EFFECT OF THERMAL EFFLUENT ON WATER QUALITY IN RELATION TO BENTHIC COMMUNITY

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BY

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MARCH 1995

DECLARATION

I hereby declare that this thesis entitled "Effect of thermal effluent on water quality in relation to benthic community" is a record of original and bonafide research carried out by me under the Supervision and guidance of **Dr.(Mrs.) S.SIVAKAMI**, Senior Scientist, Central Marine Fisheries Research Institute, Cochin and that no part there of has been presented for the award of any other degree, diploma, associateship, fellowship or other similar recognition.

Cochin - 682014
March, 1995.

M. Kailasam

(M.KAILASAM)

CERTIFICATE

This is to certify that this thesis entitled "Effect of thermal effluent on water quality in relation to benthic community" embodies the bonafide original research work conducted by **Shri.M.KAILASAM** under my supervision and guidance at Central Marine Fisheries Research Institute, Cochin. I further certify that no part of this thesis has previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles or recognition.

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PREFACE

PREFACE

In recent years, there has been a pronounced trend towards greater use of estuarine, brackish and marine waters for industrial cooling purposes. This is because, the available freshwater resources are not adequate enough to cope with the increasing demand (Leof and Ward, 1969). Due to expansion of industrial and agricultural sectors, the demand of electric power in developing nations like India, increases rapidly. Ultimately, coastal regions are selected for the installation of thermal power plants since it is a permanent water source (Markowski, 1959; Naylor, 1965; Warinner and Brehner 1967). The generation of electric power by steam involves the production of large quantities of heat. The discharge of heated effluent from the cooling condensers of thermal power plant is the source of thermal pollution which can be expected to cause changes in the aquatic fauna in the area of discharge.

Relatively little is known about the ecological sequence of imposing artificial temperature regimes on coastal environment. This is particularly true in tropical and subtropical regions where the problem of heated effluents is compounded because the organisms may already be living within a few degrees of their thermal death points (Mayer, 1914). Biological relations of temperature are of basic interest to the study of thermal pollution. Temperature is often referred to as the master factor in the environment. Interactions of temperature with other physical and chemical factors in the environment are equally important in deciding the survival of the organisms.

Monitoring is necessary to establish the magnitude, spatial distribution, and temporal distribution of anthropogenic impacts in the receiving environment. At least one biological component of the ecosystem should be monitored to ensure that unacceptable harm is not done to important species or at higher levels of biological organisation. In this respect benthic infauna are superior to many other biological groups that could be monitored because they are sedentary and must either adapt to environmental stress or perish (Bilyard, 1987). Their responses to different environmental changes facilitate the spatial definition of impacts (Gray, 1980). Benthic organisms are very sensitive to habitat disturbance, including changes of water quality and contamination of the sediments by toxic substances (Boesch and Rosenberg, 1981; Wolfe *et al.,* 1982). Because the species vary in their sensitivities to pollutants, benthic communities undergo dramatic changes both in species composition and abundance in response to pollutant stresses overtime (Hartley 1982).

With this background, the present study has been taken up in order to assess the effect of thermal effluent on water quality in relation to benthic community at Tuticorin bay South-East coast of India.

The thesis is presented in six parts.

The first part, the introduction presents a review of relevant works done in the same field and other important investigations on the impacts of heated effluent on water quality and biota of marine ecosystem, with a view to bring out the present status of our knowledge in the subject and also to stress the

importance of such study on coastal management practices by monitoring the environmental characteristics on a scientific line.

The second part, the material and methods includes information above the source of thermal effluent, a description of the study area, selection of stations and collection and estimation of hydrographical, sediment and bottom fauna samples. Details of statistical analysis carried out are also included.

Part III covers the results of hydrographical parameters such as water temperature, salinity, dissolved oxygen, pH, turbidity, nitrite, nitrate, phosphate, silicate, ammonia and productivity. Sediment characteristics such as particle size composition of sand, silt and clay, sediment nutrients, like total organic carbon, total nitrogen, total phosphorus, C/N ratio and N/P ratio estimated are also described. Species composition, population density, species diversity, species richness, species evenness and benthic biomass both wet weight and dry weight of benthic organisms are also presented. Analysis of variance (ANOVA) calculated between the stations and over seasons for all the parameters are given. Correlation co-efficient is done for all the parameters and significant relationships are described.

The interaction of various hydrographical parameters among themselves and their influence on the sediment nature and benthic faunal population with special reference to thermal effluent discharge in the waters adjacent to and away from the TTPP are compared and discussed in Part IV. Conclusions drawn based on the study are also presented.

A summary of the results along with the significant observations is presented in Part V. Part VI follows with a detailed list of literature cited at the end under "References".

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(M.KAILASAM)

INTRODUCTION

INTRODUCTION

The advancement of industrialization and urbanization along the coastal region has received considerable attention of environmental scientists in the recent past. Owing to an increasing trend in the above factors, large volume of untreated industrial, agricultural, domestic and other wastes are frequently discharged into the sea. This indiscriminate discharge of the waste materials may endanger the safety of the aquatic life and even may cause irrepairable damage to the otherwise very delicately balanced marine ecosystem. Besides, some industrial waste water may contain high concentration of toxicants at lethal or near lethal level. If such untreated waste water is discharged into the sea, the toxicants may be picked up by fishes and shell fishes and these get concentrated in the tissues until the organisms are no longer fit for human consumption (Hammond, 1971).

The ever increasing demand of electricity for industrial and domestic purposes has urged the Government, Public and Private sectors to install more and more electricity generating stations. The location of any industry is selected based on both the availability of reasonably good water for the industrial processes and the facility for discharging the wastes. The thermal power plants are always installed near to larger water bodies such as reservoir, lakes and sea and these plants use an enormous amount of water as transfer medium to remove the heat from the condensers and dissipate it into the nearest aquatic environment. The pumping rate of cooling water varies widely according to the design of the plant. Pannel *et al* (1962) have pointed out that dispersion of heat will be by mixing with water and not by cooling to

the atmosphere. As a result of this, the effects of heated effluent are felt at a greater distance from the out fall than if the heated water was spread out and cooled at the surface (Raymont and Carrie, 1964; Ansell, 1963b)

Temperature is the master factor which influences the activities of aquatic organisms such as swimming, feeding, growth reproduction, ability to resist disease and other stressful conditions to a greater extent. The temperature of natural waters in the tropics is very high, often very close to the upper lethal limit, especially during the summer months. A slight increase in temperature such as that caused by the thermal discharges therefore may often push the organisms over the tolerance limit impairing the metabolic activities (Mayer, 1914; Fry, 1947; Naylor, 1965; Jokiel and Coles 1974; Thorhaug *et al*, 1978). In thermal power plant, the water used to condense the steam is more often taken directly from the adjacent water body and discharged back into the receiving waters with a temperature rise of 6.0°C to 10°C higher than the ambient water temperature (Warriner and Brehner, 1966). An increase of 10°C causes doubling in the rate of biochemical reactions leading to increased demand of food and oxygen by the organisms (Moore, 1958). Besides, the increased temperature can cause changes of various environmental variables particularly salinity (Markowski, 1959; Thorhaug, *et al.,* 1978) dissolved oxygen (Mukhopadhyay *et al.,* 1987) primary productivity (Raymont, 1980), survival of planktonic organisms (Simpson and Dudaitis, 1981; Evans *et al.,* 1986) and distribution of benthic fauna (Markowski, 1960; Kinne, 1963; Evans, 1986; Ahmed *et al.,* 1992).

Studies have been conducted by various authors regarding the influence of thermal effluent discharge on the hydrographical features of various aquatic systems and their associated biota. That the temperature interacts with other physical and chemical parameters including pollutants of any ecosystem to produce effects more complex and varied than those resulting from any of the factors alone was reported by many authors. (Mihursky and Kennedy, 1967, Trembley, 1968; Allen, 1969). Temperature also influences the other environmental factors such as oxygen concentration, Co_2, pH, dissolved solids and toxins of aquatic system (Pennsylvania, Department of Health, 1962). Alabaster and wellcomme (1962) have stated that high temperatures may be associated with low concentration of dissolved oxygen, particularly in areas receiving oxidizable effluents as well as heat. Mayer (1914) has reported that the cause of death of aquatic organisms at higher temperatures was asphyxiation due to low oxygen level. Nugent (1970) has observed power plant to cause a decrease in the dissolved oxygen content of the cooling water on an average of about 0.4 ml/l during its passage through the condensers, Eloranta (1983) has evaluated the influence of warm water on the physical and chemical properties of pond water receiving the heated effluent from a thermal power plant.

Studies on the mortality of plankton community at the point of out fall of the cooling water from electric generating station have been carried out by many authors (Heinle, 1969; Reeve, 1970; Carpenter *et al.,* 1974; Ginn *et al.*, 1974; Brauer *et al.*, 1974; Waritswat, 1974; Huh, 1980; Simpson and Dudaitis, 1981; Evans *et al.*, 1986). Reports are also available on the impact of thermal effluent on fishes, crustaceans, molluscs and other aquatic organisms. Jones

and Randell (1973) have observed the disappearance of crustaceans, molluscs, echinoderms and fishes when the heated effluent from a power plant was introduced. The population characteristics of estuarine decapod crustaceans from the intake and discharge area of the Cader Bayou Electric Power Station before and during its installation and operation respectively were studied by Williams (1977). Species composition, abundance and distribution of macrocrustaceans and fishes in the intake area, discharge canal and cooling lake of the Cadar Bayou electric generating station, near Baytown Texas were compared by Eidmen (1978). According to Bayne *et al.*, (1977), the mussel *Mytilus edulis* from the thermal effluent discharging area of an electric generating station (England) had a higher thermal tolerance than a control population particularly in individuals similar in size and reproductive condition. Hargreaves (1977) has studied the growth of submerged caged mussels *Mytilus edulis* and *M. californians* for a period of two years in relation to thermal effluent discharge at Morro Bay, California. Kastendick *et al.*, (1981) have observed that the experimental population of mussel *M. edulis* has shown retarded growth which were reared at the out fall of the heated effluent from the nuclear power generating station, Southern California when compared to the control population. Hines (1978) has noticed a remarkable decrease in number and body size of the population of *Balanus amphitrite* living in the thermal effluent discharge canal when compared with those from the intake canal. Ehrlich (1977) has reported that the hatching success of California grunion *Leuresthes tenuis* had been significantly reduced by a non-thermal component of the effluent from an electric generating station. Fluctuations in temperature and salinity around the heated effluent discharging site were found to cause gas bubble disease and low survival rate

in macroinvertebrates and several species of fishes (Holt, 1977; Parker, 1977). Donavan *et al.*, (1977) have reported about the impact of thermal plume on fish distribution of Barnegat bay. Elevated temperatures may also tempt to increase the virulence of fish pathogens and if the temperature of the water is sufficiently high, the susceptibility of fish to these pathogens also may be increased (Clarke and Brownell, 1973). Migratory patterns of fish may be disrupted by power plant discharges which creates a temperature barrier in the rivers or estuatries which served as migration routes for fish (Mihursky, 1967; Pearse, 1969).

The significance of benthic organisms in marine ecosystem has been described by many authors (Kuriyan, 1971; Desai, 1973; Wolff and Wolf, 1977; Mills, 1975; Parulekar *et al.*, 1982; Prabhu and Reddy, 1987). Benthic organisms have an important role in the food chain of marine ecosystem at the secondary level as feeders of deteritus and plant material or at the teritiary level as food for predatory fishes. A thorough knowledge of the bottom fauna is very essential for an understanding of the food habits and proper exploitation of the demersal fishery resources, Harkantra *et al.*, (1980) and Prabhu and Reddy (1987) have demonstrated that a direct relationship exists between the abundance of bottom fauna and the demersal fish catch.

The distribution of benthos in an area has an intimate relation with its environment and is regarded as an indicator denoting the characteristics of its ecological niche (Gray, 1980; Hartley, 1982, Phillips and Segar, 1986; Bilyard, 1987). Biologists have stated that in recognizing the limitations of chemical and physical measurements of water quality, certain organisms could serve as

substitute indicators of different degrees of pollution. Organisms particularly of the bottom habitats are favoured by many in this respect since they reflect the water conditions not only at the time of sampling but also for sometime past as well.

Of the various hydrographic parameters, the temperature of water is considered to be very important in relation to distribution of benthic populations. The salt water discharge from a condenser cooling system with a higher salt concentration due to evaporation will be denser and hence tend to sink thus affecting the bottom water quality. The density and diversity of benthic infauna could be largely decreased when associated with the temperature range of 34.0°C - 37.0°C produced by a power plant (Thorhaug, 1974). Benthic population would be adversely affected by any change in the plankton community due to thermal additions, since many benthic species pass through planktonic larval stages. Warriner and Brehner (1966) have reported the lowest abundance of benthic organisms near the thermal effluent discharging site of Virgimice electric and power company at Yorktowm where the temperature ranged between 29.4°C and 35.1°C.

Mayer (1914) studying the effects of high temperatures, upon tropical marine animals reported that an increase of water temperature from 33.0°C to 38.0°C range has caused major kills of organisms such as molluscs, corals and small fishes. Walter (1968) has stated that benthic organisms may be seriously depleted quantitatively at distances up to 1200 feet from discharge point of heated effluents in summer. Variations in temperature is often found to have a major impact during the early stage of life when the majority of

benthic organisms pass through pelagic phases and losses are especially severe if water temperature and salinity are unfavourable (Tait, 1981). Carpenter *et al.*, (1974) have reported that the 70% mortality caused to the copepods entrained through the power plant is not only due to the effluent, but also the mechanical effects of their passage through the power plant. Barnacle settlement was lowered due to high velocity of water current in the vicinity of cooling water pump discharges from power generating station (Vouriner and Laithonen, 1983, Ahmed *et al.,* 1992). Roessler *et al.*, (1975) have reported that the aquatic organisms were affected by the heated effluent when the temperature is increased to 3.0°C higher than the ambient water temperature. Markowski (1960) has observed denser animal populations in the intake area than the out fall of power station cooling water.

In India, the ecology of benthic organisms both in east coast and west coast has been studied by many authors from the turn of the century. (Annandale, 1907; Annandale and Kemp, 1915; Seshappa,1953; Kuriyan 1953; Balasubramaniyam, 1961; Rajan, 1964; Kuriyan, 1967; Desai and Krishnan kutty, 1967a and 1967b; Patnaik, 1971; Kuriyan, 1972; Parulekar, 1973; Damodaran, 1973; Ganapathi and Nair, 1973; Anzari, 1974; Parulekar *et al.,* 1975; and Parulekar and wagh 1975; Ajmal khan *et al.*, 1975; Kuriyan, 1975; Harkantra, 1975; Anzari, 1977 Harkantra *et al.*, 1980; Parulekar 1980, 1982; Desai, 1983; Anwarbatcha, 1984; Harkantra and Parulekar, 1987; Varshney *et al.*, 1988; Raman and Adiseshiah 1989; Vijayakumar *et al.*, 1991; Suresh *et al.*, 1992; Jagadeesan and Ayyakkannu, 1992). Reports on recent researches on the benthic ecology in India are those by Harkantra and Parulekar (1994) and Anzari *et al.*, (1994).

Studies are also available on the importance of substratum in relation to benthic organisms. Muus (1967) has reported that the substratum is the most important factor which plays a major role in the distribution of benthic faunal assemblages. Harkantra *et al.*, (1982) have studied the distribution of benthic organisms of shelf of North Eastern Bay of Bengal in relation to sediments. Aravindakshan *et al.*, (1992) have stated that sand, clay and silt were found to be relatively the important factors controlling the benthic biomass of prawn culture fields in and around Cochin back waters. Sediment grain size as a significant parameter influencing the distribution and abundance of benthic communities has been described by Parulekar *et al.*, (1975) and Bhat and Neelankantan (1988). Chandran *et al.*, (1982) have studied the seasonal variations of benthic fauna in relation to organic carbon content of the sediment.

Eventhough studies on the ecology of bottom fauna have been undertaken extensively, very little information is available on the benthic fauna in relation to pollution. Dwivedi and Parulekar (1974) have studied the effect of oil pollution on marine biota along the Indian coastal region. Benthic population of a sewage outfall in Panjim, Goa region was worked upon by Dwivedi *et al.*, (1975). Unnithan (1976) has discussed the problems of pollution in the back waters of Kerala. Vijayan *et al.*, (1976) have reported the effects of organic pollution on some hydrographic features of Cochin back waters. Fish mortality from industrially polluted area of the Cochin back water system was investigated by Silas and Pillai (1976). Studies on the bioecology of the benthic fauna in the industrially and domestically polluted waters of Vishakhapatnam Harbour were carried out by Ganapathy and Raman (1973). Remani (1979) has

studied the benthos of Cochin backwater with special reference to pollution. Sarala Devi *et al.*, (1979) have made observations on the hydrographic features of Cochin backwaters in relation to industrial pollution. Chaetognaths and copepods from the polluted and unpolluted zones of Bombay waters were compared by Nair *et al.*, (1981). Remani *et al.*, (1983) have attempted to specify the indicator species of organic pollution in the Cochin backwaters. Venugopalan *et al.*, (1982) and Sarala Devi (1986) have studied the benthic communities of a tropical estuary in relation to industrial pollution. Studies on the marine biota of Mangalore coast in relation to industrial effluents were carried out by Devassy *et al.*, (1987). Sarala Devi and Venugopal (1989) have reported the effect of industrial effluents on the benthos of Cochin back waters. The impact of power station out-fall on coastal waters of Kalpakkam along the east coast of India was evaluated by Nair *et al.*, (1986). The problem of industrial pollution and the related fish mortality in inshore waters of Kayalpatnam, south east coast of India were discussed by Kasim *et al.*, (1991). Ahmed *et al.*, (1992) have studied the effect of Power Plant heated effluent on the distribution of sedentary fauna and flora of Kalpakkam coast. Using the diversity of algal species, Kumar and Mahadevan (1993) have assessed the effect of industrial pollution along the Tuticorin coast, south east coast of India. Chatterjee and Sharma (1994) have reported the impact of thermal effluent discharge on the distribution and reproduction of Indian major carps in Sarni reservoir, Madhya Pradesh. Raman and Prakash (1989) have assessed the plankton diversity in relation to pollution in Visakapatnam, east coast of India. The impact of industrial waste on the distribution of plankton community was studied by Sivasamy (1990) at Ennore back water, Madras coast.

Tuticorin is a major fishing port, ranking second in marine fish production in Tamil Nadu and is historically famous for valuable natural pearl and edible oyster and chank fisheries. The Tuticorin coast has potential grounds for culturing edible oysters, pearl oysters, prawns and fishes. Like any other industrial city, the Tuticorin coast also possesses many industries such as Southern Petrochemicals Industries Corporation (SPIC), Tuticorin Alkali Chemicals Limited (TAC), Heavy water plant, Madura Coats, Salt industries, Fishing harbour, Fish Processing companies and the Thermal Power plant. The Tuticorin Thermal Power Plant (TTPP) is situated at the Southern Part of Tuticorin Bay. The TTPP was established in 1979 and the plant is currently operating 3 units generating power of 630 Mega Watts (MW), which may be increased to 1550 MW in the near future. The TTPP utilizes the bay water for cooling the condensers and discharges back into the other side of the bay which results in the rise of temperature from 5.0°C to 8.0°C higher than the ambient water temperature (Kutty *et al.*, 1986). The discharge rate of thermal effluent is 115 million litres day during the operation of all 3 units (Personal Communication). This large quantity of heated effluent discharge can adversely affect the different fauna and flora in the adjacent coastal waters unless attempts are made to evaluate the effects and suggestions proposed for appropriate remedial measures.

In order to fulfill these requirements, comparisons of the pre-installation and post installation information on the quality on the water quality of the adjacent water area of the TTPP is necessary. The TTPP installed in 1979, was studied for the pre-installation, period by a very few in a general manner. Chandraseharan *et al.*, (1967) have discussed the variations

of salinity and temperature over the pearl and chank beds of Tuticorin. Chandraseharan and Sudhakar (1968) have made observations on the hydrography and planktology of pearl banks of Gulf of Mannar. Hydrographical studies in the coastal waters of Tuticorin, Gulf of Mannar was carried out by Marichamy and Pon Siraimeetan (1979). Nevertheless, similar studies on the post installation period of TTPP are not hitherto been made. This investigation is therefore taken up to study the effect of thermal effluent discharge on the water quality in relation to benthic community of Tuticorin bay with the following objectives.

(i) To assess the impact of thermal effluent on physico-chemical parameters of water in Tuticorin bay.

(ii) To evaluate the sediment particle size composition and sediment nutrients.

(iii) To estimate the distribution, composition, density, and diversity of benthic organisms in relation to thermal effluent discharge.

MATERIALS AND METHODS

MATERIALS AND METHODS

2.1 SOURCES OF THERMAL EFFLUENT

In a thermal power plant, electricity is produced from a generator which is powered by a steam propelled turbine. In the process of producing steam, the expansion of water from the liquid to gaseous state creates a pressure which is used to drive the turbine. The turning of the turbine powers the generator which produces electricity. The source of heat for boiling water is from the fossil fuel energy.

Once the generator is powered, the steam from the turbine is condensed back to liquid water and recycled to the boiler. Condensation is achieved by running cooling water through a long coiled pipe exposed to the steam. Heat is transferred through the pipe from the hot steam to the cooling water until the steam ultimately condenses. The heated effluent from the condenser is then discharged in to the adjacent water body which forms the source of thermal pollution from such a power plant. Besides,the water used in the washing of various machines involved in the electricity production is discharged along with other wastes into the bay.

2.1.1 Description of the study area

The present study was conducted at the Tuticorin bay (Latitude 8° 50' N and Longitude 78°C 8' E) situated in the Gulf of Mannar, south east coast of India (Fig.4). The Tuticorin Thermal Power Plant (TTPP) is located at the southern part of the Tuticorin bay (Plate I) which is about 6 KM away from

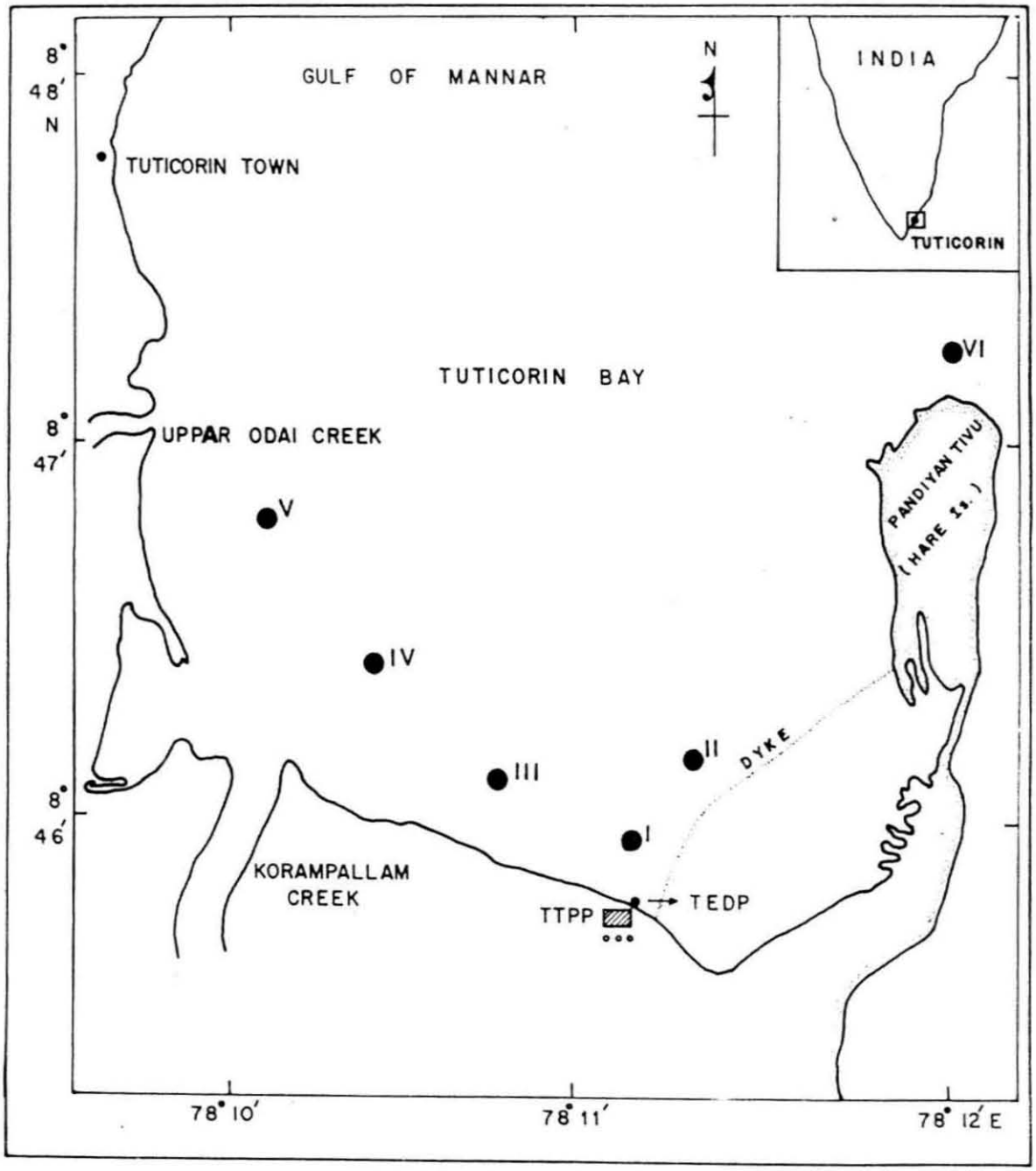

Fig. 4 Map showing the location of study area. Inset shows the South east coast of India.

Tuticorin Town. The TTPP was set up in 1979 and the first unit has started its regular functioning from January 1980 (Tamil Nadu Electricity Board, 1989 - 90). During the present study period, the plant's power generation is 630 MW with the operation of 3 units (3 x 210 MW) and there is a proposal to increase its power generation upto 1550 MW in the near future. (Indian Express daily, 1995). The TTPP discharges thermal effluent into adjacent water body after cooling the condenser.

With a view to understanding the effect of thermal effluent discharge on the adjacent bay, a total of six stations was fixed at Tuticorin bay in relation to horizontal proximity of thermal effluent discharging point (TEDP) of TTPP (Plate 1. Fig. 1A & 1B). Station I was fixed nearer to the TTPP of about 100 meters away from the TEDP (Fig. 1A). Stations II and III were fixed 300 m away from the TEDP at the lower zone towards the sea and upper zone towards the coast respectively (Plate 2. Fig. 2A, & 2B and Plate 3. Fig. 3A & 3B). Station IV was fixed in the upper zone of about 750m away. Stations V and VI were fixed in upper zone and lower zone respectively of more than 1.0 k.m away from the TEDP. While stations II and III are situated nearer to the bottom ash disposal site and the liquid waste discharging site of TTPP, respectively, stations V and VI are located nearer to the CMFRI oyster farm and Hare island respectively (Fig.4).

The present study was conducted for a period of two years from April 1990 to March 1992. With a view to finding out the seasonal variations of different environmental parameters, the study period was categorised into four seasons of summer (April - June), Premonsoon (July - September), monsoon

PLATE 1

Fig. 1A *A general view of Tuticorin Thermal power plant (TTPP) with thermal effluent discharging point and station I.*

Fig. 1B *A close up view of thermal effluent discharging point of TTPP.*

PLATE .1

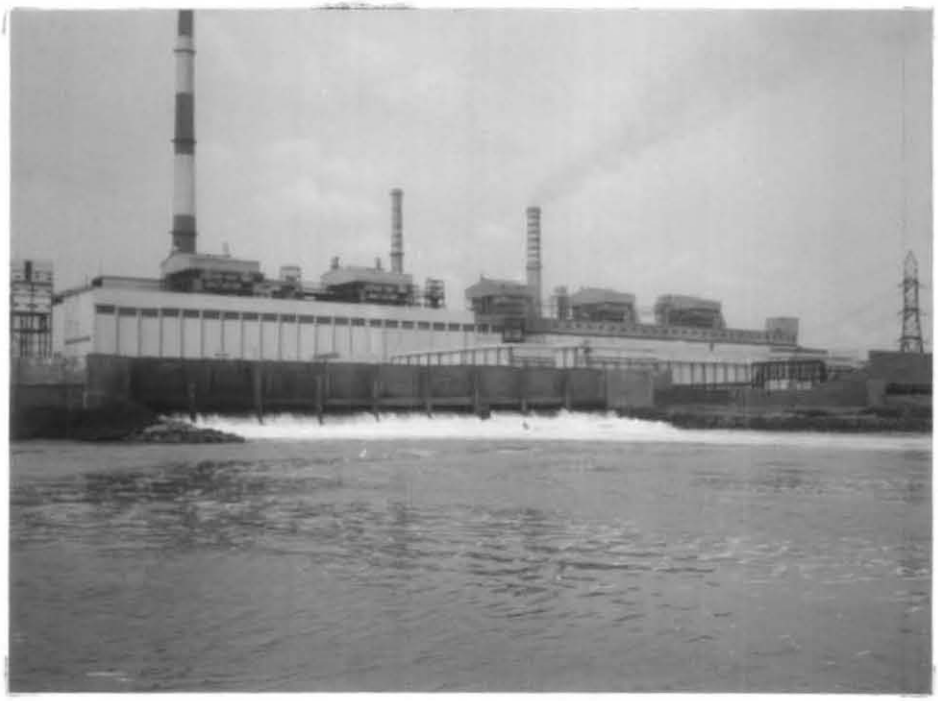

FIG.1A

FIG.1B

PLATE 2

Fig. 2A *A general view of bottom ash (slurry) discharging point.*

Fig. 2B *A view of station II with deposition of bottom ash in the open bay.*

PLATE.2

FIG.2A

FIG.2B

PLATE 3

Fig. 3A *A general view of station III with liquid waste discharging point from TTPP*

Fig. 3B *A close up view of liquid waste discharging point.*

PLATE. 3

FIG.3A

FIG.3B

(October - December) and post monsoon (January - March). The samples were collected once in every fortnight and estimations were carried out in duplicate and average values reckoned in presenting the results.

2.2 HYDROGRAPHICAL PARAMETERS

Water samples were collected from the surface and bottom layers of the sampling stations. Surface samples were collected after washing the bottles with the same water while bottom samples were collected using bottom sampler. The bottom sampler consisted of a narrow mouthed glass bottle and a cork to close the bottle. Two hose pipes, one for controlling the air and another for collecting water in the bottle were inserted through two holes in the corks. By releasing the air from the bottle through one of the hose pipes, the bottom water was filled up in the bottle through the other hose pipe by automatic suction. With a view to collecting the water samples during low tide, the sampling was done uniformly between 0700 hr. to 1000 hr. A dinghy fitted with Yamaha engine was used for collecting water samples.

2.2.1 Water Temperature

The temperature of the water samples was measured using a centigrade thermometer, graduated from 0 to 50°C. Immediately after collecting the water sample in a narrow mouthed polyethylene bottle, the thermometer was introduced in the water column upto 5 cm. and the temperature was recorded.

2.2.2 Salinity

The water samples were collected in narrow mouthed, polyethylene bottles of 300 ml. capacity. The bottles were washed with the same water before collecting samples. Salinity was estimated by following the Mohr titration method (Strickland and Parsons, 1968) as given below.

Principle

The precipitable halide halogens in the sea water sample are determined by titration with silver nitrate solution using a chromate end point.

Procedure

10 ml of water sample was titrated against the silver nitrate solution of normality 0.14N (24.5 g silver nitrate dissolved in 1000 ml. of distilled water) with 10% potassium chromate as an indicator. Care was taken to arrive at the exact end point colouration in all the samples. The volume of silver nitrate consumed for each sample was noted. Silver nitrate solution was standardised during every set of titration using the standard sea water of known salinity. Salinity of the sample was calculated using the following formula:

$$\text{Salinity (ppt)} = \frac{V_2 \times S}{V_1}$$

Where

V_2 = Volume os silver nitrate for 10ml of sea water sample.

V_1 = Volume of silver nitrate for 10ml of standard sea water.

S = Salinity of standard sea water (34.99 ppt)

2.2.3 Dissolved oxygen

The dissolved oxygen in the water samples was determined using Winkler method (Strickland and Parsons, 1968). The outline of the method is as follows:

Principle

The sample is treated with manganous sulphate and strong iodide reagent. The Manganous sulphate reacts with the dissolved oxygen and produces a brown precipitate the manganous hydroxide ($Mn(OH)_2$). Upon acidification in the presence of iodide, iodine is liberated to an amount equivalent to the dissolved oxygen present in the sample. The iodine is then titrated with standard sodium thiosulphate solution.

Procedure

The water samples were collected in 125 ml capacity Corning reagent bottle with BOD stoppers. The collection bottles were washed twice with ambient water before sampling. Care was taken to avoid entry and trapping of air bubbles during sampling. One ml of winkler A (365 g of manganous

sulphate dissolved in 1000 ml. of distilled water) and one ml of winkler B (mixture of sodium hydroxide and potassium iodide dissolved in distilled water) solutions were added immediately to the bottle containing the water sample. The stopper was carefully replaced without trapping any air bubble and the precipitate was dispersed uniformly throughout the bottle by shaking.

The precipitate was dissolved using one ml of concentrated sulphuric acid. The solution was then titrated against sodium thiosulphate solution (0.01N) using starch as an end point indicator. The dissolved oxygen was estimated using the formula:

$$\text{Oxygen (ml/l)} = \frac{V_1 \times N \times 8 \times 1000 \times R \times 0.698}{V_2}$$

where

V_1	=	Volume of sodium thiosulphate
N	=	Normality of sodium thiosulphate
V_2	=	Volume of water sample taken for titration against the sodium thiosulphate.
R	=	Correction factor
0.698	=	To convert parts per million to ml of oxygen/litre
8	=	Equivalent weight of oxygen

2.2.4 pH

Hydrogen ion concentration of the water sample was determined using a ECIL digital pH meter model. The samples collected for salinity estimation were used for pH determination also.

2.2.5 Turbidity

Turbidity was estimated by following the Nephlometric turbidity estimation technique by APHA - AWWA - APCF (1975). Samples were collected in 300 ml thoroughly cleaned glass bottles of 300 ml capacity and provided with glass stopper. Aqua analyser turbidity meter (METZ-391) manufactured by Mttzer Optical Instrument, Corporation and provided with green filter disc, was used for determination of percentage transmission of sample, along with reference standard. Formazin polymer, which has gained acceptance as the turbidity standard reference suspension, was prepared and used as the reference turbidity standard. Turbidity standard reference suspension of 40-NTU (Nephlometric Turbidity Unit) concentration was prepared weekly by diluting 10 ml stock turbidity suspension to 100 ml with turbidity free water (Distilled water filtered through 0.45 membrane filter, using a suction pump). Stock turbidity suspension of 400 NTU concentration was prepared monthly in a 100 ml of solution II (10 g Hexamethylene tetramine, dissolved in 100 ml turbidity free water) and allowing it to stand for 24 hrs at 25 ± 3°C C before diluting it to the mark and mixing.

Sample was thoroughly shaken and time was allotted until all air bubbles disappeared. The sample was then poured into the turbiditimeter tube. The tube was placed before the filter disc in the instrument and percentage transmission recorded. Similar procedure was followed for recording the percentage transmission in the standard reference suspension. Turbidity of the sample was estimated using the formula.

$$TS\ (NTU) = \frac{PTS \times TR}{PTR}$$

Where,

TS	=	the turbidity of sample in NTU,
PTS	=	percentage transmission reading of sample
TR	=	the turbidity of standard reference suspension equal to 40 NTU, and
PTR	=	the percentage transmission reading of standard reference suspension.

2.2.6 Nitrite

Nitrite was estimated by the Azo-dye method (Bendschneider and Robinson, 1952).

Principle

The determination is based on the classical Griess's reaction in which the nitrification at pH 1.5 - 2.0 is diaotized with sulphanilamide, resulting in a diazo compound, which is allowed to react with N - (1 - Naphtyl) - ethylene diamine (NNED) to form a high coloured azo - dye as end point.

Procedure

50 ml of water sample was taken in a clean conical flask and 1 ml. of sulphanilamide solution (prepared by dissolving 5 g of sulphanilamide in 50 ml of concentrated hydrochloric acid and the same solution was made upto 500 ml using distilled water) was added. The sample was mixed thoroughly and

kept aside for reaction. After 3 minutes, 1 ml of NNED solution (0.5 g of NNED dissolved in 500 ml of distilled water) was added and the sample was mixed well. Blank was prepared using distilled water and the analysis was carried out in the same manner. Standard nitrite solutions of known concentration were prepared and analysis was carried out in the same manner mentioned for water sample. Between 10 minutes and 2 hrs. afterwards, the absorbance of sample was measured against blank in the ECIL spectrophotometer at 545 nm. The sample values were calculated from the standard values and expressed in µg - at N/lit.

2.2.7 Nitrate

Nitrate was estimated following the method of Mullin and Rily (1955).

Principle

Nitrate present in the sea water is reduced quantitatively to nitrite by hydrazine in the presence of copper ions as catalyst. The nitrite thus produced is determined by diaotizing with sulphanilamide and coupling with NNED to form a highly coloured azodye as end point.

Procedure

To 50 ml of water sample, 2 ml of buffer solution (a mixture of phenol and sodium hydroxide solutions) was added. After rapid mixing, 1 ml of reducing agent (a mixture of copper sulphate and hydrazine sulphate solutions) was also added and the flasks containing the samples were kept in a dark place for about 20 hours in order to effect the reduction of nitrate. Later, 2 ml

of acetone was added to the sample. After 2 minutes, 1 ml of sulphanilamide solution was added and after keeping the sample for 2 minutes, the absorbance of the samples was measured against the distilled water blank in the ECIL spectrophotometer at 545 nm. Standard graph was prepared for standard nitrate solutions of known concentrations. The sample values were plotted in the graph and expressed in µg - at/lit.

2.2.8 Phosphate

The method described by Murphy and Riley (1962) and followed by Strickland and Parsons (1968) was used for the analysis.

Principle

The phosphate in the water sample was allowed to react with ammonium molybdate forming a complex heteropoly acid compound. This compound reduced by ascorbic acid in the presence of antimonyl tartarate as catalyst produces a blue colour of the end product.

Procedure

50 ml of water sample was taken in a clean conical flask and 5 ml of mixed reagent (Prepared by mixing the ammonium molybdate solution, diluted sulphuric acid, ascorbic acid solution and antimonyl tartarate solution) was added. The sample was mixed thoroughly. After 5 minutes, the absorbance of the sample was measured against distilled water blank using spectrophotometer at 885 nm. Turbidity corrections were done for the samples

and the sample values were calculated from the standard phosphate values. The amount of phosphate was represented in µg - at/lit.

2.2.9 Silicate

Silicate was estimated following the method described by Strickland and Parsons (1968).

Principle

The seawater sample is allowed to react with acid molybdate solution which results in the formation of silicomolybdate, phosphomolybdate and arseno-molybdate complex. A reducing solution containing metol and oxalic acid added subsequently reduces the silicomolybdate complex to produce blue colour compound as end product. Simultaneously, the reducing solution decomposes any phosphomolybdate or arsenomolybdate available in the sample, so that interference from phosphate and arsenate is eliminated.

Procedure

In a 50 ml measuring cylinder, 10 ml of acid molybdate reagent (Prepared by dissolving 4.0 g of ammonium paramolybdate in 350 ml. of distilled water to which 12.0 ml of concentrated Hydrochloric acid was added and was made upto 500 ml adding distilled water) was taken and 25 ml of seawater sample was introduced. The sample was mixed thoroughly and was allowed to stand for 10 minutes. To this, 15 ml of reducing reagent (prepared by mixing metol sulphite solution, oxalic acid solution and 50% sulphuric acid in distilled water) was added rapidly, so as to make the volume exactly to 50

ml. The sample was mixed immediately and allowed to stand for 2 to 3 hrs. in order to complete the reduction of the silicomolybdate complex. The absorbance of the sample was measured against distilled water blank at 810 nm spectrophotometrically and the values obtained were calculated in comparison with the standard silicate values. The amount of silicate was given in µg - at/lit.

2.2.10 Ammonia

Ammonia was determined following the phenol hypochlorite method (Solarazano, 1969).

Principle

Ammonia reacts moderately with hypochlorite in the alkaline solution producing monochloramine and this gives indo phenol blue colour in the presence of phenol, catalytic amounts of nitroprusside ions and excess hypochlorite.

Procedure

To 50 ml of the sample, 2 ml of phenol solution (prepared by dissolving 10 g of phenol in 100 ml of ethanol) and 2 ml of sodium nitro prusside solution (1.0 g of sodium nitro prusside dissolved in 200 ml of de-ionized water) were added. After mixing well, 5 ml of oxidizing solution (prepared by mixing 100 ml of 100 g of sodium citrate and 5 g of sodium hydroxide dissolved in 500 ml of de-ionized water and 25 ml of 1.5 N sodium hypochlorite solution) was added to the sample and mixed thoroughly. After 1 hr. the developed colour was read

spectrophotometrically against distilled water blank at 640 nm absorbance. The sample values were then calculated from the standard ammonia values and the amount of ammonia was represented in µg - at/lit.

2.2.11 Primary Production

Primary production was estimated only for surface water following the technique of light and dark bottles as described by Gaarder and Gran (1927).

Corning reagent bottles of 125 ml capacity with BOD stoppers were used for sample collection. For dark bottles, corning reagent bottles of 125 ml capacity coated with black paint and wrapped with black rexin cloth were used.

Water samples were collected fortnightly using light bottles and dark bottles and were covered tightly with the BOD stoppers. The bottles were exposed under invivo condition by immersing the bottles, in a bucket of water, collected from the site of study. With a view to find out the initial value of oxygen, water samples were collected separately and the oxygen fixed using winkler A and B solutions. After six hours, the oxygen in the light and dark bottles, was fixed using the above solution and the dissolved oxygen was estimated as described in section 2.2.3. (Page 16).

The difference of oxygen level between the light and dark bottles was considered as gross production while that of the light bottle and the initial bottles was taken as net production. The calculation was carried out using the following equation:

$$\text{Gross Primary Production (Mg C/m}^3\text{/day)} = \frac{\text{VLB - VDB x 0.536}}{\text{PQ x N}}$$

$$\text{Net Production (Mg/c/m}^3\text{/day)} = \frac{\text{VLB - VIB x 0.536}}{\text{PQ x N}}$$

Where,

VLB and VDB	=	Quantity of sodium thiosulphate titre value obtained from titration of light bottle and dark bottle respectively.
VIB	=	Quantity of sodium thiosulphate obtained from titration of initial bottle.
N	=	Incubation period
PQ	=	Photosynthetic quotient (1.2)
0.536	=	Factor to convert mg of O_2 to Mgc.

2.3 METEOROLOGICAL PARAMETERS

Data on meteorological parameters were collected on every sampling day, from the meteorological station, Port Trust, Tuticorin, situated very near to the study area. The meteorological data collected were, atmospheric temperature (°C), and rainfall (mm).

2.4 SEDIMENT ANALYSIS

Sediment samples were collected fortnightly from all the working stations using a Van Veen grab. The grab was hauled up once it penetrated the

bottom. There upon, sediment samples were collected in polythene bags and were brought to the laboratory. The sediment samples were dried in an oven at 100°C for 24 hrs and after cooling in a dessicator, were labelled and stored for further analyses of various parameters.

2.4.1 Temperature

As soon as the grab was removed from the water surface, a thermometer of 0 - 50 °C precision was inserted immediately into the sediment and the temperature level was recorded.

2.4.2 Particle size analysis

With a view to estimating the sand, silt and clay fraction of the sediment, particle size analysis was carried out following the seiving and pipette method of Krumbein Pettijohn (1938) described by Holme and Mc Intyre (1971). In order to get 10 to 25 g of silt and clay fraction for accurate calculation, 50 g of dried sediment sample was transferred to a one litre beaker. 250 ml of 6% hydrogen peroxide solution was added until there was no further reaction. The content of the beaker was washed thoroughly under gentle suction with distilled water on to a filter paper (whatman No.50) spread inside a buchner funnel. The sediment was then washed from the filter paper into a beaker using a jet of 200 - 300 ml distilled water with a camel - hair brush. To this, 10 ml of sodium hexametaphosphate dissolved in one litre of distilled water was added and stirred for 15 minutes. The sediment content in the beaker was then left to soak overnight.

On the next day, the sediment was stirred again for 15 minutes and was transferred into 62 μ sieve which was placed in a flat bottomed white basin. The sediment was wet sieved by agitating and pudding care being taken to see that the volume of distilled water used to sieve does not exceed 1 litre. The sieve and its content were kept to drain for some time and were transferred to an oven for drying out. When completely dried, the sediment sample was thoroughly agitated over a large sheet of white glaced paper. The material passed through the sieve was transferred into the suspension of silt and clay in the basin. The sediment particle retained in the sieve was collected and kept aside.

The silt and clay content in the basin along with the water was then transferred to a one litre stoppered graduated cylinder and the suspension was made exactly upto one litre by adding distilled water. The sediment was suspended by shaking the cylinder vigorously in order to disperse the contents uniformly. The cylinder was then placed upright and using a clean pipette, 20 ml of sample was taken immediately from a depth of 20 cm. The pipette sample was transferred into a pre-weighed petridish and dried in an oven at 100°C and the content was weighed. The weight of this material was considered as the total amount of sediment less than 62μ in the sample.

After re-shaking the suspension, the cylinder was kept upright, and a few seconds before the expiry of 7 minutes and 44 seconds, (based on Stoke's law) the pipette tip was lowered to a depth of exactly 10 cm below the surface of the suspension and 20 ml of sample was taken at the exact time. The pipette content was transferred to a pre-weighed petridish, and dried at 100°C and the

content was again weighed. The weight of this dried material was considered as the total amount of sediment less than the size of 15.6μ in the suspension.

After resuspending the sediment, the cylinder was placed upright. After 2 hours and 3 minutes, 20 ml of sample was taken from a depth of 10 cm. and was transferred into a pre-weighed petridish. The material was dried at 100°C and was weighed. The material was considered as the total amount of sediment less than 3.9μ size present in the suspension.

The material that remained on the 62 μ seive was regarded as the sand fraction. The weight of the pipette material was multiplied by 50 to find out the weight of the silt and clay fractions in one litre of the sample. The percentage weight of silt was calculated from the percentage of sand and clay fractions.

2.4.3 Total Organic Carbon

The method of Walkley and Black (1934) was used to determine the organic carbon content of the sediment.

Principle

Hot chromic acid was used to oxidise the organic carbon content present in the sediment and the excess acid not reduced by the organic matter was determined volumetrically with ferrous ammonium sulphate.

The outline of the method is given below.

Procedure

The sediment sample was dried in the oven at 100°C for 24 hrs and the sample was ground in an agate mortar and passed through a 0.2 mm brass sieve. To a 0.5 g of powdered sample, 10 ml of 1 N Potassium dichromate solution (49.04 g of Potassium dichromate in 1 litre of distilled water) and 20 ml of concentrated sulphuric acid containing 1.25 g of silver nitrate for every 100 ml of acid were added and swirled. The sample was heated in a water bath for 30 minutes. The material was cooled and 200 ml of distilled water was added. To this 100 ml of concentrated phosphoric acid and 1 ml of diphenylamine (0.5 g diphenylamine in a mixture of 20 ml distilled water and 100 ml concentrated sulphuric acid) solution were also added. The sample was then back titrated with 0.5 N ferrous ammonium sulphate solution (139.0 g of ferrous ammonium sulphate in distilled water, to which 7.5 ml of concentrated sulphuric acid was added and diluted to 1 litre by adding distilled water). The change from blue colour to sharp brilliant green colour was noted as the end point. Analysis was carried out in the same manner for blank using distilled water. The values were calculated using the following equation:

$$\text{organic carbon (mg/g)} = \frac{3.951}{g}\left(1 - \frac{T}{S}\right)$$

Where

S = Volume of titrant used against blank (ml)

T = Volume of titrant used against sample (ml)

g = Sample weight in gms.

2.4.4 Total Phosphorus

Total phosphorus content in the sediment was estimated following the method given in FAO (1975).

Principle

Total phosphorus was determined by prolonged nitric perchloric acid hot digestion (FAO 1975). This brings all phosphorus into solution which when allowed to react with ammonium molybdate forms a complex heteropoly acid compound. This compound was reduced by ascorbic acid into a blue colour complex in the presence of antimonyl tartarate as catalyst.

Procedure

Sediment sample was dried in an oven at 100°C for 24 h. After drying, the sediment was powdered. 0.5g of powdered sediment was taken in a 100 ml Kjeldahl flask. Few pieces of acid - washed glass beeds were introduced into the flask. 2 ml of concentrated nitric acid and 2 ml of concentrated perchloric acid were also added to the sample. The sediment sample was heated till the content was dried. The content was cooled and 10 ml of diluted sulphuric acid was added (50 ml concentrated sulphuric acid in 1 litre distilled water). It was then boiled for 10 minutes. After cooling, the solution was filtered using moistered Whatman 42 filter paper into a 250 ml volumetric flask. The content was then diluted to 250 ml by adding distilled water. To 5 ml of this solution, 25 ml of distilled water, 5 drops of 0.4 N ascorbic acid and 2 ml of sulphuric acid ammonium molybdate solution (prepared as in the phosphate estimation

of water in section 2.2.8) were added. After 5 minutes, the absorbance was measured using spectrophotometer at 885 nm against distilled water blank. The sample values were obtained from the standard phosphate values and the results were calculated using the following equation.

$$\text{Total phosphorus (mg/g)} = \frac{Pd \times V}{1000 \times X}$$

Where,

Pd = Phosphorus in digest (mg/l)

V = total volume of solution

X = Weight of sediment (g)

2.4.5 Nitrogen

Nitrogen was determined by following micro Kjeldahl's method (Barnes, 1959).

Principle

The nitrogen content of sediment sample was converted into acid ammonium sulphate by digestion with sulphuric acid in the presence of a catalyst. On preparation of the reaction mixture, alkaline ammonium was liberated which was removed by steam distillation and was absorbed in boric acid solution containing Methyl red - Methylene blue indicator and was titrated with standard HCl (0.01N HCl). The percentage of nitrogen was calculated from the titre value assuming that 1 ml of 0.01 N HCl is equivalent to 0.14 mg nitrogen.

Procedure

The sediment was dried at 100°C for 24 hrs. and was powdered. 0.1 g of the sediment sample was taken in a 100 ml capacity Kjeldahl flask. To this, 10 ml of distilled water, 4.0 ml of concentrated sulphuric acid and a pinch of catalyst (mixture of 2 g of selenium dioxide, 2 g of copper sulphate and 8 g of potassium sulphate) were added. The content was kept heating until the emission of fumes ceased. After the completion of digestion, the material was cooled and 10 ml of distilled water was added. The content was then transferred into a steam distillation unit and 0.5 ml of sodium hydroxide - thiosulphate mixture (Dissolved 50 g of sodium hydroxide and 5 g of sodium thiosulphate in 100 ml of distilled water) was added. Ammonia produced on distillation of the acid ammonium sulphate was collected into a conical flask containing 5.0 ml of 4% boric acid containing one drop of indicator dye. Collection of ammonia was continued until the colour of the boric acid changed to green. Back titration was carried out with 0.01N HCl until it revived the original colour. The percentage of nitrogen present in the sample was calculated following the formula:

$$\text{Total nitrogen} = \frac{\text{titre value x 0.14 x 100}}{\text{amount of sample}}$$

2.5 BOTTOM FAUNA

Mud samples were collected at fortnightly intervals using a Van Veen grab with an area of 0.05 M^2. After the grab was hauled up, the volume of the sediment inside the grab was checked for complete grabbing, and was collected

in a plastic bucket. Duplicate samples were collected from each station and average values reckoned in presenting the data.

The sediment sample was screened by washing and puddling through a standard circular sieve with a mesh size of 0.5 mm. The sieving process was carried out by hand sieving method keeping the sieve inside a tub of water to avoid the damage of the organisms while seiving (Mc Intyre and Holmes, 1971). After a cursory examination, the residue from the sieve were preserved in 5% formalin which was mixed with rose bengal (1 gm/L) to provide colour contrast during sorting. All the organisms retained in the 0.5 mm mesh sieve were considered as macrobenthos and were taken up for further studies.

Following the current interest in diversity as a major parameter in describing the structure of biological communities and in the belief that appropriate mathematical indices could attribute to the assessment of pollution, the following three indices namely species diversity, species richness and species evenness have been calculated.

2.5.1 Species diversity

For the present investigation of species diversity, the Shannon - Wiener index, as described by shannon and Weaver (1963) was used. The Shannon's index is derived from the following formula.

$$H = - \frac{ni}{N} \log \frac{ni}{N}$$

Where,

H = Species diversity

ni = number of individuals of the i^{th} species.

N = total number of individuals.

2.5.2 Species richness

In order to find out species richness of the benthic organisms, the following formula described by Margalef (1958) was followed:

$$R = \frac{S-1}{\ln N}$$

Where,

R = Species richness

S = number of species

N = total number of individuals

2.5.3 Species evenness

This index shows the evenness at which individuals of different species of benthic organisms are distributed.

To find out the species evenness the following formula described by Pielou (1966) was used:

$$E = \frac{H}{2 \log S}$$

Where,

E = species evenness

H = species diversity index

S = number of species

2.5.4 Benthic biomass

With a view to estimating the benthic biomass, the gravimetric method of taking the wet weight and dry weight of different groups of macrobenthic fauna was resorted to. Lovegrove (1966) has reported that changes in wet weight of biomass occurred during preservation of the first few days and thereafter an equilibrium is maintained. Therefore, in the present study, the wet weight of macrofauna was always taken four weeks after preservation to give a uniform allowance for any possible weight change during preservation. Large organisms such as prawns, fishes and crabs which occur very rarely in the grab sample were not taken into account when biomass (wet weight) was estimated. However their numerical abundance was recorded. In the case of molluscan specimens such as gastropods and bivalves, the shell was removed by using the scraper and the flesh alone was taken into account. However, the shells were not removed for relatively very small molluscan species. Wet weight was always taken after washing preserved samples.

Dry weight was taken after drying the animal tissue at 60°C for 16 hours (Lovegrove, 1966). The wet weight and dry weight of benthic organisms were represented in gam Per M^2. In presenting the data both wet weight and dry weight were taken into consideration.

For statistical analysis wet weight was considered.

2.6 STATISTICAL ANALYSES

In order to understand the relationship between the various hydrographical, sediment and benthic faunal parameters, their values were subjected to computer analysis for the estimation of correlation co-efficient "r". The significance of correlation co-efficient "r" of different parameters at different stations were tested at 1% and 5% level. Correlation coefficient was not carried out for station II due to the absence of benthic organisms at this station.

