in Chlorophyll Content of Valapattanam River Basin (mg/L)

Sampling Sites	Pre-monsoon				Monsoon			
	Chl. a	Chl. b	Chl. c	Total	Chl. a	Chl. b	Chl. c	Total
V-1	9.9	13.7	37.6	61.2	0.68	14.58	3.48	18.74
V-2	7.5	7.7	25.3	40.5	3.39	217.02	31.56	251.97
V-3	4.7	3.3	14.3	22.3	2.17	3.3	15.26	20.73
V-4	69.3	2.7	12.2	84.2	5.85	17.6	19.98	43.43
V-5	0.5	8.2	23.6	32.3	2.70	13.9	11.78	28.38

Table 6. Vegetation of Valapattanam River Basin*Mangroves*

1. *Avicennia officinalis* L.
2. *Avicennia marina* (Forsk.) Vierh.
3. *Aegiceras corniculata* (L.) Blasco
4. *Derris trifoliata* Lour
5. *Excoecaria agallocha* L.
6. *Kandelia candel* (L.) Druce
7. *Rhizophora mucronata* Lamk
8. *Rhizophora apiculata* Bl.
9. *Sonneratia caseolaris* (L.) Engl.
10. *Acrostichum aureum* L.
11. *Acanthus ilicifolius* L.

Mangrove Associates

1. *Crotalaria striata*
2. *Eupatorium odorum*
3. *Datura stramonium*
4. *Boerhaavia crispa*
5. *Pouzolzia indica*
6. *Ipomoea biloba*
7. *Premna serratifolia*
8. *Calotropis gigantea*
9. *Dargaea volubilis*
10. *Cleome viscosa*
11. *Trema orientalis*
12. *Hygrophylla spinosa*
13. *Sphaeranthus indica*
14. *Morinda citrifolia*
15. *Ichnocarpus frutescens*
16. *Pongamia pinnata*
17. *Physalis minimum*
18. *Clerodendrom inermac*
19. *Cerbera manghas*
20. *Thespesia populnea*
21. *Pandanus* sp.
22. *Zizyphus oenopla*
23. *Cardiospermum helicacabum*
24. *Commelina benghalensis*
25. *Terminalia cattapa* L.

values in the sediments (0.12-1.3 mg/100g). Available phosphorus was in the range of 1-11 mg/100g and 1-1.8 mg/100g during the pre-monsoon and monsoon seasons respectively, with notable reduction during monsoon season, especially at station I, which may be due to the leaching of phosphorus from the sandy sediments to overlying water. Sulphate content in the mangrove sediments was high due to the reduction of sulphides to sulphates with consequent formation of sulphuric acid under the anoxic conditions.

Biological studies included the plankton, benthos, chlorophyll content and bacteriological quality of water. Phytoplankton belonging to Bacillariophyceae, especially the genera *Pluerosigma*, *Coscinodiscus*, *Nitzschia* which were abundant, followed by Chlorophyceae (Table 3). Mangrove swamps are considered to be rich in phytoplankton dominated by diatoms (Vannucci, 1989). The zooplankton was represented by the Protozoa, Aschelminthes, Arthropods and Annelids (Table 3). Benthic fauna was represented by the members of Annelida, Mollusca and Arthropoda. Benthos were mainly dominated by the Polychaetes (Table 4).

The watercourses meandering the mangrove swamps are rich in plankton, prawns, reptiles, fishes, etc (Ananthakrishnan, 1982). The important genera of fishes living in mangrove sites were *Mugil*, *Wallago*, *Etroplus*, *Lutjanus*, *Penaeus*, *Sciaenids*, etc., abundance of Holothuria, Vellorita and the fiddler crab were also noticed which form the major source of food and livelihood of the local people.

Chlorophyll content was higher during the pre-monsoon than the monsoon season. The values for chlorophyll a, b, c and total chlorophyll are given in Table 5. Mangrove sites deserve to be looked upon as cauldron where a highly nutritious broth is effectively brewed by a very active microbial flora. Bacteriological studies revealed faecal contamination in all the sites, which may be due to the unhygienic practices of the people living on the banks of the river.

Mangroves being one of the most productive ecosystem and a renewable resource, detailed enumeration of the mangroves and their associates was undertaken. *Avicennia marina*, which is one of the most salt-tolerant mangrove (Downton, 1982) was noticed in the study area. Mangroves were found colonized depending on their salinity

Table 7. Medicinally important mangrove associated Flora

Plant	Family	Part	Uses
<i>Achyranthes aspera</i> L.	Amaranthaceae	Root, fruit, whole Plant	Oedema, snake venom treatment, stomach ache
<i>Aerva lanata</i> L.	Amaranthaceae	Leaf, whole plant	Diabetes
<i>Calotropis gigantea</i> R. Brown	Asclepiadiaceae	Root, latex, leaf, Flower	Asthma, cough, leprosy, acute rheumatism, skin allergy, eczema
<i>Elephantopus scaber</i> L.	Compositae	Whole plant	Poisonous wounds, piles, hair loss
<i>Vernonia cineria</i> (L.) Les.	Compositae	Whole plant	Fever, scorpion poison, malaria, conjunctivitis
<i>Eclipta alba</i> Husk	Compositae	Whole plant	Easy digestion, jaundice, night blindness, head ache, hair fall, defective eyesight, worms.
<i>Spheranthus indicus</i> L.	Compositae	Whole plant	Syphilis, skin diseases, constipation
<i>Tragea involucrata</i> L.	Euphorbiaceae	Whole plant	Cough, constipation, piles
<i>Sida</i> sp.	Malvaceae	Whole plant, root	Piles, gonorrhoea, normal delivery, fever
<i>Mimosa pudica</i> L.	Mimoseae	Whole plant	Bronchial asthma, itching
<i>Boerhavia diffusa</i> L.	Nictaginaceae	Whole plant	Rheumatism, oedema, cough
<i>Oldenlandia corymbosa</i> L.	Rubiaceae	Whole plant	Fever, jaundice, measeles
<i>Cardiospermum helicacabum</i> L.	Sapindaceae	Whole plant, leaf, seeds, root	Constipation, stomach pain, hydrocoele, arthritis
<i>Datura stramonium</i> L.	Solanaceae	Fruit, leaf, root, Flower	Bronchial asthma, acute rheumatism, preventing spasm
<i>Centella asiatica</i> . L.	Umbelliferae	Whole plant	Intelligence, fits, skin diseases
<i>Curcuma longa</i> L.	Zingiberaceae	Whole plant	Syphilis, skin diseases, constipation

tolerance. Hence, stations II & III with high mangrove density were colonized mainly by *Avicennia marina* followed by *Rhizophora mucronata*. The dominant mangrove species observed in the river basin were *Acrostichum aureum*. L., *Acanthus ilicifolius* L., *Avicennia officinalis*, L., *Avicennia marina* (Forsk) Vierh., *Kandelia candel* (L.) Druce and *Rhizophora mucronata* Lamk (Table 6). A number of medicinally important mangrove associates were also recorded (Table 7).

Conclusions

Results of the present study indicate the high productivity of mangrove sites. The mangroves contribute to this mainly by litter fall and the conversion of this to organic carbon by the microorganisms

present in this ecosystem. Nutrients were also distributed as inorganic mineral compounds from within and outside the ecosystem by tidal action. The phytoplanktons form the basis of primary productivity. The zooplanktons, which are primary consumers, contribute to secondary production. The microorganisms found in this ecosystem are mainly responsible for the mineralisation and biogeochemical cycling of nutrient and contribute significantly to the transfer of energy among various trophic levels. Higher chlorophyll content is an indication of productive ecosystem with the existence of a complex food web. The organic matter in the sediments forms the food for benthos. The mangroves being a fragile wetland ecosystem, they depend on water to disseminate their propagules. The large, buoyant

propagules are dispersed through the water by the tidal action. Hence, the distribution of mangroves is dependent on the frequency of tidal flooding, soil salinity and water logging. The overall productivity in the mangrove ecosystem is therefore controlled by salinity, pH, nutrient substances, phytoplanktonic biomass and their relationship and interaction with the physical and biotic components, resulting in a high biological productivity. The ebb and flow of the tidal cycle provide the necessary 'energy subsidies'. The mangroves are considered potential fish production sites providing congenial feeding, breeding and nursery grounds for fishes and prawns, which provide livelihood for the local people. Through adoption and implementation of proper conservation/management strategies these mangrove areas could be effectively utilized for aquaculture. Since the mangroves have innate potential to bind toxic chemicals and pollutants, the pollution of water can be reduced considerably minimizing adverse effect of pollutants on the fauna. The pH, salinity, dissolved oxygen, tidal action, high organic/inorganic nutrients together with biotic factors provide a congenial environment for the survival of mangrove ecosystem of Valappattanam river basin.

Acknowledgements

The authors are grateful to Dr. P. Basak, Executive Director, Centre for Water Resources Development and Management, Kozhikode 673 571, Kerala for facilities and encouragement. The STEC Fellowship provided by Science, Technology & Environment Department, Govt. of Kerala to one of us (KL) for undertaking the study is gratefully acknowledged.

