CHAPTER 3

ROTIFERS OF RIVER VISHWAMITRI: COMMUNITY STRUCTURE AND DYNAMICS

Extensive environmental variation is one of the most basic facts of life for any organism living in the tropical water bodies. Among the most notable contributors to this environmental variation are the temperature and chemistry of water. Chemical analysis measures an essential part of the environment and when closely related with biological study it greatly enhances its value. Hynes (1978) stated that when the chemist and the biologist both work on the assessment of pollution they can discover much more than either can alone. Physicochemical analysis of the water is an important aspect from the point of view of aquatic biology. Tebutt (1992) observed that the physicochemical characteristics of water have a direct bearing on the faunal composition of ponds. Lougheed *et al.* (1998) stated that variability in abotic factors contributes to seasonal and spatial variability in water quality characteristics and the amount of available habitat and aquatic invertebrates. Yoshinaga *et al.* (2001) also stated that animal populations live in a diversity of environments and therefore, their population dynamics are regulated by a complex mixture of environmental factors. Zooplankton species succession and spatial distribution is a function of their tolerance to various abiotic and biotic environmental parameters (Marneffe *et al.*, 1998). Most of these factors follow a seasonal pattern of change within an annual cycle. Seasonal variation is clearly driven by climate (Green, 2001). Amongst the zooplankton, rotifers due to their high turnover rates, are particularly sensitive to changes in water quality (Sladecek, 1983).

Changes in community structure can be explained numerically with diversity index (Kaushik and Saksena, 1995). These indices are useful in assessing water quality. Moreover, diversity indices are used to characterize species abundance and their relationships in the communities. These mathematical expressions describe the components of community structure namely, richness (number of species), evenness (uniformity in the distribution of individuals among species) and abundance (total number of organisms) that reveal the response of a community to the quality of its environment (Ludwig and Reynolds, 1988). In addition to the changes in the physicochemical composition, interspecific and intraspecific composition, pollution level and the presence or absence of predators are some factors influencing rotifer species composition and structure (Kaushik and Saksena, 1995).

This chapter discusses the influence of various physicochemical parameters on the rotifer community structure in the various seasons in River Vishwamitri.

MATERIALS AND METHODS

For the physicochemical analysis, water samples were collected and analyzed as per the treatise, 'Standard Methods for the Examination of Water and Wastewater', prepared and published jointly by the American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF). Sampling was done on five consecutive days in each month. Sample of each day was separately analyzed on the same day and then the data were pooled to represent the monthly data. Five samples were collected from each site in clean and contamination free polyethylene containers of two liters volume. They were maintained at 4^0C during transportation to the laboratory in order to reduce the growth of microorganisms. For oxygen estimation samples were collected in BOD bottles using a dispenser to avoid air contact, and the samples were fixed at the station itself. The water samples were collected from the middle of the stream at mid depth. Stratified random sampling was not possible as the stations were having 1m or less deep water during major part of the year. The containers were then labelled indicating the sample number, time and weather conditions.

1. Temperature

Temperature is basically important for its effect on the chemistry and biological reactions of the organisms in water. A rise in temperature of the water leads to the speeding up of the chemical reactions in water and reduces the solubility of gases and also amplifies the tastes and odors. At elevated temperatures the metabolic activity of the organisms increases,

requiring more oxygen but at the same time the solubility of oxygen decreases thus accentuating the stress.

Temperature is also very important in the determination of various other parameters such as pH, conductivity, saturation levels of gases and various forms of alkalinity.

In the present study the ambient as well as the water temperatures were measured at the site using calibrated good grade mercury filled Celsius thermometer.

2. pH

Most natural waters are generally alkaline due to presence of sufficient quantities of carbonates. However, pH of water gets drastically altered in time, because of exposure to air, biological activities and temperature changes. In natural waters, pH also changes diurnally and seasonally due to variation in photosynthetic activity, which leads to an increase in the pH value due to the consumption of CO_2 in the process. pH has no adverse effects on the health, however, a lower value below 4 will produce sour taste and higher value above 8.5 an alkaline taste.

In the present study pH was measured electrometrically using a hand held pH meter.

3. Dissolved oxygen (DO)

Dissolved Oxygen is one of the most important parameters in water assessment. It reflects the physical and biological processes prevailing in the waters. Its presence is essential to maintain the higher forms of biological life in the water. Low oxygen in the waters can kill fish and many other organisms in the water. Organisms have specific requirements of oxygen. Low oxygen concentrations are generally associated with heavy contamination by organic matter. Oxygen saturated waters have a pleasant taste while waters with less dissolved oxygen have insipid taste. The analysis for DO is a key test in water pollution and waste treatment process control (APHA, AWWA 1998).

In the present study Winkler's Modified Method as described in APHA, AWWA (1998) was employed for determining the Dissolved oxygen.

Principle: Oxygen oxidizes Mn^{2+} to a higher state of valence under alkaline conditions and that manganese in higher states of valence is capable of oxidizing I^- to I_2 under acidic conditions. Thus the amount of I_2 released is equivalent to the dissolved oxygen originally present. The iodine is measured with standard sodium thiosulfate solution and interpreted in terms of dissolved oxygen.

Procedure: Samples were collected carefully avoiding agitation and contact with air in narrow mouth glass-stoppered BOD bottles of 300mL capacity. They were allowed to overflow 2-3 times its volume. These samples were then fixed in order to prevent biological activity, which can radically change the oxygen values. Fixation was done with 1mL of each manganous sulfate ($MnSO_4$) and alkali-iodide-azide solution. The bottles were stoppered and inverted a few times for proper mixing. And were then transported to the laboratory for analysis. When the precipitate of manganous hydroxide had settled to half the volume, one-mL of concentrated Sulphuric acid was added. When the dissolution was complete 200mL of the sample was titrated against 0.025M sodium thiosulphate using starch as the indicator. The end point was determined by disappearance of the blue colour.

4. Total suspended solids (TSS)

An oven dried Whatman filter paper is weighed and then 100mL of well-mixed sample is filtered through this filter paper. This filter paper is then dried in the oven and is then weighed again. The difference in the weight is calculated as the suspended solids.

5. Chlorophyll-a

Chlorophylls a, b and c are common in freshwater algae and provide a rough estimation of biomass. However, chlorophyll-a has been found to be more reliable indicator of biomass (Trivedi and Goel, 1986).

Pheophorbide-a and pheophytin-a, two common degradation products of chlorophyll-a, can interfere with the determination of chlorophyll-a because they absorb light in the same region of the spectrum, as does chlorophyll-a. Thus acidification results in the loss of magnesium atom, converting it to pheophytin-a.

Procedure: The sample is concentrated by centrifugation after collection. The pellet so obtained is then put in a tissue grinder with 2 to 3mL of 90% aqueous acetone solution and macerated at 500g for 1 minute The sample is then transferred to a screw cap centrifuge tube. The grinder is rinsed with a few milliliters of 90% aqueous acetone and added to the extraction slurry. The total volume is adjusted to 10mL with 90% aqueous acetone. The samples are kept for 2 hours at 4°C in the dark. This is then centrifuged in closed tubes for 20 minutes at 500g. The extract is decanted into a calibrated, 15mL, screw cap centrifuge tube.

2mL clarified extract is transferred to a 1cm cuvette and optical density is read at 750 and 664nm. The extract is then acidified in the cuvette with 0.1mL 0 1N HCl. The acidified extract is gently agitated and OD is read at 750 and 665nm, 90 seconds after acidification.

7. Phosphorus

Phosphorous occurs in natural waters and in wastewater almost solely as phosphates. They occur in solution, as particles or detritus or in the bodies of aquatic organisms (APHA, AWWA 1998). Various forms of phosphates arise from a variety of sources.

Large quantities of phosphates are added when the water is used for laundering or other cleaning because these materials are major constituents of many commercial cleaning preparations. Many heavy-duty synthetic detergent formulations contain 12-13% phosphorus or over 50% polyphosphates. The use of these materials as a substitute for soap has greatly increased the phosphorous content of domestic wastewater (Sawyer *et al.*, 1994).

Orthophosphates applied to agricultural land as fertilizers are carried into surface waters with storm runoff. Organic phosphates are formed primarily by biological processes. Most of the inorganic phosphorous is contributed by human wastes as a result of the metabolic breakdown of proteins and elimination of the liberated phosphates in the urine (Sawyer *et al.*, 1994).

In the present study the Total Reactive Phosphorus of the water was estimated using the Stannous Chloride method.

Principle: Molybdophosphoric acid is formed and reduced by stannous chloride to intensely coloured molybdenum blue. The absorbance of light by this blue colour is measured at 690nm to calculate the concentration of phosphates.

Procedure: To 50mL of sample, 2mL of ammonium molybdate reagent and 5 drops of stannous chloride is added and thoroughly mixed. After 10 minutes but before 12 minutes the colour is measured photometrically at 690nm.

6. Nitrate- Nitrogen

Very few mineral sources of nitrate exist in nature. The most important source of nitrate is the biological oxidation of organic nitrogenous substances, which come in sewage and industrial wastes or produced indigenously in the waters. Domestic sewage contains very high amounts of nitrogenous compounds. Run-off from agricultural fields is also high in nitrate. Atmospheric nitrogen fixed into nitrates by the nitrogen fixing organisms is also a significant contributor to nitrates in the water. High amount of nitrates is generally indicative of pollution. In wastewater high amount of nitrogen denote anaerobic conditions and high stability of the wastes. Although high concentration of nitrates is useful in irrigation but its entry into the water resources increases the growth of nuisance algae and triggers eutrophication.

In the present study nitrate was estimated using the Cadmium Reduction Method. This method is based on the principle that NO_3^- is reduced almost quantitatively to nitrite (NO_2^-) in the presence of cadmium (Cd). It uses commercially available Cd granules treated with copper sulfate ($CuSO_4$) and then packed in a glass column. The nitrite produced thus is determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly colored azo dye that is measured colorimetrically.

Initially the cadmium granules have to be activated by first washing them with 6N HCl and then rinsing with water. These are then swirled with 2% $CuSO_4$ solution until the blue color partially fades. This is decanted and the process is repeated till a brown colloidal precipitate begins to form. Finally it is flushed gently with water to remove the copper.

The reduction column is then filled with the Cu-Cd granules. This is then washed with dilute NH_4Cl-EDTA solution. And finally activated by passing through it 100mL of a solution composed of 25% 1.0mg $NO_3^- - N$ /L standard and 75% NH_4Cl-EDTA solution.

To 25mL sample, 75mL of NH_4Cl-EDTA solution is added and mixed. This mixed sample is then passed through the reduction column and collected at a rate of 7 to 10mL/min. First 25mL are discarded and the rest is collected. And then to 50mL of this sample is added 2.0mL of the color reagent and mixed. Between 10 min and 2 hours after reduction the absorbance is measured at 543nm against distilled water blank.

Sample concentrations can then be computed by directly comparing with the standard curve, which is obtained by plotting absorbance of standards against $NO_3^- - N$ concentrations.

8. Biological Oxygen Demand (BOD)

The BOD test is widely used to determine the pollution strength of domestic and industrial wastes in terms of the oxygen that they will require if discharged into natural watercourses in which aerobic conditions exist. The test is one of the most important in stream pollution control activities. This test is of prime importance in regulatory work and in studies designed to evaluate the purification capacity of receiving bodies of water.

The BOD test is essentially a bioassay procedure involving the measurement of oxygen consumed by living organisms while utilizing the organic matter present in waste, under conditions as similar as possible to those that occur in nature.

During the present study the BOD was estimated by employing the 5-Day BOD Test.

Principle: The principle of the method involves computing the difference between the initial and final Dissolved Oxygen.

Procedure: Dilution water is prepared by bubbling compressed air into the distilled water for about 30 minutes. Then 1mL each of phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride solutions are added to the water for each liter of dilution water and mixed thoroughly. The pH of the sample is neutralized to around 7.0 by using H_2SO_4. A suitable dilution of the sample is carried out. Two sets of sample are filled in the BOD bottles. One set is kept in the BOD incubator at 20^0C for 5 days, while the other set is immediately analyzed for the dissolved oxygen content. After 5 days of incubation the first set is analyzed for the dissolved oxygen content. Similarly two sets of blank are run with dilution water.

Calculation: BOD, mg/L = (D_0-D_5) x dilution factor

Where, D_0 is the initial DO in the sample; D_5 is the DO after 5 days.

Biological Sampling

Procedure: Sampling was carried out as discussed in chapter 2. Subsamples of 1mL were taken on Sedgwick-Rafter chambers and rotifers were enumerated under Leica Advanced Research Microscope fitted with a calibrated Whipple grid. In samples containing 10 or more rotifers per field, 'field count' technique was employed. Here random fields each consisting of one Whipple grid were counted. However, for samples with less than 10 rotifers per field 'strip counting' was employed for enumeration. As rotifers are counted, a separate tally was kept for each species to permit an analysis of community structure at the sampling station.

Data Analysis

The rotifer data were quantitatively analysed using standard analytical and statistical methods with computer software packages *viz*. Excel, SPSS, RDE etc. The following formulae were used for analysis:

$$\text{Jaccard's Similarity Index } (C_j) = \frac{C}{(A+B)-C}$$

Where

A = Total number of species in habitat I, B = Total number of species in habitat II

C = Total number of species common to both the habitats

Shannon-Wiener Diversity Index (H') = $-\sum Pi \log_e Pi$

Where
$Pi = n_i/N$
n_i = Number of the individuals of the i^{th} species
N = Total number of individuals of all the species in that habitat

Margalef's Index (D) = $\frac{\sum(n_i - 1)}{\log N}$

Where
n_i = Number of the individuals of the i^{th} species
N = Total number of individuals of all the species in that habitat

Evenness/Equitability (J) = $\frac{H'}{\log S}$

Where
H' = Shannon-Wiener diversity index
S = Total number of species in the habitat

The Pearson correlation coefficient (r) was calculated to find the linear relationship between the diversity of rotifers (H') and the physicochemical parameters. Slope (b) was computed to know the rate of change along the regression line.

RESULTS

The rotifer fauna of River Vishwamitri is represented by a total of 59 species belonging to 24 genera and 17 families.

Species number

Station III has the highest number of rotifer species. This station has 40 species (table 3.3) out of the total of 59, thus harbouring about 67.8% of the total rotifer species. This was followed by station I which has 37 rotifer species (table 3.1), representing 62.7% of the rotifer fauna. Next was station II that had a total of 33 species (table 3.2) thus having about 56% of the total rotifer species. Station IV and Station V had the least number of rotifer species, a total of 12 (table 3.4) and 10 species (table 3.5) respectively, thus harbouring just about 20.3% and 16.9% of the total rotifer fauna of the river.

Exclusive species

Rotifer species that occurred at a single station have been termed as 'exclusive species' in the

present study. Twenty rotifer species out of a total of 59 species have been found to occur exclusively at one particular station. Thus 33.9% of the species can be termed as exclusive species or species occurring exclusively at a single station. From the data (Table 3.3) it is evident that station III supports the maximum number of such exclusive species. This station harbors a total of 12 such exclusive species accounting for 63% of the total exclusive species. This is followed by station I having a total of 5 exclusive species (Table 3.1), thus accounting for 21%. Station II is next, harboring 3 exclusive species (Table 3.2) and accounting for 15.8% of these exclusive species. Sites IV and V do not support any of the exclusive species.

Distribution pattern of species

As stated earlier 20 species out of the total of 59 species are exclusive. Six species of rotifers in River Vishwamitri are common and found at all five stations. Thus 10.2% of the species are commonly found at all the stations. Four species are such that they occur at four stations, i.e. 6.8% of the species can be found in at least four stations. Seven species are such that they occur at only three stations i.e. 11% species occur at three stations. 23 species occur at only two stations, thus showing that 38.98% of the species can be found at only two stations.

Similarities between regions

This involved calculating the numbers of species shared by each pair of stations. The general pattern was as expected, in that each site shares the greatest number of species with the closest other region and fewest species with the most remote region (Table 3.6). For example, station I shares 24 species with the adjoining station II and only 8 species with the remote station V. Similarly station II shares 20 species with the adjacent station III but only 8 with remote station V.

Unlike the raw figures of shared species quoted above, the similarity indices take account of the total numbers of species in the regions concerned. The Jaccard's index that is used here incorporates total from both the regions compared. Nonetheless, the index presents a broadly similar picture of faunal resemblance to the shared species and points that the greatest levels of species sharing and family sharing occur between regions that are geographically close together, and the smallest levels between regions that are far apart. In other words, whether one uses the numbers of shared species or the Jaccard's index, the conclusions on the rotifer faunal similarities are broadly similar (Table 3.7).

Species diversity

Stations I, II and III showed reasonably good rotifer species diversity whereas, Station IV and

V had lower diversity of rotifers. On the whole, however, the postmonsoon season had the highest diversity of rotifers as indicated by the Shannon-Wiener and Margalef's indices (Table 3.8) of species diversity while the lowest diversity was found during the winter months at all stations except IV and V (Table 3.8). Station I recorded the highest diversity in the month of September and the lowest in January. At station II during the months of August and September high rotifer species diversity was observed which, however, began to reduce by October and reached minimum levels in the month of December. Station III showed less variation in the rotifer diversity throughout the year however, on the whole the postmonsoon months had the highest levels of rotifer diversity, followed by the month of May. Stations IV and V had very low levels of rotifer diversity as compared to the other three stations.