Likewise, to test the effect of treatments of the above mentioned environmental parameters of each station, a two way analysis of variance (ANOVA) technique was employed and the F value was taken at 5% (significant) and 1% (Highly significant) levels respectively. In ANOVA tables, stations were considered as "treatment" and seasons as "replicate".

RESULTS

3.1 METEOROLOGICAL PARAMETERS

3.1.1 Atmospheric temperature

Atmospheric temperature of the Tuticorin bay recorded during the study period from April 1990 to March 1992 is shown in Fig.5

The atmospheric temperature was found fluctuating during different seasons with higher values observed during summer months in both the years, the peak values of 31.1°C and 30.7°C being observed during June 1990 and April 1991 respectively. The values declined gradually during the succeeding months in both the years reaching a low of 26.4°C during the monsoon months of December 1990 and January 1992 respectively.

3.1.2 Rainfall

Fig. 5 presents the rainfall record of Tuticorin bay during April 1990 to March 1992. A total of 978.2 mm of rainfall was recorded during the two years. During the first year (April 1990 to March 1991) the total rainfall amounted to 577.8 mm while during the second year (April '91 to March '92) it was 400.5 mm.

At Tuticorin, good rainfall in the normal course is limited to a few months during the year. In general, the rainfall was high during the months of October 1990 (263.4 mm), November 1990 (150.1 mm), December 1990 (67.7 mm) and January 1991 (43.8 mm) during 1990 - 1991 and during October 1991

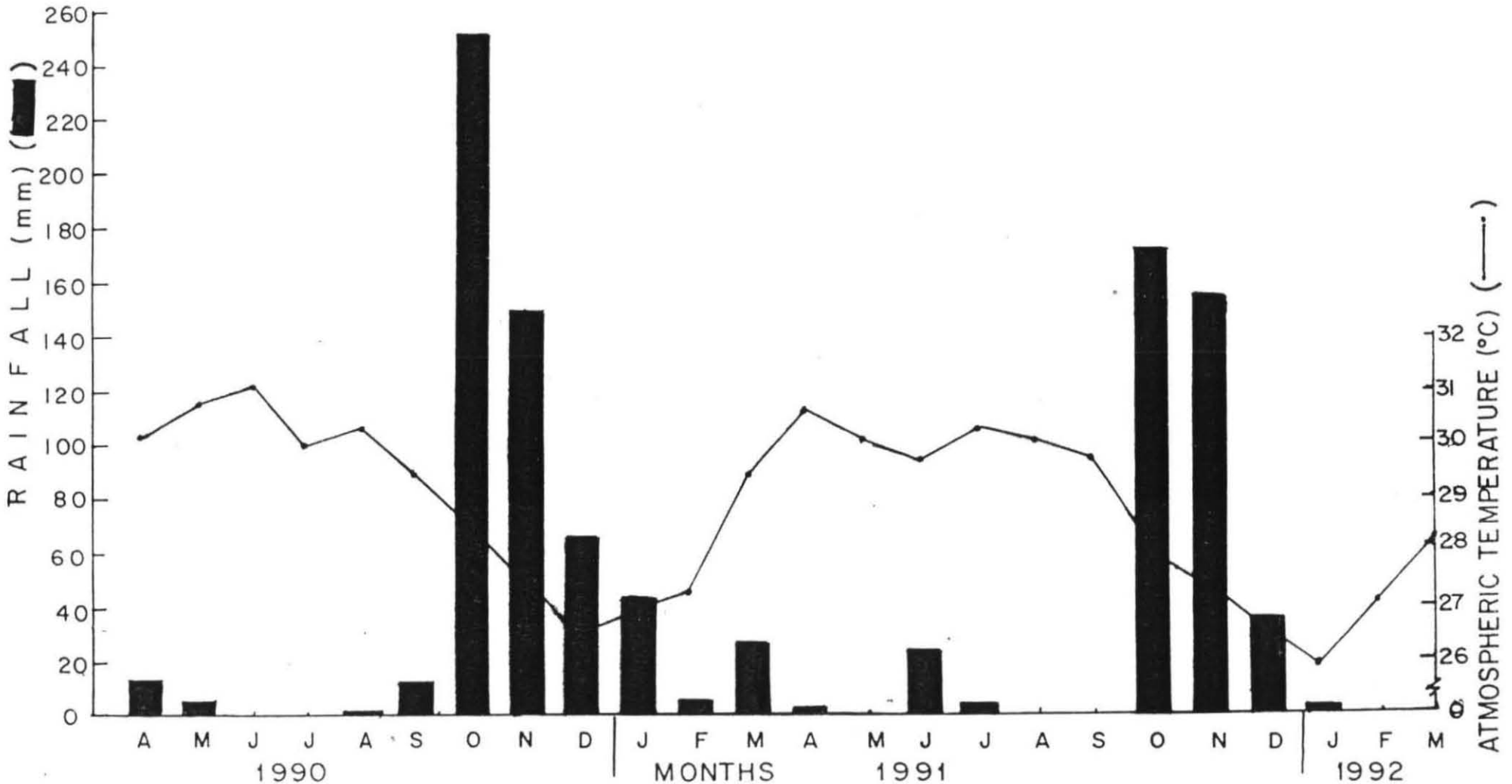

Fig. 5 ***Monthly variation of atmospheric temperature (°C) and rainfall (mm) recorded at Tuticorin bay during April 1990 to March 1992.***

(174.6 mm), November 1991 (156.5 mm) and December 1991 (37.0mm) during 1991 - 1992. Nevertheless, during the months of June 1990, July 1990, August 1991, February 1992 and March 1992, no rainfall was recorded. Confirming the influence of north east monsoon, months of October to December (monsoon season) showed higher rainfall record with summer showing lower values.

3.2 HYDROLOGICAL PARAMETERS

3.2.1 Temperature

Monthly variations in water temperature at station I to VI are given in Table 1 and Fig. 6 and 7.

The surface water temperature showed a minimum value of 34.3°C during August 1991 with the maximum value of 42.3°C during May 1991 at station I. A variation from a low of 31.1°C during August 1991 to a high of 39.0°C during May 1990 was recorded at station II. With a minimum value of 28.5°C observed during January 1992 at station III, the surface water temperature indicated a comparatively low peak value of 36.5°C during April 1991. At station IV, the minimum of 28°C. was observed during December 1990 with the maximum value of 33.0°C noticed during May 1990 and March 1992. The minimum value of 28.5°C was recorded at station V during the months of December 1990, January 1991, January 1992 and February 1992 with the maximum value of 33.0°C during the months of March 1991 and May 1991. Station VI showed a lower surface water temperature of 28.5°C during December 1990 with the higher value of 32.8°C observed during May 1990 and March 1992.

Bottom water temperature at station I showed a minimum of 34.3°C during August 1991 with a maximum of 42.0°C during April 1992. A variation from low of 31.0°C during August 1991 to a high of 37.0°C during May 1990 was noticed at station II. At station III, a minimum value of 28.5°C was recorded during January 1992 with the maximum value of 35.8°C noticed during April 1991. A lower value of 28.0°C during December 1990 and a higher value of 32.0°C were recorded during December 1990, January 1991, January 1992 and February 1992 and the maximum value of 32.3°C was observed during May 1990 and 1991. Station VI showed a lower value of 27.8°C during December 1990 and a higher value of 32°C during May 1990 and March 1991.

Among the various stations, both surface and bottom water temperature were at the maximum range of 34.3°C to 42.3°C and 34.0°C to 42.0°C respectively at station I which is nearer to the thermal effluent discharging point. The temperature regime declined gradually in the successive stations with the minimum values of 28.0°C to 32.8°C (surface) and 27.8°C to 32.0°C (bottom) noticed at station VI. It is also noticeable that stations I and III had a wider range of temperature while those at stations IV to VI had a narrower range.

Seasonally, temperature of both surface and bottom water showed peak values during summer months (April-June) and lower values during monsoon months (October-December) while depth wise, temperature at the bottom was marginally at a lower level at all the stations.

Table : 1 Monthly mean values of surface and bottom water temperature (^{o}C) at different stations during the period April 1990 to March 1992

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	42.00	41.50	39.50	37.00	38.50	39.75	37.25	36.75	38.75	38.50	37.75	41.25	41.50	42.25	39.50	37.25	36.00	39.75	38.75	39.00	37.50	38.00	37.00	39.25
	B	42.00	41.25	38.50	36.75	38.25	39.75	36.75	36.75	38.75	38.50	37.75	40.75	41.25	42.00	39.75	37.00	34.25	39.75	38.50	39.00	37.50	38.00	37.00	39.25
II	S	38.00	39.00	37.50	33.75	34.50	36.50	33.50	32.25	33.25	32.75	33.25	36.25	36.25	36.75	35.00	34.00	31.75	34.75	34.75	36.50	33.75	34.75	33.50	35.75
	B	36.75	37.00	36.50	32.50	33.75	34.75	33.00	31.25	32.25	32.25	32.25	33.50	35.13	34.75	33.50	32.75	31.00	34.00	32.75	34.25	33.38	33.75	32.50	35.00
III	S	31.75	34.00	30.75	30.75	31.00	30.25	30.75	31.75	31.50	31.75	30.50	34.50	36.50	33.80	30.00	32.50	30.25	33.00	32.75	32.75	30.75	29.75	31.25	31.50
	B	31.00	33.75	30.75	29.50	30.50	29.75	30.50	31.25	30.00	31.25	29.75	34.25	35.75	33.00	30.00	31.25	29.75	31.50	31.75	32.50	30.00	28.50	30.25	31.00
IV	S	30.75	33.00	30.75	30.25	31.50	31.00	31.00	31.25	28.50	31.25	29.75	32.50	32.75	32.50	29.75	29.25	29.75	32.50	31.25	30.75	30.75	29.00	30.75	30.25
	B	30.25	31.75	30.25	29.75	30.75	30.50	30.00	30.25	28.00	30.50	28.75	32.00	31.75	32.00	29.25	28.25	29.25	31.75	30.25	29.25	29.75	28.75	29.25	29.75
V	S	30.75	32.75	30.50	30.00	30.75	30.75	30.25	30.75	28.75	29.75	29.75	33.00	32.75	33.00	30.00	29.50	29.50	32.50	30.75	30.25	29.50	29.50	29.50	29.50
	B	30.25	32.25	32.00	29.75	30.25	30.25	29.75	29.25	28.75	28.75	29.25	32.00	31.25	32.25	29.50	29.00	29.00	31.75	30.25	30.50	29.00	28.75	28.75	29.75
VI	S	30.25	32.75	30.25	30.00	30.25	31.75	30.00	30.00	28.00	29.50	29.00	32.75	32.00	32.50	29.75	29.25	29.50	31.50	30.75	29.75	29.75	29.50	29.50	30.00
	B	30.00	32.00	30.00	29.50	30.50	31.00	29.75	29.75	27.75	29.00	28.75	32.00	31.75	31.75	29.25	28.50	29.00	31.00	30.25	29.25	29.00	28.75	28.75	29.75

S = SURFACE

B = BOTTOM

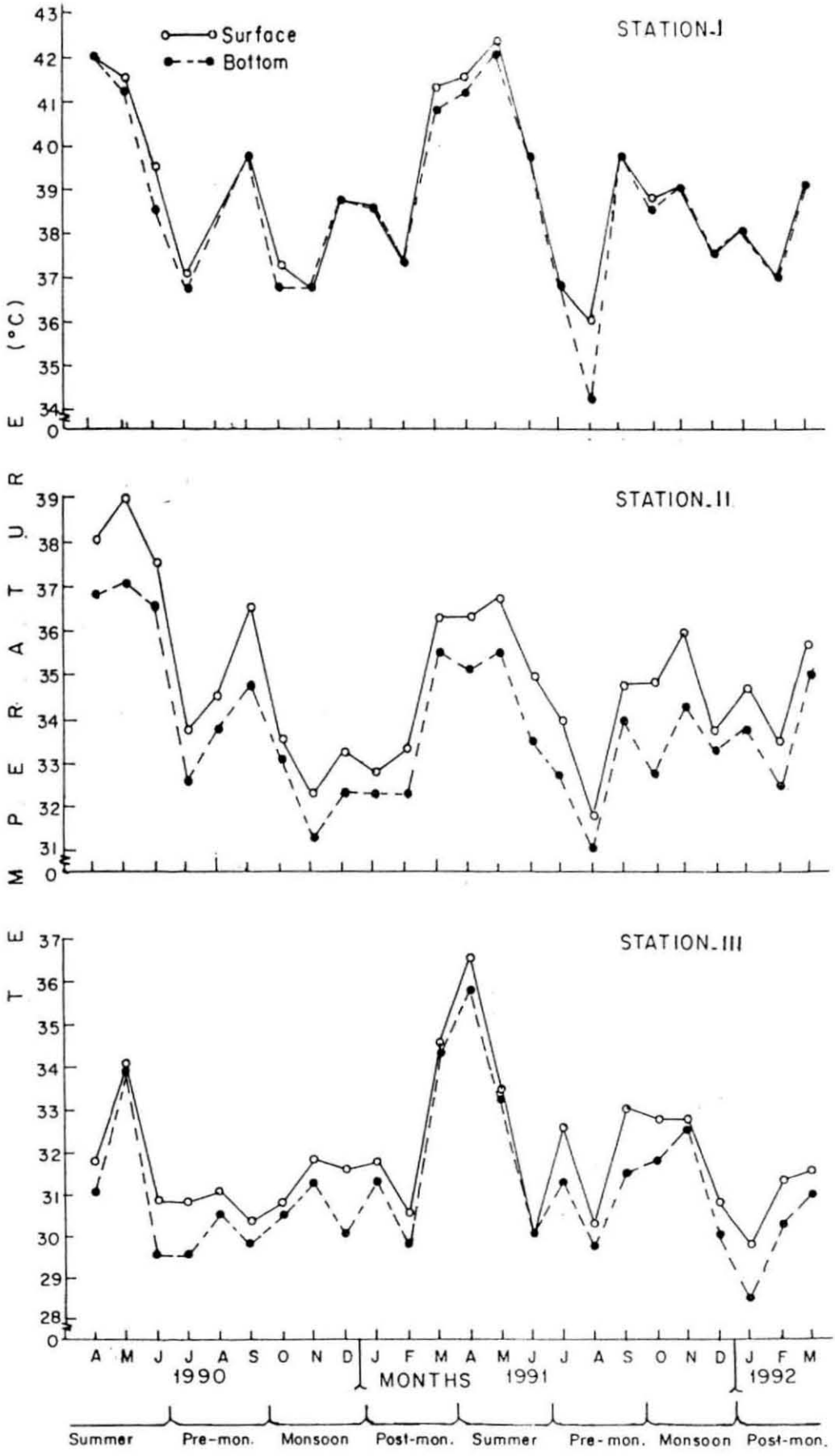

Fig. 6 Monthly variation of surface and bottom water temperature (°C) at stations I to III during April 1990 to March 1992.

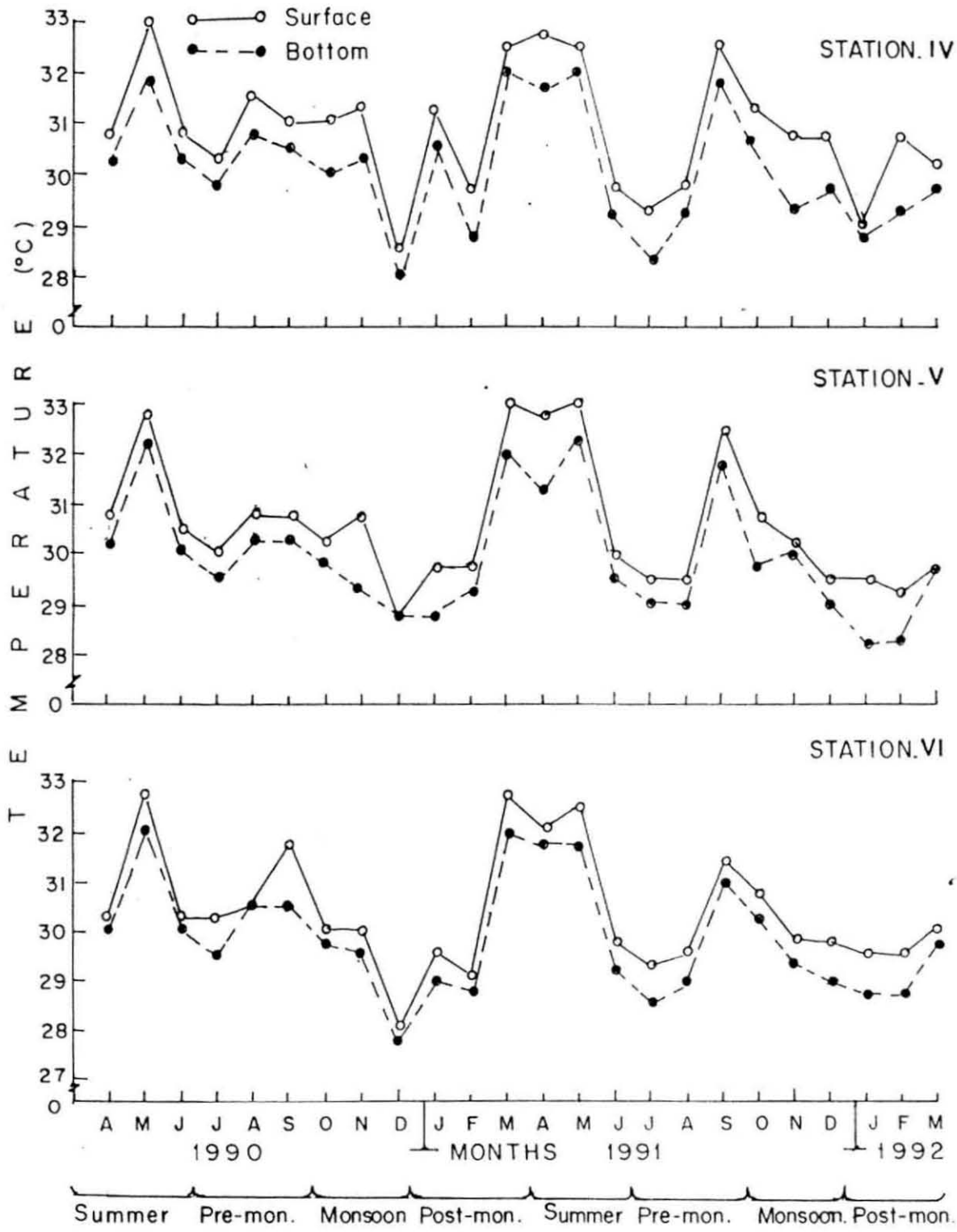

Fig. 7 ***Monthly variation of surface and bottom water temperature (°C) at stations IV to VI during April 1990 to March 1992.***

Statistical interpretation of the surface and bottom water temperature at various stations carried out is presented in table 3. Analysis of variance showed that the variations of temperature among the seasons and those among the stations were highly significant both in the surface and bottom waters.

3.2.2 Salinity

Monthly variations of surface and bottom water salinity from the station I to VI are shown in Table 2 and Fig. 8 and 9.

At station I, the surface water salinity indicated a minimum value of 31.55 ppt during January 1991 with a maximum value of 36.95 ppt during April 1991. A variation from a low of 28.93 ppt during April, 1992 to a high of 36.10 ppt during March 1991 was observed at station II. Station III showed the lowest range of salinity among all the stations with a minimum value of 22.00 ppt observed during December 1990 with a maximum value of 31.88 ppt recorded during October 1991. At station IV, the salinity range showed an increasing trend with a minimum value of 29.3 ppt observed during November 1991 and the maximum value of 36.60 ppt noticed in March 1991. With a salinity range almost at par with that of the immediately preceding stations, station V showed a range of 29.28 ppt during December 1990 to 36.93 ppt observed during March 1991. Station VI being the control station away from the shore and hence not influenced by the monsoon, showed a comparatively a high value of 30.65 ppt as minimum observed during February 1991. The maximum value at station VI was 36.08 ppt noticed during June 1991.

Table: 2 Monthly variations in the salinity (ppt) of surface and bottom water at different stations during the period April 1990 to March 1992

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	35.08	36.18	34.88	34.35	33.03	34.53	32.28	31.70	32.65	31.55	35.05	34.30	36.95	36.25	34.58	34.43	33.98	34.78	33.70	32.70	32.43	34.68	33.58	34.53
	B	34.80	34.63	33.98	32.85	33.90	34.00	32.70	32.35	31.73	31.53	32.95	35.88	36.98	35.63	35.48	34.78	35.20	35.23	35.20	34.60	33.08	33.33	33.48	33.65
II	S	35.10	35.10	31.93	30.82	31.18	31.80	31.58	30.78	29.36	32.75	32.89	34.42	34.23	36.10	34.15	34.13	33.95	35.40	35.73	33.40	32.23	32.95	34.25	33.50
	B	34.58	34.25	33.40	32.30	31.83	32.43	31.74	31.98	30.15	31.83	32.14	32.30	35.00	35.45	35.23	33.23	35.30	35.63	35.20	35.10	33.48	33.18	33.35	33.48
III	S	28.93	27.90	25.40	28.43	29.50	25.41	22.63	22.67	22.06	23.88	26.93	28.60	29.58	30.95	30.35	29.68	29.65	30.98	31.88	27.55	30.60	28.35	30.15	28.73
	B	29.20	28.74	26.37	26.80	30.10	24.90	22.53	23.00	22.65	23.10	26.44	27.0	31.60	30.25	30.13	29.55	30.39	31.78	31.34	27.59	30.13	29.32	31.10	28.83
IV	S	36.35	34.78	34.20	31.34	31.08	31.80	32.23	32.53	29.40	29.55	32.10	36.60	34.80	35.10	35.23	35.40	34.58	34.35	35.53	29.30	30.53	35.43	34.68	35.73
	B	34.88	35.20	34.80	33.83	32.84	32.20	31.73	33.48	29.00	32.30	32.80	33.58	38.85	34.38	35.03	33.63	34.80	34.70	33.93	32.40	30.53	33.45	31.93	32.37
V	S	35.60	34.35	33.95	30.83	30.45	33.00	30.75	30.35	29.28	30.93	35.00	36.93	34.98	35.83	35.63	35.23	36.33	36.50	34.90	33.08	32.18	34.45	34.73	35.08
	B	35.43	33.90	33.93	32.63	31.50	32.83	32.78	30.96	31.39	31.56	33.75	34.43	35.78	34.75	35.00	34.68	36.35	36.70	35.10	35.45	32.43	34.98	33.49	34.09
VI	S	35.53	35.63	33.65	32.33	31.83	30.80	31.10	31.95	31.78	30.25	30.65	31.92	34.40	34.38	36.08	35.00	35.00	35.20	35.20	33.43	33.83	34.68	35.20	35.83
	B	35.85	34.12	32.85	33.33	32.83	32.73	31.50	31.10	32.10	31.55	31.24	30.48	34.35	35.20	35.20	35.20	35.10	35.85	34.35	35.28	32.90	35.20	35.95	35.00

S = SURFACE

B = BOTTOM

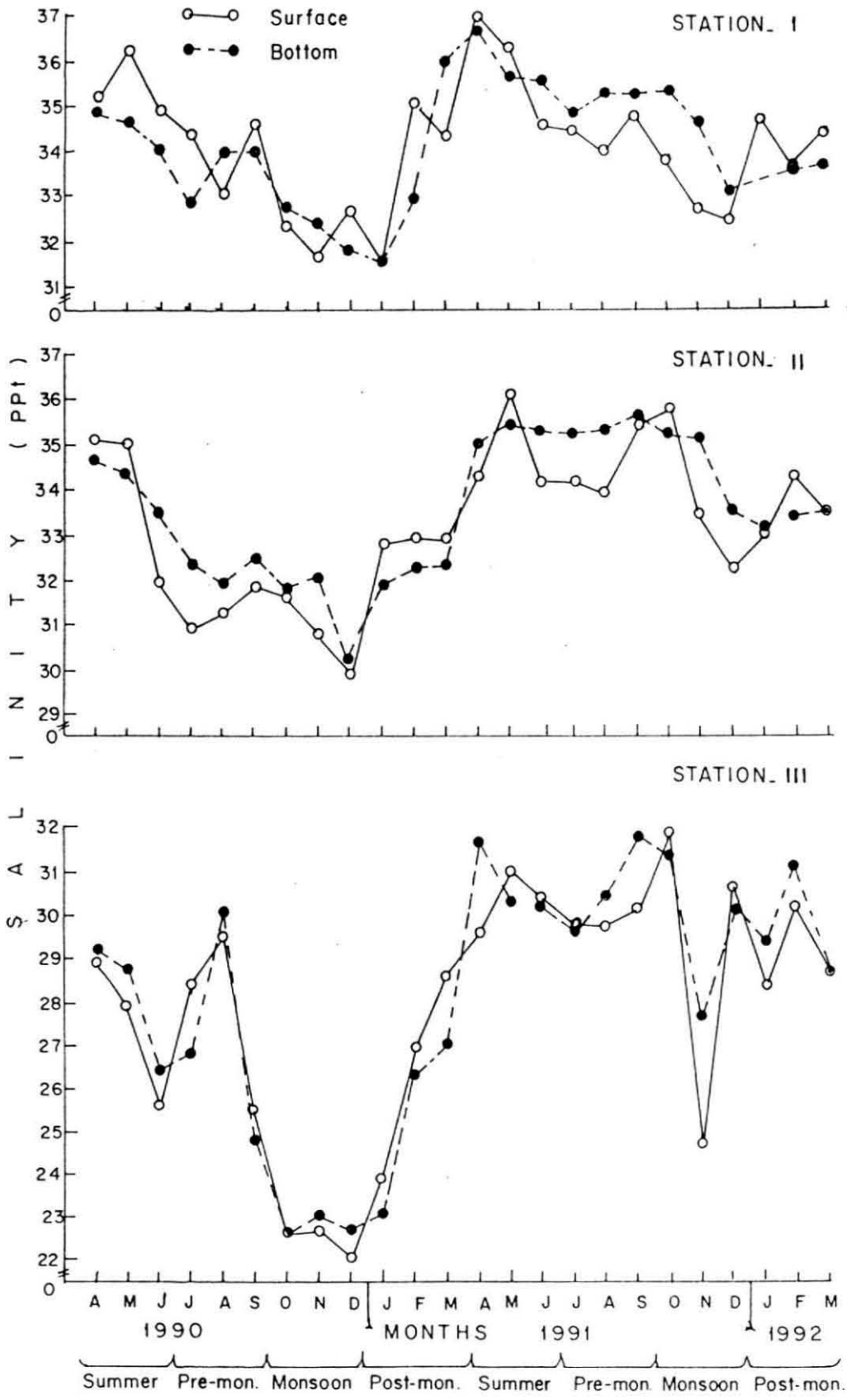

Fig. 8 Monthly variation in the salinity (ppt) of surface and bottom water at stations I to III during April 1990 to March 1992.

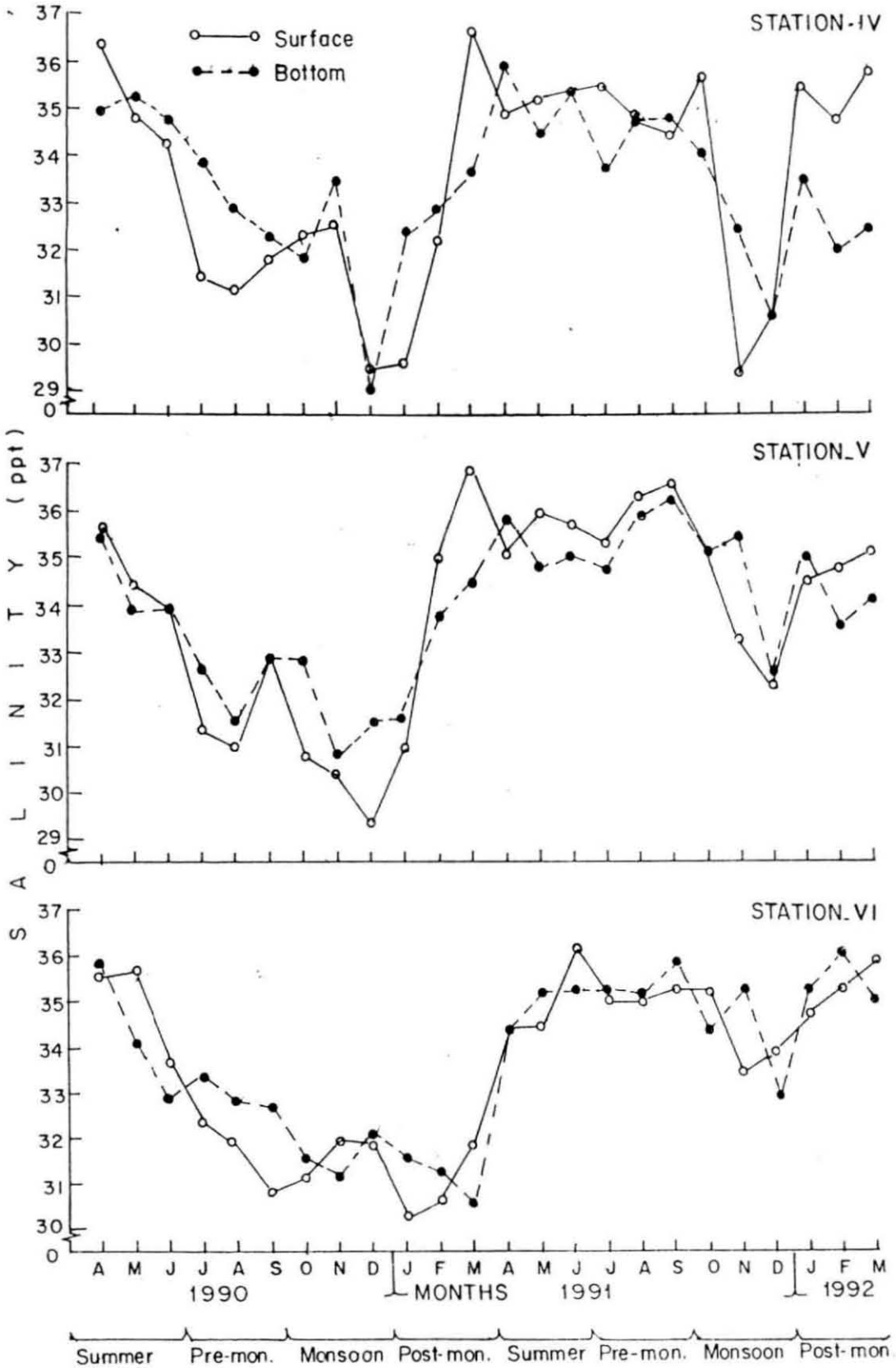

Fig. 9 Monthly variation in the salinity (ppt) of surface and bottom water at stations IV to VI during April 1990 to March 1992.

Table: 3 Two way analysis of variance (ANOVA) showing the level of significance in variation of water parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(I) TEMPERATURE Surface Water					
Treat	5	5488.856	1097.771	592.926	H.S
Repli	3	339.796	113.265	61.177	H.S
Error	543	1005.336	1.851	-	-
Bottom Water					
Treat	5	5340.347	1068.069	269.188	H.S
Repli	3	357.128	119.043	30.003	H.S
Error	543	2154.483	3.97	-	-
(II) SALINITY Surface Water					
Treat	5	3756.074	751.215	209.287	H.S
Repli	3	526.366	175.455	48.882	H.S
Error	543	1949.047	3.589	-	-
Bottom Water					
Treat	5	2586.646	517.329	182.519	H.S
Repli	3	425.681	141.894	50.062	H.S
Error	543	1539.060	2.834	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

With a range of 31.53 ppt in January 1991 to 36.98 ppt in April, 1991, station I indicated the maximum bottom water salinity among all the stations. In the succeeding experimental stations of II to V, the bottom water salinity showed a decreasing trend with station III indicating the lowest range of 23.00 ppt observed during November 1990 to 31.78 ppt noticed during September 1991. At the control station VI, the bottom water salinity ranged between 30.48 ppt and 35.95 ppt recorded during March 1991 and February 1992 respectively.

An evaluation of the seasonal pattern of both surface and bottom water salinity indicated that the summer period (April to June) showed higher values than other seasons with the lower values recorded during the monsoon months (October to December). Vertically, both the surface and bottom water salinity values were almost in the same range with minimum fluctuations in all the stations.

Statistical interpretation of the salinity values for both surface and bottom water is given in Table 3. Analysis of variance showed that the variations between the seasons and the variations between the stations are highly significant both for surface and bottom water salinity values.

3.2.3 Dissolved oxygen

Monthly variations of dissolved oxygen from the surface and bottom water at stations I to VI are shown in Table 4 and Fig. 10 and 11.

At station I, a minimum value of 3.43 ml/1 was noticed at surface during September 1991 with the maximum value of 4.33 ml/l obtained during November 1990. Station II showed a range of 3.40 ml/l during July 1991 to 4.63 ml/l during January 1991. At station III, a low value of 3.50 ml/l was observed during May 1991 while a high value of 5.03 ml/l was obtained during January 1991. Dissolved oxygen showed a minimum value of 3.33 ml/l at station IV during April 1992 with the maximum value of 5.10 ml/l recorded during February 1992. Station V with a lower value of 3.33 ml/l during April 1992 showed a higher value of 5.05 ml/l during February 1991. The surface water dissolved oxygen at station VI indicated a minimum value of 3.55 ml/l during September 1991 and March 1992 with the maximum value of 5.00 ml/l recorded during February 1991.

Among the various stations, the surface water dissolved oxygen of station I was at a lower range of 3.43 ml/l to 4.33 ml/l. The dissolved oxygen concentration showed an increasing pattern in the succeeding stations reaching a higher range of 3.55 ml/l to 5.00 ml/l at station VI. Station IV also indicated a higher dissolved oxygen concentration of 5.10 ml/l during February 1992.

Bottom water dissolved oxygen of station I showed a minimum value of 3.33 ml/l during April 1992 with a maximum value of 4.88 ml/l obtained during July 1990. At station II, a lower value of 3.35 ml/l during the months of June 1990 and July 1991 and a higher value of 4.63 ml/l during July 1990 were noticeable. Monthly mean value of bottom water dissolved oxygen recorded a low of 3.45 ml/l during July 1991 at station III with a high value

of 5.25 ml/l during January 1991. At station IV, a minimum value of 3.40 ml/l was noticed during June 1990 with a maximum value of 5.28 ml/l during December 1990. Station V showed a lower value of 3.23 ml/l during September 1991 while a higher value of 4.63 ml/l was obtained during August 1990. At station VI, a minimum value of 3.48 ml/l was observed during June 1991 with a maximum value of 4.95 ml/l noticed during December 1990.

The bottom water dissolved oxygen among the stations was found fluctuating with the station V showing the minimum range (3.23 ml/l to 4.63 ml/l) and station IV indicating the maximum range (3.40 ml/l to 5.28 ml/l).

Seasonally, it may be noticed that dissolved oxygen concentration was low during summer months of April-June with the higher values recorded during the post monsoon season (January - March) invariably in all the stations.

A comparison of the dissolved oxygen values between surface and bottom waters showed that the concentration was more at the bottom waters at stations I to III. At station IV to VI, the dissolved oxygen values showed higher values at the surface.

Analysis of variance (Table 6) indicated that the variations among the seasons and those among the stations are highly significant both at surface and at bottom water.

Table : 4 **Monthly variations in the dissolved oxygen concentration (ml/l) of surface and bottom water at different stations during the period April 1990 to March 1992**

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	3.50	3.73	3.50	4.25	3.98	3.75	4.13	4.33	4.25	4.20	4.28	3.53	3.76	3.65	3.55	3.38	3.70	3.43	3.68	3.60	3.73	3.90	3.90	3.45
	B	3.33	4.25	3.45	4.88	4.00	4.03	4.18	4.20	4.25	4.15	3.75	3.65	3.73	3.68	3.50	3.40	3.55	3.78	3.70	3.63	3.98	4.13	3.58	3.55
II	S	3.40	4.13	3.48	4.28	4.08	3.80	4.28	4.35	4.50	4.63	4.25	3.50	3.73	3.53	3.60	3.40	3.73	3.58	3.80	3.75	3.80	3.73	3.90	3.50
	B	3.38	4.35	3.35	4.63	4.08	4.00	4.25	4.40	4.40	4.38	3.90	3.70	3.80	3.70	3.60	3.35	3.55	3.50	4.00	3.68	3.83	4.18	3.58	3.43
III	S	3.55	3.88	3.83	4.55	4.80	4.90	4.63	4.68	4.95	5.03	4.50	4.40	3.88	3.50	3.75	3.65	4.10	3.83	3.60	3.73	4.25	4.20	4.58	3.63
	B	3.58	3.98	3.40	4.50	4.70	4.63	4.48	4.43	5.17	5.25	4.25	4.70	3.75	3.60	3.58	3.45	3.98	3.85	3.70	3.58	4.05	4.25	4.58	3.88
IV	S	3.33	3.58	3.83	4.80	4.78	4.18	4.10	4.60	5.05	5.03	5.10	3.60	4.18	3.48	3.65	3.65	3.88	3.78	3.48	3.68	3.70	4.85	3.95	3.68
	B	3.53	4.38	3.40	4.448	4.33	4.13	4.33	4.53	5.28	4.85	4.53	3.50	3.73	3.53	3.98	4.10	3.48	3.78	3.60	3.56	3.83	4.63	3.35	3.50
V	S	3.33	3.78	3.70	4.33	4.13	4.05	4.63	4.60	3.55	4.08	5.05	3.43	4.30	3.68	3.98	3.70	3.98	3.36	3.40	3.38	3.70	4.10	3.85	3.45
	B	3.30	3.65	3.53	4.60	4.63	3.93	4.58	4.28	4.60	4.10	4.24	3.40	3.98	3.63	4.10	3.98	3.43	3.23	3.20	3.10	3.53	4.03	3.33	3.35
VI	S	3.80	3.68	3.90	4.85	4.18	4.03	4,35	4.28	4.73	4.98	5.00	4.13	4.33	3.70	3.63	3.78	4.18	3.55	3.95	3.75	3.98	4.75	4.13	3.55
	B	3.60	4.18	3.50	4.50	4.23	4.18	4.23	4.25	4.95	4.78	4.55	3.83	4.23	3.75	3.48	3.68	3.73	3.50	4.05	3.65	3.95	4.15	3.58	3.70

S = SURFACE

B = BOTTOM

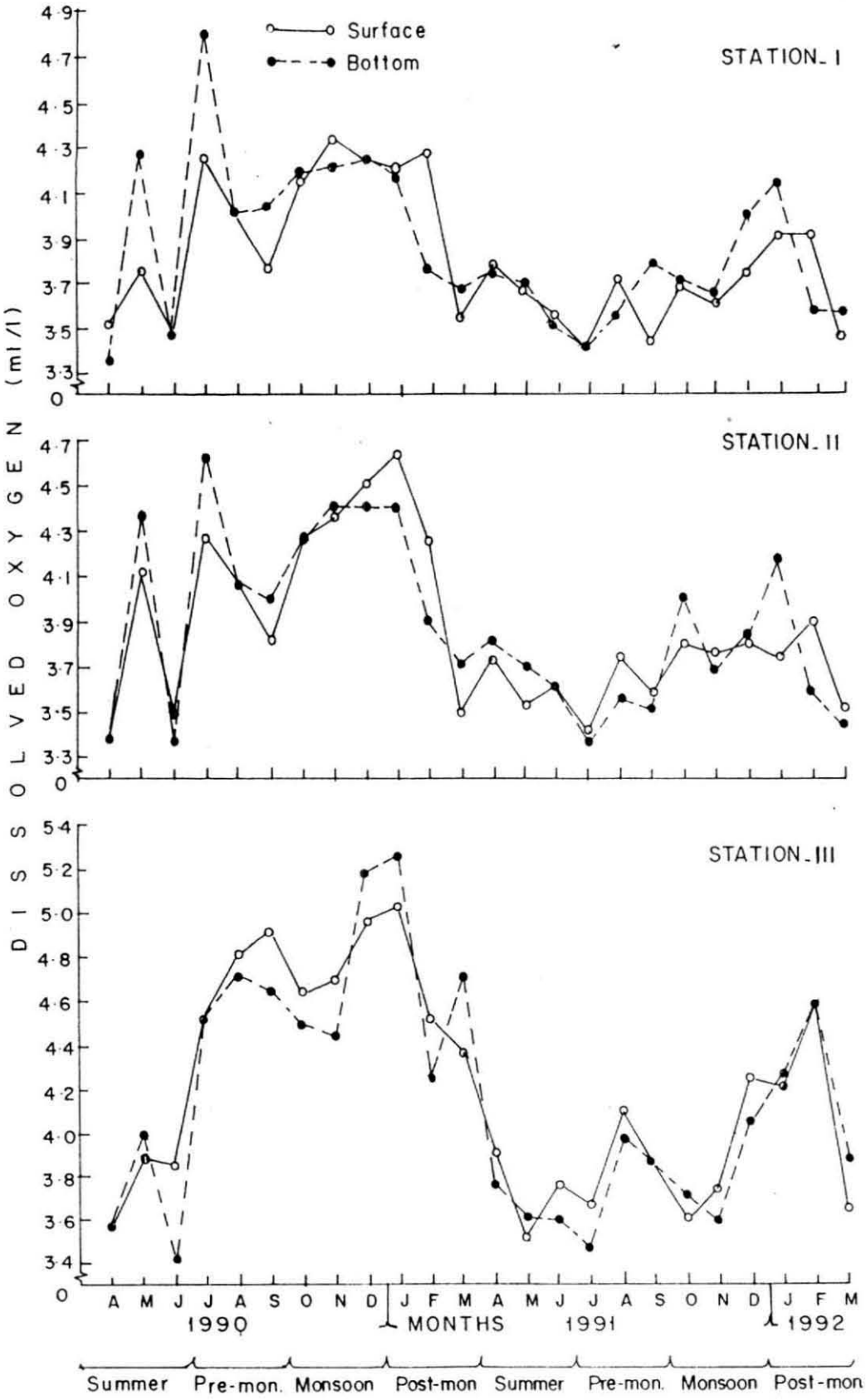

Fig. 10 Monthly variation of surface and bottom water dissolved oxygen (ml/l) at stations I to III during April 1990 to March 1992.

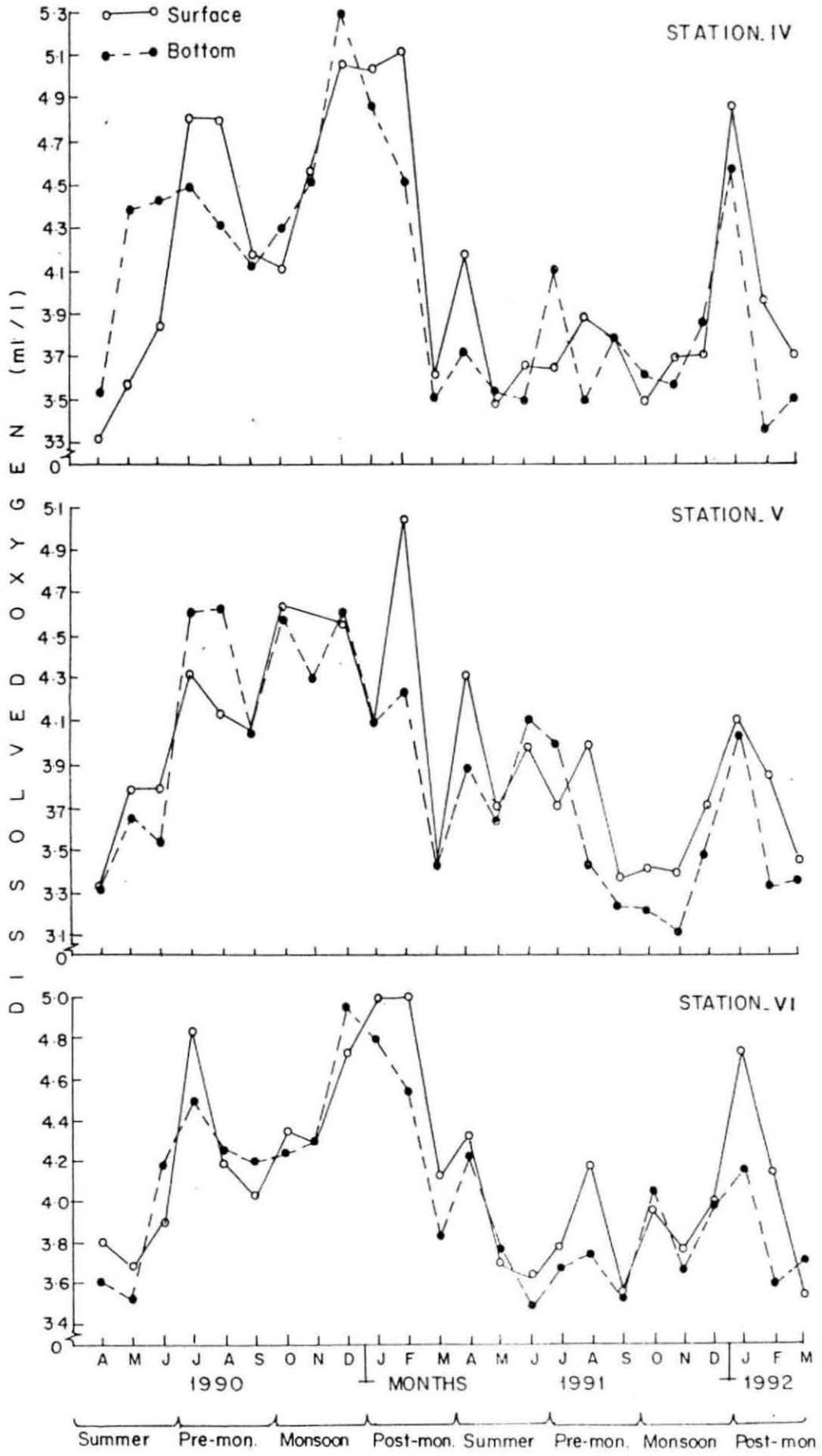

Fig. 11 Monthly variation of surface and bottom water dissolved oxygen (ml/l) at stations IV to VI during April 1990 to March 1992.

3.2.4 pH

Monthly mean values of pH estimated both at surface and bottom waters of stations I to VI are given in Table 5 and Fig. 12 and 13.

The surface water pH showed a minimum of 8.18 during July 1990 with maximum of 8.50 during June 1991 at station I. At station II, a minimum of 8.08 was recorded during July 1991 and a maximum of 8.45 during May 1991. The surface water pH of station III showed a range of 8.08 during April 1992 to 8.35 during December 1991. Surface water at station IV and V indicated similar pH range with the minimum value 8.10 observed during July 1991 at station IV and also during August 1991 at station V. The maximum value of 8.40 was noticed during June 1990 at both the stations. At station VI, the minimum value of 8.15 was observed during August 1991 with the maximum of 8.42 noticed during May 1991 and February 1992.

Monthly mean values of bottom water pH at station I showed a minimum of 8.15 during August 1991 and a maximum of 8.50 during June 1991. At station II, a lower value of 8.10 was noticed during July 1991 with a high of 8.40 during May 1991 and June 1991. Station III had a low value of 8.05 during March 1991 and April 1991 and a high value of 8.43 recorded during December 1991. Station IV recorded a minimum pH of 8.10 during August 1991 with a maximum of 8.43 during August 1990. At station V, a low of 8.10 was observed during July 1990 with a high of 8.45 during June 1991. Station VI showed a lower value of 8.18 during August 1991 with a higher value of 8.42 noticed during May 1991.

Table : 5 Monthly variations in the surface and bottom pH at different stations during the period April 1990 to March 1992

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	8.20	8.30	8.45	8.18	8.35	8.20	8.28	8.30	8.28	8.31	8.30	8.25	8.23	8.35	8.50	8.20	8.05	8.30	8.25	8.26	8.30	8.32	8.30	8.25
	B	8.30	8.33	8.40	8.20	8.30	8.28	8.30	8.28	8.33	8.30	8.38	8.28	8.23	8.39	8.50	8.23	8.15	8.30	8.28	8.30	8.30	8.33	8.30	8.30
II	S	8.30	8.23	8.35	8.28	8.30	8.33	8.33	8.31	8.30	8.27	8.30	8.32	8.30	8.45	8.35	8.08	8.13	8.33	8.30	8.30	8.25	8.30	8.23	8.30
	B	8.30	8.28	8.40	8.30	8.33	8.33	8.30	8.30	8.38	8.33	8.30	8.35	8.33	8.40	8.40	8.10	8.15	8.33	8.30	8.35	8.25	8.34	8.38	8.30
III	S	8.00	8.15	8.23	8.28	8.45	8.15	8.20	8.28	8.20	8.25	8.18	8.03	8.05	8.20	8.25	8.15	8.05	8.05	8.20	8.30	8.35	8.25	8.25	8.04
	B	8.05	8.28	8.28	8.25	8.40	8.30	8.28	8.30	8.20	8.23	8.20	8.05	8.08	8.28	8.28	8.10	8.15	8.23	8.25	8.35	8.43	8.40	8.40	8.10
IV	S	8.30	8.33	8.40	8.30	8.30	8.28	8.33	8.38	8.30	8.30	8.30	8.28	8.25	8.30	8.30	8.10	8.20	8.30	8.35	8.40	8.35	8.33	8.30	8.25
	B	8.30	8.25	8.40	8.30	8.43	8.30	8.33	8.38	8.38	8.40	8.30	8.25	8.25	8.35	8.40	8.15	8.10	8.30	8.40	8.25	8.35	8.35	8.30	8.23
V	S	8.20	8.30	8.40	8.30	8.38	8.30	8.38	8.30	8.30	8.30	8.33	8.30	8.30	8.40	8.35	8.10	8.10	8.30	8.40	8.32	8.29	8.31	8.40	8.30
	B	8.30	8.30	8.45	8.30	8.38	8.30	8.38	8.38	8.30	8.30	8.38	8.30	8.38	8.40	8.40	8.10	8.15	8.30	8.40	8.33	8.30	8.30	8.35	8.35
VI	S	8.28	8.28	8.40	8.35	8.35	8.30	8.38	8.30	8.33	8.35	8.41	8.37	8.40	8.42	8.30	8.20	8.15	8.30	8.40	8.25	8.32	8.36	8.42	8.38
	B	8.33	8.30	8.30	8.35	8.30	8.35	8.33	8.33	8.40	8.39	8.40	8.38	8.40	8.40	8.20	8.20	8.18	8.30	8.40	8.25	8.33	8.33	8.40	8.40

S = SURFACE

B = BOTTOM

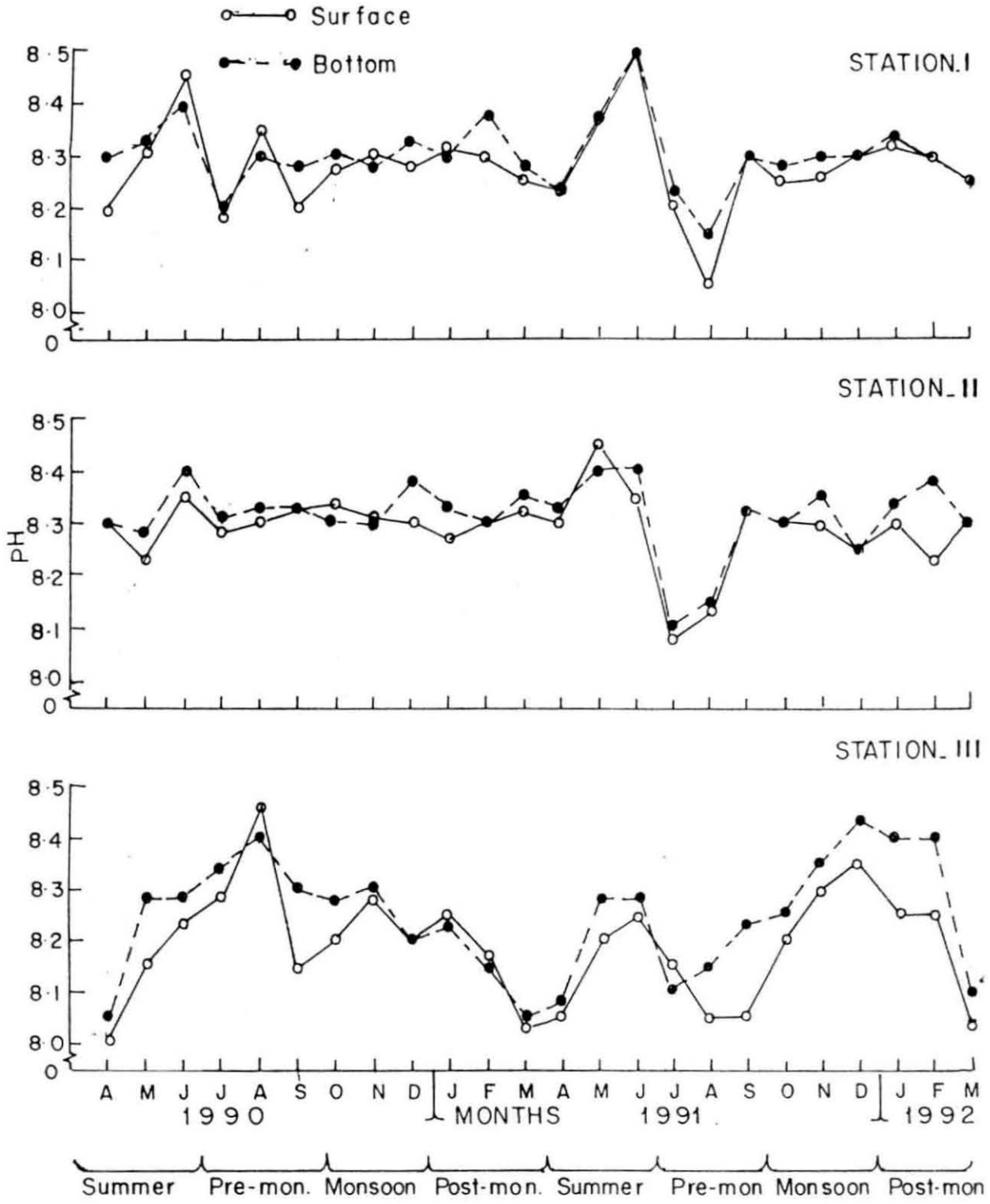

Fig. 12 Monthly variation of surface and bottom water P^H at stations I to III during April 1990 to March 1992.