References

- Ananthkrishnan, T.N. 1982. *Bioresources Ecology*. Oxford & IBM Publishing Co., New Delhi.
- APHA, 1995. *Standard Methods for the Examination of Water and Wastewater*. 16th Edn., Amer. Publ. Health Association, Washington, D.C., p. 1268.
- Badarudheen, A. and Sakkir, S. 1998. Distribution of Na & K in the sediments of Veli, Kochi & Kannur Mangroves, Kerala. *Indian. J. Mar. Sci.* **27** : 253-255.
- Badarudheen, A., Maya, K. and Sajan, K. 1997. Sediment, organic carbon and trace metal distributions in the mangrove environment at Veli, Kerala. In : Proc. IX Kerala Science Congress, January 1997, Thiruvananthapuram, Kerala. pp. 85-87.
- Biswas, Kalipada 1980. *Common Fresh and Backwater Algal Flora of India and Burma*. Delhi Periodical Experts Book Agency, p. 101.
- Chand Basha, S. 1991. Distribution of mangroves in Kerala. *Indian Forester* **117** : 439-448.
- Chand Basha, S. 1992. Mangroves of Kerala. A fast disappearing asset. *Indian Forester* **118** : 175-190.
- Davis Charles, C. 1955. *The Marine and Freshwater Plankton*, Michigan State Univ. Press, USA., p. 562.
- Dietrich Uhlmann, 1975. *Hydrobiology*. Wiley Inter Science, New York.
- Downton, W.J.S. 1982. Growth and osmotic relations of the mangrove *Avicennia marina*, as influenced by salinity. *Australian J. Plant Physiol.* pp. 519-528.
- Jhingran, V.G. 1982. *Fish and Fisheries of India*. Hindustan Publishing Corporation (India), Delhi, p. 666.
- Kathireshan, K. 1991. Uses of Mangroves, *Yojana* **35** (19) : 27-29.
- Kotpal, R.L. 1972. *A Textbook of Protozoa*. Rastogi & Co., Meerut, p. 303.
- Mohannan, C. N. 1999. Mangroves. In : *The Natural Resources of Kerala*, WWF India, Thiruvananthapuram. pp. 149-158.
- Prabhadevi, L., Natarajan, P., Saraswathy Ammal, G. and Abdul Aziz, P. K. 1996. 'Water quality and benthic fauna of the Kayamkulam backwaters and Arattupuzha coast along south west coast of India.' *Indian. J. Mar. Sci.* **25** : 264-267.
- Presscott, G.W. 1982. *Algae of the Western Great Lakes Area, with an Illustrated Key to the Genera of Desmids and Freshwater Diatoms*. Koenigstein, Otto Koeltz., p. 977.
- Trivedy, R.K. and Goel, P.K. 1984. *Chemical and Biological Methods for Water Pollution Studies*. Enviro Media Publications, Karad (India), p. 215.
- Trivedy, R.K., Goel, P.K. and Trisal, C.L. 1987. *Practical Methods in Ecology and Environmental Science*. Enviro Media, Karad (India), p. 340.
- Tomlinson, P.B. 1986. *The Botany of Mangroves*. Cambridge Univ. Press, Cambridge, U. K. p. 419.
- Unni, P. N. 1998. Biodiversity of Mangrove Vegetation in Wetlands of Kerala. Paper presented at the *International Conference on Asian Wetlands*, 29-31 January 1998, New Delhi and Bharatpur, India.
- Unni, P.N. and Jayakumar, P. 1997. Mangroves of Kerala : Need for conservation and management. Paper presented at the *International Seminar on Mangroves*, 25-27 March 1997, Andhra University Waltair, India, p. 58 (Abstr.).
- Vannucci, M. 1989. *The Mangroves and Us*. Indian Association for the Advancement of Science.
- Vannucci, M. 1991. Saving a crucial ecosystem. *The Hindu Survey of the Environment*, Madras, pp. 157-161.
- Walkley, A and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Sci.* **37** : 29-38.

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**BIODIVERSITY OF MANGROVES AND AVIFAUNA
IN WETLANDS OF KERALA**

P. N. Unni & K. Lakshmi

Centre for Water Resources Development and Management

KOZHIKODE - 673 571

Kerala state, with a coastline of 590 km gifted with the entry of tidal water regularly from the Arabian Sea and enriched by fresh water from the 41 west-flowing rivers originating from the Western Ghats, create a congenial environment for the development of mangrove vegetation along the fringes of estuaries and wetlands. Kerala, once gifted with luxuriant mangrove vegetation of about 70,000 ha, has now dwindled to an area of about 1670 ha under the control of the State government and 1500 ha under private ownership. Anthropogenic activities such as land reclamation for construction, agriculture and aquaculture - both in private and public sectors - have resulted in massive destruction of this unique, fragile, intertidal ecosystem and

the area under mangroves in the State is fast dwindling. This warrants immediate action for their conservation/management, though virtually a difficult endeavor.

Seventeen mangroves and 23 mangrove associates of the wetlands of Kerala have been enumerated, with their distribution in southern and northern districts of the State. The seventeen mangrove species comprise of three shrubs, one climber, nine small trees, three medium-sized trees and one large tree. They are *Avicennia officinalis* L., *A. marina* (Forsk.) Vierh., *Bruguiera cylindrica* (L.) Bl., *B. parviflora* W. & A. ex Griffith, *B. sexangula* (Lour.) Poir., *Rhizophora apiculata* Blume., *R. mucronata* Lamk., *Kandelia candel* (L.) Druce, *Sonneratia caseolaris* (L.) Engl., *Acanthus ilicifolius* L., *Acrostichum aureum* L., *Lumnitzera racemosa* Willd., *Derris trifoliata* Lour., *Aegiceras corniculatum* (L.) Blanco, *Excoecaria agallocha* L., *E. indica* (Willd.) Muell. Arg., and *Ceriops tagal* (Perr.) C. B. Rob. Out of the seventeen species listed above, *Avicennia officinalis*, *Avicennia marina* and *Sonneratia caseolaris* are dominant in the polyhaline regions. *Bruguiera parviflora*, *Kandelia candel*, *Acanthus ilicifolius*, *Avicennia officinalis* and *A. marina* in the mesohaline regions and *Kandelia candel*, *Sonneratia caseolaris* and *Acrostichum aureum* only in the oligohaline regions. The common mangrove associates embrace 23 species comprising of seven herbs, four shrubs, two climbers, five small trees, two medium-sized trees and three large trees.

The mangroves provide a congenial habitat for a number of native/migratory birds including waterfowl. The Vembanad-Kol wetlands are one of the richest avifaunal habitats on the west coast of India, which is considered to be the third largest wetland in India considering the total number of birds. One hundred and forty nine species including 99 species of resident/locally migratory and 50 species of migratory birds belonging to 10 families viz., Anatidae, Phalacrocoracidae, Ardeidae, Laridae, Charadriidae, Ciconiidae, Rallidae, Accipitridae, Jacanidae and Podicipididae have been reported from the Vembanad wetlands. A spectrum of 163 species of birds have been reported from the Kol lands, of which 30% are migrants. Seventy species of water birds and four migratory raptors have been recorded from the Kol lands. Out of the 163 species reported from Kol lands, twenty species are new records for Kerala, including the four endangered waterfowl viz., the Spot-billed Pelican (*Pelicanus philippensis*), Oriental Darter (*Anhinga melanogaster*), Water Cock (*Gallix cinerea*) and the Black-billed Tern (*Sterna melanogaster*).

In coastal zone management, due consideration should be given for the conservation of mangrove- avifauna biodiversity in the estuarine and intertidal zones. In this fragile ecosystem, plant/animal/microbial interactions are highly complex and little known, but is considered extremely important for their successful management to maintain sustainable production. The need and strategies for conservation/ management of this fragile ecosystem are discussed.



SPATIAL AND TEMPORAL VARIATION IN ORGANIC CARBON, NITROGEN AND PHOSPHORUS IN MANGROVE SEDIMENTS OF TWO RIVERINE ECOSYSTEMS OF KERALA

K. LAKSHMI¹, P. N. UNNI² AND N. NEELAKANTAN³

^{1&2}Centre for Water Resources Development and Management, Calicut 673 571, Kerala.

³Deptt. of Botany, University of Calicut 673 635, Kerala

Key words : Mangroves; Sediments; Organic carbon; Nitrate-nitrogen; Available phosphorus; Estuary; Thalassery river; Valapattanam river

Abstract—This paper describes the seasonal distribution of organic carbon, NO₃-N and available phosphorus in the sediments of 3 biotopes, i.e., mangrove, estuary and fresh water in the Thalassery and Valapattanam riverine ecosystems of Kerala State, South India. Clear and distinct spatial and temporal variations were observed for the above parameters in the two river basins. In the light of available information, the various factors which contribute to / influence the distribution of organic carbon, NO₃-N and available phosphorus in the ecosystems are discussed.