PHYSICOCHEMICAL PARAMETERS

1. Temperature

The temperature of the river water varied with changes in the ambient temperature at all the stations. As expected the highest values were obtained in the summer months with April having the maximum temperature values (Table 3.9). Station V showed the highest mean summer temperature followed by station IV and then by station I and lastly by station III (Figure 3.1). The lowest temperature values were recorded during the winter and ranged from 13.0°C to 19.7°C (Table 3.9). At all the stations the month of January recorded the least temperature values. The temperature during the postmonsoon season was moderate and ranged between the summer and the winter values. Station I recorded the lowest mean postmonsoon value while station IV recorded the highest mean postmonsoon temperature (Table 3.9). On the whole the mean temperature of the river water fluctuated between 13.0°C and 28.9°C.

2. pH

The mean pH values of the river varied between 7.51 and 9.01 during the study period. Station I did not show much variation in the pH levels, the maximum value of 7.89 was obtained during the month of April while the lowest value was observed in August and September (Table 3.10). Likewise at station II, the mean values varied only between 7.60 in August and September to 7.91 in December. At station III slight increase in the variation was observed with values ranging from 7.49 to 8.05. The highest pH value of 9.01 was recorded from station IV in the month of May. Here the lowest recorded pH value was 7.59 in the month of September. The pH values at station V ranged from 7.67 in September to 8.98 during May. By and large the pH values were lower in initial stations (figure 3.2) and

gradually increased downstream. Further, the summer values in general were highest and the postmonsoon values were the lowest (Table 3.10).

3. Dissolved Oxygen

The levels of dissolved oxygen fluctuated from season to season at all the sampling stations. During the sampling period mean DO values, as low as 0mg/L to as high as 7.8mg/L were obtained (Table 3.11). On the whole however, stations I, II and III showed fairly good amount of dissolved oxygen, while stations IV and V had very low levels of DO throughout the year (Figure 3.3). As expected the dissolved oxygen levels were highest during the winter season at almost all the stations (Figure 3.3) except at station V. Station III had the highest mean value (7.8mg/L) of DO in the month of January. The lowest levels at all the stations were encountered during the hot summer season (Figure 3.3). In fact during the month of April, stations IV and station V had mean DO levels equal to 0.48mg/L and 0mg/L respectively. Station II had dried up completely by the summer season. Station III showed fairly good amount (3.79mg/L) of DO even in the summer. Though station I had the highest dissolved oxygen values for the early summer season, it dried up by the end of April. Owing to the proper mixing of water during the postmonsoon period most stations showed reasonably good amount of dissolved oxygen (Table 3.11). In fact highest mean value (1.44 mg/L) of dissolved oxygen for station V was recorded during the postmonsoon season in month of August (Table 3.3). Similarly the other stations also showed good amount of dissolved oxygen during this period.

The DO values must also be seen in comparison with the BOD values. As the DO values fall there is a concomitant rise in the BOD levels. This is clearly seen in (Table 3.12). Since biologically degradable organic matter constitutes 7% of sewage, it has a direct influence on the dissolved oxygen content of the water resulting in the 'oxygen-sag curve'. As indicated in figure 3.8 the DO levels fall to such an extent that the river water nearly becomes devoid of any dissolved oxygen in the downstream direction at stations IV and V, causing anoxic conditions.

4. Total suspended solids

Much variation in the levels of TSS was recorded from all the stations (Table 3.12). Station I and II had relatively low levels of TSS as compared to stations III, IV and V. The values of TSS increased from station I to station V (Figure. 3.4). Thus station I recorded the lowest values of TSS while the highest values were met with at station V. The postmonsoon season

recorded the highest values of suspended solids (Table 3.12) from all the stations. The highest mean value of 685.20mg/L was recorded from station V in the month of August. The lowest value recorded at this station was in the month of December. Overall the winter season had the least values of suspended solids. The mean summer values were just a little higher than the winter values and thus ranged between the winter and the summer levels (Table 3.12).

5. Chlorophyll-a

The chlorophyll-a content varied throughout the study period with the maximum being recorded during the postmonsoon period and the minimum in the summer at all the stations (Table 3.13). Stations IV and V showed very low chlorophyll-a content throughout the year while station I, II and II had a good concentration of chlorophyll-a (Figure. 3.5). The mean chlorophyll-a values at station IV ranged from 4.20 in April to 21.90 in October. Similarly the mean chlorophyll-a content at station V ranged from 6.10 in April to 22.10 in October (Table 3.13). Stations I and III showed drastic fluctuations in the level of chlorophyll-a throughout the year (Figure 3.5).

6. Total Reactive Phosphate

Stations I and II showed low levels of total reactive phosphate in comparison to stations IV and V (Figure 3.6). Station III showed moderate values of total reactive phosphate. Throughout the year the highest values were obtained in the summer while the lowest during the postmonsoon season at all the stations (Table 3.14).

7. Nitrate-Nitrogen

Stations IV and V showed high levels of nitrate-nitrogen in comparison to stations I and II. An increase in the level of nitrate- nitrogen was observed from Station I to station V (Figure 3.7). By and large the highest values were obtained during the post monsoon season at all the stations (Table 3.15). The winter season showed the lowest values of nitrate-nitrogen at all the stations.

8. Biological Oxygen Demand

Post monsoon season recorded the lowest values of BOD at all the stations, while summer had the highest values (Table 3.16). The upstream stations I and II had lower BOD values as compared to the downstream stations (Figure 3.8). Highest BOD value was recorded at station V in the month of May, while the lowest value was recorded at station I in August.

DISCUSSION

Rotifer community structure and the factors affecting its diversity, abundance and richness are very complex. Contradictory reports exists on various factors that could be affecting it. Even the question of whether or not seasonality exists in the rotifer community is riddled with contradictions. Pennak (1955) from his observations concluded that there exists no seasonal periodicity in North American Rotifers. Wesenburg-Lund (1908, 1930) has shown that seasonal variations are not very marked in Danish waters. Mengestou *et al.* (1991) based on their study of rotifer dynamics in Ethiopia did not observe any consistent seasonal pattern or generalized scheme of succession in Rotifers. Nayar (1964) on the basis of his study concluded that periodicity of occurrence cannot be assigned to a particular season. However, there are few reports that conclude that rotifers from India follow a marked periodicity George (1961) attributed a summer periodicity to the rotifers in Delhi waters. Chacko and Rajagopal (1962) found that rotifers were dominant in the month of May and August. Micheal (1968) observed different peaks in slightly different period during his two years study span. Dhanapathi (1997) observed a bimodal curve of rotifer abundance from two ponds in Andhra Pradesh. During the present study a remarkable alteration in the rotifer community was observed with change in the various seasons. A less obvious change was observed on a monthly basis and hence only the seasonal data compiled by combining the monthly data has been discussed here. In the present study, rotifer diversity, richness and equitability were found to be highest during the postmonsoon season (table 3.8), followed by the summer and the least was found during the winter season. Similar results were obtained by Fernando and Rajapaksa (1983), who found rotifers in high numbers both during the dry and rainy seasons in tropical lakes. Green (1960) and Duncan and Gulati (1981) found high rotifer numbers during the flushing periods or flood cycle while Robinson and Robinson (1971) and Burgis (1974) found that rotifer numbers were highest during warm dry months and lowest during the cold period. This is only partially in agreement with the results obtained in the present study wherein too the rotifer numbers in the winter season were low.

The seasonality of rotifers can been ascribed to a number of climatological and biological factors (Mengestou *et al.*, 1991). Herzig (1987) from an intensive study on the Rotifera from temperate lakes observed that some central factors such as physical, chemical limitations, food and mechanical interference, competition, predation and parasitism regulate rotifer succession.

Many studies have been conducted to find the causative factors for the seasonal variations.

Various physicochemical factors have been studied to find the changes, if any, caused by these factors on the rotifer community.

Temperature is one such factor, which is often considered to be the most important factor determining the population dynamics of rotifers (Ruttner-Kolisko, 1975; Hofmann, 1977). In the present study it was observed that rotifers were maximum in the postmonsoon season when the temperature of water was between 24.8°C to 25.8°C. However, when the water temperature increased in the summer, in the range of 26.9°C to 27.5°C a decrease in the rotifer population was observed. In the winters also when the water temperatures fell drastically a subsequent decrease in the rotifer number was observed. It may be believed that the rotifers need an optimum temperature for survival and when the temperature varies from the optimum, the rotifer population decreases drastically. Pejler (1977), Dumont (1983) and DeRidder (1984) however, stated that most species of planktonic rotifers have a global distribution and are characterized by wide temperature tolerances, most of them occurring from close to zero to about 20 degrees Celsius or more (Berzins and Pejler, 1989). The effects of temperature on zooplankton populations are often linked with biotic effects such as increase in filamentous cyanophytes or predators (Threlkeld, 1987). More direct mechanisms include temperature sensitivity of metabolism or life history characteristics (Hebert, 1978; Taylor and Mahoney, 1988). Temperature has also been positively correlated with zooplankton birth rates and mortality in laboratory experiments (Wolfinbarger, 1999). Rotifers are able to reproduce over a wide temperature range, providing other factors are not limiting. It is however, difficult to determine the effect of temperature on an individual or population, as temperature influences other processes which in turn affect the rotifers. Additionally, the rate of biological processes is seldom influenced by temperature alone but by a number of other factors too. It is nearly impossible to separate the direct and indirect effects of temperature on other environmental factors (Galkovskaja, 1987). Berzins and Pejler (1989) designated some species, which peaked during the winter months as "winter species" and those that peaked in the summer as "summer species". However, they opined that the range of occurrence is often so wide that it is difficult to designate these as "warm-stenothermal species". Pejler (1957) suggested that genetic differences could be suspected between populations and geographic areas, where *Anueropsis fissa* and *Pompholyx sulcata* for instance, otherwise known as pronounced summer forms, were only found at comparatively low temperatures in northern Swedish Lapland. Berzins and Pejler (1989) found that many non-planktic species had their peaks at comparatively high temperatures and this could be because most of them are periphytic and dependent on macrophytes and the epiphytic flora, which develops during summer.

Thus it can be said that temperature does not solely decide when and where a species will occur. Its influence is mainly indirect enhancing or retarding development and cooperating with other biotic and abiotic factors.

Another environmental factor that could affect the composition of rotifer community is the pH of water in which they live. According to Hofmann (1977) little is known about the influence of pH on population dynamics of rotifers. However, according to Edmondson (1944) and Skadowsky (1923) pH plays a major role in the distribution of rotifers. In the present study it was observed that the pH values ranged between 7.51 and 9.01 showing that the pH was alkaline. This observation is in agreement with the observations of Subramanian *et al.* (1987) who suggested that irrespective of the geology, climate etc., the pH of Indian river waters is predominantly alkaline. Similar observations have also been made by Somashekar (1988), Venkateswarlu (1986), Bhargava (1985) and Mitra (1982). The pH values were the lowest during the postmonsoon season and ranged between 7.52 and 7.76 at all the stations. This was also the season when the rotifer diversity was at its maximum. During summer, the pH ranged between 7.74 and 8.80 while the rotifer diversity was moderate. Least diversity was seen in the winter months when the pH ranged between 7.70 and 8.35. When pH and rotifer diversity were correlated, a significant negative correlation (table 3.17) was observed. Moreover, as evidenced from the elevated slope value (table 3.17) even a slight alteration in the pH may lead to perceivable changes in the rotifer community. Contradictorily, Berzins and Pejler (1987) could not determine any correlation between peak rotifer abundance and pH and stated that rotifers as a group exhibit a very wide range of pH tolerance. They have been found in waters with pH values spanning at least 2.0 units and many are found in waters, which defer by as much as 5.0 units (Berzins and Pejler, 1987). Haque *et al.* (1988) from their study observed rotifers to be insensitive to pH. However, Green (1960) stated that there could be an optimum pH for the growth and development of a particular species. According to Berzins and Pejler (1987) several species have peak abundances in the acidic range (pH<6) and thus may be adapted to these conditions. According to Brett (1989) rotifer genera found below pH 3 can also be found in less acidic soft waters. Deneke (2000) found species richness to be generally low in highly acidic environments with pH values of 3 or less. His studies also suggested that small littoral or benthic rotifers predominate over crustaceans under highly acidic environments. Wiszniewski (1936) suggested that the most important factor influencing psammic rotifer communities is pH of the lake water. Bielanska-Grajner (2001) observed larger number of rotifer species and their higher abundance in slightly acidic to neutral waters and the lowest quantity and the number of rotifers were observed in waters with the lowest pH among psammic rotifers. On

the contrary, Prabhavathy and Sreenivasan (1977), Sampath *et al.* (1979) and Mishra and Saksena (1998) have shown rotifers dominating in alkaline waters. Finally, it may be stated from the present study that even a slight alteration in pH value will significantly affect the rotifer diversity.

Dhanapathi (2000) stated that Dissolved Oxygen (DO) plays an important role in determining the occurrence and abundance of rotifer communities. Arora (1966a) has shown that dissolved oxygen can influence the survival of rotifers. Nayar (1964) suggested that dissolved oxygen could be an important factor influencing the growth and reproduction of *Brachionus calyciflorus*. In the present study it was observed that the rotifer population was at its lowest during the winter season when the DO levels were at its maximum. Similarly, Mishra and Saksena (1998) from their studies also found that rotifer numbers were inversely proportional to the dissolved oxygen. Prabhavathy and Sreenivasan (1977) suggested that rotifers are tolerant to low dissolved oxygen values. In the current study when the dissolved oxygen levels were the lowest in the summer season the rotifer population was not at its highest, in fact moderate rotifer counts were recorded in this season. Nevertheless, it was observed that River Vishwamitri supports the highest rotifer number during the postmonsoon season when the dissolved oxygen levels were moderate. This suggests that there is no direct correlation between the dissolved oxygen levels and rotifer population. However, Green (1956) has shown that dissolved oxygen plays an important role in controlling the growth of zooplankton. Berzins and Pejler (1989) suggested that though some species may be encountered in high abundance at low oxygen values, no true anoxybionts ought to exist.

One of the effects of high suspended solid levels is increased turbidity. Increased turbidity has been shown to have a variety of influences on biota, affecting characteristics such as ecological conditions, resource availability and species interaction (Hart, 1990). Cottenie *et al.* (2001) from their study found that differences in zooplankton communities are strongly related to factors such as macroinvertebrate densities and turbidity. In the present study it was observed that the postmonsoon season had the highest suspended solid levels throughout the river and the rotifer diversity was also high. This is in complete agreement with Telesh (1995) who described rotifer diversity to be inversely proportional to transparency in highly turbid waters. Transparency in river Vishwamitri gets highly reduced in the postmonsoon season when the waters carry heavy loads of sediments from the surrounding areas. Telesh (1995) also observed that the contribution of rotifers to total zooplankton biomass was lower in less turbid waters. He described density of rotifers to be highest in the turbid section and low in regions with greater transparency. In the present study the levels of crustaceans and

copepods were low during the postmonsoon season (Pilo *et al.*, unpublished). Thus predation upon the rotifers is greatly reduced. Threlkeld (1979) also suggested that biotic mechanisms in the seasonal changes of zooplankton assemblages involve changes in predation. Increased turbidity altered predator efficiency, which might indirectly impact zooplankton community dynamics. In fact laboratory experiments illustrated asymmetrical exploitative competition between rotifers and Daphnia, leading to Daphnia dominance in absence of turbidity (Gilbert, 1985). Hart (1987) reported lower crustacean abundance in years of high turbidity. McCabe and O' Brien (1983) found that *Daphnia pulex* population growth rates were diminished in presence of suspended silt. On the other hand, Kirk and Gilbert (1990) observed that inorganic turbidity inhibited the competitive abilities of Daphnia and this competitive inhibition may have lead to a decline of cladocerans, causing a competitive lease of rotifer population.

In all, however, it can be seen that Station I, II and III, which have the highest rotifer diversity, have low suspended solids in comparison to stations IV and V. Thus it would not be completely right to believe that the rotifer diversity is directly proportional to the suspended solids. Pollard *et al.* (1998) observed that turbidity had a minimum role in regulation of zooplankton population. They found that rotifer abundance patterns and species composition as well as rotifer population dynamics were similar at low and high turbidity sites. Contrary to all the above observations Egborge (1981) observed highest rotifer numbers during periods of high water transparency.

