A COMPARATIVE STUDY OF BIODIVERSITY BETWEEN POWAI AND VIHAR LAKES IN MUMBAI

Dissertation submitted in partial fulfilment

of the requirements

for the degree of

M. F. Sc. (Aquatic Environment Management)

by

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JUNE, 2011

DEDICATED TO MY FAMILY

Dated: 30 June 2011

CERTIFICATE

Certified that the dissertation entitled "**A COMPARATIVE STUDY OF BIODIVERSITY BETWEEN POWAI AND VIHAR LAKES IN MUMBAI**" is a record of independent bonafide research work carried out by **Mr. R. Ratheesh Kumar** during the period of study from September 2010 to June 2011 under our supervision and guidance for the degree of **Master of Fisheries Science (Aquatic Environment Management)** and that the dissertation has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

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I hereby declare that the dissertation entitled "**A COMPARATIVE STUDY OF BIODIVERSITY BETWEEN POWAI AND VIHAR LAKES IN MUMBAI**" is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

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ABSTRACT

A study was conducted to compare the physicochemical parameters and biodiversity with respect to phytoplankton, zooplankton, benthos and bacteria between two freshwater lakes, Vihar inside Sanjay Gandhi National Park and Powai in the urban area of Mumbai. Among the 42 important physicochemical parameters analyzed in water and sediment of both the lakes, 39 parameters showed significant difference ($p \leq 0.05$) between the two lakes. Most of the parameters showed higher values in Powai Lake compared to Vihar. The heavy metal concentrations (Cu, Fe, Ni, Cr, Mg, Pb and Hg) in both the lakes were within the permissible limits prescribed by World Health Organization. A total of 34 genera of phytoplankters, 12 genera of zooplankters and 11 genera of macro-benthic invertebrates were observed in Powai Lake, whereas in Vihar, it was 51, 16 and 19, respectively. DGGE analysis with PCR-amplified 16s rRNA gene using universal DGGE primers (BA 338F and UN 518R), and further sequencing of excised bands obtained from polyacrylamide gel revealed the nearest identity of 145 bacteria from water and sediment of both the lakes, which included 34 bacteria from Powai sediment, 30 from Vihar sediment, 40 from Powai water and 41 from Vihar water. All the biodiversity indices calculated (Simpson's index of diversity, Shannon index, Margalef species richness index and Pielou's evenness index) for phytoplankton, zooplankton and benthos using PRIMER software showed higher values for Vihar Lake compared to Powai, indicating higher diversity in Vihar compared to Powai. The algal pollution indices (Nyggard's index and Palmer's index) showed higher value for Powai Lake than Vihar Lake, indicating the eutrophic nature of the former. Factor analysis and analysis of variance test showed significant distinction of Powai and Vihar lakes based on different physicochemical and biological parameters studied. Physicochemical and biological evaluation proved that Powai Lake is organically polluted and is less biologically diverse, whereas Vihar Lake is comparatively more diverse, unpolluted and is suitable for public

water supply. However, Vihar Lake has reached the threshold level of water quality and requires concerted efforts to maintain the quality and biodiversity.

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1. INTRODUCTION

Life is unique to our planet, Earth, and it is the planet's most precious asset. The biodiversity of planet Earth is the total variability of life forms in it. The term "Biodiversity" was coined by Wilson (1988) as the contraction of "biological diversity". "Biological diversity" means the variability among the living organisms from all sources including inter alia, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part of; this includes diversity within the species, between species and of ecosystems" (CBD, 1992). It is this biodiversity that sustains such human activities as agriculture, fisheries and forestry, and is the basis of our civilisation. The biological resources, thus, provide food, clothing, shelter, medicine, etc. to human beings. The fossil fuels such as coal, oil and natural gas that support our industry are derived from plants and animals that dominated life on the Earth millions of years ago. Since time immemorial, human beings have been depending directly or indirectly on the surrounding biodiversity and thus, biodiversity is an important contributing factor for the existence of mankind on this planet.

The exact number of species in our planet is not known; many estimates range from 10 to 20 million and India may have close to a million species, the vast majority of which remains to be named or described. The number of species that are unique to India is also high. The land mass of India incorporates four (Western Ghats, Himalayas, Indo-Burma and Nicobar islands) of the 34 global hot-spots identified, with a high proportion of endemic species and a very high rate of biodiversity loss.

This diversity, a product of billions of years of evolution, has been rapidly declining in the recent years by demographic and developmental pressure, and the climate change is exacerbating the rapid loss. Because of our intimate association with biodiversity, the loss of which is threatening our survival, it is high time to curtail the loss.

Reducing the loss of our precious biodiversity requires a comprehensive programme of documentation, monitoring and a people-oriented conservation paradigm that extends beyond the protected areas. We, therefore, urgently need to document life and at the same time, assess the changes in biodiversity and the factors influencing these changes. Cataloguing the life forms and analysing the factors influencing it form the basis of conservation.

Aquatic ecosystems are among the most diverse ecosystem types worldwide. The aquatic biodiversity is largely responsible for maintaining and supporting overall environmental health and human sustainability. Majority of India's population lives in cities, making urbanisation one of the most significant drivers of environmental change. Most water bodies become contaminated due to the incorporation of untreated solid and liquid waste, and due to other anthropogenic activities in the name of development. The rapidly expanding human population within the catchment area has brought about a series of changes in the biotic components of the lakes (Pandit, 2002). In recent years, the biologically-rich habitats have been destroyed mainly due to habitat destruction, over-harvesting, pollution, and inappropriate introduction of exotic plants and animals (Kulshrestha, 2005). In this process, the valuable ecosystem services contributed by water bodies, including biodiversity support, nutrient cycling, bioremediation, etc. are being irreplaceably lost. Changes in the water quality are reflected in the biotic community structure as shown by the occurrence, diversity and abundance pattern of species (Sanjar and Sharma, 1995). Hence, understanding the ecology and biodiversity of such an ecosystem helps in adopting proper management measures.

Freshwater systems are estimated to contain about 10% of all animal species on earth (Balian *et al.,* 2008). But community and species diversity estimates mostly refer to the macro-biological level of fishes, and it is likely that the species richness of microorganisms, which greatly contribute to the functional biodiversity of freshwater ecosystems, has been underestimated (Johns and Maggs, 1997; Gessner and Van Ryckegem, 2003).

There are numerous natural and artificial ponds, reservoirs and lakes in the Indian subcontinent (Rao, 1975). Several workers have attempted to study the hydro-biological profile and the biodiversity of the microorganisms in these lakes (Sing, 2000; Patil and Karikal, 2001; Sukand and Patil, 2003). The most important microorganisms in an aquatic ecosystem are plankton, bacteria and fungi. The phytoplankton serve as the producers in the food chain in an aquatic ecosystem and their productivity depends upon the quality of water. The abundance of zooplankton depends upon the availability of phytoplankton and they form the second trophic level in the aquatic food chain.

The phytoplankton, zooplankton and benthos provide food for fishes, and therefore, play a key role in fish production, which is the apex of aquatic productivity. Sustaining biodiversity of these organisms is essential to the health of our environment, to maintain the trophic dynamics and for the quality of human life. These microorganisms often respond quickly to environmental changes; so, the magnitude and dynamics of these organisms can also provide important indication of the quality of the system. Phytoplankton, zooplankton, benthos and other microorganisms of freshwater lakes/rivers have been studied extensively in India (Pati and Sahu, 1993; Bose and Lakra, 1994; Acharjee *et al.,* 1995; Baruah *et al.,* 1997; Anitha *et al.,* 2004; Pawar and Pulle, 2005).

Considering the above facts and remembering 2010 as the international year of biodiversity, the present work was carried out to assess, understand and compare the physicochemical parameters and the biodiversity with respect to phytoplankton, zooplankton, benthos and bacteria between Vihar Lake (inside Sanjay Gandhi National Park and thus, protected) and Powai Lake (in the urban area of Mumbai) for a short period of time. Such studies have been conducted earlier by Anon (1998), Biswas and Konar (2000), and Thorat and Sultana (2000). However, only meagre information is available on the ecology of Vihar and Powai lakes in Mumbai. Keeping this in view, it was thought to study and compare the biodiversity between the two lakes with reference to pollution, with the following objectives:

1. To compare the biodiversity between Powai and Vihar lakes with respect to phytoplankton, zooplankton and benthic organisms
2. To compare the water and sediment quality parameters between the two lakes

2. REVIEW OF LITERATURE

2.1. Definition of biodiversity

Wilson (1988) coined the term “biodiversity’ as a simple contraction of “biological diversity”. There are many accepted definitions given for biodiversity (Mc Allister, 1991; Purvis and Hector, 2000). The Convention on Biological Diversity in Article 2 defined biodiversity as “variability among living organisms from all sources which includes diversity within species, between species and of ecosystems”. The definition given by the United States Congress Office of Technology Assessment (OTA, 1987) is perhaps the most widely cited one – “Biological Diversity refers to the variety and variability among living organisms, and the ecological complexes in which they occur”.

2.2. **Importance of biodiversity**

Ehrlich and Ehrlich (1992), pointed out that biodiversity is important and needs conservation for economic, ecological, moral, social and legal reasons. It is this biodiversity that sustains such human activities as agriculture, fisheries and forestry, and is the basis of our civilisation. Biodiversity is the basis of all life on earth, providing food for man and a healthy ecosystem that sustains this food supply. But our knowledge on biodiversity is very poor, with not more than one-tenth of the world’s species presently known (Langrath, 1994). The growing awareness of biodiversity issues has brought the need for comparable and meaningful measure of diversity (Gray, 1997; McCann, 2000). The protection of biodiversity and its conservation is an insurance policy for future generations; even the forms of life that may appear to provide no human benefit now may become important as conditions may change over the coming centuries (Singh, 2004). Understanding the consequences of biodiversity changes on ecosystem functioning is becoming increasingly critical in view of the profound influence of human activity on natural ecosystems (Vitousek *et al.,* 1997), and the goods and services humans receive from them (Daily *et al.,* 2000).

2.3. Factors influencing aquatic biodiversity

The decreasing biodiversity is a threat for mankind as it destabilizes the ecosystem functioning. There is an urgent need not only to conserve, but also to improve the biodiversity level. The factors controlling the biodiversity of an area, and thus ecosystem function, are central to biodiversity research (Tilman, 2000). In recent years, the biologically-rich habitats have been destroyed mainly due habitat destruction, over-harvesting, pollution, and inappropriate introduction of exotic plants and animals (Kulshrestha, 2005). The rapidly expanding human population within the catchment area has brought about a series of changes in the biotic components of lakes (Pandit, 2002). Changes in the water quality are reflected in the biotic community structure as shown by the occurrence, diversity and abundance pattern of species (Sanjar and Sharma, 1995). Unplanned urbanization, rapid industrialization and indiscriminate use of artificial chemicals in agriculture are causing heavy and varied pollution in aquatic environments leading to deterioration of water quality and depletion of aquatic biota (Yeole and Patil, 2005).

2.4. Physicochemical parameters and nutrients

Without the knowledge of water and sediment characters, it is difficult to understand the biological phenomenon fully, because they reveal much about the general hydrobiological interrelationships. The influence of various factors on the seasonal appearance of plankton differs significantly, with the physical factors (such as temperature, depth and light intensity) being the most important and chemical (dissolved oxygen, hydrogen ion concentration, salinity, alkalinity, electrical conductivity and nutrient level) being of lesser importance (Reynolds, 1984). The relation between physicochemical parameters and diversity of organisms in the Indian context has been studied by Hedge (1985), Pollinger *et al.* (1988), Kulshreshtha *et al.* (1989), Adholia (1991), Narasimha *et al.* (2001), etc. The biodiversity of phytoplankton, zooplankton and benthos in the water body shows a correlation with reference to their occurrences, physicochemical factors and level of nutrients (Pai and Berde, 2005).

Eutrophication is another important problem that needs to be addressed. Nutrient enrichment is accompanied by structural changes in the food-webs of lakes and it makes substantial changes in fish communities and in zooplankton, phytoplankton and macrophyte assemblages (Rognerud and Kjellberg, 1984; Wright and Shapiro, 1984; Bosselmann and Riemann, 1986; Persson *et al.,* 1991). Increase in freshwater biodiversity due to the increase in nutrient concentration had been discussed in different studies (Leibold, 1999; Dodson *et al*., 2000; Dudgeon *et al*., 2006). Changes in the water quality are reflected in the biotic community structure as shown by occurrence, diversity and abundance pattern of species (Sanjar and Sharma, 1995). Hence, understanding the ecology and biodiversity of such an ecosystem helps in taking proper management measures.

2.4.1. Temperature

Temperature is known to play a prime role in the productivity of water by influencing the abundance of primary producers on which the primary consumers depend for food source and it affects not only the metabolic activities of plankton, but also their proliferation (Shukla *et al.,* 1991). Prasad (1956) has stated that temperature is the determining factor in the seasonal distribution of organisms.

2.4.2. Transparency

Light penetration in water depends upon the quantity of suspended particulate matter (Odum, 1971). Variation in light penetration may cause more drastic changes in plankton production. Hart (1988) correlated changes in zooplankton composition with changes in water transparency in a turbid subtropical reservoir.

2.4.3. Electrical conductivity

Conductivity is a measure of the total amount of ions present in a water body (Welcomme, 1976). It affects the degree of mineralization in water bodies (Junk, 1973). According to Jhingran (1988), the electrical conductance of a water body reflects the total quantity of dissolved solids and serves as a reliable indication of the edaphic characteristics.

2.4.4. Hydrogen ion concentration

According to Reynolds *et al.* (1968), pH is the most important factor regulating plankton density. George (1997) pointed out that the variation in pH is an important parameter in a water body since most of the aquatic organisms are adapted to the average pH and do not withstand abrupt changes.

2.4.5. Depth

Depth is the most important parameter among the various morphometric factors which are correlated with productivity. Shallower water bodies (lakes) have a large proportion of their substrates available in the euphotic zone (Dale and Gillespie, 1977; Purohit and Singh, 1981). Shallower lakes provide greater mixing and circulation of heat and nutrients and hence, have greater productivity. Consequently, populations of bottom fauna and sustained production of commercial fish are inversely correlated with mean depth (Rawson, 1955).

2.4.6. Dissolved oxygen

The main sources of dissolved oxygen (DO) are dissolution from the atmosphere and photosynthesis. DO is removed from the natural waters through the respiration by the biota and the decomposition of organic matter. The former depends on factors like temperature, salinity and the density of phytoplankton (Kadam *et al.,* 2005). Nandan and Patel (1991) stated that DO shares a direct relation to algal periodicity. It has also been established that there exists no better general indicator of water quality than DO.

2.4.7. Biochemical oxygen demand

Biochemical oxygen demand (BOD) has been used as a measure of the quantity of organic materials in an aquatic solution, which support the growth of microorganisms (Nandan and Patel, 1991). Higher values of BOD indicate higher consumption of oxygen and a higher pollution load. BOD is a chemical procedure for determining the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific period of time.

2.4.8. Total organic carbon

Total organic carbon (TOC) provides a speedy and convenient way of determining the degree of organic contamination. TOC in waters comes from decaying natural organic matter (NOM) and from synthetic sources. Humic acid, fulvic acid, amines and urea are types of NOM. Detergents, pesticides, fertilizers, herbicides, industrial chemicals and chlorinated organics are examples of synthetic sources. TOC provides an important role in quantifying the amount of organic contamination in water (Hendricks, 2007).

2.4.9. Alkalinity

It is reported that alkaline pH is favourable for good plankton growth and indicates its unpolluted nature (Mahajan and Kanhere, 1995). Higher values of total alkalinity might be due to the presence of excess free carbon dioxide produced as a result of decomposition process coupled with the mixing of sewage and industrial effluents (Mohanta and Patra, 2000).

2.4.10. Ammonia

The nitrogen-containing organic compounds are usually broken down by a series of microbial enzymatic actions resulting in the formation of ammonia, carbon dioxide and other end products. It was reported that ammonia is the most reliable single parameter for measuring the quality of river water (Loster, 1975). Higher concentration of ammonia is harmful to fish and other biota (Jhingran, 1991). The acidic condition of water may reduce the toxicity of ammonia due to the conversion of unionized ammonia to ammonium ions (Schmittou *et al.,* 1998).