INTRODUCTION

Mangroves, the characteristic coastal vegetation of the tropics and subtropics, forming the essential components of intertidal ecosystem, are considered the most productive, self-maintaining estuarine components of the biosphere. They are useful in a wide range of economic and ecological aspects. The ecological values are nutrient enrichment, feeding, breeding and nursery grounds for a number of marine organisms, shoreline protection, natural land reclamation and a pollution sink (Mohanan, 2000). The economic values include, the use of mangroves as timber/fuel wood, forest products, aquaculture, fry source, shore protection, agriculture, recreation and as human settlements. Kerala, which was once bestowed with a luxuriant mangrove vegetation of more than 70,000 ha, has now dwindled to an area of about 1,671 ha of which 88% are under private ownership (Chand Basha 1991, 1992). These are at present limited to isolated patches in Thiruvananthapuram, Kollam, Kottayam, Alappuzha, Ernakulam, Thrissur, Malappuram, Kozhikode, Kannur and Kasargode districts. Available data on their distribution reveals that more area under mangroves exists in the northern districts, particularly Kozhikode and Kannur. The Thalassery and Valapattanam rivers of Kannur are having the maximum area under mangroves (45% of the total area under mangroves in the State) (Unni & Jayakumar, 1997; Unni, 1998;

Mohanan, 1999). Studies have been initiated earlier on the physicochemical characteristics of major abiotic components such as water and sediments of some mangrove ecosystems (Delacered, 1983; Lafond, 1984; Badarudheen *et al.*, 1996). The role of different forms of C, N, and P in aquatic productivity has been investigated earlier (Aston & Hewitt, 1977; Bowmann, 1977; Brenzonik, 1972; Dugdale, 1967; Rhoads *et al.*, 1975; Roman & Tanore, 1978; Shanmukhappa, 1981). Seasonal variations in C, N and P in sediments of Vellar (Sivakumar *et al.*, 1983) and Cochin (Sankaranarayanan & Panampunnayil, 1979) estuaries and the nitrogen dynamics of mangroves of Ratnagiri, Maharashtra (Waghmode, 1987) estuaries have been studied in detail. Except a baseline study of the aquatic environment of the mangrove ecosystem of Valapattanam river basin, Kerala made earlier (Lakshmi *et al.*, 2000), no detailed systematic studies have been undertaken on water and sediment quality of mangroves of Thalassery and Valapattanam rivers. This paper deals with the distribution of C, N and P the three biotopes *viz.*, estuary, mangroves and fresh water of Thalassery and Valapattanam riverine ecosystems.

The accumulation of organic carbon enhances the production and associated capture and captive fishery. Organic carbon forms the basis of a dependent trophic chain of bacteria, fungi, cellular algae and other detritus feeding organisms. The main source of organic carbon in the sediments is

the runoff from the land. Abundance of particulate organic matter is characteristic of mangrove area (Vannucci, 1989). Similarly, nitrogen is an important nutrient for the growth of plants. The fecal matter of mangrove fauna, which is a source of nitrate, phosphate and other nutrients, contribute to the surface layer of sediments. The population of nitrogen fixing bacteria *viz.* *Azotobacter* spp., isolated from sediments have been reported to be very high in mangrove habitat than in marine backwaters and estuarine systems (Lakshmanaperumalsamy, 1987). Halotolerant nitrogen fixing *Rhizobium* strains have been isolated from root nodules of *Derris scandens* and *Sesbania* spp. associated with the mangrove swamps of Sunderbans (Sengupta & Chaudary, 1990). These bacteria in the mangrove sediments convert nitrogen into nitrates, which may get trapped in the fine sediments. It has been reported that in coastal waters, humic acids in water and sediments predominate due to the decay of plant and animal matter (Shanmukhappa, 1987). Generally higher organic carbon and nitrate-nitrogen in the mangrove sites is due to high concentration of humic acids in sediments, which is known to have a high C/N ratio. High levels of phosphorous and nitrogen has been reported in sediments due to the decay of mangrove foliage (Sahoo *et al.*, 1991). Significant amount of nutrients carried into coastal zone by floodwaters may be trapped by mangrove sediments and the marine environment. Ninety per cent of nutrients in marine sediments are believed to have come from the mangrove area and the remaining 10% only from non-mangrove sites (Aksornkoae & Paphavasit, 1996). Presumably, inorganic and organic matter in the mangrove ecosystem may be remineralized microbially and bound organically in the mangroves by primary and secondary producers, thus becoming sedimented in the mangroves.

STUDY AREA

The Valapattanam and Thalassery estuaries located in Kannur district of Kerala State, India were selected for the present study. The Valapattanam river having a basin area of 1867 km² and a length of 110 km and the Thalassery river basin, having a basin area of 132 km² and a length of 28 km originate from the Kannothe elevation of the Western Ghats. Sampling points were selected depending upon the variations in salinity, sources of pollution, diversity of mangroves, etc (Fig. 1).

MATERIALS AND METHODS

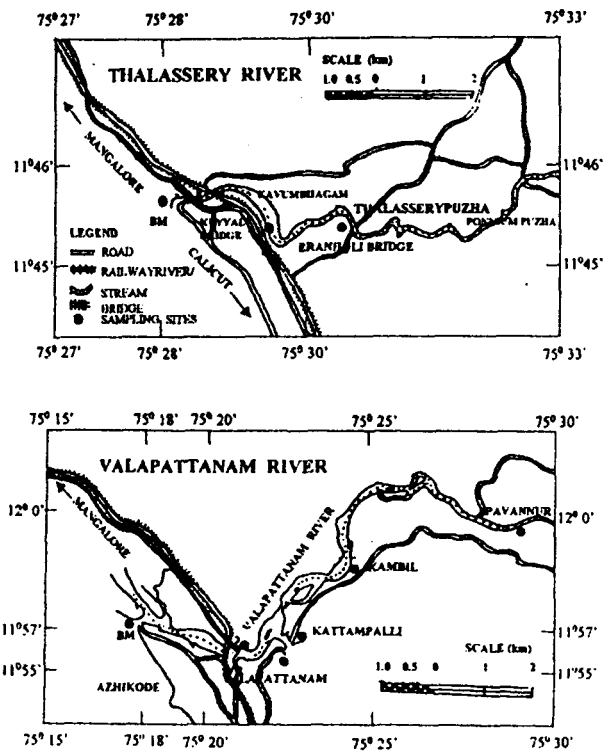


Fig. 1. Sampling Sites in Thalassery and Valapattanam River Basins

Sediment samples from the mangrove and non-mangrove sites of Valapattanam and Thalassery rivers were collected during the pre-monsoon, monsoon and post-monsoon seasons of 2000 and analyzed to compare the distribution of organic carbon, nitrate-nitrogen and available phosphorus contents. The sediment samples were collected from the sampling sites with a Van Veen Grab, air dried, pulverized, sieved through 0.5 mm mesh and analyzed for organic carbon following the method of Walkley and Black (1934). The samples sieved through 2 mm mesh were analyzed for nitrate-nitrogen following the method of Grewling and Peech (1965). The available phosphorus was analyzed following the method of Trivedi *et al.*, (1987).

RESULTS AND DISCUSSION

The distribution of organic carbon and nitrate-nitrogen and available phosphorus in the sediments of Valapattanam and Thalassery rivers during post-

monsoon, monsoon and pre-monsoon seasons are presented in (Figs. 2 and 3) respectively.

The Thalassery river sediments recorded an average organic carbon content ranging from 0.64-1.156 mg/100 g in pre-monsoon, 0.11 - 2.43 mg/100 g in monsoon and 0.22-2.37 mg/100 g in post-monsoon seasons. In the Valapattanam river, average organic carbon content ranged from 0.789 - 3.323 mg/100 g in pre-monsoon, 0.046 - 2.78 mg/100 g in monsoon and 0.079 - 3.12 mg/100 g in post-monsoon seasons.

The average nitrate-nitrogen content in the

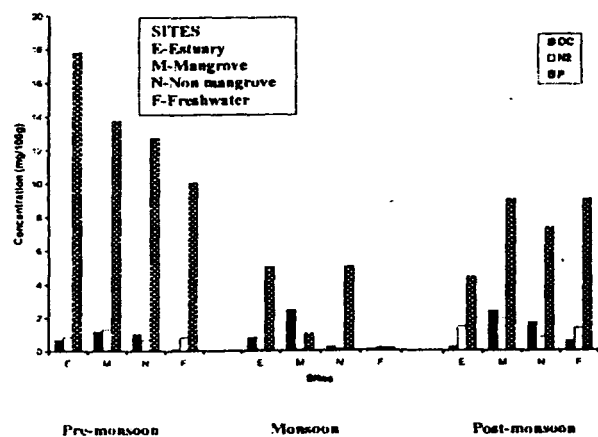


Fig. 2. Seasonal Variations in Organic C, N and P in Valapattanam River

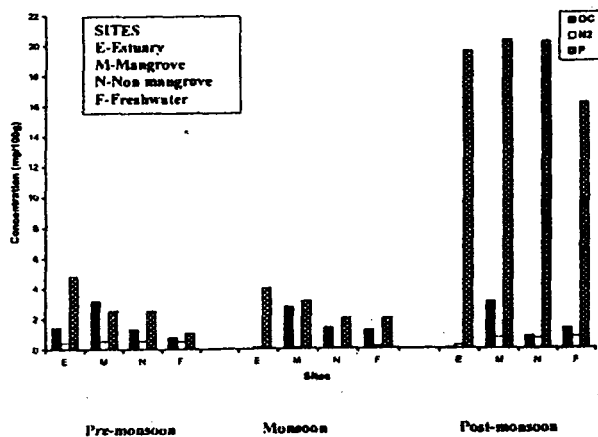


Fig. 3. Seasonal Variations in Organic C, N and P in Thalassery River

Thalassery river ranged from 0.62 - 1.26 mg/100 g in pre-monsoon, 0.051 - 0.14 mg/100 g in monsoon and 0.79 - 1.91 mg/100 g in post-monsoon seasons. In the Valapattanam river, it ranged from 0.4 - 0.54 mg/100 g in pre-monsoon, 0.06 - 0.15 mg/100 g in monsoon and 0.212 - 0.77 mg/100 g in post-monsoon seasons.