Gulati *et al.* (1992) indicated that the important factors to be examined for changes in zooplankton composition and abundance are its food and predators. Threlkeld (1979) also suggested that biotic mechanisms in the seasonal changes of zooplankton assemblages involve changes in resource availability. Cecchine and Snell (1999) stated that food limitation might be an important factor in community structuring of rotifers. In oligotrophic systems, declines in cladoceran populations are often associated with decreased total phytoplankton biomass (Sommer *et al.*, 1986). Restrictions associated with lack of optimal food (Pejler, 1977) or diverse phytoplankton as food items (Burgis, 1974) are known to be the reason for low rotifer diversity in low latitude lakes (Lewis, 1979; Fernando, 1980b). Rotifers feed on detritus, algae, etc. while some are predatory. In the present study most of the recorded rotifers are herbivorous or detritivorous (chapter 2), suggesting that the phytoplankton constitute the major source of food. Any changes in the composition of phytoplankton would lead to subsequent changes in the rotifer community. During the present study, a high positive correlation (table 3.17) was observed between the chlorophyll-a content and the

rotifer diversity. During the postmonsoon season the chlorophyll-a levels were maximum, as was the rotifer diversity. And the lowest chlorophyll-a levels were encountered in the winter season. The summer months showed a moderate chlorophyll-a level and concomitantly moderate rotifer diversity (Table 3.13). Mishra and Saksena (1998) have also observed a positive correlation between rotifer number and total phytoplankton population. It is evident from the results that stations I, II and III have higher chlorophyll-a content as compared to stations IV and V, similarly the rotifer diversity at these stations is also low as compared to stations I, II and III throughout the year. Yet another reason for low rotifer diversity downstream could be attributed to the fact that the cyanophytes (blue green algae) are disproportionately high at these stations (Pilo *et al.*, unpublished). It has been stated that blue green algae are not edible, as they are toxic to rotifers (Fulton and Pearl, 1987). Threlkeld (1979, 1986) has attributed the decline in rotifer community in mesotrophic and eutrophic systems, to the replacement of palatable forms of phytoplankton with the less palatable filamentous cyanophytes. Moreover, filamentous cyanophytes, at high densities, are reported to affect the zooplankton adversely by mechanical interference with its filtering mechanism (Webster and Peters, 1978; Porter and Orcutt, 1980).

Factors affecting the phytoplankton community would also indirectly affect the rotifer dynamics. In most freshwaters, phosphorous and nitrogen are limiting nutrient for phytoplankton growth (Plath and Boersma, 2001). Phosphate is an important nutrient, which controls plant growth (Hynes, 1978). Tebutt (1992) and Dean and Lund (1981) mention that phosphorous occur in sewage effluents due partly to human excretion and partly due to their use in synthetic detergents. Consequently in Vishwamitri River the values of Phosphate increases as sewage gets dumped into the river from station III onwards. This can be seen clearly in figure 3.14, wherein the phosphate values are lowest at station I and gradually increase from there onwards. The highest values are found at station V. This trend is seen during all the seasons. The lowest total reactive phosphate levels were encountered during the postmonsoon season while the highest values during the summer. Thus it would be expected that phytoplankton diversity and consequently rotifer diversity would be highest in the downstream stations in the summer season. This is, however, not the case. Both the phytoplankton levels (Pilo *et al.*, unpublished) and the rotifer diversity in the downstream stations are low. This could probably be due to the very low dissolved oxygen level in this stretch of the river.

In case of nitrate nitrogen the highest values are seen at the downstream stations while low values in the upstream stations (Figure. 3.7A). On the basis of the seasons the highest values

are seen during the postmonsoon while the lowest during the winter season (Figure 37B). Accordingly high rotifer diversity is seen during postmonsoon season and low during the winter. However, as far as the stations are concerned where high nitrate nitrogen values are present (downstream stations) the rotifer diversity is not correspondingly high. This could again be attributed to low DO levels at these stations.

Water pollution also affects the rotifer community. Archibald (1972), Verma *et al.* (1984) and Kulshreshtra *et al.* (1989) observed that the species diversity is high in clean waters and low in polluted waters. Banerjea and Motwani (1960) reported an appreciable fall in the rotifer species just below the effluent outfall and further reduction in the Septic zone of Suvaon stream. However, Prabhavathy and Sreenivasan (1977), Gannon and Stemberger (1978), Sampath *et al.* (1979) and Mishra and Saksena (1998) found that rotifer population was enhanced by increased load of pollution. Similarly Venkateswarlu and Jayanti (1968) recorded high counts of rotifers at polluted stations of Sabarmati River in comparison to clean stations. In River Vishwamitri the sewage pollution begins from station III, and as is evident from the data that this station on the whole has a greater diversity of rotifers throughout the year. However, towards station IV and station V the pollution load increases drastically as evidenced by the Biological oxygen demand values (table 3.16) and the dissolved oxygen levels are too low to support many organisms. At these sites the suspended solid levels are also very high which greatly reduces the transparency. This would in turn affect the light penetration required by the primary producers. All these factors combined probably account for the low diversity at these stations.

Apart from the physicochemical factors, biotic factors might also play an important role in controlling the zooplankton community structure. The presence or absence of predators also affects the rotifer populations. The negative relation between the presence of *Daphnia* and rotifers has been well documented (Fussmann, 1996). As already discussed earlier, during the postmonsoon period the cladoceran density is quite low, probably affected by the high levels of suspended solids, as a result of which the rotifers are found in high numbers.

Presence of macrophytes also affects the zooplankton diversity. Lougheed *et al.* (1998) stated that patchy distribution of aquatic vegetation contributes to seasonal variability in water quality characteristics and the amount of habitat available for aquatic invertebrates. Development of vegetation increases structural complexity, so providing more niches for rotifers. In a large body with a complex littoral zone, the numbers of rotifer species can reach over 200 (Segers and Dumont, 1995; Dumont and Segers, 1996). The macrophytes provide

more diverse habitat (Van den Berg *et al.*, 1997). In River Vishwamitri macrophytes are present in highest numbers at station III followed by stations II and I. Stations IV and V have negligible macrophyte population (Pilo *et al.*, unpublished). This could be yet another reason for higher diversity in the first three stations. Telesh (1995) also found rotifer diversity high in reed beds, the most common type of aquatic vegetation. *Typha aunguata* beds seen at stations II and III of River Vishwamitri could be another factor contributing to the higher rotifer number often present in these stations. Telesh (1995) further describes that species like *Brachionus calyciflorus*, *B. quadridentatus* and *Filinia longiseta* are commonly found in areas where macrophytic vegetations are plenty. All the above species were found at sampling stations II and III. Phytophilous species like *Platyias quadricornis*, *Mytilina ventralis* are abundant in macrophyte beds (Telesh, 1995). *Platyias quadricornis* was found at station III while *Mytilins ventralis* was located from station II of Vishwamitri.

Thus it can be seen that by and large station III seems to provide a better habitat with diverse niche for the rotifer community. This station besides receiving domestic sewage has relatively good levels of dissolved oxygen throughout the year. Moreover, there is water all through the year, at this station. The reed beds provide more varied microhabitat, which is indispensable for the survival of the periphytic rotifers. This could be the reason for a high number of exclusive species found at this station.

From the results it can also be seen that each site shares the greatest number of species with the closest other region and fewest species with the most remote region. The reason for this could be more or less similar physicochemical parameters as well as similar biotic factors between any two adjacent stations.

From the above discussion it could be concluded that pH and chlorophyll-a play a major role in influencing the rotifer community structure. Additionally, both the abiotic and biotic factors could be interacting with each other and their combined effect may be influencing the rotifer community structure.

TABLE 3.1 Species composition of rotifer community at station I

FAMILY (12)#	GENERA (17)	SPECIES (37)
Brachionidae	*Anuraeopsis*	*coelata*
		fissa
	Brachionus	*angularis*
		bidentatus
		calyciflorus
		quadridentatus
	Keratella	*procurva*
		tropica
	Plationus	*patulus*
Colurellidae	*Colurella*	*uncinata*
		obtusa
	Lepadella	*ovalis*
		patella
		*rhomboides**
Dicranophoridae	*Dicranophorus*	*australiensis*
Euchlanidae	*Euchlanis*	*meneta*
		*oropha**
Floscullariidae	*Lacinularia*	Sp.1
Hexarthridae	*Hexarthra*	*mira*
Lecanidae	*Lecane*	*bulla*
		closterocerca
		*crepida**
		*crenata**
		curvicornis
		hamata
		inermis
		leontina
		luna
		*pyriformis**
		quadridentata
		ungulata
Mytilinidae	*Mytilina*	*ventralis*
Notommatidae	*Cephalodella*	*misgurunus*
	Scaridium	*longicaudum*
Synchaetidae	Polyarthra	Sp.1
Testudinellidae	*Testudinella*	*patina*
Trichocercidae	*Trichocerca*	*braziliensis*

* Indicates exclusive species

Total number in parenthesis

TABLE 3.2 Species composition of rotifer community at station II

FAMILY (14)#	GENERA (19)	SPECIES (33)
Asplanchnidae	*Asplanchna*	*brightwelli**
Atrochidae	*Cupelopagis*	*vorax**
Brachionidae	*Anuraeopsis*	*coelata*
		fissa
	Brachionus	*angularis*
		bidentatus
		calyciflorus
		caudatus
		forficula
		quadridetatus
	Keratella	*procurva*
		tropica
	Plationus	*patulus*
Colurellidae	*Colurella*	*obtusa*
	Lepadella	*patella*
Dicranophoridae	*Dicranophorus*	*australiensis*
Euchlanidae	*Euchlanis*	*meneta*
Filiniidae	*Filinia*	*longiseta*
		opoliensis
Flosculariidae	*Lacinularia*	Sp 1
Hexarthridae	*Hexarthra*	*mira*
Lecanidae	*Lecane*	*arcula*
		bulla
		inermis
		leontina
		luna
		papuana
		quadridentata
Mytilinidae	*Mytilina*	*ventralis*
Notommatidae	*Cephalodella*	*misgurunus*
	Scaridium	*longicaudum*
Synchaetidae	*Polyarthra*	Sp.1
Philodinidae	*Rotaria*	*neptunia**

* Indicates exclusive species

Total number in parenthesis

TABLE 3.3 Species composition of rotifer community at station III

FAMILY (11)#	GENERA (16)	SPECIES (40)
Asplanchnidae	*Asplanchna*	*sieboldi**
Brachionidae	*Anuraeopsis*	*fissa*
	Brachionus	*angularis*
		calyciflorus
		caudatus
		*diversicornis**
		*falcatus**
		forficula
		quadridetatus
		*rubens**
	Keratella	*procurva*
		tropica
	Platyias	*quadricornis**
Colurellidae	*Colurella*	*uncinata*
	Lepadella	*acuminata*
		ovalis
		patella
Dicranophoridae	*Dicranophorus*	*australiensis*
	Encentrum (1)	Sp.1*
Euchlanidae	*Euchlanis (2)*	*meneta*
		*diltata**
Filiniidae	*Filinia (2)*	*longiseta*
		opoliensis
Lecanidae	*Lecane*	*arcula*
		bulla
		closterocerca
		curvicornis
		*elachis**
		hamata
		inermis
		*inopinata**
		luna
		*nana**
		papuana
		*stenroosi**
		ungulata
Notommatidae	*Cephalodella*	*misgurunus*
Synchaetidae	*Polyarthra*	Sp 1
Testudinellidae	*Testudinella*	*patina*
Trichotriidae	*Trichotria*	*tetractis**

* Indicates exclusive species; # Total number in parenthesis

TABLE 3.4 Species composition of rotifer community at station IV

FAMILY (7)#	GENERA (10)	SPECIES (12)
Brachionidae	*Anuraeopsis*	*Fissa*
	Brachionus	*Angularis*
		Quadridetatus
	Keratella	*Tropica*
	Plationus	*Patulus*
Colurellidae	*Colurella*	*Obtusa*
Dicranophoridae	*Dicranophorus*	*Australiensis*
Filiniidae	*Filinia*	*Longiseta*
Lecanidae	*Lecane*	*Bulla*
		Inermis
Synchaetidae	*Polyarthra*	Sp.1
Trichocercidae	*Trichocerca*	*Braziliensis*

TABLE 3.5 Species composition of rotifer community at station V

FAMILY (5)#	GENERA (6)	SPECIES (10)
Brachionidae	*Brachionus*	*Angularis*
		Quadridentatus
	Keratella	*Tropica*
Colurellidae	*Lepadella*	*Acuminata*
		Patella
Dicranophoridae	*Dicranophorus*	*Australiensis*
Filiniidae	*Filinia*	*Longiseta*
Lecanidae	*Lecane*	*Bulla*
		Inermis
		Pyriformis

Total number in parenthesis

TABLE 3.6 Number of rotifer species shared between sites.

STATION	I (37)	II (33)	III (40)	IV (12)	IV (10)
I	---	24	21	11	8
II	---	---	20	11	8
III	---	---	---	9	9
IV	---	---	---	---	7
V	---	---	---	---	---

TABLE 3.7 Rotifer community similarity (C_J) between the stations

STATION	I	II	III	IV	V
I	---	0.52	0.38	0.29	0.21
II	---	---	0.38	0.32	0.23
III	---	---	---	0.21	0.22
IV	---	---	---	---	0.47
V	---	---	---	---	---

TABLE 3.8 Seasonal diversity of rotifers at various sampling stations of River Vishwamitri during 2000 2001.

A) Summer

Sampling Station	Species Richness	Species Diversity		Equitability
		H'	D	
I	7	1.27	1.52	0.49
II	–	–	–	–
III	11	1.88	1.62	0.62
IV	1	0.17	0.11	0.24
V	1	0.19	0.12	0.08

B) Postmonsoon

Sampling Station	Species Richness	Species Diversity		Equitability
		H'	D	
I	23	2.56	2.91	0.63
II	17	2.30	2.63	0.57
III	14	2.31	2.21	0.57
IV	5	1.48	1.01	0.30
V	4	1.18	0.84	0.29

C) Winter

Sampling Station	Species Richness	Species Diversity		Equitability
		H'	D	
I	3	0.59	0.39	0.14
II	4	1.27	0.58	0.31
III	6	1.36	1.03	0.35
IV	3	0.72	0.54	0.18
V	2	0.57	0.30	0.14

TABLE 3.9 Monthly and seasonal temperature of water at various stations of river Vishwamitri during 2000 – 2001.

SITES	TEMPERATURE (°C)			
	MONTH		SEASON	
STATION I	March	25.50 ± 0.50*	Summer	26.95 ± 1.61*
	April	28 40 ± 0.55		
	May	Dry		
	August	23.20 ± 0.84	Postmonsoon	24.87 ± 1 41
	September	25.40 ± 0.55		
	October	26.00 ± 0.71		
	December	15.20 ± 0.91	Winter	15 70 ± 1.98
	January	13 80 ± 0.57		
	February	18.10 ± 0.74		
STATION II	March	Dry	Summer	Dry
	April	Dry		
	May	Dry		
	August	24.20 ± 0.84	Postmonsoon	25 20 ± 1 08
	September	25.10 ± 0.74		
	October	26 30 ± 0 27		
	December	14.00 ± 0 71	Winter	14 00 ± 0 71
	January	Dry		
	February	Dry		
STATION III	March	25.90 ± 0 55	Summer	27.07 ± 1.13
	April	28.30 ± 0.45		
	May	27.00 ± 0 61		
	August	24.60 ± 0.55	Postmonsoon	25.53 ± 0 99
	September	25.40 ± 0.55		
	October	26.60 ± 0.55		
	December	14 30 ± 0.45	Winter	15.13 ± 2.22
	January	13.10 ± 0.55		
	February	18.00 ± 0.71		
STATION IV	March	26.20 ± 0.27	Summer	27.40 ± 1 12
	April	28.70 ± 0.45		
	May	27.30 ± 0.45		
	August	24.20 ± 0.84	Postmonsoon	25.93 ± 1.43
	September	26.40 ± 0.55		
	October	27.20 ± 0 27		
	December	14 80 ± 0 84	Winter	15.20 ± 2.14
	January	13.00 ± 0.71		
	February	17.80 ± 0.45		
STATION V	March	26 40 ± 0.42	Summer	27.57 ± 1.16
	April	28.90 ± 0.55		
	May	27.40 ± 0.55		
	August	24.40 ± 0.89	Postmonsoon	25.80 ± 1 42
	September	25.60 ± 0.55		
	October	27.40 ± 0.55		
	December	15 60 ± 0.89	Winter	16.57 ± 2 48
	January	14.40 ± 0.96		
	February	19.70 ± 0.76		

* Values are expressed as Mean ± SD

TABLE 3.10 Monthly and seasonal values of pH at various stations of river Vishwamitri during 2000 – 2001.

SITES	pH			
	MONTH		SEASON	
STATION I	March	7.59 ± 0.06*	Summer	7.74 ± 0.17*
	April	7.89 ± 0.06		
	May	Dry		
	August	7.51 ± 0.07	Postmonsoon	7.52 ± 0.07
	September	7.51 ± 0.07		
	October	7.53 ± 0.10		
	December	7.60 ± 0.03	Winter	7.70 ± 0.10
	January	7.69 ± 0.06		
	February	7.81 ± 0.04		
STATION II	March	Dry	Summer	Dry
	April	Dry		
	May	Dry		
	August	7.60 ± 0.07	Postmonsoon	7.67 ± 0.11
	September	7.60 ± 0.05		
	October	7.81 ± 0.03		
	December	7.91 ± 0.04	Winter	7.91 ± 0.04
	January	Dry		
	February	Dry		
STATION III	March	7.99 ± 0.04	Summer	8.01 ± 0.07
	April	7.99 ± 0.07		
	May	8.05 ± 0.08		
	August	7.50 ± 0.07	Postmonsoon	7.60 ± 0.16
	September	7.49 ± 0.06		
	October	7.81 ± 0.04		
	December	7.78 ± 0.06	Winter	7.85 ± 0.08
	January	7.88 ± 0.07		
	February	7.90 ± 0.05		
STATION IV	March	8.61 ± 0.06	Summer	8.80 ± 0.18
	April	8.79 ± 0.06		
	May	9.01 ± 0.07		
	August	7.60 ± 0.05	Postmonsoon	7.67 ± 0.12
	September	7.59 ± 0.06		
	October	7.81 ± 0.04		
	December	8.18 ± 0.06	Winter	8.35 ± 0.15
	January	8.39 ± 0.07		
	February	8.48 ± 0.07		
STATION V	March	8.70 ± 0.06	Summer	8.86 ± 0.13
	April	8.88 ±0.05		
	May	8.98 ± 0.06		
	August	7.70 ± 0.04	Postmonsoon	7.76 ± 0.11
	September	7.67 ± 0.04		
	October	7.89 ± 0.06		
	December	8.00 ± 0.06	Winter	8.31 ± 0.24
	January	8.41 ± 0.05		
	February	8.53 ± 0.06		

* Values are expressed as Mean ± SD

TABLE 3.11 Monthly and seasonal concentration of dissolved oxygen at various stations of river Vishwamitri during 2000 – 2001.