2.4.11. Phosphate and nitrate

Excess concentration of nitrates and phosphates brings eutrophication, and it stimulates algal bloom (Bahura, 1998), the process that sets a chain of destruction events leading to the gross pollution of a water body (Kodarkar *et al.,* 1999). The determination of phospahate level is useful in measuring the water quality since it is an important plant nutrient and may play the role of a limiting factor among all the other essential plant nutrients (Thirumala *et al.,* 2006). Nitrate is one of the most important nutrients in an aquatic ecosystem; generally water bodies polluted by organic matter exhibit higher values of nitrate (Shanti *et al*., 2002).

2.4.12. Sodium, potassium, calcium and magnesium

Nutrients like sodium and potassium are responsible to improve biological production (Sharma, 2000). The contents of calcium and magnesium in water bodies may range from zero to several hundred milligrammes per litre (Sharma, 2000). In the aquatic environment, calcium serves as the main micronutrient for most of the organisms and magnesium is essential for the growth of chlorophyll-bearing algae and plants (Jhingran, 1991; Sharma, 2000). The hardness of a water sample depends on a complex mixture of the cations and anions, predominantly contributed by calcium and magnesium (Mairs, 1966). The ionic composition is responsible for affecting the ecology of freshwater organisms, particularly phytoplanktors as observed by Lund (1965). Sodium and potassium are supposed to be the limiting factors for biological productivity of water, as reported by Moyle (1949).

2.4.13. Heavy metals

The term “heavy metal” is widely used in literature with reference to several elements beginning with beryllium and going up to the actinides (Nair, 1984). Industrialization and urbanization have increased the anthropogenic contribution of heavy metals in the biosphere. The aquatic environment is frequently the ultimate recipient of heavy metal pollution. The prolonged exposure to metal-contaminated water is dangerous for public health and aquatic organisms (Obasohan *et al.,* 2006). Most of the ionic forms of metals are toxic to living organisms at higher concentrations, while some metal ions are toxic even at lower concentration and very few metal ions such as mercury and lead are toxic even in trace quantities (Mule and Patil, 2000). Higher content of lead in drinking water has adverse effect on central nervous system, blood cells and kidney, and may cause brain damage (Zaheeruddin and Khurshid, 1998).

The metals like iron, manganese, copper, zinc, nickel, chromium, etc. are essential for the proper functioning of biological systems. Their deficiency or excessive consumption may results in health hazards. Zaheeruddin and Khurshid, (1998) reported that the presence of heavy metals such as lead, mercury, cadmium, etc. makes the water unfit for aquatic organisms as well as for agricultural and irrigation purposes. In spite of this, some of the heavy metals are important. Metals like zinc, copper, iron, manganese, molybdenum, nickel, chromium and cobalt are called micronutrients and are toxic when taken in excess of the requirement (Blaylock and Huang, 2000).

The investigation on heavy metals in the sediment is essential to assess the extent of pollution in an aquatic system. Sediment has aptly been called as "trace element trap" (Chesyter and Stoner, 1975) because they eventually receive almost all the heavy metals, which enter the aquatic environment (Greig and Mc Grath, 1977). Iron is a relatively reactive element and occurs in three oxidation states: metallic iron (Fe 0); ferrous iron (Fe-II or Fe^{2+}); and ferric iron (Fe-III or Fe^{3+}). Chromium usually appears most commonly in the environment as a trivalent salt (Cr-III or Cr^{3+}). Hexavalent chromium (Cr-VI or Cr^{6+}) is the by-product of industrial applications including steel making, tanning, electroplating and textiles. Lead has no known biological or biochemical function and organisms are generally subjected to high concentrations only through anthropogenic activities since this metal has a low natural abundance (Friberg *et al.,* 1986). Mercury is one of the most toxic heavy metals and unlike a number of other heavy metals; it is not known to perform any essential biochemical function (Bowen, 1966). In nature, mercury can exist in any of the three inter-convertible oxidation states: Hg (0), Hg (I) and Hg (II) (Jonasson and Boyle, 1972). The crucial importance of mercury in aquatic ecosystems is the microbial conversion of inorganic Hg (II) into methyl mercury, which undergoes bio-magnification up the aquatic food chain. Among the trace metals, aluminium, iron, lead and manganese are generally found to be particularly heavily associated with particulates, only very low concentrations remaining in solution under most conditions (Phillips and Rainbow, 1994). Metals in surface waters are 1000 times lower than in the corresponding sediments (Clark *et al.,* 1997). It is well known that most dissolved trace metals are present as organic complexes in marine and river waters (Ellwood and van den Berg, 2000; van Veen *et al.,* 2001).

2.5. Biological aspects

The efforts to save species require the knowledge of the distribution of organisms in their habitats. Numerous factors, including species interactions, productivity, habitat type, colonization types and the number of species occur in a specific environment, and all these are interrelated with diversity (Dodds, 2002). Planktonic organisms in temperate lakes commonly show distinct seasonal dynamics that have been attributed mainly to changes in ambient physicochemical parameters (light, temperature and nutrients), which in turn, govern phytoplankton primary production and autotroph-herbivore interactions (Hessen *et al.,* 2005).

2.5.1. Chlorophyll

Chlorophyll-a, the active photosynthetic pigment gives an idea with regard to phytoplankton biomass (Yeragi and Yeragi, 2003). This photosynthetic pigment is essential for photosynthesis in eukaryotes, cyanobacteria and prochlorophytes because of its role as the primary electron donor in the electron transport chain (Raven *et al.,* 2005). Chlorophyll-a is regularly used as an estimate of algal biomass with blooms being estimated to occur when chlorophyll-a concentration exceeds 10 mg/l (Nedwell *et al.,* 2002).

2.5.2. Phytoplankton

Phytoplankton is the base of most of the lake food-webs and fish production is linked to phytoplankton production. Moreover, the number and species of phytoplankters serve to determine the quality of a water body (Ryder *et al.,* 1974). The physiochemical, geomorphological and sedimentary natures are always correlated with the density of plankton (Yeragi and Yeragi, 2003). The study of plankton also serves as an index of water quality in respect of industrial, municipal and domestic sewage pollution (Pati and Sahu, 1993; Acharjee *et al.,* 1995; Baruah *et al.,* 1997). The planktonic study is a very useful tool for the assessment of water quality in any type of water body and also contributes to the understanding of the basic nature and general economy of the lake (Pawar *et al*., 2006). Lehman (2000) determined the direct role of climate variation on phytoplankton community bio-volume. Hambright and Zohary (2000) concluded that disturbances can enhance phytoplankton species diversity. Goldman and Horne (1983) have reported that the dynamic features of lakes such as colour, clarity, trophic state, and zooplankton and fish production depend to a large degree on the phytoplankton. The phytoplankton community on which whole aquatic population depends is largely influenced by the interaction of a number of physicochemical factors. Davis (1955) showed that a number of physical, chemical and biological factors acting simultaneously must be taken into consideration in understanding the fluctuations of phytoplankton population.

2.5.3. Zooplankton

Various ecological aspects of zooplankton have been a subject of study in India by several workers (Somashekar *et al.,* 1994; Annapurna *et al.*, 1999). Zooplankton occupies a central position between the autotrophs and other heterotrophs, and forms an important link in the food-web of a freshwater ecosystem. The occurrence and abundance of zooplankton depend on its productivity, which in turn, is influenced by the physicochemical parameters and the level of nutrients in the water (Pawar and Pulle, 2005). The diversity and density of zooplankton populations occur in succession depending upon interspecific and intraspecific interactions, and predation potential (Fernando, 1980).

2.5.4. Benthos

In the productivity of a water body, the importance of bottom fauna as a link in the energy flow from primary production to fish yield has been stressed by many workers. Many investigators (Krishnamurthy, 1966; Bose and Lakra, 1994; Anitha *et al.,* 2004) made studies on macro-zoobenthos in India. The bottom fauna play an important role in the mineralization and recycling of organic matter. They also serve as good indicators of water pollution since they form an important food item for fishes. The benthic environment of any lake is related to the combinations of water column productivity (trophic status), circulation and sediment deposition patterns (Miller and White, 2007). The benthos is greatly reduced or absent below the thermocline in mesotrophic to eutrophic lakes, but may be found at depths up to hundreds of metres in oligotrophic lakes (Martin *et al.,* 1994, 2005).

2.5.5. Microbial community

Microbial community studies are of great importance both from the point of view of monitoring and maintaining a proper aquatic environment as well as optimum utilization of the available and added nutrients for fish production. The microbiological examination of water also has got significant importance in the case of pollution studies. The bacteriological study of natural freshwater lakes and fish ponds were carried out by Adoni (1975), and Jana and Roy (1986) showing the significant importance of bacterial communities in trophic interactions. They also pointed out that the greatest need in limnological studies is bacteriological information, which has immense applications in productivity studies. Tripathi (1997) has carried out a systematic investigation on microbiological aspects with reference to productivity potentials. Investigating the microbial communities and their function in freshwater will greatly enhance our understanding of the aquatic ecosystem (Tamaki *et al.,* 2005). Only few studies have been conducted to study the microbial community of a freshwater lake. Benthic sediment represents one of the most complex microbial habitats on Earth (Priscu *et al.*, 1998). The microorganisms in lake sediment and water play important roles in nutrient cycles such as methane production (Chan *et al*., 2005), sulphate reduction (Li *et al*., 1999) and ammonia oxidation (Hastings *et al.*, 1998). Studies employing denaturing gradient gel electrophoresis (DGGE), to compare the diversity of 16S rRNA gene amplicons obtained directly from environmental samples are very less. DGGE method can clearly indicate the existence of common groups of microorganisms in natural environment, but it does not permit the more precise identification of these microbes to the species or sub-species level. DGGE has proved to be an exceptional tool to study species diversity and bacterial community dynamics. But a more comprehensive understanding of the physiology of these organisms and their complex biogeochemical processes will require their cultivation, isolation and characterization (Bae *et al*., 2005). It is well known that more than 90% of the microorganisms existing in nature are refractory to selective enrichment cultures (Ward *et al.,* 1990). To overcome the drawbacks of these culture-dependent methods, interest is currently focused on the use of molecular biological techniques, with their powerful capacity to allow the analysis of microorganisms in their natural habitats. In this context, analysis of the 16S rRNA gene is the most widely used approach in the last decade. Of the 16S rRNA gene-based methods used for studying complex microbial populations, DGGE has received the most attention and has been successfully applied to several natural habitats. Profiling of microbial communities from soil, marine environments, hydrothermal vents, the gastrointestinal tract of humans and even the study of a microbial community resident in a medieval wall painting (Felske *et al.,* 1997; Hold *et al.,* 2001; Nicol *et al.,* 2003) has already been done using DGGE technique. More recently, DGGE has been introduced into food microbiology for the identification of microorganisms isolated in food and for evaluation of the microbial diversity during food fermentation.

2.6. Diversity indices

Diversity indices are mathematical functions which explain the number of species in a biological community (Tiwari and Chauhan, 2006). Diversity indices provide more information about community composition than simply species richness by taking the relative abundances of different species into account. The ability to quantify diversity in this way is an important tool to understand community structure. Much work has been carried out in India on freshwater habitats. However, works on statistical ecology including species richness (Margalef index R1 and Menhinick index R2), species evenness (E-1, E-2, E-3, E-4 and E-5), Shannon’s overall index of species diversity (N-0, N-1, N-2 and H') Simpson index, etc. in the lakes are scanty. Peet (1974) suggested the terminology for biodiversity measurement as “species richness” and “evenness”. Some indices called heterogeneity indices by Peet (1974) incorporate both these aspects. Magurran (1988) also described that the concept of species diversity is composed of two distinct components which are: (1) species richness, *i.e.,* the total number of species in a given area and (2) evenness, which means how the abundance data are distributed among the species. Heip (1974) described that the distribution of individuals over species is called evenness. Hurlbert (1971) noted that when all the species in a sample are equally abundant, evenness index should be maximum and it decreases towards zero as the relative abundance of the species diverges away from evenness. Heip *et al.* (1998) mentioned that Shannon-Wiener index (Shannon and Weaver, 1949) is the most widely used diversity index in ecological literature. This is a measure of the average degree of "uncertainty" in predicting, to what species an individual chosen at random from a collection of "S" species and "N' individuals will belong. The most important heterogeneity index used is the Simpson's (1949) index, which gives the probability that two individuals drawn at random from a population belong to the same species. Ludwig and Reynolds (1988) suggested a variety of different evenness indices which determine the different characteristics of species diversity. Gray (2000) discussed the species richness and stated that sample species richness almost certainly will be measured within a single habitat or assemblage, but it does not necessarily give a reliable estimate of the species richness of that habitat or assemblage. Ismael and Dorgham (2003) opined that univariate analysis uses diversity indices, which attempt to combine the data on abundances within a species in a community into a single number. The state of community can then be understood from this number.

2.7. Pollution indices

Naganandini and Hosmani (1990) reported pollution-tolerant algae and suggested the use of algae as indicators of organic pollution. Nygaard (1949) introduced five indices for the biological monitoring of aquatic habitat based on individual population of Myxophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae and a mixture of all this proportions together. According to him, certain algal groups are indicative of the levels of nutrient enrichment. Nygaard's indices are used to get a meaningful evaluation of the extent of eutrophication by many workers (Vaishali *et al.,* 2003). Palmer (1969) has also proposed an index which is based on the presence or absence of selected taxa of algae in the water sample. A definite score is assigned to each taxon and depending upon the total score, the water bodies are classified as oligotrophic, mesotrophic or eutrophic. Many ecologists calculated and determined the status of organic pollution in various aquatic ecosystems quite successfully with the help of Palmer's algal pollution index.

3. MATERIAL AND METHODS

The present study to compare the biodiversity between two lakes was conducted in Powai and Vihar lakes in Mumbai. For the purpose of study, fortnightly sampling was carried out to investigate the biological and physicochemical parameters of water and soil for a short period, from 30 November 2010 to 01 February 2011.

3.1. Description of the study area

During the British rule in India, the acute shortage of water in Bombay resulted in protests by the local residents in 1845, which led to the construction of the presently existing Vihar, Thulsi and Powai lakes under the Bombay Municipality's drinking water schemes. The lakes were constructed as the impoundments of Mithi River. The Powai-Kanheri hill range forms the catchment for these lakes.

3.1.1. Powai lake

Presently, the government of Maharashtra reports that due to the eutrophication of lake water from untreated sewage, garbage from nearby residential and slum colonies, idol immersion and silt loading, the lake water is polluted and is unfit for drinking purpose. Because of these factors, the lake might also have lost its diverse nature of population and it may not support any natural regeneration. The lake was leased out to Maharashtra State Angling Association (MSAA), Mumbai, in the year 1939 for angling, sports and recreation. The geographical details along with the morphometrics of the lake are given in tables 1 - 2 and Fig. 1.

3.1.2. Vihar lake

Vihar Lake and its catchment are protected by Brihanmumbai Municipal Corporation and Sanjay Gandhi National Park Authority. The catchment area of Vihar Lake has high hills rising on all sides. The seclusion, protection and security provided under Sanjay Gandhi National Park may help in abundant natural regeneration in the lake and helps to avoid pollution in the lake to a great extent. At present, the lake is partly meeting the drinking water needs of South Mumbai region after filtration at Bandup where a large water filtration plant is located. The geographical details along with the morphometrics of the lake are given in tables 1 - 2 and Fig. 2.

Table 1. Geomorphological and hydrological profile of Powai and Vihar lakes

Attribute	**Lake**	
	Vihar	**Powai**
Location	Sanjay Gandhi National Park, Mumbai	Northern suburb of Mumbai
State	Maharashtra	Maharashtra
Coordinates	19°07'N 72°55'E	19°08'N 72°54'E
Lake type	Reservoir, Fresh water	Reservoir, Fresh water
Construction year	1859	1891
Primary inflow	Mithi River	Mithi River
Surface area	7.29 km^2	2.10 km^2
Catchment area	18.96 km^2	6.61 km^2
Maximum depth	34 m	12 m
Surface elevation	80.42 m	58.5 m

For the present investigation, three sampling stations were selected in each lake and the coordinates were recorded using GPS (Table 2).

