

OCCASIONAL PAPER NO. 225

**RECORDS OF THE  
ZOOLOGICAL SURVEY OF INDIA**

**Studies on Macrozoobenthos of Rabindra Sarovar  
and Subhas Sarovar in Kolkata in Relation to  
Water and Sediment Characteristics**

**M. MUKHERJI  
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## **PREFACE**

During the last few decades lakes all over the world have become the focus of environmental investigations. The increased human activities including excessive dumping of organic as well as non-biodegradable wastes have brought about drastic changes in lake environment in India and especially Calcutta now Kolkata. The urban lakes in Calcutta are, in fact, predominantly plagued with problems pertaining to poor water quality, prolific growth of weeds and loss of bio-eco-aesthetic values.

Keeping in view of these threats to Rabindra Sarovar (RS), Government of India has declared this lake as a 'National Lake' under the National Lake Conservation Programme (NLCP). The basic objectives of such a designation to RS are to improve its environment along with prevention of pollution, catchment area treatment, desilting, dewatering as well as research and development studies on floral and faunal activities and related ecological aspects.

So, as a part of the NLCP, present investigations were undertaken on two major urban lake environments *viz.*, Rabindra Sarovar and Subhas Sarovar, which are located in the heart of the city, Calcutta. A comprehensive study of physico-chemical characteristics of water and sediment and benthic fauna was undertaken in the present research to cover a multitude of impairments of the aquatic system like presence of nutrient salts and estimation of benthic condition. Herein, the physico-chemical status of the lake ecosystem is described covering a wide spectrum of parameters while the study on the benthic fauna emphasized their importance as an effective tool for supplementing the physico-chemical information on the lakes. Various biological indices were calculated to reflect the overall condition of the aquatic system by a single index value. On the other hand, statistical analyses were done to elaborate the inter-relationships between the selected abiotic factors and benthic components of the lake so that the available information may clearly and convincingly demonstrate the 'health' of these two lakes.

January 7, 2004  
Kolkata

**M. Mukherji**  
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## INTRODUCTION

Despite occupying a small portion of water available in the world, lakes constitute an important component of freshwater system. They exhibit enormous diversity based on the genesis, geographical location, hydrobiological regimes and substrate factors. They are the most productive ecosystem and their importance as life supporting system in controlling water cycles and cleaning the environment has been acknowledged by wetland experts worldwide. Urban lakes in Kolkata (India) and elsewhere have an added role of recreational and aesthetic importance. Lakes, in general, possess a vast array of diversity in its faunal composition which are very dynamic and responsive to the deviations from normal ecological homeostasis.

Lakes are characterised by distinct type of biotic and abiotic environment. The physico-chemical properties of water and bottom sediment are the abiotic aspects of an aquatic ecosystem, which play a prominent role in determining the biotic community of the aquatic habitats concerned. Dissolved gases, dissolved chemicals (salts or ionic) and their interaction gain a status of influencing the water chemistry for its primary productivity and biological production. Sediments of freshwater are major sites of biological activities which include microbial degradation of detrial organic matter and biogeochemical recycling of nutrients. The underwater soil, acts as a laboratory to release the nutrients required for water productivity from the raw materials by chemical and biochemical means. Hence, the chemical properties of water reservoirs and ponds are more or less a reflection of the properties of the bottom soil (Chandra, 1997). The physico-chemical characteristics of the sediment regulate to a great extent the burrowing and tube dwelling activities, type of food, feeding, spatial and temporal abundance and seasonal variations of bottom dwelling animals (Ramachandra *et al.*, 1984).

The biotic components exhibit extensive species diversity and richness comprising of protozoa, sponges, annelids, molluscs, decapods, ostracods, cladocerans, copepods, insects, fishes, etc. These aquatic animals are classified as planktons, periphyton, aufwuchs, neuston, nekton and benthos. Benthos includes animals which (a) migrate to bottom for feeding and breeding (b) spend their lives on bottom and (c) burrowers (Petersen, 1913). They are categorised depending upon size of the organism as macro, meio and microbenthos (Mare, 1942). Macroinvertebrates, both larval forms and adults whose size varies from 3-5 mm for full grown individuals (Cummins, 1975) and are retained by 500 mm sieves are referred in this treatise as macrobenthos or more precisely as macrozoobenthos.

Benthos are significant biotic component of the aquatic ecosystem for their specialised mode of life, associated with crawling, burrowing or attaching themselves on or in the bottom, sedimentary habit, intermediate position in the trophic structure and for their role in the energy cycle. They provide important clues on the available organic matter and are known to reflect the past and present environmental condition of an ecosystem more efficiently than physical and chemical indices of water and soil (Hynes, 1960 and Hofmann, 1978). They are also regraded

as best indicators of pollution because of their constant presence, relatively long life, sedentary habit and different tolerance to stress.

It is unfortunate to note that the two urban lakes of Calcutta now Kolkata, Rabindra Sarovar and Subhas Sarovar, in spite of their aesthetic and recreational values, had received little attention in the past, Hence the present programme was undertaken to study the lake ecology based on the macrozoobenthic community of the two lakes with the following objectives

- (i) to identify the benthic biota and diversity of the two lakes,
- (ii) to study the seasonal abundance, population fluctuations, biomass and community interactions of various macrozoobenthic species of the two lakes
- (iii) to study the water and sediment characteristics which would provide information on the current status of both the lakes,
- (iv) to find out the interrelationship between these abiotic factors and major benthic species/groups.

## REVIEW OF LITERATURE

Forel has been long considered as the father of limnology for his studies on geology, physics and chemistry of Lake Geneva, Switzerland in 1892, 1895 and 1904. He also made pioneering endeavour to study the ecological status of the benthos of Lake Geneva in 1869. The first description of how light, heat, water temperature and wind mixing form the 'structure' so important in lake ecosystem was given by Leslie (1838), who interpreted his findings based on studies in Scottish lakes. Perhaps, the first man to consider lakes as functional ecological systems was Forbes (1887). Brige (1915) is noteworthy for contributing greater biological dimension to the field of limnology through his study on plankton of lakes in Europe and America. Several other workers are known to contribute towards the limnology and eutrophication of lakes (Rawson, 1960; Beeton, 1965; Herzig, 1979; Paerl and Pyne, 1979; Gehrels and Mulamootil, 1990; Di-Giovanni *et al.*, 1992; Antwi and Ofori-Danson, 1993; Mukankomeje *et al.*, 1993; Vidondo and Martinez, 1993 and Dorgeloh *et al.*, 1994).

A large number of limnological studies have been carried out in India during the past few decades on almost all kinds of aquatic habitats. Some earliest works on water quality and related habitat include those of Hamilton (1822), Day (1878), Annandale (1907) and Hutchinson (1937a). Distinct seasonal pattern of most physico-chemical parameters were observed by Ganapati and Alikunhi (1950), Ganapati and Chacko (1951), Iyenger and Venkataraman (1951), Chacko *et al.* (1953 a and b), Rao (1955), Singh (1955), Abraham (1962), George (1962), Sreenivasan (1964 a and b, 1965, 1969, 1970 a and b, 1976), Lakshminarayana (1965), Ray *et al.* (1966), Hussainy (1967), Sahai and Sinha (1969), Munawar (1970), Rai (1974), Sharma *et al.* (1978), Verma *et al.* (1978), Jana *et al.* (1980) Michael (1980), Unni (1985), Sinha

(1986), Sarwar and Wazir (1988 and 1991), Khatavkar *et al.* (1989), Jakher *et al.* (1990), Varghese *et al.* (1992), Pandey (1993), Satpathy (1993), Tanti and Saha (1993), Sinha *et al.* (1993, 1994), Gupta and Sharma (1994), Ramana and Sreeramulu (1994).

Among the best known and most investigated urban lakes are those around Udaipur (Kumar and Sharma, 1991), Kashmir lakes (Zutshi and Vass, 1973, 1978 and 1982 and Zutshi *et al.*, 1980) and lakes near Hyderabad city (Swaranlatha and Rao, 1998).

Reports on the physico-chemical properties of bottom soil of waterbodies are rather scanty, Mishra (1946) demonstrated the role of sediment characteristics in determining the nature of aquatic vegetation. Animal sediment relationship in Buzzards Bay was studied by Sanders (1958). Comprehensive ideas on the bottom soil edaphic factors with their diverse bearings and relationship with the benthos were highlighted in several reports (Ray, 1963; Mahapatra and Patrick, 1969; Mandal and Moitra, 1975a; Nasar, 1978; Gupta, 1982; Saha, 1985; Saha and Pandit, 1986; Kumari *et al.* 1990; Rao *et al.*, 1990; Choudhury, 1991; Gupta and soni, 1991; Sinha *et al.* 1992 and Agarwal *et al.* 1993).

The abundance of macrozoobenthic organisms are greatly influenced by organic matter (Cook and Johnson, 1974; Johnson *et al.*, 1989; Hornbach *et al.* 1989) and organic carbon (Datta and Malhotra, 1986; Bhat and Neelakantan, 1988) present in the sediment. More recently, the macrozoobenthic population was found to be positively correlated with soil parameters like temperature, available phosphorus and available nitrogen of freshwater ponds in West Bengal by Ghosh and Banerjee (1996).

Benthic organisms of freshwater bodies have been extensively studied by Ricker (1952) Grimas (1962 and 1965), Brinkhurst (1964), Armitage (1977), Forsyth (1978), Kaster and Jacobi (1978), Timms (1978 and 1980), Kousouris and Diapoulis (1983), Petridis and Sinis (1993, 1995 and 1997) and many others. Littoral and sublittoral zones were found to harbour more benthic species and in greater number than the profundal by Johnson and Brinkhurst (1971), Sivertsen (1983), Cowell and Vodopich (1981). Moreover, Cowell and Vodopich (1981) observed that the number of benthic taxa and density were negatively correlated to depth and positively correlated with the nature of substratum and dissolved oxygen concentration at the mud-water interface of Lake Thonotosassa, Florida. This was also supported by Scullion *et al.* (1982), Clare and Edwards (1983) and Bechara and Andreani (1989). Balla and Davis (1995) while studying the macroinvertebrates near Perth, Australia, opined that highest macroinvertebrate biomass was recorded with cyanobacterial blooms and abundant macrophytes.

The researches of Brinkhurst (1966), Mason *et al.* (1971), Brinkhurst and Cook (1974), Howmiller and Scott (1977) and Mason (1981) proved that oligochaetes favour soft bottom, eutrophic area with low oxygen and high organic content. Mouthon (1992) added that calcium salt concentration and organic matter in deep sediments are major factors in the distribution and population density of gastropods in lakes of eastern France. There were no prosobranch or bivalve molluscs in Lake Awasa, Ethiopia due to its relatively high content of sodium bicarbonate and high conductivity ( $860 \mu \text{Scm}^{-1}$ ) and its flocculant mud was

found to be unsuitable for colonization by benthic animals (Kibret and Harrison, 1989). Sallenave and Barton (1990) argued that the benthic biomass of Lake Temiskaming, Ontario – Quebec was strongly related to turbidity.

Important investigation in the field of benthic population in India were made by Srivastava (1956 and 1959), Krishnamurthy (1966), Patnaik (1971), Mandal and Moitra (1975 a and b), Raman *et al.* (1975), Gupta (1976), Abraham (1979), Vasisht and Bhandal (1979), Kaul and Pandit (1981), Gupta and Pant (1983, 1986 and 1990), Yadava *et al.* (1984), Rao *et al.* (1987), Ahmad and Singh (1989), Kaushal and Tyagi (1989), Adholia *et al.* (1990), Malhotra *et al.* (1990), Singh and Roy (1991 a and b), Bais *et al.* (1992), Barbhuyan and Khan (1992 and 1994) and Singh *et al.* (1994).

Gupta and Pant (1983 and 1986) stated that the seasonal variation in the benthic community is primarily related to temperature, availability of food and life cycle pattern while its spatial variation is related to sediment texture and degree of pollution. Bose and Lakra (1994) found a significant correlation between the population of *Chironomus* larvae and total alkalinity content in freshwater ponds of Ranchi, India. The absence of molluscs in a sewage fed pond in Uttar Pradesh as reported by Barbhuyan and Khan (1994) may be related to low levels of oxygen, high pH and due to their more sensitive nature towards organic pollution. Pandey *et al.* (1994) concluded that physico-chemical parameters of water like conductivity, pH, dissolved oxygen, bicarbonate, calcium, nitrate, phosphorus and of sediment *viz.*, conductivity, total calcium and organic matter seem to be suitable for growth and propagation of gastropods.

The faunal diversity and particularly macrobenthic community of freshwater ponds and lakes have received little attention in West Bengal (De *et al.*, 1989; Ghosh and Chattopadhyay, 1990 and 1994 and Nandi *et al.*, 1993, 1994, 2001). Some notable works on macrobenthos were done by Moitra and Bhowmick (1968), Mandal and Moitra (1975a and b), Sarkar (1989 and 1992) and Ghosh and Banerjee (1996). In case of urban lakes in Calcutta studies on zooplankton and productivity were conducted by Khan (1979, 1981, 1983 and 1984a and b). The population dynamics of *Bellamya bengalensis* in Rabindra Sarovar was studied by Khan and Chaudhuri, 1984). More recently, the conservation and management aspects of Rabindra Sarovar was dealt by Ghosh and Nandi (1996). The utilization scenario of Calcutta wetlands was studied by Mukherji *et al.* (1998). The macroinvertebrate population of urban wetlands of Calcutta were also studied by Mukherji *et al.* (2000). But these studies on Calcutta lakes had not so far aimed at arriving at any ecological interrelationship between abiotic factor and the biotic components.

## MATERIALS AND METHODS

Calcutta is located on the banks of the Hugli-Bhagirathi river and is a part of mature Ganga delta, approximately 20 ft above the sea level. The topographical features derived principally from the interaction of rivers of the Gangetic system and the sea, include a number of existing and palaeo-channels which are associated with levees and interdistributory marshes. The major slope is from north to south indicated both by the course of the Hugli

and other major channels (Chakraborti *et. al.*, 1985). The Calcutta Metropolitan Area (CMA) possess a large number of wetlands scattered all over the region with the urban, industrial and rural life of the area (Ghosh and Sen, 1988). The major wetlands of Calcutta are located between the latitudes 22°25'-22°40' north and longitudes 88°20'-88°35' east. Amongst the urban waterbodies of Calcutta, Rabindra Sarovar (RS) and Subhas Sarovar (SS) are in fact the right and left lungs of the congested metropolis proper, situated in south and east Calcutta respectively. Both the lakes are artificial reservoirs, mainly fed by rainwater and are maintained by the Calcutta Improvement Trust (CIT).

## DESCRIPTION OF THE STUDY AREA

**Ecological history :** From the second decade of the twentieth century, CIT undertook a programme of extending the city southward and eastward by acquisition of marshy land and in the process, large scale excavations were undertaken and eventually these two lakes, RS and SS with new roads, parks and neighbourhoods were developed by 1940 and 1964 respectively. During 1950's many residential settlements around RS were developed further south of Calcutta when a large population from erstwhile East Pakistan (now Bangladesh) migrated to India. The settlements in the surrounding areas of SS expanded during 1970's with the progress of reclamation of the Salt Lake for extension of the city in the east.

**Morphometric measurements :** The land and water area of RS are about 119 and 73 acres respectively. The maximum length of RS is about 1770 m and maximum width at its broadest part is 286 m (Fig.1). The perimeter of this lake is about 18,000 Rft., while mean depth varies from 9-10 m. The lake SS, has an area of 39.5 acres only (Fig. 2). The length of SS from west to east is 533 m and the breadth from south to north is 366 m.

**Present status and usage pattern :** At present both the lakes possess multifarious features for sports, recreation, swimming and other activities along with ample use of open space by large number of morning walkers. SS is widely used for game fishing purpose. Angling is held throughout the year except for a few months when the fingerlings are released into the lake. In RS no such fishing activities are held.

Both these artificial waterbodies suffer from the evils of rapid urbanisation and large scale human interferences. The residents of the adjoining slum areas of RS and SS use the lake waters for bathing and washing of clothes and utensils, etc. over the years. They have developed the practice of defecating in the open on the embankments and use the lake water for afterwash. Due to the excessive human usage there has been considerable soil erosion along the banks. The lakes have been increasingly converted into dumping sites of domestic wastes. Occasionally the carcass of dead animals are disposed in these lakes. Overgrowth of aquatic weeds *viz.*, water hyacinth, *Vallisneria* sp. and other submerged macrophytes often choked the lake water. Recently with the declaration of RS as a 'National Lake' in 1997 and again in 2000, under the National Lake Conservation Programme (NLCP) set up by the Union Ministry, it is expected that there will be improvement of its environment.

treatment of catchment area, deweeding, desilting and research and developmental studies on lake ecology.

### Collection of meteorological data

Data pertaining to maximum and minimum air temperature, maximum and minimum relative humidity and total rainfall in Calcutta, during the study period were collected from the Meteorological Office, Calcutta. The average values of the data recorded during the period 1995-1997 were represented on a monthly basis to get an overview of the climatic condition of Calcutta.

### Collection and preservation of abiotic and biotic samples

To collect data on the biotic and abiotic factors of both the lake ecosystems, sampling was done fortnightly from different sites of each lake, along the littoral/bottom zone extending from the lake margin to 3 m from the shore, usually delimited by rooted aquatic vegetation. Survey/sampling was conducted over a period of two years extending from May 1995, to April, 1997.

Three particular areas *viz.*, stations 1-3 were selected for sampling of benthic fauna in each lake. Sampling was done in triplicates from each station by means of a box-type sampler (15x 15 cm). The three stations can be categorized as follows :

#### RABINDRA SAROVAR

**Station 1** : Located in Block D of the lake in a shady undisturbed area with dense floating and submerged vegetation. The sediment of this littoral zone was found to be rich in leaf litter and detritus matter.

**Station 2** : Located in Block A of the lake in a place exposed to sunlight, partly disturbed and devoid of floating vegetation but with uniform submerged macrophytes. Silt and loam characterized the sediment.

**Station 3** : Located in Block A opposite to Station 2, in a partially shady area with polyspecific vegetation and more or less similar sediment quality.

#### SUBHAS SAROVAR

**Station 1** : Located at the western side of the lake and exposed to sunlight in a partly disturbed place devoid of floating vegetation but with dense submerged species. The bottom soil was found to have a high content of silt and clay.

**Station 2** : This station was situated at the southern side of the lake in a partially shady and mostly undisturbed place with polyspecific vegetation. The sediment quality was almost similar to that of Station 1.

**Station 3** Situated at the northern side of the lake in a shady and disturbed place with sparse floating vegetation and dense submerged macrophytes. Silt and clay were the major components of the sediment.

The location of the three stations in each lake is shown in Figs. 1 and 2.

### **Collection and preservation of water and sediments samples**

Water samples were collected fortnightly in clean glass bottles from different sites of each lake at a depth of 0.4 m from the water surface. For BOD estimation, water samples were collected separately in dark bottles. Sediment samples were collected at each site by a box type sampler (15 x 15 cm). The sediment samples were kept in clean polythene bags for further analysis.

Physico-chemical parameters like water and sediment temperature, pH, dissolved oxygen, total alkalinity and conductivity of water were determined in the field itself. Other parameters were mostly tested within 24 hours of collection. Preservation of water samples whenever necessary were done at 4°C.

### **Collection and preservation benthic fauna**

Quantitative sampling of bottom fauna was done by a box type sampler having an area of 15 x 15 cm and capable of penetrating the soft bottom to its maximum depth of 10 cm. Nine samples in triplicate from each of the three stations were collected each time from each lake. The material was washed thoroughly in a standard sieve of 0.5 mm mesh size (Jonasson, 1955; Havgaard, 1973). Qualitative sampling was done by means of handpicking, dragnetting and by the box type sampler. Samples were brought to the laboratory in plastic packets and sorted in large enamel trays. All the organisms were sorted and preserved in 4% formalin or 70% alcohol.

### **Analysis of water and sediment samples**

In case of water, 14 limnological parameters *viz.*, temperature, pH, turbidity, conductivity, total alkalinity, total hardness, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), chloride, phosphate, nitrate, nitrite and ammonium were estimated bimonthly for each lake for a period of two years. With regard to sediment, 6 parameters *viz.*, temperature, pH, phosphate, nitrate, nitrite and organic carbon were evaluated.

All the parameters were analysed following the standard methods (Piper, 1966; Jackson, 1973; Trivedy and Goel, 1984 and APHA, 1989) and by spectrophotometer, SQ 118 (Merck, Germany).

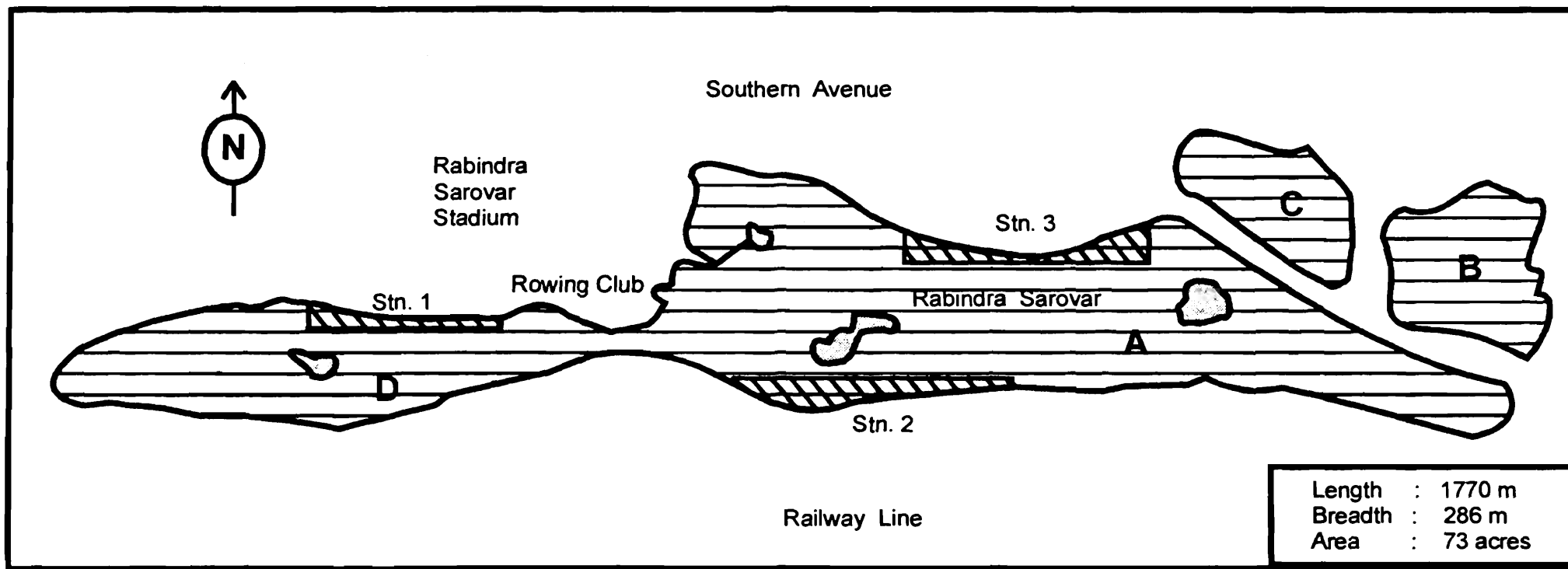


Fig. 1. Map of Rabindra Sarovar showing sampling stations.

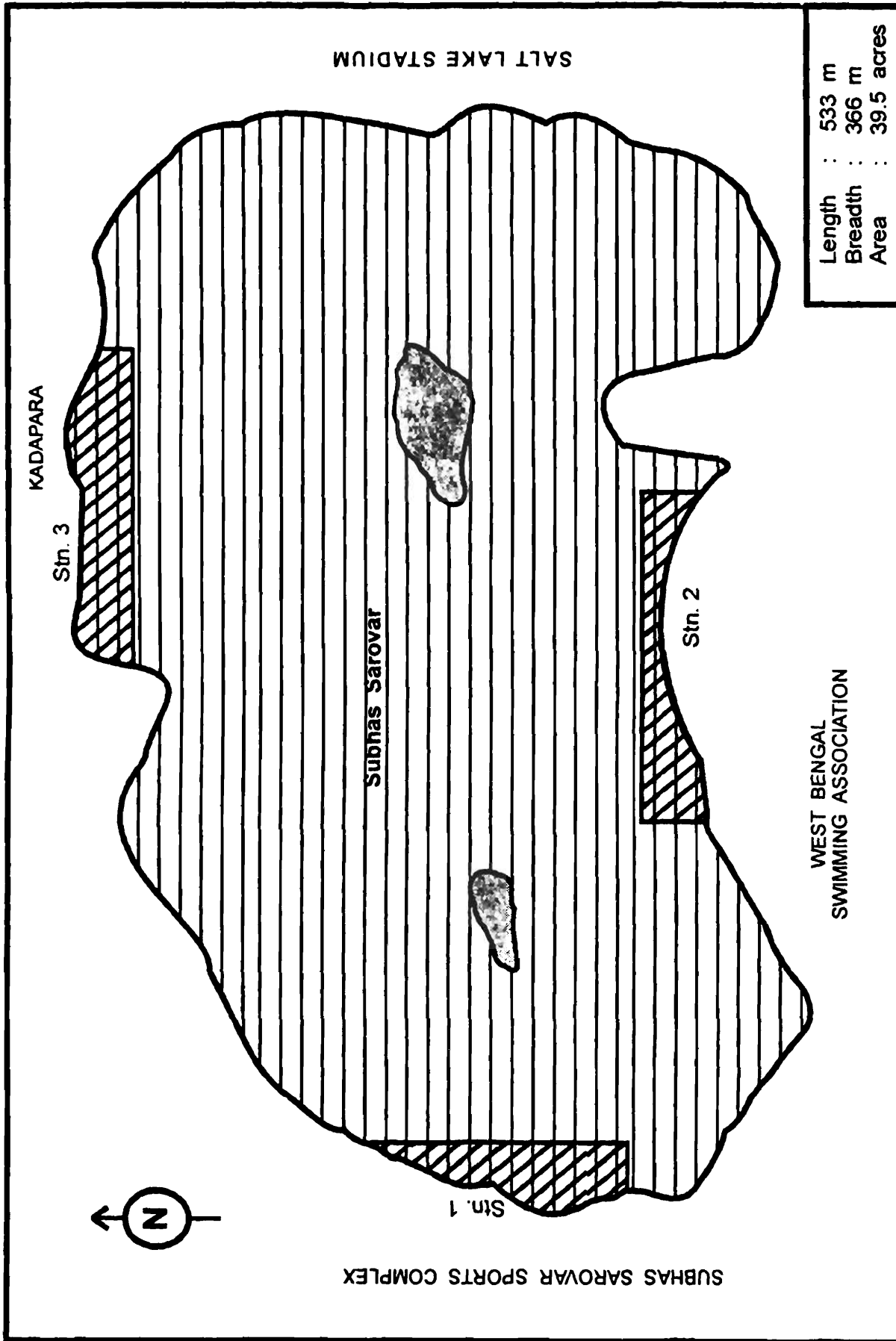


Fig. 2. Map of Subhas Sarovar showing sampling stations.

### Analysis of benthic fauna

All the benthic fauna were counted and identified to species level with the help of references (Naidu, 1965; Alcock, 1968; Sublette and Sublette, 1973; Vazirani, 1977; Subharao, 1989 and Kurian and Sebastia, 1993) and taxonomists of Zoological Survey of India, Calcutta and then analysed as follows :

(i) *Determination of population density and percentage frequency* : Population density represents the number of individuals per unit area. In this study, the number of benthic animals (groups / species) obtained in each sample was expressed as number of individuals per meter square by using the formulae put forward by Welch (1948). Percentage frequency which is the percentage of quadrats in which a given species is found is also determined.

(ii) *Estimation of biomass* : For determination of biomass (dry weight) each specimen was dried in drying oven at 105°C (Winberg, 1971) for a time until the weight became constant. Weight was taken on an electronic balance and was expressed in terms of dry weight (gm/m<sup>2</sup>).

(iii) *Calculation of biological indices* : Four biological indices viz., index of dominance (Simpson, 1949), Margalef's index (1958), Shannon-Weiner index (1949) and Evenness index (Pielou, 1966), were calculated.

### Statistical calculations

Pearson's correlation coefficients were calculated to evaluate the parametric relationships between the abiotic and biotic factors supposedly in interaction. The tests were all two tailed and the correction was tested at 5% and 1% level of significance. In any aquatic system, the occurrence and life cycle of an organism depend on the various physico-chemical factors of water and sediment. To find out the subset of physico-chemical parameters, stepwise multiple regression method was followed. Thus we had to choose a 'p' – x variable (physico-chemical parameters) that best predict the response Y (faunal density). This is a universal selection statistical procedure in which the only random variable is y and x's are treated as non-random. The significance of  $\beta_j$ 's has been tested with the help of t-statistic. The square of multiple correlation coefficient  $R^2$ , for each model indicates the variation in density explained by the p-variable. The significance of  $R^2$  is tested with the help of F-statistic.

A two way analysis of variance (ANOVA) after transforming the value of each data to  $\log(x+1)$  was calculated to find out the significance of the differences in density of the species and groups among the collected samples of each lake and season.

The whole analysis was carried out with the help of a relevant software programme under SPSS, version 6.0.

## RESULTS AND DISCUSSION

Freshwater bodies are the most vital natural resources on this planet which have been vastly exploited by mankind. Influx of nutrients from the watershed area and entry of aquatic flora and fauna help the watermass to evolve as a form and function of its own. Thus the waterbody acquires a bio-physico-chemical entity. The study of the functional relationships and productivity of freshwater communities, affected by the dynamics of their physical, chemical and biotic environment is known as Limnology (Wetzel, 1975). Since lakes have so much unity in their physical, chemical, biological and evolutionary structure, the field of limnology has been extensively developed through the study of lakes.

To study the population pattern of macrozoobenthos of RS and SS, it was essential to conduct investigations on the limnological parameters of the two lakes and also to collect data on the climatic condition of the area in which these two lakes are situated. The results of the climatological and limnological parameters are discussed below on monthly/seasonal basis.

### Climatic condition

Summer, monsoon and winter are the three distinct seasons of tropical countries including India. In Calcutta, West Bengal, the winter season sets in from November and continues till February and is characterised by low air temperature, shorter day length and rare rain.

Summer season (March – June) has higher air temperature, longer day length and occasional rain. On the other hand, the monsoon period is characterised by relatively shorter hours of sunshine, high humidity and appreciable rainfall. July marks the onset of monsoon which retreats by October with the advent of autumn with moderately hot day temperature and cooler nights (Bose, 1968).

**Air temperature :** During summer the maximum air temperature was noted to be 37.24°C in April, 1997 and minimum was 21.73°C in March, 1997 (Fig. 3). During winter 24.80°C was the maximum day temperature recorded in January, 1996 whereas 13.64°C was the minimum temperature recorded in January, 1997.

**Rainfall :** Highest rainfall was observed in September (589.20 mm in the first year) and August (626.60 mm in the second year, Fig. 3). January was found to experience least rainfall during both the years (6 mm in the first year and 1.90 mm in the second year).

**Humidity :** The percentage of relative humidity was observed to be highest during September, 1995 (97.10%) and August, 1996 (97.86%) which corresponds with the period of maximum rainfall. The lowest humidity was noticed in February (38.52%) in the first year and in March (36.97%) in the second year (Fig. 3).