SITES	DISSOLVED OXYGEN (mg/L)			
	MONTH		SEASON	
STATION I	March	4 18 ± 0 19*	Summer	4.07 ± 0.22*
	April	3.96 ± 0.21		
	May	Dry		
	August	5.32 ± 0.15	Postmonsoon	4.85 ± 0.59
	September	5.14 ± 0.15		
	October	4.08 ± 0 19		
	December	5.84 ± 0.17	Winter	6.12 ± 0 67
	January	7 00 ± 0.16		
	February	5 52 ± 0.13		
STATION II	March	Dry	Summer	Dry
	April	Dry		
	May	Dry		
	August	5.20 ± 0.16	Postmonsoon	4.67 ± 0.65
	September	4.98 ± 0.15		
	October	3 82 ± 0.25		
	December	7.08 ± 0.19	Winter	7.08 ± 0.19
	January	Dry		
	February	Dry		
STATION III	March	4.02 ± 0.18	Summer	3.79 ± 0.27
	April	3.52 ± 0.19		
	May	3.82 ± 0.18		
	August	4.98 ±0.13	Postmonsoon	4.19 ± 0.69
	September	4.20 ± 0 16		
	October	3.40 ± 0.29		
	December	5.98 ± 0.19	Winter	6.42 ± 1.05
	January	7.80 ± 0.21		
	February	5.48 ±0.19		
STATION IV	March	1.72 ± 0.13	Summer	1.11 ± 0 53
	April	0.48 ± 0.08		
	May	1.14 ± 0.11		
	August	2 10 ± 0.16	Postmonsoon	1.71 ± 0.47
	September	1.92 ± 0.19		
	October	1.12 ± 0.19		
	December	2 92 ± 0.08	Winter	2.84 ± 0.31
	January	3.12 ± 0.08		
	February	2 48 ± 0.22		
STATION V	March	0.88 ± 0.08	Summer	0.53 ± 0.40
	April	00		
	May	0 72 ± 0.08		
	August	1.44 ± 0.11	Postmonsoon	1.00 ± 0.34
	September	0.88 ± 0.08		
	October	0 68 ± 0.88		
	December	0.90 ± 0.07	Winter	0.90 ± 0.14
	January	1.04 ± 0.07		
	February	0.75 ± 0.06		

* Values are expressed as Mean ± SD

TABLE 3.12 Monthly and seasonal levels of Total Suspended Solids at various stations of river Vishwamitri during 2000 – 2001.

SITES	TOTAL SUSPENDED SOLIDS (mg/L)			
	MONTH		SEASON	
STATION I	March	63.00 ± 2.24*	Summer	66.90 ± 4.63*
	April	70 80 ± 2.28		
	May	Dry		
	August	102.80 ± 3.83	Postmonsoon	92.40 ± 9 42
	September	92.60 ± 3.13		
	October	81.80 ± 3.19		
	December	42.40 ± 3.05	Winter	52 13 ± 8.97
	January	51.60 ± 2.97		
	February	62.40 ± 3.58		
STATION II	March	Dry	Summer	Dry
	April	Dry		
	May	Dry		
	August	141.40 ± 4.51	Postmonsoon	125.13 ± 13.57
	September	123.00 ± 4.74		
	October	111.00 ± 4.00		
	December	66.20 ± 3.49	Winter	66 20 ± 3 49
	January	Dry		
	February	Dry		
STATION III	March	122.00 ± 3.16	Summer	144 87 ± 20.38
	April	143.20 ± 3.35		
	May	169.40 ± 4.77		
	August	306.80 ± 5.76	Postmonsoon	243 33 ± 47.94
	September	223.40 ± 9.58		
	October	199.80 ± 4.44		
	December	131.60 ± 3.85	Winter	145.07 ± 12.86
	January	143.60 ± 4.04		
	February	160.00 ± 6 32		
STATION IV	March	234.40 ± 6.69	Summer	285 93 ± 48.38
	April	276.60 ± 6.07		
	May	346.80 ± 7.26		
	August	475.60 ± 10.69	Postmonsoon	406.87 ± 51 79
	September	382.60 ± 9 53		
	October	362.40 ± 8.29		
	December	218.60 ± 6.35	Winter	262 13 ± 38 97
	January	258.80 ± 6.22		
	February	309.00 ± 10.34		
STATION V	March	352.00 ± 8 00	Summer	392.53 ± 34.38
	April	394.20 ± 7.01		
	May	431.40 ± 8.88		
	August	685.20 ± 16.51	Postmonsoon	590.60 ± 75.32
	September	575.60 ± 10.99		
	October	511.00 ± 8.60		
	December	290.20 ± 7.95	Winter	330.27 ± 32.03
	January	339.20 ± 8.70		
	February	361.40 ± 11.52		

* Values are expressed as Mean ± SD

TABLE 3.13 Monthly and seasonal levels of chlorophyll–a at various stations of river Vishwamitri during 2000 – 2001.

SITES	CHLOROPHYLL–a (µg/L)			
	MONTH		SEASON	
STATION I	March	72.20 ± 2.68*	Summer	54.20 ± 19.08*
	April	36.20 ± 1.30		
	May	Dry		
	August	132.00 ± 3.16	Postmonsoon	146.20 ± 14 12
	September	142.60 ± 3.29		
	October	164.00 ± 3.61		
	December	21.40 ± 0.84	Winter	17 13 ± 3 29
	January	14 20 ± 0.84		
	February	15.80 ± 0.84		
STATION II	March	Dry	Summer	
	April	Dry		
	May	Dry		
	August	103.00 ± 3.16	Postmonsoon	103.93 ± 13.00
	September	119.40 ± 3.85		
	October	89.40 ± 1.52		
	December	56.60 ± 1.52	Winter	56 60 ± 1 52
	January	Dry		
	February	Dry		
STATION III	March	62.40 ± 2.51	Summer	64.40 ± 19 00
	April	87.60 ± 3.91		
	May	43.20 ± 1.30		
	August	110.20 ± 2.28	Postmonsoon	104 80 ± 5 44
	September	98.40 ± 2 07		
	October	105.80 ± 2 28		
	December	70.49 ± 2.74	Winter	75.33 ± 13.96
	January	93 46 ± 3.15		
	February	62.04 ± 2.09		
STATION IV	March	11.80 ± 0.76	Summer	8 47 ± 2 33
	April	4.60 ± 0.55		
	May	6.20 ± 0.84		
	August	14.50 ± 0.50	Postmonsoon	18.58 ± 2.80
	September	17.80 ± 0.84		
	October	21.90 ± 0.74		
	December	11.10 ± 0.74	Winter	12.93 ± 1 44
	January	12.10 ± 0.65		
	February	14.00 ± 0.79		
STATION V	March	11.30 ± 0.76	Summer	7.53 ± 3 27
	April	6.10 ± 0.42		
	May	8.00 ± 1.00		
	August	22.10 ± 1 08	Postmonsoon	18.07 ± 3 20
	September	16.84 ± 0.93		
	October	16.80 ± 1.48		
	December	14.00 ± 1.58	Winter	12.40 ± 1.42
	January	11.80 ± 0.84		
	February	13.00 ± 1.00		

* Values are expressed as Mean ± SD

TABLE 3.14 Monthly and seasonal concentration of total reactive phosphate at various stations of river Vishwamitri during 2000 – 2001.

SITES	TOTAL REACTIVE PHOSPHATE (mg/L)			
	MONTH		SEASON	
STATION I	March	1.10 ± 0.09*	Summer	1.17 ± 0.10*
	April	1.24 ± 0.06		
	May	Dry		
	August	0.45 ± 0.03	Postmonsoon	0.53 ± 0.09
	September	0.51 ± 0.04		
	October	0.62 ± 0.06		
	December	0.79 ± 0.05	Winter	0.88 ± 0.10
	January	0 86 ± 0.04		
	February	1.00 ± 0.06		
STATION II	March	Dry	Summer	Dry
	April	Dry		
	May	Dry		
	August	0.61 ± 0.04	Postmonsoon	0 68 ± 0.07
	September	0.67 ± 0.05		
	October	0.75 ± 0 04		
	December	1.15 ± 0 05	Winter	1.15 ± 0 05
	January	Dry		
	February	Dry		
STATION III	March	1.51 ± 0.06	Summer	1.69 ± 0 17
	April	1.67 ± 0.07		
	May	1.88 ± 0.10		
	August	0.64 ± 0.04	Postmonsoon	0.73 ± 0 09
	September	0.72 ± 0.06		
	October	0.82 ± 0.05		
	December	1.27 ± 0.04	Winter	1.40 ± 0.13
	January	1.40 ± 0.05		
	February	1.54 ± 0.08		
STATION IV	March	2.63 ± 0.12	Summer	2.88 ± 0.24
	April	2.89 ± 0.09		
	May	3.13 ± 0.12		
	August	1.09 ± 0.06	Postmonsoon	1.23 ± 0 13
	September	1.22 ± 0.04		
	October	1.39 ± 0 04		
	December	1.46 ± 0.04	Winter	1 95 ± 0.63
	January	1.59 ± 0 07		
	February	2.80 ± 0 08		
STATION V	March	2.82 ± 0.10	Summer	3.30 ± 0.46
	April	3.22 ± 0.08		
	May	3.87 ± 0.13		
	August	1 38 ± 0.05	Postmonsoon	1 55 ± 0 16
	September	1.54 ± 0.05		
	October	1.73 ± 0.07		
	December	2.31 ± 0.08	Winter	2.70 ± 0.41
	January	2.57 ± 0 12		
	February	3.23 ± 0.11		

* Values are expressed as Mean ± SD

TABLE 3.15 Monthly and seasonal concentration of nitrate nitrogen at various stations of river Vishwamitri during 2000 – 2001.

SITES	NITRATE NITROGEN (mg/L)			
	MONTH		SEASON	
STATION I	March	0.50 ± 0.02*	Summer	0 54 ± 0.05*
	April	0.58 ± 0.03		
	May	Dry		
	August	0.87 ± 0.02	Postmonsoon	0.82 ± 0.05
	September	0 82 ± 0.02		
	October	0 76 ± 0.03		
	December	0.39 ± 0.02	Winter	0.49 ± 0 08
	January	0.48 ± 0.02		
	February	0 59 ± 0.03		
STATION II	March	Dry	Summer	Dry
	April	Dry		
	May	Dry		
	August	0.92 ± 0 03	Postmonsoon	0.84 ± 0 08
	September	0 84 ± 0.03		
	October	0 74 ± 0 02		
	December	0 58 ± 0 03	Winter	0.58 ± 0.03
	January	Dry		
	February	Dry		
STATION III	March	0.75 ± 0.03	Summer	0.82 ± 0.06
	April	0 83 ± 0.03		
	May	0 87 ± 0 05		
	August	1 10 ± 0 07	Postmonsoon	0.92 ± 0.14
	September	0.87 ± 0.04		
	October	0.79 ± 0.02		
	December	0.62 ± 0.02	Winter	0.64 ± 0.03
	January	0.64 ± 0.02		
	February	0.68 ± 0.02		
STATION IV	March	1.10 ± 0.03	Summer	1.22 ± 0.12
	April	1.20 ± 0 03		
	May	1.35 ± 0.11		
	August	1.40 ± 0.05	Postmonsoon	1.33 ± 0.09
	September	1.37 ± 0.04		
	October	1.23 ± 0.06		
	December	0.94 ± 0.02	Winter	0 96 ± 0.05
	January	0 94 ± 0.03		
	February	1 01 ± 0.05		
STATION V	March	1.20 ± 0.03	Summer	1.30 ± 0.08
	April	1.31 ± 0.02		
	May	1.39 ± 0.02		
	August	1 48 ± 0.05	Postmonsoon	1.41 ± 0.09
	September	1.45 ± 0.04		
	October	1.30 ± 0.03		
	December	1.12 ± 0.07	Winter	1 25 ± 0 12
	January	1.25 ± 0.05		
	February	1 37 ± 0.04		

* Values are expressed as Mean ± SD

TABLE 3.16 Monthly and seasonal values of Biological Oxygen Demand (BOD) at various sampling stations of river Vishwamitri during 2000 – 2001.

SITES	BIOLOGICAL OXYGEN DEMAND (mg/L)			
	MONTH		SEASON	
STATION I	March	16.20 ± 1.30*	Summer	17.90 ± 2.13*
	April	19.60 ± 1.14		
	May	Dry		
	August	8.40 ± 1.14	Postmonsoon	9 47 ± 1.36
	September	9.40 ± 1.14		
	October	10.60 ± 0.89		
	December	9.40 ± 1 67	Winter	11.24 ± 1.94
	January	11.04 ± 0.62		
	February	13.28 ± 0.73		
STATION II	March	Dry	Summer	Dry
	April	Dry		
	May	Dry		
	August	31.20 ± 1.64	Postmonsoon	35 47 ± 5.24
	September	33.20 ± 2.17		
	October	42.00 ± 2 45		
	December	26.40 ± 1.67	Winter	26.40 ± 1.67
	January	Dry		
	February	Dry		
STATION III	March	98.80 ± 2.28	Summer	117.20 ± 16.02
	April	116.80 ± 2.39		
	May	136.00 ± 4.69		
	August	60.20 ± 2.86	Postmonsoon	92.15 ± 30.39
	September	85 44 ± 2.75		
	October	130.80 ± 4.15		
	December	74.00 ± 2.92	Winter	107.07 ± 29.13
	January	104.80 ± 3.70		
	February	142.40 ± 3.85		
STATION IV	March	222.80 ± 4.60	Summer	246.93 ± 21.82
	April	245.80 ± 5.59		
	May	272 20 ± 9.31		
	August	92.40 ± 3.29	Postmonsoon	140 13 ± 51.63
	September	119.40 ± 3.97		
	October	208.60 ± 7.54		
	December	170.40 ± 6.23	Winter	176.40 ± 14.86
	January	163.60 ± 4.56		
	February	195.20 ± 4.60		
STATION V	March	263.80 ± 6.80	Summer	324.40 ± 64.18
	April	301.20 ± 8.32		
	May	408.20 ± 16.19		
	August	178.00 ± 5.83	Postmonsoon	220 80 ± 42 08
	September	209.80 ± 6.87		
	October	274.60 ± 7.54		
	December	235.40 ± 5.18	Winter	261 33 ± 33.18
	January	242.80 ± 5.40		
	February	305.80 ± 7.50		

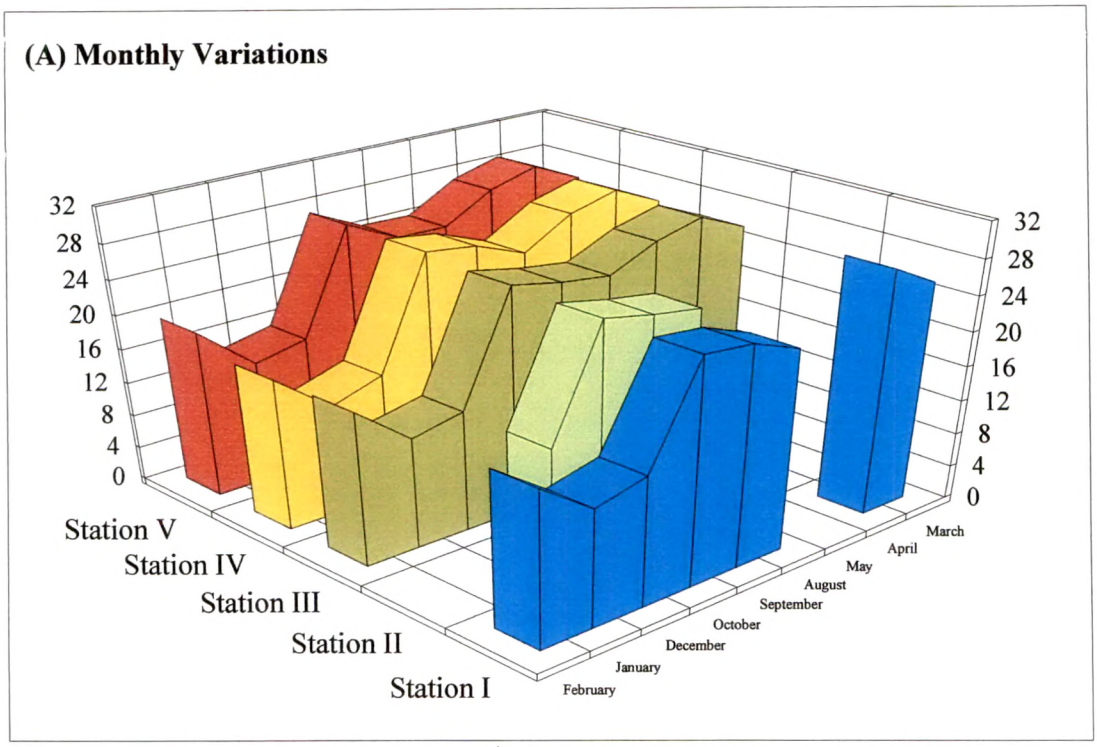
* Values are expressed as Mean ± SD

TABLE 3.17 Linear relationship between seasonal values of Shannon-Wiener diversity index and physicochemical parameters.