Table 2.Location of sampling stations

Station	**Powai Lake**	**Vihar Lake**
Station 1	19°7′26.4″N & 72°53′52.8″E	19°8′45.6″N & 72°54′57.6″E
Station 2	19°7′33.6″N & 72°54′7.2″E	19°8′24″N & 72°54′28.8″E
Station 3	19°7′51 .6″N & 72°54′28.8″E	19°8′49.2″N & 72°54′7.2″E

Fig. 1: Satellite image showing sampling stations in Powai Lake

Fig. 2: Satellite image showing sampling stations in Vihar Lake

3.2. Physicochemical parameters of water

Water samples were collected fortnightly from all the sampling stations during the morning hours between 8.00 and 11.00 am for a period of four months. Temperature, hydrogen ion concentration, transparency, conductivity and depth were measured at the site itself. For the estimation of dissolved oxygen, biochemical oxygen demand and heavy metals, water samples were collected separately in respective bottles following the APHA (2005) guidelines for sample collection and preservation. For the study of other hydrological parameters, water samples were collected in 1-l polyethylene bottles, transported to laboratory in ice box and stored at 4ºC for further analysis. Water quality parameters were estimated in the laboratory using standard procedures.

3.2.1. Temperature

Atmospheric and water temperature of the lakes were recorded using a mercury thermometer calibrated up to 0.1ºC.

3.2.2. Transparency

The water transparency was measured by a standard Secchi disc having a diameter of 30 cm. The disc was lowered in the water till it disappeared from sight followed by its slow lifting till it reappeared. The depths of disappearance and reappearance of Secchi disc were noted and an average of the two readings was taken as water transparency.

3.2.3. Electrical conductivity

The electrical conductivity of water was measured by using a portable digital conductivity meter from Eutech Instruments (India) which is having a range of 0.00 to 19.90 mS/cm.

3.2.4. Hydrogen-ion concentration

The pH was measured with the help of a portable digital pH meter from Eutech Instruments (India).

3.2.5. Depth

While the grab was operated to collect the sediment samples from different stations, depth was also measured.

3.2.6. Dissolved oxygen

The dissolved oxygen content of the water was determined by Winkler's titrimetric method as described by APHA (2005).

3.2.7. Biochemical oxygen demand

Dissolved oxygen was measured by Winkler’s method before incubation and after incubating at 20^oC for 5 days in closed BOD bottles without seeding. BOD was calculated by subtracting the final DO from initial DO.

3.2.8. Total carbon and total organic carbon

TC and TOC were measured with Hiper TOC analyzer (Thermo Scientific, Netherland) using the high temperature oxidation method. The water samples after filtration using Whatman (no. 5) filter paper were taken in the vials provided and loaded in the slots for autosampling.

3.2.9. Total alkalinity

The total alkalinity of water was estimated titrimetrically using phenolphthalein and methyl orange indicators. Both carbonate and bicarbonate alkalinities were measured following the standard methods (APHA, 2005).

3.2.10. Total nitrogen

The total nitrogen in water samples was estimated using CHNS Vario Micro Cube (Elementar Analysysteme GmbH, Germany). The water samples were weighed in microgrammes using Mettler Toledo MX/UMX balance (Mettler-Toledo Laboratory and Weighing Technologies, Switzerland) and packed compactly in pre-weighed small tin-boats before introducing them into the auto analyser.

3.2.11. Ammonia-nitrogen

Ammonia in the water samples was estimated calorimetrically using the Indo-phenol blue method; 1 ml phenol solution, 1 ml sodium nitroprusside solution and 2.5 ml oxidizing solution (alkaline citrate + sodium hypochlorite) were added to 25 ml sample in an Erlenmeyer flask. The samples were then covered and incubated at room temperature in subdued light. After 1 hour, the colour developed was measured with a double-beam spectrophotometer (Uvidec-340, Jasco, Japan) at 640 nm. Blank and standards were also treated in the same way.

3.2.12. Nitrate-nitrogen

Nitrate-nitrogen was determined using the cadmium reduction method (APHA, 2005). Nitrate is reduced almost quantitatively to nitrite in the presence of cadmium. This method employed the commercially available cadmium granules treated with copper sulphate and packed in a glass column. The nitrite thus produced was determined by diazotizing with sulphanilamide and coupling with *n*-1-Naphthyl ethylene diamine to form a coloured azo-dye, the absorbance of which was measured at 543 nm using a double-beam spectrophotometer (Uvidec-340, Jasco, Japan).

3.2.13. Phosphate-phosphorus (Reactive)

The phosphate-phosphorus levels were estimated by the ascorbic acid method (APHA, 2005) with the formation of an intensely coloured complex - molybdenum blue - and measuring the colour at 880 nm using a double-beam spectrophotometer. (Uvidec-340, Jasco, Japan).

3.2.14. Sodium, potassium and calcium

Sodium, potassium and calcium in the water samples were estimated by flame atomic emission spectrometry (FAES) using a flame photometer (Elico CL 378, India). The samples were first filtered using Whatman (no. 5) filter paper and then loaded into the aspirator. The sample was then aspirated into the burner and dispersed into the flame as a fine spray.

3.2.15. Magnesium, copper, chromium, nickel, iron and lead

A quantity of 250 ml of each sample preserved using concentrated nitric acid (pH below 2) was pre-concentrated 50 times (from 250 ml to 10 ml) on a hot plate and subjected to acid digestion by adding 10 ml of concentrated nitric acid, 4 ml of concentrated hydrochloric acid and 2 ml of concentrated hydrofluoric acid to the pre-concentrated sample in the hot plate. The digested samples were diluted to 50 ml each and subjected to analysis of the six metals (Mg, Cu, Cr, Ni, Fe and Pb) by atomic absorption spectrophotometer (AAnalyst 800, Perkin Elmer, USA) using flame atomization.

3.3. Physico-chemical aspects of sediment

Sediment samples were collected from the selected sites of the lake bed fortnightly at morning hours (8 am to 11 am) with the help of a Van Veen grab. The samples were then air-dried, ground to fine powder, sieved through a 2-mm sieve and used for further analysis using standard methods.

3.3.1. Hydrogen ion concentration

The sediment: water (1.0: 2.5) suspension was made, stirred and allowed to settle for 30 minutes. After that, it was stirred and the pH was measured using a digital pH meter (Thermo Orion Star Series, Thermo Scientific, Singapore).

3.3.2. Electrical conductivity

The sediment: water (1.0: 2.5) suspension was made, stirred and allowed to settle for 30 minutes. After that, it was stirred and the conductivity was measured using a hand held digital conductivity meter (Eutech Instruments, India).

3.3.3. Sediment texture

The sediment texture was estimated by the international pipette method (Muthuvel and Udayasoorian, 1999); 20 g of air-dried sediment sample was placed in a 500-ml beaker and 60 ml of 6% hydrogen peroxide was added to it. It was stirred well and kept on a water-bath till the frothing stopped. After that, 200 ml of 0.5 *N* HCl was added to destroy $CaCO_3$ which acts as a binding agent. The contents were then filtered through Whatman (no. 5) filter paper till the filtrate ran free of chloride. The sediment from the filter paper was transferred to a beaker and 400 ml of water and 8 ml of 1 *N* NaOH were added. The contents were placed in a mechanical shaker for 10 minutes, then transferred to a 1000-ml measuring cylinder and the volume was made up to 1000 ml with water. The contents were mixed thoroughly and kept aside undisturbed. The silt and clay fraction was pipetted out after 4 minutes 5 seconds (at 27°C) by withdrawing 20 ml of the suspension from 10-cm depth. The clay fraction was pipetted out after 6 hours 45 minutes in the same manner. The content was repeatedly washed with water and the residues were collected. All these were transferred to petri plates and dried in an oven at 105°C, cooled in desiccators and weighed. The result is expressed in percentages of sand, silt and clay. The sediment textural class was obtained using USDA textural triangle.

3.3.4. Total carbon, total hydrogen, total nitrogen and total sulphur

Total carbon, total nitrogen, total hydrogen and total sulphur in sediments were estimated using a CHNS analyser (Vario Microcube, Elementar Analysysteme GmbH, Germany). The finely powered sediment samples were weighed in microgrammes using a Mettler Toledo MX/UMX balance (Mettler-Toledo Laboratory and Weighing Technologies, Switzerland) and packed compactly in pre-weighed small tin-boats before introducing them into the auto analyser.

3.3.5. Total phosphorus

The sediment samples were digested using Supra Pure concentrated acids (Merk) in a microwave-based digestion system (Microwave 3000, Anton Parr, USA). Three replicates of about 0.250 g of sediment samples were taken in the microwave digestion vessels, to which 5 ml of concentrated nitric acid, 2 ml of concentrated hydrochloric acid and 1 ml of concentrated hydrofluoric acid were added. The vessels were capped and heated in the microwave unit at 1200 W to a temperature of 190°C for 30 minutes at a pressure of 25 bars. The digested samples were diluted to 50 ml and used for the analysis of total phosphorus.

All the glassware used for the analysis was treated with chromic acid wash solution overnight and washed with distilled water. Aliquots of 5 ml each of the digested samples were taken in a 50-ml volumetric flask and the pH was adjusted to 5 using 5 *N* NAOH and *p*-nitrophenol as the indicator. The standard colorimetric ascorbic acid method as mentioned in APHA (2005) was used for the estimation. The colour developed was measured after 10 minutes, but before 30 minutes, using a double-beam spectrophotometer (Uvidec-340, Jasco, Japan) set at 880 nm. A blank and standards were run simultaneously. The absorbance values were plotted on a standard curve to obtain the concentration of phosphorus in the samples.

3.3.6. Available phosphorus

The available phosphorus in sediment samples was estimated according to Olsen's method (Olsen *et al*., 1954). About 2.5 g of sediment samples were taken in 100-ml conical flasks, to which a pinch of activated charcoal and 50 ml of Olsen's reagent (0.5 *M* $NaHCO_3$, pH 8.5) were added. The samples were then kept for shaking for 30 minutes on a mechanical shaker. The suspensions were then filtered through Whatman (no. 5) filter paper and 5-ml aliquots of the clear and colourless filtrates were transferred into 25-ml volumetric flasks. To the aliquots, 5 ml of 1.5% ammonium molybdate solution was gradually added and the flasks were shaken slowly to drive out the CO_2 released. When frothing completely ceased, distilled water was added, washing down the sides, to bring the volume to about 22 ml; 1 ml of freshly diluted ascorbic acid solution was added to the samples and the volume was made up to 25 ml. After 10 minutes, but before 12 minutes, the blue colour intensity was read at 660 nm using a double-beam spectrophotometer (Uvidec-340, Jasco, Japan). The absorbance values were plotted on a standard curve to obtain the concentration of available phosphorus in the samples.

3.3.7. Available nitrogen

The available nitrogen in sediment samples was measured by the alkaline permanganate method using a micro-Kjeldahl unit (KEL Plus – Classic DX VA, Pelican Equipments, India). About 5 g of finely powdered sediment samples were used for the estimation following manufacturer's instruction.

3.3.8. Sodium, potassium and calcium

The sediment samples were digested the same way as that for total phosphorus. The digested samples were then diluted to 50 ml. Sodium, potassium and calcium in the samples were then estimated by flame atomic emission spectrometry (FAES) using a flame photometer (Elico CL 378, India). The samples were loaded into the aspirator where it got aspirated into the burner and dispersed to the flame as a fine spray.

3.3.9. Magnesium, copper, chromium, nickel, iron, lead and mercury

The sediment samples were digested the same way as that for total phosphorus. Digested samples were diluted to 50 ml each and subjected to analysis of the seven metals (Mg, Cu, Cr, Ni, Fe, Pb and Hg) by atomic absorption spectrophotometer (AAnalyst 800, Perkin Elmer, USA) using flame atomization. The cold vapour atomic fluorescence method (with FIAS) was used to measure the concentration of mercury.

3.4. Biological study

For biological study, the samples were collected from the respective sampling sites fortnightly during morning hours of the day between 8.00 and 11.00 am following standard sampling procedures.

3.4.1. Chlorophyll estimation

The algae from the water samples from the respective sites were concentrated using a syringe filter assembly from Millipore (India) Pvt. Ltd., Bangalore. Cellulose acetate filters of 0.45 µm diameter were used to filter 100 ml of water. After filtration, the filters with plankton concentrate were preserved in 90% acetone in amber coloured bottles. The pigments were extracted from the plankton concentrate with aqueous acetone and the optical density of the extracts was determined with a double-beam spectrophotometer (Uvidec-340, Jasco, Japan) at 750 and 664 nm before acidifying, and at 750 and 665 nm after acidifying the extract for the estimation of chlorophyll-a, following the guidelines of APHA (2005). The results are expressed in mg/m^3.

3.4.2. Phytoplankton and zooplankton study

For the qualitative and quantitative analyses, the plankton samples were collected using bolting silk cloth (no. 25) plankton net of 50 cm diameter. The samples were collected in duplicate and concentrated to 50 ml by filtering 50 l of water from the respective sites. The collected plankton samples were preserved in 5% formalin for zooplankton and 0.4% Lugol's solution for phytoplankton for further qualitative and quantitative analyses (Phillpose, 1959; Pennak, 1978). Organisms were identified using keys and monographs given by Edmondson (1992), Lund and Lund (1998), Desikacharya (1959), Graham *et al*. (2008), Prescott (1969), APHA (2005) and Adoni (1975). The counting of plankton was carried out using a Sedgwick-Rafter counting cell, adopting the procedure outlined by Welch (1948). The averages of three samples were taken into consideration and the results are given in terms of cells/litre. The photographs of all the major plankters were taken using a camera (JVC Color Video Camera, TK-C1481BEG, Thailand) attached to a Hund microscope (H600L, Hund Wetzlar, Germany). The morphometric features of the organisms were measured using the Biowizard software.

3.4.3. Benthic macro-invertebrate study

The sediment samples for benthos estimation were collected using a Van Veen grab. The samples were put in a bucket and water was added to it. The suspension was sieved out using a 0.5-mm mesh sieve. The benthic organisms were then collected from the sieve with the help of a pair of forceps and transferred into a wide-mouth plastic bottle containing rose Bengal solution. The organisms were identified using keys and monographs given by Edmondson (1992), Lund and Lund (1998), and Adoni (1975), and their species wise-numbers were noted.

3.4.4. Bacterial diversity study in lake sediment

For bacterial diversity study, sediment samples were collected from the respective sampling stations using a Van Veen grab. To minimize the risk of contamination, the samples were transferred aseptically into sterile Uricol bottles (HiMedia Laboratories Limited, Mumbai), transported in ice box and stored under refrigerated condition.

3.4.4.1. DNA extraction from sediment

The sample surface was discarded and all DNA extraction steps were carried out under sterile conditions during processing. The DNA extraction procedures were undertaken using NucleoSpin Soil DNA Extraction Kit from Macherey-Nagel, Germany (Cat. No. 740 780.50), as per the manufacturer's instruction. The DNA was dissolved in 50 µl of elution buffer and stored at -20ºC. The elute was checked for the presence of genomic DNA using 1% agarose gel prestained with ethedium bromide and visualized in DNr Bio-Imaging System (DNr Bio-Imaging Systems Ltd., Israel).

3.4.4.2. PCR amplification using universal primers

PCR amplification of bacterial 16S rRNA genes was performed using a Quanta Biotech Thermo-cycler QB-96 (Quanta Biotech Ltd., UK). The universal primers used for DGGE-PCR were BA338F (5'ACTCCTACGGGAGGCAGCAG) and UN518R (CGCCCGCCGCGCGCGGCGGGCGGGGCGGGGGCACGGGGGGACCGCGGCG).

The PCR cycle consisted of 30 cycles each of denaturation at 95ºC for 30 seconds, annealing at 61.3ºC for 30 seconds and extension at 72ºC for 1 minute, and a 15 minute final extension. The PCR products were examined by electrophoresis on 1% agarose gel prestained with ethedium bromide and visualized in DNr Bio-Imaging System (DNr Bio-Imaging Systems Ltd., Israel).