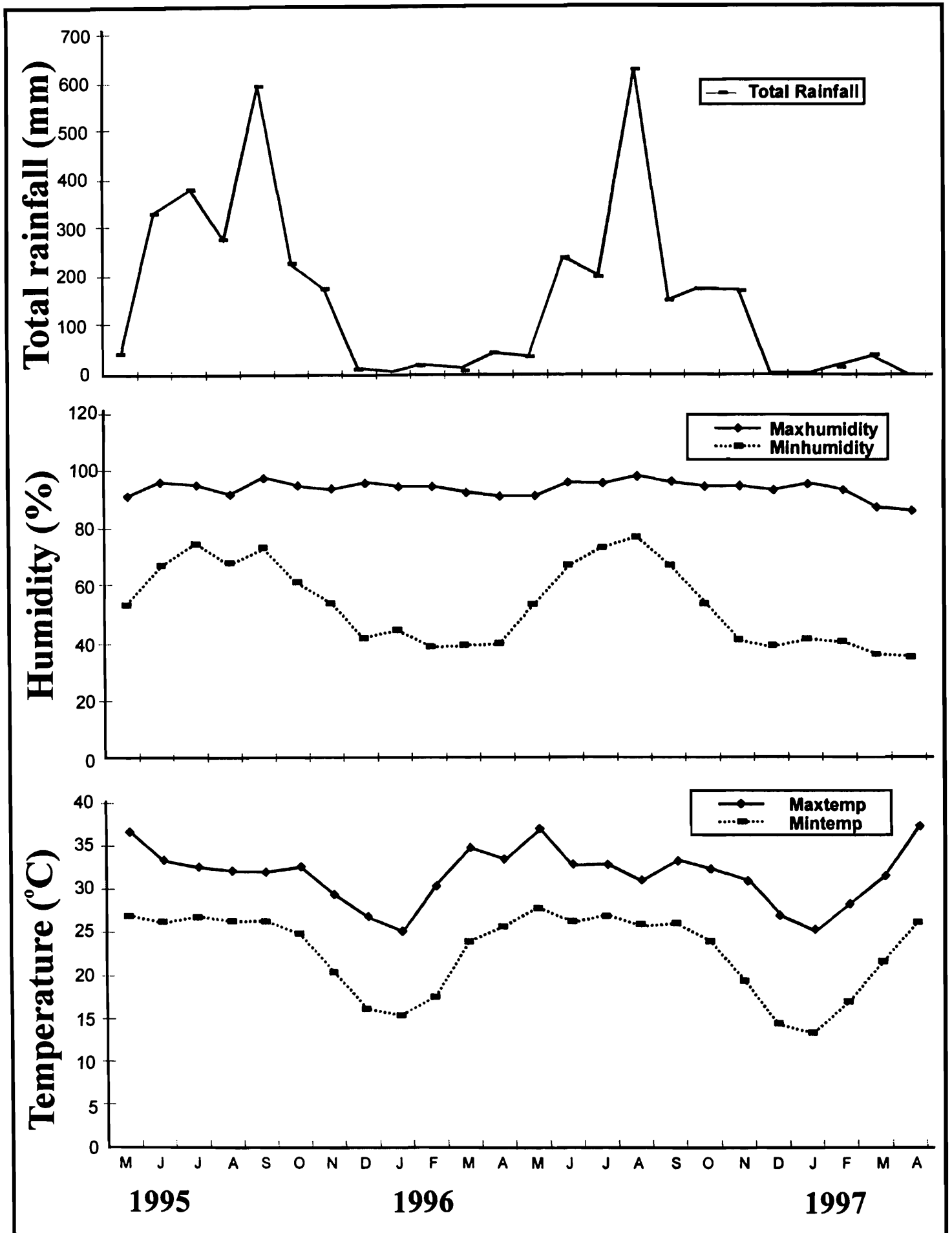


Fig. 3. Variation in climatological factors in the study region.

## Physico-chemical characteristics

The monthly variations over a period of two years and annual average of the physico-chemical parameters of water and sediment are summarized in Table 1 and 2 and Fig. 4-7 and discussed below :

### Water Characteristics

**Water Temperatures :** The annual mean water temperature fluctuated from 20.92 (January) to 32.95°C (May) in RS and from 22.31 (January) to 32.92°C in SS (Table 1 and 2), indicating a fall from October reaching a winter minima in January followed by a tendency of water to become progressively warmer from March onwards showing a summer maxima in May (Fig. 4A).

Temperature, the measure of intensity of heat stored in a volume of water is of enormous significance as it regulates the developmental rates of aquatic invertebrates and is also responsible for the release of nutrients in water by initiating the decomposition of organic matter (Kumar, 1995). Pidgaiko *et al.* (1970) concluded that temperature variation could have either a positive or negative effect on the productivity of biotic communities depending upon geographic location and basin morphometry of reservoirs. In tropical reservoirs thermal stratification is almost absent, although some ill defined thermal gradient has been reported by Sreenivasan (1969) in a few south Indian reservoirs and Patil (1989) in Waghyanala reservoir from central India. In this study, the water and air temperatures were found to go more or less hand in hand, which was probably due to moderate size of the lakes. According to Welch (1952), smaller the body of water, faster it reacts to the changes in the atmospheric temperature.

**pH :** Throughout the study period of two years, the water of both the lakes remained alkaline or calcareous (Fig. 4B) as reported by Sarwar and Wazir, (1991), Kartha and Rao (1992) and Kumar (1995) in many Indian lakes and ponds. The mean data showed maximum pH in May (8.80 in SS)/June (8.98 in RS) while minimum in October (7.72 in SS and 7.97 in RS; Table 1 and 2). Lemkuhl (1979) considered variation of pH between 6-8 to be insignificant for species distribution accepting that only low values (pH-4) could be influential *i.e.* to decrease the diversity.

In general, the pH tends to remain low during the months of October to January, increasing significantly during summer months in RS and SS as observed by Sastry and Malik (1992). The low pH level in winter season has been found to be due to increased free CO<sub>2</sub>, which is in turn related to low phytoplankton population (Armitage, 1962). Indian waters are known to exhibit unimodal, bimodal or irregular oscillations in pH during the annual cycle. Das and Srivastava (1956) reported low pH in June and high in February, whereas, Prakash (1983) reported high pH in rainy and winter seasons. David *et al.* (1969) found higher pH

during June-August and low in February (Anon, 1977). Gupta and Sharma (1994) found irregular fluctuation of pH in Amarchand reservoir, Rajasthan.

**Turbidity** : Temporal variation in turbidity showed low values during June to November period with a minimum of 9.58 NTU in July in RS and 10.33 NTU in October in SS (Table 1 and 2, Fig. 4C). During this period there was a considerable rise in the water level in both the lakes which caused the decrease in turbidity as it is known to be inversely related to water volume (Varghese *et al.*, 1992 and Patralekh, 1994). Higher values were obtained in December (20.75 NTU) in RS and in April (26.83 NTU) in SS.

Murphy (1962) mentioned that low turbidity for a reservoir is desirable as it indicates good productivity. Sallenave and Barton (1990) reported that distribution of benthic biomass was strongly related to the turbidity gradient of Lake Temiskaming, Ontario. In RS and SS, turbidity was quite low and did not pose any threat to the distribution of benthic animals.

**Conductivity** : It is a measure of the ability of a water sample to conduct an electric current and is proportional to the ionic strength of water. This mostly depends upon the nature and concentration of various dissolved ionized substances.

Conductivity varied from 465.75 (December) to 796.66  $\mu\text{mhos cm}^{-1}$  (May) in RS (Table 1), while in SS it varied from 319.50 (November) to 481.00  $\mu\text{mhos cm}^{-1}$  (April; Table 2). Unni (1985) recorded a conductivity range from 121-1111  $\mu\text{mhos cm}^{-1}$  in various reservoirs in central India. In Amaravathy and Aliyar reservoirs, Sreenivasan (1965 and 1970a) recorded conductivity of 30 and 80  $\mu\text{Scm}^{-1}$  respectively. The conductivity of two lakes under study, was moderately high specially in RS which had higher ionic content than SS.

Conductivity decreased during November to January months followed by progressive increase in summer months (Fig 4D). Such seasonal fluctuation was in concordance with the observations of Sharma *et al.* (1978); Sastry and Malik, (1992) and Varghese *et al.* (1992). The seasonal variation in the conductivity value was mostly due to the increased concentration of salts caused by evaporation in summer. Low values in winter was due to dilution effect of rainfall (Trivedy *et al.*, 1985).

**Total alkalinity** : It was as low as 301.33  $\text{mg l}^{-1}$  (October) in SS, which increased to the highest level of 417.50  $\text{mg l}^{-1}$  (May) in RS and 269.33  $\text{mg l}^{-1}$  (April) in SS (Table 1 and 2). In general, total alkalinity was found to be high during most part of the year, declining only in the months of November to January in RS and October to November in SS (Fig. 4E). Such pattern of fluctuation was reported by Sharma *et al.* (1978) and Varghese *et al.* (1992). The increase in temperature and decrease of water level due to evaporation can produce steady rise in alkalinity during summer (Hazelwood and Parker, 1961). Subba Rao and Govind (1964) and Sharma (1980) had also found inverse relationship between alkalinity and water level.

According to Reid (1961), in the maintenance of pH values between 7 to 9, bicarbonates are of great significance. Apart from bicarbonates, carbonates and hydroxides collectively

shift the pH to the alkaline side of neutrality (Wetzel, 1975). High total alkalinity values indicate higher trophic status of the waterbody as per the classification of Philipose (1960). The values of total alkalinity above  $60 \text{ mg l}^{-1}$  are indication of nutrient rich condition (Spence, 1964). RS and SS may be considered to be 'alkaliphilic' as total alkalinity ranged from 269.33 to  $415.00 \text{ mg l}^{-1}$ . However, considering Moyle's criteria (1946), both RS and SS can be regarded as 'hard water' body due to total alkalinity above  $40 \text{ mg l}^{-1}$ .

**Total hardness** : It ranged from 82.51 (October) to  $112.50 \text{ mg l}^{-1}$  (February) in RS (Table 1 and 2) and in SS it varied from 54.19 (August) to  $72.00 \text{ mg l}^{-1}$  (April). Overall variation hardness showed that its value was high in summer and winter months and low during the period of August to October (Fig. 5A) which was in concurrence to the findings of Varghese *et al.* (1992), Pathak and Shastree (1993) and Patralekh (1994), who studied freshwater bodies of central and eastern India. Increase in summer months was due to high temperature, evaporation of lake water and consequent rise in the concentration of residues in water (Sastry and Malik, 1992). Lower amount in monsoon in both the lakes was possibly due to greater dilution by rain. Shardendu and Ambasht (1988) reported that the level of hardness depends upon the water level.

The hardness of a waterbody is governed by the content of calcium and magnesium salts, largely combined with bicarbonate and carbonate and with sulphates, chlorides and other anions of mineral acids (Wetzel, 1975). Barrett (1957) observed that hard waters are more productive than soft waters. The total hardness of RS was found to be much higher than SS signifying its productive nature.

**Dissolved oxygen** : The amount of oxygen dissolved in water is essential for respiratory metabolism of most aquatic organisms and its distribution in lakes is governed by a balance between inputs from the atmosphere and photosynthesis and losses due to chemical and biotic oxidations. It affects the solubility and availability of many nutrients and therefore the productivity of aquatic ecosystems (Wetzel, 1975). Decreased level of oxygen is considered as a reliable parameter to assess the process of eutrophication (Hasler, 1947 and Edmondson, 1966).

In the present investigation, both the lakes maintained fairly congenial levels of dissolved oxygen exhibiting variations between 4.73 (July) to  $8.60 \text{ mg l}^{-1}$  (March) in RS and 3.76 (June) to  $7.80 \text{ mg l}^{-1}$  (January) in SS (Tables 1 and 2). Atkins and Harris (1924) had considered pH 8.10 or above, to be a sure indicator of dissolved oxygen. The present observation substantiate their finds.

High dissolved oxygen was noted during the months December to April and low in the months of May-June (Fig. 5B). Such seasonal fluctuation in dissolved oxygen was found to be in agreement with several reports on Indian waters by Pandey and Verma (1992), Sastry and Malik (1992), Varghese *et al.* (1992), Pathak and Shastree (1993), Gupta and Sharma (1994), Kumar (1995) and Swarnalatha and Rao (1998). High dissolved oxygen concentration in winter may be associated with increased photosynthetic activities and greater oxygen holding capacity of water at low temperature (Hutchinson, 1957). The

decrease in dissolved oxygen in summer can be correlated to high decomposition rate of organic matter (Wetzel, 1975 and Sinha *et al.*, 1994), low solubility of oxygen in water at high temperature and increased respiration by heterotrophic organisms (Patralekh, 1994).

However, Barbhuyan and Khan (1994) noted fall in dissolved oxygen concentration in postmonsoon in an eutrophic waterbody in Aligarh, Uttar Pradesh. Sarwar and Wazir (1991), while studying the physico-chemical characteristics of a freshwater pond in Srinagar, Kashmir noted higher values of dissolved oxygen during summer which may be due to active photosynthesis by luxuriant growth of macrophytes resulting in the release of oxygen as a by-product.

**BOD and COD :** Biological oxygen demand (BOD) is the amount of oxygen required by microorganisms to decompose biologically degradable organic matter in water under anaerobic condition. It is an approximate measure of the amount of biochemically degradable organic matter present in a sample. Chemical oxygen demand (COD) relates to the amount of oxygen required for chemical oxidation of organic matter. High values of both BOD and COD indicate increase in degradable organic pollution load in any waterbody. Input of large amounts of sewage effluents, human excreta and addition of non-biodegradable industrial chemicals and hydrocarbon compounds are known to cause elevation of BOD and COD levels in waterbodies (Sharma and Rajput, 1994).

In RS and SS, BOD values (Fig. 5C) were low in monsoon and postmonsoon months followed by subsequent increase in premonsoon period (March-June). In RS, it ranged from 3.83 (December) to 10.33 mg/l<sup>-1</sup> (April), while in SS a record low of 6.00 mg/l<sup>-1</sup> (November and January) and high of 15.00 mg/l<sup>-1</sup> (April) was noted (Table 1 and 2). COD also showed similar temporal variation. Minimum COD was recorded in December (23.16 mg/l<sup>-1</sup>) and January (25.77 mg/l<sup>-1</sup>) and maximum in June (46.62 mg/l<sup>-1</sup>) and May (55.40 mg/l<sup>-1</sup>) in RS and SS respectively (Table 1 and 2). Such seasonal fluctuations were in agreement with the reports made by various authors on tropical waters (Goel *et al.* 1980; Pant *et al.* 1981; Kumar and Sharma, 1991; Sastry and Malik, 1992; Varghese *et al.*, 1992; Pathak and Shastree, 1993 and Sharma and Rajput 1994).

High BOD and COD values in summer months may be due to the presence of aerobic microorganisms which can easily degrade organic matter in the presence of oxygen (Narayanan, 1980 and Kant and Raina, 1989). In the monsoon months low values of BOD and COD may be related to the dilution effect as reported by Pant *et al.* (1981) and Shaw *et al.*, (1991). Low BOD and COD in winter may be due to lesser quantity of total solids/ dissolved solids and suspended solids in water and lesser quantitative number of microbial population (Rice, 1938; Zafar, 1966 and Zutshi and Vass, 1982).

According to ICMR (1975), BOD value of 6 mg l<sup>-1</sup> or more in surface water should be taken as a critical point for classifying the waterbody as polluted. However, as per ISI (1982) standard, the permissible limit for BOD and COD is 30 mg l<sup>-1</sup> and 250 mg l<sup>-1</sup> respectively. In the present study, BOD or COD values were not found to cross the threshold limit which is indicative of no significant pollution load in both the lakes.

**Chloride** : The minimum chloride level was recorded in December (39.16 mg l<sup>-1</sup> in RS and 33.24 mg l<sup>-1</sup> in SS) and maximum in May (75.24 mg l<sup>-1</sup> in RS and 54.91 mg l<sup>-1</sup> in SS; Table 1 and 2). On seasonal basis summer months showed maximum values followed by monsoon and least in winter (Fig. 5E). Increase in chloride content of water in summer has been reported earlier by Sharma *et al.* (1978), Varghese *et al.* (1992), Sinha *et al.* (1994) and Kumar (1995). However, Pandey and Verma (1992), while studying the limnology of a temple pond in Bihar, stated decrease in chloride level in summer. On the other hand, Pathak and Shastree (1993) noted no definite seasonal pattern of chloride fluctuation.

Thresh *et al.* (1941) pointed out that high chloride concentrations are indicators of large amount of organic matter. Pollutions through human faeces, domestic sewage and bathing are the most important factors which increase chloride content and thus increase the degree of eutrophication (Sharma *et al.*, 1978 and Varghese *et al.*, 1992). In RS, the chloride content was considerably greater in comparison to SS, which indicates higher trophic status of this lake.

**Phosphate** : Phosphorus plays a major role in biological metabolism. It is least abundant but the most common element to limit biological productivity. The most significant form of soluble inorganic phosphorus is orthophosphate (PO<sub>4</sub><sup>-3</sup>). It enters freshwater from atmospheric precipitation, groundwater and surface runoff. Loading of phosphorus may also result due to inflow of fertilizers and detergents (Gainey and Lord, 1952).

In RS, orthophosphate was found to increase during the period April to September, while in SS the same was recorded from May to November months followed by a decrease during January to March in both the lakes (Fig. 6A). The maximum value was found to be 0.63 mg l<sup>-1</sup> in RS in July and 0.58 mg l<sup>-1</sup> in October in SS. Minimum level was recorded in January (0.17 mg l<sup>-1</sup> in RS) and March (0.03 mg l<sup>-1</sup> in SS; Table 1 and 2). Similar seasonal trend of fluctuation of phosphate concentration was noted by Pandey and Verma (1992), while studying the limnological status of a temple pond in Bihar. Decomposition of organic matter during summer and adsorption of phosphorus in the rainy season caused by the inflow of runoff water may be the probable reasons for higher values of phosphates in summer and monsoon period (Sharma *et al.*, 1978; Mehra, 1986 and Kumar, 1995). Low phosphate ion concentration during winter may be attributed to low bacterial decomposition capacity at low temperature and its rapid utilisation by autotrophs (Patralekh, 1994). However, Pathak and Shastree (1993) observed a summer minima and winter maxima of phosphate in Rukmini and Visar Sarovar (Bihar). Varghese *et al.* (1992) reported maximum phosphate in monsoon but minimum in summer in a polluted pond of Madhya Pradesh. Seasonal variation in phosphate was not encountered by Ganapati (1960) and Zutshi and Vass (1978).

The importance of phosphate as a nutrient element in the growth and abundance of phytoplankton is well established (Dugan, 1972). It is a pollution indicator as excess amount of phosphate may cause eutrophication in aquatic systems. A value of 0.03 mg l<sup>-1</sup> or more is considered to be a characteristic feature of an eutrophic waterbody by Sawyer (1966) and Vollenweider (1968) beyond which blooms may appear. In RS and SS, the phosphate values

**Table 1.** Values of physico-chemical parameters and 95% confidence interval of Rabindra Sarovar (RS).

Parameters	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<b>WATER</b>												
Temperature(C)	32.95 ±1.44	32.31 ±1.02	31.22 ± 0.32	31.68 ± 0.71	30.9 ± 0.48	29.97 ± 0.95	27.84 ± 0.6	22.47 ± 0.24	20.92 ± 0.88	23.30 ± 0.66	29.65 ± 0.97	30.98 ±0.66
pH	8.53 ±0.47	8.98 ± 0.77	8.42 ± 0.03	8.5 ±0.29	8.35 ±0.38	7.97 ± 0.22	8.07 ± 0.11	8.15 ± 0.13	8.17 ± 0.3	8.29 ± 0.26	8.6 ± 0.2	8.49 ±0.24
Turbidity(NTU)	12.16 ±0.6	9.91 ± 2.26	9.58 ± 1.2	10.58 ±0.99	10.41 ± 0.86	15.66 ± 2.37	17.41 ± 2.05	20.75 ± 3.76	20.58 ± 3.24	17.76 ± 2.38	16.91 ±3.33	17.58 ±3.5
Conductivity (µmhos/cm)	796.66 ± 2.28	733.33 ± 6.52	685.00 ± 2.26	646.66 ±3.25	569.66 ± 7.52	566.50 ± 5.4	509.56 ± 0.26	465.75 ± 1.89	590.00 ± 6.02	572.16 ± 4.5	547.88 ± 3.13	676.66 ± 5.8
Total alkalinity (mg/l)	417.50 ± 2.61	378.25 ± 2.35	373.66 ± 2.31	392.00 ± 3.16	328.33 ± 1.85	334.66 ± 2.30	301.33 ± 1.72	305.33 ± 1.46	325.83 ± 3.36	369.66 ± 4.10	358.33 ± 2.36	349.00 ± 2.19
Total hardness (mg/l)	106.80 ± 2.15	102.40 ± 2.44	109.18 ±7.45	101.00 ± 6.55	89.00 ±6.97	82.51 ±1.07	96.31 ± 8.56	94.86 ± 1.03	103.50 ± 2.6	112.50 ±7.58	111.38 ±3.24	106.83 ± 1.01
Dissolved oxygen (mg/l)	6.03 ± 0.85	5.20 ± 1.12	4.73 ± 0.63	6.49 ± 0.48	5.15 ± 0.8	6.21 ± 0.44	6.09 ± 0.74	7.41 ± 0.54	7.74 ± 0.77	7.40 ±0.88	8.6 ± 0.2	7.52 ±0.68
BOD(mg/l)	7.08 ±0.98	7.25 ± 0.56	6.00 ±1.13	4.66 ±1.44	4.50 ±1.49	4.00 ±1.13	4.66 ± 1.72	3.38 ± 0.31	4.00 ± 0.97	4.83 ±2.89	8.33 ±2.12	7.52 ±1.72
COD(mg/l)	41.01 ±1.34	46.62 ± 2.64	37.13 ±1.39	35.13 ±1.14	31.31 ± 6.26	30.28 ± 5.16	28.93 ± 4.64	23.16 ± 5.13	26.56 ± 3.24	31.21 ±3.76	36.50 ± 4.65	37.16 ±3.81

Table 1 contd.

Parameters	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Chloride(mg/l)	75.24 ±3.86	69.66 ±2.64	70.33 ±3.53	63.08 ±5.14	52.33 ±8.15	50.00 ±9.08	46.50 ±2.02	39.16 ±2.36	45.83 ±9.88	51.58 ±1.88	57.33 ±10.4	61.66 ±10.93
Phosphate(mg/l)	0.52 ±0.32	0.61 ±0.48	0.63 ±0.32	0.5 ±0.26	0.52 ±0.4	0.45 ±0.24	0.42 ±0.09	0.38 ±0.31	0.17 ±0.16	0.21 ±0.12	0.24 ±0.1	0.48 ±0.2
Nitrate(mg/l)	0.60 ±0.22	0.71 ±0.46	0.61 ±0.37	0.49 ±0.21	0.34 ±0.29	0.16 ±0.01	0.11 ±0.05	0.10 ±0.03	0.30 ±0.008	0.29 ±0.04	0.47 ±0.12	0.52 ±0.03
Nitrite(mg/l)	0.09 ±0.03	0.13 ±0.01	0.22 ±0.02	0.12 ±0.04	0.16 ±0.04	0.18 ±0.04	0.16 ±0.05	0.12 ±0.03	0.11 ±0.01	0.07 ±0.04	0.07 ±0.04	0.10 ±0.01
Ammonium(mg/l)	0.15 ±0.02	0.13 ±0.02	0.12 ±0.02	0.14 ±0.02	0.09 ±0.02	0.05 ±0.04	0.06 ±0.02	0.05 ±0.02	0.09 ±0.11	0.06 ±0.02	0.17 ±0.09	0.17 ±0.04
<b>SEMIDENT</b>												
Temperature(C)	32.08 ±0.76	31.78 ±0.4	31.27 ±0.12	31.53 ±0.52	30.90 ±0.26	30.63 ±0.48	27.79 ±0.76	22.77 ±0.37	21.07 ±0.84	23.45 ±0.89	29.44 ±0.56	29.85 ±0.35
pH	7.80 ±0.09	7.56 ±0.12	7.65 ±0.11	7.51 ±0.02	7.46 ±0.09	7.66 ±0.17	7.44 ±0.08	7.54 ±0.06	7.47 ±0.08	7.63 ±0.09	7.63 ±0.07	7.53 ±0.04
Phosphate (mg/l)	7.33 ±0.64	7.91 ±0.39	7.00 ±1.13	7.75 ±1.83	6.16 ±1.1	5.75 ±1.16	5.91 ±1.24	6.58 ±1.36	5.00 ±0.91	6.33 ±1.08	8.25 ±1.08	8.75 ±0.77
Nitrate(mg/l)	5.16 ±1.28	4.16 ±0.09	5.58 ±1.91	4.99 ±0.88	5.51 ±1.09	3.93 ±0.42	3.45 ±0.49	2.82 ±0.71	2.80 ±0.46	3.61 ±0.5	3.20 ±0.38	5.16 ±0.69
Nitrite(mg/l)	0.72 ±0.04	0.87 ±0.05	0.88 ±0.03	0.80 ±0.08	0.58 ±0.13	0.56 ±0.12	0.54 ±0.1	0.49 ±0.06	0.51 ±0.13	0.52 ±0.19	0.48 ±0.17	0.66 ±0.13
Organic carbon(%)	2.23 ±0.61	2.08 ±0.84	1.61 ±0.63	1.15 ±0.56	0.79 ±0.39	1.26 ±0.73	1.59 ±0.75	1.53 ±0.47	1.64 ±0.8	1.44 ±0.61	1.85 ±0.68	1.99 ±0.36

Note : The CI (Confidence interval) values show that the nutrient content of the lake did not vary much during the study period.

**Table 2.** Physico-chemical parameters and 95% confidence interval of Subhas Sarovar (SS)

Particulars	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<b>WATER</b>												
Temperature( C)	32.92 ± 0.19	31.92 ±0.52	32.6 ± 0.23	31.00 ± 0.5	32.35 ± 0.09	29.66 ± 0.3	27.85 ± 0.08	22.97 ± 0.42	22.31 ±0.69	24.44 ± 1.0	27.63 ± 1.22	29.24 ±0.72
pH	8.80 ± 0.28	8.40 ± 0.11	8.44 ± 0.11	8.60 ± 0.2	8.31 ± 0.28	7.72 ±0.18	8.04 ±0.2	7.98 ±0.09	8.41 ± 0.09	8.51 ± 0.2	8.52 ± 0.13	8.59 ±0.11
Turbidity (NTU)	23.91 ± 3.24	19.58 ± 2.61	15.66 ± 2.28	15.75 ± 4.62	13.50 ± 3.44	10.33 ± 2	14.25 ± 2.62	16.91 ±2.86	17.50 ± 0.87	19.66 ± 3.21	23.00 ±2.8	26.83 ±2.86
Conductivity (µ mhos/cm)	464.33 ± 5.4	444.33 ± 8.48	406.66 ± 6.52	393.16 ± 1.18	386.16 ± 2.96	381.50 ± 1.94	319.50 ± 4.76	320.37 ±7.2	392.08 ± 7.41	424.16 ± 0.95	390.78 ±4.5	481.00 ± 5.33
Total alkalinity (mg/l)	235.66 ± 8.68	210.00 ± 1.30	220.66 ± 1.45	210.66 ± 1.85	220.66 ± 8.57	204.66 ± 1.2	215.00 ± 1.50	223.33 ± 9.96	238.33 ± 1.98	252.00 ± 1.73	261.66 ±1.17	269.33 ± 3.62
Tota hardness	71.20 ± 2.01	62.30 ± 1.10	61.18 ± 8.55	54.19 ± 0.69	54.20 ± 1.66	60.41 ± 0.88	66.60 ±4.02	64.81 ± 2.45	64.10 ± 5.45	62.30 ± 1.07	64.23 ± 9.65	72.00 ± 0.69
Dissolved oxygen (mg/l)	5.76 ± 1.41	3.76 ± 0.52	5.05 ±0.71	4.88 ± 0.77	6.63 ± 0.68	5.56 ±1.09	6.09 ±1.22	7.40 ±1.44	7.80 ± 0.93	7.60 ± 0.87	6.88 ±1.08	5.98 ±0.38
BOD(mg/l)	12.00 ± 2.57	10.16 ± 1.98	9.33 ± 1.3	7.00 ± 1.13	7.25 ± 1.29	8.00 ±0.9	6.00 ±1.13	6.66 ±1.72	6.00 ± 0.56	9.66 ± 1.18	12.13 ±1.3	15.00 ±4.07
COD(mg/l)	55.40 ± 6.16	43.30 ± 4.31	38.25 ± 6.44	35.86 ± 7.7	30.40 ±5.95	30.25 ± 4.72	26.30 ±2.46	26.33 ±2.3	25.77 ±2.74	33.93 ± 1.92	36.33 ±1.9	39.15 ± 1.15
Chloride(mg/l)	54.91 ± 5.22	51.00 ± 0.86	45.61 ± 1.83	35.75 ± 2.57	41.95 ±5.5	35.83 ± 6.44	35.08 ± 4.95	33.24 ± 3.81	34.16 ±3.28	43.83 ± 1.61	41.66 ±1.98	45.33 ±6.44

Table 2 contd.

Particulars	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Phosphate(mg/l)	0.37 ±0.12	0.33 ±0.12	0.37 ±0.09	0.47 ±0.03	0.34 ±0.12	0.58 ±0.09	0.53 ±0.2	0.15 ±0.4	0.17 ±0.01	0.12 ±0.02	0.03 ±0.01	0.05 ±0.008
Nitrate(mg/l)	0.42 ±0.03	0.39 ±0.03	0.38 ±0.01	0.38 ±0.02	0.26 ±0.008	0.15 ±0.02	0.13 ±0.01	0.08 ±0.01	0.15 ±0.01	0.30 ±0.05	0.56 ±0.008	0.52 ±0.02
Nitrite(mg/l)	0.10 ±0.008	0.15 ±0.008	0.18 ±0.004	0.13 ±0.008	0.20 ±0.01	0.07 ±0.01	0.06 ±0.01	0.09 ±0.008	0.08 ±0.02	0.03 ±0.02	0.08 ±0.01	0.07 ±0.01
Ammonium(mg/l)	0.19 ±0.01	0.22 ±0.01	0.30 ±0.03	0.20 ±0.02	0.11 ±0.03	0.08 ±0.01	0.02 ±0.01	0.05 ±0.01	0.08 ±0.01	0.10 ±0.02	0.14 ±0.03	0.23 ±0.02
<b>SEMIDENT</b>												
Temperature( C)	32.92 ±0.16	32.51 ±0.66	32.75 ±0.48	31.79 ±0.15	32.29 ±0.36	30.23 ±0.34	28.10 ±0.56	24.03 ±0.6	21.80 ±0.83	24.31 ±1.07	26.96 ±1.37	28.67 ±0.55
pH	7.63 ±0.17	7.67 ±0.06	7.32 ±0.35	7.43 ±0.05	7.55 ±0.23	7.32 ±0.22	7.03 ±0.09	7.16 ±0.04	7.39 ±0.04	7.58 ±0.04	7.49 ±0.18	7.39 ±0.07
Phosphate(mg/l)	7.16 ±0.36	8.83 ±0.28	8.16 ±0.4	6.33 ±1.08	4.83 ±1.53	3.91 ±1.94	4.75 ±0.62	4.33 ±0.68	4.33 ±0.8	4.76 ±0.94	5.16 ±0.31	6.58 ±1.15
Nitrate(mg/l)	5.10 ±0.33	5.80 ±0.48	7.27 ±0.99	5.09 ±0.19	4.14 ±0.6	3.17 ±0.84	2.90 ±0.38	3.43 ±0.02	2.36 ±0.29	2.51 ±0.57	2.54 ±0.26	3.32 ±0.11
Nitrite(mg/l)	0.76 ±0.09	0.58 ±0.06	0.66 ±0.02	0.71 ±0.01	0.76 ±0.03	0.50 ±0.02	0.44 ±0.01	0.41 ±0.02	0.46 ±0.07	0.49 ±0.03	0.40 ±0.04	0.57 ±0.05
Organic carbon(%)	2.24 ±0.53	2.73 ±0.31	1.85 ±0.06	0.85 ±0.32	0.97 ±0.27	1.79 ±0.18	1.96 ±0.23	1.94 ±0.03	1.77 ±0.05	1.80 ±0.04	1.58 ±0.06	2.43 ±0.13

Note : CI values revealed similar trend as in Table 1. However, COD values were found to vary widely.

were always many fold higher than the critical limit signifying certain degree of eutrophication in both the lakes. The luxuriant growth of macrophytes in RS also corroborates with the presence of higher concentration of phosphates in water which stimulates the growth of the photosynthetic algae and weeds sometimes in nuisance quantities.

**Nitrate, Nitrite and Ammonium** : In aquatic ecosystems, inorganic nitrogen exist in the combined form of ammonium ( $\text{NH}_4^+$ ), nitrate ( $\text{NO}_3^-$ ), and nitrite ( $\text{NO}_2^-$ ), etc., of which nitrate is the most common form (Goldman and Horne, 1983). According to Wetzel (1983), nitrate enters a freshwater system from the drainage basin and precipitation but are highly variable seasonally and spatially.

In RS the nitrate values were found to vary from 0.10 (December) to 0.71  $\text{mg l}^{-1}$  (June), while in SS it ranged from 0.08 (December) to 0.56  $\text{mg l}^{-1}$  in March (Table 1 and 2). During the study period, the nitrate concentration of both the lakes followed approximately the same pattern, showing higher values from January to September months while steadily declined during October to December period (Fig. 6B). Similar findings were also reported by Pandey and Verma (1992) and Patralekh (1994) in freshwater ecosystems of Bihar state. It has been shown that a typical seasonal cycle of nitrate (with a maximum in summer and minimum in winter) occurs in most non-polluted waterbodies (Reynolds, 1971; Wood and Gibson, 1974 and Wilson *et al.* 1975). The appreciable rise in nitrate value in summer can be explained by the significant bacterial decomposition and nitrification of complex dead organic matter (Zafar, 1966) and by natural enrichment during monsoon. Minimum value of nitrate in winter might be due to sedimentation and biogenic uptake by phytoplankton bloom and macrophyte infestation (Brown and Austin, 1973). However, opposite trends of seasonal fluctuation of nitrate have also been reported by several workers (Pant *et al.*, 1981; Sinha *et al.*, 1994 and Kaur *et al.*, 1995). Pathak and Shastree (1993) found no seasonal trend of nitrate distribution in lentic hydrosphere of Gaya, Bihar.