	Correlation coefficient (r)	Slope (b)
Temperature	0.237	0.0334
pH	–0.784**	–1.4066
Dissolved Oxygen	0.456	0.1606
Total Suspended Solids	–0.328	–0.0016
Chlorophyll – a	0.903**	0.0159
Biological Oxygen Demand	–0.646*	–0.0048
Nitrate Nitrogen	–0.300	–0.7375
Total Reactive Phosphate	–0.800**	–0.7214

* $p \leq 0.05$; ** $p \leq 0.001$

FIGURE 3.1 Variations in the temperature (°C) of water at various stations of River Vishwamitri during 2000 - 2001



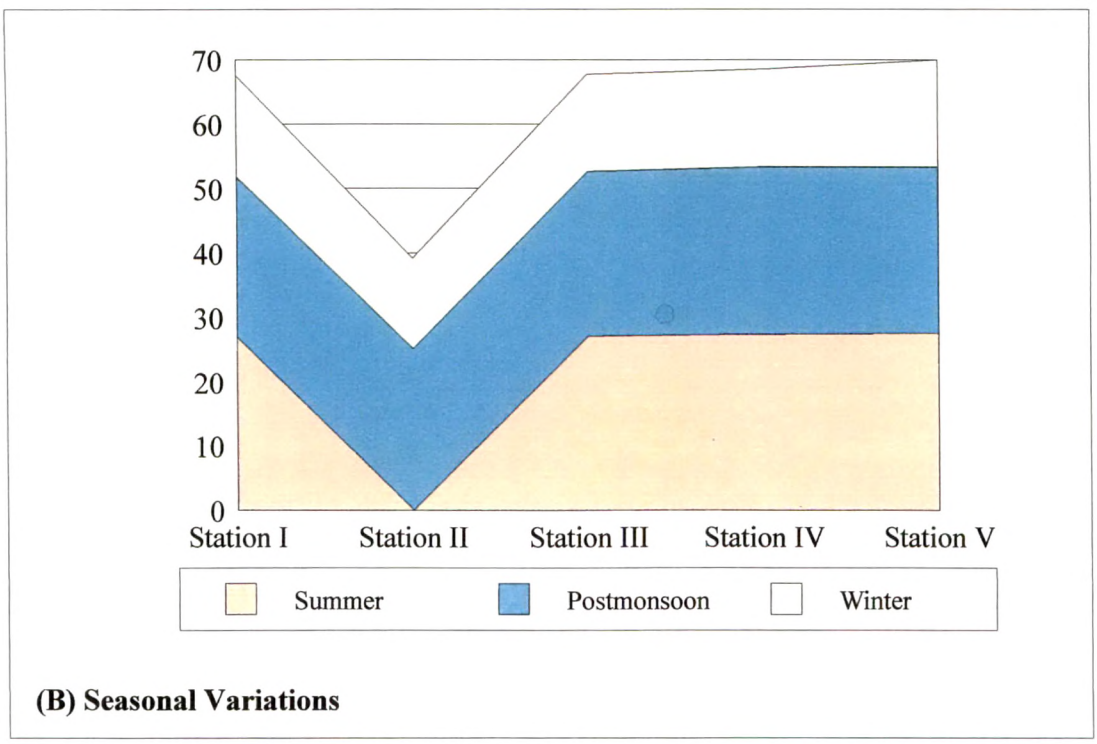
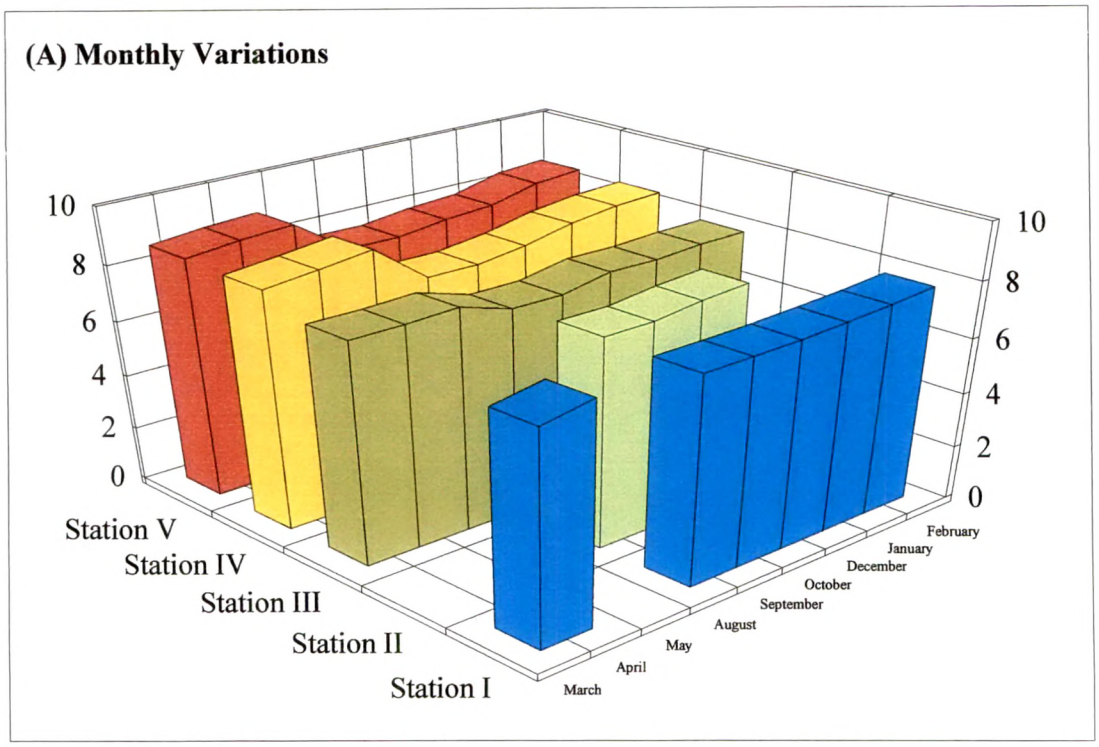


FIGURE 3.2 Variations in the values of pH in various stations of River Vishwamitri during 2000 - 2001



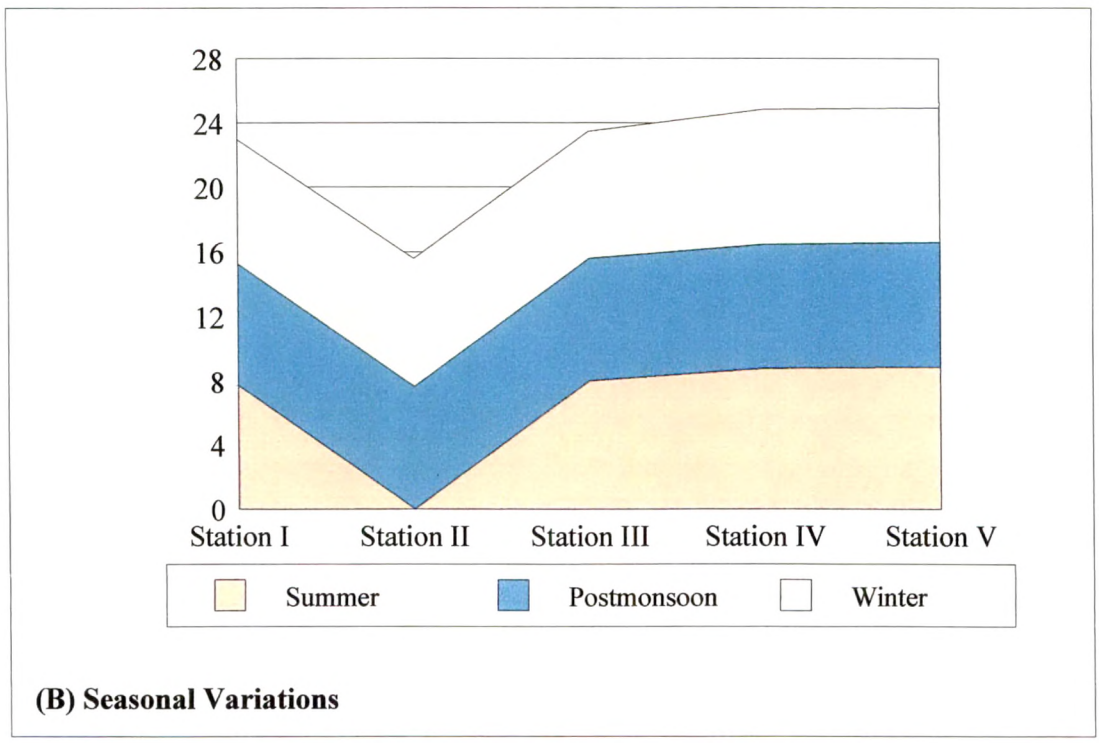
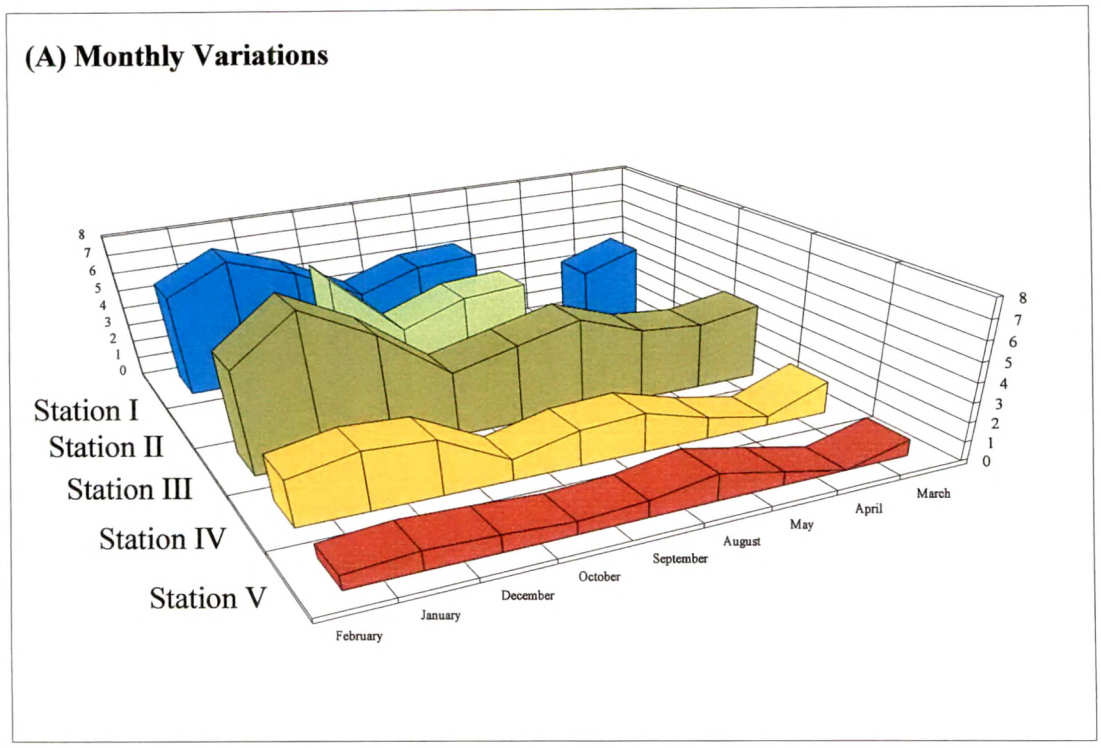


FIGURE 3.3 Variations in the levels of dissolved oxygen (mg/L) at various stations of River Vishwamitri during 2000 - 2001



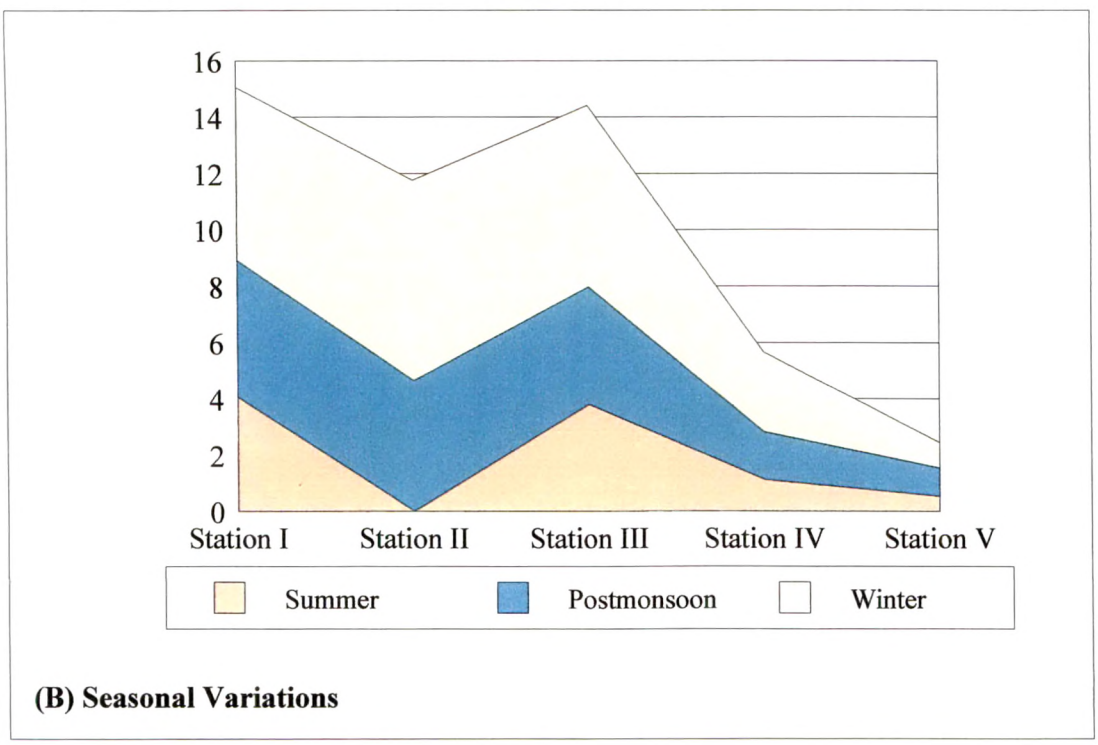
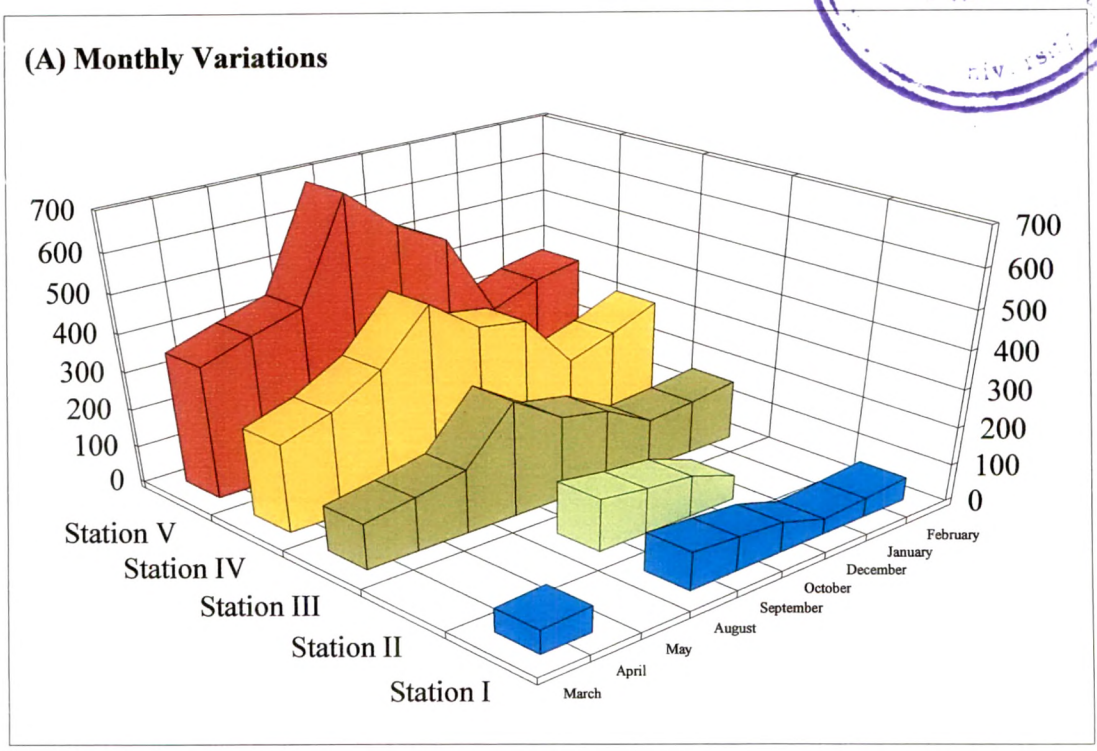


FIGURE 3.4 Variations in the levels of total suspended solids (mg/L) at various stations of River Vishwamitri during 2000 - 2001