The Thalassery river sediments recorded the average values of available phosphorus ranging from 10-17.8 mg/100 g in pre-monsoon, 0.14 - 5 mg/100 g in monsoon and 4.4-9 mg/100 g in post-monsoon respectively. In the Valapattanam river, it ranged from 1.02 - 4.8 mg./100 g in pre-monsoon, 2 - 4 mg/100 g in monsoon and 16.2 - 20.33 mg/100 g in post-monsoon seasons.

Statistical analysis revealed no significant correlation among/between the parameters, seasons and sites studied.

In all the seasons studied, the mangrove sites showed high values for organic carbon in both the riverine ecosystems. The general trend of distribution of organic carbon in the Thalassery river was mangrove > estuary > freshwater and mangrove > freshwater > estuary in the Valapattanam river. Increase in organic carbon in the mangrove sediments may be attributed to the microbial biodegradation of the mangrove litter and also the contribution from run off from the catchments upstream, *i.e.*, autochthonous in the mangrove area and allochthonous in the other two biotopes. Poor circulation in the mangrove biotope may be another reason for its high contents in the two river basins studied, as has been reported earlier (Shanmukhappa, 1987). In the Valapattanam river, slightly high values for organic carbon recorded in freshwater compared to the estuary may be due to the decomposition of solid organic wastes dumped there. High organic C values were noticed in pre/post-monsoon than in monsoon seasons. Relatively lower values for organic C during the monsoon season in these two river basins may be attributed to high dilution and circulation.

Nitrate-nitrogen was found to be high in mangrove sites of both the river basins. In the Thalassery river, the trend was mangrove > estuary > freshwater except in monsoon season where a slight increase was shown in freshwater compared to the estuary. This may be due to leaching off of nitrates from agricultural microwatersheds/*elas* upstream, while Valapattanam river basin showed a trend similar to that of organic C. In the mangrove and non mangrove areas of both the river basins, high values were reported during the pre-/post-monsoon and low in monsoon seasons, as has been reported earlier (Sivakumar *et al.*, 1983; & Shanmukhappa, 1987). High values were reported for organic C content in mangrove areas in all the three seasons studied. The mangrove sites have high humic acid content in their sediments. Hence,

nitrate-nitrogen in the mangrove sediments is biogenic *i.e.*, derived from the decayed mangrove litter. In the monsoon season, no significant difference could be noticed in the Thalassery river basin. In the Valapattanam river basin, nitrate-nitrogen values remained almost uniform during the pre-monsoon season in both mangrove and non-mangrove sites.

Available phosphorus was found to be high in estuary, followed by mangrove and fresh water sites. This may be due to the fact that concentration of phosphorus in sea water is usually higher than in freshwater (Garcia-soto *et al.*, 1990). But when mangrove and non-mangrove areas in the same site were considered, higher values were noticed in the mangrove than in the non-mangrove area. But in Thalassery river basin, non-mangrove area reported high values for P during monsoon season. The higher concentration of phosphorus in pre-/post-monsoon seasons may be due to the higher concentration of nutrients in the overlying waters which may ultimately get deposited over the sediments due to poor turbulence of water. In the monsoon season, low phosphorus content was recorded which may be attributed to the leaching off of phosphorus to the overlying water due to the fresh water influx and wave action leading to resuspension of sediments in the water column, as has been reported earlier (Sivakumar *et al.*, 1983; Satyanarayanan *et al.*, 1993; Sankaranarayanan & Panampunnayil, 1979). Another reason for decrease in phosphorus during monsoon season may be due to its higher uptake by the phytoplankton which are usually abundant in the monsoon season.

CONCLUSIONS

The study revealed distinct spatial and temporal variations in organic carbon, nitrate-nitrogen and phosphorus in both Thalassery and Valapattanam riverine ecosystems. High values of organic C, nitrate N and available P recorded in the mangrove area in comparison with the estuary and freshwater biotopes indicate that this area is more productive in both the riverine ecosystems.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. P. Basak, Executive Director, Centre for Water Resources Development and Management, Calicut, Kerala, India for facilities and encouragement. One of us (K.L.), is grateful to the State Committee on Science, Technology and

Environment (STEC), Govt. of Kerala for the award of a Junior Research Fellowship.

REFERENCES

- Aksornkoae, S. and Paphavasit, N., 1996. Effect of sea level rise on the mangrove ecosystem in Thailand. *Natl. Resour. Develop.* 43/44 : 95-104.
- Aston, S.R. and Hewitt, C.N. 1977. Phosphorus and Carbon distribution in a polluted coastal environment; *Estuar. Coast. Mar. Sci.* 5 : 243-254.
- Badarudeen, A., Damodaran, K.T., Sajan, K and Padmalal, D., 1996. Texture and geochemistry of the sediments of a tropical mangrove ecosystem, Southwest coast of India. *Environmental Geology* 27 : 164-169.
- Bowman, M.J. 1977. Nitrogen distributions and transport in Long Island Sound; *Estuar. Coast. Mar. Sci.* 5 : 531-548.
- Brezonik, P.L. 1972. Nitrogen : Source and transformations in natural waters. Allen and Kramer (Ed.) *Nutrients in Natural Waters*. Wiley Interscience, New York.
- Chand Basha, S., 1991. Distribution of mangroves in Kerala. *Indian Forester* 117 : 439-448.
- Chand Basha, S., 1992. Mangroves of Kerala: A fast disappearing asset. *Indian Forester* 118 : 175-190.
- Delacered, L.D., 1983. Heavy metal accumulation by mangrove salt marsh intertidal sediments. *Braz. J. Med.* 16 : 442-451.
- Dugdale, R.C. 1967. Nutrient limitation in the sea; Dynamics, identifications and significance. *Limnol. Oceanogr.* 12 : 685-695.
- Garcia-soto, C., de Mandariaga, I., Villate, F and Orive, E., 1990. Day to day variability in phytoplanktonic community of coastal shallow embayment in response to changes in river runoff and water turbulence. *Estuar. Coastal & Shell Sci.* 31 : 217-229.
- Grewling, T and Peech, M., 1965. *Chemical Soil Tests*. Cornell Univ. Agric. Exp. St. Bull. 960.
- Lafond, L.R., 1984. Dynamical processes in deltaic sedimentation with special respect to mangrove areas. UNDP / UNESCO, New Delhi. pp. 25-26.
- Lakshmi, K., Unni, P.N. and Neelakantan, N., 2000. Environmental status of the mangrove ecosystem in Valapattanam river basin, Kerala. *Eoc. Env. & Cons.* 6 : 363-371.
- Lakshmanaperumalsamy, P., 1987. Nitrogen fixing bacteria *Azotobacter* sp. in aquatic sediments. *Fish Technol. Soc. Fish Technol.*, Cochin 24 : 126-128.
- Mohanan, C.N. 1999. Mangroves In : *The Natural Resources of Kerala*, WWF India, Thiruvananthapuram, pp 149-158.
- Mohanan, C.N. 2000. *The mangrove wetlands*. Sci. India Mag. 3 : 18-23.
- Rhoads, D.C., Tenore, K and Browne, M., 1975. The role of suspended bottom mud in nutrient cycles of shallow embayments. In : Cronine (Ed) *Estuarine Research* Vol 1. Academic Press, London, pp. 563-579.
- Roman, M.R. and Tenore, K.R. 1978. Tidal resuspension