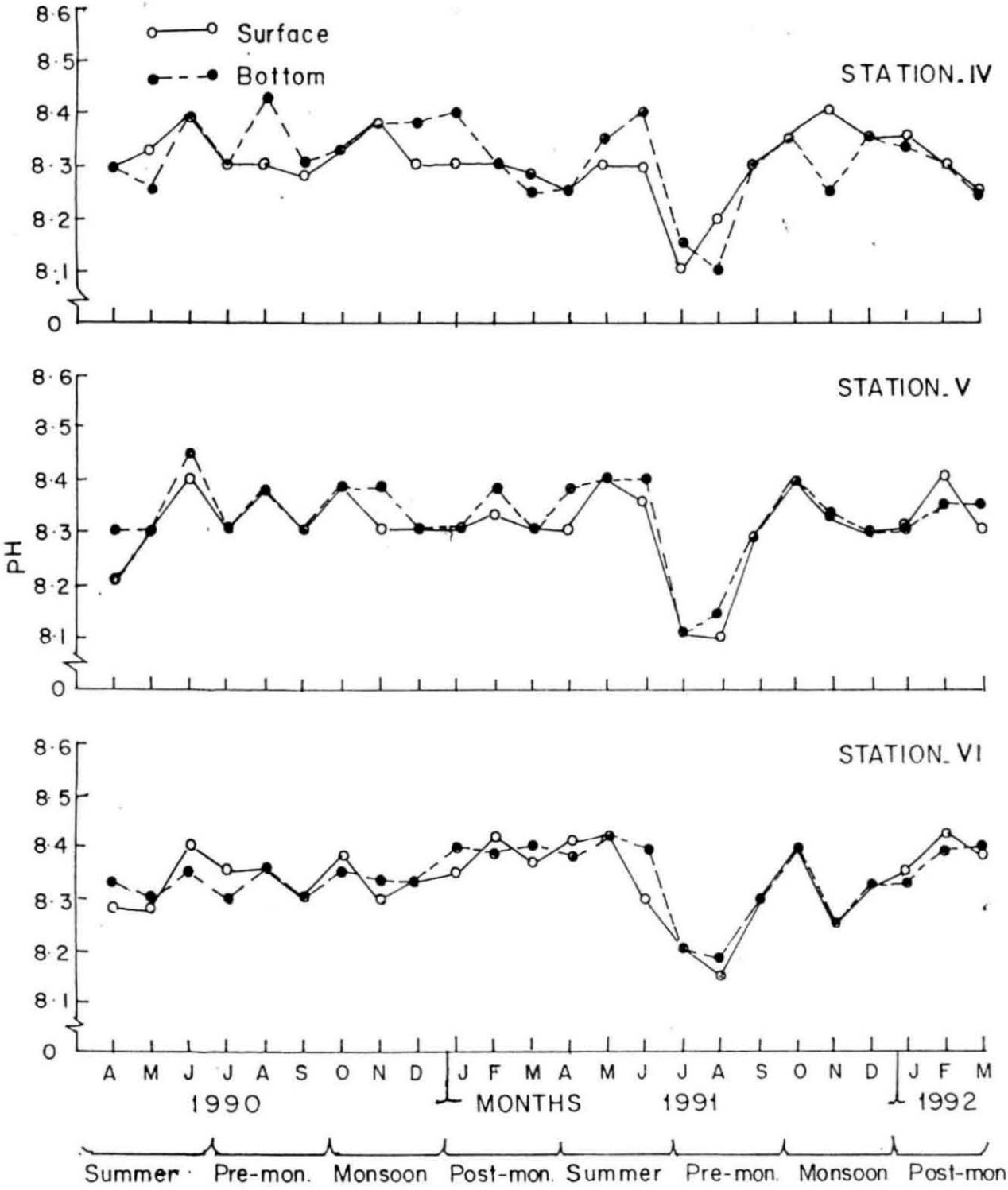

Fig. 13 Monthly variation of surface and bottom water p^H at stations IV to VI during April 1990 to March 1992.

Table: 6 Two way analysis of variance (ANOVA) showing the level of significance in variation of water parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(III) DISSOLVED OXYGEN Surface Water					
Treat	5	10.171	2.034	14.702	H.S
Repli	3	15.238	5.079	36.711	H.S
Error	543	75.127	0.138	-	-
Bottom Water					
Treat	5	7.591	1.518	11.920	H.S
Repli	3	12.292	4.097	32.172	H.S
Error	543	69.156	0.127	-	-
(IV) pH Surface Water					
Treat	5	1.034	0.207	4.054	H.S
Repli	3	0.394	0.131	2.573	S
Error	543	27.687	0.051	-	-
Bottom Water					
Treat	5	2.123	0.425	1.265	H.S
Repli	3	0.034	0.011	0.034	N.S
Error	543	182.290	0.336	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

Though remaining within a narrow range, the pH values both at surface and at bottom waters indicated a higher pH at station I which is in proximity to the effluent discharging point (8.18 - 8.50 at surface and 8.15 - 8.50 at bottom) with the lower pH indicated at station III (8.08 - 8.35 at surface and 8.05 - 8.43 at bottom) nearer to the fresh water waste discharging point.

With minimum fluctuations, the surface and bottom water pH values were noticed almost in same range. However, station III showed higher pH values in bottom water than at surface water.

The pH values both at surface and bottom showed lesser variations among the seasons with slightly higher values during summer months and lower values during premonsoon months. Concurrently, analysis of variance (Table 6) for the surface water also indicated that the variations between the seasons are significant only at 5% level. Nevertheless for the bottom water, the variations between the seasons were found to be highly significant statistically. Further, the variations of pH between the stations also were highly significant both at surface and at bottom water.

3.2.5 Turbidity

Monthly mean values of surface and bottom water turbidity at stations I to VI are given in Table 7 and Fig. 14 and 15.

The surface water turbidity at station I registered the lowest value of 0.8 Nephlometric Turbidity Unit (NTU) during September 1991 with the highest values of 3.2 NTU observed during November 1991. A variation from a low of 1.8 NTU noticed during July 1990 at station II showed a higher value of 6.4 NTU during April, 1990. With the minimum of 1.88 NTU noticed during February 1991 and the maximum of 9.40 NTU noticed during February 1991, station III was found to have the highest range among all the stations. The minimum and the maximum values of 1.60 NTU and 6.60 NTU were observed during October 1991 and February 1992 respectively at station IV. Station V also had relatively similar turbidity values ranging from 1.60 NTU during May 1991 to 6.80 NTU during August 1991. Station VI recorded a lower value of 1.20 NTU during September 1991 and a higher value of 6.60 NTU noticed during February 1991.

Bottom water turbidity values at station I showed a minimum of 1.00 NTU during September 1990 and a maximum of 2.40 NTU during May 1990. The low and the high values observed at station II were 1,80 NTU during June 1991 and 6.60 NTU during February 1991 respectively. However, station III registered the highest range with a minimum of 2.40 NTU recorded during May 1991 and January 1992 and a maximum of 10.00 NTU noticed during February 1991. Station IV showed a lower value of 2.00 NTU observed during the months of March 1991, July 1991 and March 1992 with a higher value of 6.00 NTU recorded during November 1991. With a minimum value of 2.20 NTU registered during March 1992 and a maximum value of 6.80 NTU recorded during June 1991 and December 1991 at station V, the turbidity

Table : 7 **Monthly variations in the turbidity (NTU) of surface and bottom water at different stations during the period April 1990 to March 1992**

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	2.00	2.00	2.40	2.00	1.80	1.40	2.00	2.00	1.80	1.60	2.40	2.00	1.20	1.20	1.40	1.60	1.20	0.80	2.00	3.20	1.00	1.20	1.60	2.00
	B	2.00	2.00	1.80	1.60	1.80	1.00	1.20	2.20	2.20	2.00	2.60	1.80	1.20	2.40	1.20	1.60	2.00	1.20	1.20	2.40	1.40	1.20	1.40	1.40
II	S	6.40	2.20	2.40	1.80	2.60	3.20	2.80	2.60	2.40	3.80	6.20	3.60	2.20	2.40	2.00	2.00	4.00	2.20	2.20	4.40	4.40	4.40	3.60	3.80
	B	6.40	3.00	3.60	2.80	3.00	3.00	3.00	2.80	2.60	3.20	6.60	2.40	2.00	2.00	1.80	2.60	4.80	2.80	3.80	4.60	5.40	4.80	2.00	4.80
III	S	5.80	3.80	4.00	4.20	4.60	3.60	5.40	5.30	5.40	3.60	9.40	2.80	1.88	2.80	3.60	5.75	7.80	2.40	4.00	4.40	5.20	2.60	2.20	4.60
	B	8.20	3.60	3.80	3.80	3.40	5.40	4.40	4.60	3.80	4.40	10.00	2.80	2.60	2.40	3.80	6.00	8.60	3.00	6.00	6.40	5.00	2.40	2.80	3.60
IV	S	3.80	2.40	3.20	4.00	4.20	4.00	4.40	4.60	4.00	3.60	6.60	2.00	4.00	2.80	3.20	2.00	4.60	3.00	1.60	3.60	6.20	2.60	4.00	2.00
	B	4.80	3.60	4.20	3.40	3.20	3.60	3.40	2.80	3.40	3.80	5.60	2.00	4.80	2.80	3.40	2.00	4.60	3.60	2.00	6.00	5.40	3.60	4.60	2.00
V	S	5.20	2.60	3.60	3.60	3.40	3.00	3.20	4.00	4.00	3.60	4.60	2.00	2.80	1.60	4.00	2.80	6.80	3.00	2.80	3.40	5.40	4.00	3.60	1.80
	B	5.80	4.40	3.60	3.80	3.20	3.20	3.60	4.40	5.20	4.80	5.20	3.40	2.80	4.20	6.80	3.60	6.40	3.60	3.60	6.00	6.80	6.20	2.60	2.20
VI	S	2.20	2.40	2.60	2.80	2.20	2.80	3.60	4.00	2.80	2.40	6.60	2.20	1.60	1.40	4.00	2.80	3.60	1.20	1.88	6.55	6.40	2.80	3.00	2.80
	B	2.60	2.80	3.60	3.80	3.60	4.20	3.80	4.40	3.20	4.00	5.00	2.80	2.00	1.80	4.00	2.80	4.20	2.00	2.80	4.20	5.20	3.60	2.80	2.60

S = SURFACE

B = BOTTOM

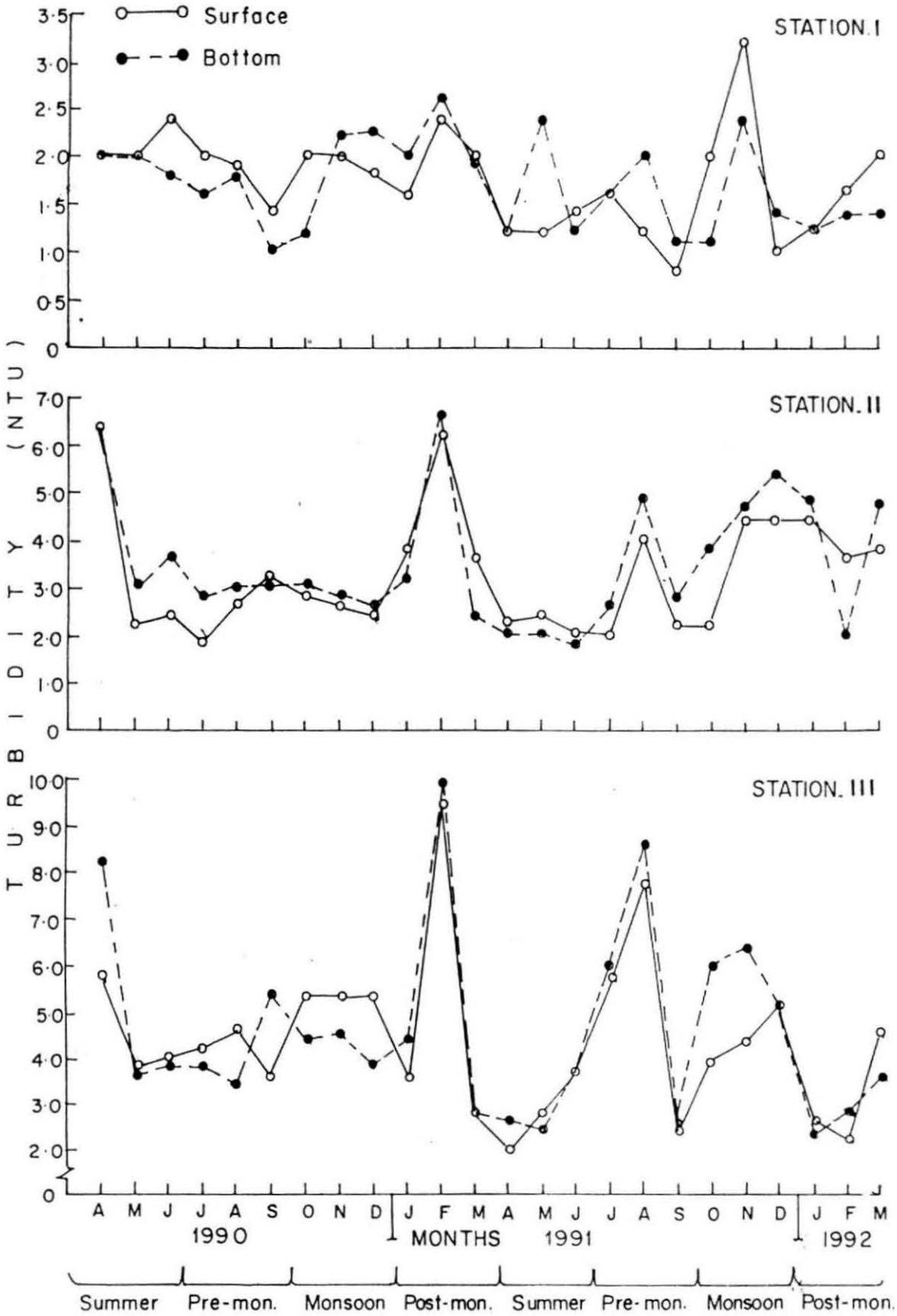

Fig. 14 Monthly variation in the turbidity (NTU) of surface and bottom water at stations I to III during April 1990 to March 1992.

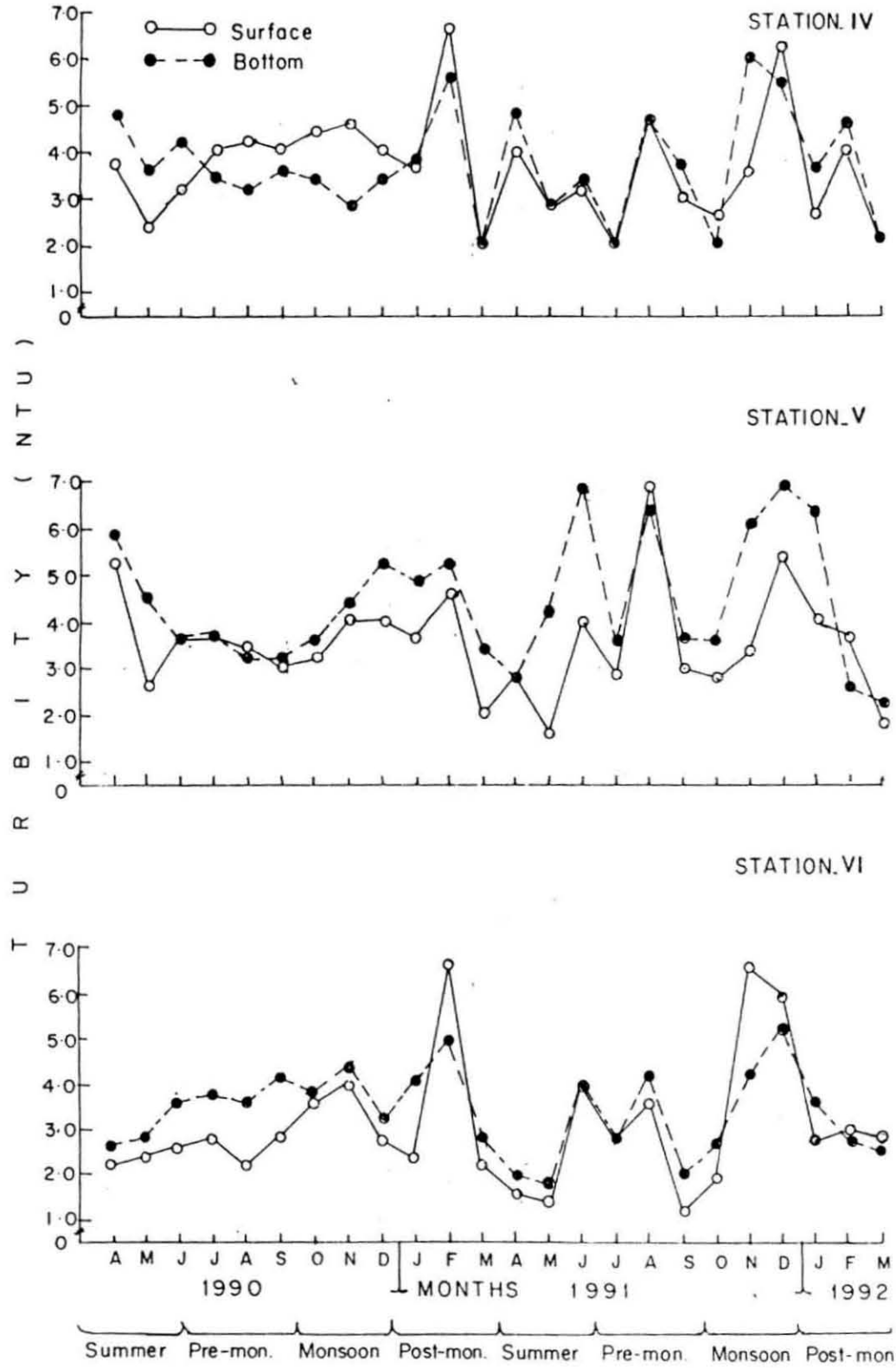

Fig. 15 Monthly variation in the turbidity (NTU) of surface and bottom water at stations IV to VI during April 1990 to March 1992.

showed a range closer to that of station IV. At station VI, the minimum value of 1.80 NTU and the maximum value of 5.20 NTU were recorded during the months of May 1991 and December 1991 respectively.

A comparison of the turbidity values among the stations indicated that station I had the lowest turbidity range both in the surface (0.80 NTU - 3.2 NTU) and bottom (1.00 NTU - 2.40 NTU) waters, while station III, which is located nearer to the fresh water liquid waste discharge point showed the highest range at surface (1.88 NTU - 9.40 NTU) and at bottom (2.40 NTU - 10.00 NTU) waters.

Between the surface and the bottom waters, a marginal high in the turbidity values was noticeable at the bottom water at all the stations.

Seasonally, the turbidity values were higher during premonsoon (July - September) and monsoon (October - December) months both at surface and bottom waters invariably in all the stations.

ANOVA (Table 9) showed that the variations between the seasons and the variations between the stations are highly significant both at surface and bottom waters.

3.2.6 Nitrite

Monthly mean values of nitrite recorded at surface and bottom waters at stations I to VI are presented in Table 8 and Fig. 16 and 17.

Nitrite of the surface water at station I and II was low, prevailing within the same range of 0.09 µg - at/l and 0.20 µg - at/l. The minimum value was recorded during December 1991 and April 1991 at Stations I and II respectively and the maximum value during June 1990 and February 1992. Station III registered the highest range among all the stations with a minimum value of 0.10 µg - at/l during the months of November 1991 and May 1991 and the maximum value of 0.38 µg - at/l during April 1990. The surface water nitrite at station IV showed a lower value of 0.08 µg - at/l in May 1991 and the higher value of 0.21 µg - at/l during June 1990. Station V indicated a nitrite range between 0.09 µg µ - at/l in November 1991 and 0.32 µg at/l in January 1991. At station VI, the surface water nitrite showed a low of 0.08 µg - at/l during May 1990 and a high of 0.27 µg - at/l during February 1991 and March 1992.

The bottom water nitrite also showed a similar distribution pattern as in surface water at stations I and II, with a range of 0.10 µg - at/l (December 1991) to 0.22 µg - at/l (June 1990 and 1991 and October 1991) and from 0.09 µg - at/l (November 1990 and April 1991) to 0.23 µg - at/l (June 1990) respectively. Station III indicated a wider range of nitrite values with a low of 0.10 µg - at/l during November 1990 and November 1991 and a high of 0.38 µ - at/l during April 1990 and March 1992. Station IV showed a minimum value of 0.11 µg - at/l during May 1991 and January 1992 and a maximum value of 0.30 µg - at/l during January 1991. A similar pattern of bottom water nitrite values was noticed at stations V and VI with a minimum of 0.09 µg - at/l during November 1991 and April 1991 at the two stations respectively.

However, the maximum values of 0.29 µg - at/l and 0.28 µg - at/l were recorded during February 1991 and December 1991 at station V and during August 1991 at station VI respectively.

A comparative analysis of surface and bottom water nitrite values among the stations indicated that station I and II had a lower concentration (surface : 0.09 µg - at/l to 0.20 µg - at/l at stations I and II; Bottom 0.10 µg at/l - 0.22 µ - at/l at station I and 0.09m µg - at/l to 0.23 µg/l at station II), with station III showing the higher values (0.10 µg - at/l to 0.38 µg - at/l) both at surface and bottom waters. When comparing the distribution of nitrite between the surface and bottom waters, it could be seen that the bottom water had a higher level of nitrite in most of the stations.

Seasonally, post monsoon period (January - March) showed a peak value while lower value was observed during premonsoon (July - September) and monsoon (October - December) months at the surface water. However, bottom water showed higher values both during post monsoon and summer months and lower values during premonsoon and monsoon months.

ANOVA showed that the variations of the nitrite values between the seasons and between the stations are highly significant both at surface and bottom water (Table 9).

Table: 8 Monthly mean values of surface and bottom water nitrite (μg-at/l) at different stations during the period April 1990 to March 1992

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	0.20	0.10	0.20	0.20	0.13	0.10	0.20	0.10	0.10	0.15	0.18	0.10	0.08	0.13	0.30	0.20	0.10	0.13	0.20	0.10	0.08	0.10	0.15	0.15
	B	0.23	0.18	0.25	0.20	0.10	0.13	0.20	0.20	0.10	0.15	0.18	0.10	0.13	0.15	0.30	0.23	0.13	0.18	0.20	0.20	0.10	0.10	0.18	0.15
II	S	0.28	0.13	0.30	0.15	0.10	0.10	0.20	0.10	0.13	0.20	0.33	0.13	0.08	0.10	0.33	0.23	0.10	0.10	0.15	0.10	0.13	0.13	0.20	0.25
	B	0.30	0.15	0.28	0.20	0.20	0.15	0.20	0.10	0.20	0.15	0.20	0.10	0.10	0.10	0.30	0.20	0.20	0.15	0.15	0.10	0.30	0.13	0.25	0.20
III	S	0.38	0.15	0.30	0.33	0.20	0.20	0.25	0.10	0.33	0.13	0.23	0.28	0.25	0.10	0.28	0.30	0.18	0.23	0.30	0.13	0.30	0.20	0.30	0.35
	B	0.38	0.23	0.28	0.35	0.20	0.25	0.30	0.10	0.20	0.23	0.23	0.30	0.30	0.20	0.23	0.35	0.23	0.15	0.30	0.10	0.30	0.30	0.30	0.38
IV	S	0.18	0.10	0.10	0.13	0.20	0.20	0.20	0.13	0.13	0.28	0.13	0.15	0.13	0.10	0.10	0.20	0.20	0.20	0.18	0.10	0.15	0.18	0.20	0.30
	B	0.30	0.23	0.28	0.23	0.18	0.13	0.20	0.20	0.18	0.25	0.38	0.18	0.20	0.10	0.30	0.25	0.18	0.13	0.20	0.20	0.20	0.10	0.20	0.23
V	S	0.10	0.10	0.20	0.20	0.20	0.20	0.10	0.10	0.20	0.33	0.33	0.10	0.25	0.10	0.20	0.20	0.20	0.20	0.15	0.10	0.30	0.20	0.20	0.15
	B	0.10	0.30	0.20	0.25	0.10	0.18	0.10	0.10	0.23	0.28	0.30	0.13	0.10	0.10	0.20	0.23	0.30	0.10	0.18	0.08	0.30	0.18	0.20	0.20
VI	S	0.13	0.10	0.15	0.20	0.23	0.23	0.15	0.10	0.23	0.23	0.28	0.10	0.10	0.10	0.20	0.23	0.20	0.20	0.15	0.13	0.23	0.18	0.20	0.28
	B	0.33	0.20	0.20	0.30	0.23	0.15	0.15	0.10	0.10	0.18	0.20	0.15	0.10	0.10	0.25	0.25	0.28	0.10	0.13	0.13	0.10	0.13	0.20	0.33

S = SURFACE

B = BOTTOM

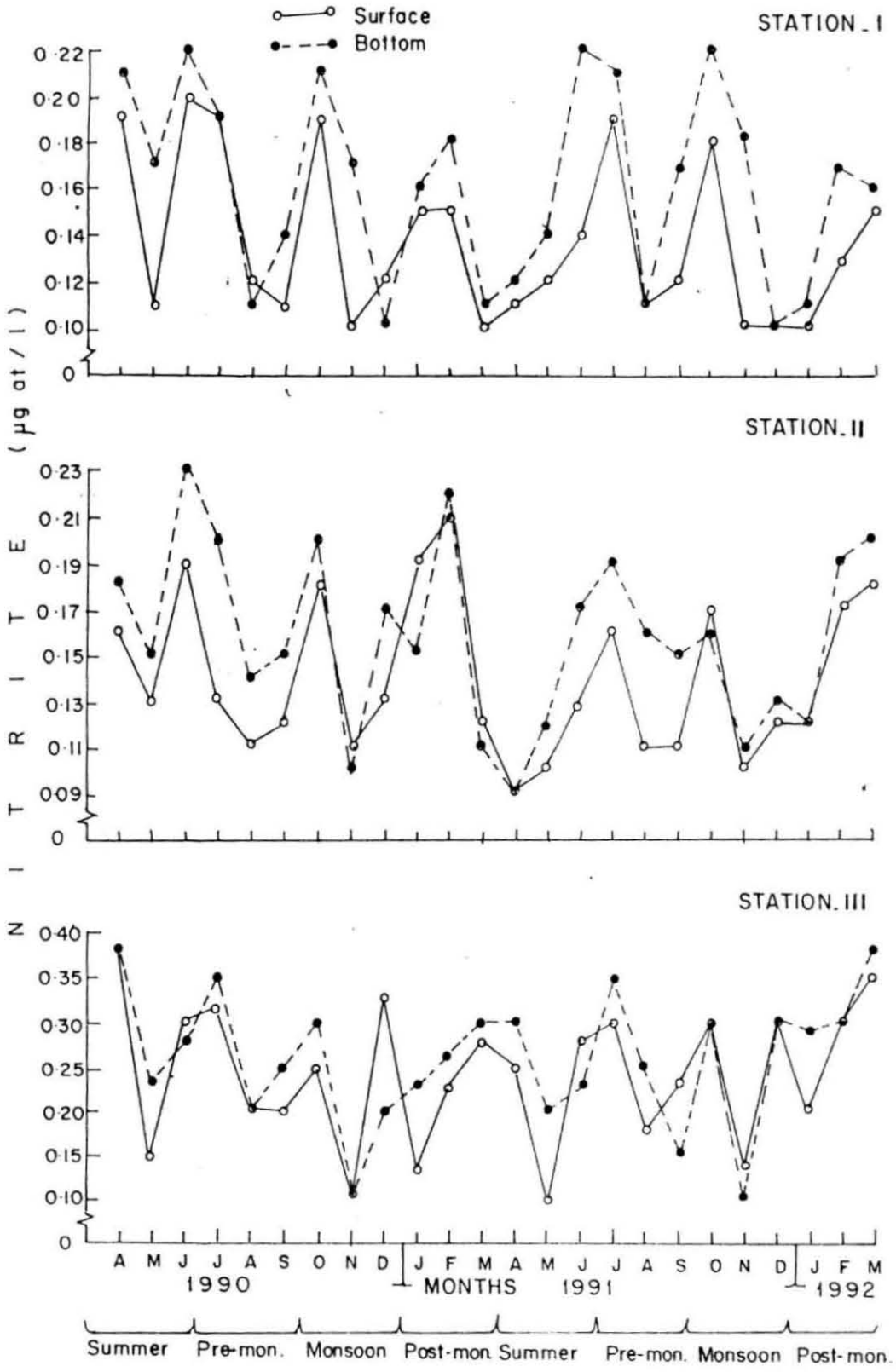

Fig. 16 Monthly variation of surface and bottom water nitrite (µg-at/l) at stations I to III during April 1990 to March 1992.

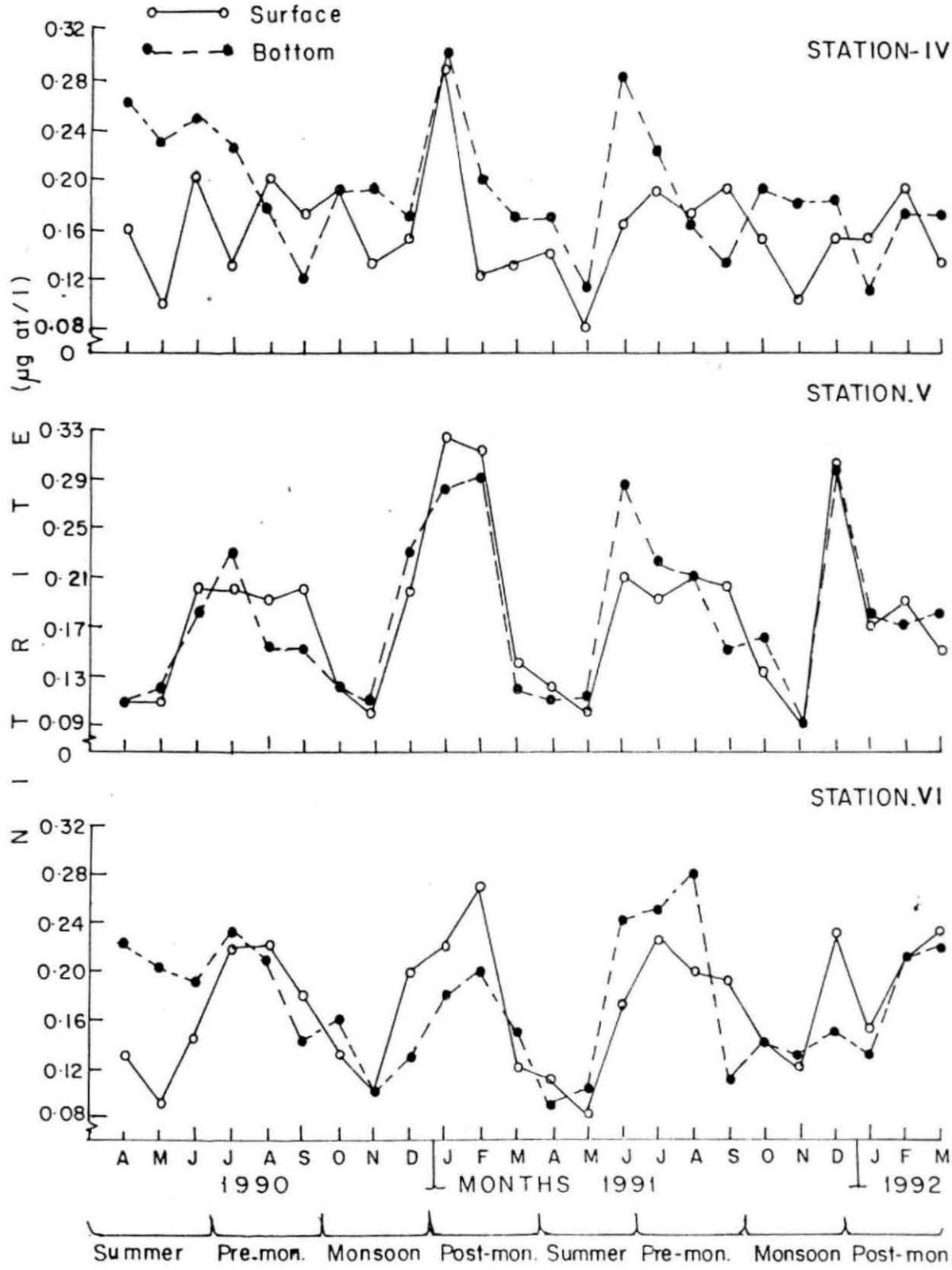

Fig. 17 Monthly variation of surface and bottom water nitrite (µg-at/l) at stations IV to VI during April 1990 to March 1992.

Table : 9 Two way analysis of variance (ANOVA) showing the level of significance in variation of water parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(III) TURBIDITY Surface Water					
Treat	5	366.356	73.271	30.501	H.S
Repli	3	45.879	15.293	6.366	H.S
Error	543	1304.411	2.402	-	-
Bottom Water					
Treat	5	533.742	106.748	44.172	S
Repli	3	19.818	6.606	2.734	H.S
Error	543	132.231	2.417	-	-
(VI) NITRITE Surface Water					
Treat	5	0.540	0.108	22.024	H.S
Repli	3	0.124	0.041	8.414	H.S
Error	543	2.663	0.005	-	-
Bottom Water					
Treat	5	0.477	0.095	18.531	H.S
Repli	3	0.150	0.050	9.678	H.S
Error	543	2.796	0.005	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

3.2.7 Nitrate

Monthly variations in the nitrate concentrations at surface and bottom water at stations I to VI are given in Table 10 Fig. 18 and 19.

The concentration of nitrate in surface water at station I varied with a minimum of 0.8 µg - at/l during October 1991 and March 1992 and a maximum of 3.08 µg - at/l during August 1990. A variation from a low of 0.93 µg/l during March 1991 to a high value of 3.3 µg- at/l in April 1990 was noticeable at station II. Station III showed a higher range in the distribution of nitrate content of the surface water among all the stations with a lower value of 1.50 µg - at/l recorded during May 1991 and a higher value of 6.28 µg - at/l during February 1991. Stations IV and V recorded the minimum value of 0.95 µg - at/l and 1.08 µg - at/l respectively both recorded during August 1990. The maximum values recorded were 2.33 µg/ at/l during April 1991 and 2.00 µg at/l during August 1990 respectively at stations IV and V. The distribution of nitrate concentration at station VI ranged with a minimum value of 1.05 µg - at/l during September 1991 and a maximum value of 2.85 µg - at/l during June 1990.

Monthly mean values of bottom water nitrate concentration at station I and II showed minimum value of 1.43 µg - at/l and 0.98 µg - at/l respectively both during November 1991. The maximum value of 4.68 µg - at/l and 4.18 µg - at/l at stations I and II respectively were recorded both during June 1991. As in surface water, station III with a lower value of 1.25 µg - at/l during October 1991 and a higher value of 6.03 µg - at/l during February 1991

registered the highest range of nitrate concentration among all the stations. At station IV, a minimum value of 1.05 µg - at/l was recorded during May 1991 with a maximum value of 2.30 µg - at/l noticed during January 1991 and January 1992. The bottom water nitrate content at stations V and VI had lesser variations. At station V, the minimum and maximum values were 1.10 µg - at/l (March 1992) and 2.88 µg - at/l (August 1990) respectively. At station VI, the values were 1.03 µg - at/l (November 1991) and 2.85 µg - at/l during (June 1991) respectively.

Among the various stations, the surface water nitrate content showed the lower level of 0.8 µg - at/l to 3.08 µg - at/l at station I and the higher range of 1.50 µg - at/l to 6.28 µg - at/l at station III. Bottom water nitrate concentration indicated a the lower range of 1.05 µg - at/l to 2.30 µg - at/l at station IV and the higher range of 1.25 µg - at/l to 6.03 µg-at/l at station III. Nitrate at the bottom water was marginally at a higher level than at the surface waters at all the stations.

Among the seasons, premonsoon months marked comparatively low concentration of nitrate with high concentration noticed during the monsoon months both at surface and bottom waters at all the stations.

Statistical interpretation of the surface and bottom water nitrate at various stations is presented in Table 12. Analysis of variance showed that the variations of nitrate among the seasons and those among the stations were highly significant both in the surface and bottom waters.

Table : 10 **Monthly mean values of surface and bottom water nitrate (μg-at/l) at different stations during the period April 1990 to March 1992**

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	0.85	1.50	3.05	2.15	3.08	1.63	1.40	1.35	2.18	1.93	1.55	1.80	1.30	1.15	1.08	1.25	1.38	0.93	0.80	0.90	0.83	1.13	1.30	0.80
	B	2.10	1.88	3.93	4.10	3.83	2.83	1.68	1.63	1.85	2.03	1.95	1.53	1.83	1.63	4.68	3.38	3.78	3.00	1.58	1.43	1.78	1.98	2.33	1.83
II	S	3.33	1.70	1.88	2.33	3.00	1.88	2.05	1.68	3.08	2.23	1.93	1.45	1.58	0.93	2.03	2.40	2.45	2.13	1.83	1.18	2.23	2.35	1.30	1.75
	B	2.30	1.48	3.85	2.25	2.93	3.20	1.48	1.28	3.20	2.78	1.78	1.65	1.18	1.05	4.18	2.20	3.28	2.85	1.23	0.98	3.40	3.00	1.75	1.80
III	S	3.25	2.60	3.35	4.58	2.30	3.15	3.85	2.55	2.30	3.35	6.28	3.43	2.73	1.50	3.23	5.03	1.80	2.68	3.58	1.95	2..15	3.08	2.23	2.15
	B	2.25	3.05	4.20	4.18	3.85	4.15	2.88	1..48	1.95	2.48	6.03	3.25	3.33	1.28	4.33	5.13	3.23	3.68	1.25	1.68	1.95	3.68	1.83	2.75
IV	S	1.35	1.18	1.45	1.78	1.45	1.70	1.80	0.95	1.28	2.08	2.05	1.58	2.33	1.05	1.30	1.78	1.48	1.15	1.65	1.05	1.30	2.15	1.05	1.40
	B	1.20	2.08	1.70	1.95	2.05	1.90	1.25	1.45	1.40	2.30	2.18	1.78	1.23	1.05	1.55	2.15	2.08	1.50	1.10	1.50	1.53	2.30	1.23	1.33
V	S	1.98	1.45	1.65	1.88	2.00	1.63	1.23	1.08	1.93	1.68	1.73	1.18	1.70	1.20	1.58	1.55	1.88	1.10	1.65	1.15	1.83	1.88	1.08	1.35
	B	2.83	1.55	1.60	2.00	2.88	2.03	1.35	1.30	1.78	2.00	1.78	1.45	1.60	1.35	1.60	1.85	2.65	1.85	1.30	1.20	2.43	2.03	1.58	1.10
VI	S	1.58	1.23	2.05	1.40	2.15	1.60	2.05	1.85	1.60	1.60	1.80	1.55	1.83	1.25	2.85	1.65	2.48	1.05	1.65	1.88	1.58	1.88	2.18	2.18
	B	1.83	1.95	1.90	2.08	2.13	1.90	1.55	1.28	1.55	1.95	2.18	1.80	1.88	1.20	2.85	2.03	2.35	1.68	1.25	1.03	1.60	1.73	1.05	1.60

S = SURFACE

B = BOTTOM

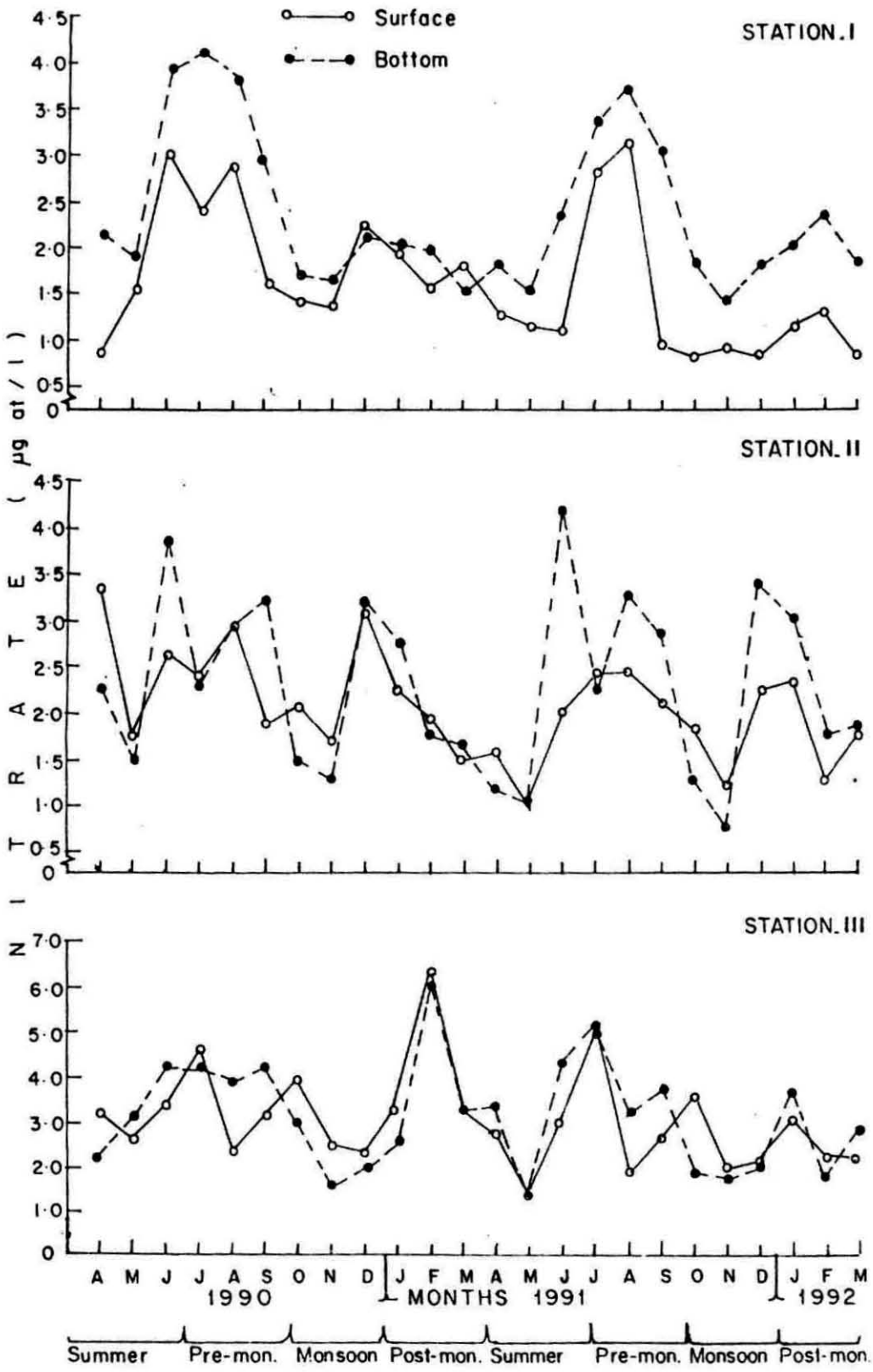

Fig. 18 Monthly mean variation of surface and bottom water nitrate (µg-at/l) at stations I to III during April 1990 to March 1992.

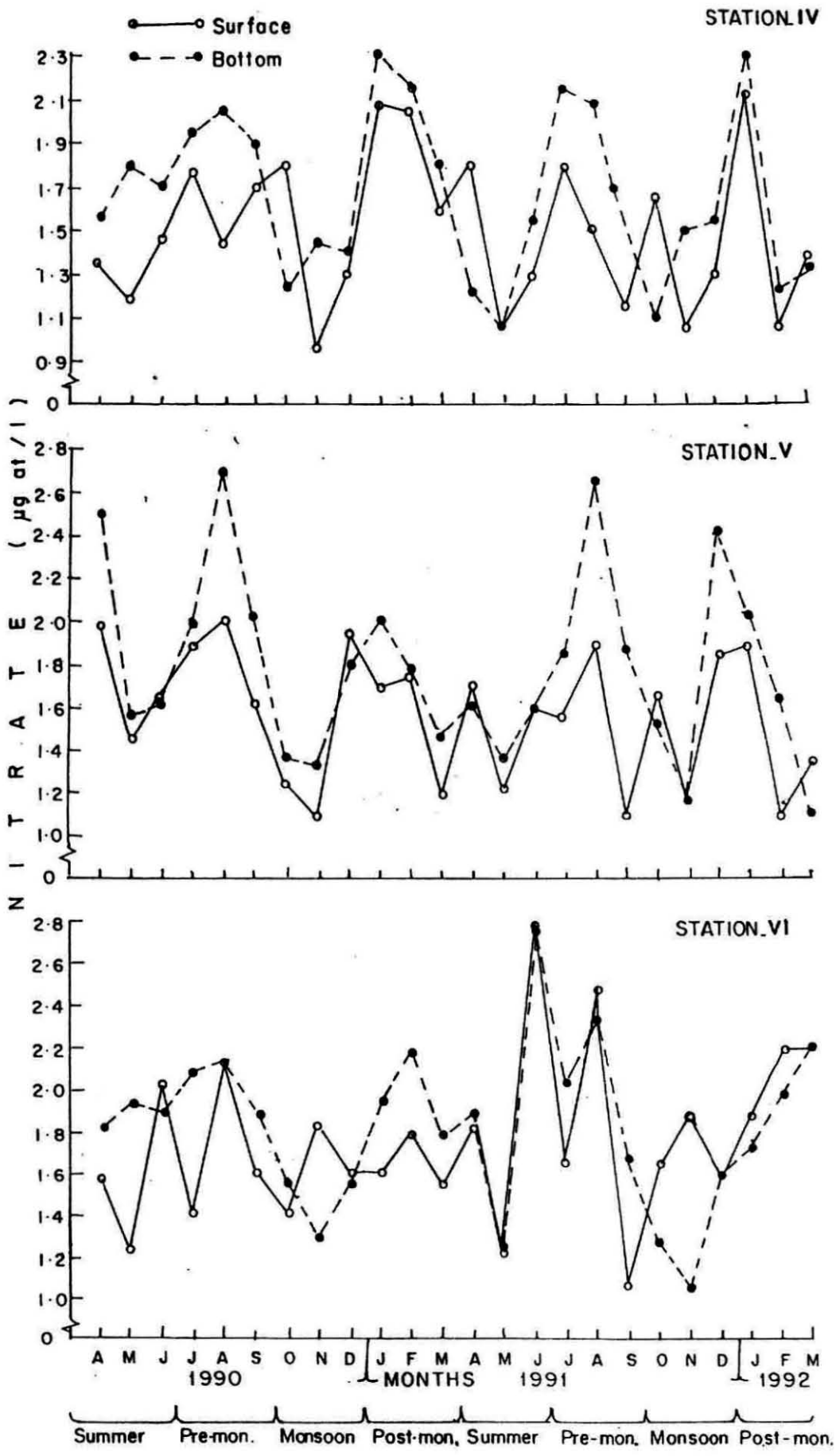

Fig. 19. Monthly mean variation of surface and bottom water nitrate (µg-at/l) at stations IV to VI during April 1990 to March 1992.

3.2.8 Phosphate

Monthly mean concentrations of phosphate in the surface and bottom water at station I to VI are shown in Table 11 and Fig. 20 and 21.

Surface water phosphate at station I indicated a minimum of 0.8 µg - at/l during October 1991 and December 1991 with a maximum of 2.30 µg - at/l during March 1991. With a variation from a low of 0.88 µg - at/l during June 1991 the phosphate concentration at station II showed a high of 2.33 µg - at/l in August 1991. Station III registered the maximum range of surface water phosphate among all the stations with a minimum and a maximum of 1.08 µg - at/l and 3.75 µg - at/l recorded during December 1990 and February 1991 respectively. The lowest values of 1.10 µg - at/l and 1.03 µg - at/l were registered at stations IV and V respectively both during April 1990, with the highest concentrations of 2.50 µg - at/l observed during March 1991 at station IV and 2.98 µg - at/l noticed during February 1991 at station V. At station VI, the phosphate concentration of surface water ranged between 0.78 µg - at/l and 2.10 µg - at/l recorded during April 1990 and March 1991 respectively.

Monthly mean values of bottom water phosphate at station I showed a low of 0.88 µg - at/l in November 1991 and a high of 2.10 µg - at/l during March 1991. A minimum of 0.98 µg - at/l and a maximum of 3.23 µg - at/l were recorded during April 1990 and February 1991 respectively at station II. The distribution of bottom water phosphate concentration at station III registered the highest range among all stations with a low of 1.10 µg - at/l observed during April 1990 and a high of 3.30 µg - at/l noticed during February 1991.

At station IV, the minimum value of 1.18 µg - at/l and the maximum value of 2.93 µg - at/l were noticed during September 1991 and March 1991 respectively. Station V showed a lower phosphate concentration of 0.90 µg - at/l in April 1990 with a high of 3.13 µg - at/l during February, 1991. The bottom water phosphate concentration at station VI indicated a low of 1.00 µg - at/l during April 1990 and a high of 2.38 µg - at/l during August 1991.

Among the various stations, the surface water phosphate levels showed a lower range (0.78 µg - at/l - 2.10 µg - at/l) at station I and a higher range (1.08 µg - at/l - 3.75 µg - at/l) at station III. Bottom water phosphate indicated a lower range (0.88 µg - at/l - 2.10 µg - at/l) at station II and a higher range (1.10 µg - at/l - 3.30 µg - at/l) at station III. Between the surface and bottom waters, the phosphate concentration showed higher values at bottom water in almost all stations.

Seasonally, post monsoon period (January - March) showed higher values with the monsoon season (October - December) registering lower values both at surface and bottom waters in all the stations.

Statistical interpretation (ANOVA) of the phosphate values is given in Table 12. ANOVA showed that the variations between the seasons and between the stations are highly significant both at surface and bottom waters.

Table : 11 **Monthly mean values of surface and bottom water phosphate (μg-at/l) at different stations during the period April 1990 to March 1992**

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	0.85	1.00	1.18	1.20	1.70	1.03	0.95	0.85	1.05	1.50	1.80	2.30	1.34	1.117	1.10	1.28	1.39	0.09	0.08	0.91	0.80	1.13	1.33	1.50
	B	1.05	1.45	1.33	1.60	1.78	1.28	1.10	0.95	1.10	1.70	1.98	2.10	1.50	1.25	0.90	1.18	1.20	1.18	0.90	0.88	1.00	1.33	1.18	0.98
II	S	0.93	2.00	1.18	1.78	2.25	1.40	1.08	1.13	1.78	1.78	1.98	2.33	1.68	2.25	0.88	2.03	2.33	1.15	1.05	1.25	2.15	1.83	1.58	1.68
	B	0.98	1.93	1.20	1.88	2.30	1.53	1.30	1.18	1.83	2.58	3.23	2.93	1.30	2.03	1.05	2.18	1.90	1.08	1.98	2.30	2.30	2.23	3.00	1.48
III	S	1.55	2.45	2.43	1.93	2.78	2.58	1.88	1.85	1.08	2.98	3.75	3.35	2.15	2.68	2.53	2.43	2.80	2.73	2.53	2.10	1.40	1.38	2.85	1.65
	B	0.98	3.03	2.55	2.05	2.98	2.98	2.13	1.20	1.20	3.15	3.30	3.23	2.25	2.43	1.55	2.95	2.33	2.65	2.55	1.85	1.35	1.60	1.83	2.33
IV	S	1.10	1.43	1.25	1.88	1.95	2.10	1.75	1.68	1.13	2.00	2.00	2.50	1.48	1.60	1.90	1.85	2.13	2.10	2.18	1.20	1.73	2.33	1.95	1.65
	B	1.20	1.53	1.50	1.88	2.08	2.03	1.83	1.78	1.23	1.58	2.33	2.93	1.58	1.88	2.13	2.33	1.93	1.18	2.70	2.08	1.30	2.20	2.03	1.48
V	S	1.03	2.00	1.85	2.05	1.98	1.15	1.68	1.08	1.48	1.68	2.98	2.33	1.30	2.18	1.78	1.88	2.08	1.40	1.73	1.38	1.40	1.63	1.63	1.33
	B	0.90	2.00	1.73	2.05	1.90	1.30	1.48	1.05	1.15	2.40	3.13	2.65	1.25	2.03	2.08	1.75	1.65	2.03	1.40	1.40	2.13	1.53	1.88	1.15
VI	S	0.78	1.90	1.08	1.38	1.40	1.38	1.10	0.93	1.13	1.35	1.93	2.10	1.05	1.73	1.13	1.75	1.58	1.18	0.95	0.90	1.05	1.35	0.85	1.23
	B	1.00	1.15	1.15	1.40	1.58	1.25	1.18	1.08	1.13	1.58	1.98	1.90	1.13	1.63	1.33	2.13	2.38	1.53	1.25	1.08	1.10	1.50	1.18	1.13

S = SURFACE

B = BOTTOM

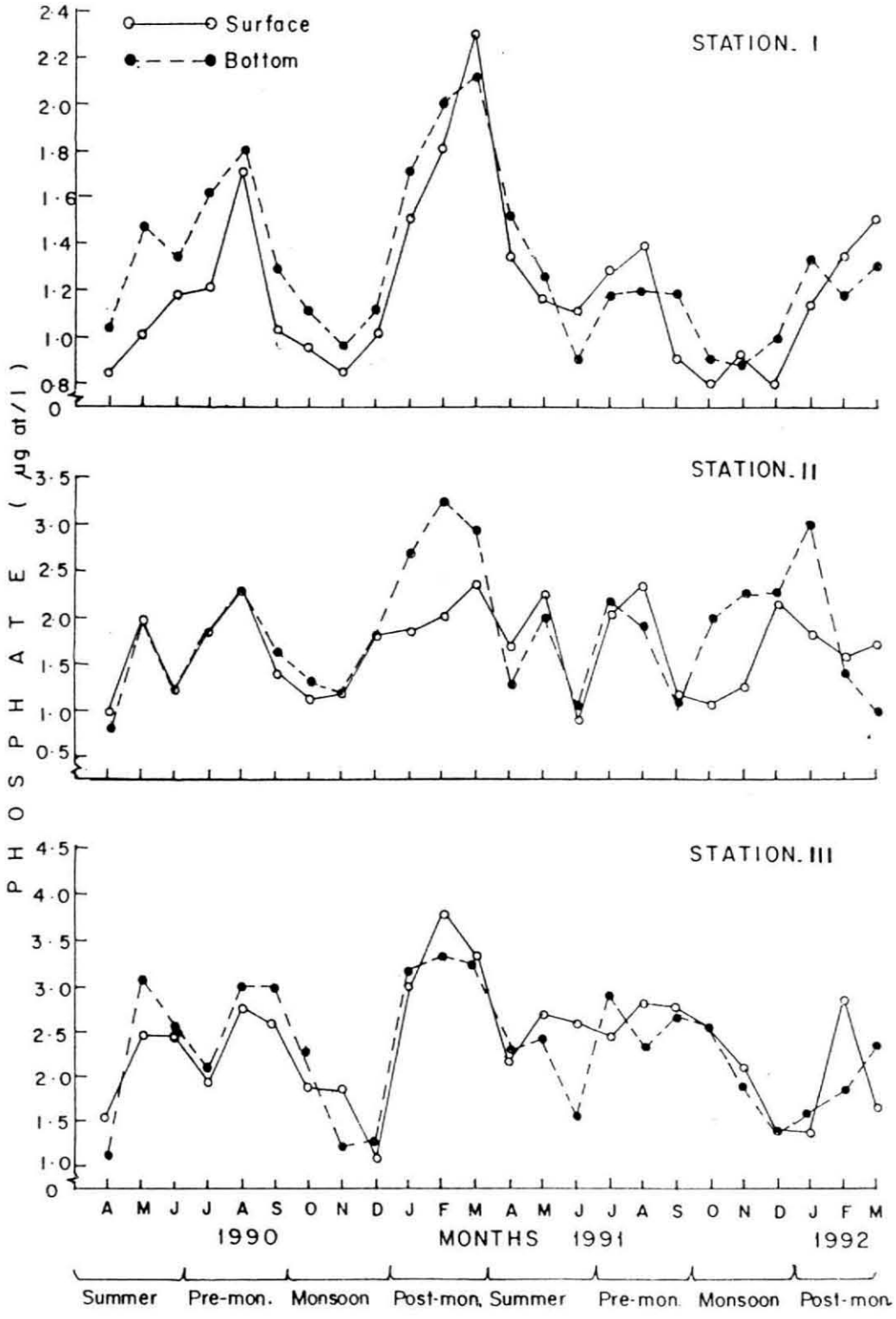

Fig. 20 Monthly variation of surface and bottom water phosphate (µg-at/l) at stations I to III during April 1990 to March 1992.