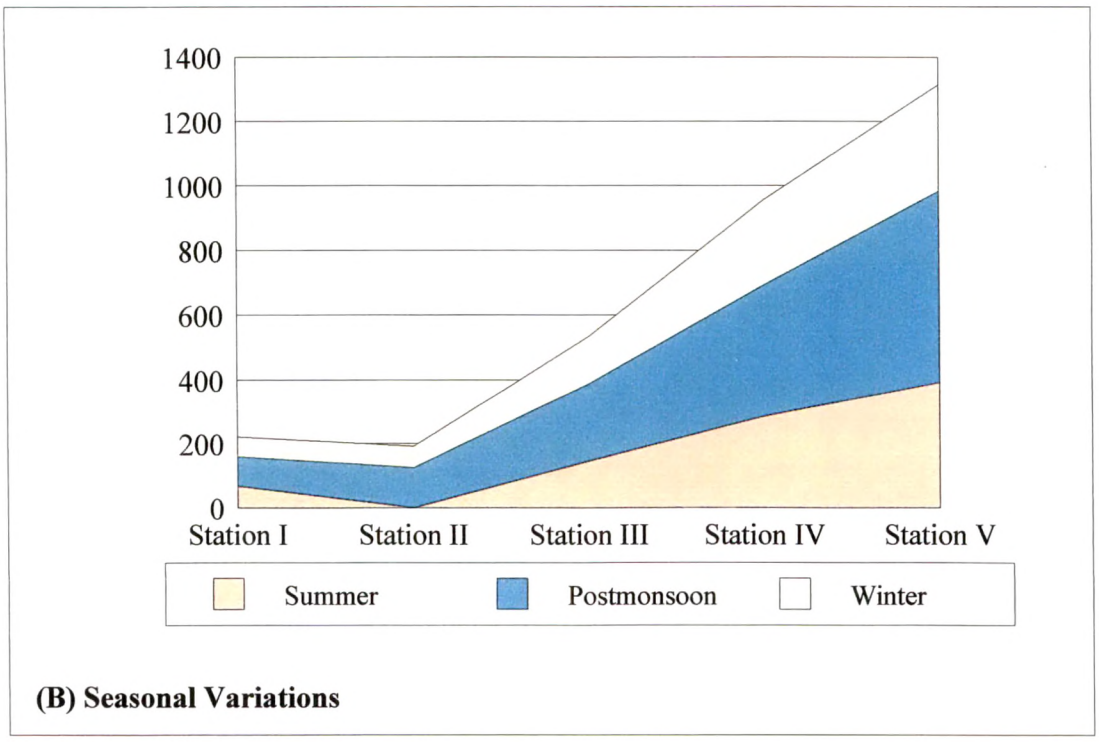
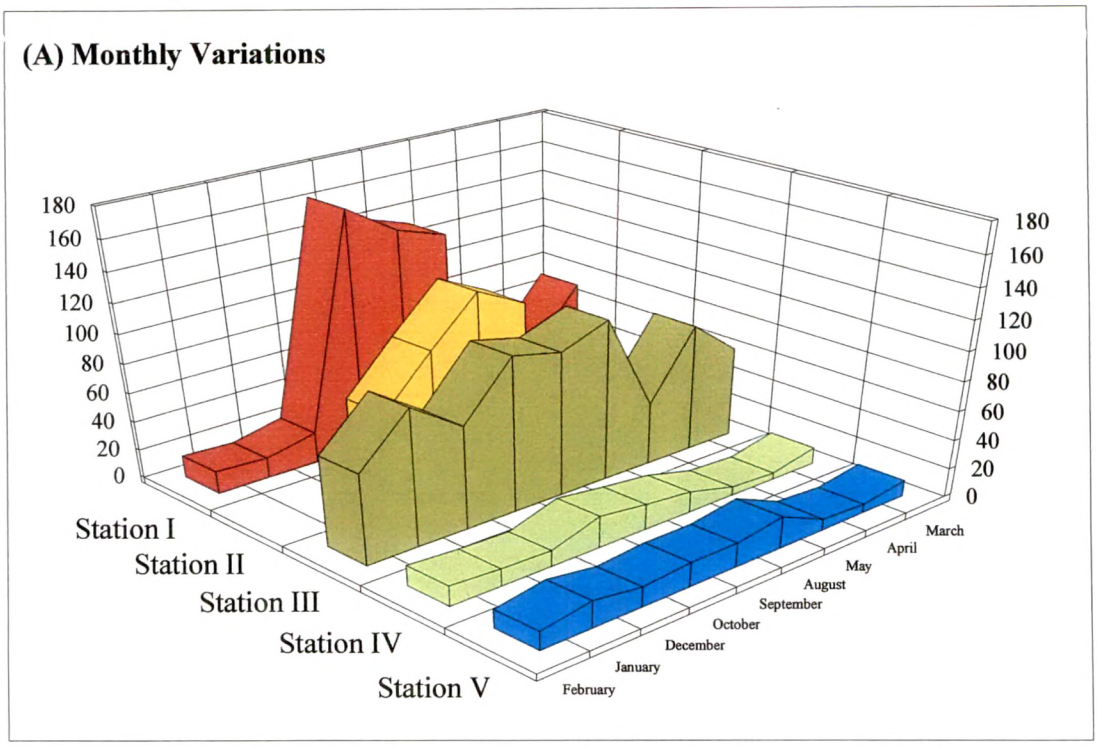


FIGURE 3.5 Variations in the levels of chlorophyll-a (µg/L) at various stations of River Vishwamitri during 2000 - 2001



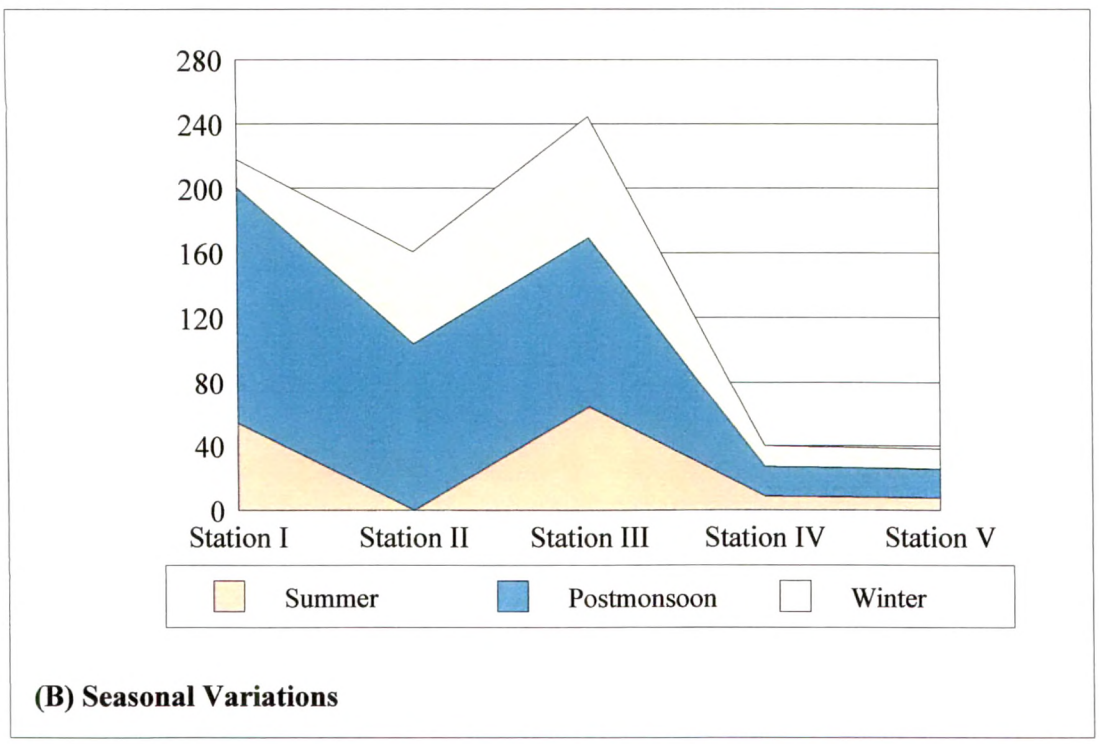
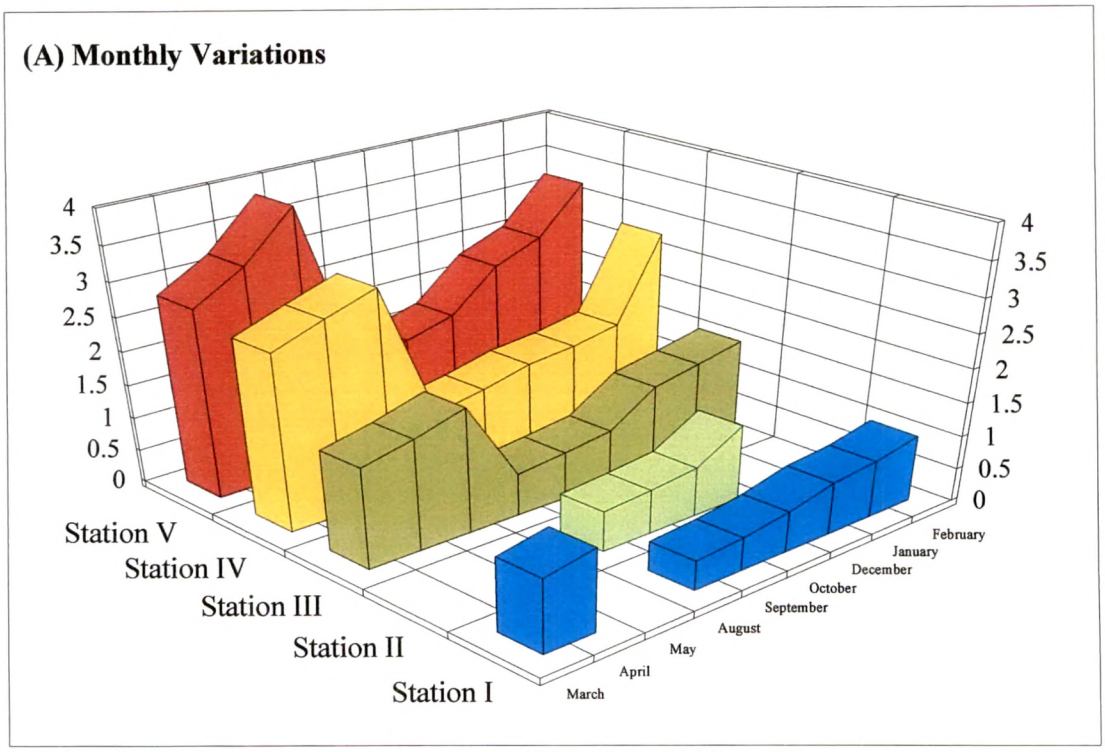


FIGURE 3.6 Variations in the levels of total reactive phosphate (mg/L) at various stations of River Vishwamitri during 2000 - 2001



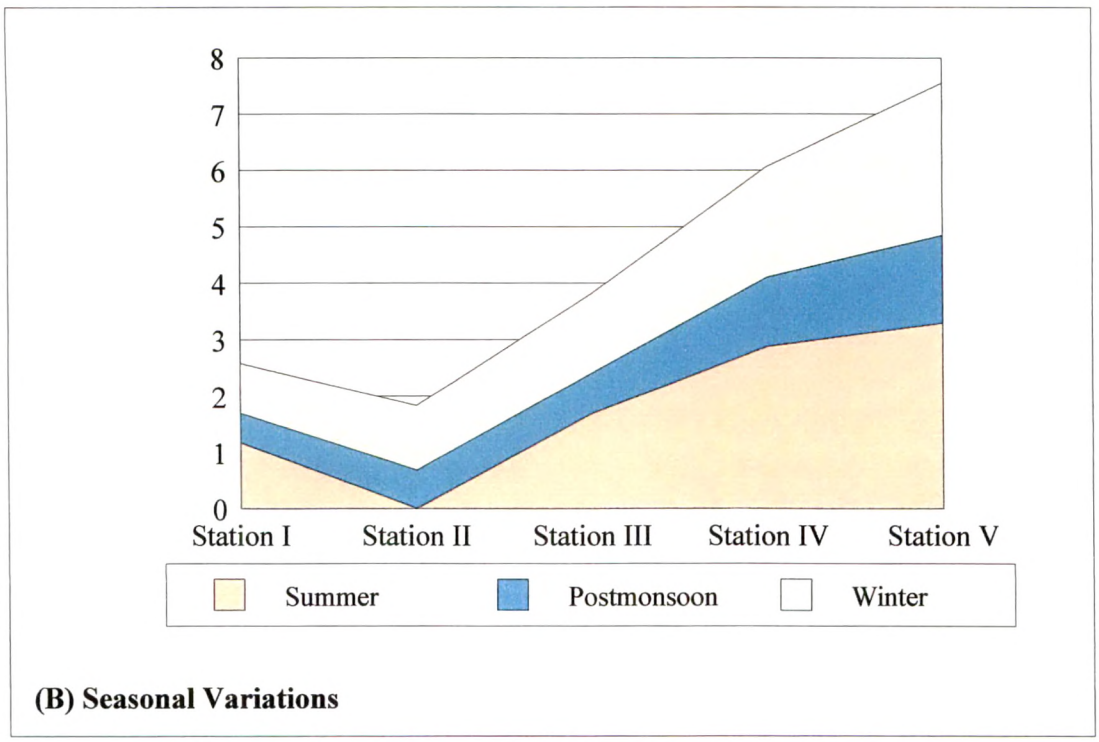
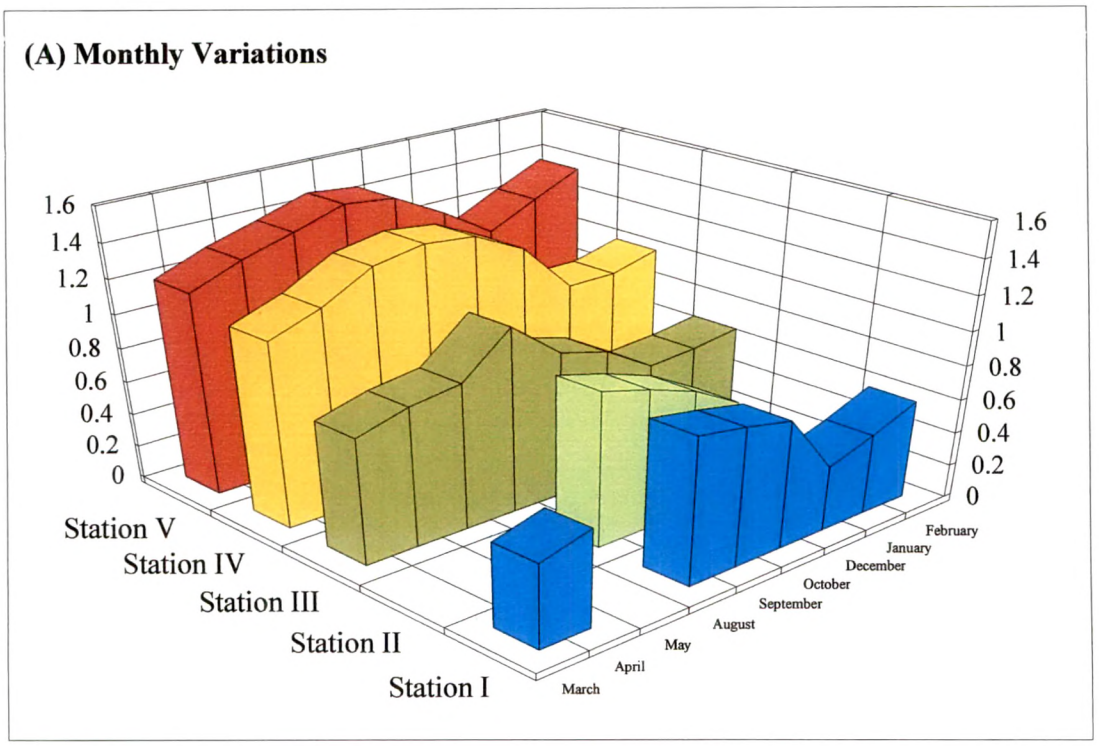


FIGURE 3.7 Variations in the levels of nitrate nitrogen (mg/L) at various stations of River Vishwamitri during 2000 - 2001