- in Buzzards Bay I. Seasonal changes in resuspension of organic carbon and chlorophyll a. *Estuar. Coast. Mar. Sc.* 6 : 37-46.
- Sahoo, J.K., Hariharan, V. and Katti, R.J., 1991. Seasonal distribution of C, N and P in the sediments of Talapady lagoon, Dakshina Kannada. *Environ. Ecol.* 9 : 516-520.
- Sankaranarayanan, V.N. and Panampunnayil, S.U. 1979. Studies on Organic carbon, Nitrogen and Phosphorus in sediments of Cochin backwater. *Indian J. Mar. Sci.* 8 : 27-30.
- Satyanarayana, D., Panigrahy, P.K. and Sahu, S.D. 1993. Texture, mineralogy, Carbon, Nitrogen and Phosphorus of Visakhapatnam shelf sediments, East coast of India. *Indian J. Mar. Sci.* 22 : 235-240.
- Sengupta, A & Chaudary, S., 1990. Halotolerant *Rhizobium* strains from mangrove swamps of the Ganges River Delta. *Indian J. Microbiol.* 30 : 483-484.
- Shanmukhappa, H. 1981. Primary productivity by phytoplankton under controlled laboratory conditions. M. Phil dissertation, Jawaharlal Nehru University, New Delhi.
- Shanmukhappa, H. 1987. Organic matter and C, N, P in sediments of Porto Novo. *Proc. Natn. Sem. Estuarine Management*. Thiruvananthapuram, Kerala, pp. 128-133.
- Sivakumar, V., Thangaraj, G.S. Chandran, R and Ramamoorthi, K., 1983. Seasonal variations in C, N and P in sediments of the Vellar estuary, Porto Novo. Mahasagar, *Bull. Natn. Inst. Oceanogr.* 16 : 175-181.
- Trivedy, R.K. Goel, P.K. and Trisal, C.L., 1987. *Practical Methods in Ecology and Environmental Science*. Enviro Media Publications, Karad, India, 340 pp.
- Unni, P.N. 1998. Biodiversity of Mangrove Vegetation in Wetlands of Kerala. Paper presented at the International Conference on Asian Wetlands, 29-31 January 1998, New Delhi and Bharatpur, India.
- Unni, P.N. and Jayakumar, P. 1997. Mangroves of Kerala : Need for conservation and management. Paper presented at the International Seminar on Mangroves. 25-27 March 1997, Andhra University, Waltair, India, p 58 (Abstr.)
- Vannucci, M., 1989. The Mangroves and Us - A synthesis of Insights. Indian Association for the Advancement of Science, New Delhi.
- Waghmode, A.P. 1987. Preliminary studies in the Nitrogen dynamics of estuarine ecosystem. *J. Mar. Bio. Assoc. India* 29 : 362-364.
- Walkley, A. and Black, I.A. 1934. An Examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Sci.* 37 : 29-38.

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Spatial and temporal variations in organic and inorganic nutrients in the mangrove sediments of Thalassery and Valapattanam river basins

Unni P N and Lakshmi K

**Centre for Water Resources Development and Management, Calicut 673 571, Kerala*

Abstract

This study presents the spatial and temporal variations in the distribution of organic carbon, NO₃-nitrogen, available phosphorus, exchangeable sodium, potassium, calcium and magnesium in the mangrove sediments of the three biotopes i.e., mangrove, estuary and fresh water, of Thalassery and Valapattanam river basins of Kerala. In both the river basins, except calcium, concentrations of other elements were high in the mangrove sediments in comparison with non-mangrove sediments. Clear and distinct spatial and temporal variations were observed in all the abovementioned parameters in the mangrove sediments. Based on the available information, various factors that contribute to and influence the distribution of organic carbon, NO₃-nitrogen, available phosphorus, exchangeable sodium, potassium, calcium and magnesium are discussed. The significance of variations in the distribution of these elements in the mangrove ecosystem is discussed.

Introduction

Mangroves, the characteristic halophilous, estuarine ecosystems of coastal areas of the tropics and subtropics, forming essential components of intertidal ecosystem, are considered the most productive, self-maintaining estuarine components of the biosphere. They are open ecosystems coupled to both upstream riverine freshwater and downstream saline estuarine systems. The nutrient input for their continuing productivity are brought in from the upstream terrestrial and downstream estuarine resources. The primary nutrients are utilized in the formation of organic matter and are released in to the ecosystem as litter fall. These nutrients are removed by the living organisms and micro organisms associated with the sediments. Alteration in the levels of any one of the nutrients affects the overall productivity of this ecosystem.

The organic matter in the sediments are remineralized into their constituent primary nutrients in a form suitable for uptake by their root system, thereby, acting as primary source of nutrients for productivity (Ananthkrishnan 1982).

Kerala, which was once bestowed with luxuriant mangrove vegetation of more than 70,000 ha, have now dwindled to an area of about 1650 ha, of which 45% are under private ownership (Chand Basha 1991, 1992). These are distributed in isolated patches in Thiruvananthapuram, Kollam, Kottayam, Alappuzha, Eranakulam, Thrissur, Malappuram, Kozhikode, Kannur and Kasaragod districts. Available data on their distribution reveals that more area under mangroves exists in the northern districts, particularly, Kozhikode and Kannur.

The Thalassery and Valapattanam rivers of Kannur are having maximum area under mangroves, which accounts to 45% of the total area under mangroves in the State. Studies initiated earlier have been centered on the physicochemical characteristics of major abiotic components such as water and sediments of some mangrove ecosystems (Delacered 1983; Lafond 1984; Badarudheen et al. 1996). The roles of different forms of C, N, and P and their seasonal variations in the sediments productivity have been investigated by many workers (Aston & Hewitt 1977; Bowmann 1977; Brenzonik 1972; Dugdale 1977; Rhoads et al. 1975; Roman & Tanore 1978; Shanmukhappa 1981; Sivakumar et al. 1983; Sankaranarayanan & Panampunnayil 1979; Wag mode, 1987). Though seasonal variations in nutrients in the mangrove sediments and their role in aquatic productivity in Thalassery and Valapattanam estuarine ecosystems have been investigated earlier (Lakshmi et al. 2000), no detailed systematic studies have been undertaken so far on water and sediment quality, distribution of organic carbon, nitrogen, phosphorus, exchangeable sodium, potassium, calcium and magnesium in the mangrove sediments of mangroves of the two riverine systems. Hence, detailed studies on the variations in the above parameters in the mangrove sediments of Thalassery and Valapattanam river systems were carried out during the pre-monsoon, monsoon and post-monsoon seasons.

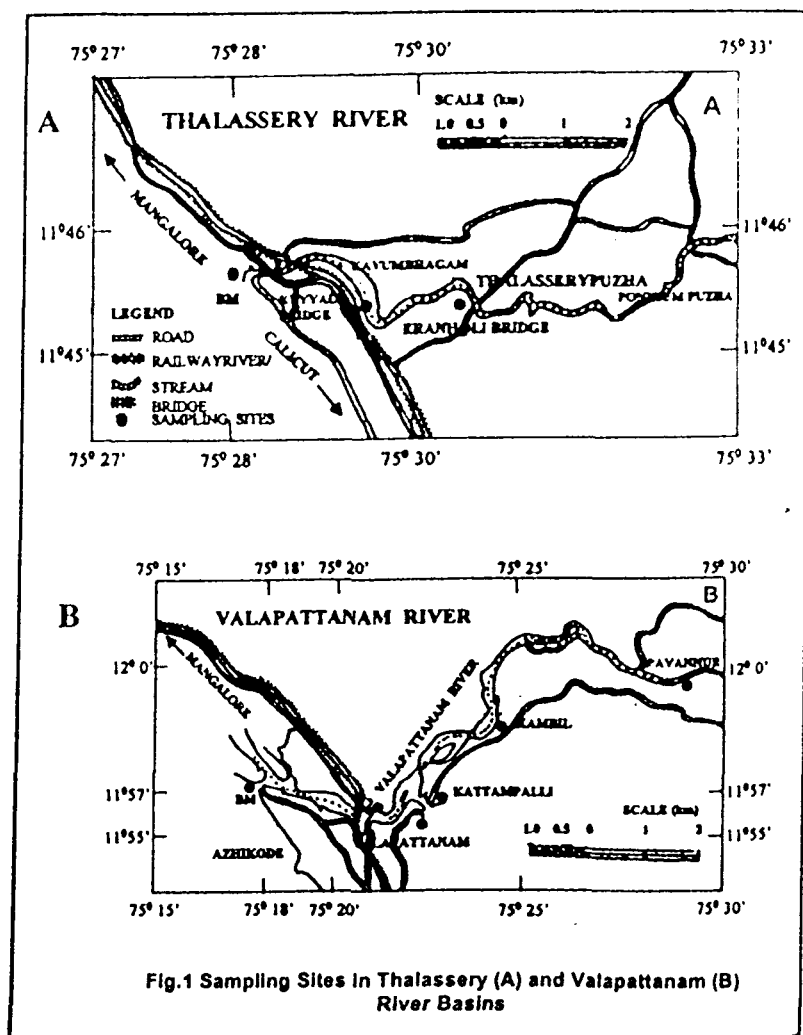
Study area

The Thalassery and Valapattanam river basins are located in Kannur district of Kerala State. The

Thalassery river basin with a basin area of 132 km² and a length of 28 km lying between 75° 18' - 75° 33' E longitude and between 11° 45' and 11° 46' N latitude (Fig.1A), as well as the Valapattanam river basin having a basin area of 1867 km² and a length of 110 km lying between 75° 18' - 75° 30' E longitude and between 11° 57' and 12° 0' N latitude, originate from the Kannothe elevation of Western Ghats and drains into the Arabian Sea (Fig. 1B). Sampling points were selected depending upon the variations in salinity, sources of pollution, diversity of mangroves, etc.

Material and methods

Sediment samples from mangrove and non-mangrove areas of both the Thalassery and the



Valapattanam rivers were collected during pre-monsoon, monsoon and post-monsoon seasons of the year. Four sediment samples, two each from mangrove and non-mangrove sites of the Thalassery River, six sediment samples, three each from mangrove and non-mangrove sites of the Valapattanam River, were collected using a Van Veen Grab. The samples were air dried, pulverized, sieved through 0.5 mm mesh and analyzed for organic carbon following the method of Walkley and Black (1934), and the samples sieved through 2.0 mm mesh were analyzed for nitrate-nitrogen following the method of Grewling and Peech (1965). The available phosphorus in the sediment samples was analyzed following the method of Trivedy et al. (1987). Exchangeable sodium, potassium, calcium and magnesium contents were analyzed after extraction with 1N ammonium acetate solution following the method of Trivedy et al. (1987).