Table: 12 Two way analysis of variance (ANOVA) showing the level of significance in variation of water parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(VII) NITRATE Surface Water					
Treat	5	169.889	33.978	96.720	H.S
Repli	3	7.322	2.441	6.947	H.S
Error	543	190.756	0.351	-	-
Bottom Water					
Treat	5	141.430	28.286	57.844	H.S
Repli	3	89.640	29.880	61.103	H.S
Error	543	265.531	0.489	-	-
(VIII) PHOSPHATE Surface Water					
Treat	5	129.131	25.826	139.277	H.S
Repli	3	24.481	8.160	44.009	H.S
Error	543	100.688	0.185	-	-
Bottom Water					
Treat	5	58.219	11.644	58.268	H.S
Repli	3	34.495	11.498	58.132	H.S
Error	543	107.402	0.198	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

3.2.9 Silicate

Monthly variations in silicate concentrations of both surface and bottom water at stations I to VI are presented in Table 13 and Fig. 22 and 23.

At station I, the silicate content exhibited a low of 1.4 µg - at/l during March 1992 and a high of 11.17 µg - at/l during May 1991. Station II indicated the minimum silicate concentration of 2.60 µg - at/l in March 1992 and the maximum content of 8.20 µg - at/l recorded in May 1991. With a lower value of 3.65 µg - at/l noticed during October 1990 and a higher value of 15.19 µg - at/l registered during March 1991, station III showed the highest range of surface water silicate among all the stations. At stations IV and V the lower values were 1.31 µg - at/l and 1.04 µg - at/l respectively both recorded during March 1992. The higher values of 12.11 µg - at/l and 9.65 µg - at/l were recorded during the months of May 1991 and June 1990 respectively at stations IV and V. The silicate content at station VI showed a minimum of 1.09 µg - at/l during March 1991 with the maximum value of 8.90 µg - at/l observed during August 1991.

Bottom water silicate concentration at station I and II showed minimum values of 1.01 µg - at/l and 0.62 µg - at/l respectively both observed during March 1991. The maximum value of 12.84 µg - at/l at station I was recorded during May 1991 and 10.36 µg - at/l at station II during August 1991. The bottom water silicate content at station III was found to be significantly high among all stations with a low of 3.59 µg - at/l prevailed during November 1991 and a high of 16.54 µg - at/l during February 1991. The silicate content

at stations IV and V was noticed to have a similar distribution pattern with a minimum of 1.07 µg - at/l recorded at both the stations during March 1991. The maximum values of 10.77 µg - at/l and 11.0 µg - at/l were recorded in the month of both during May 1990 and 1991 respectively. Station VI showed a lower silicate concentration of 0.83 µg - at/l during March 1991 and a higher concentration of 9.26 µg - at/l during the month of August 1990 and 1991.

A comparison of surface water silicate concentration among all the stations indicated the lower range (2.60 µg - at/l to 8.20 µg - at/l) at station II and the higher range (3.65 µg - at/l to 15.19 µg - at/l) at station III.

The bottom water silicate showed a lower range (0.62 µg - at/l - 10.36 µg - at/l) at station II with the higher range (3.59 µg - at/l - 16.54 µg - at/l) observed at station III. Between the surface and bottom waters, it could be noticed that the bottom water showed higher level of silicate content in almost all the stations.

Seasonal variation of both surface and bottom water silicate values indicated only narrow fluctuations. In surface water, summer and monsoon periods showed higher values with lower values noticed during post monsoon period. The silicate concentration in the bottom water was higher during premonsoon and summer months while lower values were noticeable during post monsoon months.

Table : 13 **Monthly mean values of surface and bottom water silicate (μg-at/l) at different stations during the period April 1990 to March 1992**

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	1.63	8.38	3.98	4.50	5.03	2.45	3.93	2.0	2.62	7.41	6.36	5.04	3.39	11.17	2.86	3.27	3.94	3.41	3.42	2.21	3.17	2.78	4.23	1.41
	B	5.52	5.53	4.81	7.85	4.63	3.65	2.98	2.39	4.74	8.03	6.21	1.01	3.02	12.84	3.07	5.72	5.70	2.97	3.49	3.04	6.30	4.36	4.98	1.30
II	S	3.13	6.58	5.10	3.43	5.20	3.84	6.04	4.05	6.60	7.13	5.70	5.05	4.77	8.22	3.95	3.20	5.85	4.57	4.95	4.54	6.07	3.20	5.00	2.60
	B	4.48	5.09	5.78	5.51	10.06	4.51	4.71	4.17	6.03	5.06	2.71	6.18	6.26	10.12	3.10	6.78	10.36	4.08	4.85	5.88	5.27	4.60	6.02	1.76
III	S	9.75	9.80	1.06	5.46	7.50	8.69	3.65	6.11	9.0	13.51	14.26	15.19	9.84	9.09	9.66	5.62	7.04	8.43	4.37	6.29	10.90	4.05	5.97	5.21
	B	7.17	9.65	8.08	10.34	9.49	5.65	4.46	4.07	7.59	13.17	16.54	6.54	12.55	10.97	5.00	11.96	10.13	5.78	3.63	3.59	9.10	6.14	7.88	6.07
IV	S	3.13	7.19	5.79	5.92	6.51	4.25	5.34	7.76	9.12	8.02	4.57	9.23	3.54	12.11	6.39	4.06	5.68	4.92	4.66	7.74	9.66	55.87	4.58	1.31
	B	1.82	10.77	3.35	7.81	9.63	4.36	5.67	8.11	5.36	9.64	4.23	1.07	10.66	9.31	3.04	6.50	8.09	3.24	5.43	7.85	4.43	5.01	4.75	2.05
V	S	2.37	6.92	9.65	8.11	3.98	5.89	6.35	6.45	8.26	3.17	3.66	3.03	5.70	8.01	9.47	8.59	4.27	4.92	5.89	6.04	7.08	5.76	1.89	1.04
	B	1.77	5.61	9.51	6.42	4.99	4.14	5.61	2.77	5.83	4.76	4.31	10.7	6.54	11.01	3.97	7.33	8.81	2.92	4.75	2.33	6.81	3.86	3.77	1.20
VI	S	2.04	4.01	3.56	4.65	7.72	6.43	4.44	3.25	2.48	2.80	3.17	1.09	3.29	4.40	3.38	3.74	8.90	5.21	2.15	1.23	4.23	3.74	2.26	1.19
	B	1.21	4.23	4.03	3.55	9.26	4.12	4.85	2.89	4.72	3.52	5.02	8.25	2.37	4.74	3.45	3.95	9.26	3.38	4.41	1.68	4.10	3.00	3.12	1.17

S = SURFACE

B = BOTTOM

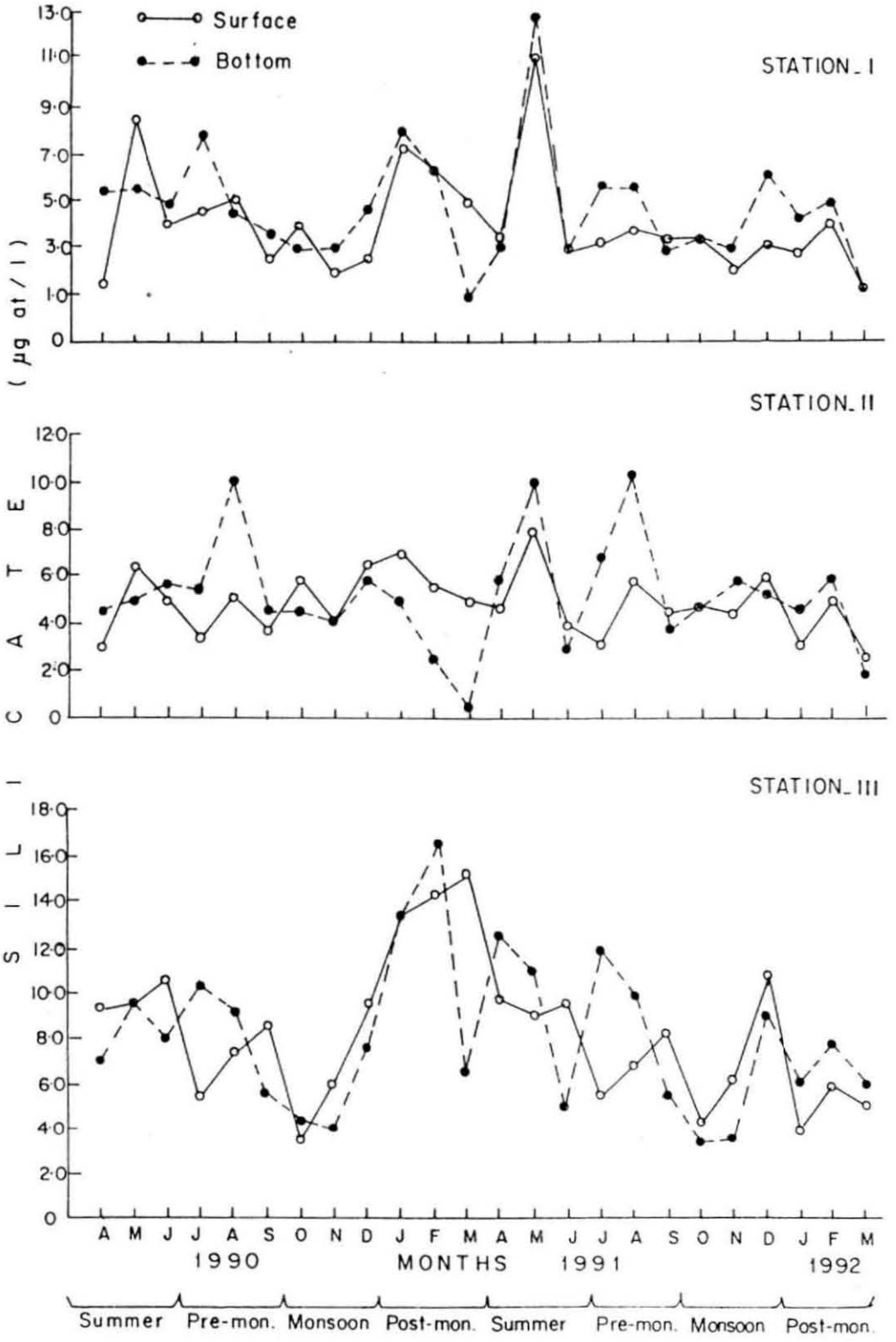

Fig. 22. Monthly variation of surface and bottom water silicate (µg-at/l) at stations I to III during April 1990 to March 1992.

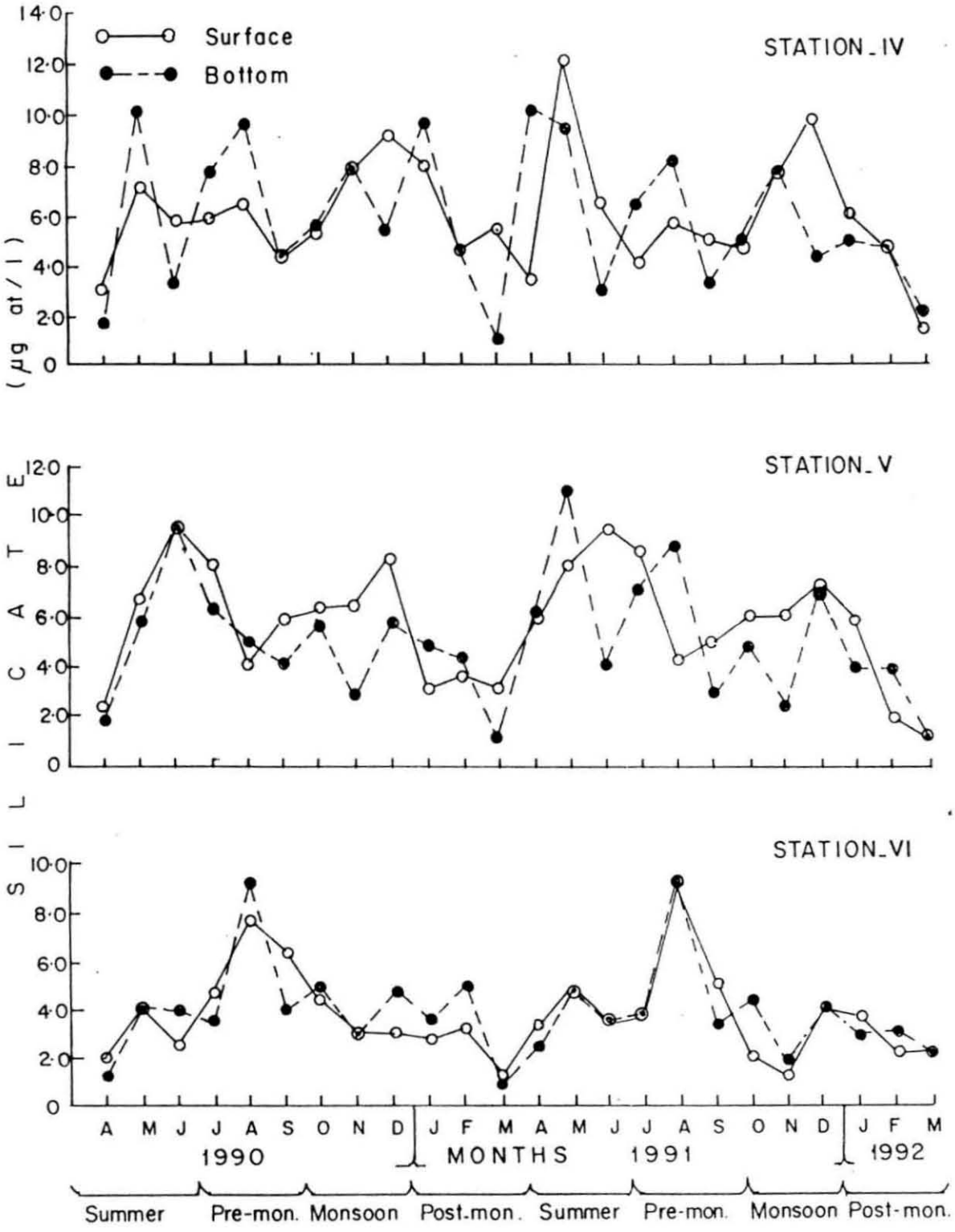

Fig. 23 Monthly variation of surface and bottom water silicate (µg-at/l) at stations IV to VI during April 1990 to March 1992.

ANOVA (Table 15) showed that the variations of silicate values between the seasons and those between the stations were highly significant both at surface and bottom waters.

3.2.10 Ammonia

Monthly mean values of ammonia concentration from surface and bottom water at stations I to VI are shown in Table 14 and Fig.24 and 25.

The surface water ammonia concentration at stations I and II showed a similar distribution pattern with the minimum value of 0.10 µg - at/l observed during April 1990 and the maximum of 0.50 µg - at/l noticed during June 1991 at both the stations. Station III with the ammonia content range of 0.25 µg - at/l (December 1991) to 0.93 µg - at/l (February 1991 and April 1991) had the highest concentration among all the stations. With a uniform minimum concentration of 0.10 ug-at/l at station IV (December 1990, 1991, January 1991, 1992 and February 1992), station V (April 1990 and January 1991) and station VI (January 1991 and January 1992), the maximum concentration at the three stations were 0.33 µg-at/l (October 1991), 0.38 µg-at/l (July 1991) and 0.25 µg-at/l (July 1990, 1991, August 1991 and October 1991) respectively. The ammonia content was at a lower level among all stations at station VI.

With a concentration marginally higher than that of the surface water in general, bottom water ammonia content at station I showed a range of 0.15 µg-at/l during January '91 and February '92 and 0.45 µg-at/l during July 1990.

Table : 14 Monthly mean values of surface and bottom water ammonia (μg-at/l) at different stations during the period April 1990 to March 1992

Station	Levels	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	S	0.13	0.35	0.40	0.45	0.30	0.25	0.30	0.23	0.20	0.15	0.30	0.25	0.10	0.20	0.50	0.50	0.35	0.30	0.25	0.30	0.30	0.15	0.20	0.23
	B	0.18	0.20	0.33	0.45	0.30	0.28	0.25	0.20	0.23	0.15	0.15	0.20	0.55	0.30	0.38	0.20	0.33	0.35	0.25	0.23	0.20	0.18	0.15	0.20
II	S	0.10	0.10	0.38	0.28	0.33	0.33	0.30	0.20	0.20	0.15	0.28	0.20	0.10	0.10	0.10	0.50	0.30	0.28	0.30	0.20	0.20	0.13	0.20	0.18
	B	0.10	0.15	0.33	0.28	0.30	0.30	0.30	0.20	0.20	0.10	0.30	0.23	0.20	0.15	0.43	0.28	0.30	0.25	0.20	0.35	0.30	0.20	0.20	0.20
III	S	0.83	0.60	0.70	0.73	0.58	0.48	0.43	0.33	0.28	0.50	0.93	0.60	0.93	0.55	0.68	0.70	0.60	0.45	0.40	0.28	0.25	0.50	0.75	0.60
	B	0.85	0.60	0.88	0.58	0.58	0.53	0.40	0.40	0.33	0.55	0.78	0.85	0.88	0.58	0.70	1.10	0.48	0.50	0.28	0.30	0.33	0.48	0.70	0.63
IV	S	0.15	0.20	0.20	0.23	0.20	0.20	0.28	0.23	0.10	0.10	0.15	0.30	0.10	0.20	0.20	0.30	0.25	0.25	0.33	0.23	0.10	0.10	0.10	0.18
	B	0.15	0.20	0.20	0.20	0.20	0.23	0.30	0.25	0.13	0.10	0.25	0.38	0.20	0.18	0.40	0.35	0.20	0.30	0.18	0.20	0.28	0.13	0.10	0.18
V	S	0.10	0.18	0.23	0.28	0.20	0.20	0.20	0.23	0.30	0.30	0.10	0.25	0.13	0.18	0.28	0.38	0.18	0.20	0.18	0.30	0.25	0.15	0.20	0.20
	B	0.10	0.20	0.25	0.28	0.20	0.20	0.20	0.23	0.30	0.20	0.20	0.28	0.25	0.30	0.25	0.35	0.23	0.25	0.10	0.18	0.30	0.20	0.20	0.15
VI	S	0.18	0.18	0.20	0.25	0.20	0.15	0.23	0.20	0.20	0.10	0.23	0.20	0.15	0.18	0.20	0.25	0.25	0.15	0.25	0.20	0.15	0.10	0.20	0.20
	B	0.10	0.18	0.20	0.23	0.20	0.23	0.23	0.20	0.20	0.13	0.25	0.25	0.15	0.18	0.20	0.25	0.20	0.20	0.23	0.20	0.20	0.10	0.18	0.20

S = SURFACE

B = BOTTOM

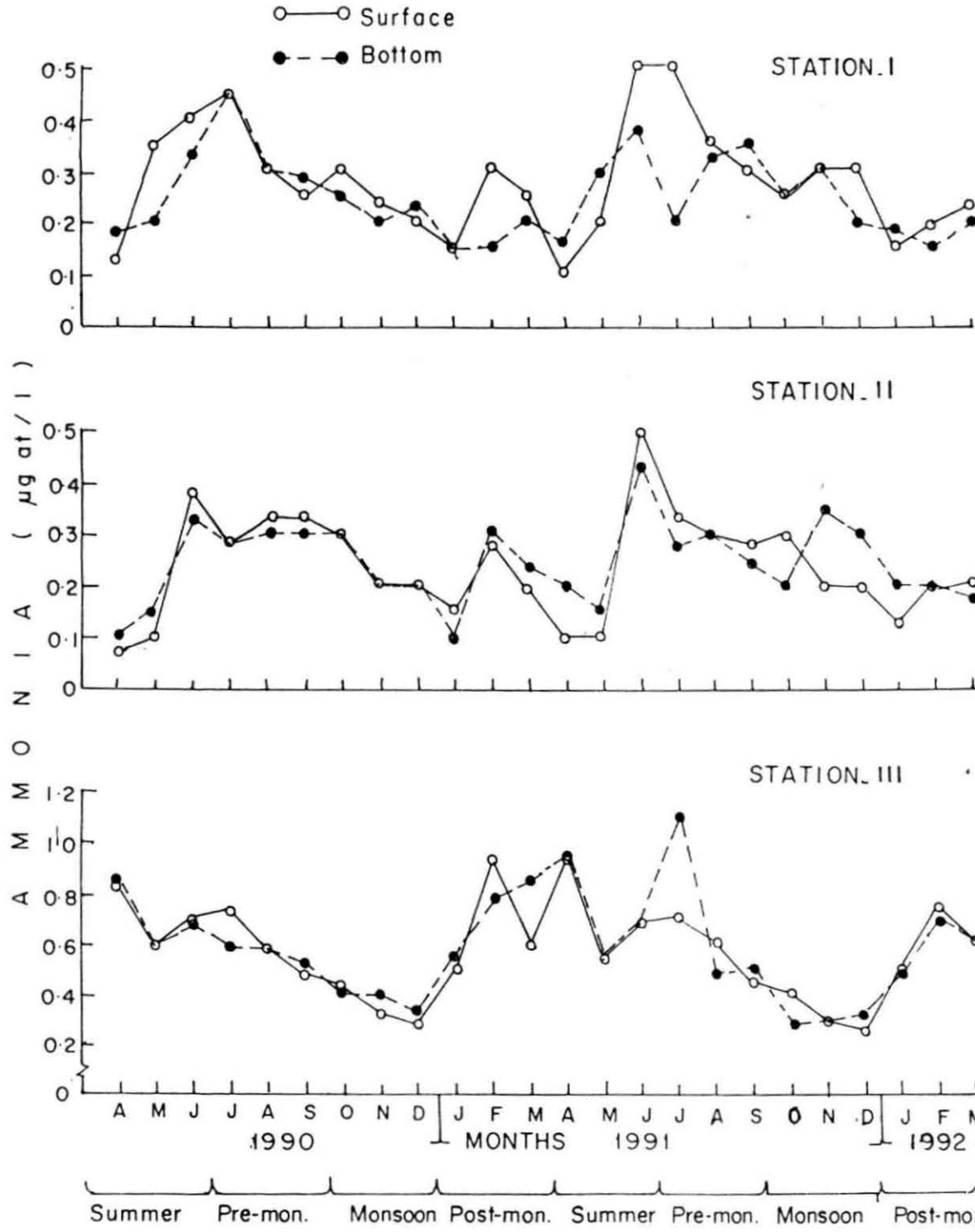

Fig. 24 Monthly variation of surface and bottom water ammonia (µg-at/l) at stations I to III during April 1990 to March 1992.

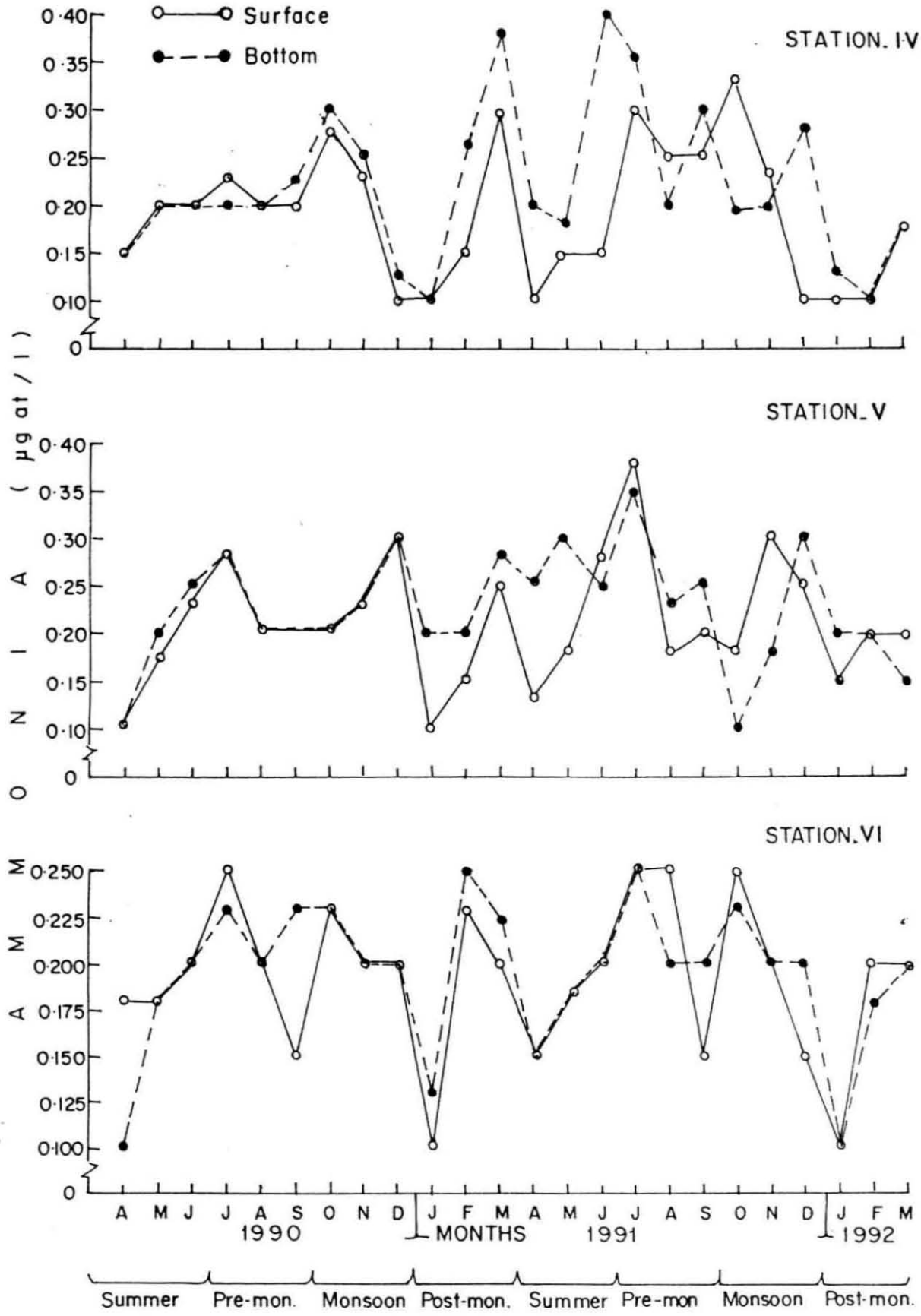

Fig. 25 Monthly variation of surface and bottom water ammonia (µg-at/l) at stations IV to VI during April 1990 to March 1992.

Table: 15 Two way analysis of variance (ANOVA) showing the level of significance in variation of water parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(IX) SILICATE Surface Water					
Treat	5	12895.389	2579.007	6.273	H.S
Repli	3	1479.167	493.056	1.1992	H.S
Error	543	22324.682	41.136	-	-
Bottom Water					
Treat	5	8902.636	1780.413	2.305	H.S
Repli	3	4421.425	1473.808	1.909	H.S
Error	543	41944.861	77.246	-	-
(X) AMMONIA Surface Water					
Treat	5	10.070	2.014	241.062	H.S
Repli	3	0.530	0.177	21.160	H.S
Error	543	4.537	0.008	-	-
Bottom Water					
Treat	5	10.695	2.139	179.620	H.S
Repli	3	0.596	0.199	16.670	H.S
Error	543	6.466	0.012	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

At station II and III though the maximum concentration of 1.10 µg-at/l was noticeable during July '91 at both the stations, the minimum values of 0.10 µg-at/l and 0.28 µg-at/l were recorded during April '90 and June '91 and October '91 respectively. Likewise, stations IV, V and VI had 0.10 µg-at/l as the minimum level (station IV during January '91 and February '92; Station V during April '90 and October '91; station VI during April '90 and January '92). The maximum level recorded was 0.40 µg-at/l (June '91), 0.35 µg-at/l (July '91) and 0.25 µg-at/l (February '91, March '91 and July '91) at the three stations respectively. Among the stations, station III showed the maximum concentration with station VI indicating a lower value.

Seasonally, pre monsoon and post monsoon periods showed the higher and the lower values respectively at the surface and bottom waters of all stations except at Station III where the higher value was obtained during summer period and the lower during monsoon period at both the levels.

Statistical interpretations of ammonia values are shown in Table 15. ANOVA showed that the variations between the seasons and the variations between the stations are highly significant both at surface and bottom waters.

3.2.11 Primary Productivity

Monthly mean values of gross and net productivity recorded from stations I to VI are shown in Table 16 Fig. 26, 27 and 28.

Among the various stations, the surface water gross and net Productivity showed considerable fluctuations, with the lower and the higher ranges observed at stations I and IV respectively. The lower range of gross and net productivity values ranged between 123.58 mgc/m^3/day (September 1991) to 531.75 mgc/m^3/day (November 1990) and 75.05 mgc/m^3/day (September 1991) to 291.58 mgc/m^3/day (February 1991) respectively at station I. At station IV, the higher values ranged between 117.90 mgc/m^3/day (March 1992) to 821.13 mgc/m^3/day (June 1991) and between 70.75 mgc/m^3/day (August 1991) to 630.35 mgc/m^3/day (June 1991) respectively.

Among the other stations, station II indicated a gross productivity range from 150.08 mgc/m^3/day - 632.48 mgc/m^3/d and net productivity range from 83.60 mgc/m^3/day to 364.48 mgc/m^3/day. Gross and net productivity at station III ranged from 171.50 mgC/m^3/day to 647.48 mgC/m^3/day and 85.75 mgc/m^3/day to 283.43 mgc/m^3/day. Station V, the gross productivity values between 167.23 mgc/m^3 day - 598.20 mgc/m^3/day with the net productivity values varying from 87.90 mgc/m^3/day to 484.50 mgc/m^3/day. Station VI indicated the gross productivity with a range of 126.48 mgc/m^3/day and 581.13 mgc/m^3/day and the net productivity between 130.58 mgc/m^3/day and 302.33 mgc/m^3/day.

Generally, during 1990-1991, both gross and net Productivity at all stations were found to be at a lower level during summer season. The values increased during premonsoon months to reach the maximum during monsoon months. During post monsoon months, the productivity values were found to

Table : 16 **Monthly mean values of gross productivity (GP) and net productivity (NP) of surface water at different stations during the period April 1990 to March 1992** **(mgC/m^3/day)**

Station	Para-meter	1990 - '91												1991 - '92											
		Apr '90	May	Jul	Jul	Aug	Sep	Oct	Nov	Dec	Jan '91	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan '92	Feb	Mar
I	GP	221.00	229.40	216.55	291.58	287.35	341.38	460.95	531.75	439.50	437.38	486.70	212.00	220.83	218.68	242.28	192.95	317.33	123.58	343.03	291.58	338.75	315.18	291.58	192.95
	NP	126.48	94.30	120.05	169.08	195.08	192.95	218.68	240.10	220.80	231.53	291.58	100.35	130.78	145.73	135.05	122.23	96.45	75.05	173.65	107.20	252.98	220.80	150.08	98.60
II	GP	195.08	180.05	240.15	220.80	388.08	439.53	630.33	484.53	420.23	385.93	364.48	244.43	632.48	364.48	559.58	365.35	263.73	313.03	315.18	413.78	150.08	366.63	192.98	165.10
	NP	124.33	94.30	143.63	122.20	364.48	220.18	362.33	216.55	225.13	220.83	145.78	145.80	276.58	242.28	315.18	218.68	96.45	192.95	171.50	195.10	83.60	242.28	98.60	150.05
III	GP	218.68	295.88	315.18	244.40	388.50	409.50	647.48	405.20	373.08	535.98	460.95	265.85	460.98	190.83	482.38	340.15	315.15	220.80	338.75	195.08	195.10	362.33	240.15	171.50
	NP	120.05	143.58	169.35	96.45	192.95	167.23	237.98	212.25	160.80	220.80	283.43	203.68	216.55	130.78	218.68	171.48	96.48	96.45	195.08	85.75	156.50	171.50	143.65	96.45
IV	GP	460.95	216.55	261.58	248.73	300.15	364.48	409.48	568.15	340.88	340.90	355.90	536.00	505.98	538.15	821.13	169.35	265.85	390.20	317.30	388.05	216.60	315.15	433.10	117.90
	NP	242.25	141.50	122.60	122.18	132.90	171.50	211.18	276.60	145.75	147.90	171.48	362.35	291.58	315.25	630.35	100.78	70.75	265.85	192.95	216.55	180.10	147.93	265.85	147.90
V	GP	338.75	385.90	265.88	375.18	465.23	338.73	598.20	452.38	508.13	505.98	289.45	176.20	583.18	437.35	591.75	435.23	531.73	336.63	244.43	267.98	242.25	358.05	167.23	218.68
	NP	152.23	220.83	169.35	195.08	291.60	242.28	237.98	261.58	315.18	317.30	143.63	197.25	225.50	150.10	289.45	244.40	484.40	244.40	131.43	145.78	87.90	242.28	143.63	150.08
VI	GP	126.48	287.28	287.30	306.63	295.88	460.95	411.65	581.03	508.13	338.75	415.93	390.20	463.13	293.73	415.93	364.48	550.98	171.48	366.60	435.23	313.03	257.28	198.33	195.10
	NP	169.38	190.80	192.95	173.68	171.50	268.00	145.78	268.00	267.98	169.38	195.08	272.28	195.83	197.23	199.38	147.90	302.33	143.63	169.35	242.28	216.53	188.65	195.08	130.58

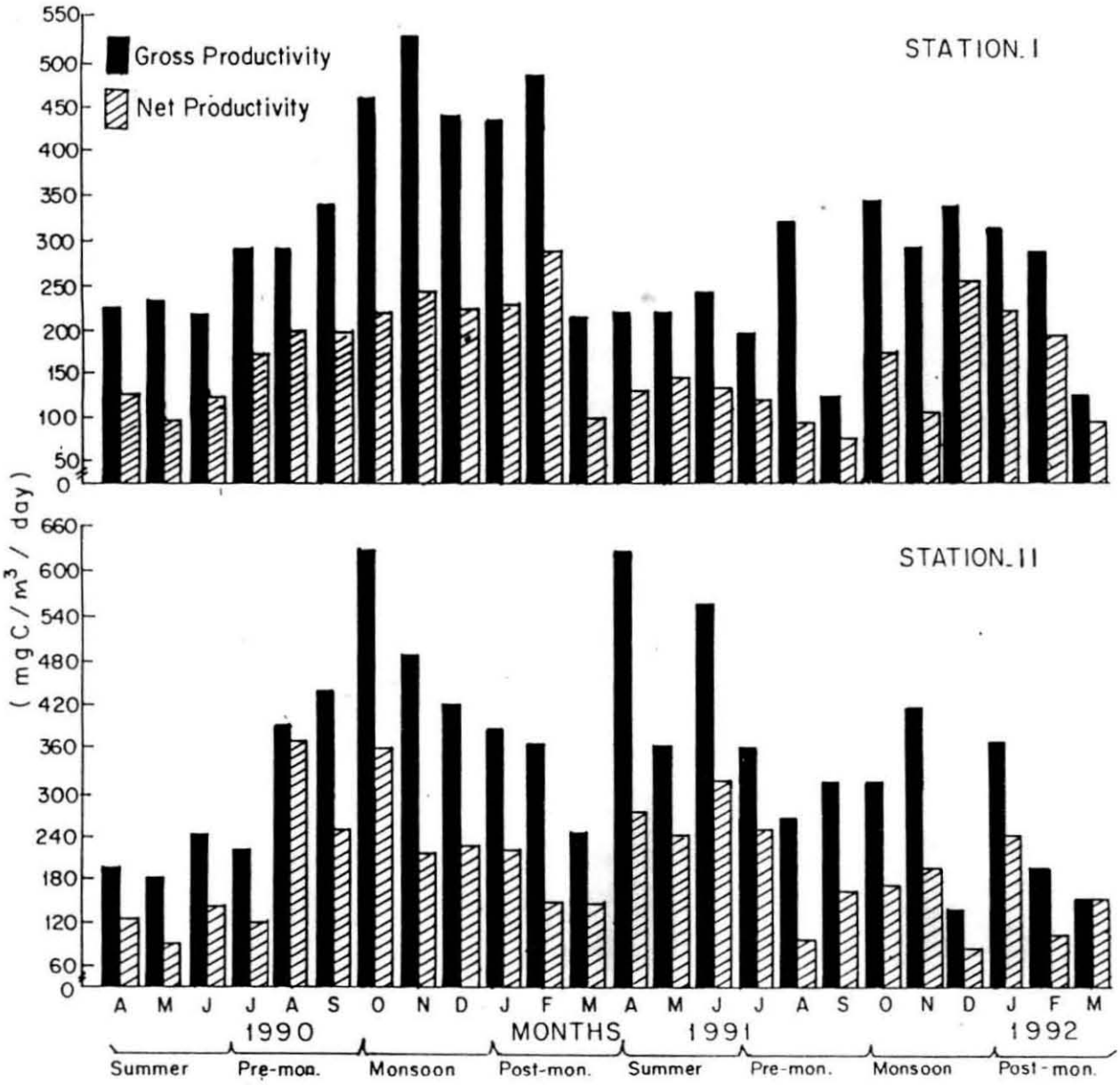

Fig. 26 Monthly variation in the gross and net productivity (mg C/M^3/day) of surface water at stations I and II during April 1990 to March 1992.

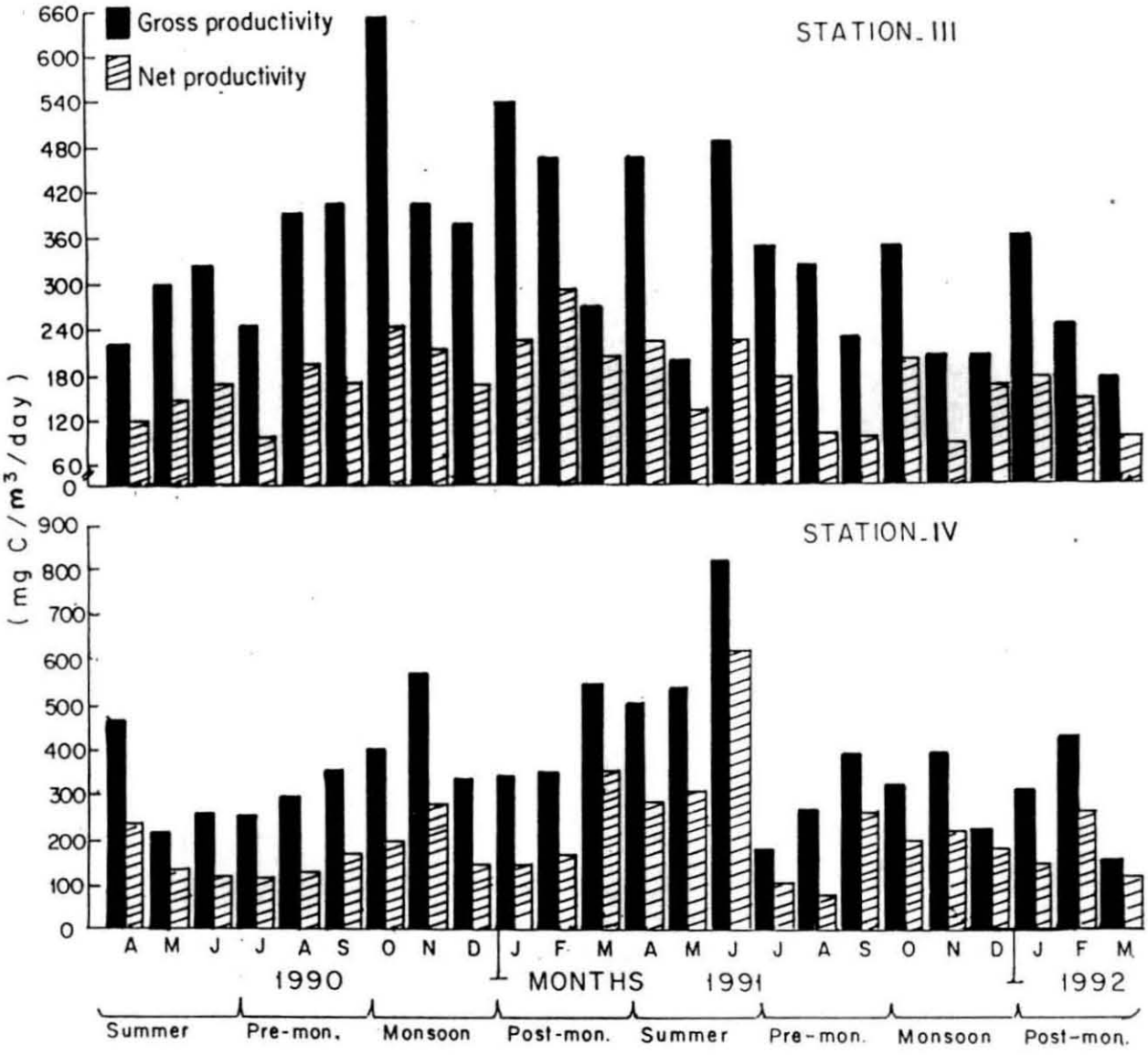

Fig. 27 Monthly variation in the gross and net productivity (mg C/M^3/day) of surface water at stations III and IV during April 1990 to March 1992.

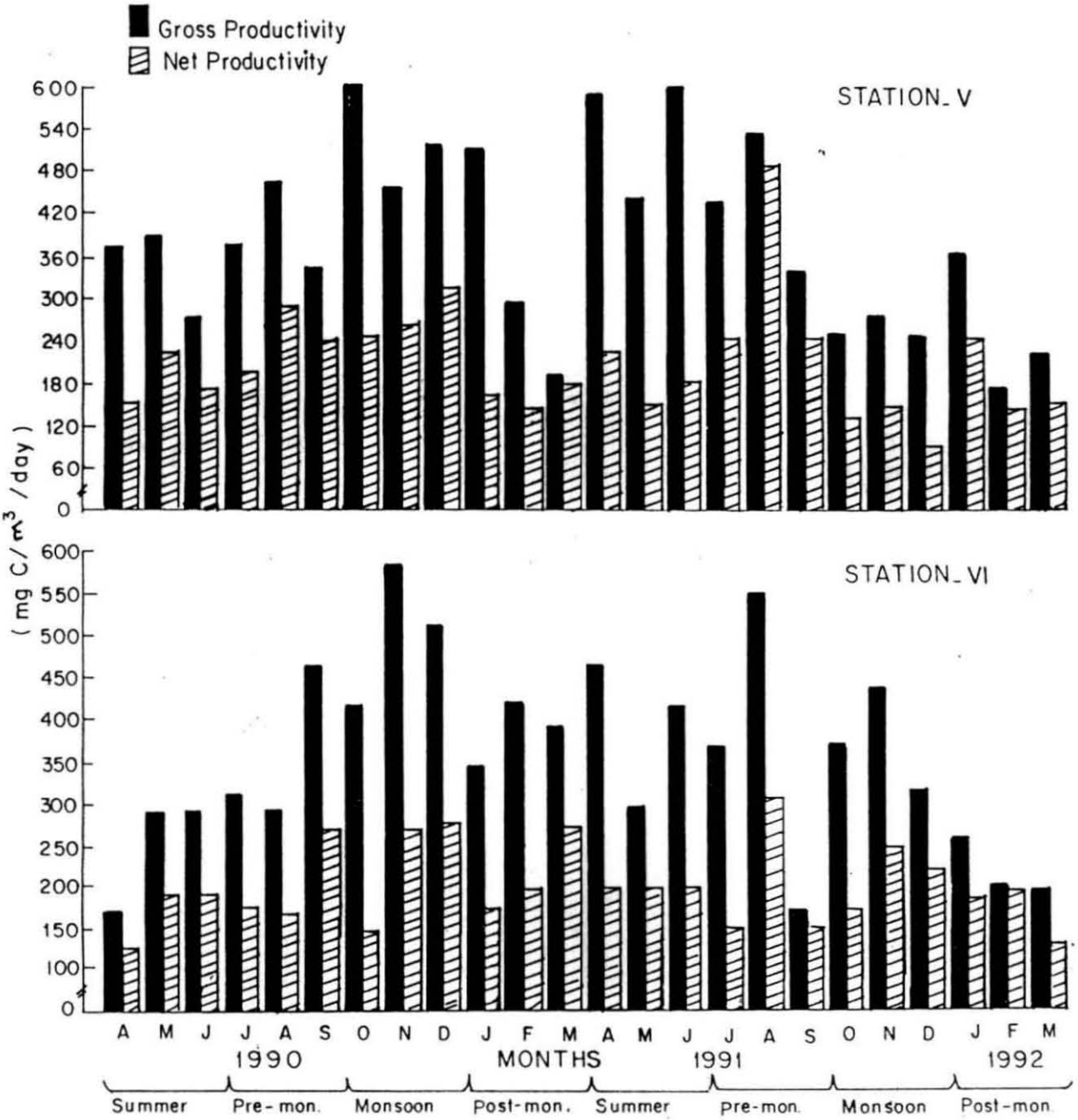

Fig. 28 Monthly variation in the gross and net productivity (mg C/M^3/day) of surface water at stations V and VI during April 1990 to March 1992.

Table:17 Two way analysis of variance (ANOVA) showing the level of significance in variation of water parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(XI) GROSS PRODUCTIVITY Surface Water					
Treat	5	366717.778	73343.556	4.226	H.S
Repli	3	545475.897	181825.299	10.575	H.S
Error	543	9335593.917	17192.622	-	-
(XII) NET PRODUCTIVITY					
Treat	5	264342.418	52868.484	5.727	H.S
Repli	3	17155.806	5718.000	0.619	N.S
Error	543	5012529.655	9231.178	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

decline invariably in all the stations. Exhibiting eventually a different picture during 1991-1992, the Primary Productivity values were high during summer months, the values reaching a low during post monsoon months in all the stations.

ANOVA indicated highly significant both between the stations and between the seasons for gross productivity (Table 17).

3.3 SEDIMENT STUDIES

3.3.1 Particle size distribution

Monthly mean of sand, silt and clay fractions in the sediment of station I is shown in Fig. 29.

It could be noticed from the figure 29 that sediment at station I contains relatively higher percentage of sand particles. The sand content ranged from 80.98% (September 1990) to 92.82% (November 1991) while the silt and clay components ranged from 5.28% (November 1991) to 13.89% (September 1990) and 3.31% (February 1991) to 6.11% (January 1991) respectively.

Fig.32 to 39 depict the seasonal variations of substratum nature at different stations. Station I was noticed to have a sandy substratum during all the seasons with lesser but varied proportion of silt and clay contents.

At station II, sediment particle size analysis was not made since the bottom layer was composed only of bottom ash discharged from the power plant (Plate 2, Fig.2B).

Monthly variations in the distribution of sand, silt and clay at station III are depicted in Fig.29.

Station III had varying percentage of sand, silt and clay contents with a higher proportion of sand particles. The sand percentage varied between 78.15% (April 1991) and 91.77% (November 1990). Silt and clay proportions ranged from 5.04% (November 1990) to 15.74% (June 1990) and 2.97% (June 1990) to 6.95% (October 1990) respectively.

Seasonal variations of sediment particle size at station III are shown in Fig.32 to 39. The nature of substratum observed at station III was sandy invariably during all the seasons. However, sand percentage values noticed were comparatively less than that of station I. Seasonally, higher percentage of sand was noticed during monsoon months at station III with summer months showing lesser percentage during both the years.

Monthly mean values of sand, silt and clay at station IV are depicted in Fig.29.

Sand particles showed a variation from 62.96% (April 1991) to 86.19% (July 1990) while silt and clay indicated a range of 8.49% (July 1990) - 29.16% (April 1991) and 8.49% (February 1992) to 12.11% (June 1991) respectively.

Fig.32 to 39 illustrate the seasonal variations of sediment particle size composition at station IV. Seasonally, station IV had higher percentage of sand especially during premonsoon and monsoon seasons. However, post monsoon (1991) and summer months (1991) showed higher proportion of silt and clay thereby indicating more of a silty sand substratum.

Monthly variations of sediment particles at station V are shown in Fig.30.

Station V had sand particle with the minimum percentage of 51.40 (May 1990) and the maximum percentage of 76.16 (December 1991). Silt indicated a range between 15.23% (December 1991) and 32.61% (August, 1991) with the clay showing a low of 7.40% (February 1991) and a high of 17.71% (September 1990).

Seasonal variations of sediment particles at station V are depicted in Fig.32 to 39. Seasonally station V did not show much variation in the distribution of sand, silt and clay. It could be seen from the above mentioned figures that silty sand substratum was noticed during all the seasons at station V.

Monthly mean of sediment particles at station VI is shown in Fig.30.

Sand particles showed the low of 69.87% (September, 1991) and the high of 86.73% (November 1991) while silt indicated a minimum of 7.21% (October 1990) and a maximum of 19.53% (August 1991). The clay content

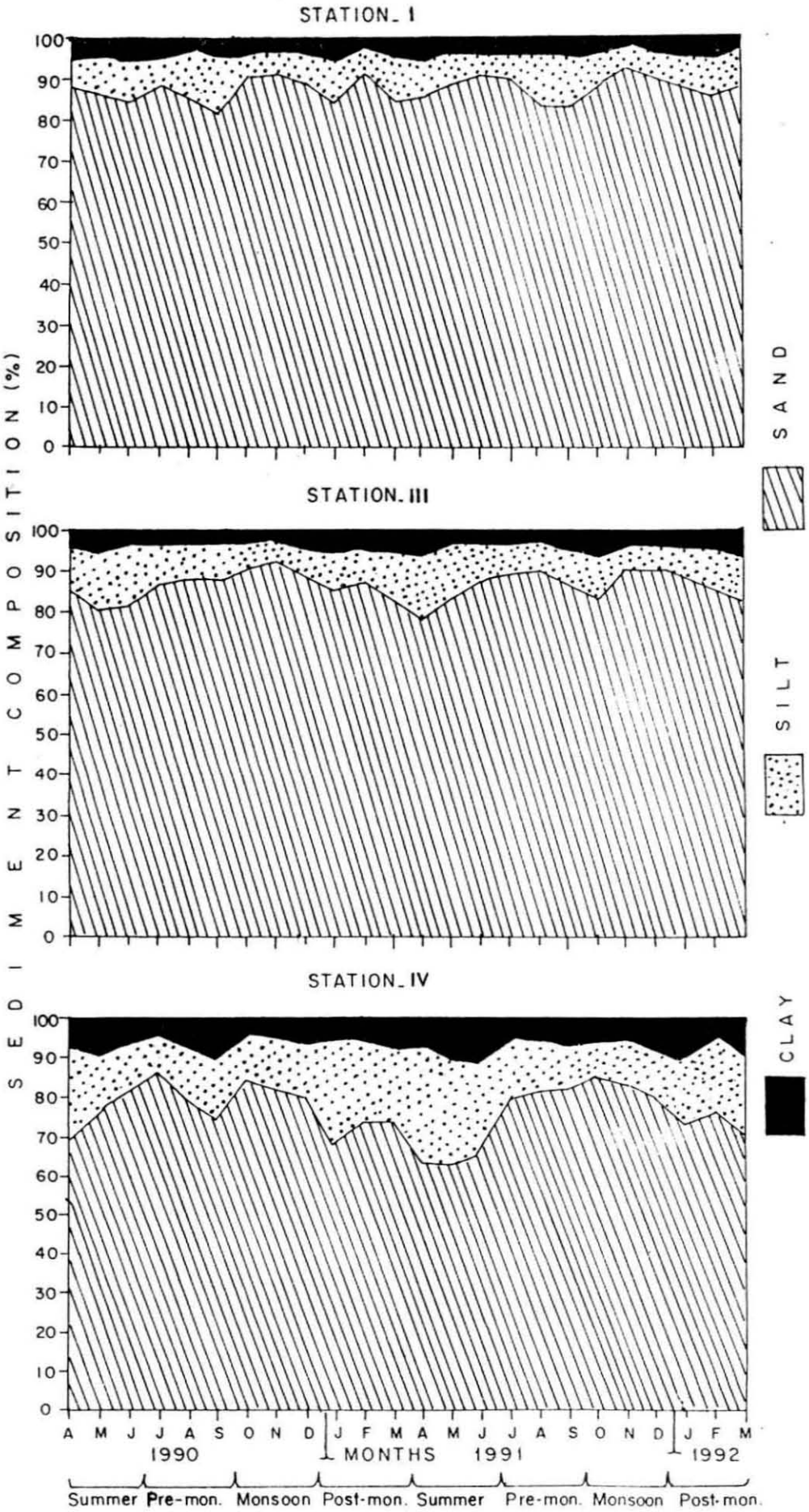

Fig. 29 Monthly variation in the percentage to sand, silt and clay of sediment at stations I, III and IV during April 1990 to March 1992.