3.4.4.3. DGGE for PCR products

Denaturing gradient gel electrophoresis (DGGE) was performed with the DCode Universal Mutation Detection System (Bio-Rad Laboratories, USA) as per the manufacturer's instructions. In brief, the amplicons were loaded on to 1-mm thick, 10% (w/v) acrylamide : bisacrylamide (37.5:1.0) gels containing a 40-60% linear gradient of formamide and urea {100% denaturing solution containing 40% (v/v) formamide and 7 *M* urea (Bangalore Genei, Bangalore)}. This was subjected to 14 hours of electrophoresis in 1X TAE buffer at 60ºC and 60 V.

3.4.4.4. Silver staining of DGGE gel

The method described by Sanguinetti *et al.* (1994) was modified and followed to stain the DGGE gels. The gels were first fixed with 20% methanol with gentle shaking in a tray for 10 minutes using a dancing shaker. Then, the gels were washed twice with deionised water for 2 minutes each. After washing, the gels were incubated in 0.7% HNO_3 for 2 minutes with gentle shaking. The gels were again washed thrice for 2 minutes each with deionised water and incubated in 0.2% $AgNO_3$ for 30 minutes. Again, the gels were washed with deionised water and the developer solution {(2.29% sodium carbonate, 0.125% formaldehyde, 0.01% sodium thiosulphate (20 mg/ml)} was poured into the tray. The first precipitate formed was quickly aspirated and the rest of the developer was added. After 1-2 minutes, the gels were soaked in 3% acetic acid to stop any further development. The gels' images were then recorded with a DNr Bio-Imaging System (DNr Bio-Imaging Systems Ltd., Israel) with white light settings.

3.4.4.5. Sequencing of excised DGGE bands

Distinct bands in all the lanes were marked, and bands which were common in a number of lanes were considered similar and only one band each from the similar positions of the polyacrylamide gel was eluted for sequencing. The dominant bands from the DGGE gels were excised with sterile cover slips and soaked overnight in 30 µl of nuclease-free water after little crushing. One microlitre of each solution was then PCR-reamplified using the same set of primers, but without GC clamp. The products were confirmed through electrophoresis on 1.5% agarose gel with ethedium bromide staining and visualized in a DNr Bio-Imaging System (DNr Bio-Imaging Systems Ltd., Israel). The re-PCR products were then purified with GeneiPure Quick PCR Purification Kit (Bangalore Genei, India). After purification, the products were stored in -80°C freezers and directly send together for sequencing to Banglore Genei. The partial bacterial 16S rRNA gene sequences were subjected to a NCBI (National Centre for Biotechnology Information) BLAST search on the GenBank nucleotide database to identify the sequences with higher similarity.

3.4.5. Bacterial diversity study in lake water

Water samples were collected aseptically in sterile Uricol (HiMedia Laboratories Limited, Mumbai) bottles, transported in ice box and stored in refrigerated condition. All further steps were carried out under sterile conditions inside a laminar flow chamber. The microorganisms were first trapped on to a membrane filter Millipore {0.22 µm, Millipore (India) Pvt. Ltd., Bangalore} by filtering 50 ml of the water sample through a sterile syringe filter assembly from Millipore (India) Pvt. Ltd., Bangalore. The membrane from the base of the filter assembly was carefully separated with a pair of sterile forceps and placed into an empty sterile petri plate. The membrane was then cut into small pieces using a pair of sterilized scissors. DNA was extracted from the bacteria trapped on these membrane pieces.

3.4.5.1. DNA extraction from water

The cut pieces of the membrane were put in HiBead tubes (HiMedia Laboratories Limited, Mumbai) and the lysozyme-SDS based phenol-chloroform extraction method was followed with slight modifications; 500 µl of lysis 1 solution (0.15 *M* NaCl, 0.1 *M* EDTA; pH 8; 15 mg lysozyme/l) was added to the bead tube and mixed by horizontal vortexing for 2 minutes. It was then incubated at 37ºC for 1 hour in a water bath. After that, 500 µl of lysis 2 (0.1 *M* NaCl, 0.5 *M* Tris-HCl; pH 8; 12% SDS) solution was added to it and incubated again for 1-2 hours at 60ºC in a water bath. The suspension was then centrifuged at 8000 *g* for 10 minutes in a Spinwin centrifuge and 1 ml of supernatant was recovered in separate vials. To this supernatant, 1 ml of saturated phenol (pH 8) was added, mixed and centrifuged at 8000 *g* for 8 minutes. The aqueous layer was recovered and an equal volume of chloroform was added, mixed and centrifuged for 5-6 minutes in Spinwin. The aqueous layer, after centrifugation, was again transferred to separate tubes, and 2 volumes of absolute ethanol were added and centrifuged for 30 minutes at 4ºC at 8000 *g* in a microprocessor-based high speed research refrigerated centrifuge (Eltek, India). The supernatant was decanted and the vials with pellets were washed with 500 µl of 70% ethanol and centrifuged at 8000 *g* for 15 minutes using the centrifuge. Finally, the vials were decanted again and kept in a dry bath (SLM-DB-120, Bangalore Genei, India) at 60ºC for some time to evaporate the remaining ethanol. The DNA was then resuspended in 50 µl of nuclease-free water and stored at -20ºC. The presence of genomic DNA was confirmed by electrophoresis.

PCR amplification, DGGE, silver staining, excitation of bands, sequencing and analysis steps for water samples were done in a similar manner for the sediment samples.

3.5. Diversity indices

Species diversity is thought of as being composed of two components, species richness and species evenness. The number of species is referred as species richness. Evenness refers to how the species abundances are distributed among the species. Diversity index helps to characterize the diversity of a sample by a single number. The present study used Margalef species richness index (d), Pielou's evenness index (j'), Simpson's index of diversity ($1-\lambda$) and Shannon index (H'). The diversity indices have been calculated using basic software Primer Version 6, to know the diversity of fauna of these lakes.

3.6. Pollution indices

Water pollution indices based on algal diversity pattern are commonly used for the detection and evaluation of water pollution. In the present study, Palmer's index and Nygaard's compound quotient were used to evaluate the organic pollution of the two water bodies.

3.6.1. Nygard's index

The formula used for calculating Nygard's compound quotient (CQ) is

CQ = (cyanophyceans + diatoms + chlorococcales + euglenophyceans)/desmids

(CQ ≤ 2 is oligotrophic, CQ 2-6 is weakly eutrophic, CQ > 6 is eutrophic)

3.6.2. Palmer's index

Palmer's Index is based on the presence or absence of selected taxa of algae in the water sample. A definite score is assigned to each taxon and depending upon the total score, the water bodies are classified as oligotrophic, mesotrophic or eutrophic. The score for individual algal taxon is given in Table 3.

Table 3. Score card for palmer's pollution index

Name of taxon	**Score**
Ankistrodesmus	2
Chlamydomonas	4
Chlorella	3
Closterium	1
Cyclotella	1
Euglena	5
Gomphonema	1
Melosira	1
Navicula	3
Nitzschia	3
Oscillatoria	5
Pandorina	1
Phacus	2
Phormidium	1
Scenedesmus	4
Stigeoclonium	2
Synedra	2

A value of 20 or above indicates high organic pollution, 15-19 indicates probable organic pollution and less than 15 indicates low organic pollution.

3.7. Statistical analysis

All measurements were carried out in triplicates. To generate different interpretations from the data, different statistical tools and techniques were used (using SAS 9.2.). These comprise analysis of variance, factor analysis, correlation plots, score plots, trend graphs, pie diagrams and bar diagrams. These statistical reports were used to compare the two lakes with respect to the physicochemical and biological parameters. Analysis of variance test was used to find whether there is any significant difference for all the phycicochemical and biological parameters between the two lakes. Factor analysis was done to explain the total variation between the lakes. Correlation matrix was also used in the present study to understand the significant correlations between important physicochemical and biological parameters in the two lakes. Diversity indices were calculated using PRIMER Version 6.

4. RESULTS

Results of the study on Powai and Vihar lakes with respect to physicochemical characteristics of water and sediment, abundance and diversity of phytoplankton, zooplankton, benthos and bacteria during the study period are presented here.

4.1. Air temperature

During the sampling period, the highest average air temperature (30.67ºC) was recorded in the second fortnight of December and the lowest (22.33ºC) in the first fortnight of February.

4.2. Water quality parameters

The water quality parameters were determined fortnightly and the station-wise mean values of triplicates with standard error for all the six samplings were calculated for both the lakes (Table 4 - 5). The mean sums of squares of water quality parameters analyzed from the analysis of variance are presented in Table 6. The model R^2 values ranged from 0.35 to 0.98. F-test proved that, there exist significant differences in each water quality parameter (except magnesium) between the two lakes. The significant variations of parameters among the different sampling periods are depicted in Table 6.

4.2.1. Temperature

The range of temperature fluctuation observed (Table 4 - 5) was between 20.3ºC (during the first fortnight of February in Powai Station 3) to 27.7ºC (during the second fortnight of December in Vihar Station 3). The water temperature was observed higher in Vihar during all the samplings (Fig. 3a).

Table 4. Water quality parameter data from three different sampling sites of Powai Lake during different samplings

No.	Parameter	15 November			01 December			15 December		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
1.	Water temp. (°C)	23.33±0.33	23.00±0.58	23.33±0.67	23.00±0.00	23.67±0.33	23.67±0.33	25.33±0.33	26.33±0.33	25.67±0.33
2.	Depth (cm)	440±0	527±0	426±0	416±0	560±0	456±0	380±0	560±0	460±0
3.	Transparency (cm)	61.67±0.88	76.67±1.20	76.67±0.33	70.67±1.20	73.33±0.33	76.33±0.88	70.67±0.67	75.00±0.58	75.67±1.20
4.	pH (no unit)	7.9± 0	8.4±0 **	8.1±0	8.1±0	8.0±0	8.1±0	7.9±0	8.0±0	7.9±0
5.	EC (mS/cm)	0.31±0.2	0.30±0	0.31±0	0.30±0	0.31±0	0.32±0	0.31±0	0.32±0	0.30±0
6.	DO	6.56±0.003	7.19±0.276	5.73±0.267	5.41±0.197	6.12±0.426	6.40±0.023	5.24±0.189	3.58±0.023	5.74±0.497
7.	BOD	3.90±0.093	2.18±0.378	3.87±0.195	3.98±0.282	3.76±0.355	4.68±0.243**	4.53±0.161	2.58±0.291	4.23±0.209
8.	Total alkalinity	136.10±2.01	139.87±3.32	141.47±3.92	141.70±3.30	145.30±3.40	147.17±2.55	159.00±2.52	137.20±4.01	150.60±3.71
9.	Reactive phosphorus	0.117±0 .004	0.108±0.003	0.163±0.003	0.135±0.002	0.130±0.004	0.125±0.001	0.210±0.006**	0.207±0.005	0.207±0.004
10.	Total nitrogen	2194.00±137	2649.67±91.5	2664.00±118.0	1759.67±226.0	2034.33±428.0	1136.33±266.0	1962.33±91.0	1888.67±46	1999.00±116
11.	Nitrate-nitrogen	0.515±0.0132	0.580±0.0020**	0.433±0.0046	0.366±0.0052	0.442±0.0105	0.418±0.0015	0.449±0.0060	0.622±0.003	0.517±0.0023
12.	Ammonia-nitrogen	0.091 ±0.001	0.083±0.009	0.097±0.001	0.113±0.003	0.061±0.002	0.061±0.003	0.475±0.002	0.299±0.009	0.556±0.010
13.	Sodium	16.07±0.409	10.13±0.384	11.80±0.321	19.63±0.328	24.07±0.203	14.57±0.536	19.40±0.173	21.57±0.033	19.60±0.115
14.	Potassium	8.97±0.409	11.07±0.033	8.70±0.351	8.00±0.116	8.40±0.115	9.30±0.115	8.03±0.088	8.27±0.033	8.03±0.067
15.	Calcium	22.53 ±0.033	14.21±0.116	14.61±0	28.57±0.524	21.27±0.133	18.93±0.498	20.47±1.372	29.80±0.173	30.47±0.067
16.	Magnesium	8.04±0.013	5.91±0.003	6.97±0.069	6.35±0.009	4.32±0.011	6.18±0.004	7.92±0.105	6.23±0.042	10.32±0.031
17.	Total carbon	67.78±6.38	68.68±2.85	71.73±0.16	72.12±3.13	88.04±0.43**	66.70±0.84	83.10±2.55	58.23±0.97	58.39±0.86
18.	TOC	39.88±4.33	39.58±2.87	43.12±0.11	40.18±3.15	47.85±0.42**	34.85±0.79	31.96±2.55	24.04±0.99	23.82±0.78
19.	Copper	0.008±0.0003	0.005±0.0006	0.006±0.0003	0.009±0.0003	0.005±0.0003	0.005±0.0003	0.006±0.0003	0.005±0.001	0.015±0.0003
20.	Chromium	0.002±0.0003	0.002±0.0001	0.003±0.0003	0.002±0.0007	0.002±0.0003	0.002±0.0007	0.001±0.0006	0.002±0.001	0.004±0.0006
21.	Iron	0.303±0.073	0.179±0.001	0.319±0.001	0.215±0.001	0.153±0.003	0.316±0.003	0.114±0.001*	0.162±0.003	0.444±0.002
22.	Nickel	0.0303±0.0	0.0273±0.004	0.0313±0.001	0.0220±0.001	0.0233±0.003	0.0213±0.002	0.0287±0.005	0.0327±0.002	0.0357±0.002
23.	Lead	0.0035±0	0.0036±0	0.0037±0	0.0038±0	0.0038±0	0.0039±0	0.0041±0	0.0043±0	0.0045±0

(*Minimum value between the two lakes; **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in mg/l)

Table 4 (contd). Water quality parameter data from three different sampling sites of Powai Lake during different samplings

No.	Parameter	01 January			15 January			01 February		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
1.	Water temp. (ºC)	21.67±0.33	21.67±0.33	23.33±0.33	21.67±0.33	21.33±0.33	20.67±0.33	21.67±0.33	20.67±0.33	20.33±0.33*
2.	Depth (cm)	670±0	590±0	572±0	374±0	580±0	393±0	446±0	521±0	395±0
3.	Transparency (cm)	83.67±0.33	77.00±0.58	82.00±0	59.33±0.33*	63.00±0.58	65.33±0.33	84.33±0.33	78.00±0.58	80.33±0.33
4.	pH (no unit)	7.9±0	8.0±0	8.2±0	8.0±0	8.1±0	7.9±0	7.9±0	7.8±0	8.1±0
5.	EC (mS/cm)	0.32±0	0.32±0	0.31±0	0.42±0	0.41±0	0.42±0	0.41±0	0.40±0	0.43±0**
6.	DO	4.54±0.188	4.71±0.131	4.46±0.179	3.98±0.087	3.58±0.244*	4.09±0.275	4.59±0.119	4.45±0.080	4.32±0.251
7.	BOD	2.45±0.086	2.48±0.337	2.23±0.381	2.84±0.047	2.35±0.047	2.61±0.165	1.77±0.067	2.12±0.093	2.18±0.190
8.	Total alkalinity	141.77±2.15	145.20±1.08	144.37±0.87	153.10±2.75**	143.63±0.48	140.33±1.39	151.10±2.21	150.80±2.63	140.30±0.99
9.	Reactive phosphorus	0.119±0.003	0.093±0.011	0.157±0.001	0.183±0.005	0.131±0.002	0.126±0.001	0.097±0.002	0.087±0.002	0.071±0.001
10.	Total nitrogen	2391.67±150	2671.00±30**	2658.00±158	1654.33±126	1754.00±208	1463.67±92	2056.00±71	2103.00±154	1852.00±53
11.	Nitrate-nitrogen	0.480±0.0012	0.572±0.0009	0.518±0.0026	0.523±0.0035	0.529±0.0046	0.575±0.0037	0.438±0.0075	0.477±0.0033	0.493±0.0105
12.	Ammonia-nitrogen	0.539±0.009	0.248±0.008	0.286±0.010	0.542±0.004	0.449±0.003	0.312±0.006	0.208±0.013	0.095±0.003	0.157±0.004
13.	Sodium	23.73±0.470	21.43±1.168	24.10±0.404	23.67±0.589	23.90±0.500	23.20±0.251	23.47±0.481	24.07±0.433	24.23±0.145**
14.	Potassium	7.73±0.088	8.27±0.033	7.93±0.033	8.33±0.088	8.27±0.120	8.87±0.033	7.90±0.058	8.13±0.067	6.33±0.088*
15.	Calcium	31.23±0.088	24.37±1.035	27.83±0.088	31.47±0.088**	19.10±0.473	31.73±0.203	31.47±0.067	30.33±0.176	31.50±0.153
16.	Magnesium	7.27±0.085	5.89±0.002	9.24±0.031	4.71±0.014	2.78±0.003	8.55±0.042	9.34±0.026	9.18±0.063	9.30±0.019
17.	Total carbon	75.21±0.59	60.78±0.26	57.22±0.75	64.64±0.95	56.52±0.14	57.28±0.19	62.71±0.85	58.04±0.24	58.78±0.88
18.	TOC	34.80±0.32	26.41±0.29	23.58±0.64	27.48±0.95	19.59±0.19	20.31±0.21	25.91±0.67	21.05±0.28	21.97±0.97
19.	Copper	0.004±0.0003	0.004±0.0003	0.009±0.0009	0.005±0.0003	0.005±0.0006	0.008±0.0006	0.007±0.0007	0.006±0.0007	0.007±0.0003
20.	Chromium	0.004±0.0009	0.001±0.0003	0.002±0.0003	0.003±0.0007	0.004±0.0012	0.003±0.0011	0.006±0.0012	0.005±0.0018	0.003±0.0007
21.	Iron	0.162±0.001	0.163±0.003	0.485±0.001	0.375±0.002	0.377±0.003	0.423±0.004	0.299±0.002	0.289±0.004	0.309±0.004
22.	Nickel	0.0313±0.002	0.0313±0.002	0.0357±0.001	0.0367±0.001	0.0363±0.003	0.0367±0.003	0.0293±0.004	0.0297±0.002	0.0390±0.001
23.	Lead	0.0045±0	0.0046±0	0.0047±0	0.0048±0	0.0049±0	0.0051±0	0.0051±0	0.0052±0	0.0053±0