Results and discussion

The distribution of organic carbon, nitrate-nitrogen and available phosphorus in the sediments of Thalassery and Valapattanam rivers during post-monsoon, monsoon and pre-monsoon seasons are presented in figures 2 and 3 respectively. Thalassery River sediments recorded an average organic carbon content ranging from 0.064-1.156 mg/100 g in pre-monsoon, 0.11-2.43 mg/100 g in monsoon and 0.22-2.37 mg/100 g in post-monsoon seasons (Fig. 2 A). In the Valapattanam River, average organic carbon content ranged from 0.789-3.184 mg/100 g in pre-monsoon, 0.046-2.78 mg/100 g in monsoon and 0.079-3.12 mg/100 g in post-monsoon seasons (Fig. 2 B).

The accumulation of organic carbon enhances the production and associated capture and captive fishery. Organic carbon forms the basis of a dependent trophic chain of bacteria, fungi,

cellular algae and other detritus feeding organisms. Similarly, nitrogen is an important nutrient for the growth of plants. The main source of organic carbon in the sediments is the runoff from the land. Abundance of particulate organic matter is characteristic of mangrove areas (Vannucci 1989). The fecal matter of mangrove fauna, which is a source of nitrate, phosphate and other nutrients, contribute to the surface layer of soil. The nitrogen fixing bacteria viz., *Azotobacter* spp. have been isolated from sediments of mangroves and their counts were high in mangrove habitat than in marine backwaters and estuarine systems (Lakshmanaperumalsamy 1987). Halo tolerant nitrogen fixing *Rhizobium* strains have been isolated from root nodules of *Derris scandens* & *Sesbania* sp. growing along the mangrove swamps of Sunderbans (Sengupta & Chaudary 1990). These bacteria in the mangrove sediments may convert nitrogen into nitrates, which get trapped in the fine sediments. The decay of plant and animal material ultimately produce humic substances, which are part of organic matter in aquatic systems. It has also been reported that in coastal waters, humic acids in water and sediments predominate (Shanmukhappa 1987). Generally, higher concentration of organic carbon and nitrate-nitrogen at the mangrove sites is due to high concentration of humic acids in the sediments, which is known to have a high C/N ratio. The phosphorus in the mangrove sediments is mainly contributed by the decay of the mangrove foliage. High levels of phosphorous and nitrogen have been reported in the sediments of Talapady lagoon, Dakshin Kannada, due to the decay of mangrove foliage (Sahoo et al 1991). Mangrove sediments and the marine environment trap significant amount of nutrients carried into coastal zone by the floodwaters. Ninety percent of the nutrients in marine sediments are believed to have come from the mangrove area (Aksornkoae & Papharasit 1996)

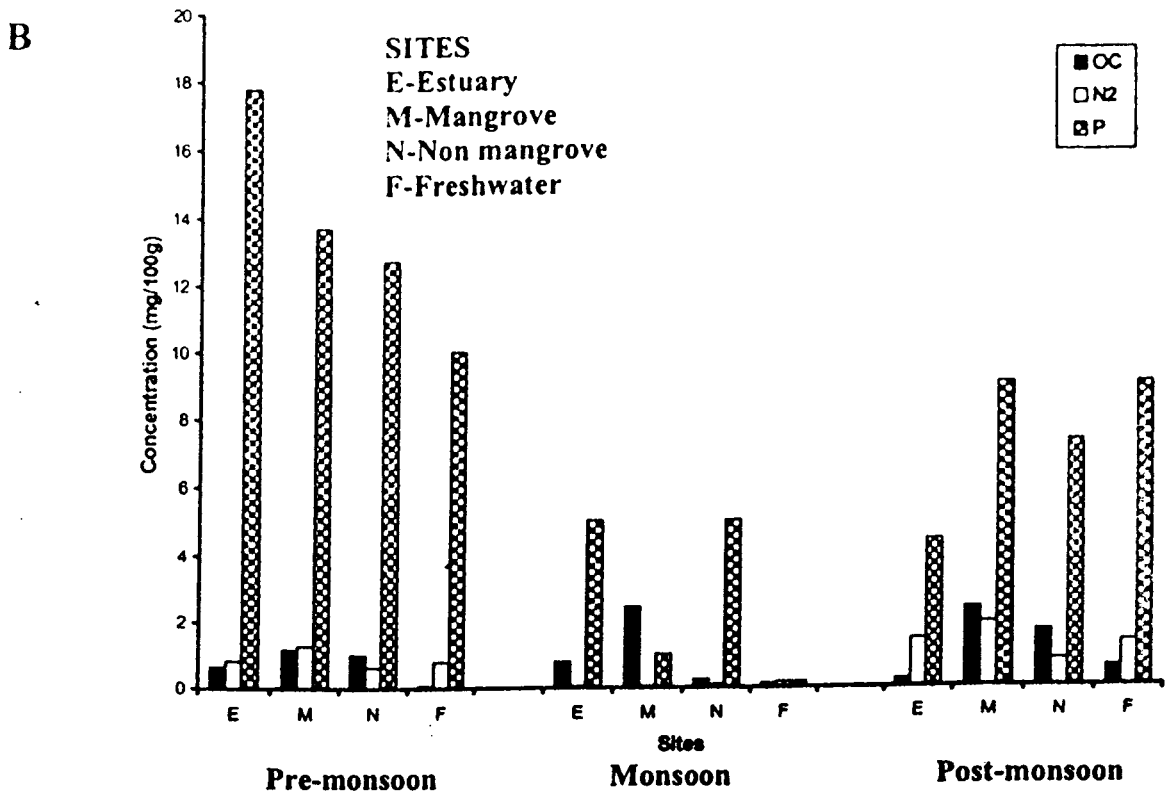
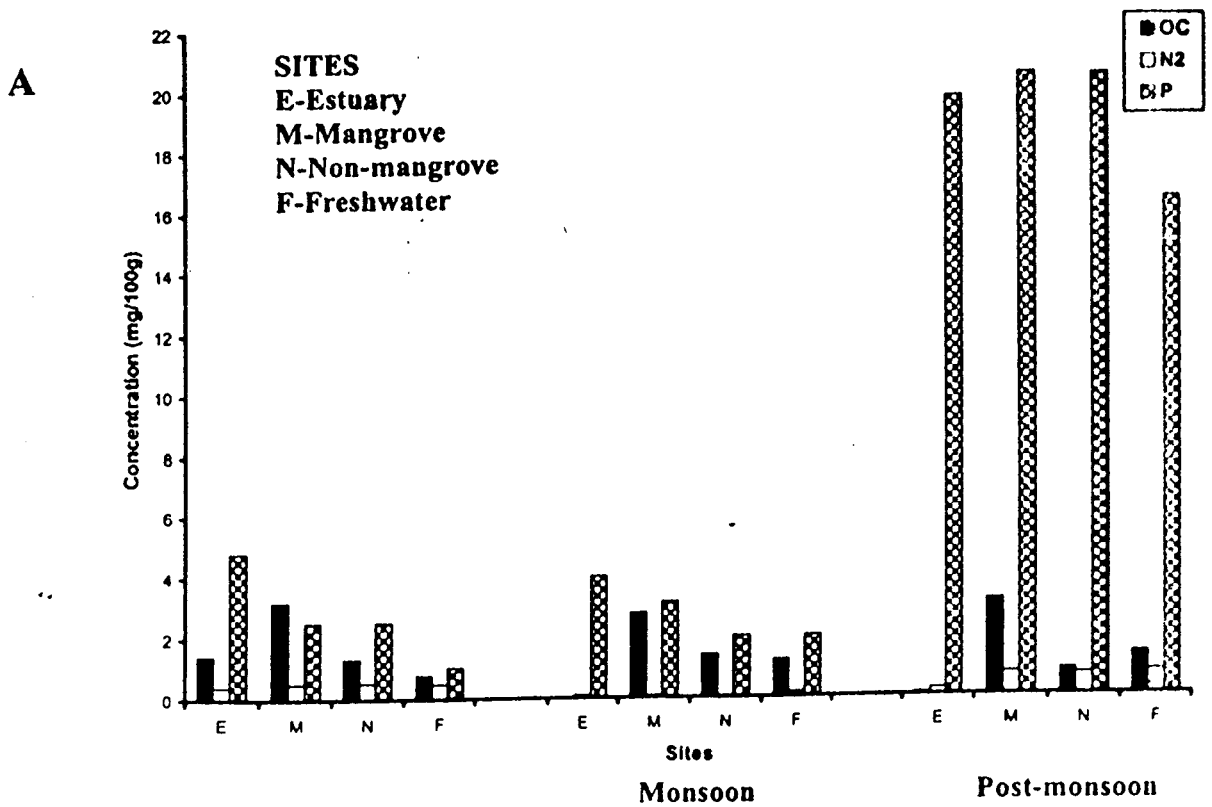


Fig. 2 Seasonal Variations in Organic C, N and P in Thalassery (A) and Valapattanam (B) River Sediments

and the remaining 10% from non-mangrove sites. Presumably, inorganic and organic matter in the mangrove ecosystem are remineralized microbially and bound organically in the mangroves by the primary and secondary producers, thus becoming incorporated into the mangrove sediments. Calcium and magnesium ions in the mangrove ecosystem are primary nutrients contributing to the productivity. The silt brought in by high tides from the sea carries substantial quantity of calcareous material from foraminifer, mollusks and other shells.