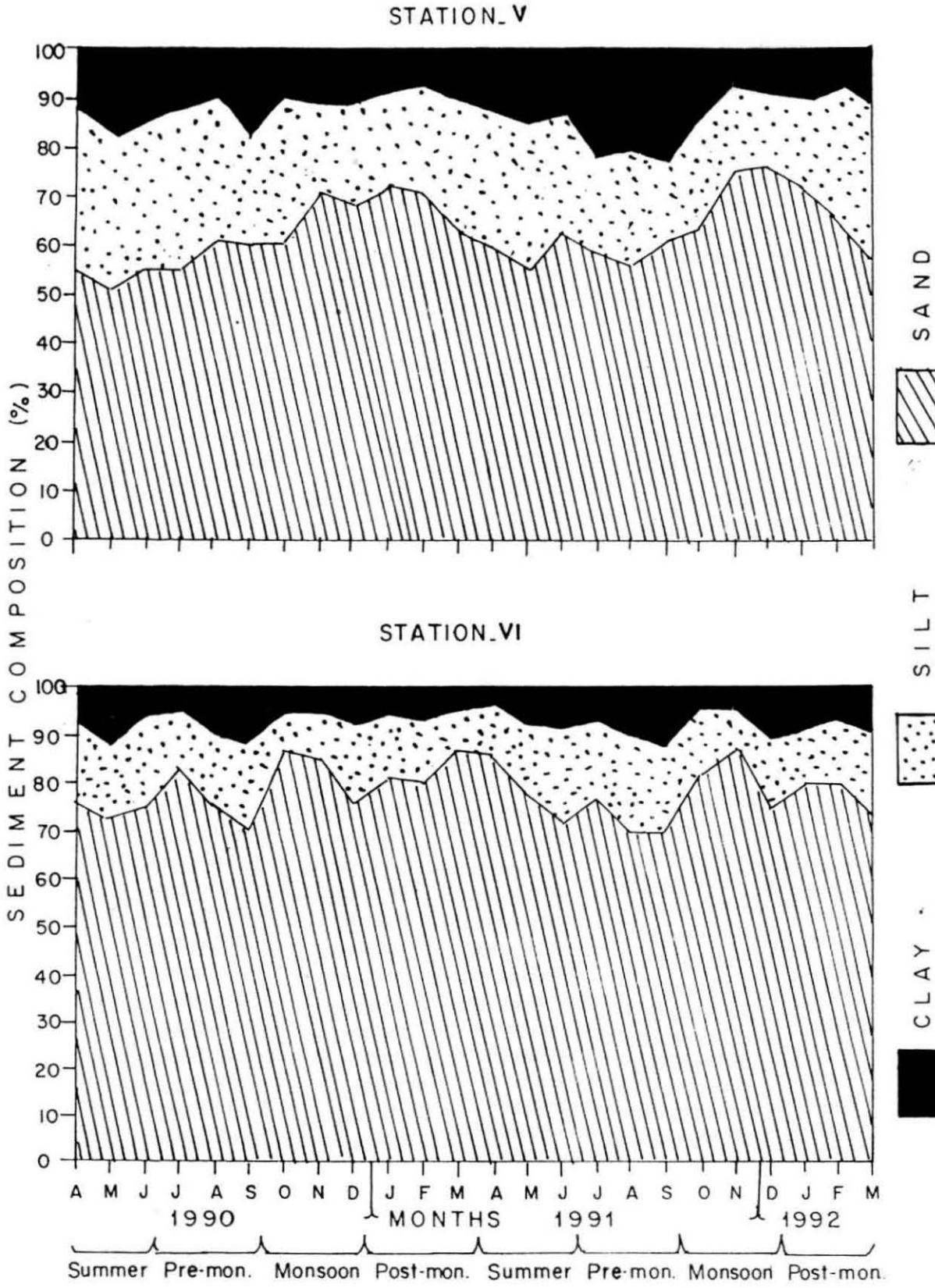

Fig. 30 Monthly variation in the Percentage of sand, Silt and clay of sediment at stations V and VI during April 1990 to March 1992.

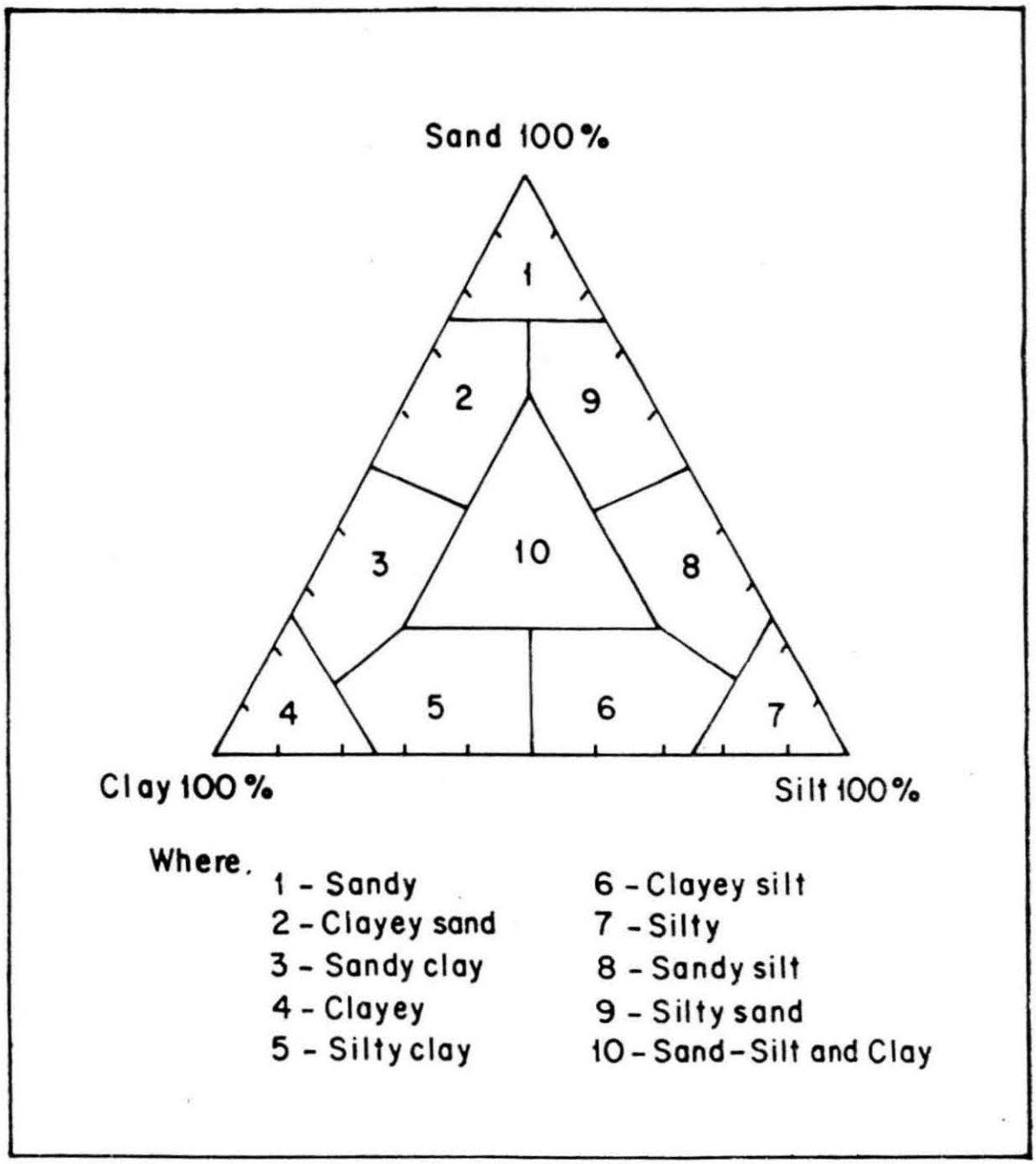

Fig. 31 Standard triangular digram representing the sediment texture

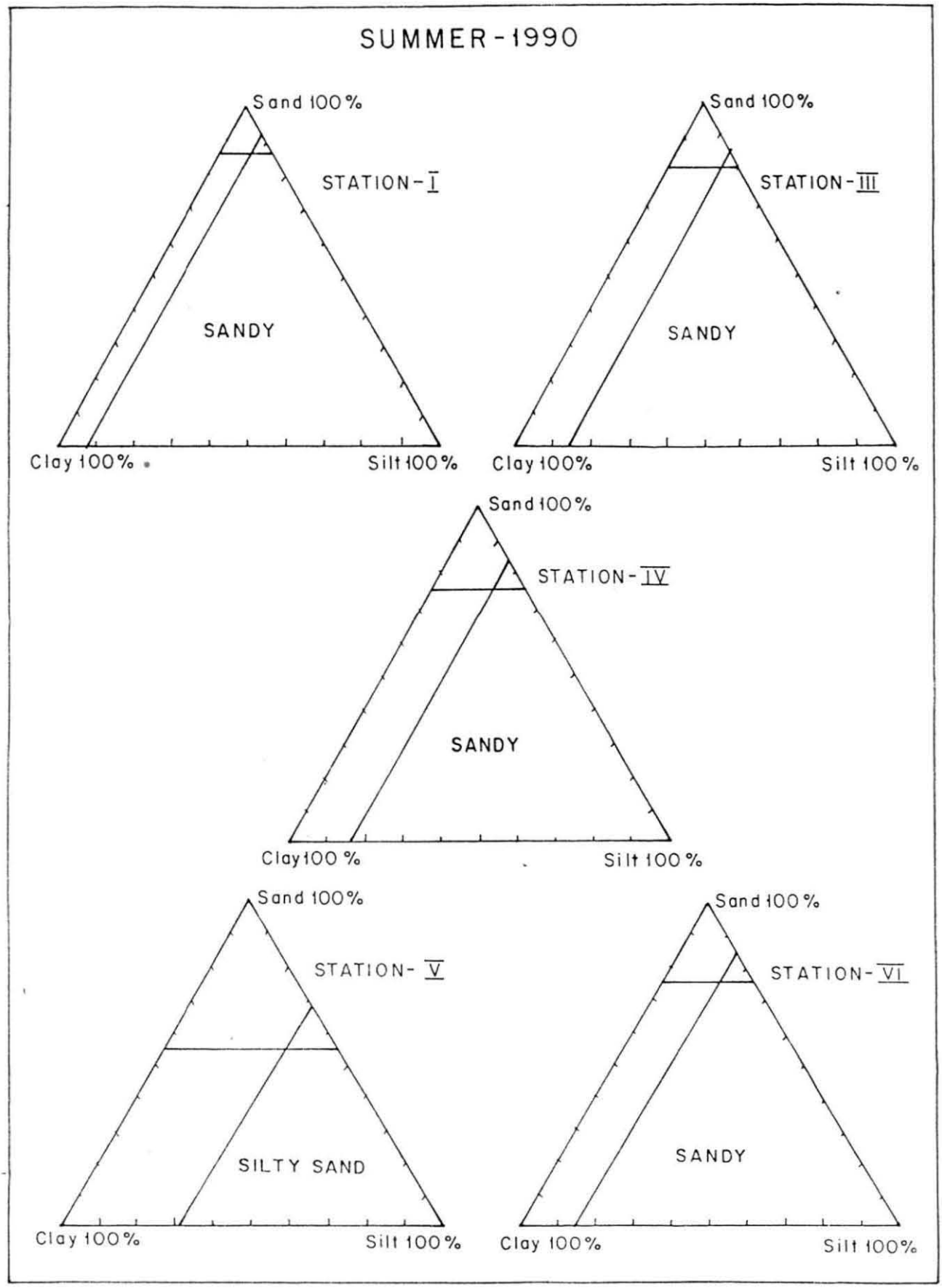

Fig 32 Triangular diagrams representing the sediment texture during summer 1990 at stations I and III to VI.

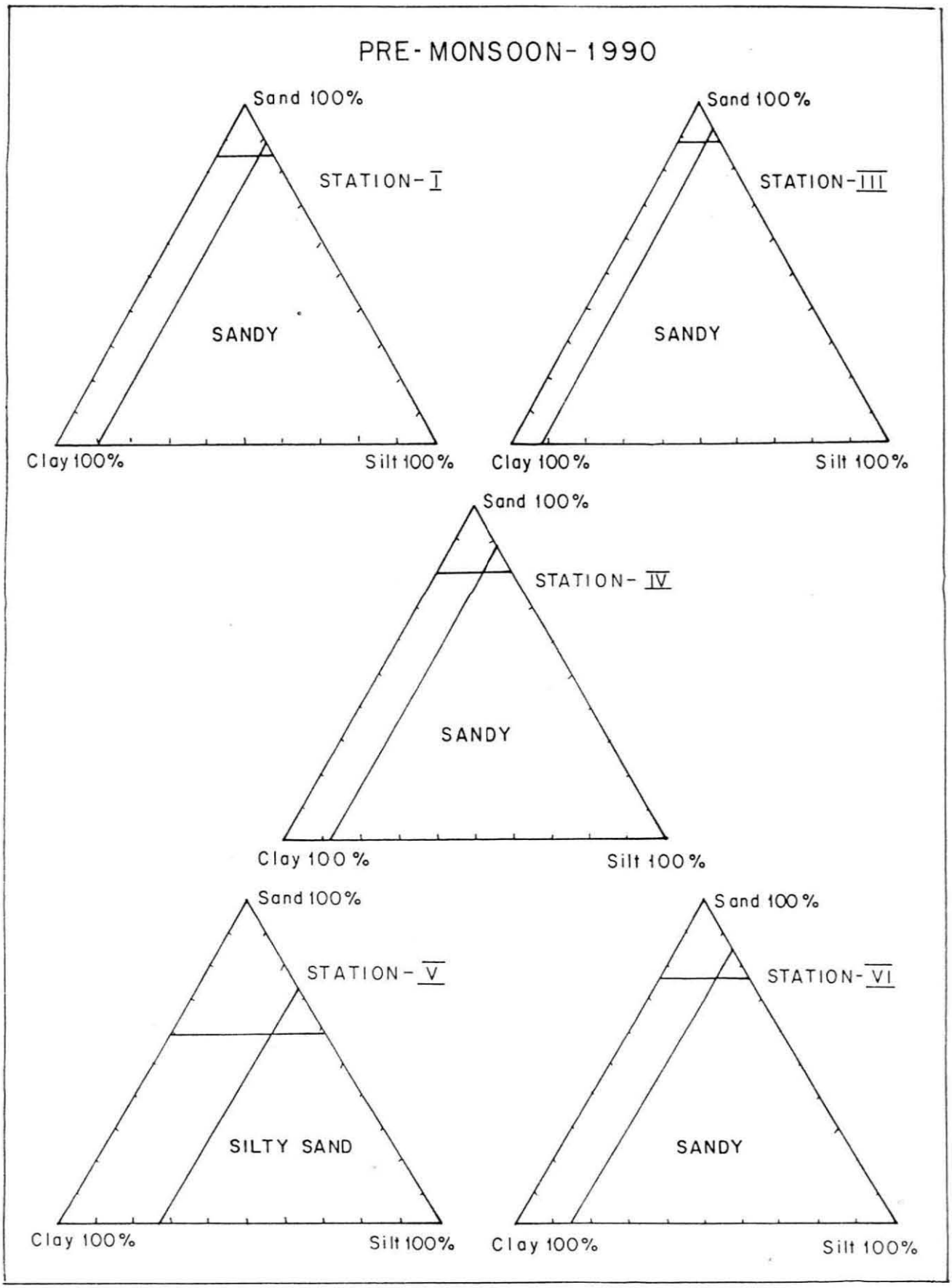

Fig. 33 Triangular diagrams representing the sediment texture during premonsoon, 1990 at stations I and III to VI.

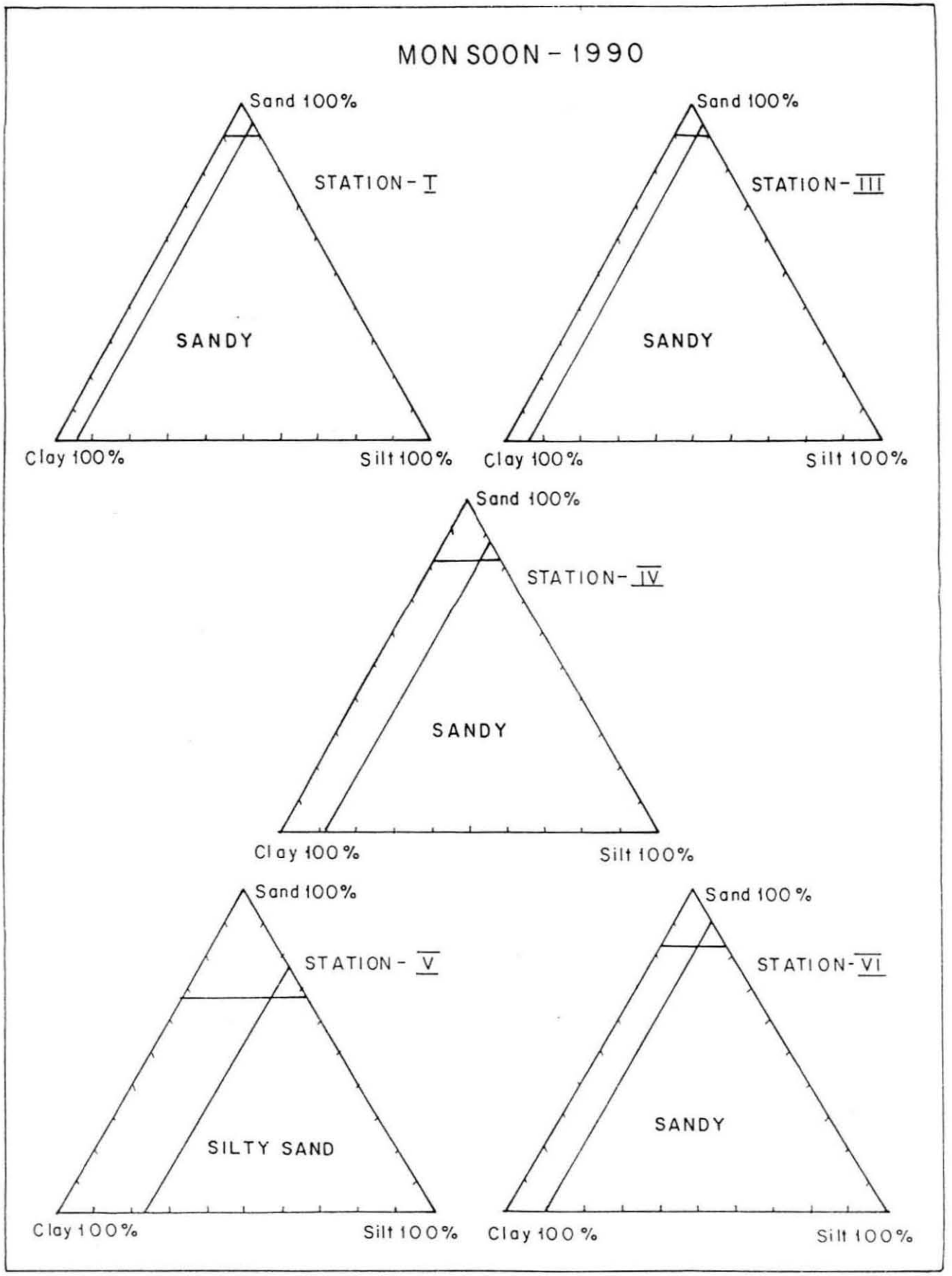

Fig. 34 Triangular diagrams representing the sediment texture during monsoon 1990 at stations I and III to VI.

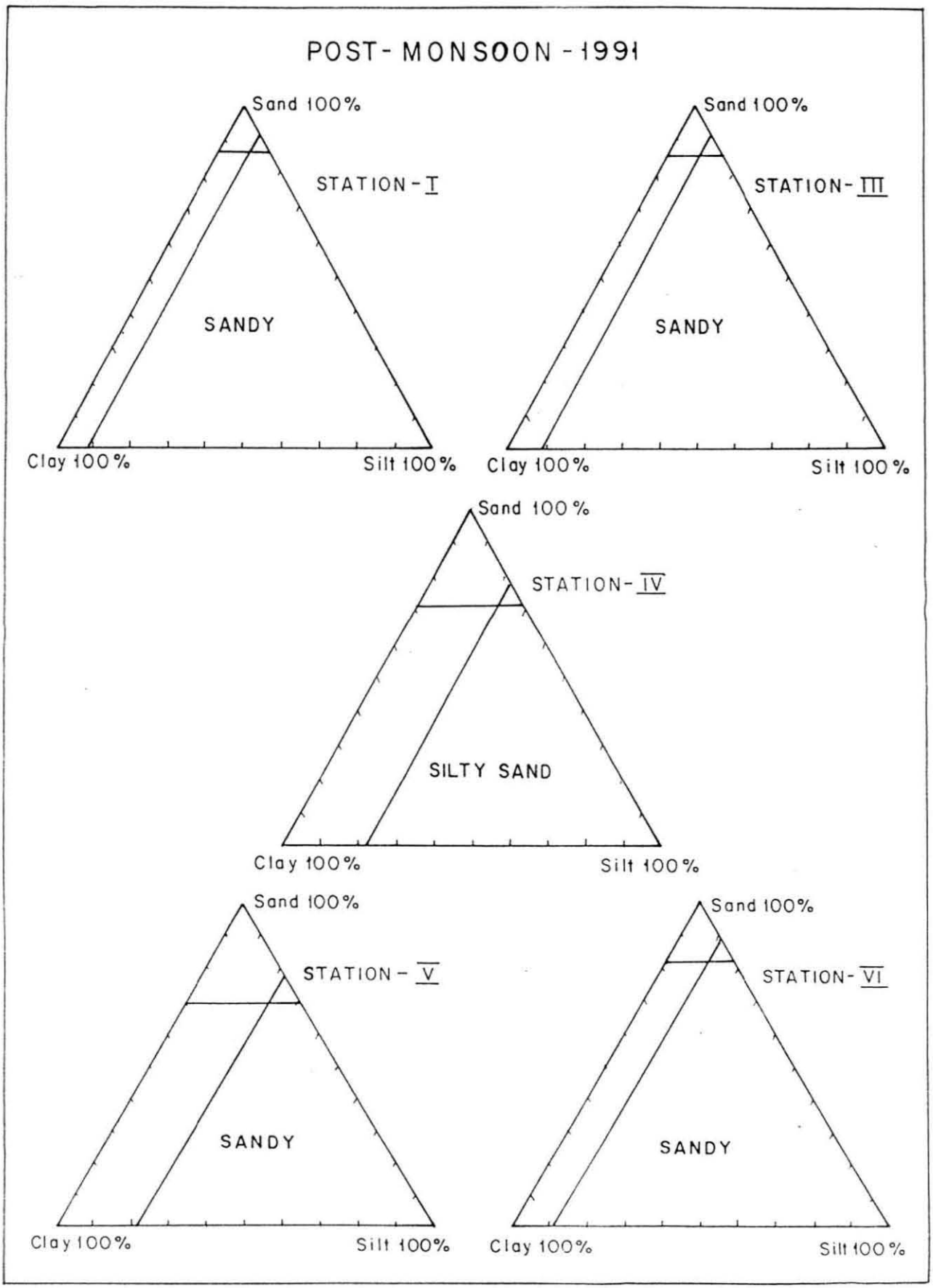

Fig. 35 Triangular diagrams representing the sediment texture during postmonsoon, 1991 at stations I and III to VI.

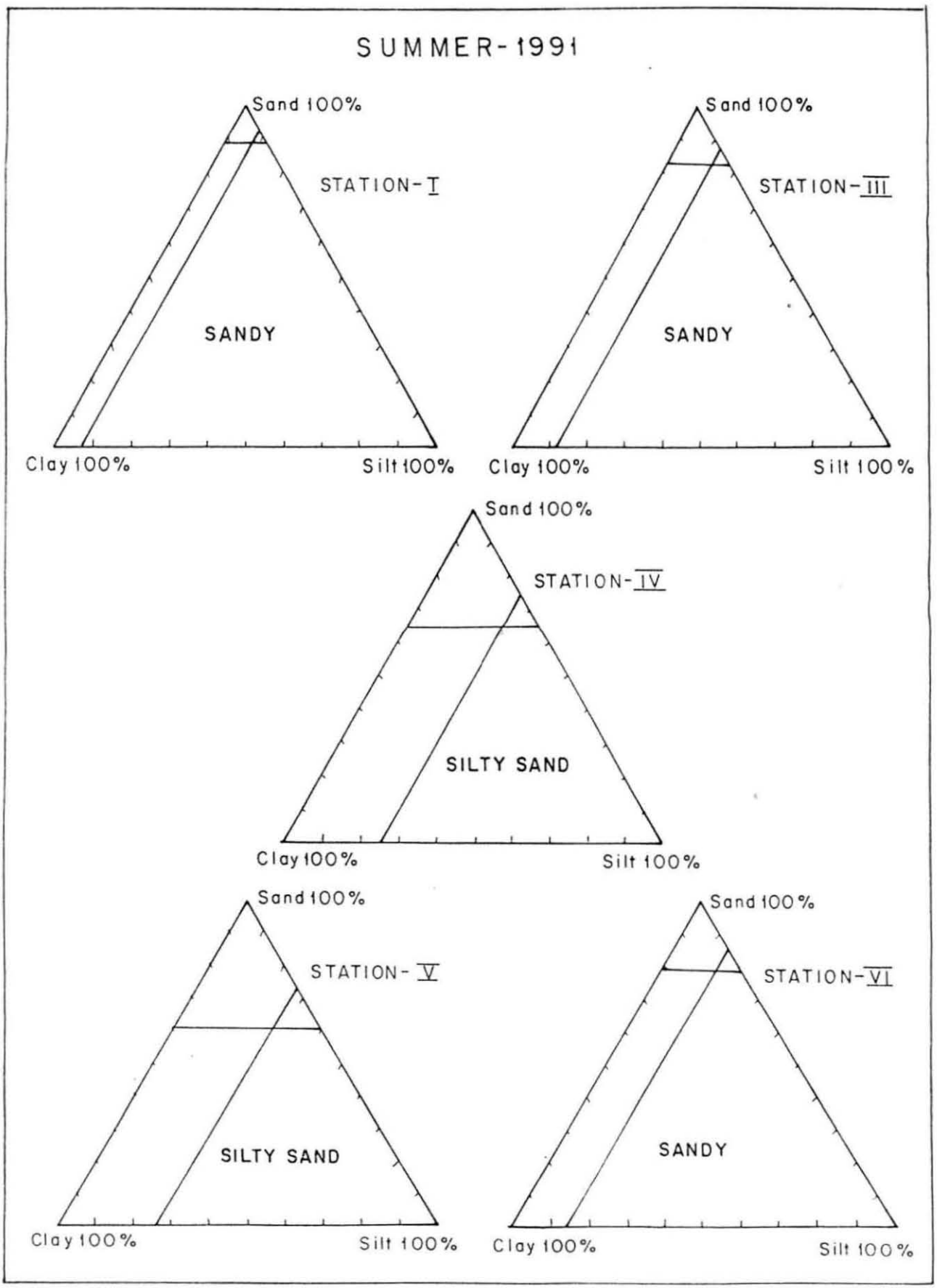

Fig. 36 Triangular diagrams representing the sediment texture during summer 1991 at stations I and III to VI.

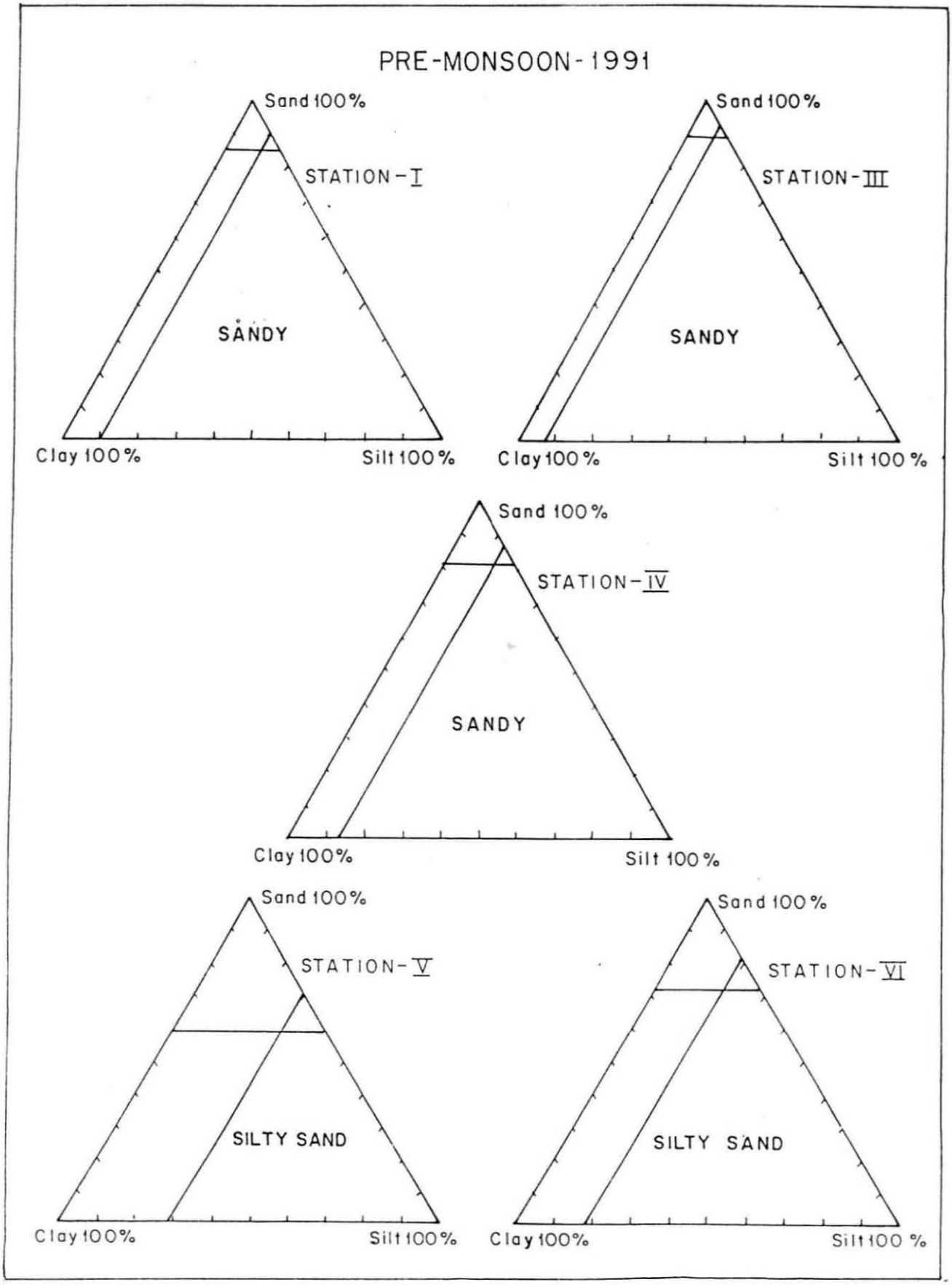

Fig. 37 Triangular diagrams representing the sediment texture during premonsoon 1991 at stations I and III to VI.

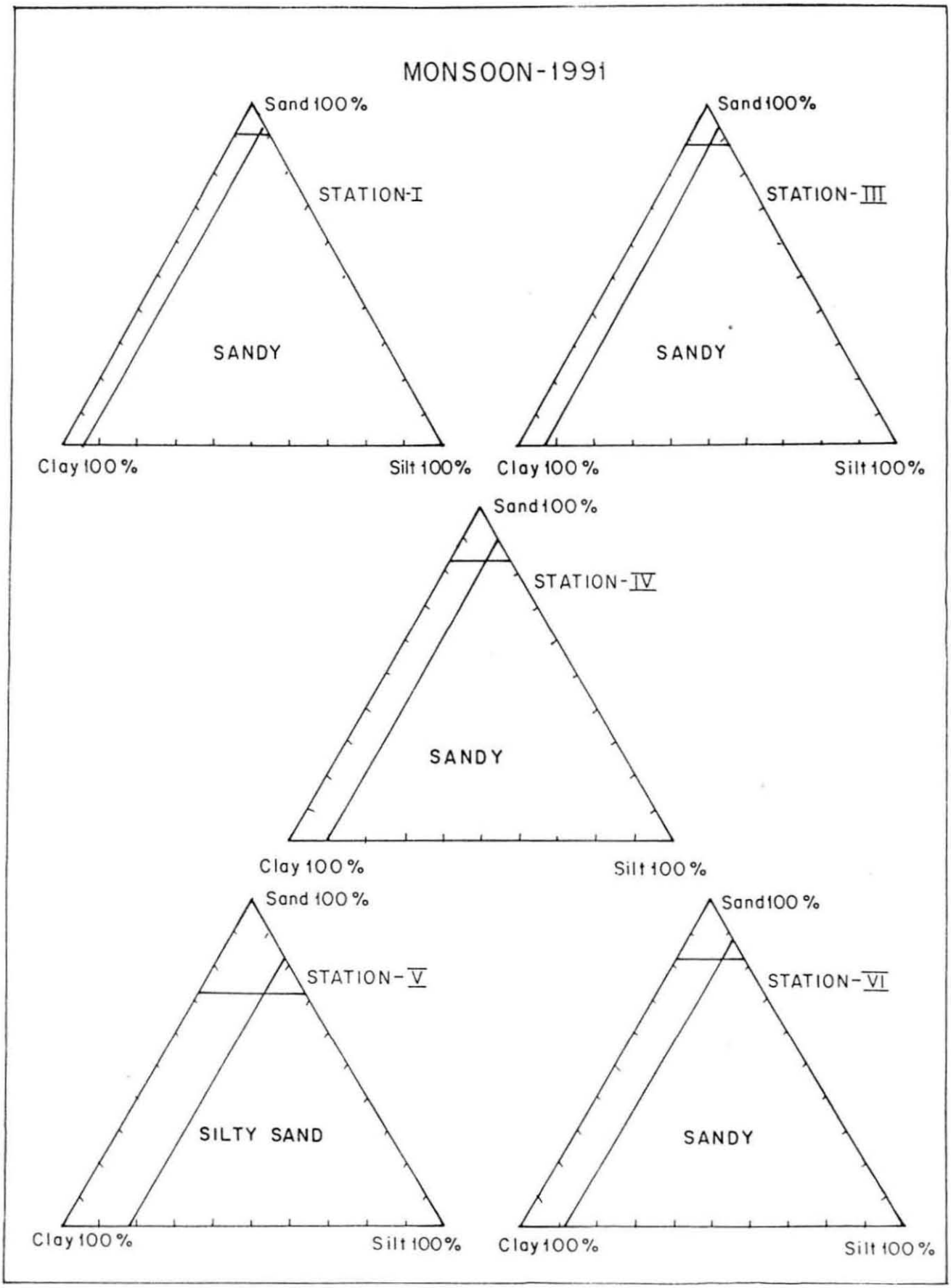

Fig. 38 Triangular diagrams representing the sediment texture during monsoon, 1991 at stations I and III to VI.

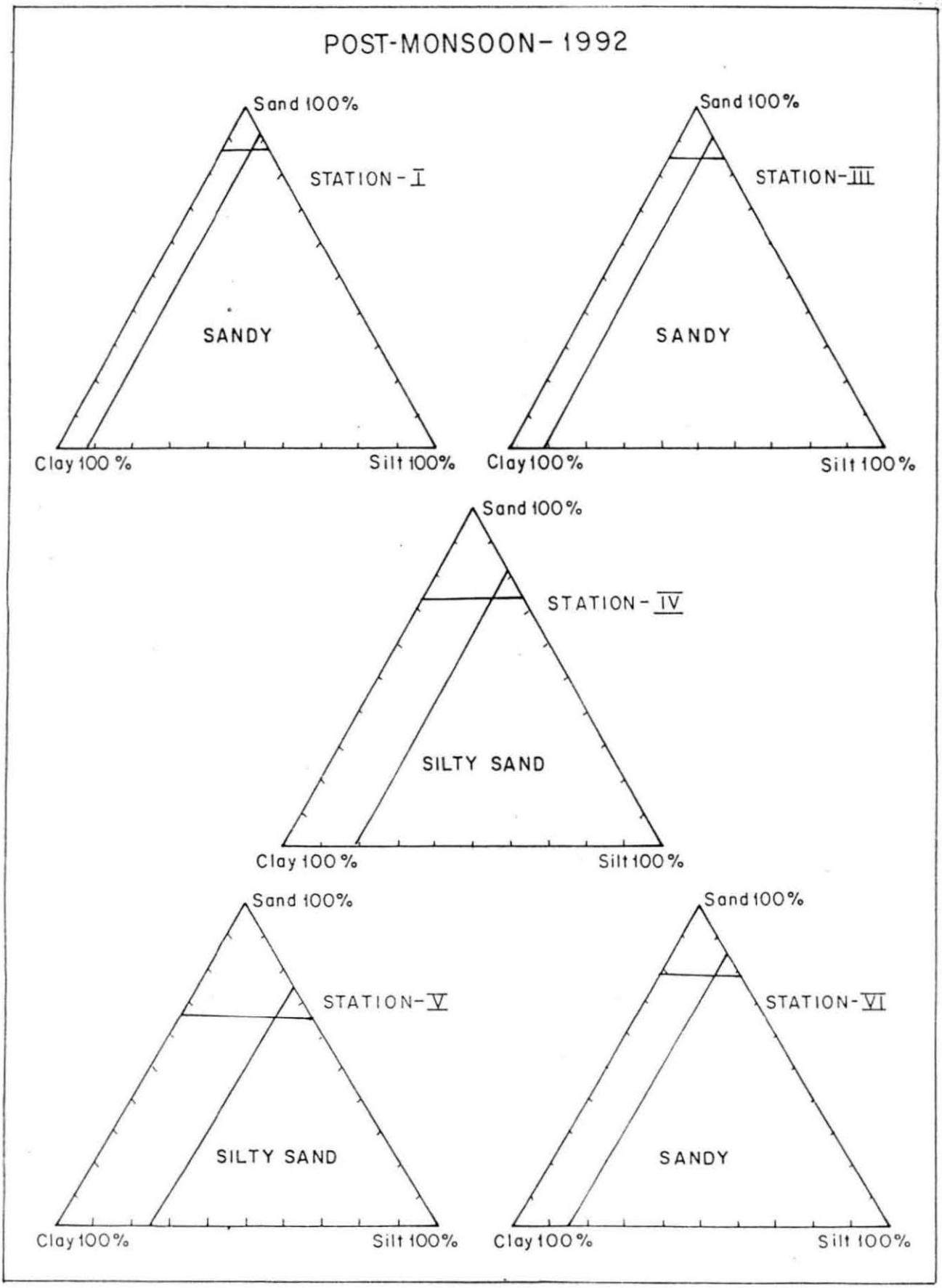

Fig. 39 Triangular diagrams representing the sediment texture during post monsoon, 1991 at stations I and III to VI.

showed a minimum of 4.44% (April 1991) and a maximum of 12.33% (May 1990).

Seasonal variations of sediment particles at Station VI are shown in Fig.32 to 39.Seasonally, station VI also did not show significant fluctuations in the distribution of sand, silt and clay. All the seasons indicated higher percentage of sand particle thus showing the nature of a sandy substratum.

Among all the stations, it could be seen that, stations I, III and VI had higher percentage of sand particles and relatively lower percentage of silt and clay, while stations IV and V had relatively higher percentage of silt and clay and lower percentage of sand.

3.2.2 Total organic carbon

Monthly mean values of Total organic carbon (TOC) in stations I and III to VI are given in Table 20 and Fig.40.

Sediment TOC showed the lowest value of 0.55 mg/g during December 1991 at station I with the highest value of 2.91 mg/g registered during August 1990. At station III, the minimum and maximum values of TOC recorded were 1.35 mg/g and 3.94 mg/g during the months of October 1990 and september 1990 respectively. With minimum fluctuations, stations IV and V showed a similar distribution pattern of sediment TOC as in the previous stations. The minimum values of 1.11 mg/g and 1.09 mg/g were recorded during December 1991 and January 1992 respectively at stations IV and V while the maximum

Table : 20 Monthly mean values of sediment total organic carbon (mg/g) at different stations during April 1990 to March 1992

Months/Year	Stations				
	I	III	IV	V	VI
April '90	2.16	3.69	2.77	2.62	2.39
May	2.63	2.76	2.78	2.28	1.72
June	1.40	1.77	2.36	2.67	1.64
July	1.60	1.89	2.43	2.83	1.61
August	2.91	3.24	4.21	4.35	3.00
September	2.59	3.94	3.85	3.94	2.80
October	1.15	1.35	1.73	1.17	1.29
November	1.17	1.63	1.57	2.12	1.69
December	1.89	2.17	1.64	1.51	1.62
January '91	2.58	1.65	1.45	1.76	1.32
February	1.27	3.21	2.27	2.60	2.50
March	1.38	1.62	1.65	1.77	1.74
April	2.28	2.07	2.38	1.76	2.07
May	2.46	3.00	2.29	2.44	1.87
June	2.78	1.73	2.58	2.93	2.49
July	1.70	2.79	1.29	2.01	1.51
August	2.75	1.86	2.58	1.46	2.20
September	1.37	3.73	2.68	3.22	1.12
October	1.39	1.74	1.96	1.86	2.10
November	0.64	1.82	1.25	1.52	1.08
December	0.55	1.89	1.11	1.33	1.22
January '92	1.44	2.03	1.69	1.09	2.45
February	1.03	2.13	3.08	1.95	1.62
March	1.50	3.61	2.17	2.16	2.50

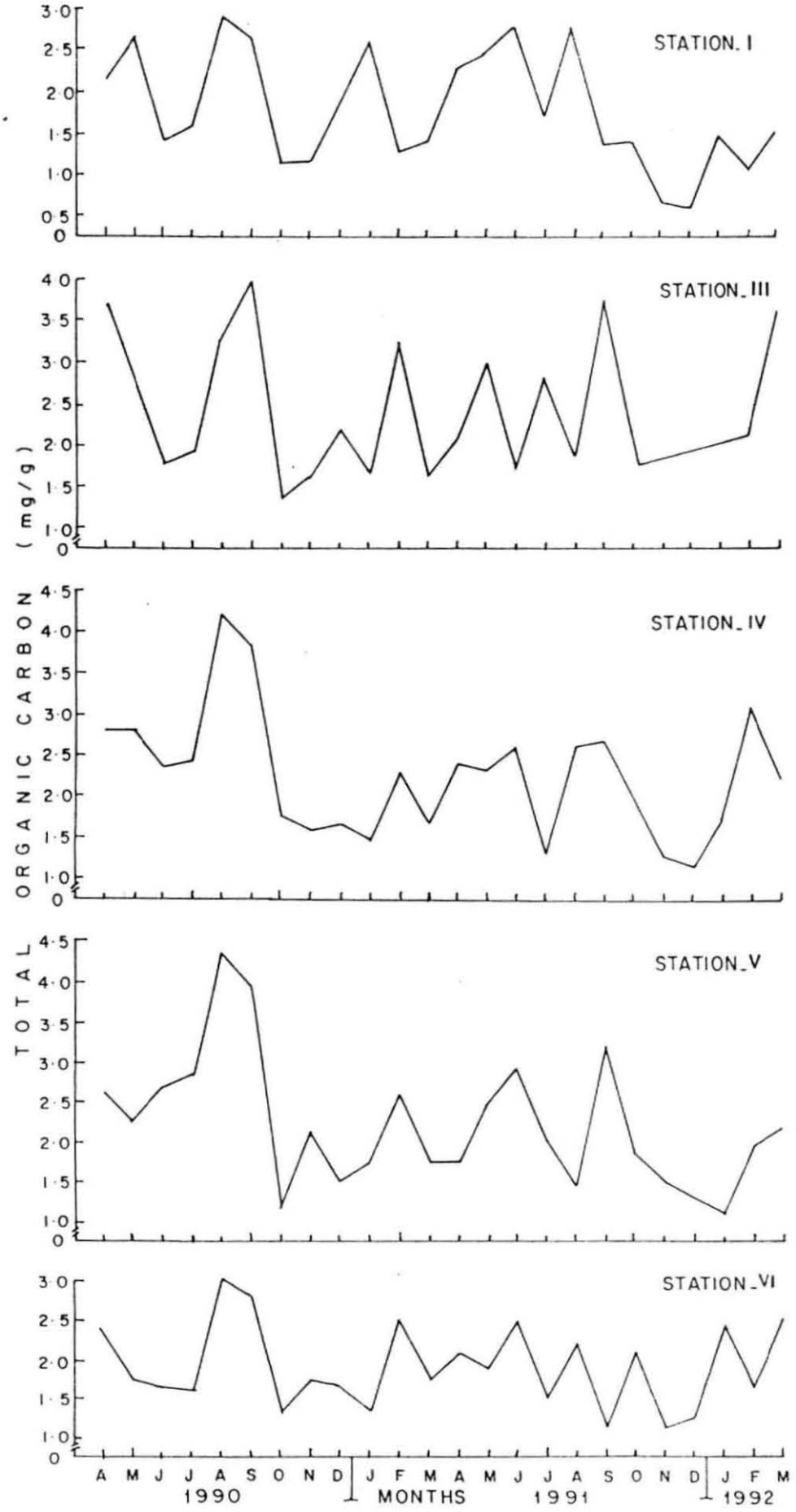

Fig. 40 Monthly variation of sediment total organic carbon (mg/g) at stations I and III to VI during April 1990 to March 1992.

value of 4.21 mg/g and 4.35 mg/g were recorded during August 1990 at both the stations. Station VI had a low TOC of 1.08 mg/g during November 1991 and a high of 3.00 mg/g during August 1990.

Among all the stations, it could be noticed that the sediment TOC concentration registered the lowest range of 0.55 mg/g to 2.91 mg/g at station I and the highest range of 1.09 mg/g to 4.35 mg/g at station V.

Seasonally, it may be seen that the concentrations were at a lower level during monsoon season at all the stations during both the years while premonsoon months registered higher values of TOC at stations III to VI. At station I, summer period showed higher values.

3.2.3 Total Nitrogen

Monthly mean values of Total nitrogen in sediment at stations I and III to VI are shown in Table 21 and Fig.41.

Station I showed a lower value of 0.18 mg/g during February 1991 and a higher value of 0.45 mg/g recorded during May 1990. A variation from a low of 0.21 mg/g. obtained during December 1990 at station III indicated a high of 0.49 mg/g during May 1990, April 1991 and May 1991. At station IV, a minimum of 0.21 mg/g of total nitrogen was recorded during December 1990 with a maximum of 0.53 mg/g noticed during the months of April 1991 and May 1991. Station V showed the lowest and the highest values of 0.25 mg/g and 0.65 mg/g respectively during December 1990 and May 1991. The sediment

Table : 21 Monthly mean values of Sediment Total Nitrogen (mg/g) at different stations during April 1990 to March 1992

Months/Year	Stations				
	I	III	IV	V	VI
April '90	0.42	0.38	0.42	0.42	0.39
May	0.45	0.49	0.49	0.51	0.45
June	0.44	0.38	0.37	0.39	0.37
July	0.26	0.29	0.34	0.38	0.41
August	0.41	0.28	0.31	0.34	0.34
September	0.37	0.35	0.34	0.31	0.32
October	0.38	0.31	0.28	0.32	0.31
November	0.31	0.24	0.24	0.28	0.25
December	0.21	0.21	0.22	0.25	0.24
January '91	0.31	0.34	0.34	0.38	0.34
February	0.18	0.31	0.30	0.28	0.31
March	0.35	0.45	0.49	0.45	0.39
April	0.38	0.49	0.53	0.59	0.42
May	0.43	0.49	0.53	0.65	0.42
June	0.43	0.43	0.43	0.44	0.34
July	0.32	0.39	0.34	0.37	0.31
August	0.34	0.34	0.32	0.34	0.34
September	0.35	0.33	0.32	0.35	0.31
October	0.34	0.31	0.28	0.33	0.27
November	0.31	0.25	0.24	0.32	0.25
December	0.23	0.22	0.21	0.27	0.24
January '92	0.27	0.30	0.31	0.35	0.39
February	0.30	0.31	0.35	0.39	0.37
March	0.34	0.27	0.37	0.34	0.38

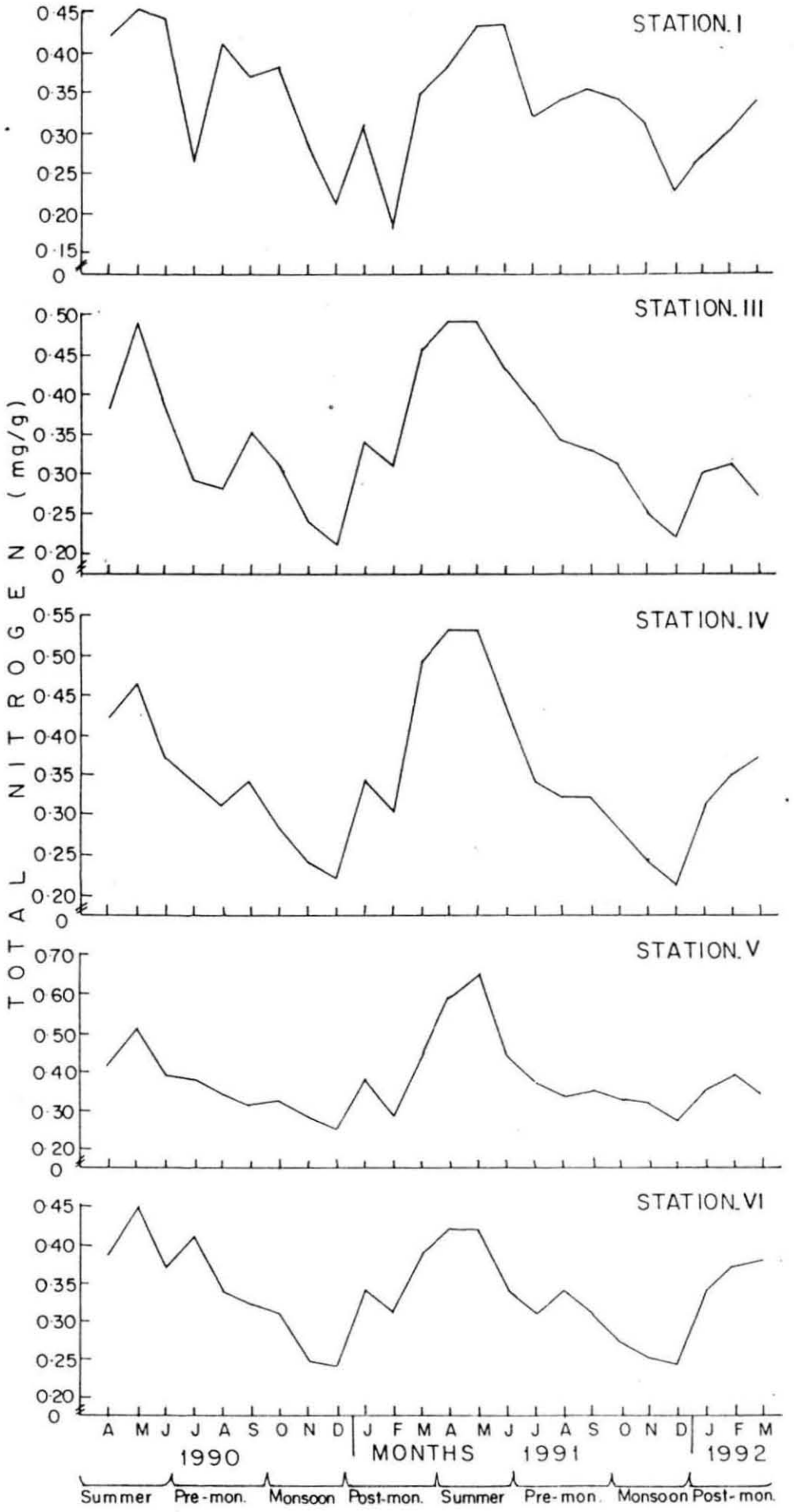

Fig. 41 Monthly variation of sediment total nitrogen (mg/g) at stations I and III to VI during April 1990 to March 1992.

total nitrogen content at station VI recorded a minimum of 0.24 mg/g during December 1990 and 1991 and a maximum of 0.45 mg/g during May 1990.

Among all the stations, the sediment total nitrogen showed the lowest range (0.18 mg/g - 0.45 mg/g) at station I and the highest range (0.25 mg/g - 0.65 mg/g) at station V.

Seasonal variations indicated that the sediment showed higher concentration of nitrogen during summer months during both the years at all stations with the maximum value recorded at station IV. The values however declined during the premonsoon and monsoon months with station III registering lower values. During post monsoon months, nitrogen content showed generally an increase in all stations.

3.2.4 C/N ratio

Monthly mean values of C/N ratio estimated from the stations I and III to VI are shown in Table 24 and Fig.42.