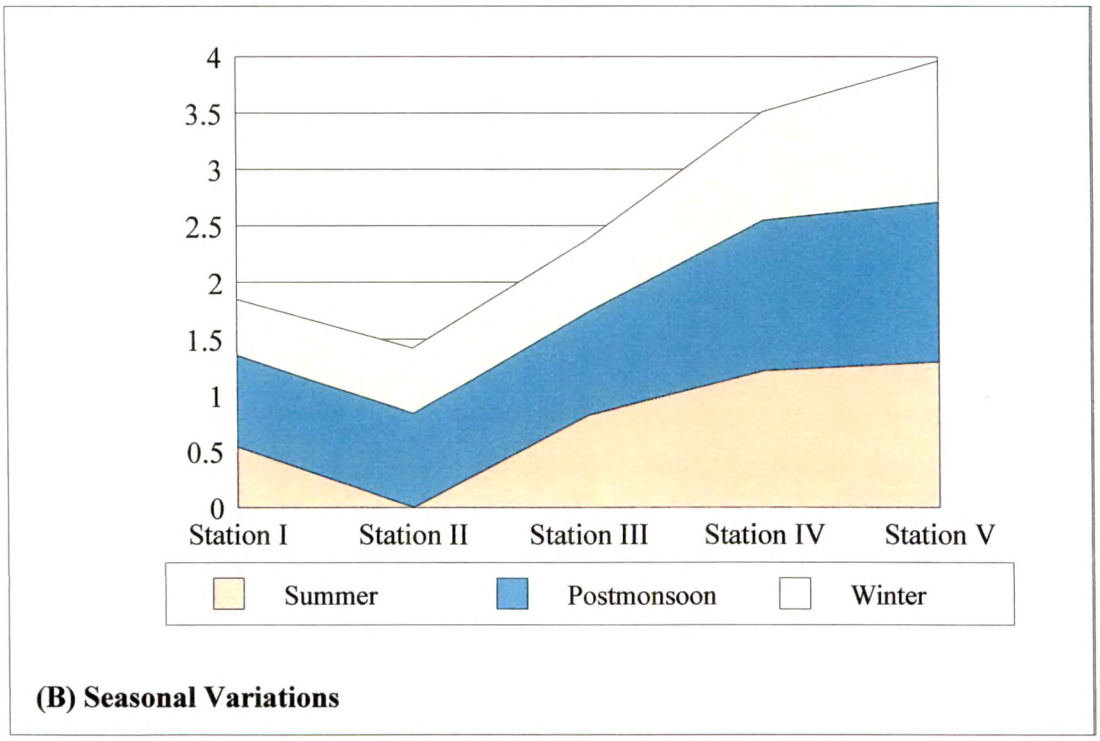
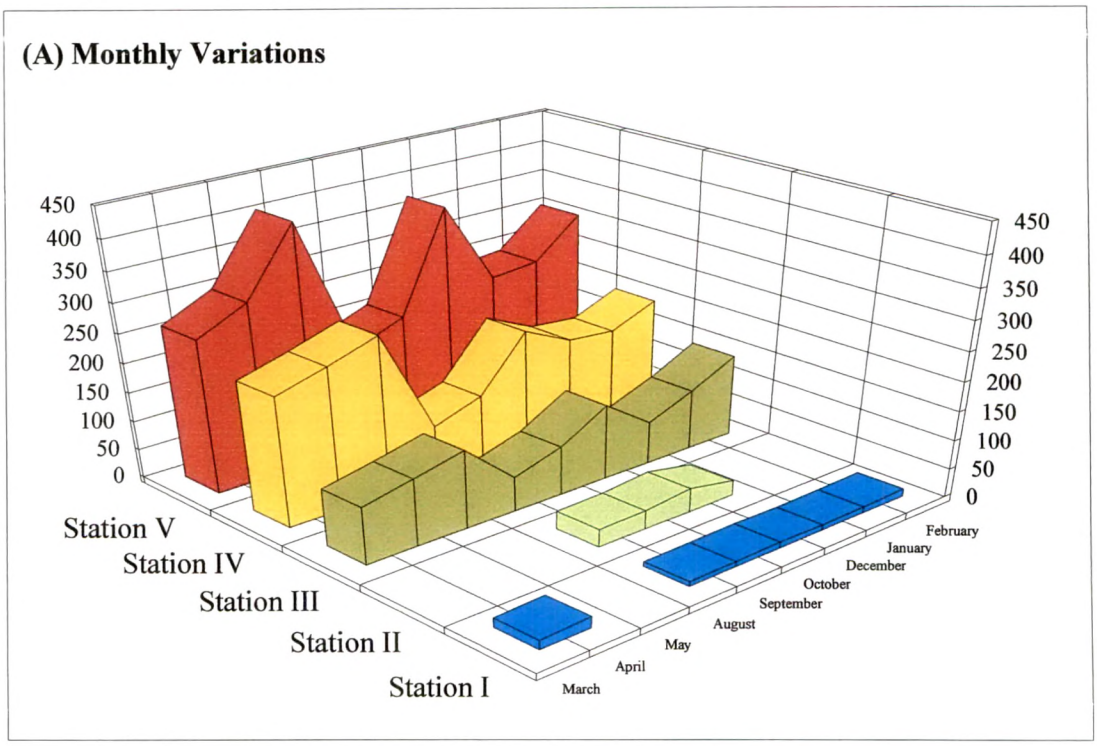


FIGURE 3.8 Variations in the levels of Biological Oxygen Demands (mg/L) at various stations of River Vishwamitri during 2000 - 2001



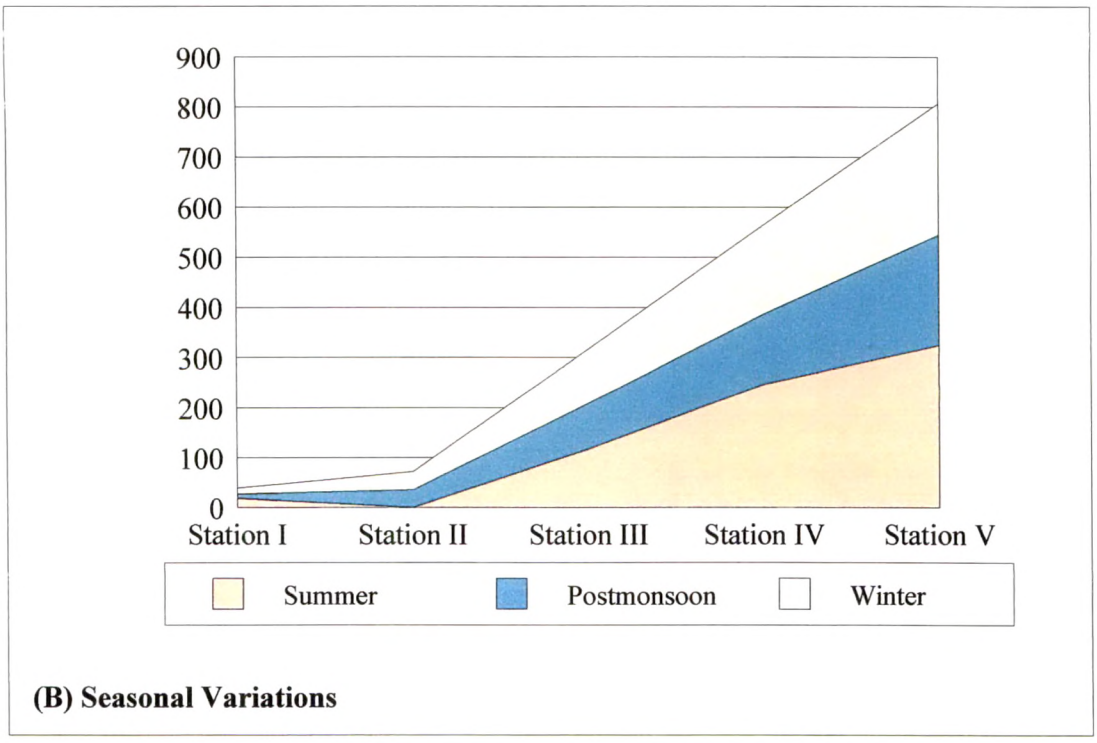


Figure 3.9 Seasonal variation in the temperature of water and rotifer diversity at various stations of River Vishwamitri during 2000-2001

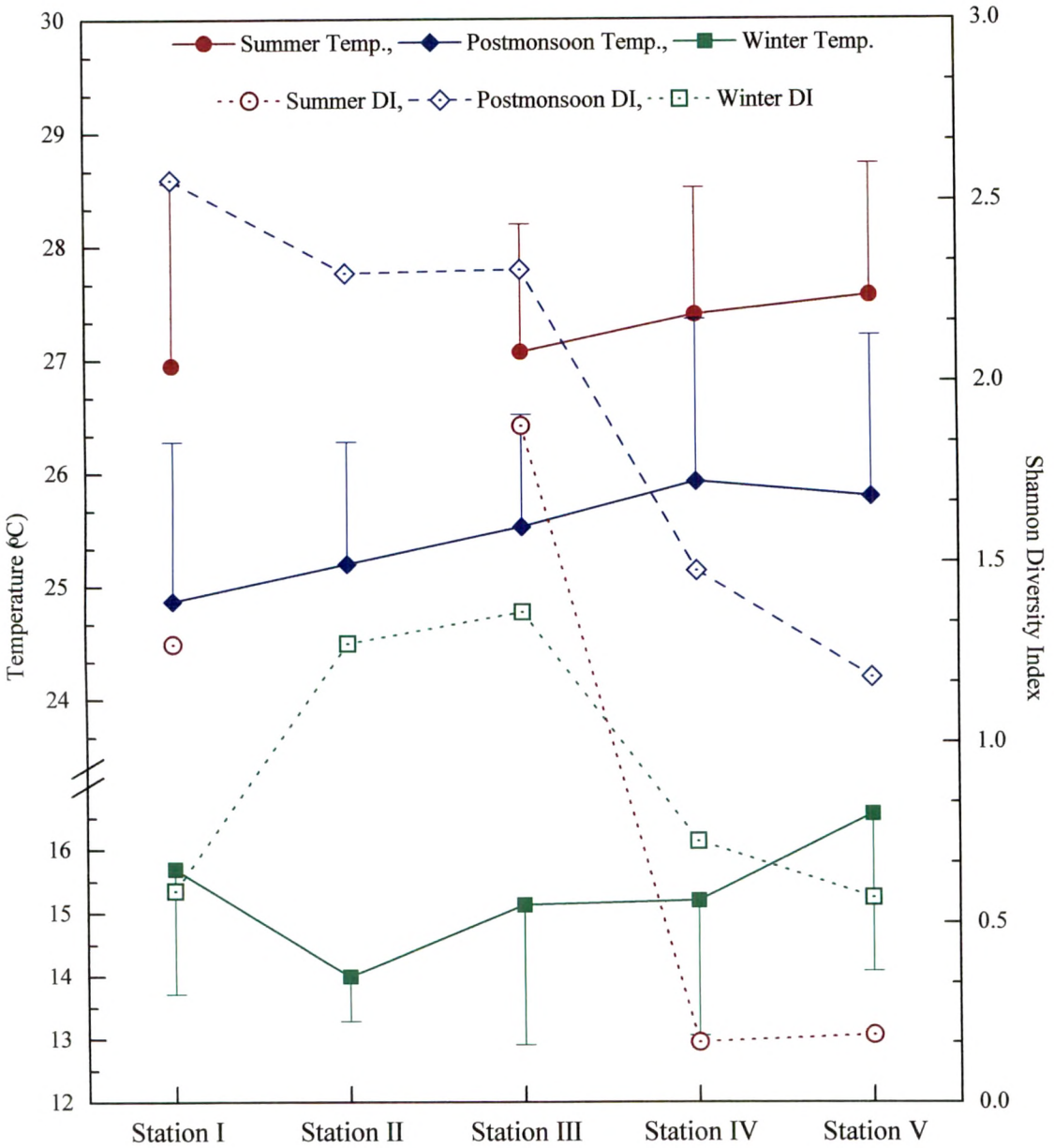


Figure 3.10 Seasonal variation in pH and rotifer diversity at various stations of River Vishwamitri during 2000-2001

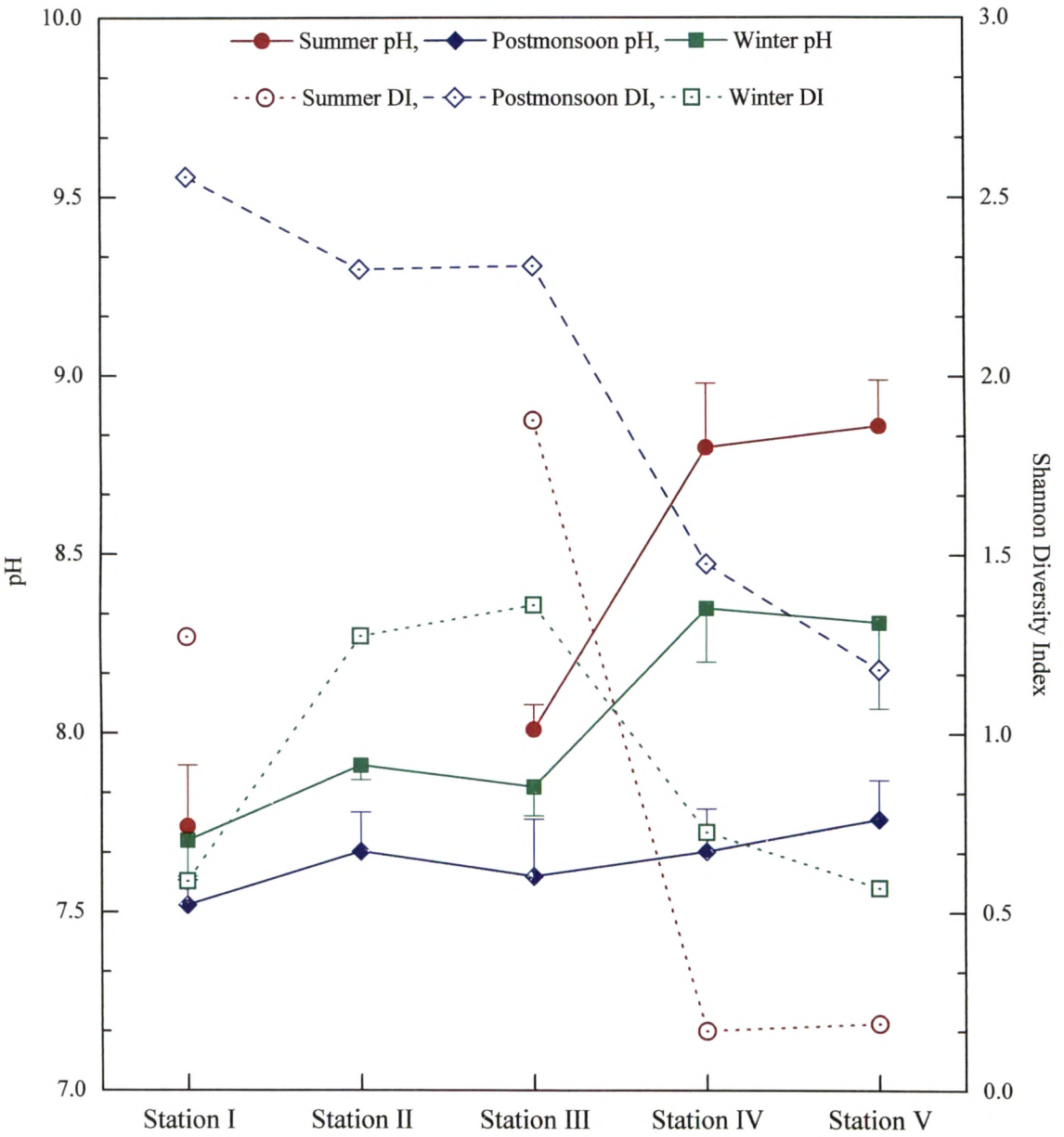


Figure 3.11 Seasonal variation in dissolved oxygen level and rotifer diversity at various stations of River Vishwamitri during 2000-2001

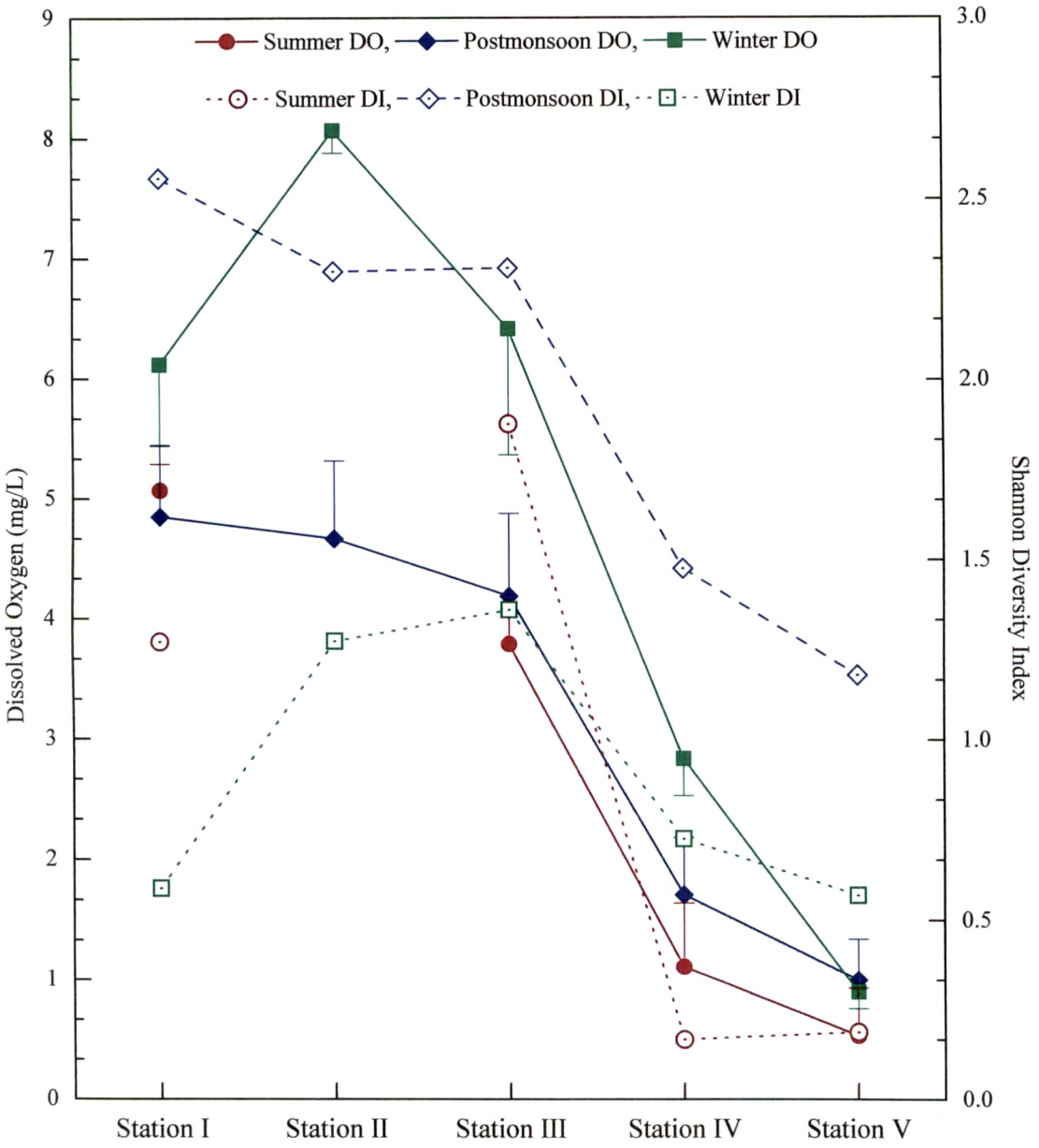


Figure 3.12 Seasonal variation in total suspended solids and rotifer diversity at various stations of River Vishwamitri during 2000-2001