(*Minimum value between the two lakes; **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in mg/l)

Table 5. Water quality parameter data from three different sampling sites of Vihar Lake during different samplings

No.	Parameter	15 November			01 December			15 December		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
1.	Water temp. (ºC)	22.33±0.33	23.33±0.33	23.33±0.33	24.00±0	23.00±0	24.00±0	26.33±0.33	27.33±0.33	27.67±0.33
2.	Depth (cm)	157±0	168±0	184±0	168±0	174±0	200±0	165±0	186±0	183±0
3.	Transparency (cm)	83.00±1.52	83.67±0.67	83.00±0.58	87.33±0.33	84.67±0.33	86.00±0.58	87.33±0.66	90.00±0.58	87.33±0.33
4.	pH (no unit)	7.8±0	7.8±0	7.9±0	7.8±0	7.7±0	7.8±0	7.6±0	7.7±0	7.6±0
5.	EC (mS/cm)	0.10±0*	0.11±0	0.12±0	0.12±0	0.11±0	0.11±0	0.13±0	0.12±0	0.12±0
6.	DO	6.8±0.17	6.3±0.04	7.7±0.27	6.3±0.30	6.2±0.19	6.0±0.07	8.8±0.12**	7.9±0.46	7.1±0.02
7.	BOD	2.11±0.08	1.57±0.14	1.10±0.21	2.13±0.08	2.17±0.16	1.93±0.03	1.66±0.41	1.54±0.17	1.48±0.15
8.	Total alkalinity	57.43±0.52	54.73±0.29	66.50±0.97	55.70±0.75	55.73±1.33	59.40±0.36	60.03±1.86	57.23±3.02	50.27±1.12
9.	React. phosphorus	0.074±0.003	0.066±0.001	0.079±0.002	0.127±0.004	0.124±0.003	0.112±0.002	0.173±0.008	0.182±0.001	0.154±0.011
10.	Total nitrogen	1472.33±103	1559.67±152	1714.67±45	494.67±42	419.00±67*	455.33±68	708.33±74	427.33±45	757.33±199
11.	Nitrate-nitrogen	0.321±0.005	0.217±0.005	0.174±0.005	0.224±0.004	0.165±0.011	0.123±0.006*	0.317±0.002	0.240±0.005	0.216±0.003
12.	Ammonia-nitrogen	0.068±0.002	0.078±0.004	0.072±0.003	0.045±0.003	0.046±0.002	0.060±0.001	0.332±0.007	0.287±0.008	0.273±0.008
13.	Total carbon	32.79±0.67	28.91±0.10	27.84±0.16	30.01±0.18	24.40±1.12	24.47±0.18	23.18±0.36	22.36±0.47	22.04±0.28
14.	TOC	22.57±0.58	19.74±0.12	18.69±0.26	17.59±0.12	14.00±0.67	14.00±0.63	9.72±0.22	9.35±0.48	9.29±0.25
15.	Sodium	2.90±0.35	4.57±0.09	6.13±0.12	6.23±0.07	6.27±0.09	6.27±0.07	1.97±0.13	1.47±0.07*	4.23±0.03
16.	Potassium	11.70±0.12	11.13±0.12	11.43±0.12	11.20±0.25	11.20±0.23	11.46±0.18	10.90±0.06	11.63±0.03	11.20±0.10
17.	Calcium	3.53±0.18	6.47±0.58	6.27±0.35	5.33±0.47	5.87±0.09	5.07±0.43	3.37±0.17	5.27±0.03	3.17±0.09
18.	Magnesium	6.32±0.0088	5.57±0.0233	4.60±0.0674	5.42±0.0369	6.44±0.0102	4.41±0.2873	12.17±0.030**	11.61±0.15	9.15±0.155
19..	Chromium	0.0053±0.0003	0.0087±0.0003	0.0073±0.0003	0.0037±0.0009	0.0070±0.0006	0.0063±0.0003	0.0027±0.0003	0.0197±0.0015	0.0043±0.001
20	Copper	0.0123±0.0009	0.0213±0.0015	0.0377±0.0262	0.0143±0.0007	0.0363±0.0009	0.0087±0.0003	0.0237±0.0003	0.0083±0.0003	0.0053±0.001
21.	Nickel	0.0193±0.0009	0.0223±0.0007	0.0247±0.0009	0.0213±0.0033	0.0223±0.0023	0.0187±0.0037	0.043±0.0015	0.0273±0.0015	0.0327±.003
22.	Iron	0.432±0.0095	0.253±0.0023	0.191±0.0034	0.537±0.0122	0.259±0.0013	0.167±0.0035	0.780±0.0124	0.232±0.0050	0.184±0.002
23.	Lead	0.0038±0	0.0039±0	0.0040±0	0.0043±0	0.0044±0	0.0045±0	0.0046±0	0.0045±0	0.0048±0

(*Minimum value between the two lakes; **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in mg/l)

Table 5 (contd). Water quality parameter data from three different sampling sites of Vihar Lake during different samplings

No.	Parameter	01 January			15 January			01 February		
		S1	S2	s3	S1	S2	S3	S1	S2	S3
1.	Water temp. (°C)	24.33±0.33	25.00±0	25.67±0.33	21.67±0.33	21.67±0.88	22.67±0.33	21.67±0.33	21.33±0.33*	22.67±0.33
2.	Depth (cm)	181±0	194±0	213±0	164±0	185±0	192±0	166±0	179±0	197±0
3.	Transparency (cm)	97.67±0.33	92.33±0.33	90.33±0.90	101.67±0.30	109.33±0.70**	102.33±0.30	109.33±1.30	91.67±0.89	100.67±2.70
4.	pH (no unit)	7.50±0*	7.60±0	7.80±0	7.70±0	7.60±0	7.60±0	7.72±0	7.79±0	7.81±0
5.	EC (mS/cm)	0.11±0	0.10±0*	0.12±0	0.23±0	0.21±0	0.22±0	0.18±0	0.24±0	0.14±0
6.	DO	7.3±0.30	7.6±0.36	5.8±0.16	6.9±0.25	5.7±0.16	5.8±0.18	5.6±0.14	5.8±0.18	5.7±0.10
7.	BOD	1.31±0.26	1.73±0.26	1.29±0.06	0.92±0.05*	1.08±0.14	1.08±0.08	1.02±0.11	0.94±0.06	1.25±0.13
8.	Total alkalinity	51.57±0.47	49.93±1.39	48.70±0.78	46.47±1.10	49.50±2.37	51.07±1.07	51.70±1.60	51.60±1.21	55.33±0.82
9.	React. phosphorus	0.077±0.003	0.110±0.009	0.112±0.001	0.072±0.002	0.010±0.001*	0.076±0.001	0.088±0.001	0.081±0.001	0.073±0.001
10.	Total nitrogen	1359.67±145	1098.33±127	1881.67±86	1087.00±34	571.00±27	842.33±80	917.67±58	701.67±51	1094.33±87
11.	Nitrate-nitrogen	0.261±0.0054	0.217±0.0020	0.208±0.0055	0.316±0.0032	0.222±0.0024	0.210±0.0038	0.283±0.0033	0.246±0.0029	0.235±0.008
12.	Ammonia-nitrogen	0.117±0.002	0.152±0.003	0.181±0.003	0.093±0.019	0.122±0.003	0.037±0.002*	0.068±0.007	0.055±0.005	0.090±0.003
13.	Total carbon	22.72±0.28	22.57±0.15	27.10±0.34	19.11±0.60	17.75±0.22	17.83±0.29*	20.61±0.89	18.34±0.08	18.96±0.10
14.	TOC	11.09±0.25	11.99±0.14	15.89±0.33	7.40±0.43	6.42±0.16	6.48±0.32	8.24±0.60	6.31±0.17*	6.67±0.35
15.	Sodium	6.10±0.11	2.63±0.18	8.47±0.67	7.73±0.50	7.20±0.29	9.30±0.60	5.90±0.11	5.87±0.34	5.70±0.26
16.	Potassium	11.33±0.067	12.30±0.058	10.87±0.089	11.40±0.100	11.10±0.058	11.23±0.089	11.47±0.067	11.23±0.067	11.13±0.120
17.	Calcium	2.17±0.09	5.83±0.07	7.13±0.07	2.17±0.07	1.73±0.21*	3.50±0.06	4.43±0.12	3.43±0.07	2.50±0.12
18.	Magnesium	7.84±0.0381	5.02±0.0004	4.28±0.0719	7.26±0.0761	5.30±0.0099	3.91±0.0109*	6.87±0.1532	6.49±0.0197	5.86±0.0279
19.	Chromium	0.0053±0.0009	0.0173±0.0003	0.0060±0.0006	0.0043±0.0012	0.0133±0.0009	0.0067±0.0003	0.0063±0.0003	0.0143±0.0015	0.0090±0.0001
20.	Copper	0.0093±0.0009	0.0143±0.0012	0.007±0.0006	0.0047±0.0003	0.1217±0.0023	0.0027±0.0003	0.0090±0.0006	0.0060±0.0006	0.0093±0.001
21.	Nickel	0.0190±0.0002	0.0437±0.0023	0.0290±0.0026	0.0257±0.0020	0.0293±0.0012	0.0230±0.0006	0.0357±0.0024	0.0240±0.0015	0.0223±0.002
22.	Iron	0.844±0.0279**	0.638±0.0003	0.159±0.0029	1.341±0.0023	0.386±0.0041	0.106±0.0032	0.923±0.0035	0.386±0.0033	0.304±0.003
23.	Lead	0.0048±0	0.0051±0	0.0051±0	0.0051±0	0.0052±0	0.0053±0	0.0055±0	0.0054±0	0.0054±0

(*Minimum value between the two lakes; **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in mg/l)

Table 6. Mean sum of squares (type 2) from analysis of variance for water quality parameters

Source	df	Avl. P	Ammonia	BOD	Chl -a	Ca	Cr	Cu	Water temp.
Between lakes	1	0.0286 **	0.5184 **	68.62 **	71176 **	12200 **	0.0008 **	0.0045 **	26.01 **
Among samplings	5	0.0237 **	0.2701 **	6.66 **	1074 **	79.16 **	0.0001	0.0007	59.72 **
Error	101	0.0004	0.0074	0.3387	145.5	16.91	0.00001	0.0003	0.787
R^2		0.79	0.71	0.75	0.84	0.88	0.43	0.37	0.80
SOURCE	**df**	**DO**	**EC**	**Fe**	**K**	**Mg**	**Na**	**Ni**	**Nitrate**
Between lakes	1	70.16 **	1.09 **	0.7676 **	237.63 **	8.35	6061.1 **	0.0005 **	1.88 **
Among Samplings	5	8.71 **	0.0458 **	0.1472 *	2.53 **	45.47 **	128.01 **	0.0003 **	0.0273 **
Error	101	0.6823	0.0002	0.0554	0.3837	2.61	6.55	0.00004	0.0023
R^2		0.62	0.98	0.35	0.87	0.47	0.91	0.37	0.90
SOURCE	**df**	**pH**	**Pb**	**TC**	**TN**	**TOC**	**T alk.**	**Transparency**	
Between lakes	1	2.49 **	0.000004 **	48766 **	3056444 **	9127 **	223023 **	9520.33 **	
Among Samplings	5	0.0967 **	0.000006 **	446.29 **	3328874 **	818.94 **	78.68 **	440.81 **	
Error	101	0.0114	1E-08	35.73	115574	15.34	3635.4	45.94	
R^2		0.72	0.96	0.93	0.80	0.91	0.98	0.72	

(**Significant at P≤0.01; *Significant at P≤0.05; df: Degrees of freedom; avl pho: Available phosphorus; chl-a: Chlorophyll-a; wt tmp: Water temperature; Talk: Total alkalinity)

4.2.2. Transparency

Highest transparency (102.33 cm) was recorded in Vihar Station 3 during the second fortnight of January and the lowest (59.33 cm) was in Powai Station 1 during the first fortnight of January (Table 4 - 5). In general, the transparency of Vihar was higher than that of Powai during all the samplings (Fig. 3b).

4.2.3. Depth

The depths of sampling stations were more in Powai than those at Vihar during all the samplings. The depth in the sampling sites of Powai ranged from 380 to 670 cm and that of Vihar from 165 to 200 cm.

4.2.4. Hydrogen ion concentration

The fluctuation of pH was observed between 7.5 and 8.4 during the different sampling periods in both Powai and Vihar lakes. The maximum pH value of 8.4 was observed during the second fortnight of November in Powai Station 2 (Table 4 - 5). In general, Powai always showed a higher pH value than Vihar during different samplings (Fig. 3c).

4.2.5. Electrical conductivity

The conductivity of the lake waters ranged between 0.10 and 0.43 mS/cm. The lowest value was observed in Vihar Lake on 15 November and the highest value of 0.43 mS/m was observed in Powai during the month of February. The same trend in fluctuation of conductivity was observed in the two lakes (Fig. 3d).

4.2.6. Dissolved oxygen

The concentration of DO (Table 4 - 5) varied from the highest of 8.8 mg/l in Vihar Station 1 (15 December) to the lowest value of 3.58 mg/l in Powai Station 2 (during second fortnightly sampling in January). In general, the concentration of DO was observed to be higher in Vihar than in Powai (Fig. 3e).

4.4.7. Biochemical oxygen demand

It was observed that the BOD values were higher in Powai stations than in Vihar during the sampling period. The trend in variation of BOD values appears to be more or less the same in the two lakes (Fig. 3f). The highest value of BOD (4.68 mg/l) was at Powai Station 3 on the first fortnightly sampling in December and the lowest value at Vihar (0.92 mg/l) on the second fortnightly sampling in January (Table 4 - 5).

4.4.8. Reactive phosphorus

The reactive phosphorus concentration was low in both the lakes during the sampling period and the values ranged from 0.01 to 0.21 mg/l (Table 4 - 5). Powai showed a higher concentration of reactive phosphorus than Vihar (Fig. 3g).