C/N ratio of the sediment at station I indicated a low of 2.06 during November 1991 and a high of 9.00 during December 1990. At station III, the sediment C/N ratio indicated a minimum of 3.60 during March 1991 and a maximum of 13.37 during March 1992. Station IV showed a lower C/N ratio of 3.37 during March 1991 and a higher value of 11.58 during August 1990. With a minimum of 2.90 observed during August 1991, station V indicated a maximum of 12.79 during August 1990. A variation from a low of 3.61 during

Table : 24 Monthly variation in the mean of Sediment C/N ratio at different stations during April 1990 to March 1992

Months/Year	Stations				
	I	III	IV	V	VI
April '90	5.14	9.71	6.59	6.24	6.13
May	5.84	5.63	5.67	4.47	3.74
June	3.18	4.66	6.38	6.85	4.43
July	6.15	6.52	7.14	7.45	3.93
August	7.10	11.57	11.58	12.79	9.12
September	7.00	11.25	11.32	12.70	8.75
October	3.03	4.35	6.18	3.65	4.16
November	3.77	6.79	6.54	7.57	6.76
December	9.00	10.33	7.45	6.29	6.75
January '91	8.32	4.85	4.26	4.63	3.88
February	7.05	10.35	7.56	9.29	8.06
March	3.94	3.6	3.37	3.93	4.46
April	6.00	4.22	4.49	2.98	4.93
May	5.72	5.45	4.32	3.75	4.95
June	6.47	4.02	6.00	6.66	7.32
July	5.31	7.15	5.00	5.43	4.87
August	8.09	5.47	7.59	4.29	6.47
September	3.91	11.30	8.38	9.2	3.61
October	4.09	5.61	7.00	5.64	7.78
November	2.06	7.28	5.21	4.75	4.32
December	2.39	8.59	5.29	4.93	5.08
January '92	5.33	6.77	5.45	3.11	7.20
February	3.43	6.87	8.80	5.00	4.38
March	4.41	13.37	5.86	6.35	6.58

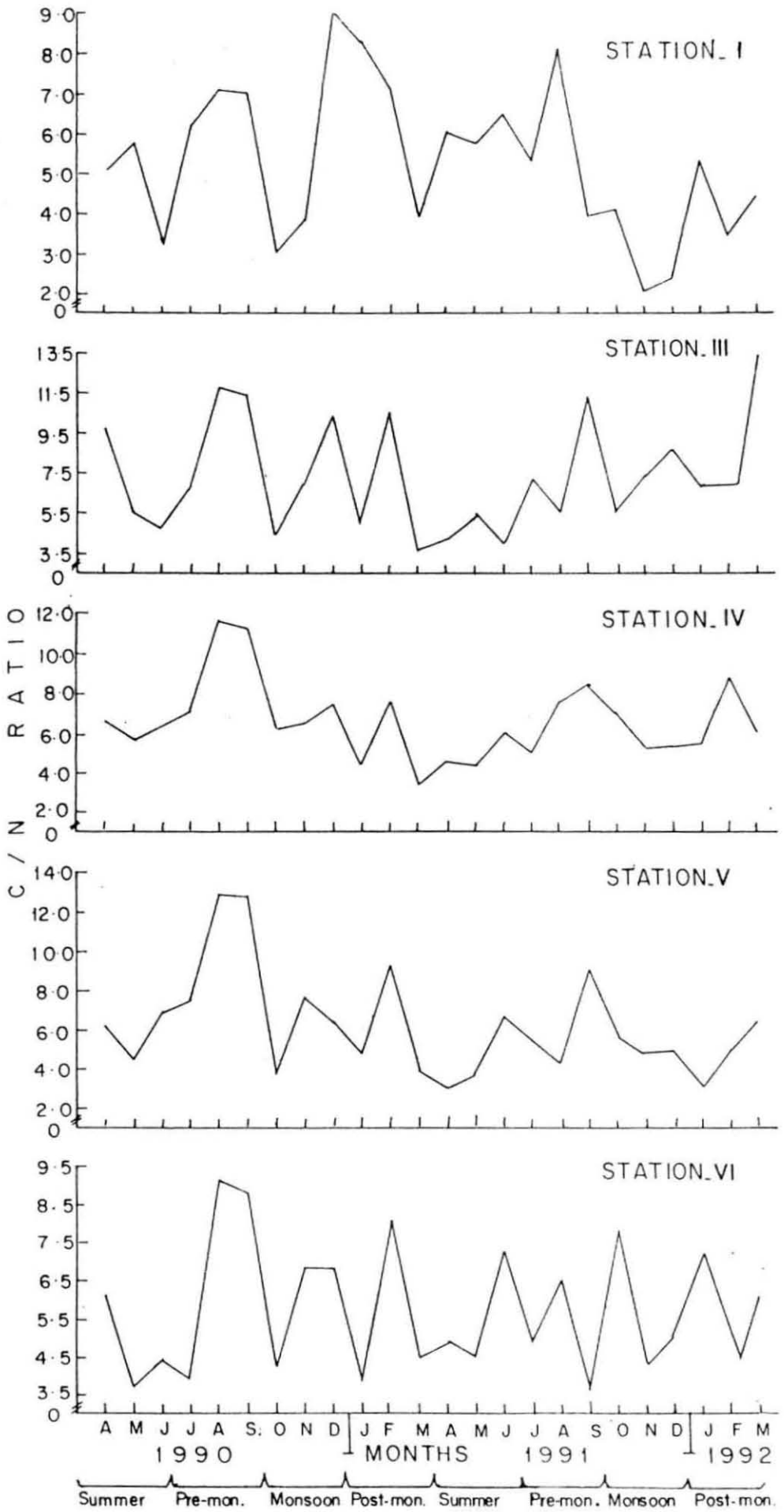

Fig. 42 Monthly variation of sediment C/N ratio at stations I and III to VI during April 1990 to March 1992.

September 1991 to a high of 9.12 during August 1990 was observed at station VI.

Among the various stations, the sediment C/N ratio was found to have a lower range of 2.06 to 9.00 at station I and a higher range of 3.60 to 13.37 at station III.

Seasonal mean values of sediment C/N ratio indicated that premonsoon months showed higher C/N ratio in most of the stations during both the years with lower values recorded during summer months.

3.3.5 Total phosphorus

Monthly variations of sediment total phosphorus at stations I and III to VI are presented in Table 22 and Fig.43.

At station, I the sediment total phosphorus showed a minimum of 0.057 mg/g during, February 1991 and a maximum of 0.112 mg/g during May 1991. A variation from a low of 0.069 mg/g during July 1990, to a high of 0.127 mg/g during May 1991 was noticed at station III. Exhibiting an almost a similar distribution pattern, stations IV, and V recorded the minimum values of 0.078 mg/g and 0.071 mg/g during December 1990 and November 1990 respectively. The maximum values of 1.62 mg/g and 1.81 mg/g at the two stations respectively were noticed during May 1991. Station VI had a low of 0.075 mg/g during December 1990 and a high of 0.123 mg/g during May 1990.

Table : 22 Monthly mean values of sediment total phosphorus (mg/g) at different stations during April 1990 to March 1992

Months/Year	Stations				
	I	III	IV	V	VI
April '90	0.090	0.099	0.104	0.101	0.108
May	0.106	0.116	0.122	0.135	0.123
June	0.094	0.097	0.093	0.097	0.093
July	0.088	0.069	0.103	0.097	0.093
August	0.083	0.078	0.092	0.086	0.088
September	0.076	0.098	0.103	0.079	0.085
October	0.091	0.088	0.086	0.087	0.089
November	0.083	0.097	0.085	0.071	0.082
December	0.064	0.075	0.078	0.075	0.075
January '91	0.086	0.096	0.116	0.111	0.093
February	0.057	0.084	0.090	0.084	0.078
March	0.102	0.109	0.132	0.127	0.100
April	0.103	0.118	0.135	0.147	0.113
May	0.112	0.127	0.162	0.181	0.112
June	0.093	0.102	0.123	0.126	0.092
July	0.089	0.092	0.109	0.105	0.100
August	0.080	0.084	0.101	0.092	0.095
September	0.091	0.097	0.111	0.107	0.093
October	0.060	0.092	0.093	0.093	0.086
November	0.087	0.086	0.094	0.102	0.082
December	0.059	0.080	0.084	0.076	0.094
January '92	0.082	0.077	0.096	0.103	0.107
February	0.092	0.100	0.110	0.111	0.096
March	0.085	0.089	0.099	0.085	0.079

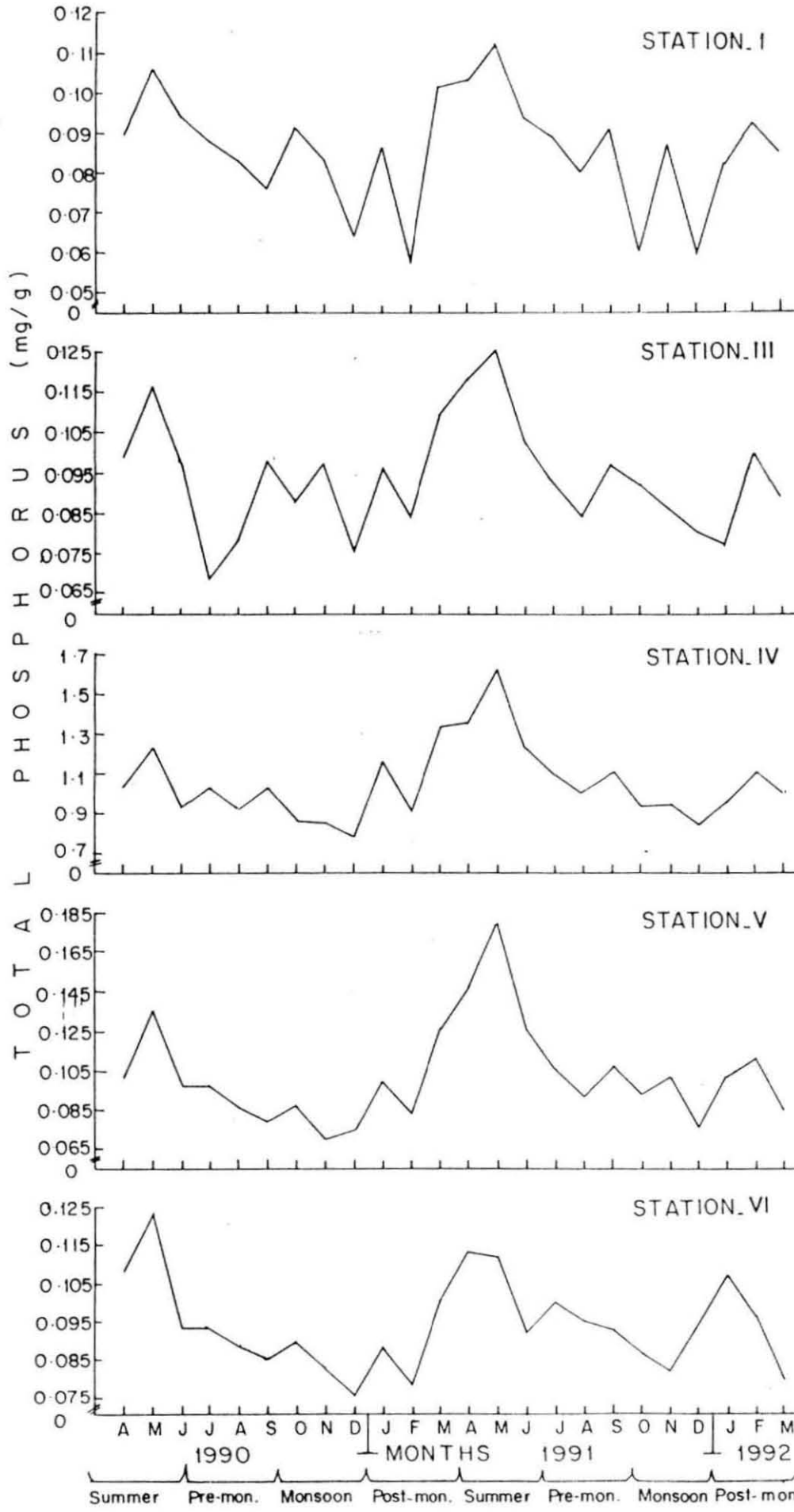

Fig. 43 Monthly variation of sediment total phosphorus (mg/g) at stations I and III to VI during April 1990 to March 1992.

A comparative evaluation of total phosphorus in the sediment among the stations indicated that station I had a lower range of 0.057 mg/g to 0.112 mg/g with the higher range of 0.071 mg/g to 0.181 mg/g recorded at station V.

Seasonally, it could be seen that the total phosphorus values showed considerable variation among the seasons with the higher values noticed during summer months and with lower values registered during monsoon months during both the years.

3.3.6 N/P ratio

Monthly mean values of N/P ratio recorded at stations I and III to VI are shown in Table 25 and Fig.44.

Monthly mean of sediment N/P ratio at station I indicated a low of 2.95 during July 1990 and a high of 5.66 during October 1991. Station III showed a minimum of 2.47 during November 1990 and a maximum of 4.33 during May 1991. The sediment N/P ratio registered a lower value of 2.50 during December 1991 and a higher value of 4.04 during April 1990 at station IV. With a minimum value of 3.14 observed during November 1991 at station V, the ratio indicated a maximum of 4.16 during April 1990. At station IV, the lowest and the highest values of 2.55 and 4.81 respectively were observed during December 1991 and March 1992.

Table : 25 Monthly mean of sediment N/P ratio at different stations during April 1990 to March 1992.

Months/Year	Stations				
	I	III	IV	V	VI
April '90	4.67	3.84	4.04	4.16	3.61
May	4.25	4.22	4.02	3.78	3.74
June	4.68	3.92	3.98	4.02	3.98
July	2.95	4.20	3.30	3.92	4.41
August	4.94	3.69	3.97	3.95	3.86
September	4.87	3.57	3.30	3.92	3.76
October	4.18	3.52	3.25	3.68	3.48
November	3.73	2.47	2.82	3.94	3.05
December	3.28	2.80	2.82	3.2	3.20
January '91	3.60	3.54	2.93	3.42	3.66
February	3.16	3.69	3.33	3.33	3.97
March	3.43	4.13	3.71	3.54	3.90
April	3.69	4.15	3.93	4.01	3.72
May	3.84	4.33	3.27	3.59	3.75
June	4.62	4.21	3.50	3.49	3.70
July	3.60	4.24	3.12	3.52	3.1
August	4.25	4.05	3.17	3.70	3.58
September	3.85	3.40	2.88	3.27	3.33
October	5.66	3.37	3.01	3.55	3.14
November	3.56	2.90	2.55	3.14	3.05
December	3.89	2.75	2.50	3.55	2.55
January '92	3.29	3.90	3.23	3.40	3.18
February	3.26	3.10	3.18	3.51	3.85
March	4.00	3.03	3.74	4.00	4.81

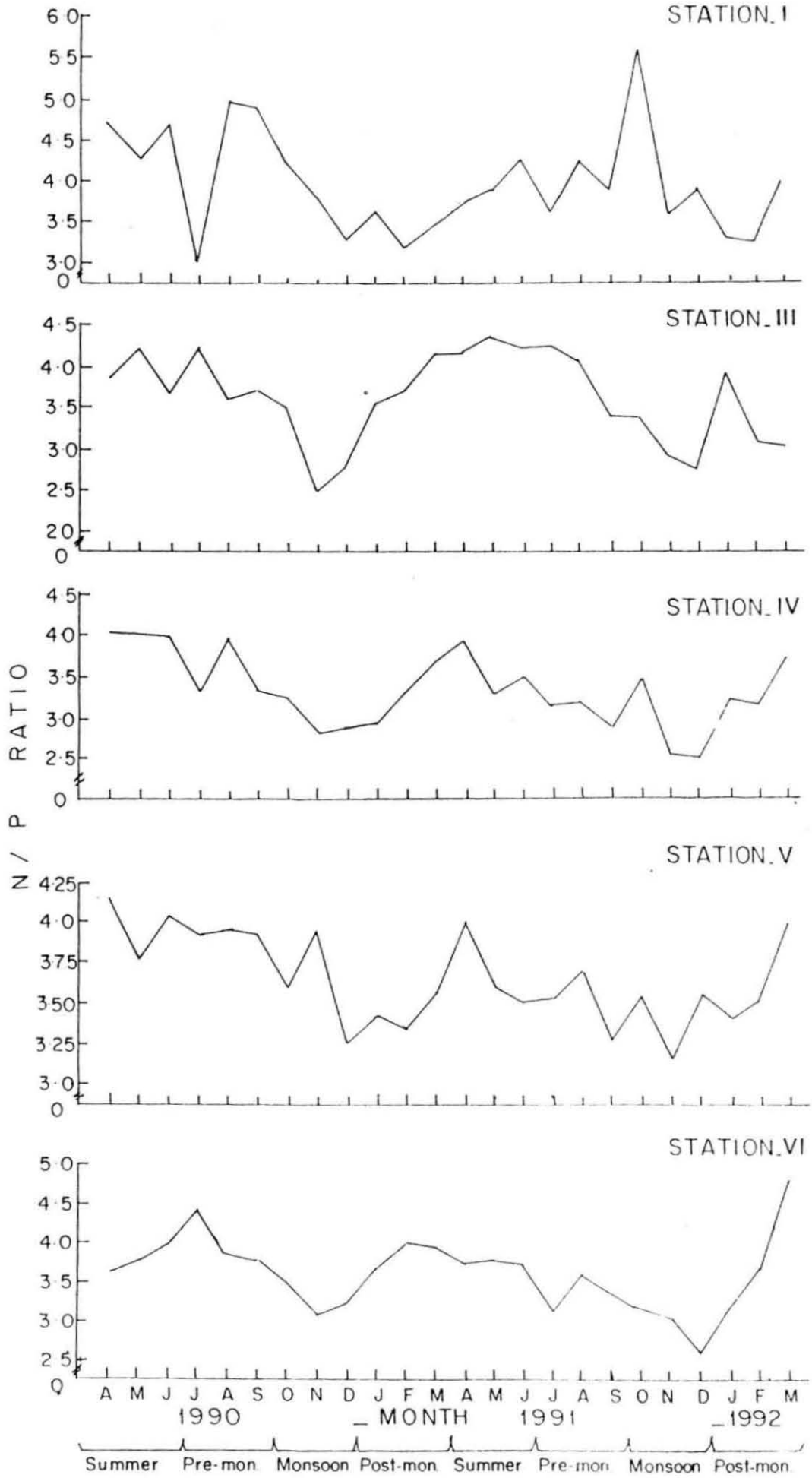

Fig. 44 Monthly variation of N/P ratio at stations I and III to VI during April 1990 to March 1992.

Table: 23 Two way analysis of variance (ANOVA) showing the level of significance in variation of sediment parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(v) Total Organic Carbon					
Treat	4	103.324	25.831	1.810	H.S
Repli	3	22.337	7.446	0.522	S
Error	452	6448.142	14.266	-	-
(vi) Total Phosphorus					
Treat	4	0.026	0.007	18.189	H.S
Repli	3	0.062	0.021	88.779	H.S
Error	452	0.106	0.000	-	-
(vii) Total Nitrogen					
Treat	4	0.101	0.025	5.317	H.S
Repli	3	1.879	0.626	131.8141	H.S
Error	452	2.147	0.005	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

A comparison of the N/P ratio values among the stations indicated that station IV and I had the lowest (2.50 - 4.04) and the highest (2.95 - 5.66) ranges respectively.

Among the seasons, it could be noticed that summer period showed higher N/P ratio during both the years. The values declined during the other seasons registering lower values during the monsoon season in almost at all the stations.

Statistical interpretation (ANOVA) of TOC, total nitrogen and total phosphorus values showed highly significant both between the stations and between the seasons (Table 23).

3.3.7 Sediment Temperature

Monthly mean values of sediment temperature recorded at stations I and III to VI are shown in Table 18.

Stations I and III had the maximum range of sediment temperature when compared to other stations. Station I showed the highest range with a low of 32.8°C during August 1991 and a high of 40.0°C during April 1991, while station III showed the minimum and maximum values of 27.0°C and 32.8°C respectively during August 1991 and March 1991. Likewise, stations IV and V indicated a similar range of sediment temperature with a minimum and maximum of 26.3°C and 31.5°C respectively recorded during July 1991 and

Table 18 Monthly mean values of sediment temperature (°C) at different stations during April 1990 to March 1992

Months/Year	Stations				
	I	III	IV	V	VI
April '90	39.4	30.8	28.2	28.7	28.5
May	39.2	31.5	30.3	31.2	31.0
June	37.0	28.6	29.2	29.0	29.0
July	34.0	28.3	28.6	28.5	28.5
August	35.2	29.1	29.0	29.3	29.0
September	38.1	27.5	28.6	29.0	29.8
October	33.8	28.2	28.7	28.2	28.2
November	34.2	28.2	28.6	27.6	26.8
December	35.6	27.6	26.9	27.2	27.2
January '91	36.1	29.1	28.3	28.0	27.5
February	35.1	27.2	27.0	28.0	27.8
March	38.0	32.8	31.5	31.5	31.1
April	40.0	31.9	30.3	30.2	30.2
May	39.2	30.2	31.2	31.1	31.3
June	39.6	28.6	28.8	27.0	28.1
July	35.0	29.0	26.3	26.3	27.5
August	32.8	27.0	28.2	30.2	28.0
September	36.3	29.3	30.3	28.9	30.0
October	36.9	29.0	29.2	29.0	28.8
November	36.2	30.8	27.6	27.8	28.2
December	36.3	28.2	27.8	27.8	26.8
January '92	35.8	27.3	27.9	27.4	27.1
February	34.2	28.2	28.0	28.2	28.0
March	36.3	30.0	28.0	28.4	27.5

Table : 19 Two way analysis of variance (ANOVA) showing the level of significance in variation of sediment parameters between stations and over seasons.

Source	D.F.	Sum SQR	Mean SQR	F.VAL	Remarks
(i) Temperature					
Treat	4	4356.221	1081.055	532.235	H.S
Repli	3	135.150	45.050	22.017	H.S
Error	452	924.879	2.046	-	-
(ii) Sand					
Treat	4	18630.128	4657.532	289.043	H.S
Repli	3	2029.603	676.534	41.985	H.S
Error	212	3416.086	16.114	-	-
(iii) Silt					
Treat	4	9063.253	2265.813	188.690	H.S
Repli	3	1061.015	353.672	29.453	H.S
Error	212	2545.722	12.008	-	-
(iv) Clay					
Treat	4	1702.418	425.605	110.867	H.S
Repli	3	155.964	51.988	13.543	H.S
Error	212	813.839	3.839	-	-

S = Significant
H.S = Highly Significant
N.S = Not Significant

March 1991 at both the stations. Station VI registered a lower value of 26.8°C during December 1991 and a higher value of 31.3°C during May 1991.

Although with significant seasonal variations observed between the years, the values in general indicated that summer and post monsoon periods experienced higher temperature regime while monsoon and premonsoon recorded lower values in almost all the stations.

ANOVA of sediment temperature indicated highly significant both between the stations and between the seasons (Table 19).

3.4 BOTTOM FAUNA STUDIES

3.4.1 Population density

Monthly variations in the population density of benthic fauna observed at stations I and III to VI are presented in Table 26.

It may be noticed from the table 26 that station I with comparatively less population density exhibited wider fluctuations with distinct seasonal periodicity during the two years under review. Thus during 1990-91, the lower density of 430 no/m^2 was noticeable during the summer month of May 1990, the density increasing thereafter reaching the peak population number of 1111 no/m^2 during the monsoon month of December 1990. During 1991 - 92 also, a similar trend is discernible with the lesser density of 454 no/m^2 observed during April 1991 and the higher population density of 1037 no/m^2 noticed during December 1991.

Station II with thick fly ash deposition was devoid of any faunal population.

Station III which is situated about 300 meters away from the TEDP, exhibited a denser population of benthos with the lower value of 1190 no/m^2 observed during the summer months of March 1991 and a higher value of 3476 no/m^2 again during the monsoon month of December 1991 as in station I. During 1991 - 1992 the minimum number of 1340/m^2 was obtained in April 1991 and the maximum value of 4935 no/m^2 recorded in August 1991 during the premonsoon season. It is interesting to note that during December 1991 of 1991 - 1992 unlike during the previous year, the benthic population showed a lesser density of 1990 no/m^2.

With a comparatively less population density, than station III and higher than that of station I, the benthic fauna at station IV showed lower values of 914 nos/m^2 and 797 no/m^2 both in the month of May during summer in 1990-1991 and 1990-1992 respectively. The population is found increasing gradually in the subsequent months reaching a peak of 2482 no/M^2 during November 1991 and 2514 no/m^2 during January 1992. the season of peak abundance being monsoon and post monsoon during the first and second years respectively.

Station V with a lesser population density than station III and IV but higher than station I had comparatively a lesser density of benthic population. The lower population of 702 no/m^2 during July 1991 and 468 no/m^2 during May 1992 at this station was noticed during premonsoon and summer seasons

Table : 26 Montly mean of bottom fauna density (number/m^2) at different stations of Tuticorin bay during April 1990 to March 1992

Months/Year	Stations*				
	I	III	IV	V	VI
April '90	524	1457	1261	994	2458
May	430	1617	914	834	2219
June	568	1554	973	824	2627
July	682	1765	1102	702	3084
August	825	2023	1003	740	3163
September	856	1461	1844	735	3012
October	820	2430	1897	1380	3579
November	926	3068	2482	1167	3071
December	1111	3476	2087	1454	2583
January '91	1079	2703	2334	1206	2929
February	628	1722	1863	902	3340
March	687	1190	1868	1077	2888
April	454	1340	906	648	3073
May	529	1852	797	468	2704
June	747	1899	876	548	2916
July	949	3389	896	623	3241
August	929	4935	1676	1051	3921
September	816	4068	1574	1271	3159
October	658	3313	1546	1147	3528
November	638	2771	2100	1127	3056
December	1037	1990	2241	1300	3223
January '92	876	1722	2514	1020	2737
February	950	1482	2183	770	2129
March	677	1637	2193	542	2071

* Station II had no benthic organisms.

respectively. The population density which increased during the subsequent months, indicated a high of 1454 no/m^2 and 1300 no/m^2 both in December during monsoon season in the two years under investigation.

Station VI with a richer benthic fauna exhibited a more or less stable population density when compared to that of other stations. Nevertheless, the seasons of low and high density were parallel with those of other stations. At station VI, during 1990 - 1991, the low density of 2219 no/m^2 was noticed during summer months of May 1990 with the higher density of 3579 no/m^2 recorded in October 1990 during monsoon season. Likewise during 1991 - 1992 also, minimum value of 2071 no/m^2 was observed during post monsoon season in March 1992 with the maximum density of 3921 no/m^2 recorded during premonsoon season in August 1991.

3.4.2 Benthic faunal composition

3.4.2.1 Group wise

The percentage of various groups of benthic organisms at stations I and III to VI during 1990 - 91 and 1991 - 92 are shown in Fig.45, 46 and 47.

It may be noticed that the benthic fauna in general was represented by groups such as gastropods, bivalves, polychaetes, crustaceans and miscellaneous species which included, Sea anemone, brittle star and fishes such as *Therapon spp.* and *Sillago sihama.*

At station I, the benthic organisms were composed mainly of gastropods which formed 91.20% (767 no/m^2) and 95.40% (780 no/m^2) during 1990-91 and 1991-92 respectively. Polychaetes which formed the other representative group in this station had a meager percentage contribution of 2.80 (22 no/m^2) and 4.30 (35 no/m^2) during the 2 years.

Station III, though had additional groups such a bivalves, crustaceans and miscellaneous species was dominated by gastropods with a contribution of 86.58% (1968 no/m^2) and 90.76% (2534 no/m^2) during 1990-91 and 1991-92 respectively.

At station IV, a change in the order of abundance of the component groups is discernible. In this station, with a contribution of 31.62% (602 nos/m^2) and 33.48% (640 no/m^2), crustaceans were the major group recorded followed by gastropod which formed 29.65% (567 no/m^2) and 25.73% (492 no/m^2) during the 2 years under observation. Polychaetes with a contribution of 18.60% (356 no/m^2) and 20.91% (400 no/m^2) and bivalves with a contribution of 16.36% (3.13 no/m^2) and 16.05% (307 no/m^2) during 1990 - 1991 and 1991 - 1992 respectively were the other major groups represented at Station IV. Miscellaneous group contributing to around 4% was rarely encountered.

Station V with a faunal composition similar to that of Station IV had crustaceans followed by polychaetes, gastropods, bivalves and miscellaneous species in the order of abundance.

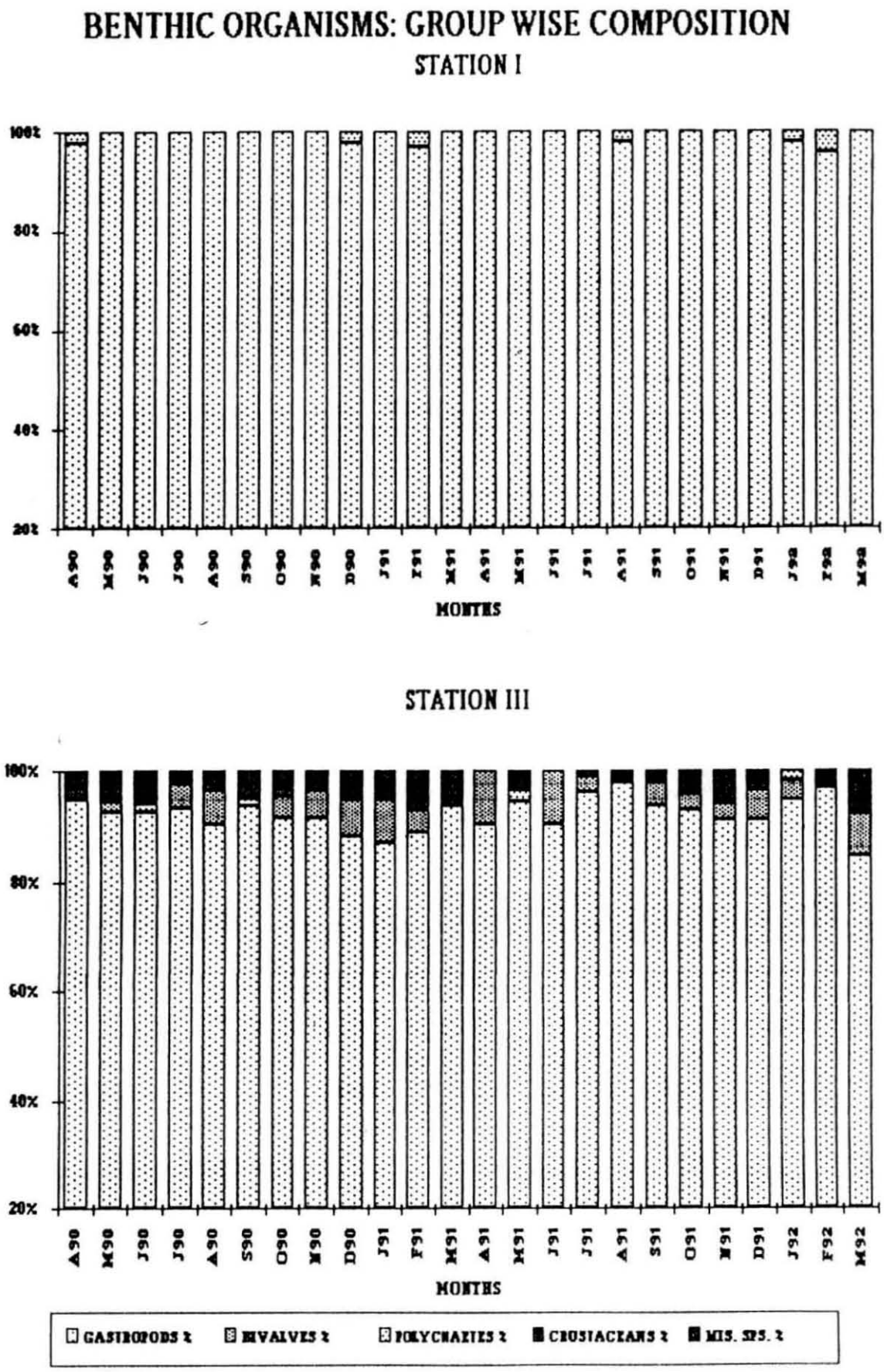

Fig. 45 Group wise composition of benthic organisms at stations I and III during April 1990 to March 1992.

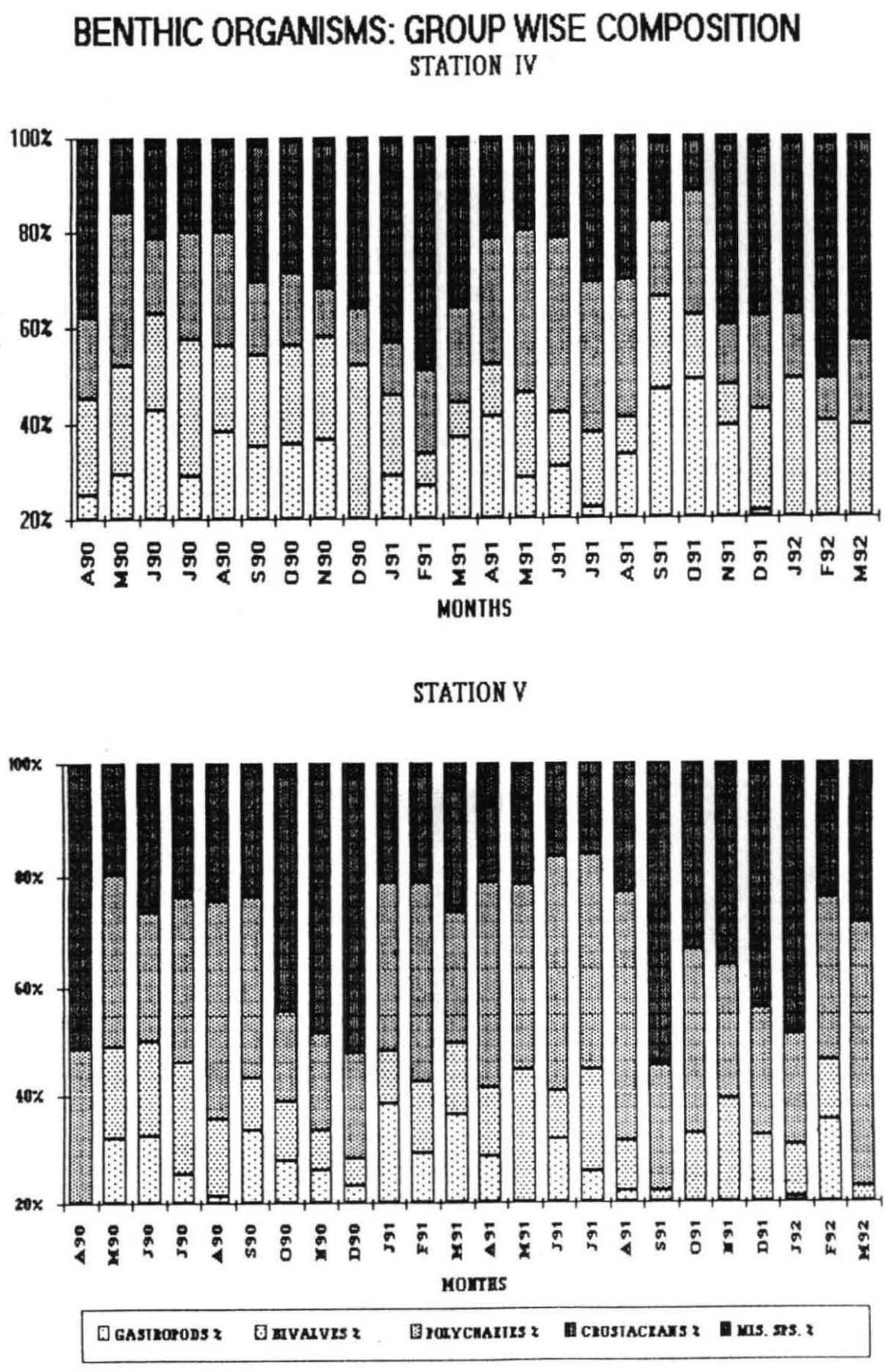

Fig. 46 Group wise composition of benthic organisms at stations IV and V during April 1990 to March 1992.

BENTHIC ORGANISMS: GROUP WISE COMPOSITION

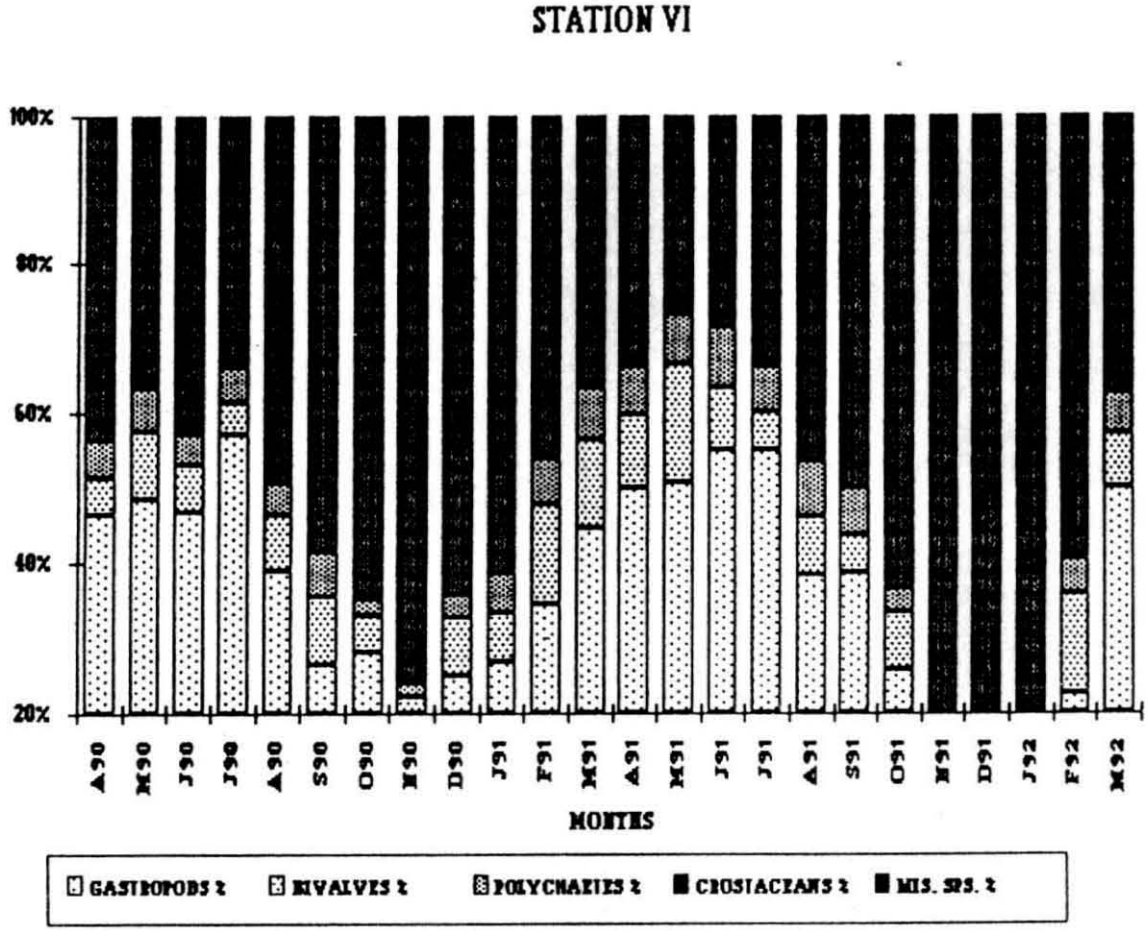

Fig. 47 Group wise composition of benthic organisms at station VI during April 1990 to March 1992.

With a clear change in the quantitative abundance, the benthic organisms at station VI was represented mainly by crustaceans which formed 50.13% (1490 no/m^2) and 51.11% (1596 no/m^2) during the 2 years respectively. Gastropods which constituted 34.90% (1053 no/M^2) and 33.83% (1056 no/m^2) during the two years was the next abundant group in this station. It may be noticed that polychaetes which formed 28.72% to 31.92% at Station V is poorly represented at Station VI with a contribution of 5.53% (167 no/m^2) and 6.06% (189 no/M^2) respectively during the years 1990 - 1991 and 1991 - 1992.

3.4.2.2 Species wise composition

Table 27 and 27A indicate the various species of benthic organisms observed at different stations. Station I was mainly dominated by the gastropod species *Cerithedia fluviatilis* which occurred throughout the period of study at this station. Besides a few unidentified polychaete species also were encountered exclusively during monsoon months at this station.

Station II had no benthic organisms, since this station was completely exposed to continuous deposition of bottom ash from TTPP.

Station III was noticed to have more number of gastropods such as *C. fluviatilis, Nassa pulla, Umbonium spp.* and the bivalve *Mesodesma spp.* Crustacean species such as juvenile *Scylla serrata* and *Penaeus semisulcatus* and other miscellaneous groups represented by the fish *Sillago sihama* and the coelenterate sea anemone were also observed at station III. In addition to this,

polychaetes such as *Nephthys spp.* and *Diopatra spp.* also were noticed at this station.

Benthic organisms at station IV were mainly constituted by crustaceans such as amphipods (*Tolerchestia gracilis*) Alphids, Branchiopods and other species such as *Sphaeroma spp. Scylla serrata, Penaeus semisulcatus, P. indicus* and *Balanus spp.* Besides polychaetes such as *Nephthys spp. Capitellids, Nerieds, Terebellids, Prionopsio spp.* and *Diopatra spp.* were also noticed at this station. Gastropod individuals such as *C. fluviatilis, N. pulla, Umbonium Spp.* and bivalves, represented by *Mesodesma spp. Solen spp.* were also observed at station IV with the lesser abundance of miscellaneous species.

Bottom fauna at station V was constituted mainly by the crustaceans such as *T.gracilis, S.serrata, P.semisulcatus, P.indicus* and *Alphids*. The second dominant group noticed at station V was polychaetes represented by *Capitellids, Nerieds, Terebellids, Nephthys spp. Prionopsio spp.* and *Diopatra spp.* Gastropod population in this station was represented mainly by *C.fluviatilis, N.pulla* and *Umbonium spp.*, while bivalves such as *Mesodesma spp. Solen spp.* and miscellaneous species such as the brittle star *Amphioplus (Amphioplus) intermedius* were rarely encountered.

Station VI had a total of 13 species of benthic organisms with the major occurrence of crustaceans *(T.gracilis, Sphaeroma spp. Branchiopods* and *S.serrata*) and gastropods *(C.fluviatilis* and *Nassa costata)*. Three groups of polychaetes such as *Nephthys spp. Nerieds* and *Diopatra spp.* and few unidentified organisms were also noticed at station VI. However, the bivalve

TABLE : 27

LIST OF BENTHIC ORGANISMS RECORDED AT VARIOUS STATIONS OF TUTICORIN BAY

STATION I	STATION III
1. *Cerithedia fluviatilis* 2. Unidentified polychaetes	**Gastropod** 1.*C.fluviatilis* 2.*Nassa pulla* 3.*Umbonium vestiarium* **Bivalves** 4.*Mesodesma spp.*
STATION II	**Crustaceans** 5.*Scylla serrata* 6.*Balanus spp.* 7.*Penaeus semisulcatus*
No benthic organisms observed	**Polychaetes** 8.*Nephythys spp.* 9.*Diopatra spp.*
	Miscellaneous species 10.*Sillago sihama* 11.*Sea anemone*

STATION IV	
Gastropods	**Crustaceans**
1. *C.fluviatilis*	11. *Tolerchestia gracilis*
2. *N. pulla*	12. *Sphaeroma spp.*
3. *U. vestiarium*	13. *Branchiopods*
	14. Juvenile *S.serrata*
	15. *P. indicus*
	16. *P.semisulcatus*
	17. Alphids
	18.*Balanus spp.*

TABLE : 27A

Polychaetes	**Bivalves**
4. *Nephythys spp.*	19. *Solen spp.*
5. *Prionopsio spp.*	20. *Mesodesma spp.*
6. *Capitellids*	
7. *Nerieds*	**Miscellaneous species**
8. *Terebellids*	21. *Therapon spp.*
9. *Diopatra spp.*	22. *S.sihama*
10. *Unidentified spp.*	23. *Sea anemone*
STATION V	
Gastropods	**Crustaceans**
1. *C.fluviatilis*	11.*T.gracilis*
2. *N.pulla*	12.*Alphids*
3. *U.vestiarium*	13.*P.semisulcatus*
	14.*S.serrata*
	15.*Balanus spp.*
	16. *Unidentified larval forms*
Polychaetes	**Bivalves**
4. *Nephthys spp.*	17. *Mesodesma spp.*
5. *Prionopsio spp.*	18. *Solen spp.*
6. *Diopatra spp.*	
7. *Nerieds*	**Miscellaneous species**
8. *Terebellids*	19. Brittle star *Amphioplus*
9. *Capitellids*	*(Amphioplus) intermedius*
10. *Unidentified* species	20. Sea anemone
STATION VI	
Gastropods	**Polychaetes**
1. *C.fluviatilis*	7. *Nephythys spp.*
2. *N.costata*	8. *Diopatra spp.*
	9. *Nerieds*
	10. *Unidentified spp.*
Crustaceans	**Bivalves**
3. *T.gracilis*	11. Mesodesma spp.
4. *Sphaeroma spp.*	
5. *Branchiopods*	**Miscellanous species**
6. *Balanus spp.*	12. *Therapon spp.*
	13. *Sea anemone*

Mesodesma spp. and miscellaneous species such as *Therapon spp. Sillago sihama* and seaanemone were sparsely represented.

Among all the stations, the species abundance was more in stations IV, V, VI, III and I in the order of abundance.

3.4.3 Species diversity

The diversity index of benthic organisms at different stations is presented in table 28 and Fig. 48 and 49.

In general, the species diversity at station I registered the lowest among all the stations. The diversity remained nil during summer months (April, May and June) since the benthic fauna was represented by a single species. Nevertheless, during the succeeding months, the values showed an increasing trend reaching the maximum of 0.28 and 0.44 both during the post-monsoon period (February 1991 and 1992) of the two years under study respectively.

The overall species diversity at station III ranged between 0.74 and 1.37. During the year 1990-91, the diversity showed a low of 0.74 during March 1991 and a high of 1.37 during December 1990. Likewise, during 1991-1992, the diversity indicated a low of 0.84 during April 1991 and a high of 1.30 during October 1991. Seasonally, the values showed lesser diversity during summer and premonsoon with higher diversity noticed during monsoon and post monsoon months.

At station IV, during 1990-91 the diversity index of benthic organisms registered a minimum of 1.84 during October 1990 and a maximum of 2.53 during the months of May 1990 and February 1991. In the second year the species diversity showed a lower value of 1.77 and a high of 2.64 during February 1992 and June 1991 respectively. It may be noticed from the table 28 that at this station summer and post monsoon period indicated higher diversity values with lower diversity noticed during monsoon months during 1990-1991. However, during 1991-1992, high diversity was noticed during summer months, with lower values recorded during post monsoon season.

The species diversity of benthic organisms at station V indicated a range between 1.70 (April 1990) and 2.58 (February 1991) during 1990-1991. During the year 1991-1992, the diversity ranged from 1.82 (September 1991) to 2.49 (April 1991) Seasonal valves of diversity index were noticed to have a minor fluctuations between the two years, at station V. During 1990-1991, the index showed a low during monsoon period and a high during post monsoon season, while during 1991-1992, the diversity noticed was lower during premonsoon and higher during summer months.

At station VI, benthic faunal diversity showed a remarkably similar trend during both the years. During 1990-1991 a minimum value of 0.94 and a maximum of 1.69 were observed during November 1990 and April 1990 respectively. Likewise, during the second year, the diversity values ranged between 0.87 (November 1991) and 1.65 (May 1991). Seasonally, the diversity

Table : 28 Monthly mean values of benthic species diversity estimated at different stations during April 1990 to March 1992 (H' Values)

Months/Year	Stations*				
	I	III	IV	V	VI
April '90	0.00	1.05	2.07	1.70	1.69
May	0.00	1.00	2.53	2.37	1.66
June	0.00	0.79	2.29	2.39	1.51
July	0.13	0.85	2.33	2.32	1.42
August	0.11	0.97	2.26	2.18	1.50
September	0.22	0.84	2.08	2.17	1.31
October	0.11	0.97	1.84	2.07	1.24
November	0.18	1.14	1.89	1.84	0.94
December	0.19	1.37	2.28	1.92	1.27
January '91	0.09	1.22	2.13	2.40	1.35
February	0.28	1.01	2.63	2.58	1.59
March	0.00	0.74	2.28	2.46	1.65
April	0.00	0.84	2.44	2.49	1.56
May	0.00	1.01	2.29	2.20	1.65
June	0.12	0.92	2.64	2.32	1.59
July	0.00	1.09	2.54	2.22	1.34
August	0.11	1.09	1.90	2.27	1.42
September	0.38	0.95	2.47	1.82	1.41
October	0.13	1.30	2.43	2.27	1.15
November	0.25	1.16	2.21	2.32	0.87
December	0.28	1.14	2.35	2.27	0.89
January '92	0.22	1.16	2.01	2.24	1.08
February	0.41	0.87	1.77	2.32	1.49
March	0.00	1.04	1.89	2.05	1.52

* Station II had no benthic organisms.

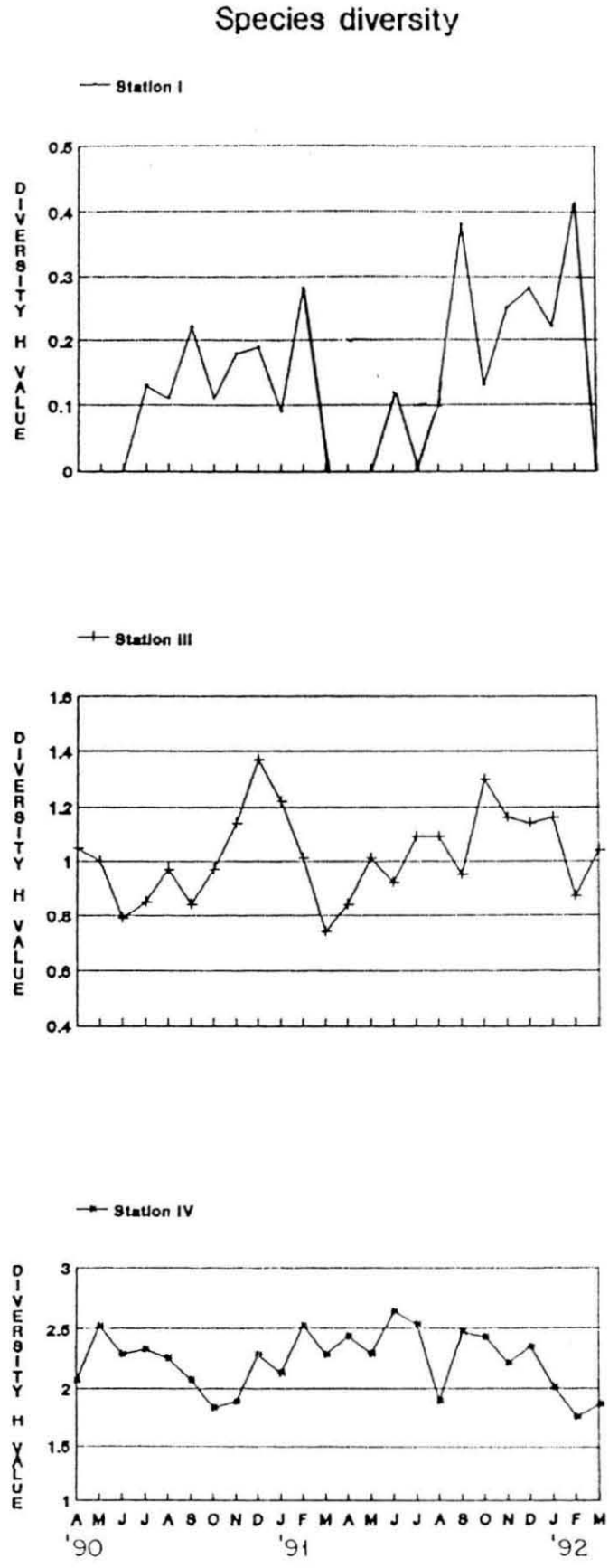

Fig. 48 Monthly variation in the species diversity of benthos at stations I III and IV during April 1990 to March 1992.

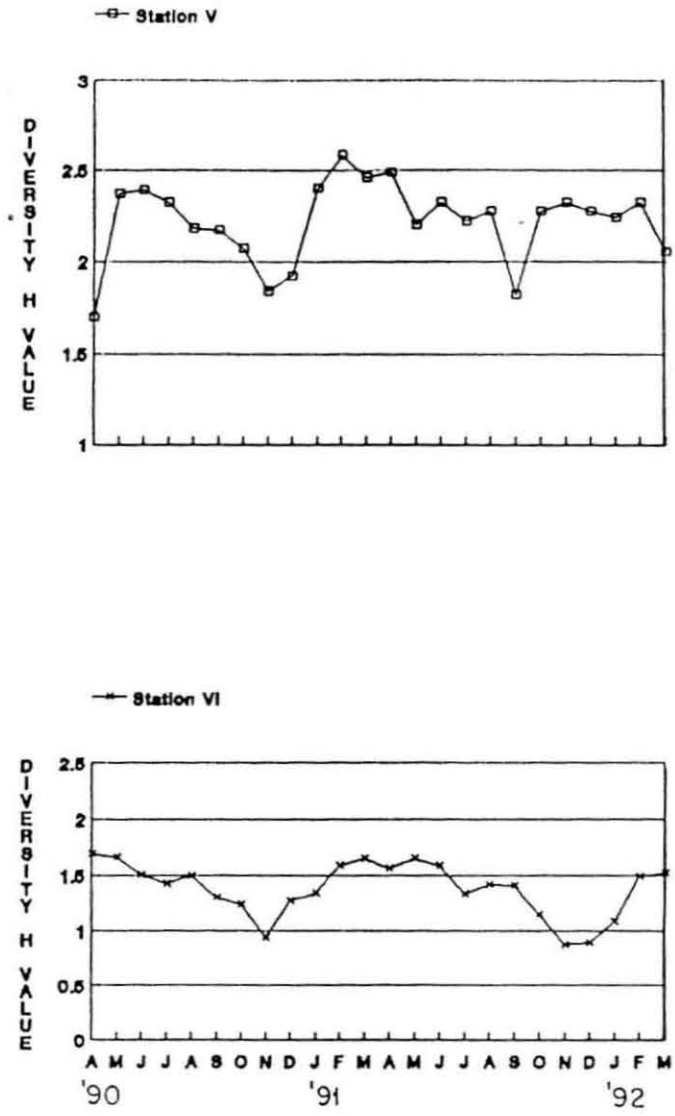

Fig. 49 Monthly variation in the species diversity of benthos at stations V and VI during April 1990 to March 1992.

index indicated lower values during the monsoon months and higher values during summer months of both the years at this station.

Among all the stations, the benthic faunal diversity was noticed to be the highest at station IV (2.64 during June 1991) while station I indicated the lowest during summer months of both the years.

3.3.4 Species richness

Monthly variations in the species richness of benthic fauna at station I and III and VI are presented in table 29 and Fig.50 and 51.

In general at station I, species richness was nil during summer months of both the years 1990-1991 and 1991-1992, since only one species of *C.fluviatilis* dominated during this period, However, during 1990-1991, the maximum value of 0.31 was recorded during February 1991 while during 1991-1992 the higher value of 0.30 was noticed during September 1991 and February 1992. Species richness did not show notable variations among the seasons at Station I. Nevertheless, the values were high during the monsoon month of February during both the years.

At station III, the values of species richness ranged between 0.42 (March 1991) and 0.86 (December 1990) during 1990-1991. Likewise, during the second year, the values ranged from 0.40 (June 1991) to 0.86 (October 1991). It may be noticed that higher species abundance was observed during monsoon months of both the years with lesser abundance noticed during post

monsoon and summer periods respectively during the years 1990-1991 and 1991-1992.

Station IV with comparatively high values of species richness especially during post monsoon and premonsoon months, had the peak values of 2.62 and 2.33 recorded during December in both the years. The minimum values of 1.53 (November 1990) and 1.47 (April 1991) were observed during monsoon and summer seasons respectively during the years 1990-1991 and 1991-1992.

Abundance of benthic organisms at station V showed a range from 1.27 (November 1990) to 1.94 (June 1990) during 1990-1991. During 1991-1992, the values ranged between 1.27 (March 1992) and 1.95 (December 1991). Seasonally,species richness of benthic organisms was more during premonsoon and monsoon periods during 1990-1991. During 1991-1992, a similar pattern of species abundance was noticed with the maximum abundance during monsoon period and the minimum abundance during premonsoon months.

At station VI, species richness showed a lower value of 0.87 during November 1990 and a higher value of 1.66 in April 1990 during 1990-1991. During 1991-1992, a minimum of 0.86 and a maximum of 1.27 were observed during October 1991 and May 1991 respectively. Seasonal abundance indicated a clear pattern with a low value during summer months and a high during monsoon months during both the years.