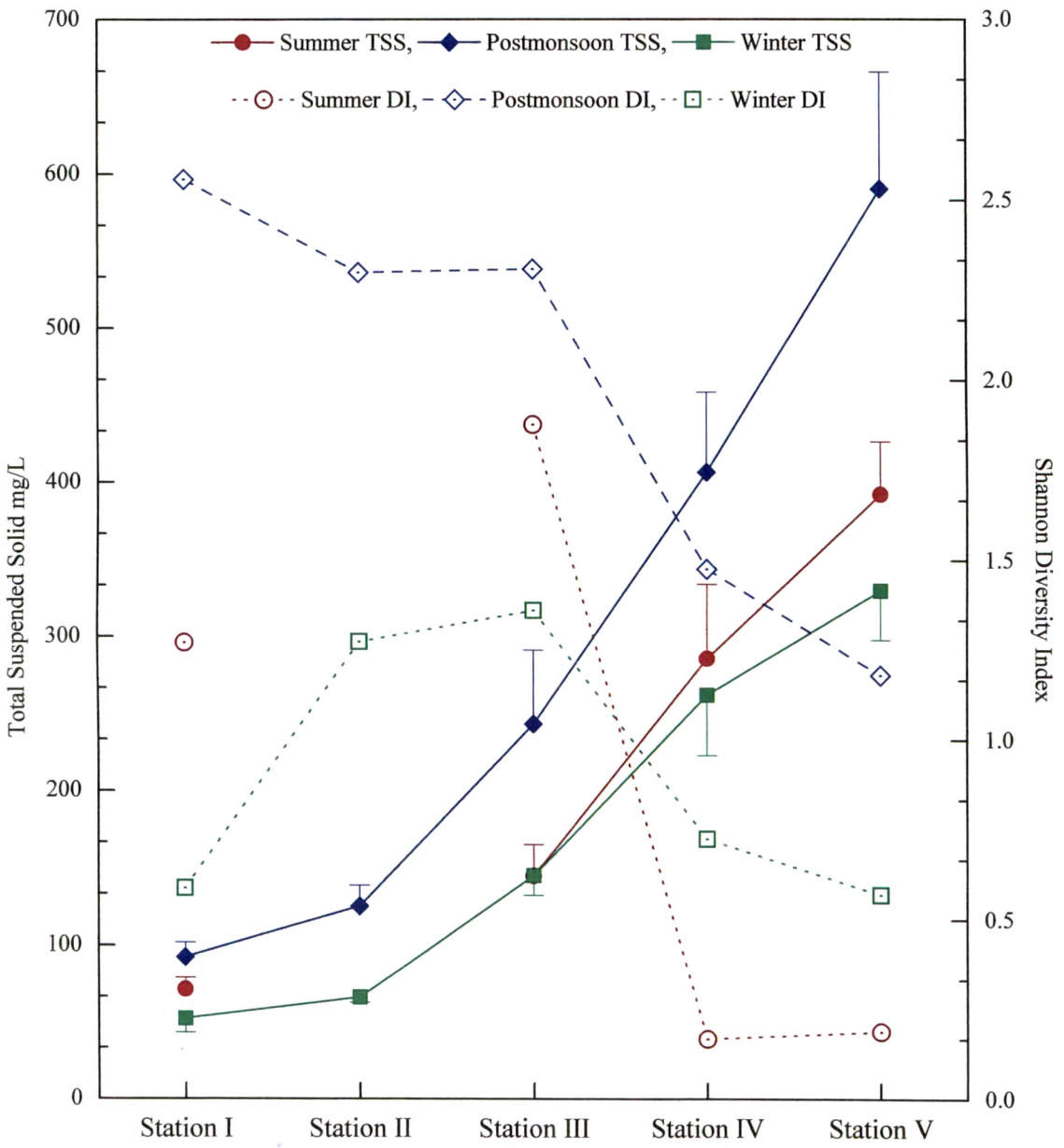


Figure 3.13 Seasonal variation in the levels of chlorophyll-a and rotifer diversity of River Vishwamitri during 2000-2001

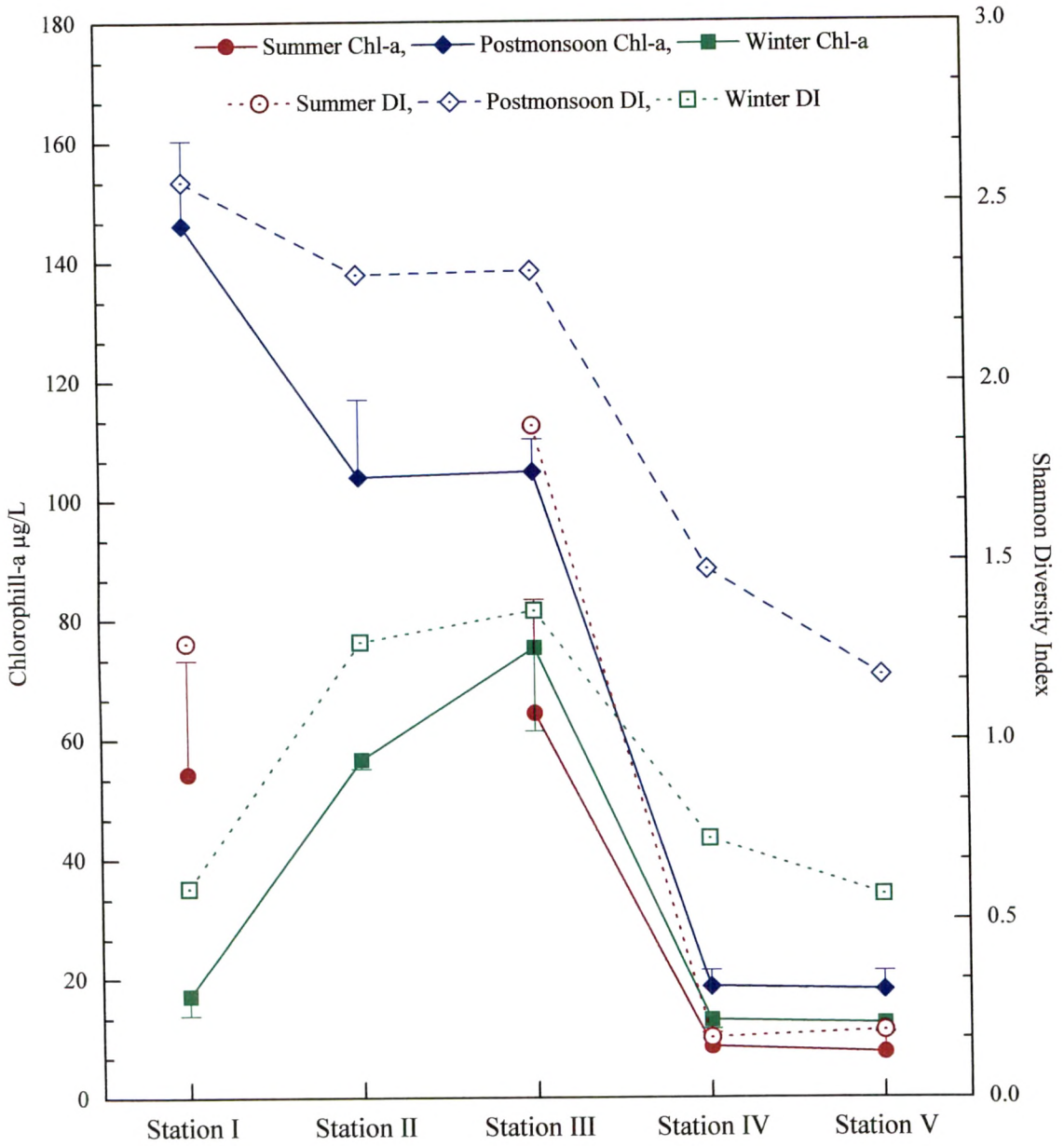


Figure 3.14 Seasonal variation in the amount of total reactive phosphate and rotifer diversity at various stations of River Vishwamitri during 2000-2001

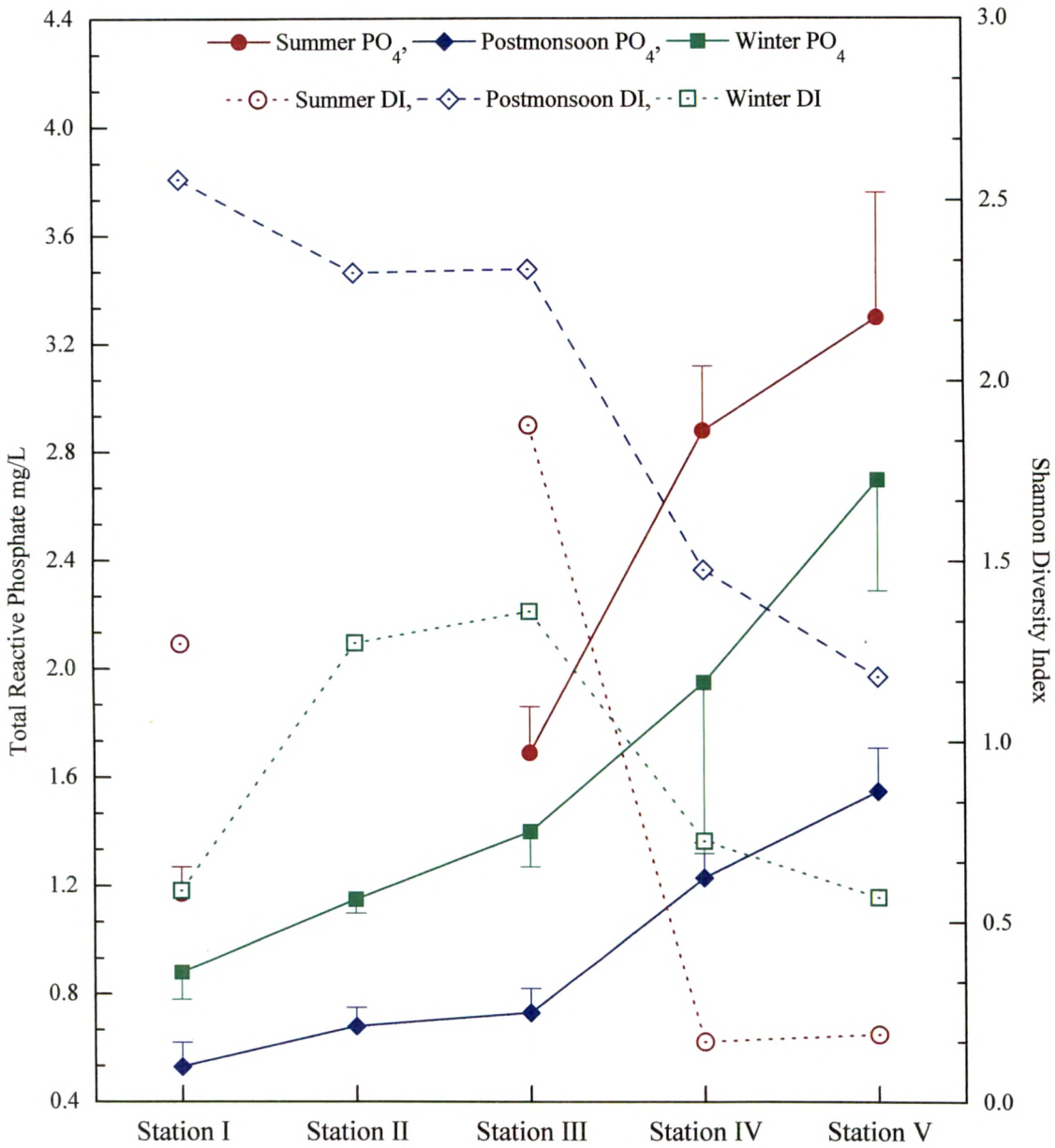


Figure 3.15 Seasonal variation in the concentration of nitrate nitrogen and rotifer diversity at various stations of River Vishwamitri during 2000-2001

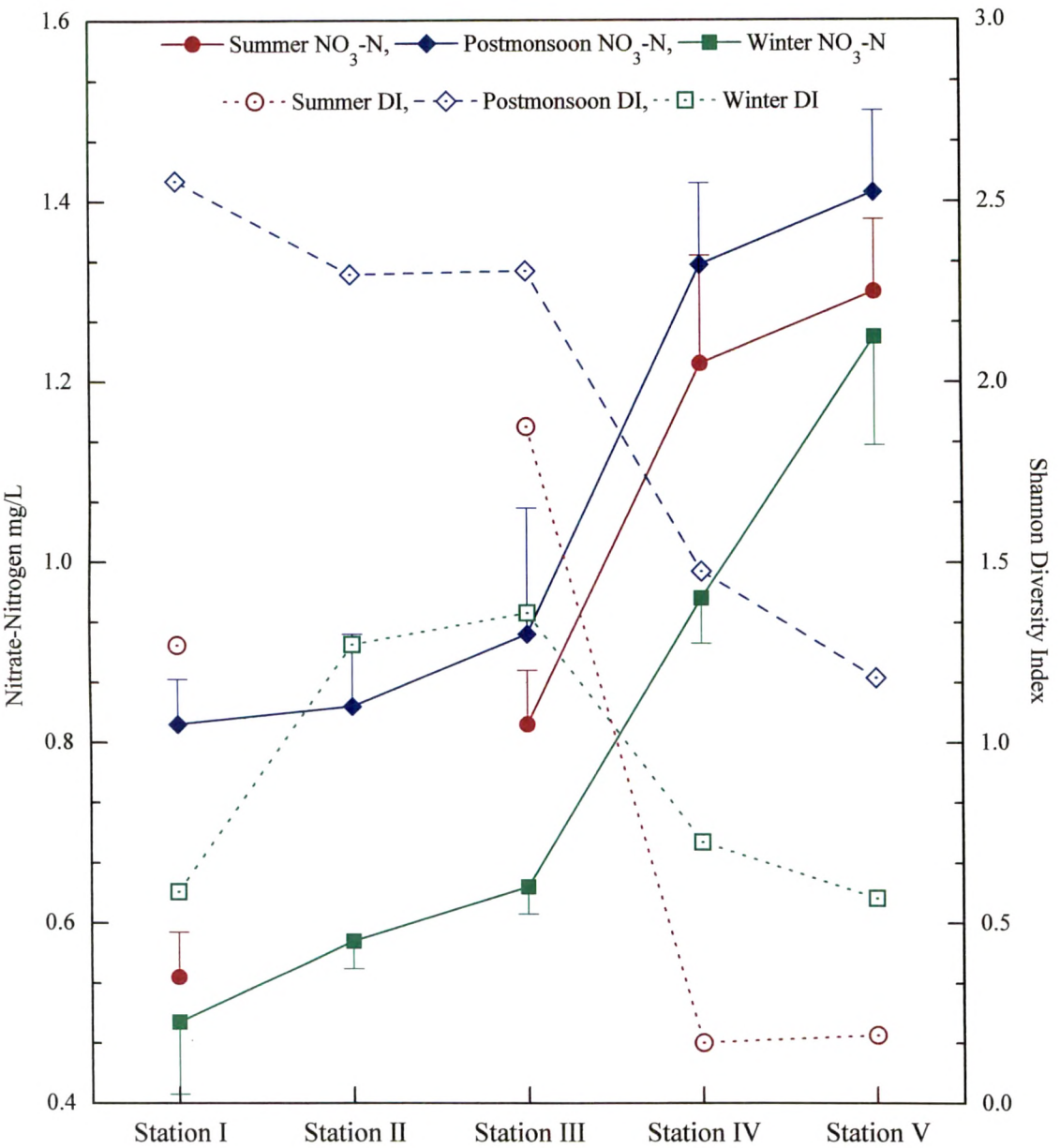


Figure 3.16 Seasonal variation in biological oxygen demand and rotifer diversity at various stations of River Vishwamitri during 2000-2001