High concentration of nitrate nitrogen has been taken as an eutrophication index. Ganapati (1960) pointed out that tropical waters particularly unpolluted ones are deficient in nitrates and a concentration beyond 0.15  $\text{mg l}^{-1}$  is indicative of eutrophication (Sawyer, 1966). In both the lake systems under study, nitrate value was higher than the prescribed limit denoting a process of progressive eutrophication specially in RS where nitrate values were higher in comparison to SS.

Nitrite concentration, on the other hand, is usually very low ( $<0.01 \text{ mg l}^{-1}$ ) unless organic pollution is high. This is due to the fact that  $\text{NO}_2^-$  gets readily oxidised to  $\text{NO}_3^-$  and rarely accumulates in well oxygenated water or is converted to ammonia in anoxic waters (Goldman and Horne, 1983 and Wetzel, 1983).

The temporal variations of nitrite in RS and SS were found to follow the same trend as nitrate, exhibiting higher values during June to November and low during December to February months (Fig. 6C). Mean value was as low as 0.07  $\text{mg l}^{-1}$  (February/March) and 0.03  $\text{mg l}^{-1}$  (in February) in RS and SS and as high as 0.22  $\text{mg l}^{-1}$  (July) and 0.20  $\text{mg l}^{-1}$  (September) in the two respective lakes (Tables 1 and 2). Low values of nitrite especially

in SS, signify low organic pollution load in both the lakes. Ganapati (1941) and Sreenivasan (1964b) have recorded total absence of nitrite in their observation.

Ammonia is generated by heterotrophic bacteria as an end product of decomposition of organic matter or as excretory product of aquatic animals. It is present primarily as  $\text{NH}_4^+$  ions and is readily assimilated by plants in the trophogenic zone (Toetz, 1971). The distribution of  $\text{NH}_4^+$  in freshwater is highly variable seasonally and spatially and depends upon the level of productivity of the lake and extent of pollution from organic matter (Wetzel, 1983). The concentration is usually low in aerobic water, below  $0.1 \text{ mg l}^{-1}$  (Ellis *et al.*, 1946 and Goldman and Horne, 1983) because of utilisation by plants in the photic zone.  $\text{NH}_4^+$  is oxidised to  $\text{NO}_2$  and  $\text{NO}_3$  by bacterial nitrification which are very active at moderately high temperature (Pathak and Shastree, 1993).

In RS, ammonium was found to range from  $0.05$  (December) to  $0.17 \text{ mg l}^{-1}$  (April) while in SS it varied from  $0.02$  (November) to  $0.30 \text{ mg l}^{-1}$  (July; Tables 1 and 2). Low concentrations were noted from October to December months which gradually increased during March to August (Fig. 6D). High level of  $\text{NH}_4^+$  in SS may, probably be due to less macrophytic density in the photic zone. High  $\text{NH}_4^+$  in summer has been earlier reported by Goel *et al.* (1980) and Varghese *et al.* (1992). According to Sharma *et al.* (1978) highest ammonium content in water correspond with the period of high decomposition rate (summer and rainy season). At this time ammonia may also be released due to anoxic conditions (Mortimer, 1971). The present observations are in conformity with this general trend. However, Pant *et al.* (1981) while studying the pollution aspects of Lake Nainital, Uttar Pradesh, reported highest average concentration of ammonia during winter.

### Sediment Characteristics

**Sediment Temperature :** The temperature of sediment varied from  $21.07$  to  $32.08^\circ\text{C}$  in RS and from  $21.80$  to  $32.92^\circ\text{C}$  in SS (Tables 1 and 2). Soil temperature fluctuation was in confirmation with water temperature, showing minimum value in January and maximum in May (Fig. 6E).

**pH :** Sediment pH ranging between  $6.50 - 7.50$  has been considered to indicate productive soils which favours the growth and activity of microorganisms, mineralisation of organic matter with subsequent release of nutrients (Chandra, 1997).

In RS, the sediment pH was observed to vary from  $7.44$  to  $7.80$  while in SS it ranged from  $7.03$  to  $7.67$  (Table 1 and 2) remaining alkaline although the study period, indicating the productive nature of both the lakes. Bais *et al.* (1992) had also reported alkaline sediment pH in Sagar Lake, Madhya Pradesh but Mandal and Moitra (1975a), while studying the bottom soil of a freshwater pond at Burdwan, West Bengal, noted acidic pH. Mehrotra and Jhingran (1986), reported near neutral ( $6.50-7.10$ ) soil reaction in Gulariya reservoir, Uttar Pradesh. The pH of the soil showed no consistent temporal variation in RS and SS (Fig. 7A). Kumar and Sant (1981), Ahmad *et al.* (1996) also reported no discernible pattern of sediment pH variation.

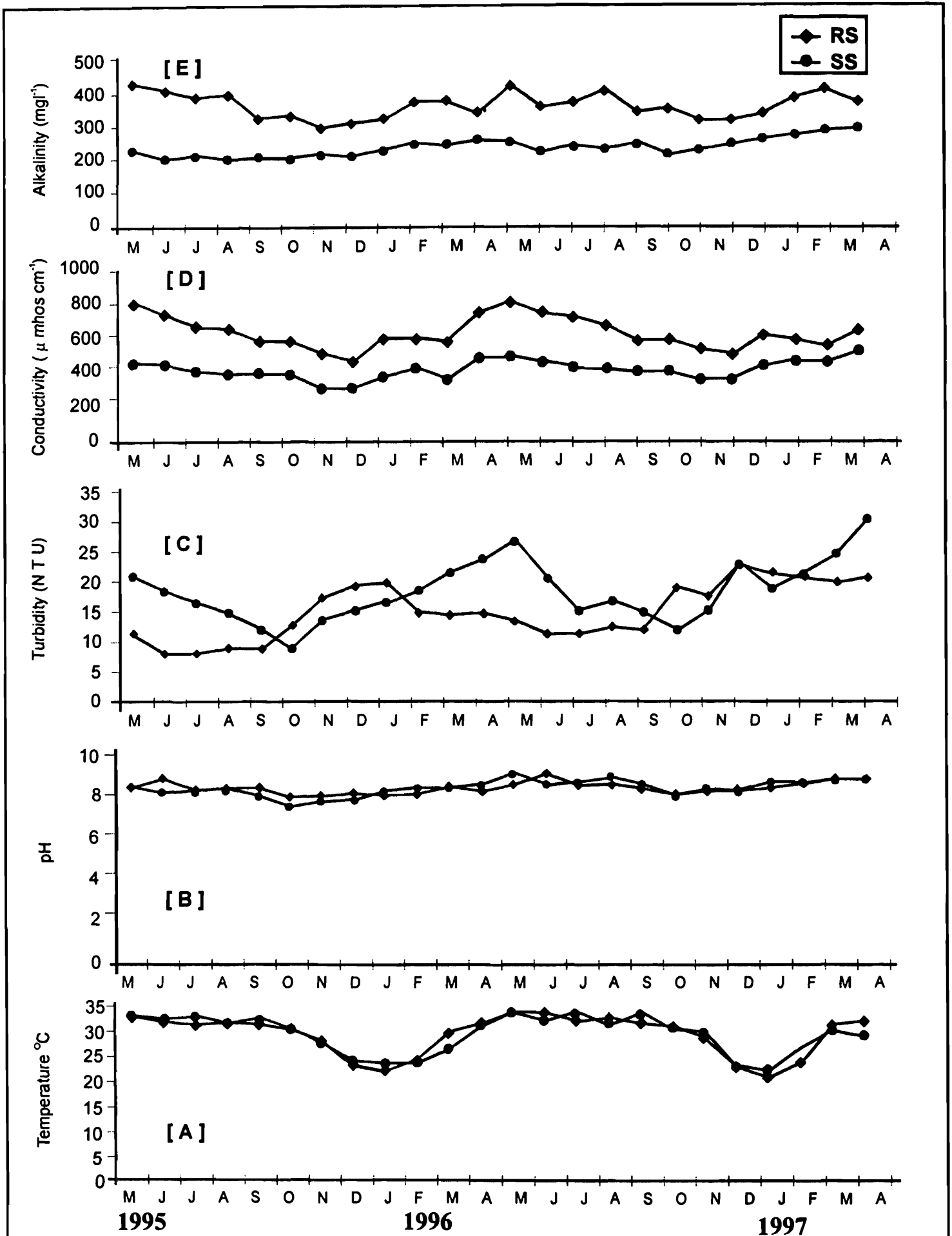


Fig. 4. Monthly variations (1995 - 1997) in physico-chemical parameters of RS and SS.

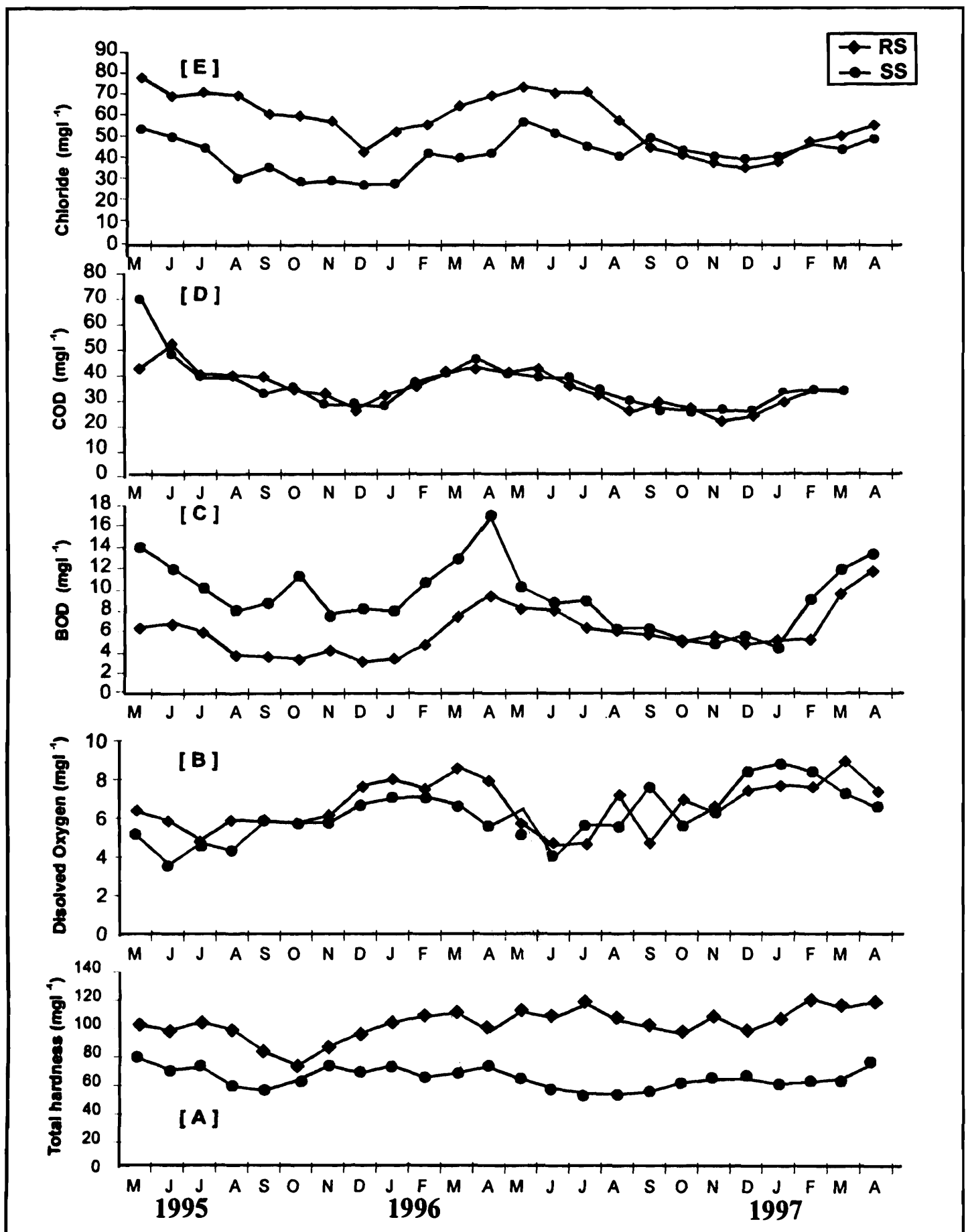


Fig. 5. Monthly variations (1995 - 1997) in physico-chemical parameters of RS and SS

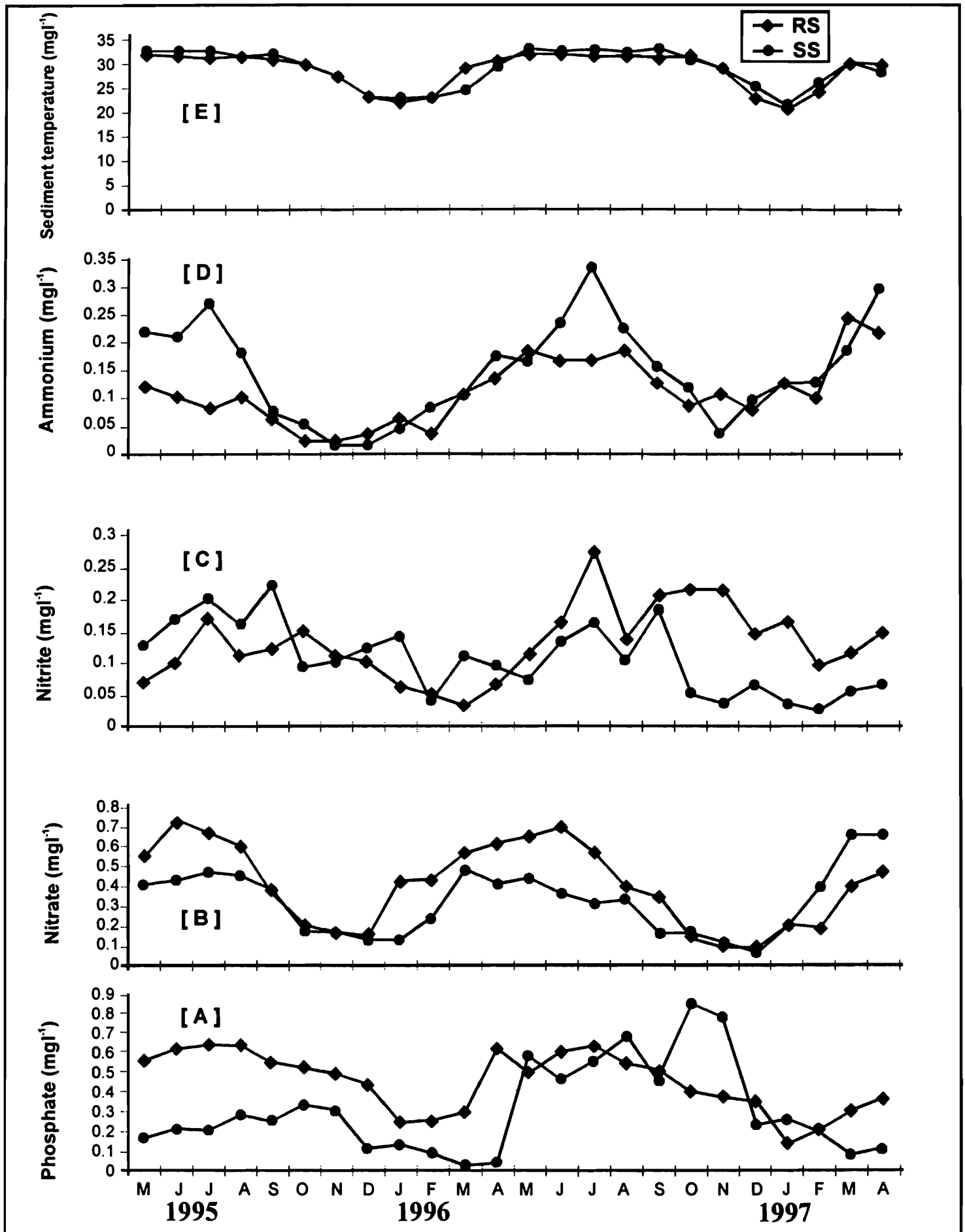


Fig. 6. Monthly variations (1995 - 1997) in physico-chemical parameters of RS and SS

**Phosphate** : Due to its reactive nature phosphorus ions form insoluble compounds with calcium under alkaline condition and also remain adsorbed on colloidal complexes. In addition organic forms of phosphates are present in bottom soil which are mineralised in organic forms by bacteria (Chandra, 1997).

For the period of two years, bottom phosphates of SS and RS was found to be higher from March to August and lower during October to January (Fig. 7B). Minimum average value was noted in January ( $5.00 \text{ mg l}^{-1}$ ) in RS and October ( $3.91 \text{ mg l}^{-1}$ ) in SS, while maximum level of phosphate was recorded in April ( $8.75 \text{ mg l}^{-1}$ ) in RS and June ( $8.83 \text{ mg l}^{-1}$ ) in SS (Tables 1 and 2).

Increase in concentration in monsoon may be due to allochthonous inputs into the lakes as a result of surface runoff from adjoining drainage basin (Agarwal *et al.*, 1993 and Ahmad *et al.*, 1996). However, rise in summer season can be attributed to rapid decomposition of humus (Singh and Roy, 1991a and Sinha *et al.*, 1992) or by the release of phosphate from the dead cells of algae and diatoms (Mandal and Moitra, 1975a).

**Nitrate and Nitrite** : Nitrogen in soil is present mostly in inorganic form *viz.*,  $\text{NO}_3$  and  $\text{NO}_2$ . They are known to play an important role in plant growth and are essential macronutrients which brings about changes in microclimate. Nitrates are formed from organic nitrogenous compound by decomposition, ammonification and nitrification brought about by the activities of bacteria (Mandal and Moitra, 1975a).

The temporal fluctuation of bottom nitrate and nitrite of RS and SS showed similar pattern, with higher values during April to September months and sharp decline during November to January (Fig. 7C and D). The nitrate concentration (Table 1 and 2) was found to be minimum in January ( $2.80 \text{ mg l}^{-1}$  in RS and  $2.36 \text{ mg l}^{-1}$  in SS) and maximum in July ( $5.58 \text{ mg l}^{-1}$  in RS and  $7.27 \text{ mg l}^{-1}$  in SS). Nitrite values were much less in comparison to nitrate. Minimum level was noted in March in both the lakes ( $0.48 \text{ mg l}^{-1}$  in RS and  $0.40 \text{ mg l}^{-1}$  in SS) but July month showed maximum value in RS ( $0.88 \text{ mg l}^{-1}$ ) and highest value of  $0.76 \text{ mg l}^{-1}$  was noticed in May and September in SS (Table 1 and 2). Increase in nitrate and nitrite during monsoon and summer had been reported earlier by Moitra and Bhowmick (1968), Mandal and Moitra (1975a) and Ahmad *et al.* (1996). Saha (1985) attributed the rise in nitrate of the bottom soil during monsoon to the addition of nitrogenous compounds by leaching of rain water through catchment areas and surrounding fields. Decreased amount of nitrate and nitrite during winter may be due to lower nitrification rate resulting from the decline in temperature at the mud water interface (Gupta and Pant, 1989).

**Organic carbon** : In lakes autochthonous organic matter is derived from plankton, macrophytes, fish and other aquatic biota, while the allochthonous sources are (i) plant litter carried into the lake with surface runoff or blown into the lake by wind (ii) disposal of domestic wastes (Mandal and Moitra, 1975a and Gupta and Pant, 1989). Organic carbon present in organic matter plays an important role in soil fertility, macrophytic growth and propagation of benthic population. A wide variety of factors including sediment texture, productivity of overlying waters, current, temperature and dissolved oxygen appear to influence the distribution of organic carbon in sediments (Jayaraj and Reddy, 1992).

During the period of study, the percentage of organic carbon on monthly basis varied from 0.79(September) to 2.23%(May) in RS while in SS it fluctuated between 0.85 (August) and 2.73% in June (Table 1 and 2). Greater value of organic carbon percentage was obtained from March to June, which decreased during July to September period (Fig. 7E).

In tropical countries the decomposition of detrital matter is expected to continue throughout the year though it accelerates in warmer period (Saha, 1985). During summer months under high temperature, the decomposition of algae and macrophytes increases, causing enhancement of organic carbon percentage (Agarwal *et al.*, 1993). However, the decrease in organic carbon during monsoon months might be due to sedimentation of allochthonous silt and clay from the surrounding areas (Bais *et al.*, 1992).

Organic carbon less than 0.50% can be considered low for pond soil, the range of 0.50-1.50% is average while 1.50-2.50% is considered to be optimal for productivity (Chandra, 1997). In RS and SS, the organic carbon percentage was found to be greater than 1.50% for most part of the year indicating a high productive bottom with rich organic content.

**Texture analysis :** Textural classification recognizes three basic groups of soil, namely, clay, silt and sand. The sediment (Fig. 8) of RS was silt loamy type (silt – 70.93 to 74.52%; sand – 16.96 to 24.58% and clay – 0.90 to 12.10%), while SS had silty soil (Silt – 77.58 to 82.59%; sand – 8.31 to 13.79% and clay – 4.90 to 13.70%).

The distribution and abundance of benthic organisms are correlated with the particulate composition, soil texture and organic matter content of the sediment. Rao *et al.*, (1990) while studying the textural analysis of Ganghisagar lake, Madhya Pradesh reported large accumulation of silt and clay in the sediment. Oommachan and Belsare (1986) reported mainly sandy sediment of Lower lake of Bhopal. *Limnodrilus* sp. was reported by them to be abundant in sediments containing 49.40% silt and clay, whereas *Branchiura* sp. was found in sandy sediments and fine grained silty sediments. They also stressed that oligochaetes specially tubificids have wide range of particle preference (Ramesh Babu, 1979).

### Biological Characteristics

Benthos are the biocoenoses of the solid-liquid interface. They form an important component of the secondary production of aquatic ecosystem, mainly utilizing the energy of decaying organic matter settled at the bottom as organic detritus. Hence, the benthic animals play a major role in the detritus food chain being involved in the process of mineralization and recycling of organic matter (Singh and Sinha, 1993).

The pattern of distribution and abundance of species has been a fundamental theme in the study of ecological communities (May, 1975). The temporal and spatial distribution of a population is a fundamental characteristic and property of a species which reflects environmental pressure and behavioural pattern (Parson *et al.* 1977). In the present treatise, considering the importance of benthic organisms as indicator species, source of food for fish and a major component of the secondary productivity, it has been felt imperative to study the qualitative and quantitative composition of the benthic fauna present in the urban lake

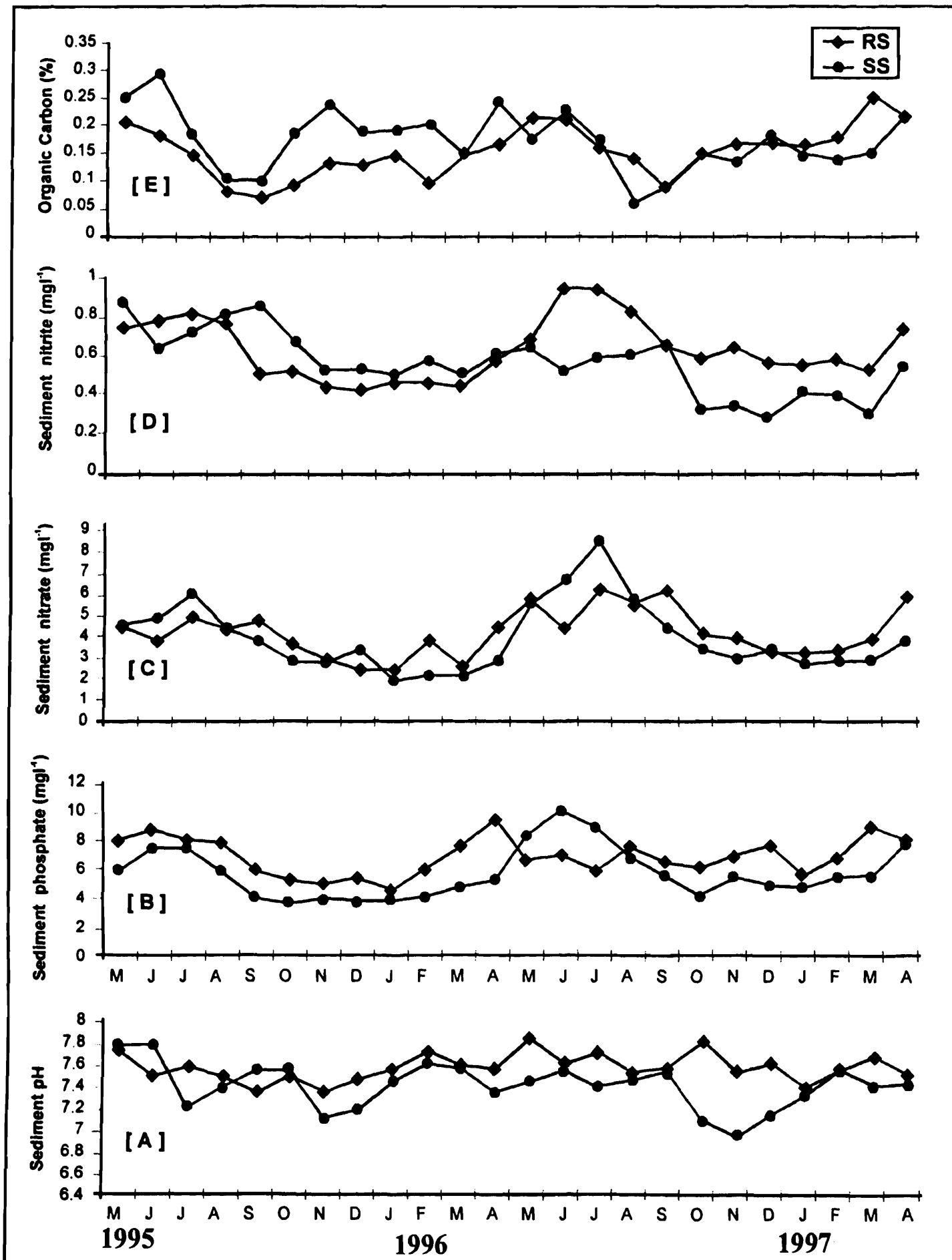


Fig. 7. Monthly variations (1995 - 1997) in physico-chemical parameters of RS and SS.

habitats of Calcutta. For studying the population pattern of macrozoobenthos of RS and SS, detailed knowledge on the composition distribution and abundance of the bottom biota both in relation to time and space is very essential. As such both the qualitative and quantitative studies conducted in Rs and SS are highlighted as follows.

### Qualitative Composition of Benthic Fauna

Both qualitative and quantitative samplings were done from the two lakes by hand picking, dragnetting and by the box type sampler. Qualitative sampling was done mainly to understand the composition of species in these two lakes.

Qualitative sampling of macrozoobenthic organisms revealed the presence of 32 species of bottom fauna belonging to three phyla comprising 8 major groups viz., Oligochaeta, Hirudinea, Crustacea, Odonata, Coleoptera, Diptera, Gastropoda and Bivalvia, during 1995-1997 in RS and SS (Table 3). However, each lake harboured only 29 species. *Hirudinaria manillensis*, *Sartoriana spinigera* and *Varuna litterata* were not encountered in RS, while *Lamellidens corrianus*, *Parreysia caerulea* and *P. pachysoma* were not reported in SS.

**Oligochaeta** : It was represented by only two species, *Limnodrilus hoffmeisteri* and *Branchiura sowerbyi*, belonging to the family Tubificidae. The former species was more abundant in both the lakes.

**Hirudinea** : *Hemiclepsis marginata*, *Hirudinaria manillensis* and *Placobdella emyda* were the three species representing this group. But they were very poorly represented both in number and percentage in RS and SS.

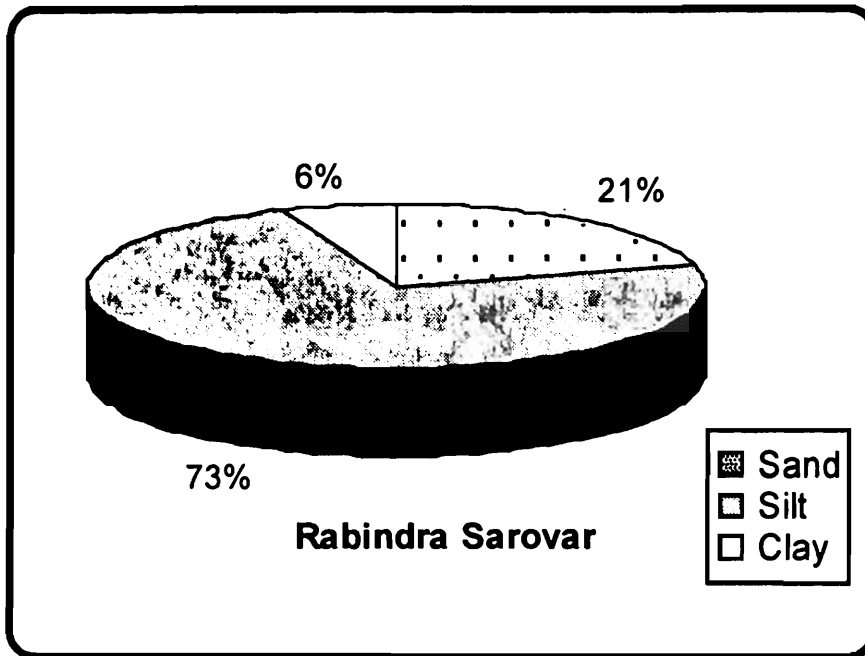
**Crustacea** : This group was represented by 4 species including an isopod, 2 species of crab (*Sartoriana spinigera* and *Varuna litterata*) and a freshwater prawn (*Macrobrachium dayanum*). They form a minor portion of the macrobenthic sample, apparently going down to the bottom for feeding purpose only.

**Odonata** : Two species viz., *Pseudagrion* sp. (Family Coenagrionidae) and *Brachythemis* sp. (Family Libellulidae) were the only benthic odonates which were seldom encountered during sampling.

**Coleoptera** : Only one species, *Hydrocoptus subvittulus* belonging to Dytiscidae family represented this group. It was poor in RS and moderately present in SS.

**Diptera** : Chironomid larvae belonging to Family Chironomidae, were the only dipterans found to be truly benthic in nature and had higher population in SS.

**Gastropoda** : This was the largest group of benthic animals in terms of number, density and percentage. A total of 14 species under 6 families [Viviparidae – 1 species, Pilidae - 1 species, Bithyniidae – 2 species, Thiaridae – 5 species, Lymnaeidae – 2 species, Planorbidae – 3 species ] constitute this group in both the lakes.

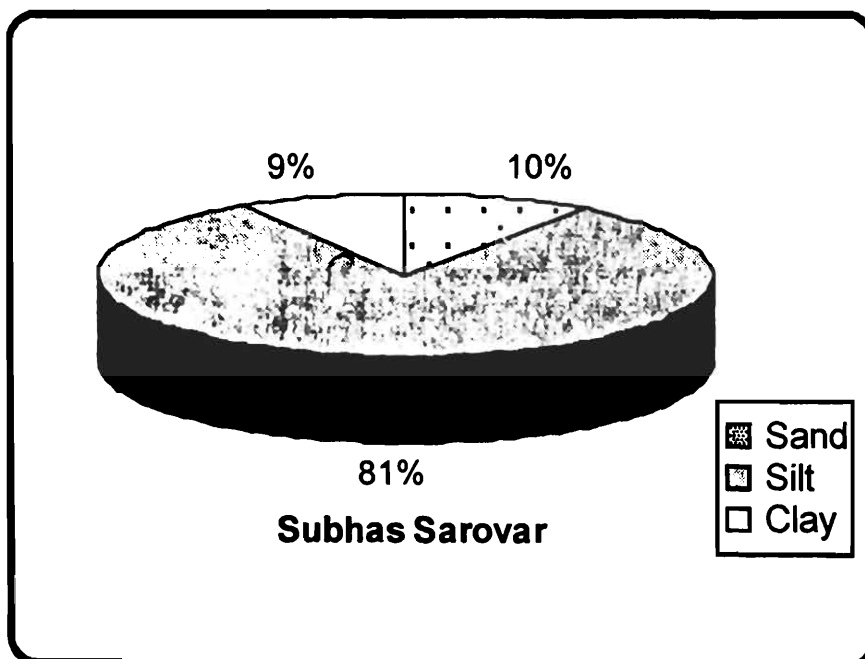


**SILT** - 70.93% to 74.52%  
(Mean - 72.51%)

**SAND** - 16.96% to 24.58%  
(Mean - 21.45%)

**CLAY** - 0.90% to 12.10%  
(Mean - 6.03%)

**Sediment - Silt loamy type**



**SILT** - 77.58% to 82.59%  
(Mean - 80.49%)

**SAND** - 8.31% to 13.79%  
(Mean - 10.27%)

**CLAY** - 4.90% to 13.70%  
(Mean - 9.23%)

**Sediment - Silty type**

**Fig. 8.** Sediment texture analysis of RS and SS.

**Table 3:** Composition and diversity of macrobenthic fauna of Ranindra Sarovar and Subhas Sarovar :

Group / Species		RS	SS
<b>Phylum : ANNELIDA</b>			
Group I.	OLIGOCHAETA		
	Family Tubificidae		
	1. <i>Limonodrilus hoffmeisteri</i> Claparede	+	+
	2. <i>Branchiura Sowerbyi</i> Beddard	+	+
Group II.	HIRUDINEA		
	Family Glossophonidae		
	3. <i>Hemiclepsis marginata asiatica</i> Morre	+	+
	4. <i>Placobdella emyda</i> Harding	+	+
	Family Hirudidae		
	5. <i>Hirudinaria manillensis</i> (Lesson)	-	+
<b>Phylum : ARTHROPODA (CRUSTACEAENS)</b>			
Group III.	CRUSTACEA		
	Family ?		
	6. Isopods (unidentified)	+	+
	Family Palaemonidae		
	7. <i>Macrobrachium dayanum</i> (Henderson)	+	+
	Family Gecarcinucidae		
	8. <i>Sartoriana spinigera</i> (Wood-Mason)	-	+
	Family Grapsidae		
	9. <i>Varuna litterata</i> (Fabricius)	-	+
<b>(INSECTS)</b>			
Group IV.	ODONATA		
	Family Libellulidae		
	10. <i>Brachythemis</i> sp.	+	+
	Family Coenagrionidae		
	11. <i>Pseudagrion</i> sp.	+	+
Group V.	COLEOPTERA		
	Family Dytiscidae		
	12. <i>Hydrocoptus subvittulus</i> Motes	+	+

Table 3 Contd.