Table : 29 Monthly mean values of benthic Species Richness at different stations of Tuticorin bay during April 1990 to March 1992. (R' Values)

Months/Year	Stations*				
	I	III	IV	V	VI
April '90	0.00	0.69	1.68	1.59	1.66
May	0.00	0.68	1.80	1.78	1.43
June	0.00	0.54	2.03	1.94	1.27
July	0.15	0.67	2.14	1.53	1.62
August	0.15	0.79	1.74	1.51	1.49
September	0.15	0.69	1.86	1.67	1.13
October	0.15	0.64	1.85	1.66	1.10
November	0.15	0.62	1.53	1.27	0.87
December	0.29	0.86	2.62	1.79	1.02
January '91	0.14	0.76	2.06	1.83	1.25
February	0.31	0.54	2.12	1.68	1.23
March	0.00	0.42	2.12	1.86	1.25
April	0.00	0.42	1.47	1.85	1.24
May	0.00	0.66	1.65	1.30	1.27
June	0.15	0.40	2.06	1.60	1.25
July	0.00	0.62	2.21	1.40	1.11
August	0.15	0.59	1.89	1.44	1.09
September	0.30	0.72	2.17	1.55	1.24
October	0.15	0.86	1.91	1.70	0.86
November	0.15	0.76	1.96	1.71	1.00
December	0.14	0.53	2.33	1.95	1.11
January '92	0.29	0.67	1.92	1.73	1.13
February	0.30	0.68	1.95	1.65	1.17
March	0.00	0.81	1.95	1.27	1.18

* Station II had no benthic organisms.

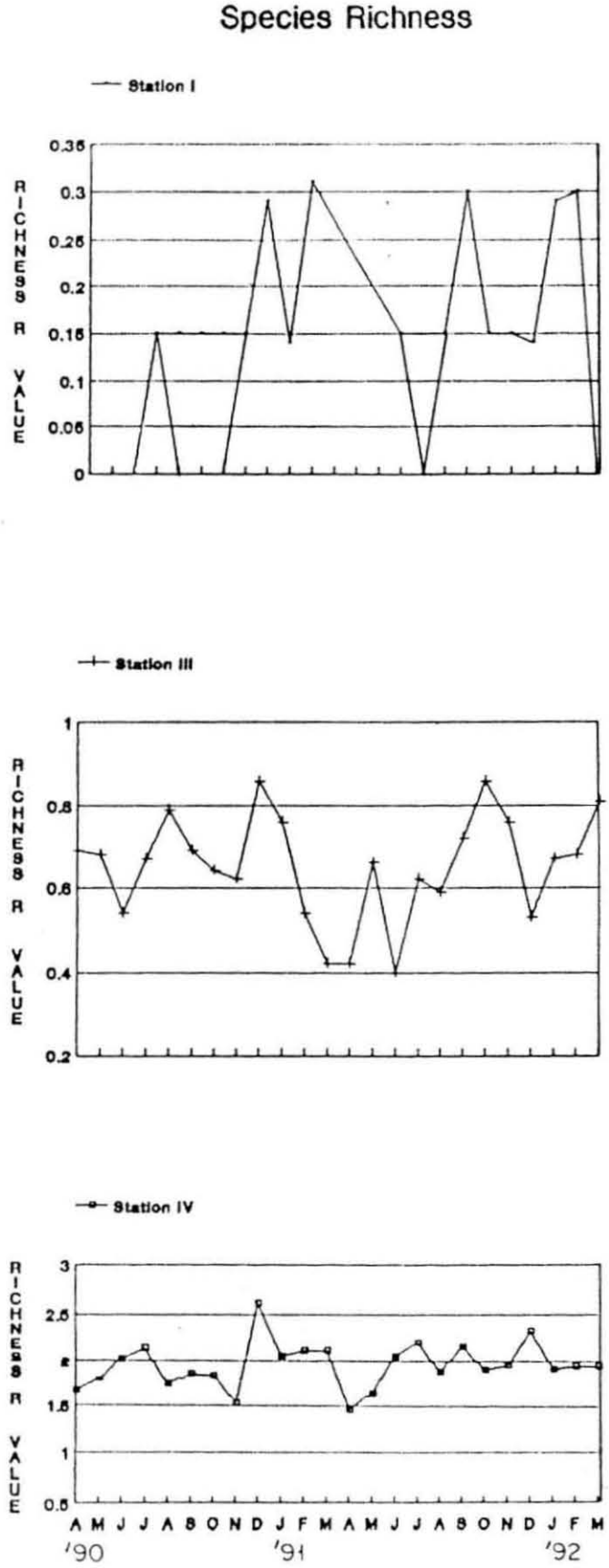

Fig. 50 Monthly variation in the species richness of benthos at stations I, III and IV during April 1990 to March 1992.

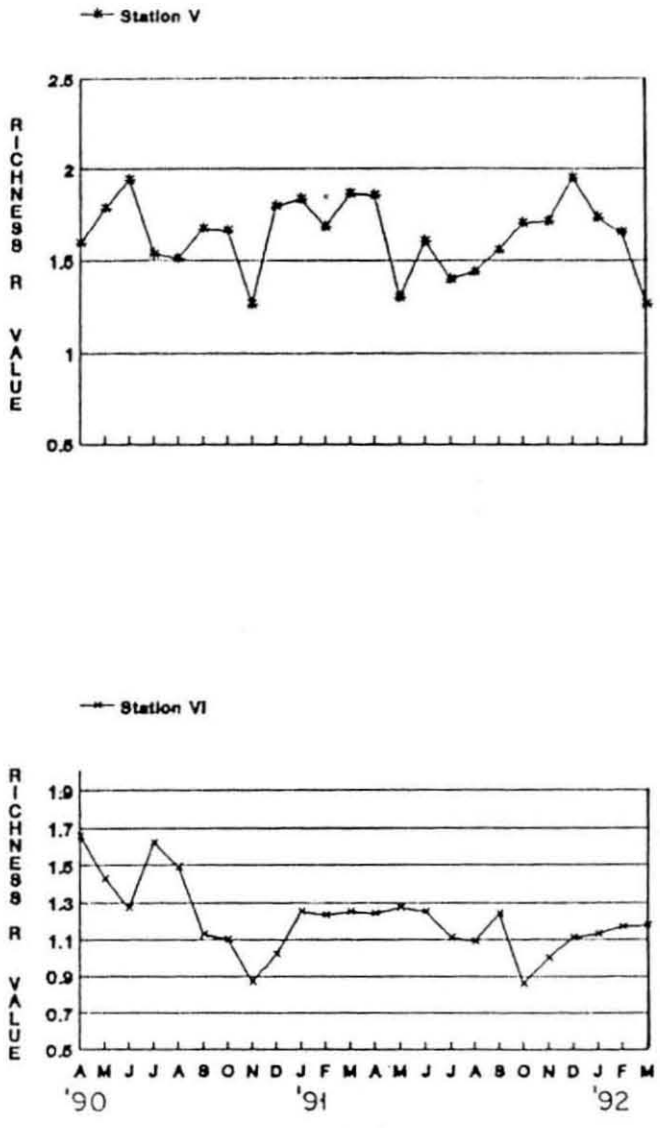

Fig. 51 Monthly variation in the species richness of benthos at stations V and VI during April 1990 to March 1992.

Among the stations I to VI, highest value of species richness of 2.62 was observed during December 1990 at station IV while station I indicated the lowest values during summer months of both the years.

3.4.5 Species evenness

Monthly values of species evenness worked out during the study period from April 1990 to March 1992 at stations I and III to VI are given in table 30 and Fig. 52 and 53.

Station I was found to have the lowest species evenness when compared to other stations because of the single species domination observed throughout the period of study. In general, species evenness showed almost a nil value during summer season of both the years. However, the maximum of 0.025 and 0.032 was observed during the premonsoon (September 1990) and monsoon (December 1991) months of 1990-1991 and 1991-1992 respectively.

The evenness in the distribution of benthic organisms at station III ranged between 0.25 (August 1990) and 0.44 (February 1991) during 1990-1991. During the 1991-1992, the values increased from 0.27 (September 1991) to 0.53 (December 1991). Seasonally, benthic organisms animals were distributed more evenly during post monsoon and summer periods during 1990-1991 and 1991-1992 respectively while premonsoon season indicated lesser evenness during both the years.

At station IV, during 1990-1991, species evenness showed a variation from a low of 0.39 during the monsoon month of October 1990 to a high of 0.96 during the summer month of May 1990. Likewise, during 1991-1992, a minimum of 0.32 and a maximum of 1.05 were noticed during February 1992 and April 1991 respectively. Seasonal values showed higher evenness during summer months and lower evenness during monsoon months during both the years.

The evenness in the distribution of bottom fauna at station V indicated a minimum of 0.41 during April 1990 and a maximum of 1.11 during February 1991 during 1990-1991. During the second year, the range noticed was from 0.47 (September 1991) to 0.92 (April 1991 and June 1991) Seasonal values showed higher evenness during post monsoon and summer seasons during 1990-1991 and 1991-1992 respectively with monsoon season showing lower value during both the years.

At station VI, species evenness varied from 0.22 (November 1990) to 0.39 (May 1990 and February 1991) during 1991 - 1992. As in stations IV and V, seasonal values at station VI indicated higher evenness during summer months and lower evenness during monsoon months of both the years.

Among the stations, station V indicated a maximum value of 1.11 during February 1991 while nil value was noticed at station I during summer months of both the years.

Table : 30 Monthly variation mean values of benthic species evenness at different stations during April 1990 to March 1992

Months/Year	Stations*				
	I	III	IV	V	VI
April '90	0.000	0.37	0.58	0.41	0.34
May	0.000	0.34	0.96	0.81	0.39
June	0.000	0.30	0.63	0.76	0.32
July	0.014	0.27	0.62	0.92	0.24
August	0.012	0.25	0.72	0.79	0.29
September	0.025	0.26	0.50	0.71	0.30
October	0.012	0.33	0.39	0.58	0.27
November	0.020	0.43	0.47	0.59	0.22
December	0.110	0.42	0.44	0.45	0.32
January '91	0.010	0.40	0.46	0.77	0.29
February	0.016	0.44	0.72	1.11	0.39
March	0.000	0.37	0.55	0.94	0.38
April	0.000	0.44	1.05	0.92	0.38
May	0.000	0.35	0.81	0.89	0.42
June	0.013	0.50	0.93	0.92	0.39
July	0.000	0.39	0.78	0.91	0.31
August	0.012	0.39	0.41	0.87	0.35
September	0.230	0.27	0.68	0.47	0.31
October	0.014	0.38	0.74	0.72	0.31
November	0.028	0.37	0.54	0.77	0.17
December	0.032	0.53	0.53	0.62	0.16
January '92	0.130	0.44	0.43	0.70	0.22
February	0.026	0.48	0.32	0.83	0.38
March	0.000	0.31	0.37	0.85	0.40

* Station II had no benthic organisms.

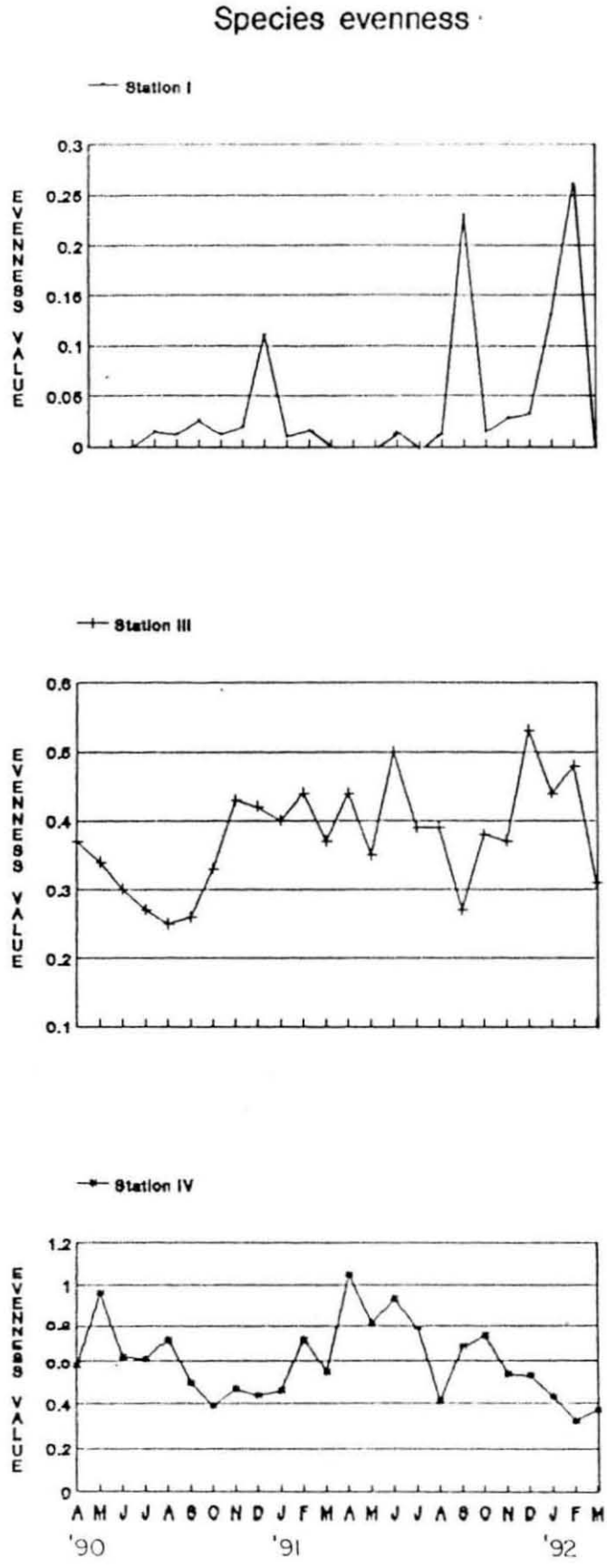

Fig. 52 Monthly variation in the species evenness of benthos at stations I, III and IV during April 1990 to March 1992.

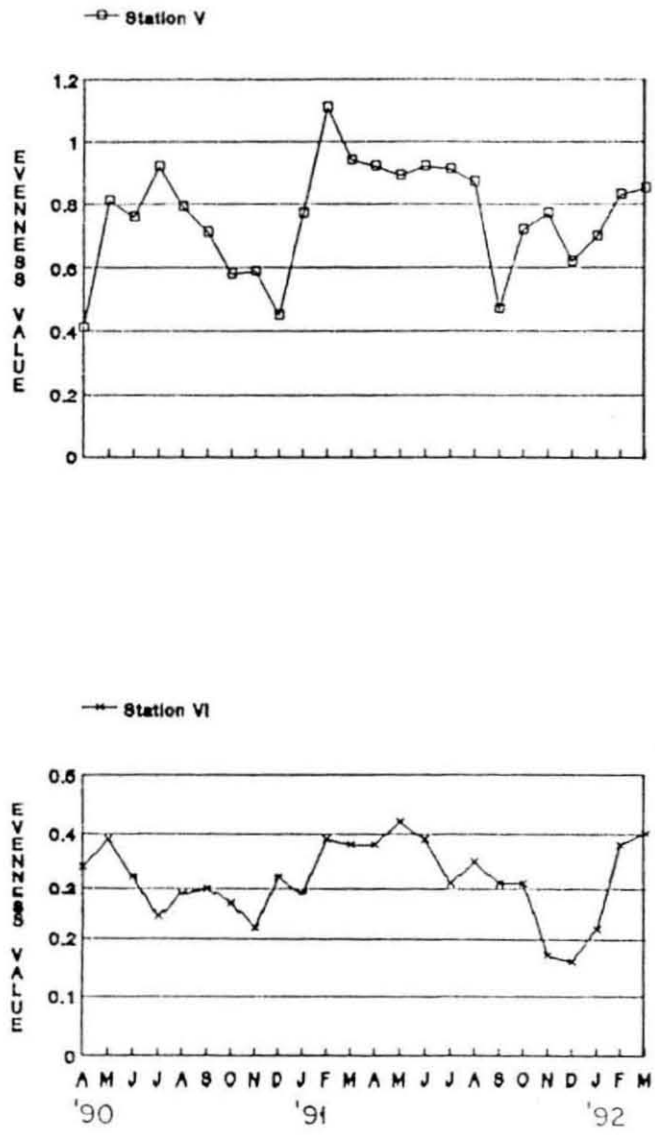

Fig. 53 Monthly variation in the species evenness of benthos at stations V and VI during April 1990 to March 1992.

3.4.6 Benthic Biomass

. Monthly mean values of total benthic biomass (wet weight) at stations I and III to VI are given in Table 31 and Fig.54 and 55.

Biomass distribution at station I was low in the month of April during the two years under study, the value being 5.26 and 5.75 gm/m^2 respectively. The higher values of 24.59 and 12.94 gm/m^2 were also observed during the same month of January in the two years. Season wise, the biomass values showed notable variations at station I. It could be seen from the Table 31 and Fig.54 that benthic biomass was more during monsoon season with lower values discernible during summer months of both the years.

At station III, the biomass distribution indicated a minimum value of 4.24 gm/m^2 during April 1990 and a maximum of 9.0 gm/m^2 during November, 1990, in 1990-1991, while during 1991 - 1992 the bio-mass values varied from a low of 4.68 gm/m^2 during March 1992 to a high of 8.89 gm/m^2 during September 1991. Exhibiting a pattern similar to that of population density, seasonal variations of biomass indicated lower values during summer months and higher values during monsoon months for the year 1990-1991. During 1991-1992, the biomass showed a different pattern indicating lower value during post monsoon period and higher biomass during premonsoon season.

Benthic biomass distribution a Station IV showed lower values of 10.0 gm/m^2 during March 1991 during 1990-1991 and 7.26 gm/m^2 during June 1991 in 1991-1992. The higher biomass values of 27.12 gm/m^2 were obtained during

November, 1990 and October 1991 respectively during 1990-1991 and 1991-1992. Seasonal values showed a similar pattern of biomass distribution during both the years indicating lower values during summer months and higher values during monsoon months.

At station V, the biomass values ranged from a low of 4.16 gm/m^2 during July 1990 to a high of 8.33 gm/m^2 during January 1991 in 1990-1991. During 1991-1992, the values indicated a trend almost similar to that of previous year with a minimum of 4.30 gm/m^2 during July 1990 and maximum of 8.39 gm/m^2 during February 1992. Seasonal variations in the biomass distribution at station V showed lower values during pre-monsoon period during the year 1990-1991 and monsoon period during the year 1991-1992. Higher biomass values were noticed during post monsoon periods of both the years.

Benthic biomass distribution at station VI showed a minimum values of 14.66 gm/m^2 and 13.24 gm/m^2 during the two years both observed during the month of December. Maximum values of 28.49 gm/m^2 was noticed during March 1991 and May 1991 during the years 1990-1991 and 1991-1992 respectively. Seasonally, biomass values were low during premonsoon season during the year 1990-1991 and during monsoon season in 1991-1992 while the higher values were noticed during summer months of both the years.

Monthly mean values of total benthic biomass in terms of dry weight at stations I and III to VI are given in table 32 and Fig.56 and 57.

Table : 31 Monthly mean wet weight values of benthic biomass (gm/m^2) estimated at different stations during April 1990 to March 1992

Months/Year	Stations*				
	I	III	IV	V	VI
April '90	5.26	4.24	14.06	4.79	24.71
May	10.12	5.34	13.43	5.26	24.66
June	10.47	7.21	14.41	6.08	23.30
July	10.79	8.56	16.11	4.16	19.60
August	12.60	7.17	21.02	4.99	18.66
September	9.60	4.63	21.75	5.64	19.97
October	11.17	7.70	21.66	6.23	25.25
November	18.82	9.00	27.12	5.28	14.83
December	21.22	8.77	14.90	5.05	14.66
January '91	24.59	7.45	17.07	8.33	20.99
February	9.81	5.18	17.40	7.63	23.41
March	12.59	4.26	10.00	5.56	28.49
April	5.75	5.75	9.75	4.50	23.06
May	7.20	6.57	8.37	4.32	28.53
June	9.86	7.65	7.26	4.49	23.41
July	12.44	8.02	14.42	4.30	21.04
August	6.56	6.70	21.00	5.67	19.42
September	6.48	8.89	22.21	5.55	22.38
October	8.99	6.32	26.36	4.42	15.32
November	11.24	6.89	23.45	4.48	14.55
December	9.45	8.69	17.25	4.34	13.24
January '92	12.94	6.35	19.07	6.31	14.79
February	8.72	4.86	15.66	8.39	17.33
March	7.84	4.68	19.89	4.32	22.20

* Station II had no benthic organisms.

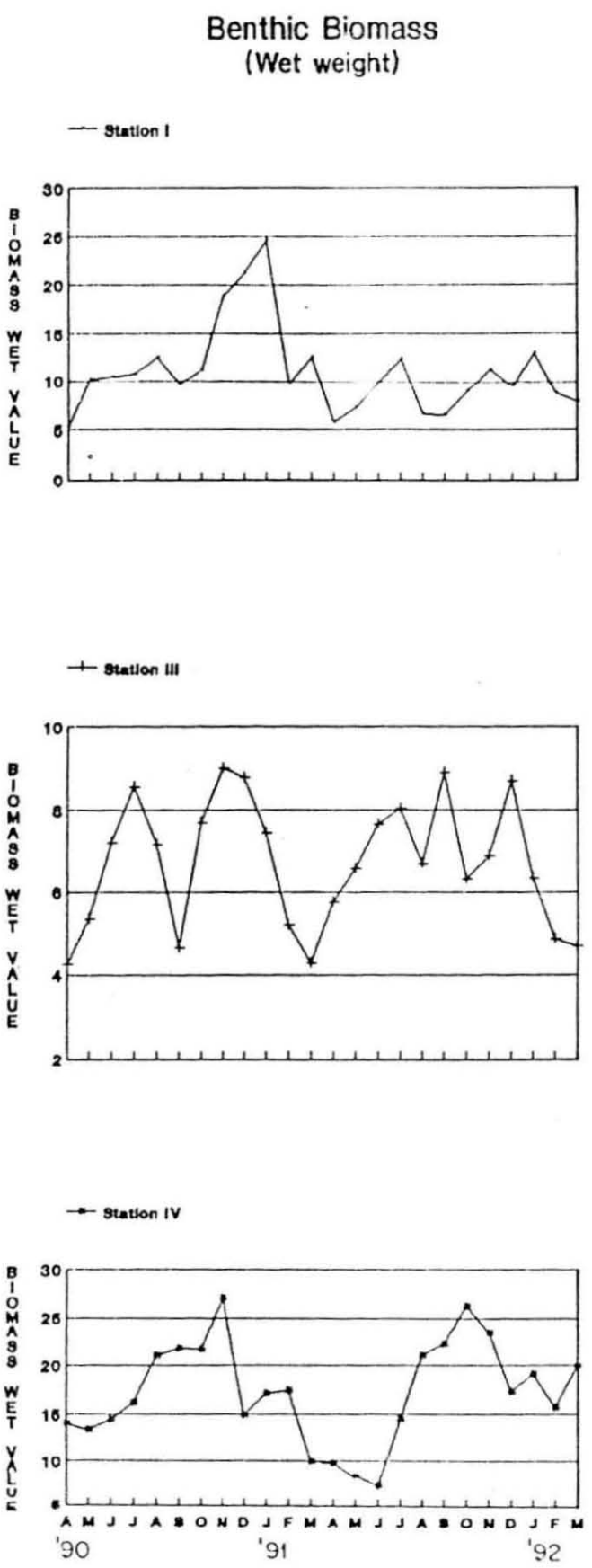

Fig. 54 Monthly variation in the wet weight (gm/M^2) of benthic biomass at stations I, III and IV during April 1990 to March 1992.

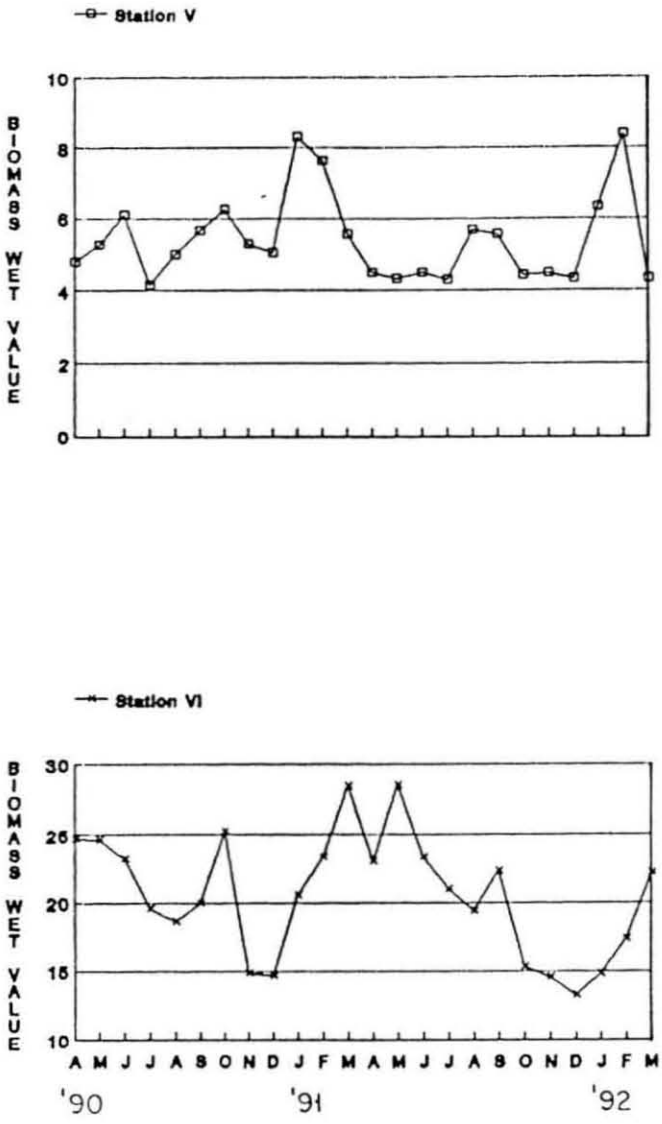

Fig. 55 Monthly variation in the wet weight (gm/M^2) of benthic biomass at stations V and VI duri April 1990 to March 1992.

Table:32 Monthly mean dry weight values of benthic biomass (gm/m^2) estimated at different stations during April 1990 to March 1992

Months/Year	Stations*				
	I	III	IV	V	VI
April '90	1.47	1.24	2.24	1.26	3.12
May	2.11	1.49	2.06	1.48	3.20
June	2.23	1.68	2.32	1.68	3.08
July	2.06	1.74	2.54	1.30	2.24
August	2.59	1.64	3.06	1.29	2.18
September	1.98	1.44	3.12	1.50	2.36
October	2.33	1.70	3.14	1.61	3.42
November	3.12	1.78	4.00	1.52	2.16
December	3.33	1.82	2.30	1.46	2.32
January '91	3.40	1.27	2.48	1.50	3.12
February	1.89	1.06	2.38	1.90	3.44
March	2.14	1.12	1.90	1.49	3.90
April	1.36	1.36	1.78	1.38	3.66
May	1.47	1.48	1.72	1.30	3.80
June	1.80	1.59	1.56	1.42	3.78
July	2.42	1.62	1.82	1.26	3.32
August	1.60	1.56	2.20	1.70	2.98
September	1.59	2.00	2.12	1.68	3.01
October	1.80	1.52	3.78	1.12	2.49
November	2.01	1.48	3.49	1.08	2.23
December	1.80	1.54	2.80	1.11	1.98
January '92	3.40	1.36	2.92	1.44	1.70
February	1.81	1.22	2.68	1.72	2.12
March	1.60	1.16	2.79	1.30	2.40

* Station II had no benthic organisms.

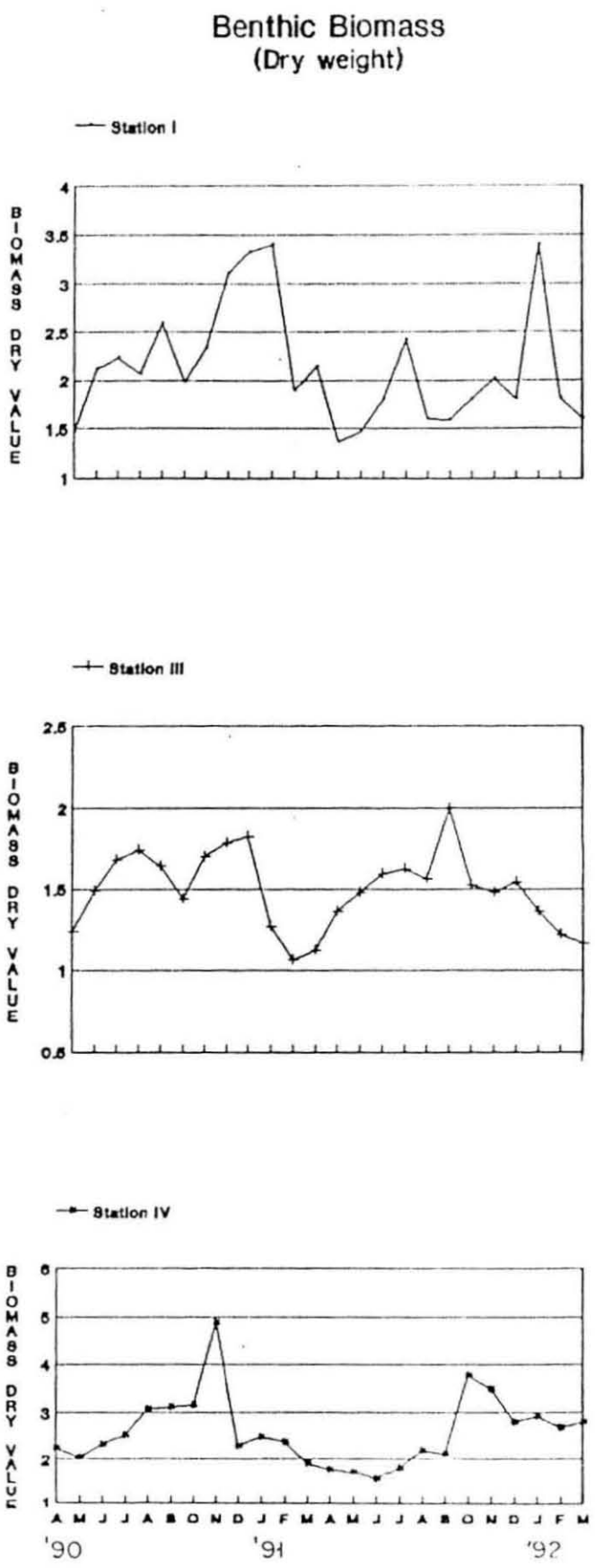

Fig. 56 Monthly variation in the dry weight (gm/M^2) of benthic biomass at stations I, III and IV during April 1990 to March 1992.

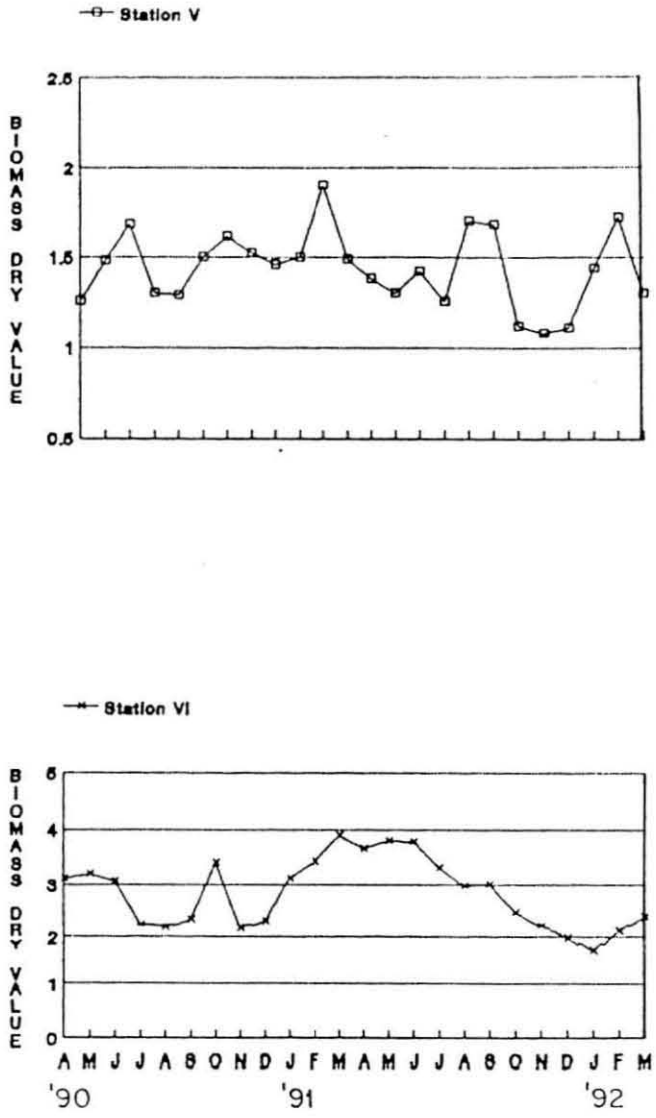

Fig. 57 Monthly variation in the dry weight (gm/M^2) of benthic biomass at stations V and VI during April 1990 to March 1992.

The dry weight of benthic biomass indicated more or less a similar trend with wet weight biomass. The values showed a range of 1.36 g/m^2 during April 1991 and 3.40 g/m^2 during January 1991 and January 1992 at station I. The biomass dry weight at station III evinced a low of 1.06 g/m^2 during February 1991 and a high of 2.0 g/m^2 during September 1991.

Station IV showed the lowest value of 1.56 g/m^2 during June 1991 with the highest value of 4.0 g/m^2 during November 1990. The benthic biomass dry weight estimated at station V indicated a minimum value of 1.08 g/m^2 during November 1991 with the maximum of 1.90 g/m^2 estimated during February 1991.

The dry weight value of benthic biomass observed at station VI was with a lower value of 1.70 g/m^2 during January 1992 and a higher value of 3.90 g/m^2 during March 1991.

3.5 STATISTICAL RELATIONSHIPS

Estimates of correlation co-efficient exhibiting inter relationship of different parameters in different stations are given in tables 33 to 42.

STATION I (Table 33 & 38)

The water temperature showed significant positive correlation with salinity ($r = 0.6025$; $P \leq 0.01$) but indicated significant negative correlation with benthic total numbers ($r = -0.7090$; $P \leq 0.01$) and benthic biomass ($r = -0.4956$; $P \leq 0.05$). The water temperature also showed negative correlation

with dissolved oxygen (r = 0.3252) and benthic species diversity (r= -0.3385) although the values were statistically insignificant.

Salinity indicated significant negative correlation with dissolved oxygen ($r = -0.5776$; $P \leq 0.01$) benthic total numbers ($r=-0.6098$; $P \leq 0.01$) and benthic biomass (wet weight) ($r = -0.7099$; $P \leq 0.01$) while it evinced significant positive correlation with ammonia ($r = 0.5014$; $P \leq 0.05$).

Correlation of dissolved oxygen with benthic biomass was positive and significant ($r = 0.4560$; $P \leq 0.05$).

In the case of turbidity, significant positive correlation was noticeable only with silicate ($r = 0.4176$; $P \leq 0.05$).

Nitrate was noticed to have significant positive correlation with ammonia ($r = 0.4407$; $P \leq 0.05$).

Ammonia showed negative correlation with benthic total numbers ($r = -0.3666$) and benthic biomass ($r = -0.366$) although the values were statistically insignificant.

Correlation of benthic total numbers was positive and significant with benthic biomass ($r = 0.6266$; $P \leq 0.01$) and with species diversity ($4 = 0.4476$; $P \leq 0.05$).

Table: 38 Estimates of correlation co-efficient between sediment parameters and benthic fauna at station I

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10
1.	Sand	1.000									
2.	Silt	-0.9243**	1.000								
3.	Clay	-0.6778**	0.3665	1.000							
4.	Total organic carbon	-0.4783*	0.4627*	0.3115	1.000						
5.	Total nitrogen	-0.1978	0.0910	0.3045	0.3115	1.000					
6.	Total phosphorus	-0.3231	0.2855	0.2596	0.8412**	0.7458**	1.000				
7.	Temperature	-0.2720	0.0376	0.1733	0.0808	0.4449*	0.3737	1.000			
8.	Population density	-0.0829	0.1299	-0.0391	-0.1244	-0.4484*	-0.5526**	-0.0570**	1.000		
9.	Biomass	-0.0620	-0.0752	0.0252	-0.0318	-0.2531	0.3896	-0.2728	-0.6266**	1.000	
10.	Species diversity	0.0729	0.0425	-0.2268	-0.4563*	-0.4818*	-0.5711**	-0.2052	0.4476*	0.0550	1.000

* = 1% level
** = 5% level

Sediment sand indicated negative correlation with sediment total organic carbon ($r = -0.4783$; $P - \leq 0.05$) while silt evinced positive correlation with total organic carbon ($r = 0.4627$; $P \leq 0.05$).

Total organic carbon of the sediment correlated negatively with species diversity ($r = -0.4563$; $P \leq 0.05$) while total phosphorus showed negative correlation both with species diversity ($r = - 0.4484$; $P \leq 0.05$) and benthic total numbers. ($r = - 0.4484$; $P \leq 0.05$). Sediment total nitrogen also was negatively correlated with benthic total numbers ($e = -0.5526$; $P \leq 0.01$) and species diversity ($r = 0.5711$; $P \leq 0.01$).

STATION III (Table 34 & 39)

At station III, correlation of salinity with dissolved oxygen was negative and significant ($r = - 0.4305$; $P \leq 0.05$)

pH indicated negative correlation with nitrite ($r = - 0.4046$, $P \leq 0.01$) and with ammonia ($r = -0.5895$; $P \leq 0.01$).

Positive correlation of nitrate was noticed with phosphate ($r = 0.4831$; $P \leq 0.05$), silicate ($r = 0.4163$; $P \leq 0.05$) and ammonia ($r = 0.5580$; $P \leq 0.01$) while ammonia evinced negative correlation with benthic biomass ($r = -0.4084$; $P \leq 0.05$).

Correlation of sediment sand was negative with sediment total phosphorus ($r = -0.6583$; $P \leq 0.01$) and total nitrogen ($r = -0.6803$; $P \leq 0.01$) but

Table: 34 Estimates of correlation co-efficient between water parameters and benthic fauna at station III

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	Temperature	1.000												
2.	Salinity	0.0406	1.000											
3.	Diss. oxy.	-0.0363	-0.4306*	1.000										
4.	pH	-0.2689	-0.0130	0.1677	1.000									
5.	Turbidity	-0.3036	-0.0406	-0.2663	0.0270	1.000								
6.	Nitrite	-0.1433	0.1427	-0.1272	-0.4026	0.0270	1.000							
7.	Nitrate	0.2121	-0.1239	-0.1305	-0.1923	0.2155	0.2650	1.000						
8.	Phosphate	0.3423	0.0923	0.0863	-0.1949	0.0346	0.0476	0.4831*	1.000					
9.	Silicate	-0.0196	-0.0299	0.0071	-0.1410	0.2610	0.1619	0.4163	0.3454	1.000				
10.	Ammonia	0.1968	0.0525	-0.2675	-0.5895	0.0364	0.551*	0.5580**	0.3258	0.4019	1.000			
11.	Pop. density	-0.2372	0.2241	0.0056	-0.666	0.3115	-0.3135	-0.1452	-0.0522	-0.0460	-0.3797	1.000		
12.	Biomass	-0.2662	-0.0681	0.0938	0.3295	-0.1508	-0.3195	-0.0534	-0.2917	0.0188	-0.4084*	0.5592**	1.000	
13.	Species diversity	0.3312	-0.0658	0.2638	-0.3673	-0.1436	0.0691	-0.0593	0.2410	-0.3546	0.1806	-0.1370	-0.2788	1.000

* = 1% level
** = 5% level

Table : 39 Estimates of correlation co-efficient between sediment parameters and benthic fauna at station III

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10
1.	Sand	1.000									
2.	Silt	0.9597**	1.000								
3.	Clay	-0.6732**	0.4385**	1.000							
4.	Total organic carbon	-0.1603	0.1529	0.1201	1.000						
5.	Total nitrogen	-0.6583**	0.6744**	0.3331	0.1129	1.000					
6.	Total phosphorus	-0.6803**	0.7183**	0.2874	0.0947	0.8345**	1.000				
7.	Temperature	0.6204**	0.5479**	0.3451	0.1130	0.6471**	0.5273**	1.000			
8.	Population density	0.4757*	-0.4979**	-0.2142	-0.1378	-0.3075	-0.3387	-0.3748	1.000		
9.	Biomass	0.5300*	-0.4567**	-0.5026*	-0.3667	-0.3981	-0.4114	-0.3093	0.5592**	1.000	
10.	Species diversity	-0.1236	0.0208	0.3412	-0.2409	0.1649	0.1868	0.3574	-0.2788	-0.2788	1.000

* = 1% level
** = 5% level

was positive with benthic total numbers ($r = 0.4757$; $P \leq 0.05$) and with benthic biomass ($r = -0.4567$; $P \leq 0.01$).

Sediment clay indicated negative correlation with benthic biomass ($r = -0.5026$; $P \leq 0.05$).

STATION IV (Table 35 & 40)

At Station IV water temperature showed positive and significant correlation with salinity ($r = 0.4850$; $P \leq 0.05$)

Salinity correlated negatively with benthic total numbers ($r = -0.6873$; $P \leq 0.01$) but positively with species diversity ($r = 0.4603$; $P \leq 0.05$). Dissolved oxygen evinced positive correlation with nitrate ($r = 0.4562$; $P \leq 0.05$).

Sediment sand showed negative correlation with sediment total phosphorus ($r = -0.6775$; $P \leq 0.01$) and with total nitrogen ($r = -0.7011$ $P \leq 0.01$) while it correlated positively with benthic biomass ($r = 0.6475$; $P \leq 0.01$).

Correlation of sediment silt was positive and significant with sediment total phosphorus ($r = 0.6195$; $P \leq 0.01$) and total nitrogen ($r = 0.6262$; $P \leq 0.01$) but was negative with benthic biomass ($r = -0.5910$; $P \leq 0.01$).

Likewise sediment clay also indicated positive correlation with total phosphorus ($r = 0.4560$; $P \leq 0.05$) and total nitrogen ($r = 0.4946$; $P \leq 0.05$) but was negatively correlated with benthic biomass ($r = -0.4482$; $P \leq 0.05$).

Table : 35 Estimates of correlation co-efficient between water parameters and benthic fauna at station IV

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	Temperature	1.000												
2.	Salinity	0.4850*	1.000											
3.	Diss. oxy.	-0.3032	-0.1654	1.000										
4.	pH	0.0774	-0.0510	0.3491	1.000									
5.	Turbidity	-0.1811	0.0054	-0.1462	0.0664	1.000								
6.	Nitrite	-0.3036	0.0662	0.0398	0.0124	0.2803	1.000							
7.	Nitrate	-0.2126	0.1865	0.4562*	-0.1738	0.0587	0.1419	1.000						
8.	Phosphate	0.0640	0.118	-0.1050	-0.0850	-0.3349	-0.0533	0.2323	1.000					
9.	Silicate	0.1778	0.3076	0.2323	-0.1086	-0.1240	-0.2066	0.2169	-0.0228	1.000				
10.	Ammonia	0.1027	0.2544	-0.0904	-0.2137	0.1647	-0.2681	0.0980	0.2489	0.2897	1.000			
11.	Pop. density	-0.3323	-0.6873**	0.2272	0.1041	0.2237	0.1804	0.0333	0.0125	-0.2447	-0.2488	1.000		
12.	Biomass	-0.1823	-0.2250	0.0758	0.0503	0.0025	-0.2093	0.0334	0.0521	0.0669	-0.2421	0.5253**	1.000	
13.	Species diversity	0.1401	0.4603*	0.0904	0.0986	-0.0173	0.2938	0.1568	0.1211	0.0340	0.3931	-0.5838**	-0.4219*	1.000

* = 1% level
** = 5% level

Table : 40 Estimates of correlation co-efficient between sediment parameters and benthic fauna at station IV

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10
1.	Sand	1.000									
2.	Silt	-0.9355**	1.000								
3.	Clay	-0.6051**	0.3598	1.000							
4.	Total organic carbon	-0.1109	-0.1667	0.1483	1.000						
5.	Total phosphorus	-0.6775**	0.6195**	0.4560**	-0.2104	1.000					
6.	Total nitrogen	-0.7011**	0.6262**	0.4946*	-0.2727	-0.8961**	1.000				
7.	Temperature	-0.3373	0.2591	0.2041	-0.2796	0.5518**	0.5502**	1.000			
8.	Population density	0.2193	-0.1041	-0.2711	0.1565	-0.4972*	-0.6090**	-0.1844	1.000		
9.	Biomass	0.6475**	-0.5910**	-0.4428	-0.0043	-0.6842**	-0.7498**	-0.0836	0.5253**	1.000	
10.	Species diversity	-0.1471	0.0293	0.2522	0.1010	0.2722	0.2499	0.0221	-0.5838**	-0.4219*	1.000

* = 1% level
** = 5% level

Correlation of sediment total phosphorus was negative with benthic total numbers ($r = -0.4972$: $P \leq 0.05$) and with benthic biomass ($r = -0.6842$: $P \leq 0.01$).

Sediment total nitrogen evinced negative correlation with benthic total numbers ($r = -0.6090$; $P \leq 0.01$).

STATION V (Table 36 & 41)

Water temperature was noticed to have positive correlation with salinity ($r = 0.4425$; $P \leq 0.05$;) while it indicated negative correlation with nitrate ($r = -0.4409$; $P \leq 0.05$).

Salinity showed negative correlation with dissolved oxygen ($r = -0.4581$; $P \leq 0.05$) and with benthic biomass ($r = -0.6686$; $P \leq 0.01$)

Correlation of nitrite with phosphate was positive and significant ($r = 0.4294$; $P \leq 0.05$).

Phosphate evinced positive correlation with benthic biomass ($r = 0.4066$; $P \leq 0.05$) and with species diversity ($r = 0.5980$); $P \leq 0.01$).

Silicate showed positive relationship with ammonia ($r = 0.4460$; $P \leq 0.05$)

Table : 36 Estimates of correlation co-efficient between water parameters and benthic fauna at station V

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	Temperature	1.000												
2.	Salinity	0.4426*	1.000											
3.	Diss. oxy.	-0.3932	-0.4581*	1.000										
4.	pH	0.2332	-0.1958	0.0152	1.000									
5.	Turbidity	-0.3767	-0.0093	0.0883	-0.2072	1.000								
6.	Nitrite	-0.4409*	-0.3308	0.1095	-0.3373	0.3706	1.000							
7.	Nitrate	-0.2565	-0.0020	0.1831	-0.4013	0.3477	0.2182	1.000						
8.	Phosphate	0.1032	-0.2986	0.0567	0.0080	0.2026	0.4294*	0.0443	1.000					
9.	Silicate	0.0095	0.0315	0.3306	-0.1432	0.0353	0.1938	0.3352	0.1321	1.000				
10.	Ammonia	-0.0039	0.0294	0.2990	-0.3122	0.0015	0.1830	-0.0093	0.3216	0.4460*	1.000			
11.	Pop. density	-0.2149	-0.0624	0.0760	-0.0987	0.3766	0.0013	0.0826	-0.0739	-0.2330	-0.1014	1.000		
12.	Biomass	-0.3291	-0.5686**	-0.0679	0.0798	0.1676	0.2604	0.0342	0.4066*	-0.1736	-0.1812	0.2326	1.000	
13.	Species diversity	0.0071	-0.2124	0.0141	0.0980	-0.0261	0.4004	-0.3102	0.5980**	0.2546	0.3069	-0.2408	0.2354	1.000

* = 1% level
** = 5% level

Table : 41 Estimates of correlation co-efficient between sediment parameters and benthic fauna at station V

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10
1.	Sand	1.000									
2.	Silt	-0.9277**	1.000								
3.	Clay	-0.6868**	0.3657	1.000							
4.	Total organic carbon	-0.4272*	0.2806	0.5191**	1.000						
5.	Total phosphorus	-0.3545	0.2824	0.3339	-0.0059	1.000					
6.	Total nitrogen	-0.5257**	0.4452*	0.4434*	0.0823	0.9552**	1.000				
7.	Temperature	-0.3005	0.2180	0.3242	0.3288	0.5632**	0.5874**	1.000			
8.	Population density	0.5257**	-0.4710*	-0.3936	-0.4547*	-0.4852*	-0.5769**	-0.1933	1.000		
9.	Biomass	0.2998	-0.1929	-0.3716	-0.0880	-0.1048	-0.1679	-0.1992	0.2326	1.000	
10.	Species diversity	0.1823	0.1663	-0.1310	-0.1566	0.2405	0.1532	-0.0221	-0.2408	0.2354	1.000

* = 1% level
** = 5% level

Sediment sand indicated negative correlation with total organic carbon ($r = -0.4272$; $P \leq 0.05$) total nitrogen ($r = -0.5257$; $P \leq 0.01$) and with benthic total numbers ($r = -0.5257$; $P \leq 0.01$).

Correlation of silt was positive with total nitrogen ($r = 0.4452$; $P \leq 0.05$) but was negative with benthic total numbers ($r = -0.4710$; $P \leq 0.05$).

Sediment clay showed positive correlation with total organic carbon ($r = 0.5191$; $P \leq 0.01$) and with total nitrogen ($r = 0.4434$; $P \leq 0.05$).

STATION VI (Table 37 & 42)

It may be seen that at Station VI, water temperature was negatively but significantly correlated with turbidity ($r = -0.5167$; $P \leq 0.01$) but was positively correlated with benthic biomass ($r = 0.6044$; $P \leq 0.01$) and with species diversity ($r = 0.4346$; $P \leq 0.05$).

Salinity evinced negative correlation with turbidity ($r = -0.5204$; $P \leq 0.01$) and with ammonia ($r = -0.4269$; $P \leq 0.05$).

Correlation of PH was negative with turbidity ($r = -0.4384$, $P \leq 0.05$) and was positive with species diversity ($r=0.4669$, $P \leq 0.05$).

Turbidity was found to have positive correlation with benthic total numbers ($r = 0.4148$, ≤ 0.05) while it showed negative correlation with biomass ($r = -0.4465$ $P \leq 0.05$) and species diversity ($r = -0.5110$; $P \leq 0.05$).

Table: 37 Estimates of correlation co-efficient between water parameters and benthic fauna at station VI

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	Temperature	1.000												
2.	Salinity	-0.0877	1.000											
3.	Diss. oxy.	-0.1618	-0.4014	1.000										
4.	pH	0.1922	0.0356	0.0354	1.000									
5.	Turbidity	0.5167**	-0.5204**	0.2265	-0.4384*	1.000								
6.	Nitrite	-0.1919	0.1533	-0.2655	0.2010	0.0087	1.000							
7.	Nitrate	-0.0468	-0.1653	-0.0058	0.0605	0.2446	0.5103*	1.000						
8.	Phosphate	0.0914	-0.1609	-0.1109	0.1213	0.0656	0.1989	0.4339*	1.000					
9.	Silicate	-0.0991	-0.0671	0.1784	-0.0353	0.1931	-0.0097	0.1959	0.3804	1.000				
10.	Ammonia	-0.0512	-0.4269*	-0.1286	-0.0543	0.2752	0.0678	0.0467	0.3659	0.1898	1.000			
11.	Pop. density	-0.1223	-0.2554	0.0918	-0.2046	0.4158*	-0.1925	0.2213	0.4877*	0.5748**	0.2895	1.000		
12.	Biomass	0.6044**	-0.1943	-0.2777	0.3911	-0.4465*	0.2272	0.3155	0.2740	-0.1996	0.1216	-0.1446	1.000	
13.	Species diversity	0.4346*	-0.0104	-0.2192	0.4669*	-0.5110	0.4904*	0.4546*	0.2503	-0.0561	-0.0549	-0.3597	0.8029**	1.000

* = 1% level
** = 5% level

Table : 42 Estimates of correlation co-efficient between sediment parameters and benthic fauna at station VI

Sl. No.	Parameters	1	2	3	4	5	6	7	8	9	10
1.	Sand	1.000									
2.	Silt	-0.9619**	1.000								
3.	Clay	-0.9077**	0.7583**	1.000							
4.	Total organic carbon	-0.3341	0.4075*	0.1663	1.000						
5.	Total phosphorus	-0.0119	-0.0319	0.0766	-0.0258	1.000					
6.	Total nitrogen	0.0539	0.0418	0.0629	0.2493	0.7173**	1.000				
7.	Temperature	0.2648	-0.3011	-0.1645	-0.0158	0.2255	0.3591	1.000			
8.	Population density	0.1253	-0.1048	-0.1358	-0.0744	-0.2235	-0.4487*	-0.0135	1.000		
9.	Biomass	-0.0258	0.0039	0.0563	0.0927	0.4376*	0.7096**	0.5073*	-0.1446	1.000	
10.	Species diversity	-0.2693	0.2893	0.1975	0.3820	0.4137*	0.8038**	0.2778	0.3597	0.8029**	1.000

* = 1% level
** = 5% level

Nitrite evinced positive correlation with species diversity ($r = 0.4905$, $P \leq 0.05$). Likewise, correlation of nitrate was also positive with species diversity ($r=0.4546$, $P \leq 0.05$).

Correlation of phosphate with benthic total numbers was positive and significant ($r = 0.4877^{*}$; $P \leq 0.05$).

Correlation of sediment total phosphorus was positive with benthic biomass ($r = 0.4376$; $P \leq 0.05$) and with species diversity ($r = 4137$; $P \leq 0.05$).

Sediment total nitrogen evinced negative correlation with benthic total numbers ($r = -0.4487$;$P \leq 0.05$) while it correlated positively with benthic biomass ($r = 0.7096$; $P \leq 0.01$) and with species diversity ($r = 0.8038$; $P \leq 0.01$).

Sediment temperature showed positive correlation with benthic biomass ($r = 0.5073$; $P \leq 0.05$).

Comparing the correlation co-efficient interrelationship of different hydrographical parameters among all the stations, positive correlation between temperature and salinity was noticed at stations I, IV and V whereas negative correlation of salinity with dissolved oxygen was observed only at sections I and V. Salinity showed positive correlation with ammonia at stations I and VI while negative correlation of salinity with benthic total number was observed at station I and IV. Dissolved oxygen indicated negative correlation with benthic biomass at stations I and V. Correlations between silicate and ammonia at stations III and V were positive and significant.

Correlation studies between sediment particle size and nutrients indicated negative correlation of sand with sediment total organic carbon (TOC) at stations I and V while sediment silt showed positive correlation with TOC at stations I and VI. Correlation of sediment sand with total nitrogen was negative at stations III, VI and V while the same stations showed positive correlation between sediment silt and total nitrogen.

Between sediment grain size and benthic population density, sand was found to have positive correlation with benthic total numbers at stations III and V and also with benthic biomass at stations III and IV. Positive correlations was also observed between sediment silt and benthic numbers at stations III and IV while the same relationship was noticed between silt and benthic biomass at stations III and IV.