It was observed from the study that in all the seasons, mangrove site showed high values of organic carbon content in both the rivers. The general distribution trend in the Thalassery river was Mangrove>Estuary>Freshwater. But in Valapattanam river the trend was Mangrove>Freshwater>Estuary. The increase in organic matter in the mangrove sediments may be due to the microbial biodegradation of mangrove litter and also from run off from the catchments upstream i.e., autochthonous in the mangrove area and allochthonous in other two biotopes. Poor circulation in the mangrove biotope is another reason for its high contents as has been reported earlier (Shanmukhappa, 1987). Similar situation was observed in these two river basins. But, in Valapattanam River, the slightly high organic carbon content in freshwater than estuary may be due to the decomposition of animal wastes dumped there. High values for organic carbon were noticed in pre/post monsoon than in monsoon seasons. Earlier studies by Shanmukhappa (1981) showed an increase in organic carbon in the monsoon season. Relatively lower values for organic carbon in these two river basins during the monsoon season may be attributed to high dilution by rainwater. When mangrove and non-mangrove areas in the same sites were considered, high organic carbon values were reported in the mangrove sediments,

which may be the contribution from the decomposed mangrove litter.

The average nitrate-nitrogen content in the Thalassery River, it ranged from 0.62-1.26 mg/100 g in pre-monsoon, 0.051-0.14 mg/100 g in monsoon and 0.79-1.91 mg/100 g in post monsoon seasons (Fig. 2 A). In the Valapattanam River it ranged from 0.4-0.54 mg/100 g in pre-monsoon, 0.06-0.15 mg/100 g in monsoon and 0.21-0.77 mg/100 g in post-monsoon seasons (Fig. 2 B).

The Thalassery River sediments recorded the average values of available phosphorus ranging from 10-17.8 mg/100 g in pre-monsoon, 0.14-5 mg/100 g in monsoon and 4.4-9 mg/100 g in post-monsoon respectively (Fig. 2 A). In the Valapattanam River it ranged from 1.02-4.8 mg/100 g in pre-monsoon, 2-4 mg/100 g in monsoon and 16.2-20.33 mg/100 g in post-monsoon seasons (Fig. 2 B).

It was observed from the present study that available phosphorus was found to be high in the estuary, followed by the mangrove area and the fresh water zone. This may be due to seawater intrusion, because the concentration of phosphorus in seawater is usually higher than freshwater. But when mangrove and non-mangrove areas in the same sites were considered high values were noticed in mangrove area than in non-mangrove area. But in Thalassery river basin, non-mangrove area reported high values during monsoon season. The higher concentration of phosphorus in pre-/post-monsoon seasons is due to the higher concentration of nutrients in the overlying waters, which ultimately get deposited over the sediments due to poor turbulence of water column. In monsoon low values of phosphorus is reported which is due to the leaching of phosphorus to the overlying water because of fresh water influx and severe agitation due to wave action leading

to re suspension of sediments in the water column. Similar trends have been reported earlier in the Vellar estuary, Vishakhapattanam shelf and Cochin backwaters respectively (Sivakumar et al. 1983; Satyanarayanan et al. 1993; Sankaranarayanan & Panampunnayil 1979). Another reason for decrease in phosphorus during monsoon may be the high uptake of this element by phytoplankton, which is usually abundant during the monsoon season.

Variations in the mean concentrations of exchangeable sodium, potassium, calcium and magnesium in the mangrove and non-mangrove sites of Thalassery and Valapattanam rivers during the pre-monsoon, monsoon and post-monsoon are presented in Figure 3 A and B respectively.

The study revealed considerable variations in the nutrient concentration of the two river sediments. In all the three seasons studied, the post-monsoon samples recorded higher values and the monsoon season recorded lower values, which may be due to high dilution, circulation and mixing in the estuarine systems. Sodium, potassium, calcium and magnesium showed higher concentration in the mangrove sediments in comparison with the non-mangrove sediments, while calcium showed an inverse relationship with higher concentration in the non-mangrove site. Increased concentration of sodium, potassium, calcium and magnesium in the mangrove site may be attributed either to the cation exchange or adsorption of these nutrients on to the clayey mangrove sediments, as has been reported earlier (Badarudeen & Sakkir, 1998). These unprecipitated elements may be present in the aqueous solution, filling the pore spaces of the sediments. The higher concentration of sodium and potassium in the mangrove site may also be due to the seawater intrusion and consequent adsorption of these nutrients on to the clayey sediment particles. The primary source of

sodium in the mangrove environment may be the weathered product of plagioclase feldspars and the source of potassium may be from weathering of rocks rich in orthoclase, microcline and biolite, as has been reported earlier (Badarudeen & Sakkir 1998). The decomposed vegetative parts of mangroves may also contribute potassium. Compared to sodium, lower concentration of potassium may be attributed to the removal of this ion by the mangrove flora.

The lower values of calcium in the mangrove environment recorded in the present study may be attributed to the breakdown of this mineral by the sulphur bacteria present in the mangrove sediments, which may ultimately be made to other organism. Magnesium being an important constituent of chlorophyll, the increased concentration of magnesium in the mangrove sediments may be attributed to the decomposition of the mangrove litter, thereby releasing the element into the ecosystem.

The study revealed sharp seasonal and site-wise variations in exchangeable sodium, potassium, calcium and magnesium ions in the sediments of the Thalassery and Valapattanam rivers. The sediment acts as a sink of these elements, which are released, into overlying waters for utilization by the phytoplankton, which form the basic components of primary productivity. The zooplanktons, which are the primary consumers, contribute to the secondary productivity. The microorganisms in this ecosystem help in mineralization and biogeochemical cycling of nutrients and contribute significantly to the transfer of energy between various trophic levels resulting in the existence of a complex food web. The mangrove flora directly takes up the rematerialized nutrients. Hence, higher concentration of these elements in the mangrove area supports the high productivity of this ecosystem.

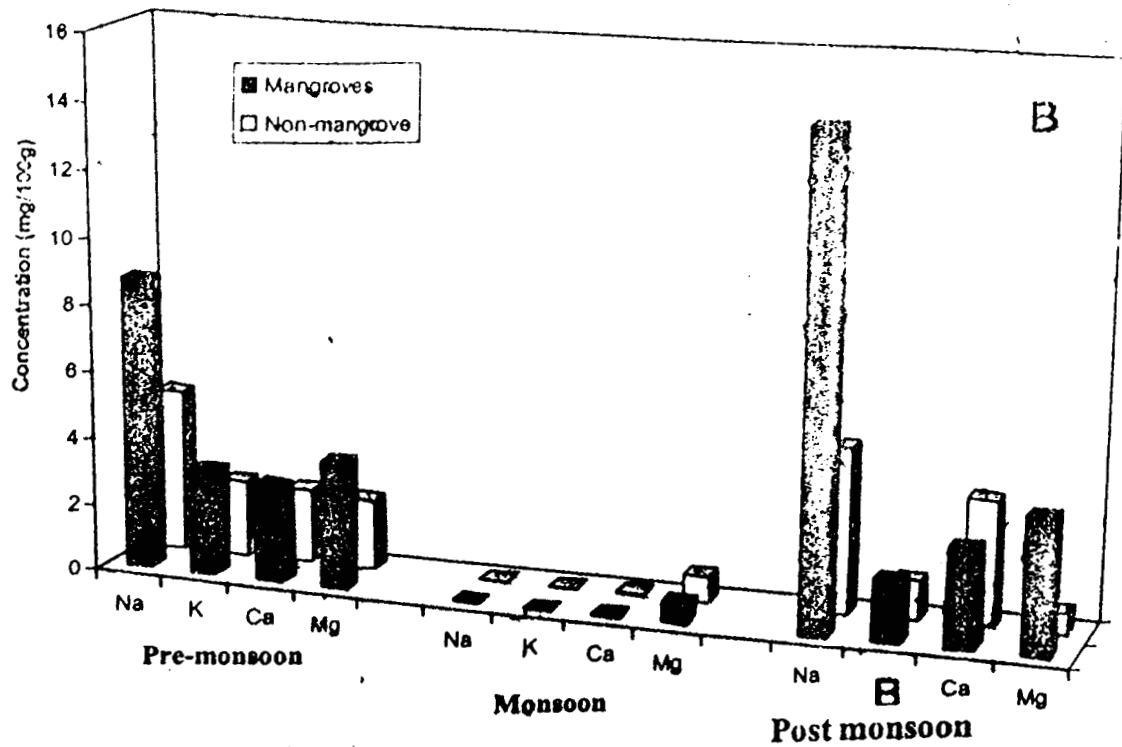
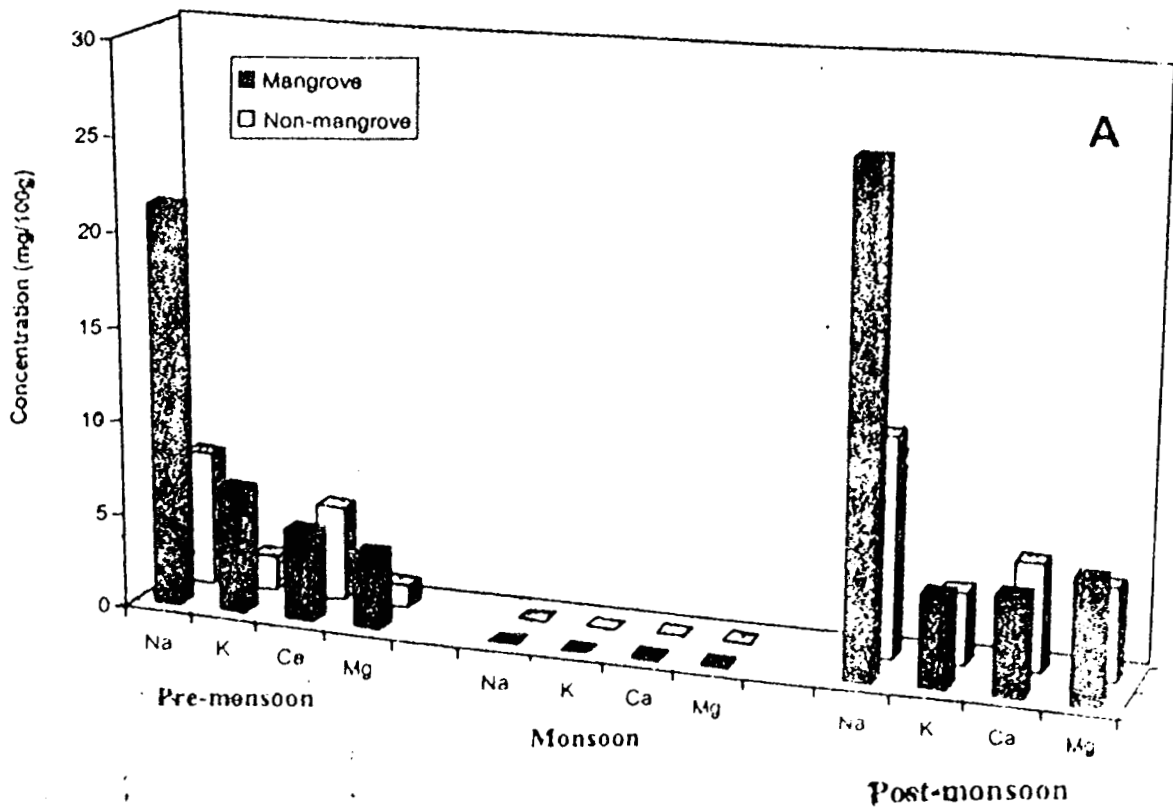