Group / Species		RS	SS
Group VI.	DIPTERA		
	Family Chironomidae		
	13. <i>Chironomid larvae</i>	+	+
	<b>Phylum : MOLLUSCA</b>		
Group VII.	GASTROPODA		
	Family Viviparidae		
	14. <i>Bellamyia bengalensis</i> (Lamarck)	+	+
	Family PILIDAE		
	15. <i>Pila globosa</i> (Swainson)	+	+
	Family BITHYNIIDAE		
	16. <i>Gabbia orcula</i> Frauenfeld	+	+
	17. <i>Dignostoma cerameopoma</i> (Benson)	+	+
	Family THIARIDAE		
	18. <i>Thiara scabra</i> (Müller)	+	+
	19. <i>Thiara granifera</i> (Lamarck)	+	+
	20. <i>Thiara lineata</i> (Gray)	+	+
	21. <i>Thiara tuberculata</i> (Müller)	+	+
	22. <i>Brotia costula</i> (Rafinesque)	+	+
	Family LYMNAEIDAE		
	23. <i>Lymnaea acuminata</i> Lamarck	+	+
	24. <i>Lymnaea luteola</i> Lamarck	+	+
	Family PLANORBIDAE		
	25. <i>Indoplanorbis exustus</i> (Deshayes)	+	+
	26. <i>Gyraulus convexiusculus</i> (Hutton)	+	+
	27. <i>Gyraulus labiatus</i> (Benson)	+	+
Group VIII.	BIVALVIA		
	Family UNIONIDAE		
	28. <i>Lamellidens corrianus</i> Lea	+	-
	29. <i>Lamellidens marginalis</i> (Lamarck)	+	+
	Family AMBLENIDAE		
	30. <i>Parreysia caerulea</i> (Lea)	+	-
	31. <i>Parreysia pachyasoma</i> (Benson)	+	-
	Family PISIIDAE		
	32. <i>Pisidium clarkeanum</i> G. & H. Nevill	+	+

**Bivalvia** : Five species of bivalves belonging to two families (Unionidae and Pisidiidae) comprised of this group which had a higher population distribution in RS.

The presence of 32 benthic species comprising of 8 major groups (Oligocheata, Hirudinea, Crustacea, Odonata, Coleoptera, Diptera, Gastropoda and Bivalvia) belonging to 3 phyla (Annelida, Arthropoda and Mollusca) indicating diversity of the macrobenthic fauna in these two lake ecosystems. The composition of species, however, differs marginally in these two lakes. *Hirudinaria manillensis*, *Sartoriana spinigera* and *Varuna litterata* were not reported from RS, while 3 species of bivalves *Lamellidens corrianus*, *Parreysia caerulea* and *P. pachysoma* though encountered in RS were not noted in SS. The bivalve species are usually embedded partly in sand/mud. In RS the bottom being silt loamy type it offers a better habitat for bivalve species.

The number and composition of macrobenthic species of these two lakes were almost the same as both of them represent urban lakes in Calcutta, having almost similar physiographical and hydrobiological conditions. Composition and density of species of macrozoobenthos occurring in lakes vary widely due to differences in lake area, climatic and geographical conditions, total number of samples taken, analytical procedures and time and technique of sampling (Victor *et al.*, 1981; Ali *et al.*, 1978 and Sarkar, 1989). In various literatures dealing with macrobenthos of the Indian subcontinent, Ali *et al.*, (1978) reported 57 species in a pond in Dacca (Bangladesh), 18 species were noted from ponds of Patna (Bihar) by Ahmad and Singh (1989) and a total of 30 taxa of benthic macroinvertebrates were collected from Lake Nainital (Uttar Pradesh) by Gupta and Pant (1990). Survey of benthic community in West Bengal revealed the presence of 21 species in a pond of Burdwan (Mandal and Moitra, 1975b). While Sarkar (1989) noted 19 species from ponds located at Sonamukhi and in 1992, he reported 13 species from a lentic pond in Calcutta. In the present study, 32 species of macrobenthic animals have been recorded. It proved that RS and SS have considerable species diversity in comparison to other lakes and ponds of eastern India.

### Quantitative evaluation of benthic fauna

**Population density (Total benthos number m<sup>-2</sup>)** : The biannual variation in population density of total benthos showed approximately similar seasonality during two successive years (Fig. 9A) under study. The density of total macrobenthos ranged from 3234 to 8071 m<sup>-2</sup> in RS and 2675 to 6092 m<sup>-2</sup> in SS (Table 4). The temporal fluctuation in benthic population was characterised by two troughs (October and April in SS and August and April in RS), with intermittent rise in population in March (5169 m<sup>-2</sup>) in SS and February (6943 m<sup>-2</sup>) and July (8071 m<sup>-2</sup>) in RS.

The nature of substrate and available detritus control the composition and distribution of benthic fauna in an aquatic system (Cummins *et al.*, 1972). In the two lakes under study, decaying organic matter are more or less abundantly available. The green vegetation along the embankments as well as decomposition of aquatic macrophytes are the primary source

of leaf litter into the lakes. Moreover, the bottoms of both the lakes are muddy, mainly clay and silt, with high organic enrichment which favour positive establishment of animal communities, especially gastropods, biavales, oligochaetes and insects as evident from the Figure 10 (Please vide infra) which showed the predominance of molluscs and oligochaetes in the benthic habitat.

Gupta (1976) stressed that aquatic vegetation plays an important role in an aquatic ecosystem for harbouring macrobenthic fauna. The submerged and emergent macrophytes provide excellent diverse niches for several insects both larvae and adult and offer suitable substrata for adult insects and molluscs (McLachlan, 1975; Soszka, 1975; Gupta, 1976 and Maitland, 1978). The higher population density of macrobenthos in RS than SS was probably related to the macrophytic density and diversity which was much high in RS than SS. Moreover, in SS, the macrophytes were extensively removed for angling purposes from time to time, thus destroying the natural habitats of gastropods and insects.

Thienemann (1925) considered that a lake bed producing more than 1000 individuals  $m^{-2}$ , should be considered as highly productive. Gupta (1981) argued that Nainital Lake (Uttar Pradesh) was hyper eutrophic as the mean annual density of different macrobenthic species was calculated as 1655  $m^{-2}$ . Bose and Lakra (1994), reported two mesotrophic ponds in Ranchi as their density varied from 730 – 2943  $m^{-2}$ . In the present investigation, the macrobenthic density of RS and SS far exceeds the above values. Hence, keeping in view the suggestions of the above authors it can be ascertained that both the lakes are highly productive in nature. Similar high density of benthic animals had been reported earlier by Timms (1982), who found the mean number of benthic species in lakes of New Zealand to range from 75 to 7295  $m^{-2}$ . Gupta and Pant (1990) noted the average monthly density of macrobenthos of Lake Nainital to vary from 357 to 3047  $m^{-2}$ . More recently, the total number of benthos of a shallow eutrophic pond in Uttar Pradesh was reported to range from 3924 to 6583  $m^{-2}$  by Barbhuyan and Khan (1992).

The fluctuation in distribution and abundance of different forms of aquatic organisms from year to year and within the same year was attributed to disturbance of their habitat by Holme (1961), corroborating the earlier observations of Anderson and Hooper (1956), Ruggles (1959), Oliver (1960) and later by Gupta (1976) in fresh water impoundments. Different authors have attributed seasonal variations to different causes, such as lifecycle pattern, food quality and quantity, biotic interactions during competition and predation, changes in particle size and organic matter contents of sediments (Sanders, 1958; Kajak and Dusoge, 1968; Whitlatch, 1977 and Cowell and Vodopich, 1981). In the present study temporal and spatial variation in densities during the two successive years in both the lakes, were a consequence to changes in habitat affected by edaphic and endogenous factors like periodical removal of macrophytes, lowering of water level during summer and rain water incursion during monsoon.

A search in literature reveals that the studies involving variation in total macrobenthic population indicated one or two maxima during the year. Ricker (1952) reported a trough in the benthos population in winter (January) and peak in summer and monsoon months from

a lake in British Columbia. Srivastava (1956 and 1959), Mandal and Moitra (1975b), Raman *et al.* (1975), Vasisht and Bhandal (1979), Malhotra *et al.* (1990) and Singh *et al.* (1994) reported that total macrobenthos density reached high concentration during monsoon season (August – September) and lower in winter (January – February). Michael (1968) also found a single peak of abundance in March in a tropical fish pond of West Bengal. Kajak and Dusoge (1975a and b) reported two maxima (during spring and autumn) of macrobenthic population in the temperate lake Taltowisko and Mikolauskie (Poland). Gupta and Pant (1990) while studying the seasonal abundance of benthic macroinvertebrates in Lake Nainital, Uttar Pradesh (now Uttaranchal), noticed that the total benthic population showed two peaks (May and December). The occurrence of two peaks seems to be related with the availability of food in the form of dead planktonic organisms and also with temperature.

During this investigation, the population density of benthic animals in SS, was generally higher in monsoon months (July to September), declining in the months of October to January. But in RS, there was a sudden decrease in the population of benthic animals during the month of August, probably due to habitat disturbance and rise in water level during monsoon. The number of gastropods and oligochaetes were also reduced drastically during this month. Severe fall in population due to heavy rainfall has also been reported by Khan and Chaudhuri (1984) and Singh and Roy (1991a). Juvenile recovery of the population density, however, was quick as the density had increased considerably in the following month. This is probably due to the fact that gastropods mainly *Bellamya bengalensis* and *Thiara granifera* breed all the year round, and immature stages of these species were found throughout the study period.

**Biomass estimation :** The temporal variation in the macrobenthic biomass ranged from 286.84 – 846.55 gm m<sup>-2</sup> in RS and from 204.88 – 632.30 mg m<sup>-2</sup> in SS (Table 4). The macrobenthic biomass of SS was lower than that of RS. This was probably due to the abundance of *Lamellidens* sp. in RS which had greatest biomass among the benthic species. In SS, the bivalve species showed infrequent occurrence, hence the value of total biomass of this lake was low in comparison to RS. The benthic biomass in RS showed higher values during May to July months, followed by a trough in August. During September – October months there was some recovery of the biomass. Post monsoon season was characterised by low values of biomass in both the years (Fig. 9B). In SS, maximum biomass was observed during the months of May to September, thereafter the biomass varied irregularly. However, the postmonsoon season in SS also exhibited low biomass of the total macrozoobenthic species as seen in RS (Table 4, Fig. 9B).

The benthic macroinvertebrate biomass has been reported to be similar to the total abundance by various authors like Sarkar (1989), Gupta and Pant (1990) and Wones and Larson (1991). The temporal variation in the biomass of benthic organisms in both RS and SS, was more or less in accordance to the population density pattern, showing low values in postmonsoon and high values in premonsoon and monsoon months, although the taxonomic composition of the biomass was quite different. The peak in biomass during July/August months can be related to the abundance of the species like *Bellamya bengalensis*, *Thiara*

**Table 4.** Monthly variation in density (no./m<sup>2</sup>), biomass (gm/m) and 95% confidence interval of macrobenthic fauna in RS and SS.

Months	Rabindra Sarovar		Subhas Sarovar	
	Density	Biomass	Density	Biomass
May	5738 ±19.87	538.5 ±5.09	5311 ±18.82	625.11 ±6.36
June	5391 ±18.22	544.67 ±7.98	5462 ±18.98	564.76 ±5.24
July	8071 ±25.87	846.55 ±4.00	6092 ±19.88	632.3 ±4.35
August	3234 ±9.10	286.84 ±6.63	5699 ±19.29	577.63 ±2.77
September	4844 ±18.72	613.03 ±4.68	4374 ±14.03	505.35 ±1.11
October	5350 ±19.50	520.27 ±3.61	2675 ±10.41	314.42 ±2.62
November	5159 ±19.26	428.52 ±14.81	3923 ±15.37	432.09 ±1.10
December	6234 ±20.21	429.34 ±11.31	4699 ±15.83	366.28 ±3.42
January	6730 ±23.39	321.19 ±7.81	4535 ±10.79	241.45 ±2.86
February	6943 ±24.16	347.88 ±6.52	5119 ±23.70	222.59 ±2.14
March	6068 ±18.87	303.27 ±2.48	5169 ±21.97	261.86 ±5.15
April	4861 ±18.52	363.15 ±2.44	3464 ±15.27	204.88 ±2.32

**Note :** High values of CI (Confidential interval) was due to high values of total benthic density and biomass in both the lakes.

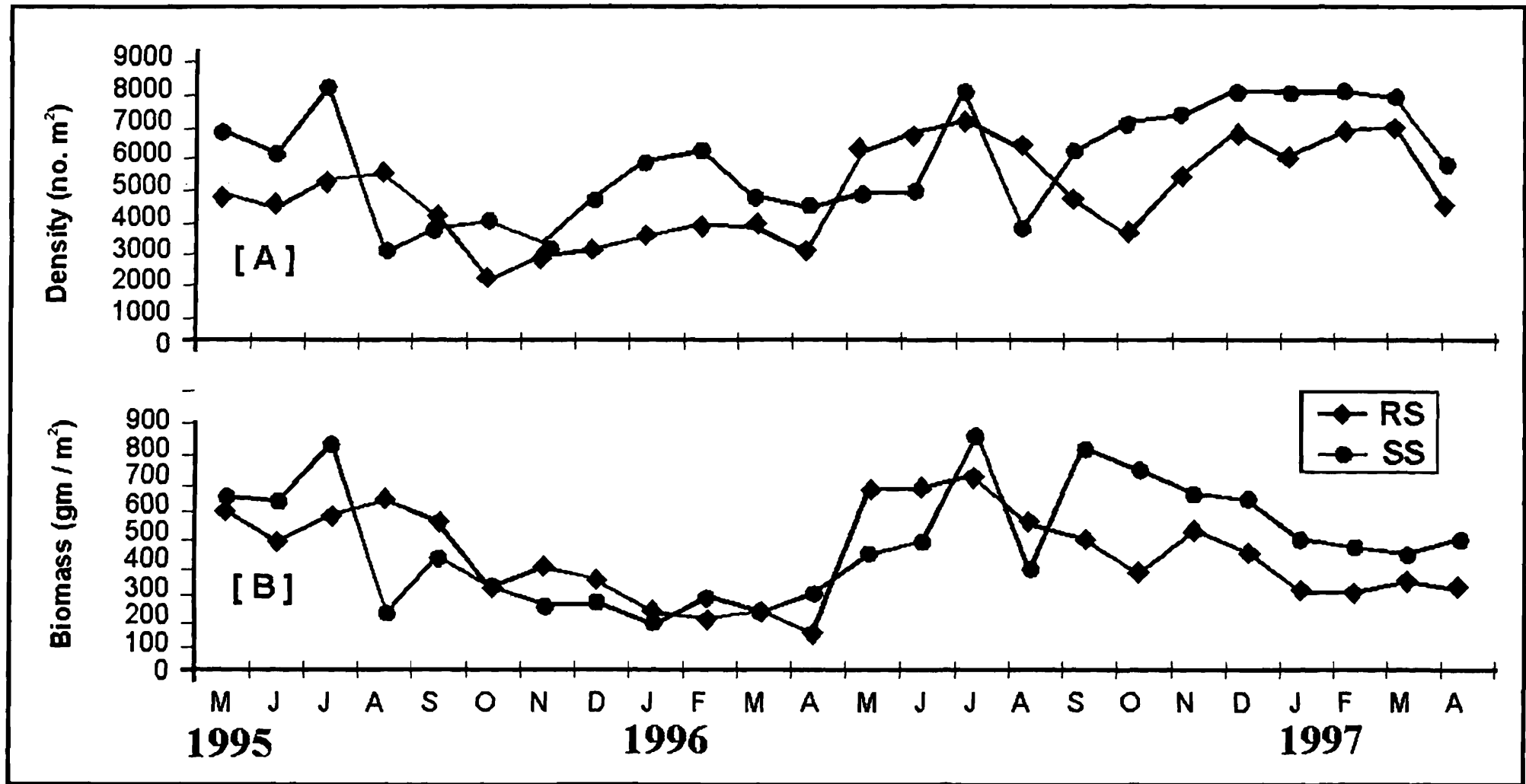


Fig. 9. Monthly variations (1995 - 1997) in density and biomass of total benthos in RS and SS.

**Table 5** : Seasonal abundance (no./m<sup>2</sup>), distribution and 95% confidence interval of macrobenthic groups in RS and SS.

Seasons	Oligochaeta	Coleoptera	Diptera	Gastropoda	Bivalvia
<b>Premonsoon</b>					
RS	1839 ±45.97	5 ±0.28	12 ±1.55	3482 ±57.05	172 ± 5.49
SS	1837 ±60.07	61 ±7.50	28 ± 2.17	2806 ±81.16	117 ±6.24
<b>Monsoon</b>					
RS	950 ±48.61	0	3 ±0.37	4313 ±97.32	106 ±4.37
SS	1425 ±54.96	13 ±1.05	0	3165 ± 96.95	63 ± 3.55
<b>Postmonsoon</b>					
RS	2294 ±75.91	0	19 ±1.45	3783 ±17.72	163 ± 10.07
SS	1992 ±72.66	11 ± 6.82	26 ±1.73	2434 ± 53.65	83 ± 4.53

**Note** : Oligochaeta and Gastropoda showed wide variations in terms of CI as they had greater abundance and the represented data are pooled as seasonal means.

*granifera*, *T. tuberculata* and *Brotia costula* which are rich in biomass. Low value of biomass during postmonsoon months was due to lower density of these species and dominances of *Gabbia orcula* and oligochaetes which are poor in biomass.

**Seasonal abundance and distribution** : The density of the benthic groups showed marked seasonal pattern in both the lakes (Table 5). The oligochaete population was highest during postmonsoon (2294 m<sup>-2</sup> in RS and 1992 m<sup>-2</sup> in SS) and lowest in monsoon (950 m<sup>-2</sup> in RS and 1425 m<sup>-2</sup> in SS). The gastropod population was well represented in all the seasons, reaching a peak in monsoon (4313 m<sup>-2</sup> in RS and 3165 m<sup>-2</sup> in SS). Both RS and SS exhibited maximum bivalve population during premonsoon season (172 m<sup>-2</sup> in RS and 117 m<sup>-2</sup> in SS) and minimum during monsoon (106 m<sup>-2</sup> in RS and 63 m<sup>-2</sup> in SS). The other groups, Coleoptera and Diptera were favoured by summer/premonsoon season, while Crustacea and Odonata had greater population during postmonsoon.

Distinct seasonal variation in population of the sixteen dominant macrobenthic species was also evident from the present investigation (Table 6). Monsoon season boosted the density of species like *Bellamya bengalensis* (829 m<sup>-2</sup> in RS and 1412 m<sup>-2</sup> in SS), *Digoniostoma*

*cerameopoma* (312 m<sup>-2</sup> in RS and 69 m<sup>-2</sup> in SS), *Thiara granifera* (2146 m<sup>-2</sup> in RS and 595 m<sup>-2</sup> in SS), *T. tuberculata* (407 m<sup>-2</sup> in RS and 429 m<sup>-2</sup> in SS) and *Brotia costula* (87 m<sup>-2</sup> in RS and 158 m<sup>-2</sup> in SS). On the other hand, the population of *Gabbia orcula*, *Gyraulus labiatus* and *Limnodrilus hoffmeisteri*, reached the maximum during postmonsoon season indicating that they preferred the winter season for breeding as evidenced by the presence of immature forms in the community. However, the other species *Thiara scabra*, *Lamillidens* spp. and *Hydrocoptus subvittulus* showed increased density in premonsoon season.

**Temporal abundance and distribution of groups :** The benthic fauna of the two lakes comprised a total of 8 groups of which Hirudinea, Crustacea, Odonata, Coleoptera and Diptera have low percentage (often less than 1). Gastropoda, Oligochaeta and Bivalvia were the three most dominant groups with respect to number and percentage (Tables 7 and 8, Fig. 10).

**Oligochaeta :** The seasonal and monthly fluctuation of oligochaetes showed opposite trend to that of gastropods (Fig. 10A) having maximum density during postmonsoon. The percentage was high during winter culminating in a peak in January/ February (43% in RS and 55.90% in SS). The peak was followed by a trough in May in SS (23.43%) and September in RS (5.84%; Table 8).

The oligochaete density varied from 283 (September) to 2959 m<sup>-2</sup> (February) in RS and from 763 (October) to 2862 m<sup>-2</sup> (February) in SS, (Table 7). The population showed marked increase during December to April months followed by a gradual decrease, specially during August to October months.

**Crustacea :** The crustacean number and percentage were found to be higher in SS than RS. It showed marked seasonal fluctuation, increasing during postmonsoon (November – January) after a low population in monsoon (Table 7). Maximum density was observed to be 32 m<sup>-2</sup> (December) and 10 m<sup>-2</sup> (February) in SS and RS respectively. The crustacean percentage reached a peak (0.68%) in December in SS and in February (0.14%) in RS (Table 8).

**Odonata :** This minor group had very low percentage in both RS and SS. However, in RS its density was higher than in SS showing maximum abundance of 10 m<sup>-2</sup>, in January (Table 7).

**Coleoptera :** The population distribution and percentage of occurrence of Coleoptera was found to be significantly high in SS than RS. During March/April its percentage increased to 3.38% in SS and 0.16% in RS (Table 8). The density was also maximum in March (175 m<sup>2</sup>) and moderate during the other months in SS (Table 7).

**Diptera :** The mean density of this group was observed to be more in SS than RS, showing higher abundance in post and premonsoon periods (December-May) than monsoon months (July to October). In RS, the highest density and percentage were noticed in February/March (39 m<sup>-2</sup>, 0.57%), while in SS the same values were 48 m<sup>-2</sup> (March) and 1.32% (April) respectively (Tables 7 and 8).

**Table 6 .** Seasonal abundance (no./m<sup>2</sup>) with 95% confidence interval and distribution of macrobenthic species in RS and SS.

Species	Rabindra Sarovar			Subhas Sarovar		
	Premonsoon	Monsoon	Postmonsoon	Premonsoon	Monsoon	Postmonsoon
<b>OLIGOCHAETA</b>						
<i>Limnodrilus hoffmeisteri</i>	1832 ±45.63	944 ±48.89	2268 ±74.59	1804 ±60.65	1372 ±54.43	1972 ±72.54
<i>Branchlura sowerbyi</i>	7 ±0.62	7 ±0.26	26 ±1.53	33 ±1.42	54 ±2.35	21 ±2.61
<b>COLEOPTERA</b>						
<i>Hydrocoptus subvittulus</i>	5 ±0.28	0	0	61 ±17.5	13 ±1.05	15 ±1.45
<b>DIPTERA</b>						
Chironomid larvae	12 ±1.55	3 ±0.17	19 ±1.45	28 ±2.17	0	26 ±1.73
<b>GASTROPODA</b>						
<i>Bellamyia bengalensis</i>	442 ±5.53	829 ±39.74	433 ±14.99	1251 ±25.84	1412 ±25.61	882 ±38.55
<i>Gabbia orcula</i>	608 ±22.57	446 ±18.82	878 ±17.2	679 ±35.97	447 ±34.52	774 ±42.62
<i>Digoniostoma cerameopoma</i>	155 ±3.82	312 ±30.38	46 ±1.72	44 ±1.90	69 ±3.62	29 ±1.53

Table 6 contd.

Species	Rabindra Sarovar			Subhas Sarovar		
	Premonsoon	Monsoon	Postmonsoon	Premonsoon	Monsoon	Postmonsoon
<i>Thiara scabra</i>	17 ±1.39	11 ±1.75	7 ±1.92	45 ±4.27	8 ±1.78	14 ±1.24
<i>Thiara granifera</i>	1552 ±64.98	2146 ±92.11	1635 ±41.25	383 ±21.11	595 ±29.9	323 ±8.14
<i>Thiara lineata</i>	5 ±1.4	3 ±0.69	3 ±0.18	39 ±3.00	48 ±2.58	34 ±1.36
<i>Thiara tuberculata</i>	363 ±9.36	407 ±10.05	314 ±6.03	252 ±7.09	429 ±8.87	269 ±10.22
<i>Brotia costula</i>	55 ±2.88	87 ±3.07	53 ±7.47	104 ±3.06	158 ±10.34	91 ±11.57
<i>Gyraulus labiatus</i>	287 ±39.72	74 ±2.20	413 ±31.83	10 ±1.39	0	21 ±1.89
<b>BIVALVA</b>						
<i>Lamellidens corrianus</i>	20 ±1.15	11 ±1.47	6 ±1.03	0	0	0
<i>Lamellidens marginalis</i>	48 ±1.26	30 ±1.49	20 ±1.28	4 ±0.29	0	2 ±0.47
<i>Pisidium clarkeanum</i>	104 ±6.51	66 ±3.82	137 ±3.75	113 ±3.62	83 ±3.54	82 ±4.53

Note : Species with least density (*Branchiura sowerbyi*, *Hydrocoptus subvittulus*, chironomids, *Lamellidens corrianus* and *L. marginalis*) showed least variation in CI.

**Gastropoda** : In RS and SS the gastropod percentage varied from 52.62 to 91.23% and 39.73 to 73.92% respectively. The percentage declined considerably from January to April, followed by a sharp rise during the period May to November (Table 8)

However, the population abundance of gastropods remained predominantly high during the two years of study in both RS and SS (Fig. 10). Annual temporal variation showed that during premonsoon and monsoon seasons, the gastropod density was mainly contributed by the species *Bellamyia bengalensis* and *Thiara granifera*, while the postmonsoon density was due to high population of *Gabbia orcula*. In RS, the gastropod abundance varied from 2300 to 6589 m<sup>-2</sup> and in SS from 1428 to 4147 m<sup>-2</sup> (Table 7).

**Bivalvia** : In RS, the bivalve group did not show any regular pattern of monthly variation, mainly due to the fact that the 3 bivalve species, *Lamellidens corrianus*, *L. marginalis* and *Pisidium clarkeanum* had different temporal abundance. But in SS, where *P. clarkeanum* was the only predominant bivalve species, its abundance was found to increase during December to July then gradually decreasing in the months of August to November (Fig. 10). In general, the average monthly density of bivalves lied between 22 (November) and 211 m<sup>-2</sup> (March) in SS and between 28 (November) and 274 m<sup>-2</sup> (February) in RS (Table 7). The percentage data of bivalve also showed the same trend. The peak was observed in March (4.03% in RS and 4.08% in SS) and trough in November (0.54% in RS and 0.56% in SS; Table 8).

Overall, among the eight groups discussed above, Gastropoda, Bivalvia and Odonata had higher percentage in RS, while Oligochaeta, Crustacea, Coleoptera and Diptera were more abundant in SS. In general, postmonsoon season was found to favour higher population of Oligochaeta, Crustacea, Odonata and Coleoptera, but Gastropoda had greater population in premonsoon and monsoon season.

**Temporal abundance and distribution of species** : Of the 32 species found in RS and SS, 8 were abundant species (*Limnodrilus hoffmeisteri*, *Bellamyia bengalensis*, *Gabbia orcula*, *Digoniostoma cerameopoma*, *Thiara granifera*, *T. tuberculata*, *Brotia costula* and *Gyraulus labiatus*) as they exhibited percentage frequency above 50% in any of the lakes under study (Table 9) and 8 more species (*Branchiura sowerbyi*, *Hydrocoptus subvittulus*, chironomid larvae, *Thiara scabra*, *T. lineata*, *Lamellidens corrianus*, *L. marginalis* and *Pisidium clarkeanum*) were regarded more or less common as their frequency of occurrence in the quantitative samples ranged 1% to 50%. The rest 16 species were of rare occurrence (below 1%) in respect to benthic community (Table 3). The density, seasonal variation and distribution pattern of the abundant and common species has been discussed below:

***Limnodrilus hoffmeisteri*** : It was noted to be the most significant and dominant oligochaete species in both the lakes. The overall mean density was found to be 1681.16 m<sup>-2</sup> in RS and 1715.91 m<sup>-2</sup> in SS (Table 9). It constituted 99.25% and 98.00% of the total oligochaete and 29.83% and 32.45% of the total benthos number in RS and SS respectively. Temporal fluctuation showed low abundance of *L. hoffmeisteri* in August/September and greater values during the rest of the year specially in the months December to April when

**Table 7:** Temporal variation of density (mean no./m<sup>2</sup>) and 98% confidence interval of different macrobenthic groups in RS and SS.