A correlation among the sediment nutrients and also with benthic fauna, showed that sediment total phosphorus had positive correlation with sediment total nitrogen in all the stations and negative correlation with benthic total numbers at stations I, IV, and V.

DISCUSSION

DISCUSSION

Water has been the major resource for producing and cooling the high pressure, high-temperature steam used to drive the huge turbo-generators in a thermal power station. The cooling water, mostly returned to its source near the point of abstraction at a high temperature, changes the temperature regime of the receiving water. Changes of temperature have certain indirect effects by altering some of the physical properties of the water, notably the density, viscosity and the solubility of gases. Thermal power generation may also have effects on chemical constituents like oxygen, carbon dioxide, several other gases, calcium, pH, carbonates, metals, metal salts and organic matter. Biologically, since each species owns a particular thermal optimum, a change in temperature may lead to selection of species which are more tolerant to the near temperature and also may lead to the replacement of a desirable species by an undesirable one. The temperature is also found to influence the substrate materials and the distribution of sessile benthic organisms. The Tuticorin Thermal Power Plant is reported to discharge 115 million litres of cooling water into the adjacent Tuticorin bay. The impact of the thermal effluent discharge from TTPP on the water quality of Tuticorin bay with special reference to benthic community is discussed here.

Among all the meteorological parameters, rain fall in any climatic condition will have profound influence on the ecological characteristics. The rain along the Indian coast is represented mainly by South West monsoon and North East monsoon, the latter being prominent along the east coast especially

during the period from October to December. The rainfall pattern along the entire South east coast is similar during north east monsoon months (Murugan and Ayyakkannu, 1991). In the present study, the evaluation of rainfall data along the Tuticorin bay during the period from April 1990 to March 1992 showed high rainfall during north east monsoon months of October - December during both the years with other months particularly south west monsoon season indicating sporadic rainfall. Similar observations are also made by Malu Pillai (1962), Marichamy *et al.*, (1985) Mathew (1990) and Lal (1991) along the Tuticorin Coast.

Atmospheric temperature of Tuticorin coast is reported to be high during the summer months of April-June and low during the colder months of October-December with the maximum and minimum values noticed during April/May and January, months respectively (Victor and Velayuthan, 1987). Gopinathan and Rodrigo (1991) have also reported a similar pattern of atmospheric temperature while studying the primary production of Tuticorin waters, in the Gulf of Mannar area. The present study also reveals that summer months of April and June had maximum atmospheric temperature which declined to a minimum during the north east monsoon months of December-January during both the years. While it is well known that higher atmospheric temperature is caused by dry climatic conditions during summer seasons, the lowering of atmospheric temperature during monsoon months may be attributed to strong cold wind, high humidity and precipitation (Malu Pillai, 1962).

The surface water temperature regime in the Tuticorin waters is reported to exhibit a bimodal oscillation with the maxima during March-April and in September-October months and two minima during June-July and December-January months (Malu Pillai, 1962; Chandrasekharan and Sudhakar, 1968; Marichamy and Pon Siraimeetan, 1979; Marichamy *et al.*, 1985). While the surface water temperature maxima may be attributed to the gradual heating effect during the respective dry seasons, the declining trend may be owing to the on-set of colder weather and the commencement of north east winds after the month of October (Chandrasekharan *et al.,* 1967) thereby showing that the surface water temperature is influenced to a great extent by the atmospheric temperature as is also observed by Chacko *et al.*, (1954), Prasad (1957), Marichamy and Pon Siraimeetan (1979) and Gopinathan and Rodrigo (1991). Substantiating this, Marichamy and Pon Siraimeetan (1979) have stated that both the atmospheric temperature and surface water temperature along Tuticorin bay showed a steadily increasing trend during the winter period reaching a peak during the month of April declining thereafter to a low during December-January months. In the present study also it was found that, the surface and bottom water temperature of Tuticorin bay showed a peak during the summer months of April-May, declining thereafter to a minimum during June-July months again rising to a peak in September-October and decreasing gradually towards December-January months during the years 1990-91 and 1991-'92.

Water temperature is vitally important in determining the distribution, metabolism and life histories of aquatic organisms (Hines, 1978; Kinne, 1970;

Newell, 1965). One of the two physical characteristics of any aquatic habitat most altered by electricity generating installation is the temperature, the other being water movement. A rise in temperature has been considered to be an adverse alteration of the water quality and an alteration of even 1.0°C may affect the biota directly or indirectly (Naylor, 1965). The temperature rise in cooling water between the intake and outfall is usually in the range of 8.0 - 12.0°C though it may go up to 15.0°C to 16.0°C (Schubel and Marcy 1978). In the present case, station I which is situated near the thermal effluent discharging point showed a temperature range between 34.0°C and 42.2°C with a difference of 8.0°C. Station II, situated in the lower zone of about 300 m away from thermal effluent discharging point showed a temperature range between 31.1°C and 39.0°C with a difference of 7.9°C. At station III, surface water temperature was within a range 28.5°C to 36.8°C with a difference of 8.0°C. However stations IV, V and VI which are located about 750 - 1500 M away from TEDP have indicated the difference of only 5.0°C and below.

A comparison of temperature pattern among various stations showed that station I, situated only 100 meters away from TEDP has a higher thermal plume ranging between 34.0°C and 42.3°C when compared to 28.5°C and 33.0°C of station V which is located 1.5 K.M. away from TEDP. It may therefore be surmised that the temperature regime in the vicinity of thermal effluent discharge is influenced to a great extent by the cooling water discharge from the power plant. This is further substantiated by the fact that while in station II and III which are situated 300 meters away in the lower and upper zone respectively away from the TEDP also showed an increase in temperature of

7.9°C and 8.0°C, while stations IV, V and VI situated about 750 meters and 1.5 K.M. respectively from the TEDP indicated a difference of only 5.0°C and below, thereby showing the reduced effect of thermal effluent discharge. Confirming this view, Langford (1983) states that the warm effluent is normally thoroughly mixed within 300 - 400 m down stream of an out fall, resulting in an overall elevated thermal plume. Mukhopadhyay *et al.*, (1987) also have stated that the heated effluent discharged from the cooling plant of the thermal power station into the Hooghly estuary influences the estuarine water temperature down stream up to 400 - 500 meters during low tide and upto 100 meters up stream during high tide. Further, in the present case a comparison of the highest surface water temperature of 42.3°C recorded at station I during May 1991 with the lowest temperature of 33.0°C noticed at station V during the same month, also indicates that the surface water temperature at Station I was influenced by the thermal effluent discharge with a difference of 9.3°C than that of station V. This also leads to the conclusion that the effect of cooling water discharge decreases with the increase in distance from the TEDP, thus indicating the effect of mixing and dilution. Further, station II located in the lower zone with a higher temperature range of 31.1°C - 39.0°C was found to be more influenced by the tidal flow than that of station III located in the upper zone from the TEDP where the temperature range was low between 26.5 - 36.8°C.

The effect of cooling water discharge on the receiving water depends on many factors including dilution, water current, shape, size and construction of outfall, plant operating condition and maintenance programme (Langford,

1983). Nevertheless, the maximum discharge temperature at thermal power stations depends mainly on the intake temperature especially, if the ambient water temperature itself is high and it is also drawn from surface layers of the near shore waters (Thorhaug and Roessler 1977; Thorhaug, 1974; Kolemainen *et al.*, 1975). In the present study, a comparison of the maximum surface water temperature observed at various stations indicated that, station I had the maximum temperature of 42.3°C during summer month of May 1991, while during the same month, Station V indicated the lowest temperature of 33.0°C which is the maximum temperature of station V during the period of study. Considering the surface water temperature of station V as the ambient temperature by virtue of its lowest value, it may also be concluded that the increase in temperature experienced at station I may be attributed to higher ambient temperature, probably caused by the continuous discharge of thermal effluent.

Since, solar radiation is absorbed in the upper strata of water, the sea like any other water body tends to show thermal stratification especially during summer. According to Kinne (1967), ocean temperature range decreases with increase in depth. However, close inshore, there may be no stratification because of turbulence and tidal currents. Since the cooling water is generally abstracted from shallow coastal waters, where there may be thorough mixing due to tidal currents an almost similar temperature pattern at surface and bottom water may be expected. This may be reason accountable for the higher temperature noticed both at surface and bottom waters at station I. According to Nayler (1965) when thermal discharges are released to partly enclosed bays

or docks, plumes may mix or disperse slowly and high temperature may occur at the bottom. The clear demarkation between the surface and bottom water temperature discernible at station II and III, probably indicates such as a slow process of mixing of the thermal effluent. At stations IV, V and VI as is expected, the surface and bottom water temperature did not show notable variations.

A comparison of the surface water salinity at different stations showed that at station III, where the waste water is discharged had the lower salinity range between 22.00 ppt and 31.88 ppt. It is also noticeable that stations II, IV, V and VI had almost similar pattern of salinity ranging from 28.93 ppt to 36.93 ppt. However at station I, situated nearer to the TEDP, the salinity showed a higher profile ranging between 31.55 ppt and 36.95 ppt. This may be on account of the higher temperature regime prevailing in this area causing evaporation and increased salinity. Statistically also, a positive correlation was noticed between temperature and salinity at station I. This is further substantiated by the observation of Ahmed *et al.,* (1992) that there exists a positive correlation of salinity with water temperature at the out fall site of thermal effluent along the Kalpakkam Coast.

Seasonally, an evaluation of salinity level in the present study showed higher values during summer months of April and May declining to a minimum during the monsoon month of October-December invariably in all the stations. While the reasons for the higher salinity values may be attributed to factors such as evaporation, dominance of neritic water and lack of fresh water

in flow during summer months (Murugan and Ayyakkannu 1991; Nair and Ganapathy, 1986), the lower values may be due to the influence of inflow of terrestrial rain vater during north east monsoon months (Chandrasekharan *et al.*, 1968) or to current from north which brings in waters of low salinity (Chandrasekharan and Sudhakar, 1968). Similar observations are also made by Jayaraman (1954) and Malu Pillai (1962) along Tuticorin coast.

The surface and bottom waters among the stations showed lesser variations in the values of salinity except during the pre monsoon months of July-September which may be on account of the intrusion of neritic water as has also been observed by Murugan and Ayyakkannu (1991) along the Uppannar back water, South east coast of India. A comparison of the salinity level observed between the years in the present study indicated that the values were higher during the first year (1990-91) than during the second year (1991-92) probably caused by the lesser rainfall recorded during the first year.

It has been generally observed that the effect of salinity on the oxygen uptake is complicated because of the fact that the oxygen content of the water is inversely related to its salinity (Kinne, 1964a). A correlation of salinity with the dissolved oxygen at different stations in the present study has indicated negative correlation and this may probably be due to the influence of temperature which is reported to have direct relationship with salinity.

Oxygen has been considered to be one of the important constituents of biological significance which can be influenced by thermal power generating systems. The saturated concentration of oxygen is inversely proportional to the

temperature and it ranges from 14 mg/l at 0°C to 7.5 mg/l at 30.0°C (Macan, 1963; Kumar, 1981). The fact that high temperatures may be associated with the low concentration of dissolved oxygen particularly in areas receiving oxidizable effluents as well as heat has been established by Moore (1958) and Alabaster and Welcomme (1962). In the present study, an inverse relationship between water temperature and dissolved oxygen was noticed mainly at station I, II and III which are nearer to the thermal effluent discharging point where the bottom water dissolved oxygen was higher than in other stations. It may also be noticed that station I showed lower dissolved oxygen value of 3.43 to 4.33 ml/l when compared to that of other stations (3.33 to 5.10 ml). This may probably be due to the effect of thermal plume prevailing in this area since it is predicted that dissolved oxygen concentration may be reduced because of its lower solubility at higher temperature (Langford, 1983). A similar observation was also made by Nugent (1970) who has reported that the concentration of dissolved oxygen in the cooling water is decreased to about 1 ml/l as it passes through the plant and down the effluent canal in which the temperature noticed was higher than that of ambient water. Ahmed *et al.*, (1992) also have made similar observations along the Kalpakkam coastal waters. Concurrently, in stations IV, V and VI, the dissolved oxygen concentration showed higher values with corresponding lower temperature ranges.

Seasonally, it is noticeable that dissolved oxygen content estimated in the present investigation has indicated the maxima during the colder monsoon months of December-February with the minimum values obtained during the summer months of April-June both at surface and bottom waters thereby

substantiating the inverse relationship between dissolved oxygen and temperature. Statistically also, the variation in dissolved oxygen among the seasons are highly significant both at surface and bottom water.

An evaluation of the pH values obtained at different stations in the present study indicated that maximum values were obtained at station I thereby showing a positive correlation with temperature and negative correlation with dissolved oxygen. The pH values at Station II is also found to have negative correlation with dissolved oxygen. This may probably be due to the influence of increased temperature and high salinity leading to more of alkaline condition resulting in high pH. Sverdrup (1961) also states that below the minimum oxygen layer there is generally a gradual increase in pH. At station III, a comparatively low pH value was obtained with a simultaneous reduction in salinity, probably caused by the influence of fresh water liquid waste discharged from the TTPP in this region. It was also found that the pH in the present study exhibited a negative correlation with nitrite and ammonia and this may possibly on account of the increasing load of nutrients in the fresh water discharged at station III. The statement that distribution of pH is dependent on the concentration of ammonia in water by Stickney, (1979) holds good in this context. Stations IV, V and VI did not evince much variations in their pH values.

Turbidity is one of the important physical parameters of sea water which has a significant bearing on its productivity (Kinne, 1961; Kuriyan, 1974). According to Williams (1962), turbidity modifies the transmission of light

through a column of the sea water and the total extinction varies proportionately to the concentration of suspended solid material. Filter feeding organisms such as oysters are very sensitive to suspended silt and other substances and an increase in concentration of such substances may decrease the pumping rate of the filter feeding mechanisms (Lunz, 1938; Loosanoff and Tommers, 1948). Kastendick *et al.*, (1981) have stated that the heated effluent discharge causes the transport of bottom waters upward which carries large amounts of suspended materials from the bottom to the surface creating turbidity plume at the surface. In the present study, it is noticeable that station I located only 100 m away from TEDP has the lowest turbidity range (0.8 - 3.2 NTU at surface water and 1.00 - 2.40 NTU at bottom water). It is understood that cooling water at TTPP is sent through the filters and settled in the tank before being used for cooling purpose and the turbidity of intake water is thus minimized to some extent (Personnel communication). Further, since the thermal effluent is discharged over the years continuously at this region, the fine suspended particles must have been taken away from the discharging point by water current and this must have lead to the sandy nature of the bottom. The particle size noticed at Station I was also found to be dominated by sand (80.98 - 92.82%). Nevertheless, high turbidity values at station III (1.88 - 9.4 NTU at surface water and 2.40 - 10.00 NTU at bottom water) may be attributed to the entry of dense fresh water wastes.

Seasonally, pre monsoon and monsoon months have indicated higher turbidity values invariably in all the stations and this may be owing to the influence of coastal currents as is also observed by Satpathy *et al.*, (1986) along

Kalpakkam coastal waters. Turbidity in the present investigation is found to show positive correlation with water nutrients and this may be due to a thorough mixing of bottom nutrients and thereby releasing the nutrient to the surface water.

It is well known that inorganic nutrients of sea water such as nitrite, nitrate, phosphate, silicate and ammonia play an important role in the production and growth of phytoplankton. The formation of silicaseous shells of certain marine diatoms can also be influenced by the concentration of nutrients available in water (Atkins, 1926; Harvey, 1928). The influence of increased temperature on the nutrient concentration of the receiving water near the thermal power plants is a matter of interest. Raymont (1980) suggested that the increased productivity was the result of more efficient use of nutrients at higher temperatures. On the otherhand Tait (1981) has attributed the depressed phytoplankton production to the nutrient limitations caused by thermal discharge.

An evaluation of the nutrients such as nitrite, nitrate and phosphate at the surface and bottom waters of different stations clearly indicates their lesser concentration at station I and III which are nearer to the TEDP. Tait (1981) postulates that lesser concentration of nutrients may be due to their uptake for phytoplankton productivity. Nevertheless, in the present case, since the primary productivity values are also at a lower level at stations I and II, it is possible that the depletion in nutrients in water at stations I and II is not due to utilisation by phytoplankton, but is probably due to impact of thermal

discharge resulting in nutrient limitations and depressed phytoplankton production in the adjacent areas of TEDP. Tait (1981) also has stated that the rate of photosynthesis increases with rising temperature upto a maximum, but then diminishes sharply with further rise of temperature.

Among all the stations, station III, was found to have the higher concentration of nutrients which may be on account of the enrichment of this station with the liquid waste discharge from TTPP, for the liquid waste discharged from power plant also contains sewage waste rich in nutrients (Ross 1959; Tait, 1981). It may also be noticed that the nutrients at other stations did not show much variations, probably because of the similar range of the concentration making it difficult to detect the variations in the field (Langford, 1983).

Bottom water indicated higher values of inorganic nutrients than surface at all the stations. Gopinathan and Rodrigo (1991) also have observed slightly higher level of nutrients at the bottom water especially during November to January months probably because of the obvious reason of thorough mixing enabling the release of nutrients from the sediment.

Seasonally, it is discernible that post monsoon months of January tn March indicated higher values of nitrite concentration with pre monsoon months of July-September showing lower values. This is parallel to the report of Gopinathan and Rodrigo (1991) who have also reported single peak concentration of nitrite during February to May in the Tuticorin waters. High values obtained during post monsoon months in the present study could be

attributed to the nutrient run-off through terrestrial rain water and also the resultant increase in the level of excreta and decomposition of organic matter as is also reported by Venugopalan and Rajendran (1975) at Vellar estuary, East coast of India.

The distribution of nitrate and phosphate in marine water has close parallelism between their concentration (Sverdrup, 1961). According to Redfield (1934), elements such as nitrate-nitrogen and phosphate-phosphorus maintain a constant ratio in the sea water, since they are returned to the water in the same proportion in which are removed. In the present study also, it is noticeable that nitrate indicated a positive correlation with other nutrients such as phosphate and silicate.

Seasonally, the nitrate concentration showed higher values during summer and monsoon periods, probably caused by the evaporation and terrestrial run off respectively. The values were low during pre monsoon months, which may be due to routine utilization. (Tait, 1981).

A comparison of the nitrate content between the surface and bottom water indicated high values in bottom water and this may probably be caused by the release from the sediment layer to the bottom layer of water. While studying the nutrient enrichment between coastal marshes and coastal waters, Nixon (1980) has also reported higher values of nitrate in bottom water than surface water.

Seasonally, the present observation evinced irregular pattern of phosphate levels indicating higher values during post monsoon months. Bottom water indicated higher values of phosphate than the surface water. Gopinathan and Rodrigo (1991) also have observed slightly higher level of phosphate at the bottom water especially during November - January months probably because of the obvious reason of thorough mixing enabling the release of phosphate from the sediment.

The concentration of silicate in the surface waters in general is reported to be in reduced concentration because of the utilisation by diatoms (Raymont, 1980). However, according to Atkins (1926) and Harvey (1928), the formation of silicious shells of certain marine diatoms can be influenced by the concentration of nutrients available in sea water. Among the different stations studied under the present investigation, silicate concentration was found to be at a lower level at station II and higher level at station III. While the minimum values obtained at station II may be attributed to lack of sediment influx caused by the discharge of bottom ash, the maximum values at station III may be due to the inflow of liquid waste rich in nutrients. It may also be added that all the other stations except station III showed almost a similar range of silicate concentration.

Seasonally, although the silicate concentration in the present study did not evince a definite pattern during the different seasons, monsoon months were found to indicate slightly higher values and this may be on account of the influence of terrestrial rain water run off and the associated low salinity in the

surface waters. (Sankaranarayanan 1969; Propp, 1977) or to a high degree of turbulence releasing silica from the sediments into the bottom waters (Sverdrup, 1961). However, during the present study, water temperature and salinity have not shown any statistical relationship in most of the stations with silicate probably due to the lesser fluctu'tions noticed.

The ammonia is generally formed in the aquatic systems by the excretion of organisms and the decomposition of organic nitrogenous materials. The main inorganic forms of ammonium can be utilised as nitrogen sources by the majority of algal species. There are advantages in terms of energetics when nitrogen is taken up as ammonia since this form can be used directly in the synthesis of amino acids (Cooper, 1937). In this study, the ammonia estimated at various stations indicated higher range at station III (0.25 µg at/l - 0.93 µg-at/l surface and 0.88 µg at/l -1.10 µg-at/l at bottom) with other stations IV, V and VI indicating narrow variation both at surface and bottom waters. According to Stickney (1979), nitrification may be more significant in certain micro-environments where ammonia is being released in the decomposition of organic material. In the present investigation also, it is possible that the higher concentration of ammonia recorded at station III may probably be due to the influence of liquid waste discharge which also contain domestic sewage because addition of sewage can increase the release of nutrients (Tait, 1981). It may also be noticed that the ammonia concentration in other stations indicated an almost a similar pattern of distribution though with comparatively elevated concentration in the bottom waters of station I. This may be attributed to factors such as high density of gastropod population and

sandy nature of the bottom with reduced nitrogen fixing process. Besides, elevated temperature and pH also might have contributed to the marginally higher concentration of ammonia since the state in which ammonia occurs in water is mainly related to temperature and ionic strength of solution (Mayo, 1971).

The distribution of ammonia in the present study did not show a definite pattern of distribution during different seasons. However, it may be noticed that ammonia content was more during summer season in most of the stations, which may be attributed to the effect of movement and mixing of water thus indirectly influencing the release of nutrients to the eutrophic level (Tait, 1981).

The level of primary production in an aquatic system can be used as a tool to estimate the standing crop of phytoplankton community (Thangaraj, 1984). Primary productivity varies considerably in proportion to environmental parameters such as light intensity, turbidity, water temperature and inorganic nutrients available in the water (Raymont, 1980). The present study showed the highest gross and net productivity at station IV and the lowest range at station I. The high value of primary production noticed at station IV may be attributed to the release of rich inorganic nutrients from the sediment since the highest sediment nutrients was also recorded at this station. It is also noticeable that eventhough, station III had higher nutrients, the primary productivity noticed was of a low order probably an account of higher turbidity recorded at this station. Likewise at station I, the primary productivity noticed

was comparatively low, which may be because of the higher water temperature recorded, since temperature beyond the optimum level can inhibit release of nutrients (Tait, 1981). Further Langford (1983) also has stated that the rate of photosynthesis will fall if the water temperature increases above the optimum range. Obviously, the primary productivity also showed higher values during the summer months seasonally. This is in agreement with the statement of Manikandavelu and Ramadhas (1994) and Gopinathan *et al.*, (1994) that summer months from October to December generally exhibited higher values of primary production along Tuticorin coastal waters, South east of India. Nevertheless, at station I summer months indicated lower values, which may again be attributed to the impact of extremely higher temperature on the productivity..

The proportion of sand, silt and clay is of importance for the distribution of many organisms since the porosity and interstitial space are directly controlled by the relative abundance of different sized particles and these parameters are critical for organisms within the sediment. Food availability to the benthic organisms is related to sediment particle size for many deposit feeders (Driscoll 1964). Among the sand, silt and clay particles, silty sediment is understood to accommodate a more diversified benthic fauna by virtue of the rich nutrient contents in contrast to the sandy bottom which can hold lesser bottom fauna and reduced retention of nutrients. In the present investigation, a comparison of the different sediment particles of the different stations indicated that stations I, III and VI were found to have more sand component of 80.98 to 92.82% with the silt and clay forming 5.28 to 13.89 and 3.31 to

6.11% respectively. The reason for high sand content at Station I may probably be due to the continuous discharge of thermal effluent at this site, which could have enhanced the devastation of finer particles through water movement resulting the increased level of sand component. The sediment texture is dependent on the size, shape and degree of packing of particles and these are controlled by water movement (Frenchel, 1972, Webb 1969; Gray, 1974). Among all the stations, the lowest level of sand content (51.40 - 76.16%) was recorded at station V with the highest percentage of silt (15.23 - 32.61%) and clay 7.40 - 17.71%). Likewise, station IV also showed lower sand content (62.96 - 86.19%) while silt (8.49 - 29.16%) and clay (8.49 - 12.11%) evinced higher proportions when compared to that of stations I, III and VI. Higher levels if silt and clay contents noticed at stations IV and V may be owing to the influence of fresh-water inflow which tend to bring large volume of organic load from terrestrial source through korampallam and uppar creeks situated near to stations IV and V respectively during monsoon months.

Seasonal differences in the percentage of sand, silt and clay fractions did not indicate significant variations at stations I, III, V and VI. However, station IV showed more of sandy substratum during pre monsoon and monsoon months while during post monsoon and summer months, it was mainly sandy silt in nature. Since station IV is located near to the Korampallam creek, the heavy rain followed by the entry of terrestrial run-off during monsoon months must have enhanced the deposition of sand particles at this station and reason for the silty-sand during summer and post monsoon months may be due to the flocculation and settling of fine fractions at the bottom. This is in conformity

with the reports of Sivakumar *et al.*, (1983) and Veerayya and Murty (1974) who have also observed a similar trend along the Vellar estuary, east coast of India and Vembanad lake south west coast of India respectively.

Estimation of total organic carbon (TOC) in the sediment is an important tool in studying the fertility and productivity of any aquatic environment. A series of reactions either chemical or biochemical generally take place within the bottom soil resulting in the release of nutrient elements to the overlying water. The dynamicsof these processes greatly influence the growth and abundance of micro and macro benthic organisms which serve themselves as food for fish and prawns. Organic carbon content is found to be more in silt dominated type of sediments exhibiting an inverse relationship with grain size (Kalesha 1979, Seralathan and Seetaramaswamy, 1979; Vander Leoff *et al.,* 1981; and Prabhu and Reddy, 1987). In the present study also high level of total organic carbon was noticed in the silty sand substratum at stations IV and V with lesser organic carbon content in the sediment of lesser silt component at station I, III and VI. This is in conformity with the statement of Jones (1950) that finer particles have higher water holding capacity enabling retention of decaying organic matter which, on bacterial decomposition enriches the sediment with nutrients.

The sediment total organic carbon (TOC) recorded in the present investigation was found to be of a lower range when compared to the values obtained from estuaries. In the Vellar estuary (Sivakumar *et al.,* 1983) have reported a TOC range of 0.90 to 17.0 mg/g while in the Cochin back water, the

TOC range recorded was between 7.4 and 38.4 mg/g (Sankaranarayanan and Panampunnayil, 1979). In the Coleroon estuary, the values obtained were within a range of 1.0 - 13.8 mg/g (Jagadeesan and Ayyakannu, 1992). On the other hand, the TOC recorded in the Tuticorin bay of present study was of a lower level ranging between 0.55 - 4.35 mg/g. While the higher range of TOC reported in the estuaries may be on account of the luxuriant organic productivity of the overlying water mass and nutrients brought to the estuaries by terrestrial run-off during monsoon months, the lower values obtained in the bay may be due to the restriction of land drainage during the North east monsoon months with hot seasons prevailing during other months of the year.

Seasonal values of sediment TOC in the present study has indicated higher values during summer and post monsoon months while pre monsoon and monsoon months evinced lower values. This is in agreement with the report of Nair *et al.*, (1983) and Thangaraj (1984) on their studies in the Ashtamudi estuary and Vellar estuary respectively. The seasonal variation may also be related to the plankton activity in the overlying water, the humic material brought in from the land and also to the oxidation of organic matter by organisms living in the bottom (Sankaranarayanan and Panampunnayil, 1979).

Sediment total nitrogen indicated higher values at station V which may be due to silty-sand nature of the sediment. In other stations where the sand component dominated, the values of total nitrogen were comparatively low. This observation is in agreement with the statement of Rittenberg *et al.*, (1955)

who has opined that, the particle size of the sediment is an important factor which controls the total nitrogen content of the sediment and that the finer sediment contains more nitrogen than the coarser sand. The reason for this may probably be attributed to the trapping of detritus by finer particles, resulting in an increased bacterial activity.

As has been noticed in TOC, the distribution of total nitrogen in Tuticorin Bay was of lower level when compared to the higher values reported in Vellar estuary (Sivakumar *et al.*, 1983), marine zone of Vellar estuary (Thangaraj, 1984) and in the Mangalore coast (Reddy and Hariharan, 1986). The reason for such high values of total nitrogen reported was attributed to high organic production and the inflow of domestic and industrial wastes. The comparatively lower values obtained in the present investigation may be owing to the lack of organic load from the terrestrial source to the Tuticorin Bay. As in TOC the total nitrogen and C/N ratio also showed higher values at station III and lower values at station I, the reasons attributable being influence of terrestrial run-off and oxidation of organic matter at station III and sandy nature with resultant reduction in the oxidation of organic matter at station I.

The seasonal values of sediment total nitrogen did not indicate much variations. Nevertheless, summer months evinced higher values and pre monsoon and monsoon months indicated lower values thus showing a parallel relationship with the TOC of the sediment.

Although C/N ratio did not indicate notable seasonal variations, pre monsoon months showed higher values while summer evinced lower. The reason for lower range during summer months may be due to oxidation of organic matter leading to decreased C/N ratio.

N/P ratio was noticed to have lesser fluctuations in all the stations, the values varying between 2.47:1 (Station III) to 5.66 (Station I). Sen Gupta (1976) has reported an N/P ratio 13.8:1 for natural plankton and 18.2:1 for culture plankton. Rettenberg et al., (1955) have reported low N/P values for the sediments of catalina, Santa Barbara and Santa Monica basins as 5.8:1, 3.3:1 and 1.4:1 respectively. The low N/P ratio observed in the present study thus clearly indicates that the major portion of the phosphorus in the sediments may be of abiogenic origin.

Seasonal values of N/P ratio did not indicate a definite pattern in all the stations. However, lower N/P was noticed during monsoon months while summer showed higher. This is in conformity with the results of Sankaranarayanan and Panampunnayil (1979) and Ghosh and Choudhary (1989). The high N/P ratio recorded during summer months could be deduced to the decomposition of planktonic material causing a release of high organic content into the soil. Similar observations were also made by Sivakumar (1983) in Vellar estuary, South East coast of India.

Results of sediment temperature in the present investigation has indicated maximum of values (32.8-40.0°C) at station I while other stations showed comparatively low values. The higher sediment temperature at station

I may be on account of the continuous flow of heated water discharge. It is possible that the higher temperature prevailed in bottom water at station I has influenced the temperature of sediments also. Seasonally, summer months indicated maximum values, with the monsoon and pre monsoon recorded minimum values, thus exhibiting a parallelism similar to the trend of water temperature.

There is an increasing awareness of the usefulness of benthic community in the detection and monitoring of coastal and estuarine changes. Reish (1972) has stated that being sessile and borrowing in habit, the bottom living organisms are the major casualties of any major environmental or man made changes. Heat, a significant form of pollution is known to enhance all the biological activities resulting in increased oxygen demand of the organisms. Concurrently, a rapid destruction of organic matter results with a limited selection of organisms in thermally polluted areas. Using the quantitative and qualitative site specific data that benthic infauna provide, it is also possible to establish regulatory criteria for water quality based on values of benthic variables such as density, biomass and diversity.

Species composition of benthic organisms can vary depending upon changes of certain environmental parameters like water temperature, salinity, dissolved oxygen, sediment texture and food availability (Humprey, 1972; Kuriyan, 1977; Harkantra *et al.*, 1980; Anzari *et al.*, 1986; Sarala Devi, 1986; Coles *et al.*, (1990). Thorhaug and Roessler (1977) while studying the impact of thermal effluent on the biota of Biscayme bay have reported that the sea

grass community *Thalassia Spp.* and associated organisms changed in species composition, diversity and density both seasonally and annually thus showing the influence of high water temperature caused by thermal effluent discharge. Vernberg and Vernberg (1972) have observed that when potentially lethal thermal extremes are being experienced by a mobile animal, it may seek a more preferred temperature while the less mobile and sessile animals may use some functional ploy to survive. In the present study, it may be noticed that station I was dominated by the occurrence of only one species of the gastropod *C.fluviatilis*. This indicates that other organisms which are very much sensitive to the higher water temperature range (34.3°C - 42.3°C) might have moved away from the area with the more tolerant *C.fluviatilis* surviving near the TEDP. Emphasizing the temperature tolerance capacity of *C.fluviatilis*, Fernando *et al.*, (1983) have stated that the species occurs more in numbers during peak summer months in Vellar estuary, South east coast of India. While studying the behavioural responses of gastropod animals such as *C.repidula, C.fornicata* and *Nerita tessetata*, Fraenkel (1960), Wilkens and Fingerman (1965) and Newell and Kofoed (1977b) have observed that they can withstand wider changes of water temperature.

Pfitzenmeyer and Drobeck (1967) and Gray (1974) have stated that, molluscan organisms are capable of existing even at higher temperature since they have certain adaptive mechanisms of burrowing in the sediment, forming cluster etc., besides certain physiological adaptations. According to Vermeij (1973) with the approach of stressful high temperature conditions, less mobile and sessile animals may adapt certain behavioural responses such as

clustering where the temperature of the animals of the centre may be 5-10°C lower than the ambient temperature. In this study also, it is noticed that *C.fluviatilis* formed groups or clusters at Station I. One of the other adaptations exhibited by *Cerithedia spp* against extreme desiccation and temperature is the development of comparatively slender and larger shells (Vermeij, 1973). *C.fluviatilis* individuals in the present case at station I were found to be slender and larger when compared to the shells of the species in other stations.

Parulekar *et al.*, (1980) have reported that the intertidal *C.fluviatilis* was found more in numbers even under low saline condition along the Goa coast, while Fernando *et al.*, (1983) have reported high occurance of same species at high saline condition along Vellar estuary. In the present study, *C.fluviatilis* is the only species noticed at all the stations under varying saline conditions thus once again confirming the tolerance capacity of *C.fluviatilis* to wider fluctuations in salinity.

Among all the stations, gastropod individuals were found dominantly at stations I, III and VI where the bottom was sandy, while stations IV and V were dominated by crustaceans and polychaetes with more of silt and clay in the sediment. At station VI in addition to the gastropods, crustaceans also constituted a major component of the benthic fauna. It has already been established that sediment texture plays an important role in the distribution of benthic organisms (Damodaran, 1973; Harkantra *et al.* 1980; Varshney *et al.*, 1988). On the other hand, silt clayey and sandy clayey bottom were noticed

to have more polychaetes and crustaceans by virtue of the soft nature particles and rich supply of organic matter (Parulekar, and Dwivedi, 1974; Harkantra and Parulekar, 1987). Harkantra *et al.*, (1982) have stated that the polychaete species such *Turbellaria spp* are restricted only to silty clay and clayey sand substratum. In the present context also, stations IV and V with more of silt and clay sediment were found to have more of polychaetes and crustaceans. From the present observation, it may therefore be concluded that, the seston feeding animals such as molluscs were restricted to sandy areas of low silt and clay proportion, with the detritus and deposit feeders preferring more of muddy areas.

The distribution and density of benthic organisms in a particular locality is dependent on various environmental parameters like water temperature, salinity, dissolved oxygen, sediment particle size and on biological factors like food availability and prey-predator relationship. According to Vernberg and Vernberg (1972), any one factor such as water temperature, desiccation or salinity may not reach a critical lethal level in the field but the debilitating sub-lethal effects in combination with other adverse factors such as higher temperature and salinity can prove to be lethal. It has also been found that these factors may have short-term as well as long term effect not only on the adult but through the various developmental stages also thus affecting the distribution of the benthic population to a considerable extent.

Of the various environmental factors, that influence the density of benthic fauna, the temperature plays a decisive role either directly affecting

the metabolic rate of the benthic organisms or through the combined effect of salinity and light. High temperature regime can alter the normal physiological functions of aquatic fauna by creating stress to the organisms and affecting their population density (Kinne, 1961). In the present investigation, the density of macrobenthic organisms has been found to be as low as 430 nos/m^2 at Station I where the temperature range was 34.3°C - 42.3°C. Evidently in other stations, the density ranged up to 4935 nos/m^2 (Station III) where the temperature range was only 28.5°C - 36.5°C, thus showing that temperature may be one of the factors influencing the density of benthic organisms. Further, statistically also, it is found that, station I showed negative correlation between total number of benthos and temperature while other stations did not indicate any such significant relationship.

Several studies have demonstrated a correlation between the salinity tolerance limit and distribution of benthic organisms (Seshappa, 1953; Pauli Bagge, 1969; Kuriyan, 1972; Coles and Mc Cain, 1990). Parameters such as salinity and temperature are found to interact to influence the distribution of benthic animals (Jones, 1950; Bullock, 1955; Kinne, 1967; Wade, 1972; Evans *et al.*, 1986). In the present study at station I, salinity indicated a negative correlation with benthic density which may be because of the wider fluctuations noticed in the values of salinity at this station. This is in agreement with the report of Wade (1972) who has stated that the benthic communities may result in lower densities if there is a physiological stress due to fluctuations in the salinity values. Apart from station I, at station IV also, the statistical correlation between salinity and population density was found

to be negative and this may be on account of the influence of terrestrial rain water through Korampallam Creek which is situated adjacent to this station thus causing fluctuations in the salinity values especially during monsoon months. However, in other stations like II, V and VI, no significant statistical relationship was observed between salinity and benthic faunal density.

Oxygen levels greatly influence benthic species distribution (Gallardo, 1963; Spotte, 1979). Organisms inhabiting soft substratum are typically exposed to the low oxygen levels. A decrease in oxygen content will inhibit pumping rates and feeding in tubiculous worms, crustaceans, polychaetes, molluscs and lower chordates (Vernberg and Vernberg, 1972). However, in the present study, no statistical correlation was noticed between dissolved oxygen and population density which may probably be due to the uniform distribution in the values of dissolved oxygen at different stations.

Turbidity may be a limiting factor for the survival and distribution of benthic organisms especially of suspension feeders (Holme, 1961). However, in the present study, although the turbidity values observed was low at station I, it did not show any statistical relationship with benthic fauna.

Although, the distribution and density of benthic organisms in a particular locality is dependent on various environmental parameters, the particle size of sediment is also a major factor which can determine the population density of benthic faunal group (Bloom *et al*, 1972; Brodovsky, 1964; 1965). Clarke and Brownell (1973) have pointed out that sediment particle size is considered to be the most important parameter which can significantly

influence the density of benthic faunal composition. Newell (1965) also has stated that the population densities of bottom fauna, sediment grain size and organic carbon concentration are strongly inter-related and the highest density of deposit feeders occurred in areas of fine grained sediments and of high levels of organic carbon. According to Tait (1981) larger particles are more difficult to displace and ingest and hence are less populated whereas in soft mud organisms can burrow through pushing the particles aside. However, in the present investigation, the population density noticed was higher at Station III (1190 no/m^2 -4935 Nos/m^2) and at Station VI (2071 no./m^2 - 3921 no./m^2) where the sediment had 78.15 - 91.77 and percentage of sand respectively. This may be because of the dominance of the molluscan group, *C.fluviatalis* at station III and *T.gracilis* at station VI.

Examining the feeding response of inter-tidal gastropod *Hydrobia ulvae*, Barnes (1959) also have concluded that there are other environmental factors than sediment particles that influence the distribution of benthic organisms. In the present study, dissolved oxygen and turbidity did not show any significant relationship with the density of bottom fauna. On the other hand, salinity within a range of 31.53 ppt - 36.98 ppt and water temperature ranging between 34.33^{oC} and 42.3°C indicated negative correlation with the density of benthic population at station I. Therefore, it may safely be concluded that the lower density noticed at station I may be due to the influence of higher water temperature and salinity, for temperature and salinity interact to influence the distribution of benthic organisms.

Species diversity is a measure of the number of Species present and their numerical abundance in an area. The mechanisms responsible for the fluctuations in species diversity is still a matter of dispute. Various factors such as time (Fischer, 1960; Simpson and Dutaites 1981) climatic stability (Klopfer, 1959) spatial heterogeneity (Simpson and Dutaites 1981), competition (Dobzhansky, 1950) and predation (Paine, 1966) were found to influence the species diversity. Changes in the environmental parameters such as water temperature, salinity, dissolved oxygen and sediment particle size can adversely affect the distribution and survival of many bottom living organisms thus altering their diversity (Kinne, 1970).

According to Tait, (1981), low diversity and higher population levels of a few organisms denote some major stressful conditions eliminating many species but promoting survival of a few and that the species diversity can be used as an index for assessing a stressful environment. In the present investigation, water temperature and salinity at station I showed negative correlation with species diversity although it was not statistically significant. However in other stations IV, V and VI, species diversity was found to be high coupled with lower temperature and salinity thereby emphasizing the impact of stressful condition of temperature and salinity at the station I situated nearer to TEDP.

That particle size of the substratum can also influence the diversity of benthic fauna was stated by Sanders, (1958) and Christei (1975). In the present study, station I where the bottom was sandy in nature had the lowest

benthic faunal diversity with the dominance of single species *C.fluviatilis*. While station IV and V where the bottom was silty - clayey had higher diversity values. However station III and VI inspite of the sandy bottom had higher diversity when compared to that of station I. This also leads to the conclusion that low diversity at station I was caused not only due to sandy nature, but due to the stressful condition caused by higher temperature and salinity

Benthic biomass of an area has a significant bearing on determining the fishery resources of that region (Prabhu and Reddy, 1987). Arntz (1980) studying the association of benthos with demersal fisheries concluded that they form food items for fish of commercial value. In any aquatic environment, the biomass of benthos can vary considerably based on their distribution and density. Environmental characteristics such a hydrographical and sediment parameters may have an important role to fix the total benthic biomass of any aquatic ecosystem (William, 1981). Benthic biomass may be altered according to the fluctuations of temperature, salinity, dissolved oxygen and sediment texture (Geddes, 1976; spotte, 1979; Saila 1976; Singh, 1987). In the Present study, the water temperature and salinity showed negative correlation with benthic biomass especially at station I while in other stations, there was no significant relationship noticed. This clearly indicates that the upper range of temperature and salinity might have devasted many organisms at this station thus decreasing the biomass value. Srinivasan (1982). Sugunan (1983) and Singh (1987) studying the effect of salinity on benthic biomass in prawn culture fields stated that a gradual decrease in the values of benthic biomass

was noticed during the onset of monsoon season probably caused by the sudden change in salinity. Similar inverse relationship between salinity and benthic biomass was also reported by many authors (Pauly, 1975; Geddes, 1976; Williams, 1981).

The number of species, abundance of biomass and composition of benthic macrofauna was found to change abruptly at 2.0 mg/l of oxygen concentration (Naylor, 1965). However, Spotte (1979) stated that the dissolved oxygen content of more than 3.0 ml/l may note be a limiting factor for benthic animals. In the present case, the benthic biomass was positively correlated with dissolved oxygen only at station VI and this may be due to the highest biomass value noticed at this station with the dissolved oxygen value ranging upto 4.88 ml/l. It may also be noticed that other stations did not indicate any statistical relationship. Further, the dissolved oxygen content noticed at various stations was above 3.0 ml/l throughout the period of study thus showing that dissolved oxygen did not act as a limiting factor on benthic biomass value in the study area.

In Cochin backwaters Desai (1971) has observed more number of molluscan individuals when the sediment was dominated by sand particles. According to Saila (1976), the highest biomass in a benthic environment was associated with coarse grained sediment which favours the presence of more number of suspension feeders such as molluscan organisms. In the present study also, the benthic biomass indicated higher values in order of abundance at stations VI, IV and I where the bottom was sandy in nature. In these

stations, the gastropod organisms were of high occurrence probably because of their preference for a sandy bottom. Nevertheless, at station V, the biomass noticed was of lower value with the presence of less gastropods and relatively more polychaetes and this is in corroboration with the higher proportion of silt and clay present in the sediment. It is possible that filter feeding organisms such as gastropods might have moved away from the clayey substratum thus adopting an evassive mechanism so as to escape the clogging of their feeding apparatus with clay (Sanders, 1958; Christie, 1975). The positive correlation evinced by the benthic biomass with sediment sand particles and negative correlation with silt and clay statistically at stations IV and V substantiate the above observation.

An evaluation of the species richness (SR) and species evenness (SE) at different stations showed that station I which is located nearer to the TEDP had low species richness (0-0.31) and low species evenness (0-0.26) with the major representation of the gastropod *C.fluviatilis*. On the other hand, at stations IV and V, these values were found to be high (SR = 1.47 - 2.62 and SE = 0.32 - 1.05 at Station IV and SR = 0 - 1.27; SE = 0.41 - 1.11 at Station V. with the representation of more of benthic organisms. Since it has been established that parameters such as benthic density, diversity biomass, richness and evenness are inter related and are subject to the influence of various biotic and abiotic factors, the values observed in the species richness and evenness at Stations I, IV and V may be attributed to tolerance, evasion and other adaptations developed by these organisms.

CONCLUSION

Among the various maritime states of India, Tamil Nadu with an estimated fish potential of 3.25 lakh tonnes occupies the fourth place in the marine fish production of the country. (Dharmaraja *et al.,* 1987). Tuticorin fisheries harbour is one of the major fisheries harbours of the state contributing to about 33,972 tonnes of fish (CMFRI, 1994) of which the major portion is constituted by demersal fishes, like silver bellies, scianids, perches and elasmobranches. Besides, Tuticorin water is also suitable for culture of valuable penaeid prawns, edible oysters, pearl oysters and other shell fishes. It is an established fact that the abundance of benthic organisms has direct correlation with the demersal fish catch (Prabhu and Reddy, 1987). An alteration in benthic ecology can affect the marine fish production in general and demersal fishes in particular.

The TTPP is reported to discharge 115 million litres/day of thermal effluent with the production of 630 MW electricity. It is also proposed that the TTPP will increase its electricity production upto 1550 MW in near future. Proportionately, the effluent discharge rate will also be escalated.

The present study indicated the prevalence of higher water temperature range between 34.3°C and 42.3°C upto 100m distance from the effluent discharging point. This condition is found to render the ecosystem unsuitable for the settlement of many organisms except for the survival of the heat

tolerant gastropod *C.fluviatilis*. Station II, which is continuously exposed to the deposition of bottom ash is found to be devoid of benthic organisms. Since, the deposition of bottom ash is a continuous process, it is possible that animal life in the area is greatly affected.

The generation of electricity is very important in order to meet the electricity demand from various industrial and agricultural sectors. At the same time the life of aquatic organisms and ecological balance are also equally important from an environmental conservation point of view. Therefore, it is very essential that appropriate remedial measures are resorted to inorder to protect marine life from the stresses caused by thermal pollution.

The usage of warm water effluent for aquaculture practices is of recent interest and generally is in practice in temperate countries (Langford, 1983). In tropical countries like India, where the water temperature is nearer to lethal limit especially during summer months, the scope for usage of heated effluent for aquaculture purposes is limited. Therefore, it is suggested that the thermal effluent can be diverted into a confined area and after cooling the effluent there, the same water can be recycled and used for cooling the condensers.

Dumping of the bottom ash directly into the sea is a long term problem especially for the recruitment of native species in this region. From the present study, it is found that a large extend of bay area is being utilized for the disposal of bottom ash making the area devoid of any trace of animal life in the bottom. Since, the bottom ash is an indispensable part of thermal power

stations, it is suggested that profitable use of bottom ash be made in the production of building materials such as bricks and cement which will help in a long way in meeting the ever increasing demand of construction materials.

SUMMARY

SUMMARY

1. The present investigation on the "Effect of thermal effluent on waterquality in relation to benthic community"was carried out for a period of two years from April 1990 to March 1992.

2. The study was conducted at Tuticorin bay, Gulf of Mannar, East coast of India, where the Tuticorin thermal power plant is discharging the thermal effluent into the adjacent bay water.

3. A total of six stations was fixed at different distances from the thermal effluent discharging point (TEDP) with a view to assess the impact of thermal effluent on hydrographical parameters, sediment particle size, nutrients, and benthic faunal community.

4. The study area received a total rainfall of 577.8 mm during the year 1990-1991 and 400.5 mm during 1991-92 with the peak rainfall noticed during north east monsoon months of October, November and December.

5. Atmospheric temperature indicated higher values during summer months of April, May and June and lower values during monsoon months of October to December during both the years.

6. Water temperature showed bimodal oscillation with two maxima during April-May and September - October and two minima during June-July and December - January during both the years under study.

7. Among the various stations, both surface and bottom water temperature were at the maximum range of 36.0°C to 42.3°C and 34.3°C to 42.0°C respectively at station I which is close to the thermal effluent discharging point. The temperature regime declined gradually in the successive stations reaching a minimum range of 28.0°C to 32.8°C at surface and 27.8°C to 32.0°C at bottom waters at station VI.

8. The present study also indicated higher range of water temperature with wider fluctuation only at stations, I, II and III which are located 100m, 300m in the lower zone and 300m in the upper zone respectively away from TEDP. Stations IV, V and VI situated 750m, and 1.5m away from TEDP did not show notable fluctuations in the values of water temperature. This shows that the effect of cooling water discharge decreases with the increase in distance from the TEDP, thereby indicating the process of mixing and dilution of thermal effluent with the receiving water upto a certain distance

9. Surface and bottom water temperature showed almost a similar range in their values at station I while station II and III indicated higher values at the surface and lower values at the bottom. This is because of thorough mixing of thermal effluent with the receiving bay water at station I and the slow process of mixing of thermal effluent with the bottom water at stations II and III.

10. Temperature showed positive correlation with salinity and negative correlation with dissolved oxygen mostly at all the stations.

11. Salinity showed the highest range at station I and the lowest range at station III. The high value of salinity observed at station I may be on account of the higher water temperature prevailed there causing evaporation. Salinity also evinced positive correlation with water temperature at station I. However, the low value of salinity estimated at station III may be attributed to freshwater liquid waste water discharge from TTPP nearer to this station thus reducing the salinity level.

12. Seasonally, summer showed higher values of salinity with the monsoon and post monsoon seasons indicating lower values, the higher values caused mainly by evaporation and lower values by the monsoon.

13. A comparison of the salinity values estimated between the two years showed higher range during the first year (1990-91) than the second year (1991-92) probably caused by the lesser rainfall recorded during the first year.

14. An inverse relationship between water temperature and dissolved oxygen was noticed mainly at stations I, II and III. Which may be on account of the effect of thermal plume prevailing in this area.

15. The values of pH both at surface and bottom waters indicated higher values at station I, which also indicated a positive correlation with temperature and negative correlation with dissolved oxygen. Station IV, V and VI did not indicate much variations in the values of pH.

16. Turbidity evinced the lowest range at station I and the highest range at station III, the lower value caused by the less turbid thermal effluent discharge and the higher value, influenced by the denser freshwater liquid waste discharge.

17. Turbidity indicated positive correlation with silicate, both the values being low at station I.

18. Among the inorganic nutrients in water, silicate showed higher values followed by nitrate, phosphate ammonia and nitrite at all the stations.

19. In general, station III indicated the maximum range of inorganic nutrients than those of other stations, probably caused by liquid waste discharge at this station. Bottom water had also indicated the release of nutrients from the sediments to bottom water layer.

20. Station I had lower range of water nutrients, probably caused by the continuous flow of thermal effluent, the current thus formed scouring away the finer sediment particles rich in organic nutrients. Evidently, station I also showed the highest percentage of sand particle with the lower percentage of silt and clay than other stations.

21. Among the various stations, gross productivity of surface water showed a notable variation with the lowest range at station I and the highest range at station IV. Net productivity of surface water also showed a similar trend. While the low in the value of primary production noticed at station I may be on account of thermal plume noticed at this station, the highest value at station IV may be owing to the rich nutrients content, favoured by congenial temperature condition. In support of this, station IV had the highest species diversity with the lowest noticed at station I.

22. Particle size distribution, showed higher percentage of sand and lower percentage of silt and clay at station I, III and VI in comparison with the higher percentage of silt and clay and lower percentage of sand at stations IV and V.

23. Station II was devoid of sediment particles since it was exposed to continuous deposition of bottom ash discharged from TTPP.

24. Sediment sand showed negative correlation with sediment nutrients such as total organic carbon, total nitrogen and total phosphorus while silt and clay indicated positive correlation with nutrients at all the stations.

25. The sediment total organic carbon, total nitrogen and total phosphorus concentration registered the lower ranges at station I and the higher ranges at station V.

26. The sediment C/N ratio indicated the lowest range at station I while the N/P ratio showed irregular pattern in their distribution at various stations.

27. Seasonally, the distribution of sediment nutrients at various stations indicated higher values during summer and pre monsoon months and lower during monsoon months.

28. Sediment temperature in the present study showed higher values at station I and lower values at other stations thus showing a parallelism with water temperature probably caused by the heated effluent discharge.

29. The density of benthic population was as low as 430 nos/m^2 at station I where the highest regime of water temperature prevailed. Evidently,in other stations, the density ranged upto 4935 m^2 (station, III) where the temperature range was between 28.5°C and 36.5°C.

30. Benthic faunal density indicated negative correlation with the water temperature and salinity at station I.

31. Station III recorded more number of bottom fauna probably caused by the entry of liquid waste rich in inorganic nutrients thus favouring the settlement of many gastropod individuals.

32. The population density of benthos was higher in the order of abundance in stations III, VI, IV, V and I.

33. Benthic population at station I was solely represented by the gastropod *Cerithedia fluviatilis* throughout the period of study thus showing its suitability to withstand even the highest water temperature range. Cluster formation of *C.fluviatilis* was noticed at Station I whereas in other station it was of irregular distribution.

34. Station II was devoid of any benthic fauna since the bottom at this station was continuously disturbed by the deposition of thick bottom ash.

35. Species-wise, the benthic fauna at Tuticorin bay was mainly dominated by more number of gastropod organisms, followed by crustaceans and polychaetes. However, station V indicated dominance of crustaceans followed by polychaetes, gastropods and bivalves.

36. Polychaete species composition was higher at station IV and V than at the other stations, thus indicating a preference for silty sand bottom.

37. The species diversity indicated the lowest at station I where the single species dominance of *C. fluviatilis* was noticed. This lowest diversity war not only due to sandy nature of the bottom but also due to other stress factors of higher water temperature and salinity prevailed at this station. Evidently, water temperature at station I showed negative correlation with species diversity.

38. Station IV had the highest values of species diversity, which may be because of higher proportion of silt and clay, favouring better survival of many organisms.

39. Benthic biomass in terms of both wet weight and dry weight was the richest at station VI followed by stations IV, I, III and V. While the rich biomass may be attributed to the presence of more gastropod organisms at stations VI, IV and I, the poor biomass noticed at station V may be because of less gastropods and more polychaetes occurred at this station. Sediment sand particle showed positive correlation with benthic biomass at station IV.

40. Eventhough, the population density of benthos was higher at station III, the biomass was lower at this station which may be because of the smaller sized gastropods of lesser weight occurred at this station.

41. As is expected, species richness and species evenness were lower at station I and higher at stations IV and V.

42. It is suggested that the thermal effluent, instead of being discharged into the bay, may be diverted and reused after cooling and that the bottom ash may be utilised for the production of building materials such as bricks and cement.

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