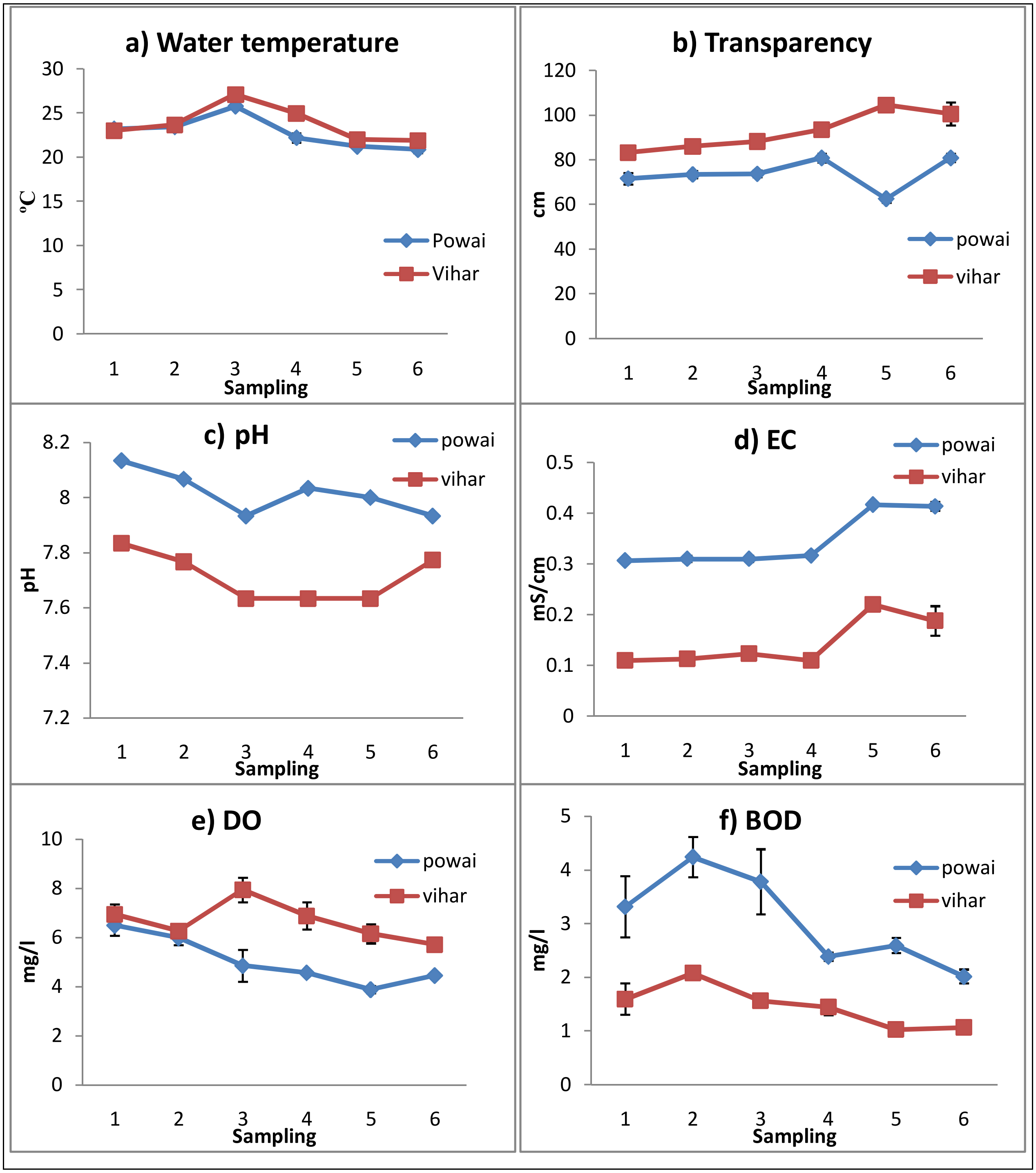

Fig. 3. Changes in water quality parameters between Powai and Vihar lakes during different samplings

4.4.9. Total nitrogen

The maximum value of total nitrogen (2671 mg/l) was observed at Powai Station 1 during the sampling on 01 January and the minimum (419 mg/l) was observed at Vihar Station 2 on 01 December (Table 4 - 5). A similarity in the trend of nitrogen concentration was observed between the lakes (Fig. 3h).

4.4.10. Nitrate-nitrogen

The nitrate-nitrogen concentration fluctuated from 0.12 to 0.58 mg/l in the two lakes (Table 4 - 5); however, higher concentration was observed in Powai Lake than in Vihar Lake (Fig. 3i).

4.4.11. Ammonia-nitrogen

The concentration of ammonia-nitrogen ranged from 0.037 to 0.550 mg/l in the two lakes (Table 4 - 5). The highest value of 0.55 mg/l was observed at Powai Station 3 on 15 December. Powai stations showed higher concentrations of ammonia than those of Vihar, but the trend observed between the lakes during the sampling was almost similar (Fig. 3j).

4.4.12. Total carbon and total organic carbon

Both total carbon and TOC concentrations were higher in Powai Lake than in Vihar with the highest value of 88.04 and 47.85 mg/l, respectively, in Station 2 on 01 December. The lowest values observed were in Vihar with 17.48 and 6.31 mg/l, respectively (Table 4 - 5). A similar trend of variation was observed in both the lakes during the different samplings (Fig. 3k - l).

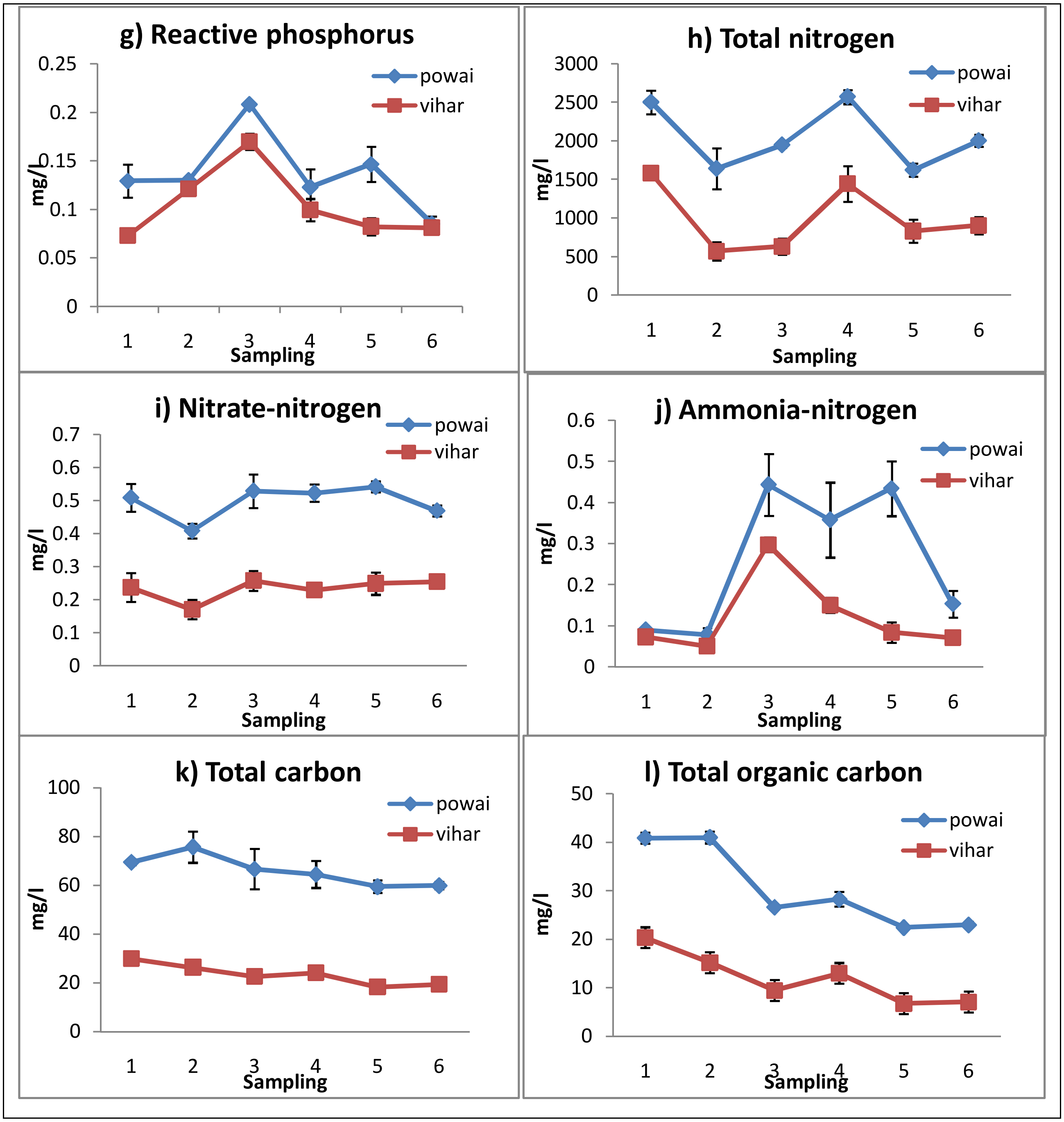

Fig. 3 (contd). Change in water quality parameters between Powai and Vihar lakes during different samplings

4.4.13. Total alkalinity

The observations presented in tables 4 and 5, and Fig. 3m show that there was no wide fluctuation in the total alkalinity of the two lakes during the different samplings; however, higher levels of alkalinity were observed in Powai Lake in all the samplings compared to Vihar. The range of total alkalinity values observed were from 48.79 (Vihar Station 3 on 01 January) to 153.10 mg/l $CaCO_3$ (Powai Station 1 on 15 January).

4.4.14. Sodium and potassium

Compared to Vihar, the sodium concentration was found to be higher during all the samplings in Powai with a maximum of 24.23 mg/l in the third station during the sampling in January (Table 4 - 5). The minimum value of sodium (1.47 mg/l) was observed in Vihar Station 2 during the second fortnightly sampling in December. Potassium concentration showed a higher range in Vihar Lake with the maximum value of 12.30 mg/l (Station 2 on 01 January). The trends in the variation of both are shown in Fig. 3n - o.

4.4.15. Calcium and magnesium

The range of calcium concentration (Table 4 - 5) was from 1.73 mg/l in Vihar (Station 2 on 15 January) to 31.73 mg/l in Powai (Station 3 on 15 January). During all the samplings, Powai showed higher calcium concentration than Vihar (Fig. 3p). In case of magnesium, no significant difference in concentration was observed between the two lakes (Fig. 3q). The concentration of magnesium observed ranged from 3.91mg/l (Vihar Station 3 on 15 January) to 12.17 mg/l (Vihar Station 1, 15 December).

4.4.16. Iron

The iron content (Table 4 - 5) in the water ranged from 0.114 mg/l in Powai Lake (Station 1 on 15 December) to 0.844 mg/l in Vihar Lake (Station 1 on 01 January). Higher concentrations of iron were observed in Vihar Lake during all the samplings than that in Powai Lake. The trend in the variation of iron concentration during the different samplings is shown in the Fig. 3r.

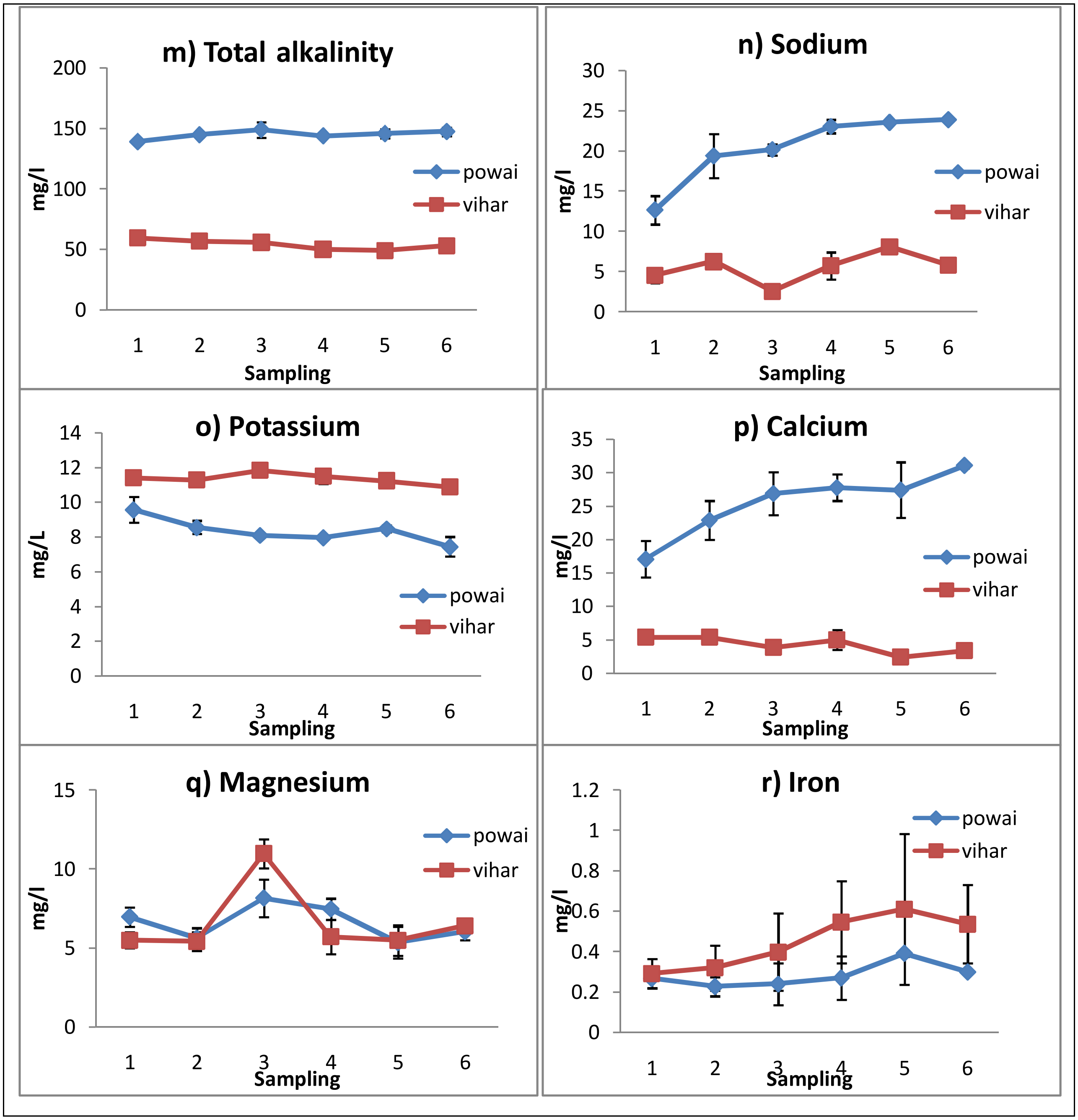

Fig. 3 (contd). Change in water quality parameters between Powai and Vihar lakes during different samplings

4.4.17. Copper, chromium, nickel and lead

The concentrations of all the trace metals studied were found below the critical limits in both the lakes (Table 4 - 5). The copper, chromium and lead concentrations were observed higher in Vihar Lake than in Powai (Fig. 3s – v).