Group	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<b>Oligochaeta</b>												
RS	1782 ±79.12	1218 ±53.84	1323 ±58.06	860 ±38.63	283 ±11.72	1335 ±59.35	1348 ±69.47	1973 ±85.44	2894 ±92.72	2959 ±89.24	2322 ±90.05	2034 ±91.83
SS	1245 ±52.61	1557 ±65.42	1833 ±77.87	1944 ±80.1	1161 ±43.43	763 ±31.28	1367 ±62.57	1384 ±58.67	2356 ±92.95	2862 ±84.16	2672 ±51.88	1875 ±92.34
<b>Coleoptera</b>												
RS	1 ±0.3	4 ±1.26	0	0	0	0	0	0	0	0	5 ±1.95	8 ±2.26
SS	28 ±1.29	11 ±1.07	0	26 ±1.90	11 ±1.92	16 ±1.13	9 ±1.99	0	14 ±1.18	20 ±1.13	175 ±2.59	29 ±5.98
<b>Diptera</b>												
RS	9 ±1.98	1 ±0.64	2 ±0.72	0	8 ±1.45	0	4 0	18 ±1.92	13 ±2.98	39 ±1.06	35 ±2.6	2 ±0.15
SS	9 ±1.07	8 ±1.95	0	0	0	0	3 ±0.13	26 ±1.9	29 ±1.06	46 ±3.39	48 ±2.88	46 ±3.71
<b>Gastropoda</b>												
RS	3823 ±23.61	3982 ±24.84	6589 ±36.38	2300 ±10.21	4420 ±27.63	3944 ±26.22	3775 ±24.06	4041 ±22.79	3661 ±17.08	3654 ±17.54	3448 ±14.15	2676 ±12.99
SS	3927 ±23.92	3813 ±22.09	4147 ±21.26	3656 ±18.93	2998 ±16.80	1860 ±12.83	2500 ±15.97	3182 ±17.71	1986 ±10.13	2067 ±98.13	2054 ±94.86	1428 ±64.97
<b>Bivalvia</b>												
RS	122 ±1.05	185 ±22.32	154 ±24.59	70 ±1.87	134 ±6.13	66 ±9.85	28 ±4.35	196 ±8.53	153 ±6.5	274 ±7.15	245 ±6.17	134 ±2.50
SS	98 ±3.39	74 ±9.07	111 ±8.73	70 ±9.93	42 ±1.3	29 ±1.21	22 ±2.08	75 ±3.47	129 ±5.17	106 ±4.27	211 ±9.12	83 ±3.54

**Note :** The CI values showed similar trend as in Table 5 & 6

**Table 8.** Percentage distribution (in average) of different groups in RS and SS

Groups	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<b>Oligochaeta</b>												
RS	31.05	22.6	16.36	26.58	5.84	24.95	26.13	31.65	43.00	42.61	38.25	41.83
SS	23.43	28.5	30.08	34.1	27.54	28.51	34.83	29.45	51.92	55.9	51.68	54.11
<b>Hirudinea</b>												
RS	-	-	-	-	-	0.05	-	-	-	-	-	0.04
SS	-	-	-	-	-	-	-	-	-	-	-	-
<b>Crustacea</b>												
RS	0.01	0.03	0.03	0.12	-	0.03	-	0.03	-	0.14	0.09	0.1
SS	0.09	-	0.03	0.03	0.07	0.30	0.58	0.68	0.50	0.37	0.19	0.08
<b>Odonata</b>												
RS	-	-	-	0.03	-	-	0.07	0.06	0.14	0.11	0.14	0.02
SS	-	-	-	0.03	-	-	-	-	-	-	-	0.02
<b>Coleoptera</b>												
RS	0.01	0.07	-	-	-	-	-	-	-	-	0.08	0.16
SS	0.52	0.20	-	0.45	0.26	0.60	0.23	-	0.30	0.39	3.38	0.83
<b>Diptera</b>												
RS	0.15	0.01	0.02	-	0.16	-	0.07	0.28	0.19	0.56	0.57	0.04
SS	0.17	0.14	-	-	-	-	0.07	0.55	0.64	0.90	0.92	1.32
<b>Gastropoda</b>												
RS	66.62	73.85	81.63	71.09	91.23	73.72	73.17	64.82	54.40	52.62	56.80	55.04
SS	73.92	69.80	68.06	64.14	71.12	69.50	63.71	67.71	43.77	40.37	39.73	41.21
<b>Bivalvia</b>												
RS	2.12	3.43	1.90	2.16	2.76	1.23	0.54	3.14	2.27	3.94	4.03	2.75
SS	1.84	1.35	1.82	1.22	0.99	1.08	0.56	1.59	2.84	2.07	4.08	2.39

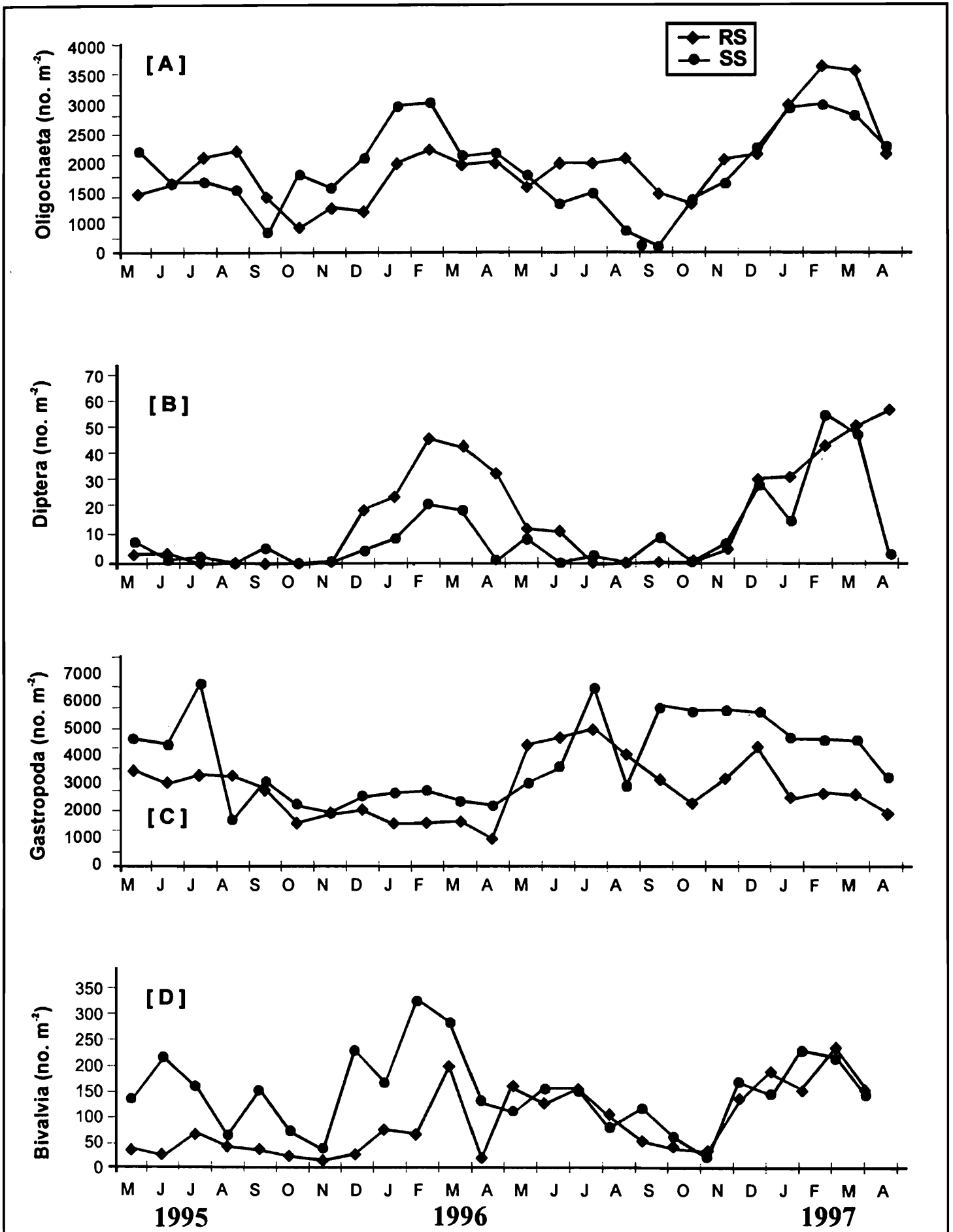


Fig. 10. Monthly variations (1995 - 1997) in group density in RS and SS.

the population peaks were attained (Fig. 11A). The mean temporal variation of its density showed peak in February (2930 m<sup>-2</sup> in RS and 2842 m<sup>-2</sup> in SS) and trough in September (275 m<sup>-2</sup> in RS) and October (734 m<sup>-2</sup> in SS; Tables 10 and 11).

***Branchiura sowerbyi*** : The population did not exhibit any definite seasonal pattern (Fig. 11B). In RS, the peak in mean annual density was observed in January (47 m<sup>-2</sup> ) but in SS, the peak was in September (80 m<sup>-2</sup>; Tables 10 and 11). This species was far less abundant and found in few numbers specially in RS where its overall density was calculated to be 13.25 m<sup>-2</sup> only. SS showed comparatively higher abundance of this species (35.75 m<sup>-2</sup>; Table 9). It contributed 1.95% and 0.74% of the oligochaete and 0.67% and 0.22% of the total benthos density in SS and RS respectively.

***Hydrocoptus subvittulus*** : This sole coleopteran species was ill distributed in RS (mean density was 1.50 m<sup>-2</sup>) whereas in SS, the mean density was recorded to be 29.50 m<sup>-2</sup> (Table 9). It contributed to a minor portion of total benthos density representing only 0.02% in RS and 0.55% in SS. The population pattern was characterised by a remarkable surge in February-April period, showing a peak of 8 m<sup>-2</sup> in RS and 175 m<sup>-2</sup> in SS (Tables 10 and 11). However, during rest of the year, it showed infrequent abundance (Fig. 11C).

**Chironomid larvae** : The mean density of this dipteran larvae was noted to be 10.91 m<sup>-2</sup> in RS and 17.91 m<sup>-2</sup> in SS (Table 9). It represented only 0.18% of total benthos density in RS and 0.33% in SS. During the two years of study, it was observed that the population was low during monsoon, whereafter it gradually increased from December to April (Fig. 11D) showing peak in March (48 m<sup>-2</sup> in SS) and February (39 m<sup>-2</sup> in RS; Tables 10 and 11).

***Bellamya bengalensis*** : This was one of the most significant benthic species which contributed to 43.06% (SS) and 14.03% (RS) of the Gastropoda population and 27.58% and 9.40% of the total benthos density in SS and RS respectively. The biannual mean density of *Bellamya bengalensis* was much higher in SS (1181.50 m<sup>-2</sup>) than RS (568 m<sup>-2</sup>; Table 9). Temporal variation over a period over two years, showed that its population remained moderately high throughout the year, decreasing only during the months January to April (Fig. 11E). Mean annual density was maximum in July (1375 m<sup>-2</sup> in RS) and May (2000 m<sup>-2</sup> in SS), and minimum in the month of February (221 m<sup>-2</sup> in RS and 511 m<sup>-2</sup> in SS; Tables 10 and 11).

***Gabbia orcula*** : The biannual average density of this species was more or less equal in both the lakes (633.25 m<sup>-2</sup> in SS and 643.91 m<sup>-2</sup> in RS; Table 9). It represented 16.94% and 21.71% of the gastropod population and 11.34% and 13.90% of the total benthos density in RS and SS respectively. Fluctuation in the population pattern was almost the same in both the years (Fig. 12A). The annual mean values were characterised by two troughs in September (267 m<sup>-2</sup> in RS and 144 m<sup>-2</sup> in SS) and April (355 m<sup>-2</sup> in RS and 180 m<sup>-2</sup> in SS), followed by a gradual increase resulting in peaks in June (1010 m<sup>-2</sup> in SS)/July (661 m<sup>-2</sup> in RS) and December (1302 m<sup>-2</sup> in SS)/January (1111 m<sup>-2</sup> in RS; Tables 10 and 11).

***Digoniostoma cerameopoma*** : RS had a greater density of this species as its two year mean was 170.75 m<sup>-2</sup> whereas in SS it was only 47.33 m<sup>-2</sup> (Table 9). It comprised 2.89% and

**Table 9.** Mean population density (no./m<sup>2</sup>) and 95% confidence interval of macrobenthic species in RS and SS.

Group / Species	Rabindra Sarovar		Subhas Sarovar	
	Population density (mean)	Confidence interval	Population density (mean)	Confidence interval
<b>OLIGOCHAETA</b>				
<i>Limnodrilus hoffmeisteri</i>	1681.16	± 44.41	1715.91	± 36.13
<i>Branchiura sowerbyi</i>	13.25	± 2.35	35.75	± 1.11
<b>COLEOPTERA</b>				
<i>Hydrocoptus subvittulus</i>	1.5	± 0.51	29.5	± 2.66
<b>DIPTERA</b>				
Chironomid larvae	10.91	± 1.58	17.91	± 1.12
<b>GASTROPODA</b>				
<i>Bellamyia bengalensis</i>	568	± 16.90	1181.5	± 29.12
<i>Gabbia orcula</i>	643.91	± 14.7	633.25	± 21.38
<i>Dignoniosstoma cerameopoma</i>	170.75	± 11.26	47.33	± 1.63
<i>Thiara scabra</i>	11.75	± 1.81	22.33	± 1.63
<i>Thiara granifera</i>	1777.83	± 39.37	433.83	± 13.24
<i>Thiara lineata</i>	3.66	± 1.64	40.33	± 1.3
<i>Thiara tuberculata</i>	361.33	± 15.88	316.41	± 6.60
<i>Brotia costula</i>	64.75	± 3.21	117.41	± 7.01
<i>Gyraulus labiatus</i>	258.25	± 17.44	10.08	± 1.85
<b>BIVALVIA</b>				
<i>Lamellidens corrianus</i>	12	± 1.28	0	0
<i>Lamellidens marginalis</i>	32.66	± 2.38	2	± 0.42
<i>Pisidium clarkeanum</i>	102.33	± 9.53	85.66	± 8.44

**Note :** *Limnodrilus hoffmeisteri*, *Bellamyia bengalensis*, *Dignoniosstoma cerameopoma*, *Thiara granifera*, *T. tuberculata*, *Brotia costula*, *Gyraulus labiatus* and *Pisidium clarkeanum* were found to vary widely and the represented data are annual means.

**Table 10.** Monthwise population density (meanno./m<sup>2</sup>) and 95% confidence interval of different species of macrobenthos in RS

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<b>OLIGOCHAETA</b>												
<i>Limnodrilus hoffmeisteri</i>	1781 ±29.82	1212 ±23.23	1320 ±14.73	850 ±26.27	275 ±9.21	1330 ±27.83	1336 ±31.34	1958 ±15.72	2847 ±3.84	2930 ±47.75	2306 ±15.16	2029 ±21.61
<i>Branchiura sowerbyi</i>	1 ±1.72	6 ±1.13	4 ±13.13	10 ±4.07	8 ±1.13	5 ±1.13	13 ±6.70	15 ±5.18	47 ±12.59	29 ±8.26	16 ±5.98	5 ±1.13
<b>COLEOPTERA</b>												
<i>Hydrocoptus subvittulus</i>	1 ±1.30	4 ±2.26	0	0	0	0	0	0	0	0	5 ±1.95	8 ±2.26
<b>DIPTERA</b>												
<i>Chiomid larvae</i>	0 ±2.98	1 ±0.64	2 ±1.72	0	8 ±3.45	0	4 ±0	18 ±7.92	13 ±2.98	39 ±7.06	35 ±12.60	2 ±1.95
<b>GASTROPODA</b>												
<i>Bellamyia bengalensis</i>	503 ±67.03	463 ±30.12	1375 ±30.40	475 ±15.95	893 ±28.00	572 ±62.98	485 ±75.47	583 ±59.64	443 ±11.75	221 ±35.72	369 ±65.65	434 ±22.74
<i>Gabbia orcula</i>	589 ±70.57	573 ±26.36	661 ±13.33	302 ±10.78	267 ±28.46	554 ±38.24	697 ±95.74	897 ±40.18	1111 ±27.83	807 ±31.1	914 ±25.30	355 ±18.70
<i>Digonistoma cerameopoma</i>	209 ±12.84	146 ±12.84	763 ±27.80	199 ±47.05	227 ±13.20	57 ±26.09	46 ±13.71	31 ±7.06	37 ±18.89	71 ±26.30	116 ±21.57	147 ±15.54
<i>Thiara scabra</i>	15 ±3.91	14 ±4.92	16 ±6.88	14 ±1.13	5 ±2.26	10 ±1.13	11 ±1.13	4 ±1.13	6 ±1.95	8 ±4.07	9 ±3.91	29 ±1.30
<i>Thiara granifera</i>	2054 ±67.20	2174 ±57.09	3090 ±86.01	846 ±42.14	2379 ±88.00	2269 ±92.24	2070 ±55.44	1907 ±85.70	1184 ±59.79	1380 ±80.25	833 ±18.20	1148 ±63.65

Table 10 contd.

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr.
<i>Thiara lineata</i>	14 ±1.26	6 ±1.95	0	0	8 ±2.98	3 ±1.95	9 ±2.98	0	4 ±1.95	0	0	0
<i>Thiara tuberculata</i>	356 ±6.26	466 ±25.26	523 ±16.89	366 ±10.90	452 ±18.20	287 ±12.23	270 ±37.34	402 ±19.27	273 ±37.11	311 ±40.83	260 ±23.76	270 ±32.81
<i>Brotia costula</i>	52 ±10.78	53 ±9.66	93 ±6.88	45 ±5.18	121 ±14.43	87 ±5.18	55 ±15.35	60 ±11.81	42 ±13.71	54 ±10.87	57 ±9.85	58 ±10.04
<i>Gyraulus labiatus</i>	33 ±4.07	88 ±2.35	69 ±13.33	53 ±2.26	69 ±4.92	106 ±13.20	133 ±17.41	157 ±39.69	562 ±35.22	801 ±38.55	892 ±29.59	136 ±15.67
<b>BIVALVIA</b>												
<i>Lamellidens corrianus</i>	28 ±5.98	31 ±6.79	19 ±7.92	9 ±5.98	10 ±1.13	6 ±1.95	1 ±1.13	3 ±1.95	9 ±5.18	9 ±4.07	12 ±2.98	7 ±3.39
<i>Lamellidens marginalis</i>	56 ±8.53	49 ±7.06	36 ±1.13	20 ±6.52	28 ±1.95	36 ±10.78	14 ±4.07	9 ±1.95	19 ±6.29	39 ±2.26	38 ±8.15	48 ±4.92
<i>Pisidium clarkeanum</i>	38 ±10.26	105 ±12.84	100 ±13.71	42 ±16.31	96 ±16.97	24 ±13.04	13 ±2.98	185 ±7.06	125 ±7.41	226 ±31.37	195 ±11.91	79 ±1.13

Note: The CI values showed similar trends as in Table 9.

Table 11. Monthwise population density (mean no./m<sup>2</sup>) and 95% confidence interval of different species of macrobenthos in SS.

Species	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<b>OLIGOCHETA</b>												
<i>Limnodrilus hoffmeisteri</i>	1215 ±18.88	1512 ±21.14	1795 ±26.00	1877 ±24.63	1081 ±11.81	734 ±19.37	1355 ±47.77	1358 ±27.35	2332 ±32.36	2842 ±24.53	2650 ±39.79	1840 ±32.47
<i>Branchiura sowerbyi</i>	30 ±1.13	45 ±11.13	38 ±7.06	67 ±5.09	80 ±11.81	29 ±7.41	13 ±1.95	26 ±6.29	24 ±2.98	20 ±9.25	22 ±8.53	35 ±7.92
<b>COLEOPTERA</b>												
<i>Hydrocoptus subvittulus</i>	28 ±6.29	11 ±4.07	0	26 ±9.90	11 ±4.92	16 ±1.13	9 ±2.99	0	14 ±5.18	35 ±1.13	175 ±2.59	29 ±5.98
<b>DIPTERA</b>												
Chironomid larvae	9 ±4.07	8 ±1.95	0	0	0	0	3 ±1.13	26 ±10.9	29 ±7.06	46 ±3.39	48 ±6.88	46 ±7.71
<b>GASTROPODA</b>												
<i>Bellamya bengalensis</i>	2000 ±20.21	1772 ±13.56	1741 ±13.46	1446 ±22.5	1349 ±31.41	1110 ±14.14	1382 ±15.95	1003 ±22.18	633 ±47.05	511 ±55.4	709 ±14.76	522 ±25.92
<i>Gabbia orcula</i>	889 ±22.97	1010 ±16.28	820 ±23.37	675 ±17.07	144 ±24.55	148 ±6.88	239 ±30.6	1302 ±26.78	741 ±8.02	813 ±15.02	638 ±4.92	180 ±10.03
<i>Digoniostoma cecrameopoma</i>	67 ±4.92	31 ±12.84	56 ±21.85	84 ±18.54	111 ±10.90	25 ±7.06	16 ±4.07	18 ±4.92	32 ±9.25	50 ±3.91	53 ±4.07	25 ±8.48
<i>Thiara scabra</i>	13 ±4.92	5 ±2.26	15 ±4.93	10 ±3.39	2 ±1.13	4 ±1.13	5 ±1.95	11 ±5.18	19 ±5.98	21 ±3.91	96 ±11.5	67 ±17.12
<i>Thiara granifera</i>	562 ±43.83	577 ±11.13	818 ±43.70	618 ±28.45	788 ±11.47	157 ±7.06	308 ±13.76	445 ±11.75	271 ±19.74	269 ±19.29	200 ±9.66	193 ±24.34

Table 11 contd.

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<i>Thiara lineata</i>	45 ±1.89	79 ±5.18	15 ±4.07	40 ±6.29	60 ±21.5	76 ±9.85	27 ±5.87	53 ±11.31	21 ±4.07	35 ±9.85	26 ±1.95	7 ±4.07
<i>Thiara tuberculata</i>	213 ±11.47	221 ±16.6	490 ±7.41	498 ±7.92	427 ±11.64	302 ±15.84	418 ±20.06	258 ±18.2	183 ±16.67	215 ±14.83	212 ±8.15	360 ±15.2
<i>Brotia costula</i>	139 ±6.29	117 ±11.31	188 ±19.62	288 ±18.82	117 ±11.47	40 ±9.66	102 ±6.29	94 ±2.98	74 ±11.88	92 ±12.88	91 ±7.92	67 ±9.66
<i>Gyraulus labiatus</i>	0	0	1 ±1.13	0	0	0	4 ±1.13	0	14 ±2.98	64 ±10.98	30 ±9.25	8 ±1.95
<b>BIVALVIA</b>												
<i>Lamellidens marginalis</i>	8 ±1.95	5 ±1.13	0	1 ±1.13	0	0	3 ±1.95	1 ±1.13	3 ±2.26	0	3 ±1.95	0
<i>Pisidium clarkeanum</i>	91 ±1.95	69 ±17.12	111 ±6.88	69 ±6.29	42 ±11.98	29 ±8.15	20 ±6.78	74 ±12.44	126 ±11.97	106 ±13.11	208 ±15.84	83 ±10.76

Note : The variations as represented by CI values of different species are similar to Table 10.

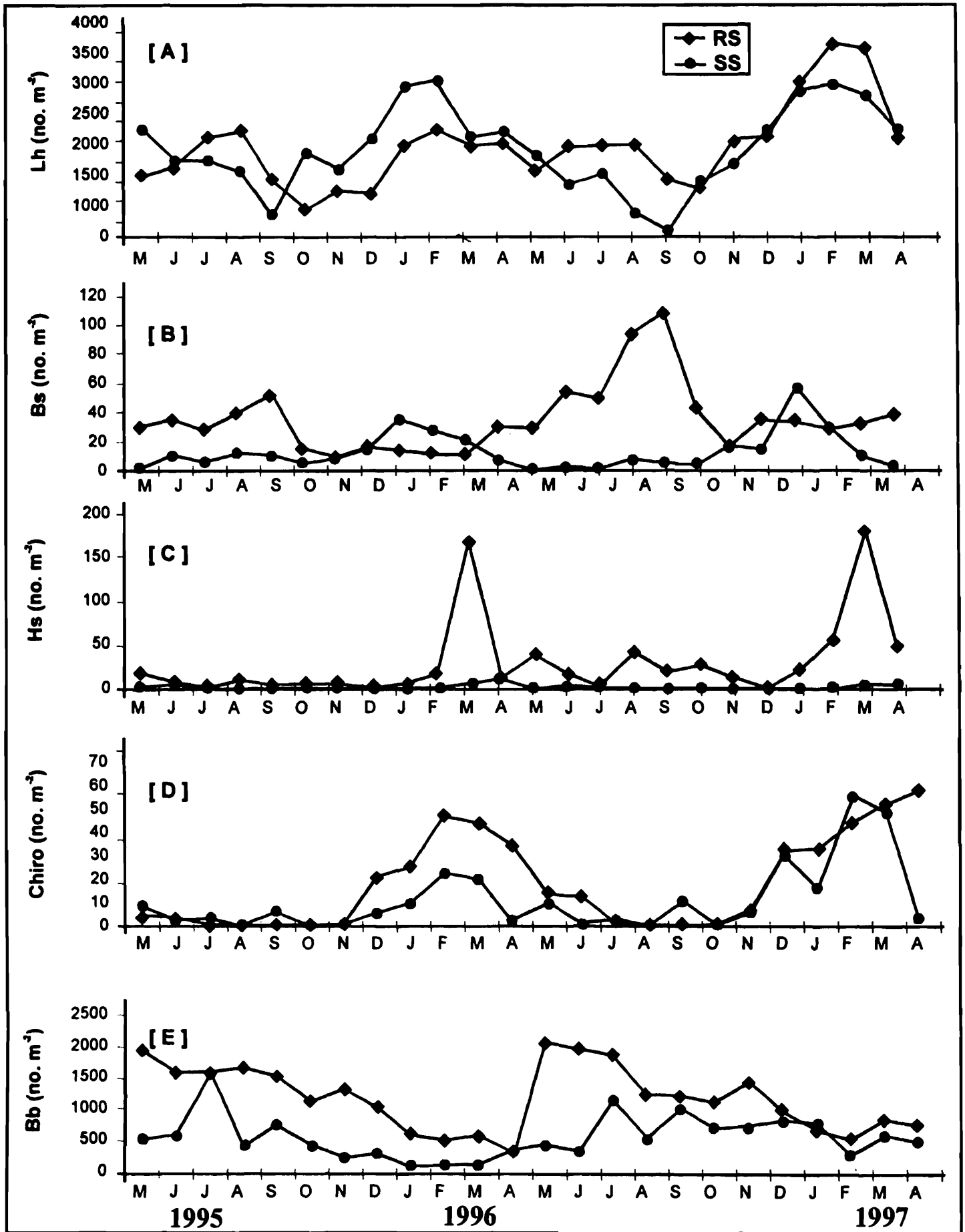


Fig. 11. Monthly variations (1995 - 1997) in density of major macrobenthic species (Lh - *Limnodrilus hoffmeisteri*, Bs - *Branchiura sowerbyi*, Hs - *Hydrocoptus subvittulus*, Chiro - Chironomid larvae, Bb - *Bellamyia bengalensis*) in RS and SS.

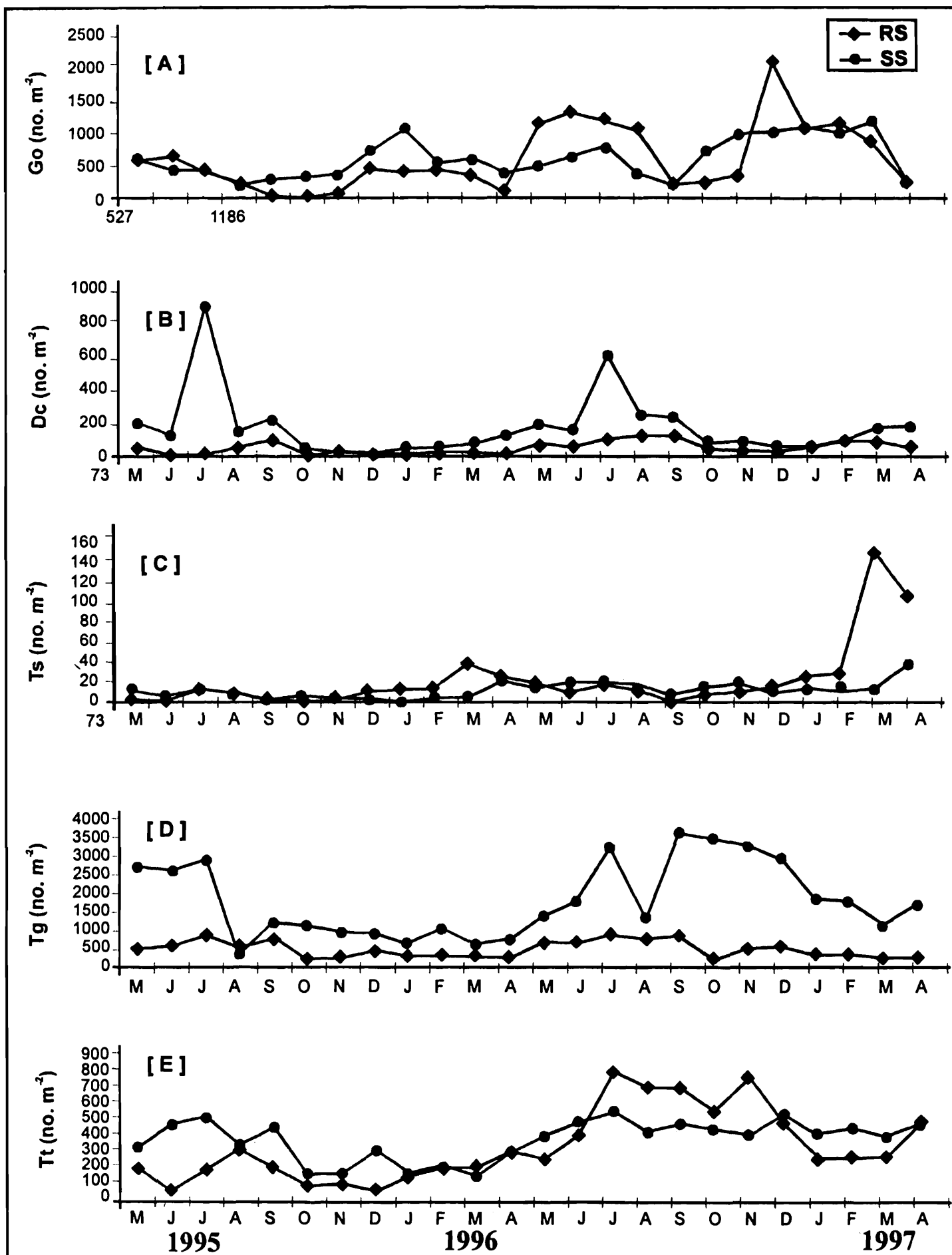


Fig. 12. Monthly variations (1995 - 1997) in density of major macrobenthic species (Go - *Gabbia orcula*, Dc - *Digoniostoma cerameopoma*, Ts - *Thiara scabra*, Tg - *Thiara granifera*, Tt - *Thiara tuberculata*) in RS and SS.

0.9% of the total benthos density and 4.32% and 1.41% of the gastropod population in RS and SS respectively. As evident from Fig 12B, the population curve was low during October to January months and higher during the period July to September. The mean annual value ranged from 31 (December) to 763 m<sup>-2</sup> (July) in RS and from 16 (November) to 111 m<sup>-2</sup> (September) in SS (Tables 10 and 11).

***Thiara scabra*** : The maximum population was observed in March-April months (96 m<sup>-2</sup> in SS and 29 m<sup>-2</sup> in RS) which decreased to a minimum level in September in SS (2 m<sup>-2</sup>) and December in RS (4 m<sup>-2</sup>; Tables 10 and 11, Fig. 12C). SS had a higher distribution of *T. scabra*, as its mean biannual density was 22.33 m<sup>-2</sup> in SS and 11.75 m<sup>-2</sup> in RS (Table 9). It constituted 0.30% and 0.68% of gastropod density and 0.20% and 0.43% of total benthos in RS and SS respectively.

***Thiara granifera*** : It was found to be the most dominating and significant gastropod species in respect of number, other than *Bellamya begalensis* contributing 46.89% and 15.68% of the gastropod density and 31.39% and 10.04% of the total benthos density in RS and SS respectively. The average density was much higher in RS (1777.83 m<sup>-2</sup>) than SS (433.83 m<sup>-2</sup>; Table 9). In RS, the population curve showed a sudden dip in August, which was succeeded and preceded by peaks in both years of study. This was probably due to destruction of habitat and rise in water level in monsoon. The population showed greater values in the second year remaining high during most part of the year, decreasing slightly during January to April months. More or less similar variation in population was noticed in SS (Fig. 12D). The annual density ranged from 157 (October) to 818 m<sup>-2</sup> (July) in SS and 833 (March) to 3090 m<sup>-2</sup> (July) in RS (Tables 10 and 11).

***Thiara lineata*** : The distribution and numerical representation of this species was very poor in RS, where its mean density was calculated to be 3.66 m<sup>-2</sup>, while in SS it was 40.33 m<sup>-2</sup> (Table 9). It comprised 0.10% and 2.07% of the gastropod density and 0.06% and 1.33% of the total benthos density in RS and SS respectively. The seasonal pattern of this species could not be ascertained as pure traits of *T. lineata* could only be determined in adult forms (Bentham Jutting, 1956).

***Thiara tuberculata*** : In RS and SS, this species was uniformly distributed, the biannual mean density being 361.33 m<sup>-2</sup> (RS) and 316.41 m<sup>-2</sup> (SS; Table 9). It represented 8.78% (RS) and 11.42% (SS) of the gastropod density and 5.88% (RS) and 7.31% (SS) of the total benthos density. The temporal variation of the population showed increasing trend in the months of April to September, reaching the maximum value in July (523 m<sup>-2</sup>) in RS and August (498 m<sup>-2</sup>) in SS. Thereafter the population gradually decreased attaining minimum level in March (260 m<sup>-2</sup>) in RS and in January (183 m<sup>-2</sup>) in SS (Tables 10 and 11). This species had good representation in both the years, decreasing marginally for a few months in the postmonsoon season (Fig. 12E).

***Brotia costula*** : The monthly trend showed maximum density of 121 m<sup>-2</sup> in September in RS and 288 m<sup>-2</sup> in August in SS, usually remaining high in monsoon period. Its abundance showed minimum values in January (42 m<sup>-2</sup> in RS) and October (40 m<sup>-2</sup> in SS; Table 10 and

11 & Fig. 13A). This species constituted 1.51% and 3.64% of the gastropod density and 1.01% and 2.33% of the total benthos in RS and SS respectively. Mean density was found to be greater in SS ( $117.41 \text{ m}^{-2}$ ) than RS ( $61.75 \text{ m}^{-2}$ ; Table 9).

***Gyraulus labiatus*** : This species had poor distribution and abundance in SS, mean density being  $10.08 \text{ m}^{-2}$ , while in RS, it was moderately present ( $258.25 \text{ m}^{-2}$ ; Table 9). It contributed 7.10% and 0.29% of the gastropod density and 4.75% and 0.19% of the total benthos density in RS and SS respectively. In both the years, the population tend to be low during May to August, but gradually increased in the monsoon months, attaining higher values during the months of December to April (Fig. 13B). The maximum annual mean density was recorded to be  $892 \text{ m}^{-2}$  in March in RS and  $64 \text{ m}^{-2}$  in February in SS (Tables 10 and 11).

***Lamillidens marginalis*** : This common bivalve species comprised 27.95% and 2.00% of the bivalve density and 0.78% and 0.03% of the total benthos number in RS and SS respectively. It had poor distribution and irregular abundance in SS as evident from Fig 13C which shows its density over a period of two years in both the lakes. In SS, the mean density of two years was only  $2 \text{ m}^{-2}$  while in RS the same was  $36.22 \text{ m}^{-2}$  (Table 9). The population pattern showed high density in premonsoon, resulting in a peak in May ( $56 \text{ m}^{-2}$  in RS) and low values in postmonsoon showing least density in December ( $9 \text{ m}^{-2}$  in RS; Tables 10 and 11).