Fig. 3 Distribution of Exchangeable Sodium, Potassium, Calcium and Magnesium in Valapattanam (A) and Thalassery (B) River Sediments

Conclusions

Distinct spatial and temporal variations in organic carbon, nitrate-nitrogen, phosphorus, exchangeable sodium, potassium, calcium and magnesium were observed. The study revealed a strong correlation of nitrate-nitrogen and phosphorus with organic carbon content in the mangrove sites in both Thalassery and Valapattanam river basins. As high values of the above nutrients were observed in the mangrove area when compared to estuary and freshwater biotopes, it can be concluded that the mangrove ecosystem is more productive.

Acknowledgements

The authors are grateful to the Executive Director, Centre for Water Resources Development and Management, Kozhikode 673 571, Kerala for the facilities and encouragement. The Junior Research Fellowship provided by the Science, Technology & Environment Department, Government of Kerala to Ms K Lakshmi, for undertaking this study is gratefully acknowledged.

References

- Aksornkoae, S & Papharasit, N., 1996. Effect of sea level rise on the mangrove ecosystem in Thailand. *Natl. Resour. Develop.* 43/44: 95-104
- Ananthakrishnan, T. N., 1982. *Bioresources Ecology*. Oxford & IBH Pub. Co., New Delhi, pp 131 - 142
- Aston, S. R & Hewitt, C. N., 1977. Phosphorus and carbon distribution in a polluted coastal environment. *Estuar. Coast. Mar. Sci.* 5: 243 - 254
- Badarudeen, A., Damodaran, K. T., Sajan, K & Padmalal, D., 1996. Texture and geochemistry of the sediments of a tropical mangrove ecosystem, Southwest coast of India. *Environ. Geol.* 27: 164 - 169
- Badarudeen, A & Sakkir, S., 1998. Distribution of Na and K in the sediments of Veli, Kochi and Kannur mangroves, Kerala. *Indian J. Mar. Sci.* 27: 235 - 255
- Bowman, M. J., 1977. Nutrient distributions and transport in Long Island Sound. *Estuar. Coast. Mar. Sci.* 5: 531 - 548
- Brenzonik, P. L., 1972. Nitrogen, Source and transformations in natural waters. Allen & Kramer (Ed.) *Nutrients in Natural Waters*. Wiley Interscience, New York
- Chand Basha, S., 1991. Distribution of mangroves in Kerala. *Indian Forester* 117: 439-448
- Chand Basha, S., 1992. Mangroves of Kerala: A fast disappearing asset. *Indian Forester* 118: 175-190
- Dugdale, R. C., 1967. Nutrient limitation in the sea; Dynamics, identifications and significance. *Limnol. Oceanogr.* 12: 685 - 695
- Delacerd, L. D., 1983. Heavy metal accumulation by mangrove salt marsh intertidal sediments. *Braz. J. Med.* 16: 442 - 451
- Grewling, T & Peech, M., 1965. *Chemical Soil Tests*. Cornell Univ. Agric. Exp. Station, Bull. 960
- Lakshmi, K., Unni, P. N & Neelakantan, N., 2000. Environmental status of the mangrove ecosystem in Valapattanam river basin, Kerala. *Ecol. Environ. & Conserv.* 6: 363 - 371
- Lakshmi, K., Unni, P. N & Neelakantan, N., 2002. Spatial and temporal variation in organic carbon, nitrogen and phosphorus in the mangrove sediments of two riverine ecosystems of Kerala. *Asian J. Microbiol. Biotech. Env. Sc.* 4: 259-263
- Lafond, L. R., 1984. Dynamical processes in

deltaic sedimentation with special respect to mangrove areas. UNDP/UNESCO, New Delhi, pp 25-26

Lakshmanaperumalsamy, P., 1987. Nitrogen fixing bacteria *Azotobacter* sp. in aquatic sediments. *Fish. Technol. Soc. Fish. Technol. Cochin* 24: 126 -128

Rhods, D. C., Tennore, K & Browne, M., 1975. The role of suspended bottom mud in nutrient cycles of shallow embayment. In: Cronine (Ed.) *Estuarine Research Vol. 1. Academic Press, London*, pp 563 – 579

Roman, M. R & Tennore, K. R., 1978. Tidal resuspension in Buzzards Bay I. Seasonal changes in resuspension of organic carbon and chlorophyll a. *Estuar. Coast. Mar. Sci.* 2: 235-240

Satyanarayanan, D., Panigrahy, P. K & Sahu, S. D., 1993. Texture, mineralogy, Carbon, Nitrogen and Phosphorus of Visakhapatnam shelf sediments, East coast of India. *Indian J. Mar. Sci.* 22: 235-240

Sahoo, J. K., Hariharan, V & Katti, R. J., 1991. Seasonal distribution of C, N & P in the sediments of Talapady lagoon, Dakshina Kannada. *Environ. Ecol.* 9: 516 -520

Sankaranarayanan, V. N & Panampunnayil, S. U., 1970. Studies on organic carbon, nitrogen and phosphorus in sediments of Cochin backwater. *Indian J. Mar. Sci.* 8: 27-30

Shanmukhappa, H., 1981. Primary Productivity by Phytoplankton Under Controlled Laboratory Conditions. M. Phil dissertation, Jawaharlal Nehru University, New Delhi

Shanmukhappa, H., 1987. Organic matter and C, N, P in Sediments of Porto Novo. *Proc. Natn. Sem. Estuarine Management. Thiruvananthapuram, Kerala.* pp 128-133

Sivakumar, V., Thangaraj, G. S., Chandran, R & Ramamoorthi, K., 1983. Seasonal variations in C, N & P in sediments of the Vellar estuary, Porto Novo. *Mahasagar –Bull. Natn. Inst. Oceanogr.* 16: 175–181

Sengupta, A & Chaudary, S., 1990. Halo tolerant Rhizobium strains from mangrove swamps of the Ganges River Delta. *Indian J. Microbiol.* 30: 483 – 484

Trivedy, R. K., Goel, P. K & Trisal, C. L., 1987. *Practical Methods in Ecology and Environmental Science.* Environ Media publications, Karad, India, 340 pp

Vannucci, M., 1989. *The Mangroves and Us.* Indian Association for the Advancement of Science, New Delhi

Waghmode, A. P., 1987. Preliminary studies in the Nitrogen dynamics of estuarine ecosystem. *J. Mar. biol. Assoc. India* 29: 362 – 364

Walkley, A & Black, I. A., 1934. An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil. Sci.* 37: 29 – 38

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