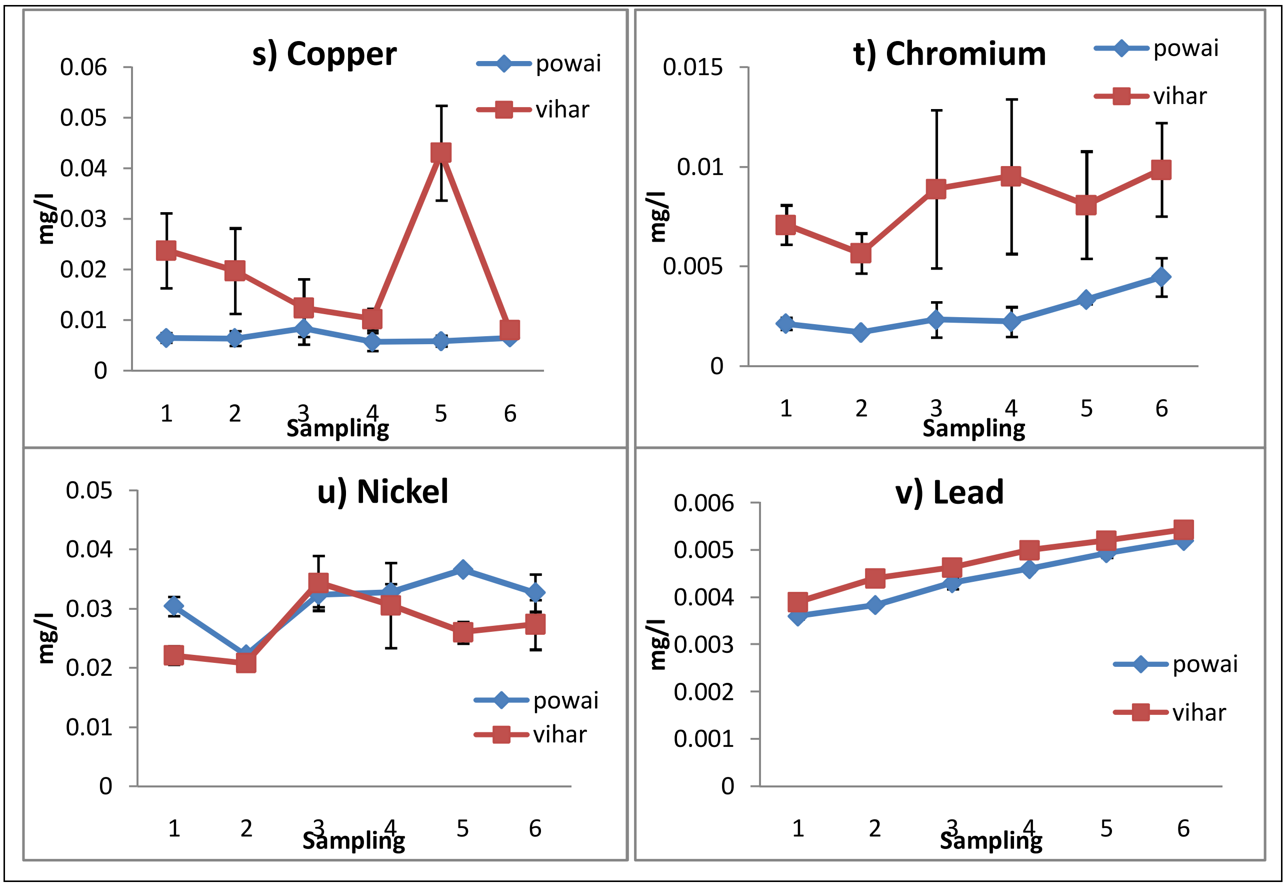

Fig. 3 (contd). Change in water quality parameters between Powai and Vihar lakes during different samplings

4.3. Sediment quality parameters

The sediment quality parameters were determined fortnightly and the station-wise mean values of triplicates with standard error for all the six samplings were calculated (Table 8 - 9). The mean sums of squares of sediment quality parameters analyzed from the analysis of variance are presented in Table 7. The model R^2 values ranged from 0.32 to 0.95. F-test proved that there exist significant differences in most of the sediment quality parameters between the two lakes (Table 7). The significant variations of parameters among the different sampling periods are also depicted in the table. The sediment texture of all the sampling stations of Powai Lake was found to be silty-loam with an average of around 46% silt and 26% sand, whereas the overall sediment texture of all the sampling stations of Vihar Lake was found to be clayey-loam with around 40% sand and 30% clay.

Table 7. Mean sums of squares (type 2) from analysis of variance for sediment quality parameters

source	df	pH	EC	TN	TC	TS	CN	AN	TP	AP
Between lakes	1	0.0065	55.55 **	739.14 **	55956 **	11702 **	0.0114	124 **	0.7168 **	0.0105 **
Sampling	5	0.7544 **	0.4801 **	22.13 **	349.11	84.79	42.57 **	0.1806 *	0.3757 **	0.0001
Error	101	0.0798	0.0637	3.11	215	56.99	7.81	0.0611	0.0247	0.0001
R^2		0.32	0.90	0.73	0.73	0.68	0.32	0.95	0.51	0.70
source	**df**	**Cu**	**Fe**	**Mg**	**Pb**	**Ni**	**Cr**	**Na**	**K**	**Ca**
Between lakes	1	0.0761 **	28299 **	284.15 **	0.0088 **	0.0317 **	0.3555 **	207.11 **	15.76 **	2.42 *
Sampling	5	0.0018 *	336.42	5.28 **	0.0004 **	0.0029 **	0.0259	11.01 **	0.2984 *	4.54 **
Error	101	0.0006	225.26	1.05	0.0001	0.0014	0.0024	0.5475	0.1125	0.3765
R^2		0.58	0.57	0.74	0.49	0.34	0.61	0.83	0.60	0.40

(**Significant at P≤0.01; *Significant at P≤0.05; df: Degrees of freedom; TS: Total sulphur; CN: CN ratio; AN: Available nitrogen; TP: Total phosphorus; AP: Available phosphorus)

Table 8. Sediment quality parameters from three different sampling sites of Powai Lake during different samplings

No.	Parameter	15 November			01 December			15 December		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
1.	pH (no unit)	7.81±0.00	7.92±0**	7.63±0	7.47±0	7.69±0	7.31±0	7.27±0	7.83±0	7.45±0
2.	EC (mS/cm)	1.62±0	1.87±0	1.51±0	1.93±0	2.14±0	1.47±0	1.80±0	2.21±0	1.43±0
3.	Total nitrogen	6.24±0.15	8.05±0.11	5.22±0.08	8.79±0.02	10.12±0.08	10.08±0.14	15.10±0.38**	7.80±0.06	4.77±0.45
4.	Available nitrogen	3.14±0.04	3.35±0.01	3.22±0.02	2.95±0.14	2.88±0.09	2.86±0.13	3.45±0.01**	3.33±0.05	3.00±0.02
5.	Total carbon	69.69±0.28	86.26±0.15	57.09±0.80	79.01±0.54	79.38±0.96	86.01±0.31	78.91±0.93	42.45±1.60	23.99±0.37
6.	Total sulphur	19.00±0.93	33.14±0.32	20.81±0.45	34.33±0.69	15.46±0.21	36.80±1.35**	35.03±0.72	7.22±0.07	6.14±0.30
7.	CN ratio	11.18±0.22	10.72±0.15	10.94±0.13	8.99±0.05	7.85±0.15	8.54±0.09	5.24±0.07	5.45±0.24	5.11±0.40
8.	Total phosphorus	0.89±0	0.80±0	0.83±0	1.04±0	0.73±0	0.75±0	0.91±0	0.60±0*	0.83±0
9.	Available phosphorus	0.06±0	0.07±0	0.06±0	0.05±0	0.07±0	0.07±0	0.06±0	0.05±0	0.07±0
10.	Copper	0.19±0**	0.13±0	0.13±0	0.18±0	0.13±0	0.12±0	0.15±0	0.14±0	0.09±0
11.	Iron	84.78±0.20	80.85±1.04	83.91±0.02	94.69±0.28	84.12±0.33	83.69±0.13	74.80±0.66**	91.99±0.34	90.81±0.45
12.	Lead	0.09±0**	0.06±0	0.05±0	0.08±0	0.05±0	0.05±0	0.05±0	0.04±0	0.03±0
13.	Mercury (mg/kg)	0.371±0	0.261±0	0.164±0	0.391±0**	0.273±0	0.287±0	0.341±0	0.227±0	0.121±0
14.	Nickel	0.18±0	0.19±0	0.19±0	0.20±0	0.20±0	0.20±0	0.18±0	0.19±0.03	0.17±0
15.	Chromium	0.19±0	0.23±0.01	0.25±0	0.24±0	0.25±0	0.22±0	0.19±0	0.32±0	0.17±0
16.	Sodium	7.66±0.01	7.46±0.01	7.77±0.02	8.02±0.01	9.49±0.25	8.06±0.05	8.62±0.06	7.87±0.02	9.75±0.09
17.	Potassium	2.45±0.01	1.96±0.01	1.72±0.05	3.45±0.01**	2.75±0.02	2.28±0.03	2.78±0.02	2.29±0.01	1.93±0.01
18.	Calcium	7.76±0.05**	7.98±0.02	8.38±0.01	8.11±0.01	9.28±0.02	9.48±0.01	9.49±0.02	8.46±0.02	9.76±0.11
19.	Magnesium	6.09±0.01	5.15±0.01	5.65±0.02	7.14±0.01	5.20±0.04	6.70±0.04	5.71±0.03	3.47±0.03	5.16±0.01

(*Minimum value between the two lakes, **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in g/kg)

Table 8(contd). Sediment quality parameters from three different sampling sites of Powai Lake during different samplings

No.	Parameter	01 January			15 January			01 February		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
1.	pH (no unit)	7.31±0	7.52±0	7.41±0	7.44±0	7.82±0	7.52±0	7.16±0	7.37±0	7.17±0
2.	EC (mS/cm)	1.33±0	1.40±0	1.27±0	1.10±0	1.27±0	1.14±0	1.90±0	2.63±0**	1.43±0
3.	Total nitrogen	7.45±0.10	2.82±0.06	6.93±0.12	7.60±0.24	7.03±0.06	8.12±0.09	9.85±0.02	7.13±0.26	6.78±0.07
4.	Available nitrogen	3.41±0.04	2.75±0.12	2.64±0.13	2.95±0.10	3.12±0.09	2.95±0.03	2.95±0.04	3.00±0.01	3.43±0.02
5.	Total carbon	80.55±0.30	29.16±0.17	68.20±0.44	68.36±2.00	60.77±0.36	69.21±0.48	92.50±0.63**	60.95±0.71	59.27±0.91
6.	Total sulphur	32.50±6.79	2.28±0.37	25.59±0.4	18.39±1.56	18.02±0.59	27.78±0.32	23.39±1.02	10.33±0.06	23.96±0.62
7.	CN ratio	9.12±1.85	10.35±0.21	9.84±0.12	9±0.13	8.64±0.07	8.53±0.04	9.40±0.08	8.56±0.22	8.74±0.05
8.	Total phosphorus	0.98±0	0.65±0	0.70±0	1.27±0	0.95±0	1.02±0	1.35±0	1.07±0	1.12±0
9.	Available phosphorus	0.05±0	0.06±0	0.06±0	0.06±0	0.07±0**	0.07±0	0.06±0	0.07±0	0.07±0
10.	Copper	0.18±0	0.14±0	0.11±0	0.16±0	0.13±0	0.11±0	0.16±0	0.12±0	0.10±0
11.	Iron	77.00±0.78	93.84±0.17	82.33±0.12	82.19±0.22	87.16±0.05	86.03±1.63	81.83±0.5	87.87±0.45	85.21±0.19
12.	Lead	0.07±0	0.04±0	0.04±0	0.07±0	0.05±0	0.05±0	0.08±0	0.06±0	0.05±0
13.	Mercury (mg/Kg)	0.334±0	0.231±0	0.199±0	0.236±0	0.249±0	0.229±0	0.287±0	0.242±0	0.173±0
14.	Nickel	0.18±0	0.24±0**	0.19±0	0.18±0	0.22±0	0.18±0	0.18±0.01	0.22±0	0.19±0
15.	Chromium	0.20±0	0.34±0**	0.23±0	0.18±0	0.32±0	0.24±0	0.21±0	0.33±0	0.21±0
16.	Sodium	8.64±0.30	10.90±0.14**	9.43±0.19	8.08±0.05	8.75±0.16	7.63±0.04	7.91±0.06	7.73±0.03	7.38±0.02
17.	Potassium	2.64±0.02	2.14±0.02	2.09±0.02	2.55±0.02	2.00±0.04	1.71±0.03	2.26±0.01	2.02±0.01	1.96±0.02
18.	Calcium	8.63±0.04	9.15±0.05	9.02±0.05	8.31±0.07	8.78±0.03	8.94±0.01	9.69±0.06	10.31±0.09**	9.12±0.10
19.	Magnesium	7.58±0.04	4.51±0.04	6.20±0.03	7.19±0.03	3.29±0.03	4.33±0.05	7.31±0.01**	6.74±0.01	7.13±0.01

(*Minimum value between the two lakes; **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in g/kg)

Table 9. Sediment quality parameters from three different sampling sites of Vihar Lake during different samplings

No.	Parameter	15 November			01 December			15 December		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
1.	pH (no unit)	7.91±0	7.73±0	7.81±0	7.82±0	7.64±0	7.70±0	7.83±0	7.57±0	7.93±0
2.	EC (mS/cm)	0.20±0	0.24±0	0.21±0	0.12±0	0.21±0	0.26±0	0.23±0	0.32±0	0.17±0
3.	Total nitrogen	2.13±0.01	2.13±0.01	1.95±0.19	2.08±0.03	3.67±0.14	2.74±0.02	4.20±0.05	5.88±0.68	2.66±0.25
4.	Available nitrogen	0.66±0.11	1.17±0.05	0.92±0.16	1.07±0.08	1.18±0.11	1.05±0.08	0.96±0.03	0.90±0.07	0.95±0.02
5.	Total carbon	10.66±0.51	23.07±3.51	18.61±1.62*	8.89±0.94	28.62±0.73	21.10±0.36	36.02±0.81	38.69±5.34	16.00±2.36
6.	Total sulphur	0.47±0.12	0.35±0.06	1.28±0.16	0.64±0.09	0.57±0.02	0.53±0.03	0.91±0.07	0.81±0.06	0.49±0.05
7.	CN ratio	5±0.23±0.23	10.81±1.58	9.56±0.52	4.28±0.47	7.81±0.11	7.65±0.14	8.57±0.19	6.54±0.18	5.95±0.36
8.	Total phosphorus	1.19±0	1.11±0	0.97±0	1.24±0	1.06±0	0.76±0	1.10±0	0.76±0	0.68±0
9.	Available phosphorus	0.05±0	0.05±0	0.03±0*	0.04±0	0.05±0	0.04±0	0.04±0	0.05±0	0.04±0
10.	Copper	0.10±0	0.11±0	0.07±0	0.11±0	0.11±0	0.06±0	0.08±0.03	0.11±0	0.10±0
11.	Iron	97.91±0.35	106.70±0.74	114.30±1.07	91.99±0.94	101.97±1.32	133.60±0.46	97.23±0.12	120.20±4.63	144.60±0.70
12.	Lead	0.04±0	0.03±0	0.04±0	0.03±0	0.03±0	0.04±0	0.03±0	0.04±0	0.04±0
13.	Mercury (mg/kg)	0.045±0	0.051±0	0.063±0	0.051±0	0.064±0	0.057±0	0.043±0	0.032±0*	0.056±0
14.	Nickel	0.17±0	0.21±0	0.12±0	0.20±0	0.20±0.01	0.15±0	0.19±0	0.23±0	0.12±0
15.	Chromium	0.13±0	0.20±0	0.16±0	0.13±0	0.19±0	0.17±0	0.15±0	0.21±0	0.16±0
16.	Sodium	6.14±0.03	5.45±0.02	5.73±0.02	6.85±0.05	5.40±0.02	6.72±0.07	6.43±0.07	6.08±0.02	6.27±0.02
17.	Potassium	1.41±0.01	1.28±0.01	1.31±0.02	1.36±0.01	1.24±0.01	1.33±0.01	1.52±0.03	1.23±0.02	1.50±0.02
18.	Calcium	8.46±0.01	8.58±0.01	8.91±0.02	9.20±0.06	9.56±0.01	10.05±0.04	8.16±0.06	8.98±0.03	9.27±0.05
19.	Magnesium	3.25±0.01	4.16±0.1	2.13±0.01	2.19±0	4.25±0.02	1.92±0.06	2.17±0.03	2.26±0	1.86±0.03

(*Minimum value between the two lakes; **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in g/kg)

Table 9(contd). Sediment quality parameters from three different sampling sites of Vihar Lake during different sampling