***Lamellidens corrianus*** : This species was never obtained in qualitative or quantitative samples of SS. However, in RS it showed low annual density ( $12 \text{ m}^{-2}$ ; Table 9). It represented 7.08% of the bivalve density and 0.19% of total benthos density in RS. Monthly variation of its population showed greater values in May-July ( $31 \text{ m}^{-2}$  in June) and lower values in November-December months ( $1 \text{ m}^{-2}$ ; Table 10).

***Pisidium clarkeanum*** : It was noted to be the most common bivalve species representing 64.93% and 98% of the bivalve density and 1.69% and 1.68% of the total benthos density in RS and SS respectively. The biannual average density was marginally higher in RS ( $102.33 \text{ m}^{-2}$ ) than SS ( $85.66 \text{ m}^{-2}$ ; Table 9). The species was found throughout the study period, the population increasing considerably during December to March (Fig. 13D) when juvenile forms were observed signifying their breeding season. Temporal variation in the density showed maximum value in March ( $208 \text{ m}^{-2}$ ) in SS and in February ( $226 \text{ m}^{-2}$ ) in RS. Thereafter it declined gradually showing low values in September to November months, the trough was recorded in November ( $20 \text{ m}^{-2}$  in SS and  $13 \text{ m}^{-2}$  in RS; Tables 10 and 11).

Oligochaetes, insects and molluscs constitute the bulk of bottom fauna in lakes, reservoirs and ponds of tropical and subtropical regions (Cowell and Vodopich, 1981; Gupta and Pant, 1986, Kaushal and Tyagi, 1989, Bais *et al.*, 1992 and Bose and Lakra, 1994). In the present study gastropods, oligochaetes and bivalves were found to be most prominent benthic groups, in accordance to the reports of the above mentioned authors.

Insect dominated over other benthic groups constituting 35.92% of the total biota in Loni reservoir (Madhya Pradesh) followed by oligochaetes and molluscs (Gupta, 1976). The study

of Abraham (1979) showed that the benthic composition of Bhavanisagar reservoir of Tamil Nadu was largely made of oligochaetes and chironomids. Gupta and Pant (1983) reported '*Chironomus – Tubifex*' community of Nainital Lake, Uttar Pradesh. In Mansarovar reservoir, Bhopal, Adholia *et al.*, (1990), encountered Diptera (87.2%) as the most prominent representative of benthic fauna. However, molluscan dominance over the quantitative samples of macrozoobenthos, have been reported by several workers (Sarkar, 1989 and 1992 and Malhotra *et al.*, 1990) which is in agreement to the present study. In the littoral zone of RS and SS, gastropods alone constituted 39.73-91.23% of the total benthic fauna. Molluscan dominance in waterbodies is attributed to soft organically rich bottom (Datta and Malhotra, 1986) and the absence of pollution (Olive and Dambach, 1973). Oommachan and Belsare (1985) and Rao *et al.* (1987) observed high molluscan population in shallow niche and least in deeper zone. Presence of macrophytes and substratum explains most of the differences in the gastropod distribution in the littoral zone of lakes (Okland, 1990). Mouthon (1992) argued that the littoral dwelling gastropods have particular affinity for lakes with high organic matter contents.

*Bellamyia bengalensis*, *Gabbia orcula*, *Thiara granifera* and *T. tuberculata* were the most dominant species of the group Gastropoda in RS and SS. The monthly variation in their density determine the variation in the percentage and density of Gastropoda. Higher abundance of Gastropoda in the premonsoon and monsoon period was due to increase in the number of *Bellamyia bengalensis*, *Digoniostoma cerameopoma*, *Thiara scabra*, *T. granifera*, *T. tuberculata* and *Brotia costula* during those months. Immature stages of *Bellamyia bengalensis*, *T. granifera*, *T. tuberculata* and *Brotia costula* were found throughout the year, although their number enhanced significantly during May to September months. Khan and Chaudhuri (1984), noted that viviparids breed continuously throughout the year because of moderate food supply in tropical waters. Muley (1977) and Subha Rao and Mitra (1982) suggested that *Thiara* spp. are continuous breeder and adults were found all round the year.

*Gyraulus labiatus* and *Gabbia orcula* were observed to have greater density in postmonsoon season, caused by the recruitment of juvenile ones into their community. These two species were responsible for the gastropod density in the postmonsoon season. Gupta and Pant (1990) also reported larger population of *Gyraulus* species in winter and smaller during summer and rainy months. It had low abundance in SS, may be due to less macrophytic density (Singh and Sinha 1993).

In this study, 5 species of bivalves were recorded of which *Parreysia caerulea* and *P. pachysoma* were rarely encountered in quantitative sampling. *Pisidium clarkeanum* and *Lamellidens marginalis* were the most common bivalves. Mandal and Moitra (1975b), Vashist and Bhandal (1979) and Bonacina *et al.* (1991) reported the presence of these species in lakes and reservoirs. Bivalves have a much greater bathymetric amplitude than gastropods. In littoral zone where oxygen is not a limiting factor, bivalves seem to be more sensitive than gastropods (Mouthon, 1992) and are generally related to the sediments containing high values of calcium salts (Aho, 1966). They utilize mainly detritus and algae indicating their ability to exploit areas with maximum food supply (Kaushal and Tyagi, 1989). The abundance of bivalves in RS than SS, may be due to presence of more leaf litter/detritus in RS.

The soft clay soil with decaying leaves and other organic matter observed in the bottom soil, influence the growth and abundance of oligochaete population as it provides an ideal medium for these worms to feed and burrow. Brinkhurst (1966), Brinkhurst and Cook (1974) and Mason *et al.* (1971) stated that *Limnodrilus hoffmeisteri* preferred littoral and sublittoral zones and its occurrence nearly alone and in great abundance would indicate deteriorated water quality (Howmiller and Scott, 1977; Das 1978 and Mason, 1981). Jonasson (1969) and Mason (1981) noted that the tubeficids are well adapted to low oxygen content. They are capable of surviving in water with low dissolved oxygen as their blood is rich in haemoglobin. David and Ray (1966) urged that oligochaetes increase with eutrophication and can survive in an environment where anaerobic/saprobic bacterial activity is intense. Oligochaetes have also been reported to increase in number in waterbodies polluted from domestic sewage (Odum, 1971). The view of the above two workers holds true for the two lakes, RS and SS.

*Limnodrilus* species was found in large number while the density of *Branchiura* species was significantly less in the two lakes under study. Such dominance of *Limnodrilus* species has been reported by several workers (Milbrink, 1973; Gupta and Pant, 1990; Petridis and Sinis 1993; Singh and Sinha, 1993 and Bose and Lakra, 1994). The occurrence of *Limnodrilus* species may be attributed to increased eutrophication of a lake or to the increased sedimentation of organic matter (Aston, 1973 and Marshall, 1978). Gupta (1976) recorded *Branchiura sowerbyi* in stray numbers. It has been reported by Oommachan and Belsare (1986) to be found in sandy sediments and fine grained silty sediments. The importance of this species as an indicator of pollution had been well documented by several workers (Brinkhurst, 1965 and Brinkhurst and Cook, 1974).

Cowell and Vodopich (1981) had found uniformity in the abundance of oligochaetes throughout the year. Here in the present study too, oligochaetes were found in good numbers in all the months of the year. Mandal and Moitra (1975b) and Barbhuyan and Khan (1992) reported the peak in oligochaete number in November. Sarkar (1989) found that oligochaetes were abundant in summer and winter. The present research was in conformity with these authors as their density and percentage was found to be higher in pre- and postmonsoon season decreasing in monsoon season. The maximum number of oligochaetes during winter season might be due to availability of large quantity of organic matter because of lesser decomposition rate, moderate and congenial bottom climate (Bais *et al.*, 1992).

Carr and Hiltunen (1965) classified waterbodies as slightly polluted when oligochaete density ranges from 100-999 m<sup>-2</sup>, moderately polluted when the population varies from 1000-5000 m<sup>-2</sup> and heavily polluted when its density is above 5000 m<sup>-2</sup>. According to the above classification both RS and SS fall under the second category being moderately polluted. Gauffin and Tarzwell (1952), however, were of the view that single species merely cannot be used as an indicator of pollution.

Chironomids form a significant portion of the benthic fauna and act as an important part of the food chain (Wilhm and Dorris, 1966). They are inhabitants of mud rich in organic detritus (Wiederholm, 1984 and Petridis and Sinis, 1993). Gauffin and Tarzwell (1956)

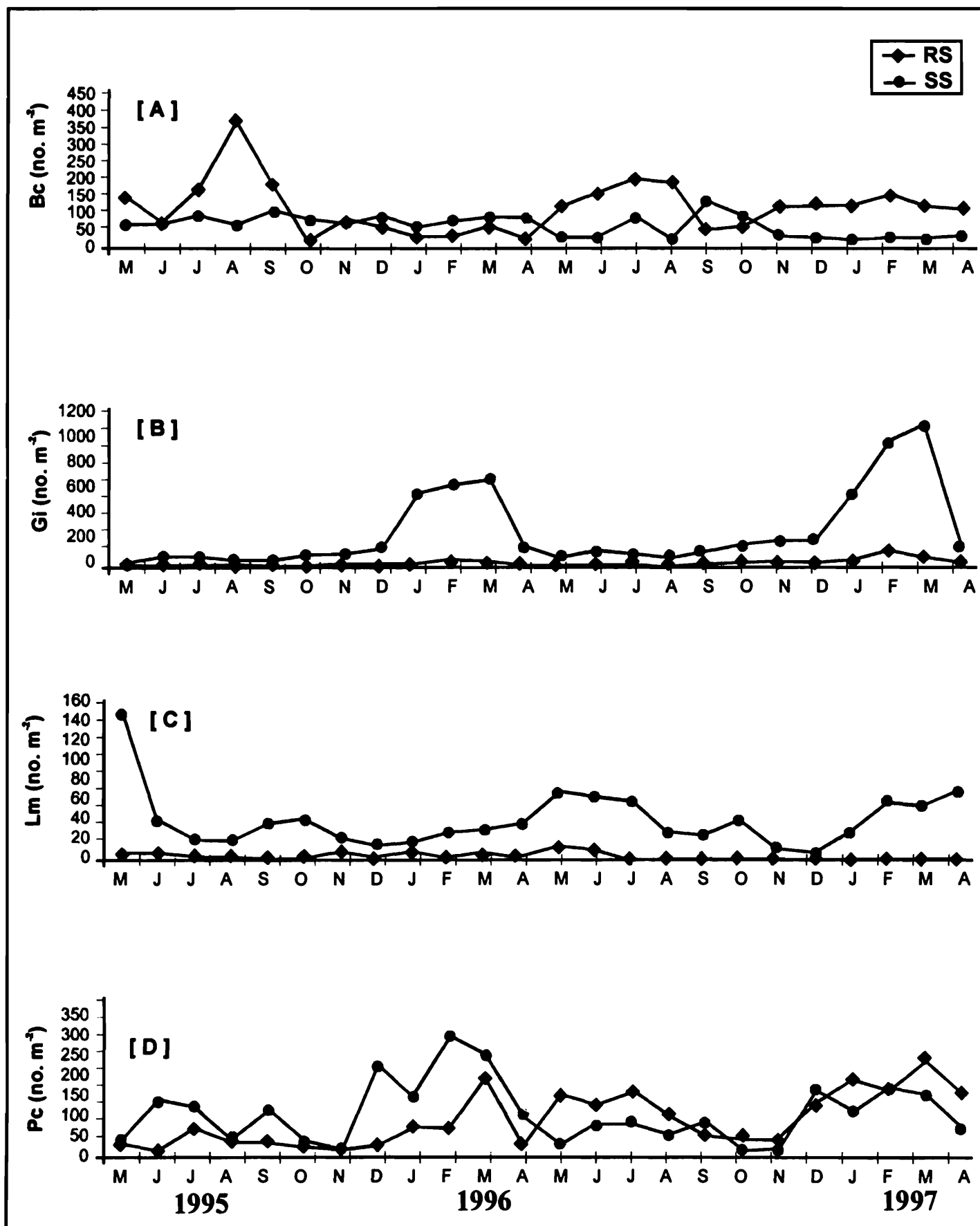


Fig. 13. Monthly variations (1995 -1997) in density of major macrobenthic species (Bc - *Brotia costula*, Gi - *Gyraulus labiatus*, Lm - *Lamellidens marginalis*, Pc - *Pisidium clarkeanum*) in RS and SS.

reported that larvae of Chironomidae are able to live in water with low dissolved oxygen concentration. Chironomids have been used as indicators of trophic state and/or pollution (Moore, 1978 and Kaul and Pandit, 1981). Vass *et al.* (1977) and Das (1978) recognised *Chironomus* spp. as pollution indicator in Dal Lake and Nainital Lake respectively. Gupta and Pant (1986) reported greater abundance of chironomids in region marked by a higher percentage of silt and clay. They were found to be positively correlated with depth and proportion of silt by Krieger and Ross (1993). In this study, the density and percentage of chironomids were not very high to denote any grave pollution status of both the lakes.

The population of chironomid larvae have been reported to increase during winter months (November to February) by many authors like Mandal and Moitra (1975b), Bass (1986), Malhotra *et al.* (1990), Singh and Roy (1991b) and Barbhuyan and Khan (1992). These findings in tropical waters also consolidated this study where chironomids showed greater abundance in March – April months. Rapid larval developments of chironomids (Cowell and Vodopich 1981) and large amount of organic matter (Olive and Dambach, 1973) may be the effective cause of their increase in population. Higher percentage of particulate organic matter, which allow more space, more food and make the animal easier to burrow, might be the factor responsible for high percentage of chironomids.

### Community Analysis

The structure and functioning of animal communities and the impact of them on natural or man induced change has meagre understanding. A substantial body of quantitative theory on communities have been deployed especially by the 'Hutchinson-MacArthur' school, that allows both the organisation of data on communities and also possess a number of hypothesis that require confirmation, refinement or refutation by field data (Southwood, 1978). Details of theoretical studies and examples of field work are given by MacArthur and Wilson (1967), MacArthur (1972), May (1975 and 1976), Cody and Diamond (1975) and Pianka (1976 a and b).

To understand a particular biotic community or assemblage it is very important to work out some indices of species structure. Four indices namely, Index of dominance, Margalef's index, Shannon-Weiner index and Evenness index and were estimated for the purpose of community analysis of the benthic habitat of RS and SS.

**Index of dominance :** Within a major community there are species or groups which largely control the energy flow and strongly affect the environment of all other species and they are known as ecological dominants. The degree to which dominance is concentrated in one or many species can be expressed by an appropriate index of dominance, that sums each species importance in relation to the community as a whole. The index of dominance (Simpson, 1949) is the sum total of the squares of the proportion of the species in the community and is expressed as :

$$c = \sum (n_i / N)^2$$

where,  $c$  = index of dominance,  
 $n_i$  = importance value for each species (number of individuals, biomass, production, etc.) and  
 $N$  = total of importance values.

The value of (c) varies from 0 to 1. Higher diversity values reflect diversified resources in the habitat available for components of the community. Decreased values indicate increase by an average species resulting in the lowering of the number of coexisting species in the community.

Any community is characterised by a few common species with large number of individuals in association with many rare species with few individuals. The few common species or 'dominants' largely account for the energy flow in each trophic level, but it is the large number of rare species that mostly determine the "species diversity" of the community (Odum, 1971). The ratio between the number of species and importance values (numbers, biomass, productivity etc.) of individuals is called species diversity. It tends to be low in physically controlled ecosystem and high in a stable and biologically controlled ecosystem. Species diversity has a number of components, particularly on species richness and individual richness (Preston 1948; Good 1953 and Brillouin, 1960).

**Margalef's Index** : One of the major components of species diversity is called the 'species richness' or variety components or Margalef's diversity index (d) and is expressed by simple ratio between total species (s) and total number or importance values (N).

$$d = \frac{s-1}{\text{Log}N} \quad \text{as proposed by Margalef (1958)}$$

This index commonly varies between 1 and 5 and larger the index a more healthy body of water. When it tends towards 1 pollution is thought to increase and a damage should be suspected.

**Shannon-Weiner Index** : In estimating species diversity probably the most widely used index is the Shannon-Weiner (1949) index given by the formulae.

$$\bar{H} = \sum (n_i / N) \log (n_i / N)$$

where  $\bar{H}$  = Shannon - Weiner index,  
 $n_i$  = importance value of each species  
 $N$  = total of importance values.

This index is one of the best for making comparisons where one is not interested in separating out diversity components because it is reasonably independent of sample size. The value of this index can theoretically range from 0 to infinity. However, values normally range from 0 to 4. Wilhm and Dorris (1968), after examining diversity in a range of polluted and

unpolluted streams, concluded that the value of  $\bar{H}$  greater than 3 indicated clean water, values in the range of 1 to 3 were characterized by moderately polluted conditions and values less than 1 characterized heavily polluted conditions.

**Evenness Index :** Another component of diversity is called 'evenness' or 'equitability' in the apportionment of individuals among the species. It is noted that both evenness and Shannon-Weiner index behave inversely to the index of dominance, since high values indicate a low concentration of dominance. It is the apportionment of individuals among the species in the community and is expressed as :

$$e = \frac{\bar{H}}{\text{Log}S} \text{ according to Pielou (1966)}$$

where e = evenness index  
 H = Shannon-Weiner index  
 S = number of species

The index of dominance ranged from 0.23 to 0.33 in RS and from 0.25 to 0.35 in SS. Margalef's index varied from 2.53 to 3.45 in RS and from 2.23 to 3.04 in SS (Table 12). The maximum value of Shannon-Weiner index was recorded to be 2.62 in RS and 2.70 in SS, while the minimum value was 2.17 and 2.23 for the respective lakes. Evenness index showed values ranging from 0.60 to 0.70 in RS and 0.58 to 0.73 in SS.

A widely used approach to describe the response of both communities to environmental changes had been the calculation of dominance diversity indices (Modde and Drewes, 1990) and these emphasize the use of maximum information. But Hawkes (1979) and Winget and Mangum (1979) argued that dominance diversity indices are ineffective in evaluating several forms of environmental influence. However, Pianka and Huey (1971) stressed on index of dominance (c) which is sample size dependent and reflects the proportional abundance of species richness and individual richness. MacArthur (1965 and 1972) explained the diversity variation on the basis of resource, resource utilization and niche overlap. The index of dominance value is always higher where the community is dominated by a fewer number of species and lower where the dominancy is shared by a large number of species (Whittaker, 1965), or the total population of the community is uniformly distributed among different species that mainly occurs in clean and pollution free waters (Osborne *et al.*, 1976). The Simpson's index varies between 0 and 1. In RS, its value varied from 0.23 to 0.33 and in SS, from 0.25 to 0.35 (Table 12). The values of this index were slightly higher in SS than RS. Thus following MacArthur's (1965 and 1972) explanation, it can be inferred that the habitat of both the lakes have diversified resources with lower diversity of their utilization by an average species, providing a condition for higher co-existence of species as well as high amount of niche overlap i.e. sharing of resources among the coexisting species. Low values of this index indicate that there is fairly uniform distribution of different macrozoobenthic species in the benthic community reflecting moderately clean and relatively pollution free water of both RS and SS.

Species diversity had been termed as “non-concept” by Hurlbert (1971) and meaningless because to him the diversity indices which are necessarily linear in nature, do not represent the actual situation. But Hill (1973) suggested that it is an extremely useful notion that can be defined as the effective number of species present, either in broader geographic area, a community or a portion. The number of species present in a community is variously referred to as “species richness” and / or species diversity. Various indices of diversity weighed these two components rather differently (Hill, 1973) and some indices all but ignore one component or the other (Pianka and Huey, 1971). Mason (1981) quoted from a number of studies that the ‘species richness’ is better and more realistic indicator of diversity rather than information-statistics.

The high value of ‘species richness’ or Margalef’s index reflects the suitability of habitat for the organisms in one hand while on the other it is correlated with longer food chain and complex food web of the ecosystem and also relatively more stable community (Margalef, 1956). In RS the ‘species richness’ (d) values ranged from 2.55 to 3.45, while in SS it varied from 2.33 to 3.04 (Table 12). Moderately high ‘species richness’ of both the lakes signify a suitable habitat for the benthic animals, complex and long food web of the ecosystem and a fairly stable community (Sinha *et al.*, 1993).

Several authors have questioned the use of Shannon’s diversity index stating that it depends upon a hypothetical number of species and must be considered as an empirical value (Peet, 1974). Washington (1984) cited a lack of exploration of its biological relevance. Nichols (1973) criticized the past use of diversity indices in San Francisco Bay estuary stating that they were employed without regard for standardizing methodology and species identification, or an understanding of the natural biological processes that affect them. Most of the criticisms have been subjective. While in applied studies  $\overline{H}$  values give additional information to ecologists which enable them to ask questions and formulate hypothesis about the environment. Harrel *et al.* (1976) stated that the diversity values should always be used to compliment tabular analysis for taxa distribution and abundance with physico-chemical data. According to Whittaker (1977), the Shannon-Weiner index is actually not a real assessment of the species diversity in a community but the relative importance value of the species taken into account. That is why the index obtained by the formulae is a good indication of water quality of the habitat and forms a base for biomonitoring. Hughes (1978) discussed factors other than pollution that could affect  $\overline{H}$  values and concluded that they were useful indices of community structure but cannot stand alone.

Wilhm and Dorris (1968) suggested the utility of the species diversity index in assessing water quality. In the present study, the  $\overline{H}$  was calculated to lie between 2.17 to 2.62 in RS and 2.00 to 2.58 in SS (Table 12). After application of the relationships put forward by Wilhm and Dorris (1966) between the diversity values and pollution status of the waterbody it can be concluded that both the lakes are at an intermediate state of environmental stress and pollution, being in a more or less stable condition.

The 'evenness component of diversity' or evenness based on Shannon-Weiner diversity index is thought to denote a balanced relation between the species and individual richness of a sample. The evenness values as already stated were found to range between 0.60 and 0.73 in RS and between 0.58 and 0.73 in SS (Table 12), signifying a greater equatability in the apportionment of individuals among the species in both RS and SS.

Community dynamic studies conducted by several workers using macrozoobenthos report same pattern of biological distribution as met in the present study (Harrel, 1966; Ewing, 1964; Wilhm *et al.*, 1978; Krishnamoorthi and Sarkar, 1979 and Jhingran *et al.*, 1989). On the basis of foregoing findings and discussion it can be concluded that the habitat of RS and SS are moderately polluted as evident from the resultant values of Shannon-Weiner index, with no obvious stress as the communities are stable with long food chain and complex food web. From the values of concentration of dominance it can be inferred that the resources in the habitats of both the lakes are diversified and an average species of the communities have low diversity utilization. The components of the communities share the resources and there is niche overlap to a greater extent which supports more species and *vice versa*.

### Statistical Analysis

In an aquatic system the temporal and spatial variation in the quality and quantity of macrobenthic animals chiefly depend upon the physico-chemical parameters of water and sediment (Ghosh and Banerjee, 1996). The abundance of each species may be dependent on a certain combination of these parameters. At a particular place relationship may or may not exist between every pair of parameters and species.

For each site and each sampling date, the triplicated values of 20 environmental variables and faunistic abundance (number of total benthos and number of organisms of different groups and species per square meter) were first averaged. Their mean values were considered as independent replicates over time. The huge volume of data generated from two years of study in RS and SS were subjected to different statistical analysis, namely (i) Pearson's correlation coefficient (ii) stepwise multiple regression analysis and (iii) ANOVA – 2 way, in order to find out the interdependence between biological components and physico-chemical characteristics.

**Pearson's correlation coefficient :** Pearson's correlation coefficients were calculated to determine a relationship between every abiotic (physico-chemical parameters of water and sediment) and biotic variables i.e. density of total benthos, groups (Oligochaeta, Crustacea, Coleoptera, Diptera, Gastropoda and Bivalvia) and fairly abundant species.

**Correlation between total benthos and water parameters :** The correlation between water parameters and total benthos of RS and SS are given in Tables 13 and 14. Total benthos was found to have positive correlation with total hardness ( $r = 0.4801$ ,  $p < 0.05$ ) and negative correlation with phosphate ( $r = -0.4678$ ,  $p < 0.05$ ) in RS, whereas in SS, pH ( $r = 0.6281$ ,  $p < 0.01$ ) and ammonium ( $r = 0.4416$ ,  $p < 0.05$ ) were found to be positively correlated with the density of total benthos.

**Table 12.** Values of Shannon - Weiner index (annual mean) with 95% confidence interval in RS and SS.

Month	Rabindra Sarovar		Subhas Sarovar	
	Shannon-Weiner index	Confidence interval	Shannon-Weiner index	Confidenc interval
<b>May</b>	2.52	±0.46	2	±0.29
<b>June</b>	2.43	±0.09	2.06	±0.10
<b>July</b>	2.32	±0.24	2.3	±0.11
<b>August</b>	2.62	±0.22	2.41	±0.11
<b>September</b>	2.17	±0.31	2.12	±0.14
<b>October</b>	2.33	±0.24	2.01	±0.19
<b>November</b>	2.31	±0.06	2.13	±0.18
<b>December</b>	2.25	±0.15	2.11	±0.21
<b>January</b>	2.4	±0.06	2.11	±0.38
<b>February</b>	2.24	±0.47	2.17	±0.28
<b>March</b>	2.41	±0.27	2.24	±0.24
<b>April</b>	2.52	±0.22	2.58	±0.29

Note: There was not much variation in CI of Shannon - Weiner index in both the lakes.

**Correlation between total benthos and sediment parameters (Tables 13 and 14) :** Total benthos was found to show positive correlation with organic carbon in both the lakes ( $r = 0.4666$ ,  $p < 0.05$  in RS and  $r = 0.4944$ ,  $p < 0.05$  in SS). Sediment phosphate ( $r = 0.5425$ ,  $p < 0.01$ ) and nitrate ( $r = 0.5472$ ,  $p < 0.01$ ) were noted to have positive effect on the density of total benthos in SS.

**Correlation between benthic groups/species and water parameters :** The density of oligochaetes were found to exhibit a strong positive relationship with turbidity ( $r = 0.6234$ ,  $p < 0.01$  in RS and  $r = 0.4624$ ,  $p < 0.05$  in SS) and dissolved oxygen ( $r = 0.6881$ ,  $p < 0.01$  in RS and  $r = 0.4526$ ,  $p < 0.05$  in SS) and negative relationship with nitrite ( $r = 0.4892$ ,  $p < 0.05$  in RS and  $r = 0.4318$ ,  $p < 0.05$  in SS) in both the lakes (Tables 13 and 14). In addition to these parameters, pH ( $r = 0.5394$ ,  $p < 0.01$ ) and alkalinity ( $r = 0.6913$ ,  $p < 0.01$ ) were noticed to have strong positive influence on the oligochaete number in SS. In RS, water temperature ( $r = -0.6540$ ,  $p < 0.01$ ) and phosphate ( $r = -0.6777$ ,  $p < 0.01$ ) showed negative correlation with oligochaete density.

The predominant oligochaete species, *Limnodrilus hoffmeisteri*, also showed similar relationship with the various abiotic variables (Tables 15 and 16) in addition to a significant positive effect of total hardness ( $r = 0.4169$ ,  $p < 0.05$ ) on its density in RS and a negative correlation with nitrate ( $r = -0.4410$ ,  $p < 0.05$ ) in SS. The other oligochaete species *Branchiura sowerbyi* showed negative interdependence with water temperature ( $r = -0.7649$ ,  $p < 0.01$ ), COD ( $r = -0.4581$ ,  $p < 0.05$ ), chloride ( $r = -0.5069$ ,  $p < 0.05$ ) and phosphate ( $r = -0.5932$ ,  $p < 0.01$ ) in RS (Table 15). Only turbidity ( $r = 0.4591$ ,  $p < 0.05$ ) was found to be positively correlated with the density of this species.

Phosphate ( $r = 0.4284$ ,  $p < 0.05$  in RS and  $r = 0.4207$ ,  $p < 0.05$  in SS) showed a positive relationship with the fluctuation in crustacean density in both RS and SS (Tables 13 and 14). A significant positive correlation was also noted to exist between crustacean population and dissolved oxygen ( $r = 0.4148$ ,  $p < 0.05$ ) in RS and chloride ( $r = 0.8672$ ,  $p < 0.01$ ) in SS. Parameters like BOD ( $r = -0.4814$ ,  $p < 0.05$ ), COD ( $r = -0.4300$ ,  $p < 0.05$ ), nitrite ( $r = -0.4385$ ,  $p < 0.05$ ) and nitrate ( $r = -0.4601$ ,  $p < 0.05$ ) showed a negative effect on Crustacea in SS (Table 14).

Odonates showed a positive correlation with turbidity ( $r = 0.5473$ ,  $p < 0.01$ ) only and negative correlation with conductivity ( $r = -0.4396$ ,  $p < 0.05$ ), COD ( $r = -0.5087$ ,  $p < 0.05$ ), chloride ( $r = -0.6098$ ,  $p < 0.01$ ), phosphate ( $r = -0.5001$ ,  $p < 0.05$ ) and nitrate ( $r = -0.5115$ ,  $p < 0.05$ ) in RS (Table 13).

In RS coleopteran density was found to be positively dependent on pH ( $r = 0.4330$ ,  $p < 0.05$ ), COD ( $r = 0.4760$ ,  $p < 0.05$ ), nitrate ( $r = 0.4321$ ,  $p < 0.05$ ) and ammonium ( $r = 0.4320$ ,  $p < 0.05$ ; Table 13). However, in SS turbidity ( $r = 0.4209$ ,  $p < 0.05$ ), alkalinity ( $r = 0.5243$ ,  $p < 0.01$ ) and nitrate ( $r = 0.5338$ ,  $p < 0.01$ ) were noticed to possess a positive effect but nitrite ( $r = -0.5086$ ,  $p < 0.05$ ) showed a negative relationship with Coleoptera (Table 14). The sole coleopteran species, *Hydrocoptus subvittulus* exhibited similar correlation in both the lakes (Tables 15 and 16).

Water temperature ( $r = -0.4599$ ,  $p < 0.05$  in RS and  $r = -0.5943$ ,  $p < 0.01$  in SS) and phosphate ( $r = -0.6686$ ,  $p < 0.01$  in RS and  $r = -0.6389$ ,  $p < 0.01$  in SS) showed a negative influence while turbidity ( $r = 0.5039$ ,  $p < 0.05$  in RS and  $r = 0.7112$ ,  $p < 0.01$  in SS) and dissolved oxygen ( $r = 0.5238$ ,  $p < 0.01$  in RS and  $r = 0.5804$ ,  $p < 0.01$  in SS) exhibited a positive effect on the dipteran density in both the lakes (Tables 13 and 14). Apart from these parameters, total hardness ( $r = 0.4298$ ,  $p < 0.05$ ) showed a positive correlation with dipteran population in RS. In SS total alkalinity ( $r = 0.8243$ ,  $p < 0.01$ ) had a positive influence and nitrite ( $r = -0.5792$ ,  $p < 0.01$ ) a negative influence on the numerical abundance of Diptera. The population of chironomid larvae belonging to this group also showed similar results (Tables 15 and 16).

Significant positive correlation was found to exist between physico-chemical factors like temperature ( $r = 0.4856$ ,  $p < 0.05$ ), pH ( $r = 0.4992$ ,  $p < 0.05$ ), phosphate ( $r = 0.5470$ ,  $p < 0.01$ ), ammonium ( $r = 0.5342$ ,  $p < 0.01$ ) and gastropod density in SS and between nitrite ( $r = 0.6751$ ,  $p < 0.01$ ) and Gastropoda in RS (Table 13 and 14). Only total hardness ( $r = -0.5448$ ,  $p < 0.01$ ) showed a negative effect on the gastropod density in SS.

The main gastropod species, *Bellamya bengalensis* showed similar positive correlation with temperature ( $r = 0.7247$ ,  $p < 0.01$ ), phosphate ( $r = 0.5963$ ,  $p < 0.01$ ) and ammonium ( $r = 0.4701$ ,  $p < 0.05$ ) and negative correlation with total hardness ( $r = 0.4096$ ,  $p < 0.05$ ) in SS (Table 16). It was found to be positively related to nitrate content ( $r = 0.6926$ ,  $p < 0.01$  in RS and  $r = 0.4216$ ,  $p < 0.05$  in SS) and negatively to dissolved oxygen ( $r = -0.4551$ ,  $p < 0.05$  in RS and  $r = -0.4776$ ,  $p < 0.05$  in SS) in both the lake systems (Tables 15 and 16).

In RS, the density of *Gabbia orcula* exhibited negative correlation with temperature ( $r = -0.6120$ ,  $p < 0.01$ ), COD ( $r = -0.4376$ ,  $p < 0.05$ ), chloride ( $r = -0.4862$ ,  $p < 0.05$ ) and phosphate ( $r = -0.7028$ ,  $p < 0.01$ ) and positive correlation with turbidity ( $r = 0.6540$ ,  $p < 0.01$ ) and dissolved oxygen ( $r = 0.4617$ ,  $p < 0.05$ ; Table 15). In SS, it showed direct relationship with pH ( $r = 0.4496$ ,  $p < 0.05$ ; Table 16).

The density of *Digoniostoma cerameopoma* was noted to be positively influenced by pH ( $r = 0.5992$ ,  $p < 0.01$ ) in SS (Table 16), chloride ( $r = 0.4286$ ,  $p < 0.05$ ), nitrite ( $r = 0.4424$ ,  $p < 0.05$ ) and nitrate ( $r = 0.4646$ ,  $p < 0.05$ ) in RS (Table 15) and by temperature ( $r = 0.4375$ ,  $p < 0.05$  in RS and  $r = 0.4384$ ,  $p < 0.05$  in SS) in both the lakes. Its density was negatively related to total hardness ( $r = -0.6467$ ,  $p < 0.01$ ) in SS, while in RS, a negative correlation existed between the density of *D. cerameopoma* and turbidity ( $r = -0.5595$ ,  $p < 0.01$ ) and also dissolved oxygen ( $r = -0.5473$ ,  $p < 0.01$ ).

Turbidity ( $r = 0.6257$ ,  $p < 0.01$ ), alkalinity ( $r = 0.7657$ ,  $p < 0.01$ ) and nitrate ( $r = 0.6398$ ,  $p < 0.01$ ) were found to have a positive correlation with the abundance of *Thiara scabra* in SS (Table 16) while in RS, dissolved oxygen ( $r = 0.4438$ ,  $p < 0.05$ ) and ammonium ( $r = 0.6720$ ,  $p < 0.01$ ) showed the same positive relationship (Table 15). Only nitrite ( $r = -0.4763$ ,  $p < 0.05$ ) was found to show a negative correlation with this species in SS.

**Table 13.** Correlation coefficient (r value) between different benthic groups / total benthos and physico-chemical parameters in RS

Parameters	GROUPS							
	Oligochaeta	Crustacea	Odonata	Coleoptera	Diptera	Gastropoda	Bivalvia	Total benthos
<b>WATER</b>								
Temperature	-0.6540**					- 0.4599*		
pH				- 0.4330*				
Turbidity	0.6234**		0.5473**		0.5039*			
Conductivity					0.4396*			
Total alkalinity							0.4676*	
Total hardness			0.4298*			0.4801*		
Dissolved								
Oxygen	0.6881**	0.4148*			0.5238*			
COD			- 0.5087*	0.4760*				
Chloride			- 0.6098*					
Phosphate	- 0.6777**	0.4284*	- 0.5001*		-0.6686**			- 0.4678
Nitrate			- 0.5115*	0.4321*			0.4323*	
Nitrite	- 0.4892*					0.6751**	-0.4710*	
Ammonium				0.4320*				
<b>SEDIMENT</b>								
Temperature	- 0.6877**				-0.4442*			
Phosphate				0.7091**				
Nitrate	-0.5596**							
Nitrite	- 0.4103*					0.4178*		
Organic carbon								0.4666*

\* Significance level at 0.05; \*\* Significance level at 0.01

**Table 14.** Correlation coefficient (r value) between different benthic groups / total benthos and physico-chemical parameters in SS

Group	WATER PARAMETERS													
	Temperature	pH	Turbidity	Total alkalinity	Total hardness	Dissolved oxygen	BOD	COD	Chloride	Phosphate	Nitrate	Nitrite	Ammonium	
<b>Oligochaeta</b>		0.5394**	0.6234*	0.6913**		0.4526*							-0.4652*	
<b>Crustacea</b>							-0.4814*	-0.4300*	0.8672**	0.4207*			-0.6001**	
<b>Coleoptera</b>			0.4209*	0.5243**							-0.5086*			
<b>Diptera</b>	-0.5943**		0.7112**	0.8243**		0.5804**					-0.6389**	-0.4868*	-0.5131*	
<b>Gastropoda</b>	0.4856*	0.4992*			-0.5448**					0.5470**			0.8574**	0.5342**
<b>Bivalvia</b>		0.5602**	0.5753**	0.7285**		0.4264*							-0.4605*	
<b>Total benthos</b>		0.6281**			-0.5591**								0.5472**	0.4416*

Table 14 Contd.

Group	SEDIMENT PARAMETERS				
	pH	Phosphate	Nitrate	Nitrite	Organic carbon
Oligochaeta			-0.4652*		
Crustacea	-0.5431**		-0.6001**		
Coleopetera					
Diptera			-0.4868*	-0.5131*	
Gastropoda		0.7503**		0.8574**	
Bivalvia			-0.4605*		
Total benthos		0.5425**		0.5472**	0.4944*

\* Significance level at 0.05; \*\* Significance level at 0.01

*Thiara granifera* was observed to be positively influenced by temperature ( $r = 0.5939$ ,  $p < 0.01$ ), phosphate ( $r = 0.4232$ ,  $p < 0.05$ ) and ammonium ( $r = 0.4686$ ,  $p < 0.05$ ) in SS and by nitrite ( $r = 0.7157$ ,  $p < 0.01$  in RS and  $r = 0.6209$ ,  $p < 0.01$  in SS) in both the lakes (Tables 15 and 16). Total hardness ( $r = -0.4898$ ,  $p < 0.05$ ) was negatively correlated to *T. granifera* in SS.

Significant positive correlation was found to exist between two physico-chemical parameters like pH ( $r = 0.4086$ ,  $p < 0.05$  in RS and  $r = 0.4172$ ,  $p < 0.05$  in SS) and ammonium ( $r = 0.5048$ ,  $p < 0.05$  in RS and  $r = 0.4346$ ,  $p < 0.05$  in SS) and *Thiara tuberculata* in both the lakes (Table 15 and 16). However, in SS, phosphate ( $r = 0.7045$ ,  $p < 0.01$ ) exhibited a direct relationship with the variation of density of *T. tuberculata*. In RS, total hardness ( $r = 0.5212$ ,  $p < 0.01$ ) and nitrite ( $r = 0.5552$ ,  $p < 0.01$ ) also showed a positive correlation with this species.

Water temperature ( $r = 0.4082$ ,  $p < 0.05$ ), pH ( $r = 0.4138$ ,  $p < 0.01$ ) and ammonium ( $r = 0.4667$ ,  $p < 0.05$ ) were observed to have a strong positive influence on the population of *Brotia costula* in SS (Table 16). However, in RS, turbidity ( $r = -0.4906$ ,  $p < 0.05$ ) and total hardness ( $r = -0.4854$ ,  $p < 0.05$ ) showed negative correlation with the same species (Table 15).

The correlation coefficient ( $r$ ) was calculated to be positive indicating positive interdependence between *Gyraulus labiatus* and turbidity ( $r = 0.5243$ ,  $p < 0.01$ ) and also with total hardness ( $r = 0.4544$ ,  $p < 0.05$ ) and dissolved oxygen ( $r = 0.6852$ ,  $p < 0.01$ ) in RS (Table 15), while in SS, it showed the same correlation with alkalinity ( $r = 0.5913$ ,  $p < 0.01$ ) and dissolved oxygen ( $r = 0.5202$ ,  $p < 0.01$ ; Table 16). Negative correlation was found to exist between this species and water temperature ( $r = -0.5114$ ,  $p < 0.05$ ) and also phosphate ( $r = -0.8132$ ,  $p < 0.01$ ) in RS and with nitrite ( $r = -0.4253$ ,  $p < 0.05$ ) in SS.

In RS, alkalinity ( $r = 0.4676$ ,  $p < 0.05$ ) and nitrate ( $r = 0.4323$ ,  $p < 0.05$ ) exhibited strong positive correlation, while nitrite ( $r = -0.4710$ ,  $p < 0.05$ ) showed negative correlation with bivalve density (Table 13). On the other hand, in SS parameters like pH ( $r = 0.5602$ ,  $p < 0.05$ ), turbidity ( $r = 0.5753$ ,  $p < 0.05$ ), alkalinity ( $r = 0.7285$ ,  $p < 0.01$ ), dissolved oxygen ( $r = 0.4264$ ,  $p < 0.05$ ) and nitrate ( $r = 0.4655$ ,  $p < 0.05$ ) had a positive influence and nitrite ( $r = -0.5015$ ,  $p < 0.05$ ) had a negative influence on the abundance of bivalves (Table 14).

Water temperature ( $r = 0.5255$ ,  $p < 0.01$ ), pH ( $r = 0.6296$ ,  $p < 0.01$ ), conductivity ( $r = 0.7446$ ,  $p < 0.01$ ), alkalinity ( $r = 0.6922$ ,  $p < 0.01$ ), BOD ( $r = 0.5836$ ,  $p < 0.01$ ), COD ( $r = 0.6860$ ,  $p < 0.01$ ), chloride ( $r = 0.6829$ ,  $p < 0.01$ ), phosphate ( $r = 0.4617$ ,  $p < 0.05$ ) and nitrate ( $r = 0.6527$ ,  $p < 0.01$ ) showed a positive effect on the population of the most common bivalve, *Lamellidens marginalis* in RS. Only turbidity ( $r = -0.5063$ ,  $p < 0.05$ ) showed a negative relationship with this species (Table 15). The other *Lamellidens* species, *L. corrianus* revealed very similar relationship with the above mentioned parameters (Table 15).

In SS, the density of the species *Pisidium clarkeanum* was observed to be positively dependent on pH ( $r = 0.5528$ ,  $p < 0.01$ ), turbidity ( $r = 0.5646$ ,  $p < 0.01$ ), alkalinity ( $r = 0.6158$ ,  $p < 0.01$ ), dissolved oxygen ( $r = 0.4322$ ,  $p < 0.01$ ) and nitrate ( $r = 0.4620$ ,  $p < 0.05$ ) and negatively dependent on nitrite ( $r = -0.5012$ ,  $p < 0.05$ ; Table 16). However, in RS this species

**Table 15.** Correlation coefficient (r value) between different benthic species and physico-chemical parameters in RS.

Parameters	Species						
	L.h.	B.s.	H.s.	Chiro	B.b.	G.o	D.c.
<b>WATER</b>							
Temperature		-0.7649**		-0.4599*		-0.612**	0.4375*
pH			0.433*				
Turbidity		0.4591*		0.5039*		0.6540**	-0.5595**
Conductivity							
Total alkalinity							
Total hardness	0.4169*			0.4298*			
Dissolved oxygen	0.6849**			0.5238**	-0.4551*	0.4617*	-0.5473**
BOD							
COD		-0.4581*	-0.4760*			-0.4376*	
Chloride		-0.5069*				-0.4862*	0.4286*
Phosphate	-0.7021**	-0.5932**		-0.6686**		-0.7028**	
Nitrate			0.4321*				0.4646*
Nitrite	-0.4352*				0.6926**		0.4424*
Ammonium			0.4320*				
<b>SEDIMENT</b>							
Temperature	-0.6438**	-0.7662**				-0.5809**	
Phosphate				-0.4442*			0.4589**
Nitrate			0.7091**		0.4140*		0.6058**
Nitrite	-0.5237**	-0.4668*			0.4435*		0.5493**
Organic carbon						0.4825*	

Table 15 Contd.

Parameters	Species							
	T.s.	T.g.	T.t.	B.c.	G.l.	L.c.	L.m.	P.c.
<b>WATER</b>								
Temperature					-0.5114*	0.4318*	0.5255*	-0.4234*
pH			0.4086*			0.7079*	0.6296**	
Turbidity				-0.4906*	0.5243**	-0.4566*	-0.5063*	
Conductivity						0.6707**	0.7446**	
Total alkalinity						0.7318**	0.6922**	
Total hardness			0.5212**	-0.4854*	0.4544*			
Dissolved oxygen	0.4438*				0.6852**			0.4598*
BOD						0.5814**	0.5836**	
COD						0.5705**	0.6860**	
Chloride						0.5069*	0.6829**	
Phosphate					-0.8132**		0.4617*	-0.4382*
Nitrate						0.6022**	0.6527**	
Nitrite		0.7157**	0.5552**					-0.5476**
Ammonium	0.6720**		0.5048*					
<b>SEDIMENT</b>								
Temperature					-0.5061*	0.4369*	0.5166**	-0.4412*
Phosphate	0.5709*					0.4460*	0.4153*	
Nitrate			0.4311*		-0.4729*	0.4939*		-0.4130*
Nitrite		0.4715*	0.7560**				0.4973*	
Organic carbon			0.4872*	0.6521**		0.4903*	0.5191**	

\* Significance level at 0.05; \*\* Significance level at 0.01

L.h. – *Limnodrilus hoffmeisteri*, B.s. – *Branchiura sowerbyi*, H.s.- *Hydrocoptus subvittulus*, Chiro – Chironomid larvae, B.b.-*Bellamyia bengalensis*, G.o.- *Gabbia orcula*, D.c.-*Digoniostoma cerameopoma*, T.S.- *Thiara scabra*, T.g. *Thiara granifera*, T.t. *Thiara tuberculata*, B.C.- *Brotia costula*, G.l – *Lamellidens comianus*, L.m.-*Lamellidens marginalis*, P.c.-*Pisidium clarkeanum*.

**Table 16.** Correlation coefficient (r value) different benthic species and physico-chemical parameters in SS.

Parameters	Species					
	L.h.	H.s.	Chiro.	B.b.	G.o.	D.c.
<b>WATER</b>						
Temperature			-0.5943**	0.7247**		0.4384**
pH	0.5278**				0.4496*	0.5992**
Turbidity	0.4642*	0.4209*	0.7112**			
Total alkalinity	0.6897**	0.5243**	0.8243**			
Total hardness				-0.4096*		-0.6467**
Dissolved oxygen	0.4543*		0.5804**	-0.4776*		
Phosphate			-0.6389**	0.5963**		
Nitrate	-0.4410*	0.5338**				
Nitrite		-0.5086**	-0.5792**	0.4216*		
Ammonium				0.4701*		
<b>SEDIMENT</b>						
Phosphate				0.6682**	0.6212**	
Nitrate			0.5131*	0.8512**	0.5758**	0.4515*
Nitrite	-0.4700*		-0.4868			
Organic carbon						0.6840*

Table 16 contd.

Parameters	Species					
	T.s.	T.g.	T.t.	B.c.	G.l.	P.c.
<b>WATER</b>						
Temperature		0.5939**		0.4082*		
pH			0.4172*	0.4138*		0.5528**
Turbidity	0.6257**					0.5646**
Total alkalinity	0.7657**				0.5913**	0.6158**
Total hardness						
Dissolved oxygen					0.5202**	0.4322*
Phosphate		0.4232*	0.7045**			
Nitrate	0.6398**					0.4620*
Nitrite	-0.4763*	0.6209**			-0.4253*	-0.5012*
Ammonium		0.4686*	0.4346*	0.4667*		
<b>SEDIMENT</b>						
Phosphate		0.6103**	0.4954*	0.4751*		
Nitrate		0.8315**	0.5757**	0.5639*		
Nitrite		0.4434*				-0.4741*
Organic carbon		0.4709*		0.4076*		

\* Significance level at 0.05;      \*\* Significance level at 0.01

L.h.- *Limnodrilus hoffmeisteri*, H.s.- *Hydrocoptus subvittulus*, Chiro.- Chironomid larvae, B.b.- *Bellamyia bengalensis*,

G.o.- *Gabbia orcula*, D.c.- *Digoniostoma cerameopoma*, T.s – *Thiara scarbra*, T.g. – *Thiara granifera*, T.t.- *Thiara tuberculata*

B.c. – *Brotia costula*, G.l *Gyraulius labiatus*, P.c.- *Pisidium clarkeanum*.

showed positive relationship only with dissolved oxygen ( $r = 0.4598$ ,  $p < 0.05$ ) and negative correlation with temperature ( $r = -0.4234$ ,  $p < 0.05$ ), phosphate ( $r = -0.4382$ ,  $p < 0.05$ ) and nitrite ( $r = -0.5476$ ,  $p < 0.01$ , Table 15).

**Correlation between benthic groups/species and sediment parameters :** Sediment nitrite ( $r = -0.4103$ ,  $p < 0.05$  in RS and  $r = -0.4652$ ,  $p < 0.05$  in SS) was found to have a negative correlation with oligochaete density in both the lakes (Table 13 and 14). In RS, sediment temperature ( $r = -0.6877$ ,  $p < 0.01$ ) and nitrate ( $r = -0.5596$ ,  $p < 0.01$ ) were also noted to have an inverse relationship with oligochaete density. The two oligochaete species *L. hoffmeisteri* and *B. sowerbyi* also exhibited similar dependence on sediment temperature, nitrite and nitrate (Table 15 and 16) in both the lakes.

In SS, crustacean density was found to be negatively affected by sediment pH ( $r = -0.5431$ ,  $p < 0.01$ ) and nitrite ( $r = -0.6001$ ,  $p < 0.01$ ).

In RS, a strong positive relationship was noticed to occur between sediment phosphate concentration ( $r = 0.7091$ ,  $p < 0.01$ ) and density of Coleoptera (Table 13) as well as with the species *H. subvittuslus* (Table 15).

Diptera in general and chironomid larvae showed negative correlation with sediment temperature ( $r = -0.4442$ ,  $p < 0.05$ ) in RS and with nitrite ( $r = -0.4868$ ,  $p < 0.05$ ) and nitrate values ( $r = -0.5131$ ,  $p < 0.05$ ) in SS (Tables 13-16).

Gastropoda showed significant positive relationship with sediment phosphate ( $r = 0.7503$ ,  $p < 0.01$ ) and nitrate ( $r = 0.8574$ ,  $p < 0.01$ ) in SS and with nitrite ( $r = 0.4178$ ,  $p < 0.05$ ) in RS (Tables 13 and 14). Amongst the gastropod species, *B. bengalensis* ( $r = 0.6682$ ,  $p < 0.01$ ), *G. orcula* ( $r = 0.6212$ ,  $p < 0.01$ ), *T. granifera* ( $r = 0.6103$ ,  $p < 0.01$ ), *T. tuberculata* ( $r = 0.4954$ ,  $p < 0.05$ ) and *B. costula* ( $r = 0.4751$ ,  $p < 0.05$ ) in SS and *T. scabra* ( $r = 0.5709$ ,  $p < 0.01$ ) in RS showed positive relation with sediment phosphate concentration (Tables 15 and 16). *T. granifera* showed significant positive correlation with sediment nitrite ( $r = 0.4715$ ,  $p < 0.05$  in RS and  $r = 0.4434$ ,  $p < 0.05$  in SS) in both the lakes. Other species like *B. bengalensis* ( $r = 0.4435$ ,  $p < 0.05$ ), *D. cerameopoma* ( $r = 0.5493$ ,  $p < 0.01$ ) and *T. tuberculata* ( $r = 0.7560$ ,  $p < 0.01$ ) also exhibited similar positive interaction with nitrite in RS (Table 15). *B. bengalensis* ( $r = 0.4140$ ,  $p < 0.05$  in RS and  $r = 0.8512$ ,  $p < 0.01$  in SS), *D. cerameopoma* ( $r = 0.4515$ ,  $p < 0.05$  in RS and  $r = 0.6058$ ,  $p < 0.01$  in SS) and *T. tuberculata* ( $r = 0.4311$ ,  $p < 0.05$  in RS and  $r = 0.5757$ ,  $p < 0.01$  in SS) in both the lakes and *G. orcula* ( $r = 0.5758$ ,  $p < 0.01$ ), *T. granifera* ( $r = 0.8315$ ,  $p < 0.01$ ) and *B. costula* ( $r = 0.5639$ ,  $p < 0.01$ ) in SS showed positive interaction with nitrate. However, a negative relationship was noted to occur between nitrate and *G. labiatus* ( $r = -0.4729$ ,  $p < 0.05$ ) in RS. Other parameters like sediment temperature showed positive correlation with *D. cerameopoma* ( $r = 0.4589$ ,  $p < 0.05$ ) and negative correlation with *G. orcula* ( $r = -0.5809$ ,  $p < 0.05$ ) and *G. labiatus* ( $r = -0.5061$ ,  $p < 0.05$ ) in RS (Table 15). Organic carbon was found to have significant positive relationship with *G. orcula* ( $r = 0.4825$ ,  $p < 0.05$ ), *T. tuberculata* ( $r = 0.4872$ ,  $p < 0.05$ ) and *B. costula* ( $r = 0.6521$ ,  $p < 0.01$ ) in RS and with *D. cerameopoma* ( $r = 0.6840$ ,  $p < 0.01$ ), *T. granifera* ( $r = 0.4709$ ,  $p < 0.05$ ) and *B. costula* ( $r = 0.4076$ ,  $p < 0.05$ ) in SS (Tables 15 and 16).

The group Bivalvia revealed inverse relationship with sediment nitrite only ( $r = -0.4695$ ,  $p < 0.05$ ) in SS (Table 14). Similar relationship with nitrite was only exhibited by the common bivalve species. *P. clarkeanum* ( $r = -0.4741$ ,  $p < 0.05$ ) in SS (Table 16). In RS, this species also showed a negative correlation with sediment temperature ( $r = -0.4412$ ,  $p < 0.05$ ). The other two bivalve species, *L. marginalis* and *L. corrianus* showed positive correlation with sediment temperature, phosphate, nitrite and organic carbon in RS (Table 15).

**Stepwise multiple regression :** Stepwise multiple regression was adopted to know which physico-chemical parameters affect the abundance of total benthos, groups and species and also to what extent. The Tables 17-20 represent the partial regression coefficient ( $b_j$ ) and its standard error, corresponding to each independent variable i.e., physico-chemical parameters of water and sediment which is supposed to be included in final regression equation. The partial regression coefficient ( $b_j$ ) determines the expected change in density of species/groups/total benthos caused by the unit increase/decrease of the corresponding independent variable, other variables remaining unchanged. The tables also present the coefficient of determination ( $R^2$ ) for species/groups/total benthos, which measures their percent variation explained by the independent variables used in the final equation. The accuracy of the regression equations were tested with  $R^2$  and F value.

**Multiple regression analysis of physico-chemical parameters and total benthos (Tables 17 and 18) :** In SS, pH and total hardness of water were found to be important factors affecting the total benthos density and explained 61% variation in it. However, in RS, only total hardness bore a linear relationship with total benthos and 23% variation in its density was explained.

**Multiple regression analysis of physico-chemical parameters and groups/species :** In RS, out of 20 parameters only dissolved oxygen, alkalinity and sediment temperature were found to be significantly affecting the oligochaete density and explained 75% variation in it (Table 17). The density of the two oligochaete species, *L. hoffmeisteri* and *B. sowerbyi* were found to be influenced by phosphate, nitrite, sediment temperature and organic carbon (Table 19).

In case of Crustacea, both water and sediment phosphate jointly explained 39% of variation in its density. Chloride and sediment phosphate showed strong impact on the abundance of Odonata, explaining 54% variation in its density. About 61% variation in coleopteran density was explained by sediment phosphate and nitrite, while in case of Diptera total alkalinity and phosphate were noted as two important factors causing 56% variation in its density.

Only nitrite was noticed to bear a positive linear relationship with Gastropoda, accounting for 45% of its variation in density. For all the regularly occurring gastropod species, physico-chemical parameters like dissolved oxygen, phosphate, nitrite, ammonium, COD, BOD, sediment phosphate, sediment nitrite, nitrate and organic carbon were found to affect their density. It is interesting to note that in case of *T. tuberculata*, phosphate and sediment nitrite

could explain 71% of its variation, while in *G. labiatus*, 80% of its variation was caused by phosphate and COD (Table 19). The abundance of Bivalvia was observed to be governed by pH and nitrite of water which together explained 36% of its variation in density. Amongst the three bivalve species, *L. marginalis* showed that 81% variation in its number was caused by turbidity, BOD and organic carbon of sediment (Table 19). In case of the other two species, *L. corrianus* and *P. clarkeanum*, pH, turbidity, phosphate, nitrite and BOD were found to affect their density.

In SS, total alkalinity was seen to bear a linear but positive relationship with the group Oligochaeta, which was also reflected in its species *L. hoffmeisteri* explaining 48% of its variation in density (Tables 18 and 20). Conductivity, nitrite, nitrate, sediment pH and organic carbon were found to cause 80% variation in the density of Coleoptera. In case of Crustacea, water temperature, chloride and sediment pH, together accounted for 94% variation in its density. Parameters like water temperature, alkalinity, nitrate and BOD were found to govern the abundance of dipteran species jointly explaining 95% of the variation in its density.

The density of Gastropoda was noted to be positively influenced by dissolved oxygen, phosphate and sediment nitrate which explained 85% variation in its density (Table 18). Water temperature, pH, conductivity, alkalinity, dissolved oxygen, phosphate, nitrite, nitrate, ammonium, sediment phosphate, sediment nitrite, sediment nitrate and organic carbon were found to be important factors affecting the density of species under the group Gastropoda. Amongst the salient results, it can be noted that 89% variation in the density of *B. bengalensis* was caused by water temperature, pH, ammonium and sediment nitrate. Around 85% variation in the abundance of *D. cerameopoma* could be explained by water temperature, pH, dissolved oxygen and organic carbon. In case of *T. scabra* 84% variation was under the influence of pH, alkalinity, nitrate and sediment nitrite. About 93% variation in the density of *T. granifera* was due to nitrite, sediment nitrate and organic carbon. Similarly, 82% variation in the density of *T. tuberculata*, was caused by conductivity, alkalinity, phosphate and sediment nitrate (Table 20). The group Bivalvia was noticed to be affected significantly by total alkalinity which alone explained 53% variation in its density. The bivalve species, *P. clarkeanum* in SS, also showed similar values (Tables 18 and 20).

### **Analysis of variance (ANOVA – 2 way)**

The variation in group and species density with respect to different seasons (assumed as premonsoon, monsoon and postmonsoon seasons) and sampling stations together with their interactions was studied by using two way analysis of variance (ANOVA). The values of all the biotic variable were transformed to  $\log(x+1)$  in order to attain a homogeneity of variance.

Binomial distribution is a discrete probability distribution and consists of a series of 'n' independent, trials. If the probability of 'success' in each trial is constant p, and the probability of 'failure' is q then the probability of x successes (and obviously n-x failure) is given by the formula :

$$f(x) = {}^nC_x p^x q^{n-x}$$

where  $x = 0,1,2,\dots,n$   
 P and q are positive fractions ( $p+q=1$ )

In the present study nine samples were taken ( $n=9$ ). As the majority of the species were present in all the samples collected hence, for a particular species 'A' the value of p is always 1 and  $q=0$ . Therefore, the binomial distribution for such a species will have no relevance with the study.

On the other hand the coefficient of similarity (Sorenson, 1949) is an established index to study the distribution pattern of species in a particular community/habitat and is calculated by the formula.

$$S = 2C/A+B$$

- Where, S = Sorenson's index of similarity
- A = number of species in sample A
- B = number of species in sample B
- C = number of species common to both the samples.

It measures the similarity in the species composition in different samples. The value of S ranges between 0-1. Value 0 indicates complete dissimilarity and 1 denotes maximum similarity between samples.

In the present study, Sorenson's index of the benthic samples was calculated between the three stations of each lake and is represented in Tables A and B.

**Table A.** Values of Sorenson's index of similarity between the three different stations of RS

Station	1	2	3
1			
2	0.80		
3	0.81	0.82	

**Table B.** Values of Sorenson's index of similarity between the three different stations of SS.

Station	1	2	3
1			
2	0.84		
3	0.82	0.84	

As evident from the above values of S in both the lakes there was uniform distribution of the major benthic species with no remarkable station impact. However, all the biotic variables were brought under logarithmic transformation.

**Table 17.** Results of stepwise multiple regression of groups / total benthos and physico-chemical parameters in RS.

Group	Parameter	$\beta_j$	S.E.	$\beta_0$	S.E.	R <sup>2</sup>
<b>Oligochaeta</b>	Dissolved oxygen	194.9120*	89.9671			
	Alkalinity	9.7363**	2.9242			
	Sediment temperature	-159.5340**	33.7017	1514.0326	1211.8249	0.7545**
<b>Crustacea</b>	Phosphate	-11.3720*	4.2203			
	Sediment phosphate	1.6980**	0.5266	-3.8510	3.5894	0.3932**
<b>Coleoptera</b>	Sediment phosphate	1.7110**	0.3002			
	Sediment nitrite	-6.1903*	2.6073	-6.3077**	2.1708	0.6080**
<b>Diptera</b>	Alkalinity	0.1411*	0.0601			
	Phosphate	-69.6450**	13.7138	-9.0702	20.9466	0.5617**
<b>Gastopoda</b>	Nitrate	1787.2656**	4164.8372	1593.7761*	580.4683	0.4557**
<b>Bivalvia</b>	pH	109.6476*	51.5762			
	Nitrate	-662.5130*	259.2070	-672.1855	435.6881	0.3596**
<b>Total benthos</b>	Total hardness	72.2822*	28.1567	-1577.2571	2870.6120	0.2305*

\* Significance level 0.05; \*\* Significance level 0.01

**Table 18.** Results of stepwise multiple regression of groups / total benthos and physico-chemical parameters in SS.

Groups	Parameters	$\beta_j$	S.E.	$\beta_0$	S.E.	R <sup>2</sup>																																																																							
<b>Oligochaeta</b>	Total alkalinity	23.0442**	5.1347	-3549.8441**	1190.2607	0.4779**																																																																							
	Temperature	-2.2544**	0.4075				<b>Crustacea</b>	Chloride	0.2718**	0.0194	242.7343**	52.9184	0.9385**	Sediment pH	-24.0420	7.4809	<b>Coleoptera</b>	Conductivity	-0.5534**	0.1369	217.3806	203.0368	0.8040**	Nitrate	224.9764**	39.1317	Nitrite	-573.6282**	95.9091	Sediment pH	66.2694*	30.0511	Organic carbon	-18.6130*	8.4916	<b>Diptera</b>	Temperature	-3.4929**	0.3444	5.4200	18.0746	0.9551**	Total alkalinity	0.3910**	0.0533	Nitrate	32.1311**	9.8744	BOD	1.3860**	0.4097	<b>Gastropoda</b>	Dissolved oxygen	448.0799**	131.3432	-4015.1333**	1103.8021	0.8556**	Phosphate	1487.6648*	686.7898	Sediment nitrate	1013.1351**	116.4405	<b>Bivalvia</b>	Total alkalinity	2.2946**	0.4600	437.5880**	106.6337	0.5307	<b>Total benthos</b>	pH	3483.8667**	871.2197	-1550.1951	8105.8934
<b>Crustacea</b>	Chloride	0.2718**	0.0194	242.7343**	52.9184	0.9385**																																																																							
	Sediment pH	-24.0420	7.4809				<b>Coleoptera</b>	Conductivity	-0.5534**	0.1369	217.3806	203.0368	0.8040**	Nitrate	224.9764**	39.1317		Nitrite	-573.6282**	95.9091				Sediment pH	66.2694*	30.0511	Organic carbon	-18.6130*	8.4916	<b>Diptera</b>	Temperature	-3.4929**	0.3444	5.4200	18.0746		0.9551**	Total alkalinity	0.3910**				0.0533	Nitrate	32.1311**	9.8744	BOD	1.3860**	0.4097	<b>Gastropoda</b>	Dissolved oxygen		448.0799**	131.3432	-4015.1333**				1103.8021	0.8556**	Phosphate	1487.6648*	686.7898	Sediment nitrate	1013.1351**	116.4405	<b>Bivalvia</b>	Total alkalinity	2.2946**	0.4600	437.5880**	106.6337	0.5307	<b>Total benthos</b>	pH	3483.8667**	871.2197
<b>Coleoptera</b>	Conductivity	-0.5534**	0.1369	217.3806	203.0368	0.8040**																																																																							
	Nitrate	224.9764**	39.1317																																																																										
	Nitrite	-573.6282**	95.9091																																																																										
	Sediment pH	66.2694*	30.0511																																																																										
	Organic carbon	-18.6130*	8.4916																																																																										
<b>Diptera</b>	Temperature	-3.4929**	0.3444	5.4200	18.0746	0.9551**																																																																							
	Total alkalinity	0.3910**	0.0533																																																																										
	Nitrate	32.1311**	9.8744																																																																										
	BOD	1.3860**	0.4097																																																																										
<b>Gastropoda</b>	Dissolved oxygen	448.0799**	131.3432	-4015.1333**	1103.8021	0.8556**																																																																							
	Phosphate	1487.6648*	686.7898																																																																										
	Sediment nitrate	1013.1351**	116.4405																																																																										
<b>Bivalvia</b>	Total alkalinity	2.2946**	0.4600	437.5880**	106.6337	0.5307																																																																							
<b>Total benthos</b>	pH	3483.8667**	871.2197	-1550.1951	8105.8934	0.6097**																																																																							
	Total hardness	-138.0374	40.5662																																																																										

\* Significance level at 0.05; \*\* Significance level at 0.01

**Table 19.** Result of stepwise multiple regression of species and physico-chemical parameters in RS.

Species	Parameters	$\beta_i$	S.E.	$\beta_o$	S.E.	R <sup>2</sup>
<b>OLIGOCHAETA</b> <i>Limnodrilus hoffmeisteri</i>	Phosphate Nitrate Organic carbon	-3760.0361** -6932.2637** 523.6653*	749.7169 2121.8460 246.9893	3504.0981**	594.7881	0.7033*
<i>Branchiura sowerbyi</i>	Sediment temperature	-2.5548 **	0.4568	84.0619 **	13.1550	0.5870
<b>COLEOPTERA</b> <i>Hydrocoptus subvittulus</i>	Sediment phosphate Sediment nitrite	1.71107 ** -6.1903*	0.3002 2.6073	-6.3077**	2.1707	0.6080**
<b>DIPTERA</b> Chironomid larvae	Total alkalinity Phosphate	0.1410* -69.6450	0.0601 13.7138	-9.0702	20.7466	0.5617**
<b>GASTROPODA</b> <i>Bellamya bengalensis</i>	Nitrite Ammonium Sediment phosphate	5475.1453** -2226.5640* 145.7651	906.5380 1025.6224 45.9708	-915.6843*	322.5767	0.6551**
<i>Gabbia orcula</i>	Phosphate Organic carbon	-1188.6479** 227.8361*	252.3400 83.2542	805.2513**	188.1112	0.6269**
<i>Digoniostoma cerameopma</i>	Sediment nitrate	107.9311**	30.2204	-278.4160*	131.3096	0.3670**

Table 19 Contd.

Species	Parameters	$\beta_i$	S.E.	$\beta_o$	S.E.	R <sup>2</sup>
<i>Thiara scabra</i>	Dissolved oxygen Ammonium	17.3846** 579.9934	5.7777 120.9197	-143.1157**	39.8897	0.6168**
<i>Thiara granifera</i>	Nitrite BOD	14241.2072 29.5382	2367.4219 10.3615	-286.6458	356.3658	0.6483**
<i>Thiara tuberculata</i>	Phosphate Sediment nitrite	-375.1051 903.5104	115.0070 124.6349	-82.6578	71.8847	0.7158**
<i>Brotia costula</i>	Organic carbon	-42.3689**	10.5029	130.6033**	17.1350	0.4251**
<i>Gyraulus labiatus</i>	Phosphate COD	-2115.7539** 19.9717	238.0831 5.2095	502.0680**	139.5403	0.8007**
<b>BIVALVIA</b> <i>Lamellidens corriamus</i>	pH BOD	22.2117** 0.3469	4.8760 0.1072	-177.1645**	40.6383	0.6670**
<i>Lamellidens marginalis</i>	Turbidity BOD Organic carbon	-5.0627** 0.7900* 50.5797**	0.9634 0.3387 9.2283	49.7773**	16.2745	0.8072**
<i>Pisidium clarkeanum</i>	Turbidity Phosphate Nitrite	-11.5033** -425.4942 -687.7050	3.5438 97.1317 173.3728	542.3019**	93.3936	0.6435**

\* Significance level at 0.05; \*\* Significance level at 0.01

**Table 20.** Results of stepwise multiple regression of species and physico-chemical parameters in SS.

Species	Parameters	$\beta_i$	S.E.	$\beta_o$	S.E.	R <sup>2</sup>
<b>OLIGOCHAETA</b> <i>Limnodrilus hoffmeisteri</i>	Total alkalinity	23.0073**	5.1500	-3576.7847**	1193.8148	0.4756**
<b>COLEOPTERA</b> <i>Hydrocoptus subvittulus</i>	Conductivity	-0.5534**	0.1369			
	Nitrite	-5730.6282**	95.9091			
	Nitrate	224.9764**	39.1317			
	Sediment pH	66.2694**	30.0511			
	Organic carbon	-18.6130*	8.4916	-217.3806	203.0368	0.8040**
<b>DIPTERA</b> Chironomid larvae	Temperature	-3.4929**	0.3444			
	Total alkalinity	0.3910**	0.0533			
	Nitrate	32.1311**	9.8744			
	BOD	1.3860**	0.4097	5.4200	18.0746	0.9551**
<b>GASTROPODA</b> <i>Bellamya bengalensis</i>	pH	549.3450	198.2167			
	Ammonium	-5242.5835**	1106.6826			
	Sediment nitrate	444.4711**	57.1316			
	Sediment temperature	67.3382	19.5805	-6180.7299**	1718.6183	0.8919**
<i>Gabbia orcula</i>	Total alkalinity	-14.5896*	5.9180			
	Dissolved oxygen	489.2419**	122.8432			
	Sediment phosphate	443.3265	72.6464	-1465.9290	893.0439	0.6652**
<i>Digoniostoma cerameopoma</i>	Temperature	7.2432*	1.3809			
	pH	23.8146*	10.4992			
	Dissolved oxygen	16.7047**	3.9017			
	Organic carton	-27.8190**	5.8312	-410.8626**	87.3580	0.8567**

Table 20 contd.

Species	Parameters	$\beta_i$	S.E.	$\beta_o$	S.E.	R <sup>2</sup>
<i>Thiara scabra</i>	pH	-28.2885*	13.1109	93.8433	92.0786	0.8390**
	Total alkalinity	0.7107**	0.2244			
	Nitrate	141.2197**	26.5754			
	Sediment nitrite	-76.3860*	27.1479			
<i>Thiara granifera</i>	Nitrite	1502.7265*	589.1412	112.3060	139.2085	0.8272**
	Sediment nitrate	125.3858**	21.3497			
	Organic carbon	-150.0169**	51.5701			
<i>Thiara tuberculata</i>	Conductivity	-1.5748*	0.6588	-1146.739**	275.2811	0.8214**
	Total alkalinity	6.8352**	1.3824			
	Phosphate	738.5465**	122.6824			
	Sediment nitrate	82.7643**	20.0133			
<i>Brotia costula</i>	Sediment nitrate	29.5169**	9.2151	6.9673	39.3428	0.3180**
<i>Gyraulus labiatus</i>	Total alkalinity	0.5295**	0.1540	-112.1511**	35.6986	0.3496**
<b>BIVALVIA</b>						
<i>Pisidium clarkeanum</i>	Total alkalinity	2.2942**	0.4562	-439.5597**	105.7597	0.5347**

\* Significance level at 0.05; \*\* Significance level at 0.01

Two way Analysis of Variance was calculated on the basis of 3 factors (n=3) between (i) groups/species density (number/m<sup>2</sup>), (ii) seasons (premonsoon, monsoon and postmonsoon) and (iii) stations (1-3 for each lake) as mentioned above Tables 21 and 22). The results of ANOVA (Tables 21 and 22) showed significant seasonal variation in Diptera (F = 11.30, p<0.01 in RS and F = 9.88, p<0.01 in SS) in both the lakes. Crustacea also revealed seasonal variation in SS ( F = 5.08, p<0.05). Amongst the species, the density of *D. cerameopoma* showed strong seasonal variation (F = 7.12, p<0.01) in RS, while *B. bengalensis* (F = 4.06, p<0.05), *G. labiatus* (F = 4.19, p<0.05) and *T. granifera* (F = 3.65, p<0.05) showed the same in SS.

Marked difference with respect to sampling stations was evident in bivalve density (F = 3.98, p<0.05 in RS and F = 12.50, p<0.01 in SS) in both the lakes. In RS, oligochaetes also showed overall significant station variation (F = 17.83, p<0.01). Species like *G. labiatus* (F = 8.16, p<0.01), *L. hoffmeisteri* (F = 16.55, p<0.01) in RS and *P. clarkeanum* (F = 10.24, p<0.01) and *T. scabra* (F = 13.03, p<0.01) in SS, showed significant difference from one station to another.

In RS, the density of odonates showed significant difference in relation to season (F = 11.60, p<0.01) and station (F = 3.69, p<0.05). Amongst the species, *B. sowerbyi* and *L. marginalis* also revealed variation in density with respect to season and station (Tables 21 and 22).

The abundance of Gastropoda in RS, was observed to have strong difference with respect to station (F = 18.08, p<0.01) and 2-way interactions in relation to season-station (F = 3.36, p<0.05). The same relationship was also reflected amongst three gastropod species namely *B. bengalensis*, *T. granifera* and *T. scabra* in RS.

Significant variation in season, station and their interactions was found only in the group Coleoptera in RS. The sole coleopteran species *H. subvittulus* also revealed the same relationship. Other species like *B. costula*, *G. orcula* in RS and *D. cerameopoma* in SS showed similar kind of two-way interactions.

Studies on the abundance of benthic invertebrate population in relation to environmental factors have been conducted in lakes (Curry, 1965 and Oliver, 1971). The nature of interactions and relationship between the abiotic and biotic factors of aquatic ecosystem is not simple. Hence the following discussion deals with the observations of one level in relation to other with reference to their influence on each other.

In the present study, the abundance of total benthic organisms was found to be positively correlated to total hardness, pH, ammonium of water and sediment phosphate, nitrate and organic carbon. Ghosh and Banerjee (1996), while studying the macrobenthic faunal diversity of pisciculture ponds of West Bengal, noted strong positive correlation between total benthos and sediment nitrogen, phosphorus and organic carbon. Adholia *et al.* (1990) also noted a positive relationship between total benthos and sediment phosphate. Increased input of organic materials resulted in increase of macrozoobenthic invertebrate population (Danell and Anderson,

**Table 21.** Analysis of variance (2-way) of various benthic groups and species in different seasons and stations in RS.  
[SS - Sum of squares, MS - MS Mean square]

Group / Species	Season	Station	Season x Station	Residual	Total
	DF=2	DF=2	DF=4	DF=27	DF=35
<b>OLIGOCHAETA</b>					
SS (MS)	0.196(0.098)	2.243 (1.122)	0.121 (0.030)	1.698 (0.063)	4.258 (0.122)
F value	1.555	17.836**	0.481		
<i>Limanodrilus hoffmeisteri</i>					
SS (MS)	0.147 (0.074)	2.026 (1.013)	0.063 (0.016)	1.653 (0.061)	3.888 (0.111)
F value	1.201	16.549 **	0.258		
<i>Branchiura sowerbyi</i>					
SS (MS)	2.521 (1.261)	2.323 (1.161)	1.028 (0.257)	5.989 (0.222)	11.861 (0.339)
F value	5.683 **	5.236 *	1.158		
<b>COLEOPTERA</b>					
<i>Hydrocoptus subvittulus</i>					
SS (MS)	0.944 (0.472)	0.457 (0.229)	0.915 (0.229)	1.609 (0.060)	3.926 (0.112)
F value	7.919 **	3.837 *	3.837 *		
<b>DIPTERA</b>					
Chironomid larvae					
SS (MS)	4.847 (2.423)	0.720 (0.360)	0.524 (0.131)	6.680 (0.247)	12.772 (0.365)
F value	9.795 **	1.455	0.53		
<b>GASTROPODA</b>					
SS (MS)	0.123 (0.062)	1.369 (0.685)	0.509 (0.127)	1.022 (0.038)	3.024 (0.086)
F value	1.625	18.081**	3.359 *		
<i>Bellamyia bengalensis</i>					
SS (MS)	0.283 (0.142)	1.510 (0.755)	0.830 (0.207)	1.902 (0.070)	4.525 (0.129)
value	2.011	10.720 **	2.945 *		
<i>Gabbia orcula</i>					
SS (MS)	0.590 (0.295)	1.819 (0.909)	0.885 (0.221)	1.562 (0.058)	4.856 (0.139)
value	5.099 **	15.719 **	3.824 *		

Table 21 contd.

Group / Species	Season	Station	Season x Station	Residual	Total
	DF=2	DF=2	DF=4	DF=27	DF=35
<i>Digoniostoma cerameopoma</i>					
SS (MS)	1.831 (0.916)	0.502 (0.251)	0.402 (0.100)	3.468 (0.128)	6.203 (0.177)
F value	7.128 **	1.954	0.782		
<i>Thiara scabra</i>					
SS (MS)	0.418 (0.209)	4.045 (2.022)	2.667 (0.667)	4.077 (0.151)	11.206 (0.320)
F value	1.384	13.393 **	4.416 **		
<i>Thiara granifera</i>					
SS (MS)	0.332 (0.166)	0.965 (0.483)	0.872 (0.218)	1.954 (0.072)	4.123 (0.118)
F value	2.296	6.672 **	3.012 *		
<i>Thiara turbercuolata</i>					
SS (MS)	0.052 (0.026)	0.081 (0.040)	0.492 (0.123)	1.440 (0.053)	2.065 (0.059)
F value	0.487	0.756	2.307		
<i>Brotia costula</i>					
SS (MS)	0.547 (0.274)	9.948 (4.974)	0.612 (0.153)	1.438 (0.053)	12.545 (0.358)
F value	5.139 *	93.392 **	2.874 *		
<i>Gyraulus labiatus</i>					
SS (MS)	1.569 (0.785)	4.172 (2.086)	0.523 (0.131)	6.902 (0.256)	13.167 (0.376)
F value	3.069	8.161 **	0.511		
<b>BIVALVIA</b>					
SS (MS)	0.540 (0.270)	0.677 (0.338)	0.551 (0.138)	2.296 (0.085)	4.063 (0.116)
F value	3.173	3.981 *	1.620		
<i>Lamellidens corrinus</i>					
SS (MS)	0.768 (0.384)	0.087 (0.044)	2.015 (0.504)	5.316 (0.197)	8.186 (0.234)
F value	1.950	0.222	2.559		
<i>Lamellidens marginals</i>					
SS (MS)	1.998 (0.999)	1.944 (0.972)	0.702 (0.175)	5.258 (0.195)	9.901 (0.283)
F value	5.130 *	4.991 *	0.901		
<i>Pisidium clarkeanum</i>					
SS (MS)	7.074 (3.537)	12.023 (6.012)	7.984 (1.996)	66.301 (2.456)	93.382 (2.668)
F value	1.440	2.448	0.813		

\* Significance level at 0.05; \*\* Significance level at 0.01

**Table 22.** Analysis of variance (2-way) of various benthic groups and species in different seasons and stations in SS.  
[SS – Sum of squares, MS – Mean square]

Groups / Species	Season	Station	Season x Station	Residual	Total
	DF=2	DF=2	DF=4	DF=27	DF=35
<b>OLIGOCHAETA</b>					
SS (MS)	0.186 (0.093)	0.135 (0.068)	0.114 (0.029)	1.308 (0.048)	1.744 (0.050)
F value	1.921	1.397	0.589		
<i>Limodrilus hoffmeisteri</i>					
SS (MS)	0.176 (0.088)	0.147 (0.073)	0.141 (0.035)	1.421 (0.053)	1.884 (0.054)
F value	1.667	1.394	0.668		
<i>Branchiura sowerbyi</i>					
SS (MS)	2.035 (1.017)	0.546 (0.273)	0.292 (0.073)	10.617 (0.393)	13.489 (0.385)
F value	2.587	0.694	0.186		
<b>CRUSTACEA</b>					
SS (MS)	3.623 (1.812)	0.478 (0.239)	0.552 (0.138)	9.627 (0.357)	14.280 (0.408)
F value	5.081 *	0.67	0.387		
<b>COLEOPTERA</b>					
<i>Hydrocoptus subvittulus</i>					
SS (MS)	1.940 (0.970)	0.162 (0.081)	1.418 (0.355)	10.786 (0.399)	14.307 (0.409)
F value	2.428	0.203	0.888		
<b>DIPTERA</b>					
Chironomid larvae					
SS (MS)	10.758 (5.379)	0.109 (0.055)	0.597 (0.149)	7.425 (0.275)	18.890 (0.40)
F value	19.561 **	0.199	0.543		
<b>GASTROPODA</b>					
SS (MS)	0.270 (0.135)	0.092 (0.046)	0.017 (0.004)	1.496 (0.055)	1.876 (0.054)
F value	2.437	0.83	0.078		
<i>Bellamyia bengalensis</i>					
SS (MS)	0.644 (0.322)	0.008 (0.004)	0.051 (0.013)	2.139 (0.079)	2.841 (0.081)
F value	4.063 *	0.049	0.160		
<i>Gabbia orcula</i>					
SS (MS)	0.246 (0.123)	0.232 (0.116)	0.545 (0.136)	5.116 (0.189)	6.139 (0.175)
F value	0.649	0.613	0.719		

Table 22 contd.

Group / Species	Season	Station	Season x Station	Residual	Total
	DF=2	DF=2	DF=4	DF=27	F=35
<i>Digoniostoma cerameopoma</i>					
SS (MS)	0.908 (0.454)	1.048 (0.524)	1.565 (0.391)	3.631 (0.134)	7.151 (0.204)
F value	3.374 *	3.895 *	2.909 *		
<i>Thiara scabra</i>					
SS (MS)	0.082 (0.041)	7.690 (3.845)	1.706 (0.426)	7.966 (0.295)	17.443 (0.498)
F value	0.138	13.033 **	1.446		
<i>Thiara granifera</i>					
SS (MS)	1.561 (0.780)	0.196 (0.098)	1.802 (0.450)	5.770 (0.214)	9.328 (0.267)
F value	3.652 *	0.458	2.108		
<i>Thiara tuberculata</i>					
SS (MS)	0.871 (0.435)	0.223 (0.112)	0.395 (0.099)	2.166 (0.080)	3.655 (0.104)
F value	5.427 **	1.393	1.231		
<i>Brotia costula</i>					
SS (MS)	0.235 (0.118)	0.327 (0.163)	0.138 (0.034)	1.813 (0.067)	2.513 (0.072)
F value	1.751	2.431	0.514		
<i>Gyraulus labiatus</i>					
SS (MS)	2.785 (1.393)	0.014 (0.007)	1.564 (0.391)	8.974 (0.332)	13.337 (0.381)
F value	4.190*	0.021	1.176		
<b>BIVALVIA</b>					
SS (MS)	0.334 (0.167)	3.212 (1.606)	0.394 (0.099)	3.468 (0.128)	7.409 (0.212)
F value	1.301	12.502 *	0.768		
<i>Lamellidens marginalis</i>					
SS (MS)	0.432 (0.216)	0.091 (0.046)	1.289 (0.322)	3.361 (0.124)	5.173 (0.148)
F value	1.736	0.368	2.589		
<i>Pisidium clarkeanum</i>					
SS (MS)	0.197 (0.099)	4.138 (2.069)	0.027 (0.007)	5.452 (0.202)	9.813 (0.280)
F value	0.487	10.245 **	0.033		

\* Significance level at 0.05; \*\* Significance level at 0.01

1982) and it can be related to enrichment of nutrient (Nalepa, 1987). Correlation between organic enrichment and abundance of benthic species have also been reported by Howmiller and Scott (1977) and Mozley and Howmiller (1977). Mouthon (1992) noted that total density of benthic animals had greater affinity for systems rich in calcium carbonate. This was in confirmation to the present study, where total hardness was found to have a positive effect on the total benthos density in RS. Both Pearson's correlation and multiple regression analysis showed similar results. Bose (1968) found that temperature and total alkalinity greatly influenced the abundance of benthic organisms. However, Kansanen *et al.* (1990) found no relation between the abundance of total zoobenthos and any water quality, in a lake of Southern Finland.

Sarkar (1989), while studying the macrobenthos of a freshwater pond in West Bengal, reported positive influence of alkalinity, pH, dissolved oxygen and water temperature on oligochaetes. Annelids were reported to be positively dependent on available nitrogen and phosphorus (Sarkar, 1992). Singh and Sinha (1993) observed positive interaction between total alkalinity and oligochaete density in freshwater ponds of Bihar. In the present communication increase in the oligochaete density was noted to be favoured by increase in turbidity, dissolved oxygen, pH and alkalinity which is in accordance to the findings of the above authors. Sallenave and Barton (1990) while studying the turbidity gradient of Lake Temiskaming, Ontario-Quebec, noted that tubificids were positively correlated to turbidity, which also supports the present findings. The positive correlation of oligochaetes including its species *L. hoffmeisteri* with dissolved oxygen is due to the fact that both showed higher values in winter and lower values in summer. i.e. similar temporal fluctuation. *L. hoffmeisteri* is known to be prevalent in sediment rich with organic carbon (Aston, 1973; Marshall, 1978 and Schrijvers *et al.* 1995) which was also reflected from the results of multiple regression analysis showing positive regression coefficient ( $\beta_j = 523.6653$ ,  $p < 0.05$ ) value of organic carbon. However, Kansanen *et al.* (1990) did not find any significant correlation between the number of oligochaetes and any water quality parameters. On the contrary, Adholia *et al.* (1990) found negative correlation between oligochaetes, pH, alkalinity, dissolved oxygen, COD, chloride, and total hardness.

In RS, the crustacean density was found to be positively correlated with dissolved oxygen and in SS its density was negatively correlated to BOD and COD. Malhotra *et al.* (1990) observed that crustacean exhibited peak during high oxygen content of water in Lake Mansar, Jammu.

The population of *Chironomus* sp. has been reported to be positively correlated with turbidity, specific conductance, COD and total phosphorus by Kansanen *et al.* (1990). Bose and Lakra (1994) during their study on freshwater ponds in Ranchi found positive relationship between chironomids and alkalinity ( $r = 0.57$ ,  $p < 0.05$ ). In the present study, chironomids under the group Diptera showed positive correlation with turbidity, total hardness, alkalinity and dissolved oxygen.

Total hardness and pH explain most of the difference in gastropod distribution in the littoral zone of lakes (Okland, 1990) and they are known to have greater affinity for lakes

with high organic matter (Mouthon, 1992). Malhotra *et al.* (1990) attributed the dominance of Mollusca in waterbodies to alkaline nature of water and high concentration of calcium (Tudorancea, 1972). Sarkar (1989 and 1992) found that molluscs have no relation to sediment pH but was positively correlated to available nitrogen and available phosphorus of sediment and alkalinity, pH, dissolved oxygen and temperature of water. Molluscs are reputed to be sensitive to pH as stated by Sutcliffe and Carrick (1973). The observations of the present investigation were found to corroborate with the above mentioned views. The gastropod density was found to show positive correlation with water temperature, pH, phosphate, nitrite, ammonium and sediment phosphate, sediment nitrate and sediment nitrite. Multiple regression also showed that dissolved oxygen, phosphate and sediment nitrate together positively affect the gastropod population in SS. Water temperature and pH were noted to have positive  $\beta_j$  values for *B. bengalensis* and *D. cerameopoma*. Alkalinity was found to have positive influence on many gastropod species namely, *T. scabra*, *T. tuberculata* and *G. labiatus*. Dissolved oxygen possessed positive influence on *G. orcula*, *T. scabra* and *G. labiatus*. The nutrient of water and sediment were found to have positive effect on the density of species like *B. bengalensis*, *G. orcula*, *D. cerameopoma*, *T. scabra*, *T. granifera*, *T. tuberculata* and *B. costula*. Bivalves also revealed similar correlations showing positive interdependence on various physico-chemical parameters. The two important bivalve species *L. marginalis* and *L. corrianus* showed positive correlation with temperature, pH, conductivity, alkalinity, BOD, COD, chloride, phosphate and nitrate of water and temperature, phosphate, nitrite and organic carbon of sediment.

Analysis of variance showed overall significant seasonal variation of groups like Coleoptera, Diptera and Crustacea and species like *B. bengalensis*, *G. orcula*, *D. cerameopoma*, *T. granifera*, *T. tuberculata*, *B. costula*, *G. labiatus*, *L. marginalis*, *B. sowerbyi*, *H. subvittulus* and chironomid larvae, which was in affirmity to their temporal variation. Significant differences were noticed among different benthic groups, insects, oligochaetes and molluscs as well as seasons and months in a freshwater pond in West Bengal by Sarkar (1989). Harris *et al.* (1992) reported highly significant differences in population density of benthic macroinvertebrates between sampling stations and seasons in course of their study on the ecology of the La Trobe river, Australia. In the present investigation, significant variation between season and stations was noted in the groups Coleoptera and Gastropoda and species like *B. bengalensis*, *G. orcula*, *D. cerameopoma*, *T. granifera* and *B. costula*.

Though a large quantity of data was collected on physico-chemical parameters of water and sediment as well as on identifying and quantifying benthic species of Rabindra Sarovar and Subhas Sarovar, a few factors such as redox potential, sediment particle size and sediment oxygen level that influence directly the distribution and abundance of benthos were not measured as these two urban freshwater lake ecosystems have almost uniformly fine sediment particles and almost similar oxygen level. Furthermore, the role of benthic and benthovorous fish that can have greater impact on the distribution and abundance of benthic invertebrates was not ascertained as these two lakes hardly harbour appreciable population of benthic and benthovorous fish. Rabindra Sarovar is not utilized for fish culture for about two decades, while Subhas Sarovar is used for game fishing of major carps only. Therefore,

the chances of influencing of total benthos population by benthic fish species directly by feeding on benthos and indirectly through 'bioperturbation' are possibly of minimum extent. Still, it would be inappropriate to attribute the observed changes in the abundance of benthos exclusively to variations in certain chemical parameters. The density of total benthos appears to be regulated primarily by sediment characteristics and indirectly by water conditions. The diversity of hydrophytic vegetation and the nature of substratum of lake bottom may play a significant role in the population and distribution pattern of the benthic communities. However, the present work as well as limnobiological studies on zooplankton, macrophyte associated macrofauna, etc. (Khan, 1979, 1981; Mukherji *et al.*, 1998, 2000; Ghosh and Nandi, 1996; Nandi, 2000; Pal, 2000; Sinha, 2001) conducted by this department may be useful for formulation of a holistic conservation and management action plan of these two urban lakes in Kolkata.

## CONCLUSION

Two years of rigorous and extensive survey reveals that both the lakes have more or less similar ecological status, but RS exhibits an elevated state of eutrophication than SS. This is reflected by greater nutrient concentration and greater macrophytic density and diversity in RS. The presence of 32 benthic species projects the rich macrobenthic biodiversity of these two lakes. The occurrence of these species in eutrophic waterbodies signify their adaptiveness to varying lake environment conditions which provide suitable substrata for annelids, crustaceans, insects and molluscs. In general, Gastropoda, Bivalvia and Odonata had greater distribution in RS while Oligochaeta, Crustacea, Coleoptera and Diptera showed more abundance in SS. Species like *Limnodrilus hoffmeisteri*, *Hydrocoptus subvittulus*, *Gabbia orcula* and *Gyraulus labiatus* had maximum population during postmonsoon while *Bellamyia bengalensis*, *Digoniostoma cerameopoma*, *Thiara granifera*, *T. tuberculata* and *Brotia costula* showed high population during premonsoon and monsoon. The values of community indices specially Shannon-Weiner index revealed moderate scale of pollution in the two lakes.

Both RS and SS are integral and invaluable components of Calcutta's urban ecology. Hence it is essential to have a constructive knowledge of their ecosystem including their flora, fauna, water and sediment status, for which the present investigation was assigned. From the present study it is suggested that the two lakes, RS and SS needs to be protected from further deterioration of water quality and excessive human interference. Little attention and care from the governing body and the lake dependent people, can enable these two urban lakes to flourish, sustain biodiversity and provide infinite utilities to humanity.

## SUMMARY

1. The present research paper dealing with the ecology, population and distribution pattern of macrozoobenthos was undertaken to study the benthic diversity, seasonal abundance, population fluctuation and community interaction of two urban lakes of Calcutta, namely,

Rabindra Sarovar (RS) and Subhas Sarovar (SS). The physico-chemical parameters of water and sediment were tested to find out the influence and interrelationship between the abiotic factors and major benthic species.

2. Qualitative sampling was done by means of hand picking, dragnetting and a box type sampler (15 x 15 cm). Quantitative sampling was done fortnightly from each lake for a period of two years by the box type sampler. The density of benthic species was expressed as number of organisms per square meter. Various community indices were calculated to understand the structure and functioning of the animal community. Limnological parameters were tested following standard methods. Statistical analysis were carried out by computerized statistical package, SPSS version 6.0.

3. The physico-chemical parameters showed distinct temporal/seasonal variation in both the lakes. The pH values revealed alkaline nature of water. The water of both the lakes became more turbid during December to April period due to decrease in water level and with rise in water level in monsoon turbidity was found to decrease.

4. The ionic strength of RS was greater than SS, as evidenced by the higher conductivity values of RS. Increase in the concentration of salts resulted in the increase of conductivity in summer due to evaporation in both RS and SS. Total alkalinity and total hardness had higher values in RS and exhibited similar seasonal variation.

5. The dissolved oxygen content of RS was greater than SS. On the other hand, BOD and COD values were higher in SS than RS. Dissolved oxygen level increased in December to April months probably due to greater oxygen holding capacity of water at low temperature. BOD and COD values were higher in premonsoon due to higher water temperature and increased activities of aerobic microorganisms which can easily degrade organic matter in the presence of oxygen.

6. The nutrients viz., chloride, phosphate and nitrate had higher concentration in RS indicating its higher trophic status in comparison to SS. The presence of dense macrophyte vegetation in RS may be due to its higher nutrient content. Premonsoon and monsoon season experienced increase in nutrient load in both the lakes probably due to decrease in water level and inflow of runoff water from the surrounding areas respectively. Ammonium content was higher in the water of SS which was probably due to less macrophytic density in the photic zone.

7. The sediment of RS was silt loamy type with higher percentage of silt and sand. But the sediment of SS was silty type with higher percentage of silt and clay. The sediment nutrients also showed similar pattern of seasonal fluctuation as its water counterparts. The presence of more than 1.50% organic carbon in the sediments of both the lakes was indicative of productive bottom with rich organic content. The organic carbon percentage was higher in the months of March to June due to higher decomposition rate.

8. Qualitative analysis of the benthic animals revealed the presence of 32 species belonging to 3 phyla and 8 major groups in both the lakes.

9. The density of total benthos was higher in RS probably due to greater macrophytic density in RS which provide suitable substrata for adult insects and molluscs, Gastropoda, Oligochaeta and Bivalvia were the most dominant groups in terms of number and percentage in both the lakes due to the abundance of organic matter and muddy bottom which favour positive establishment of benthic communities.

10. The benthic biomass of SS was comparatively poor than RS. This was due to greater abundance of *Lamellidens* spp. In RS which had the highest biomass among the benthic species. In general, the benthic biomass was more or less in accordance to the population density pattern of total benthos.

11. Gastropoda, Bivalvia and Odonata had higher percentage in RS, while Oligochaeta, Crustacea, Coleoptera and Diptera were more abundant in SS. Postmonsoon season was found to favour Oligochaeta, Crustacea, Odonata and Coleoptera population but Gastropoda had greater population in premonsoon and monsoon season which was mainly contributed by the species *Bellamyia bengalensis*, *Digoniostoma cerameopoma*, *Thiara scabra*, *T. granifera*, *T. tuberculata* and *Brotia costula*. The other two gastropod species, *Gabbia orcula* and *Gyraulus labiatus* had greater density in postmonsoon season.

12. *B. bengalensis*, *T. scabra*, *B. costula*, *Branchiura sowerbyi*, *Hydrocoptus subvittulus* and chironomid larvae had higher density in SS, while *D. cerameopoma*, *T. granifera*, *G. labiatus*, *L. marginalis* and *L. corrianus* had greater abundance in RS. *G. orcula*, *T. tuberculata* and *Pisidium clarkeanum* had approximately uniform distribution in RS and SS. The differences in the distribution of these benthic organisms might be due to textural difference of the two lakes in combination with physico-chemical factors.

13. Statistical analysis revealed that the abundance of total benthos was positively correlated to total hardness, pH, ammonium of water and sediment phosphate, nitrate and organic carbon.

14. Oligochaete density was noted to be favoured by turbidity, dissolved oxygen, pH and alkalinity.

15. The gastropod density showed positive correlation with water temperature, pH, phosphate, nitrite, ammonium and sediment phosphate, sediment nitrate and sediment nitrite. Alkalinity was found to have positive influence on many gastropod species like *T. scabra*, *T. tuberculata* and *G. labiatus*. Dissolved oxygen possessed positive influence on *G. orcula*, *T. scabra* and *G. labiatus*. The nutrients of water and sediment have positive effect on *B. bengalensis*, *G. orcula*, *D. cerameopoma*, *T. scabra*, *T. granifera*, *T. tuberculata*, and *B. costula*.

16. The bivalves, *Lamellidens* spp. showed positive correlation with temperature, pH, conductivity, alkalinity, BOD, COD, chloride, phosphate, nitrate of water and temperature, phosphate, nitrite and organic carbon of sediment.

17. Analysis of variance showed significant seasonal variation of groups like Coleoptera, Diptera and Crustacea and species like *B. bengalensis*, *G. orcula*, *D. cerameopoma*, *T.*

*granifera*, *T. tuberculata*, *B. costula*, *G. labiatus*, *L. marginalis*, *B. sowerbyi*, *H. subvittulus* and chironomid larvae, which was in affinity to their temporal variation. Significant variation between season and station were noted in Coleoptera, Gastropoda and species like *B. bengalensis*, *G. orcula*, *D. cerameopoma*, *T. scabra*, *T. granifera* and *B. costula*.

18. Based on the density of oligochaetes (Carr and Hiltunen, 1965), being the best indicators of water quality, both RS and SS belong to the category of moderately polluted waterbodies. From the values of the community indices viz., index of dominance, Margalef's index, Shannon-Weiner index and evenness index, it can also be inferred that both RS and SS are moderately polluted, with no obvious stress as the communities are stable with the available resources in the habitats of both the lakes.

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