No.	Parameters	01 January			15 January			01 February		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
1.	pH (no unit)	7.57±0	7.43±0	7.21±0	7.67±0	6.37±0*	6.71±0	7.88±0	7.23±0	7.37±0
2.	EC (mS/cm)	0.22±0	0.13±0	0.21±0	0.20±0	0.26±0	0.10±0*	0.11±0	0.24±0	0.20±0
3.	Total nitrogen	2.88±0.17	2.08±0.30	1.73±0.28	1.34±0.07	1.76±0.02	1.49±0.13	2.03±0.01	3.76±0.2	1.13±0.08*
4.	Available nitrogen	1.02±0.02	1.21±0.09	1.01±0.06	0.96±0.04	1.19±0.08	0.99±0.09	0.49±0.08	0.46±0.06*	0.58±0.05
5.	Total carbon	17.99±0.32	10.51±0.86	33.34±0.91	12.59±1.09	17.86±1.66	13.43±0.66	18.84±0.54	34.40±2.16	11.74±0.57
6.	Total sulphur	1.32±0.29	0.13±0.01*	0.42±0.07	3.06±1.75	0.62±0.03	0.48±0.08	1.95±1.24	0.98±0.05	0.44±0.06
7.	CN ratio	6.29±0.40	5.24±0.74	20.66±4.43	9.40±0.37	10.11±0.84	9.09±0.50	9.28±0.28	9.14±0.11	10.45±0.41
8.	Total phosphorus	1.18±0	1.07±0	1.02±0	1.47±0**	1.26±0	1.17±0	1.39±0	1.00±0	0.99±0
9.	Available phosphorus	0.04±0	0.05±0	0.04±0	0.03±0	0.05±0*	0.03±0	0.05±0	0.05±0	0.04±0
10.	Copper	0.08±0	0.09±0	0.08±0	0.06±0	0.08±0	0.05±0	0.05±0	0.09±0	0.06±0
11.	Iron	120.37±2.24	133.20±0.06	137.03±2.69	90.05±0.13	121.40±1.78	147.00±0.86	85.82±0.22	116.67±0.41	155.80±0.7**
12.	Lead	0.04±0	0.03±0*	0.05±0	0.04±0	0.04±0	0.04±0	0.04±0	0.04±0	0.04±0
13.	Mercury (mg/kg)	0.062±0	0.059±0	0.057±0	0.052±0	0.062±0	0.049±0	0.048±0	0.067±0	0.034±0
14.	Nickel	0.19±0	0.21±0	0.11±0	0.11±0	0.21±0	0.07±0	0.10±0	0.19±0	0.07±0*
15.	Chromium	0.07±0	0.09±0	0.08±0	0.07±0	0.10±0	0.05±0*	0.09±0	0.15±0	0.05±0
16.	Sodium	6.59±0.05	6.01±0.04	6.42±0.07	3.52±0.10	3.33±0.29*	3.66±0.09	6.09±0.08	4.86±0.05	5.68±0.09
17.	pPtassium	1.86±0.02	1.24±0.02	1.64±0.03	2.12±0.05	1.64±0.01	1.74±0.01	1.7±0.04	1.48±0.01	1.61±0.02
18.	Calcium	8.49±0.03	8.83±0.06	10.16±0.06	8.43±0.03	8.80±0.03	10.02±0.08	8.73±0.06	9.89±0.06	11.52±0.10
19.	Magnesium	1.50±0.01*	2.36±0.21	1.17±0.01	2.27±0.09	4.24±0.30	2.04±0.02	2.60±0.03	3.44±0.14	2.33±0.03

(*Minimum value between the two lakes; **Maximum value between the two lakes; s1, s2, s3 are sampling stations; Units other than mentioned are in g/kg)

4.3.1. Hydrogen ion concentration

The pH value of sediment ranged from 6.37 to 7.92 in the two lakes (Table 8 - 9). The Vihar lake sediment showed higher pH values than Powai during the sampling period (Fig. 4a).

4.3.2. Electrical conductivity

The conductivity of Vihar Lake (Table 8 - 9) was found to be less than that of Powai (Fig. 4b); the values ranged from a minimum of 0.1 mS/cm in Station 3 of Vihar during the second fortnightly sampling in January to the maximum value of 2.63 mS/cm of Powai Station 2 (15 February).

4.3.3. Total nitrogen and available nitrogen

Powai Lake showed (Table 8 - 9) more of total and available nitrogen in the sediments than Vihar during all the samplings (Fig. 4c - d). The lowest values for total nitrogen and available nitrogen (1.13 and 0.46 g/kg, respectively) were observed in Vihar sediment during February, and the highest values of 15.06 and 3.45 g/kg, respectively, were observed at Powai Station 1 (15 December).

4.3.4. Total carbon

The highest concentration of total carbon (92.55 g/kg) was observed in Powai sediment during the sampling in February and a minimum of 18.61 g/kg was observed at Vihar Station 3 sediment on 15 November (Table 8 - 9). Generally, Powai samples showed higher levels of carbon than those of Vihar during all the samplings (Fig. 4e).

4.3.5. Sulphur

The concentration of sulphur ranged from a minimum value of 0.13 g/kg in Vihar to a maximum of 36.84 g/kg in Powai. Compared to Powai, the sulphur concentration in Vihar was found to be very low during all samplings (Fig. 4f).

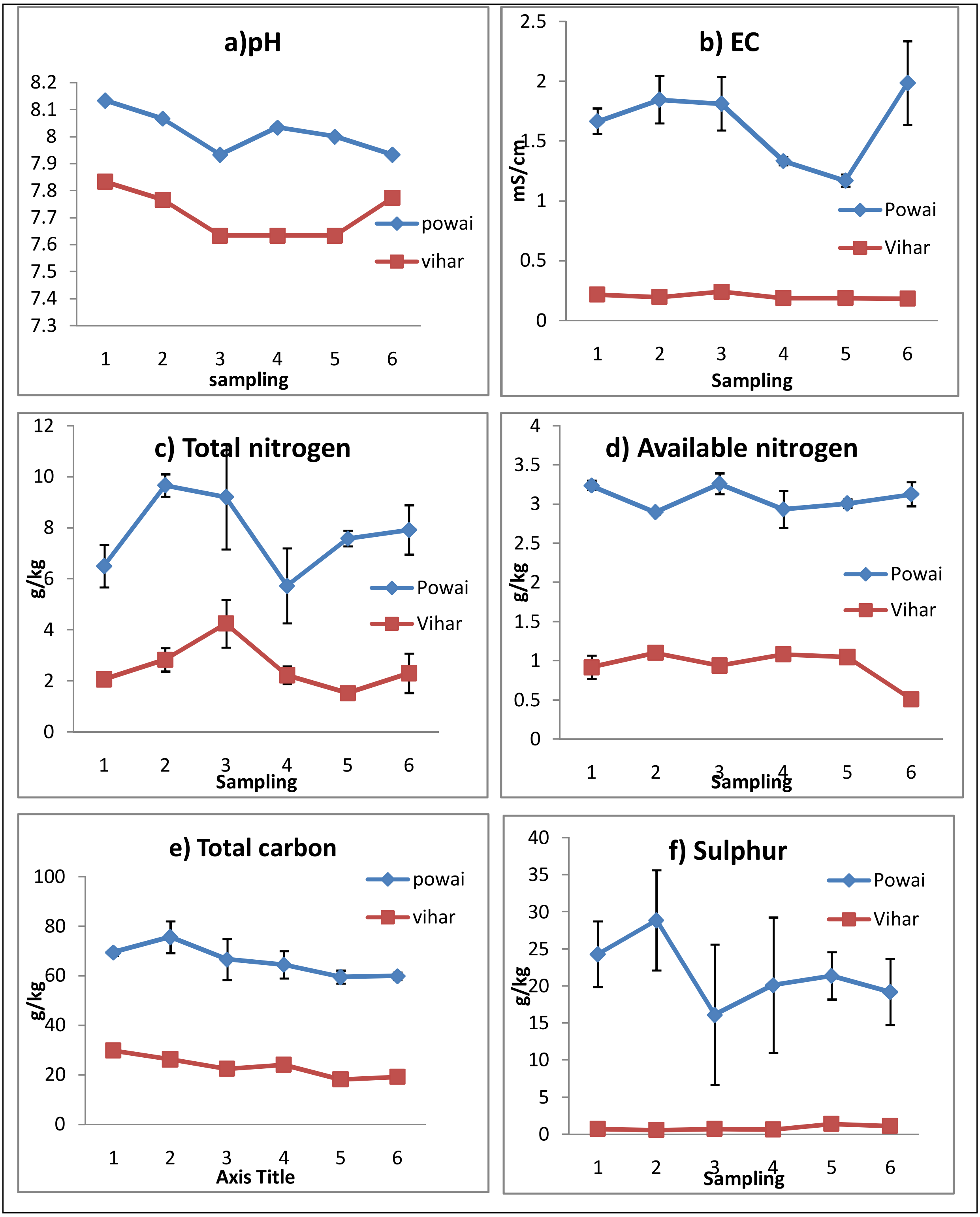

Fig. 4. Differences in sediment quality parameters between Powai and Vihar lakes during different samplings

4.3.6. Total phosphorus and available phosphorus

Total phosphorus concentration was found to be higher in Vihar Lake sediment, whereas the available phosphorus concentration was found to be higher in Powai during all the samplings (Fig. 4g - h). The range of total phosphorus obtained was from a minimum of 0.6 g/kg in Powai to a maximum of 1.47 g/kg in Vihar, whereas available phosphorus was found from 0.03 g/kg to 0.07 g/kg in the two lakes (Table 8 - 9).

4.3.7. Sodium and potassium

Sodium and potassium values were found to be higher in Powai sediment than in Vihar throughout the sampling period (Fig. 4i - j). For sodium, the minimum value of 3.33 g/kg was observed at Vihar and a maximum of 10.94 g/kg in Powai. For potassium, the minimum of 1.23 g/kg was observed in Vihar and a maximum value of 3.45 g/kg was observed in Powai (Table 8 - 9).

4.3.8. Calcium and magnesium

Magnesium concentration was observed to be higher in Powai sediment, whereas a similar trend was observed for calcium in both the lakes (Fig. 4k - l). The quantity of calcium in sediment ranged from 7.76 to 10.31 g/kg in the two lakes. The range observed for magnesium was from a minimum of 1.5 g/kg in Vihar to a maximum of 7.31 g/kg in Powai (Table 8 - 9).

4.3.9. Iron and copper

Copper was observed to be higher in Powai sediment than in Vihar, but Vihar sediment showed high quantity of iron than Powai (Fig. 4m - n). The concentration of iron varied from a minimum of 74.83 g/kg in Powai sediment during the sampling on 15 December at Station 1 to a maximum of 155.83 g/kg in Vihar during the sampling on 01 February at Station 3. Copper ranged from 0.05 g/kg in Vihar sediment during the sampling on 15 January (Station 3) to a maximum value of 0.19 g/kg during the second fortnightly sampling of November at Powai Station 1 (Table 8 - 9).

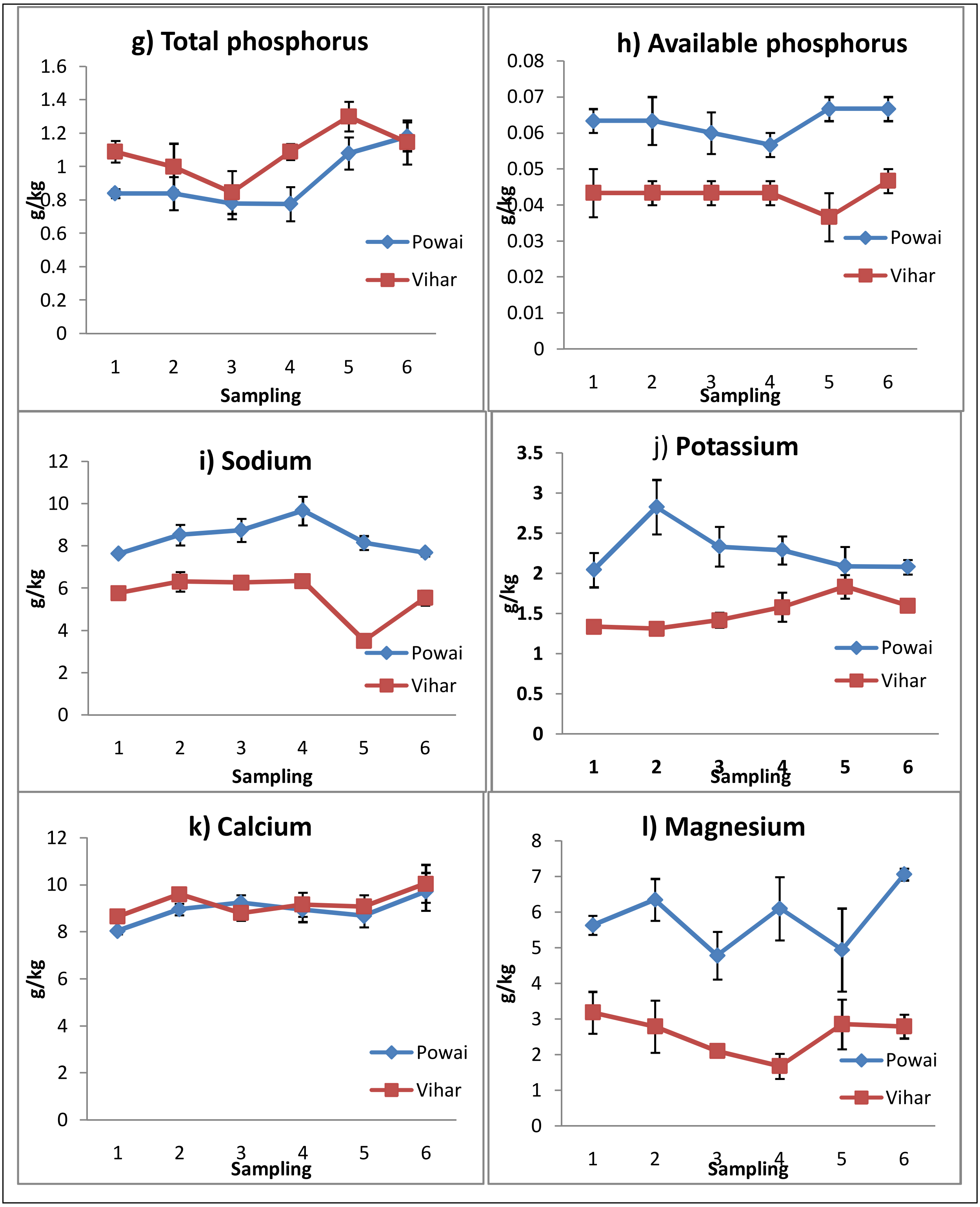

Fig. 4(contd). Differences in sediment quality parameters between Powai and Vihar lakes during different samplings

4.3.10. Lead, chromium, nickel and mercury

Lead, chromium, nickel and mercury showed higher concentrations in Powai sediment than in Vihar throughout the sampling period (Fig. 4o - r). Most of the heavy metals analyzed were found to be within the critical limits in both the lakes. Lead concentration ranged from 0.03 g/kg (Vihar Station 1 on 01 January) to a maximum of 0.09 g/kg (Powai Station 1 on 15 November). Chromium ranged from 0.05 g/kg (Vihar Station 3 on 15 January) to 0.34 g/kg (Powai Station 1 on January). The fluctuation in nickel concentration was observed from 0.07 g/kg (Vihar Station 3 on 01 February) to 0.24 g/kg (Powai Station 1 on 01 January). The concentration of mercury was found to be higher in Powai than in Vihar. The concentration ranged from 0.032 to 0.390 mg/kg (Table 8 – 9).

4.4. Chlorophyll-a content

Chlorophyll-a content (Table 10) was found to be higher in Powai Lake than in Vihar during all the samplings (Fig. 5). The values ranged from 8.90 mg/m^3 (in Vihar Station 2 on 15 November) to 103.24 mg/m^3 (in Powai Station 3 on 15 January).

Table 10. Chlorophyll-a (mg/m^3) from three different sampling sites of Powai and Vihar lakes during different samplings

Vihar Lake								
15 November			**01 December**			**15 December**		
S1	S2	S3	S1	S2	S3	S1	S2	S3
26.70	8.90*	21.36	30.26	10.68	23.10	21.36	17.80	21.36
01 January			**15January**			**01February**		
S1	S2	s3	S1	S2	S3	S1	S2	S3
32.04	10.68	40.94	26.70	24.92	24.92	21.36	23.14	19.58
Powai Lake								
15 November-			**01 December-**			**15 December-**		
S1	S2	S3	S1	S2	S3	S1	S2	S3
48.06	60.52	54.53	85.44	74.76	80.10	80.10	62.30	64.08
01 January-			**15 January-**			**01 February-**		
S1	S2	S3	S1	S2	S3	S1	S2	S3
60.52	58.74	84.67	83.66	97.90	103.20**	85.44	76.54	69.42

(*Minimum value between the two lakes; **Maximum value between the two lakes)

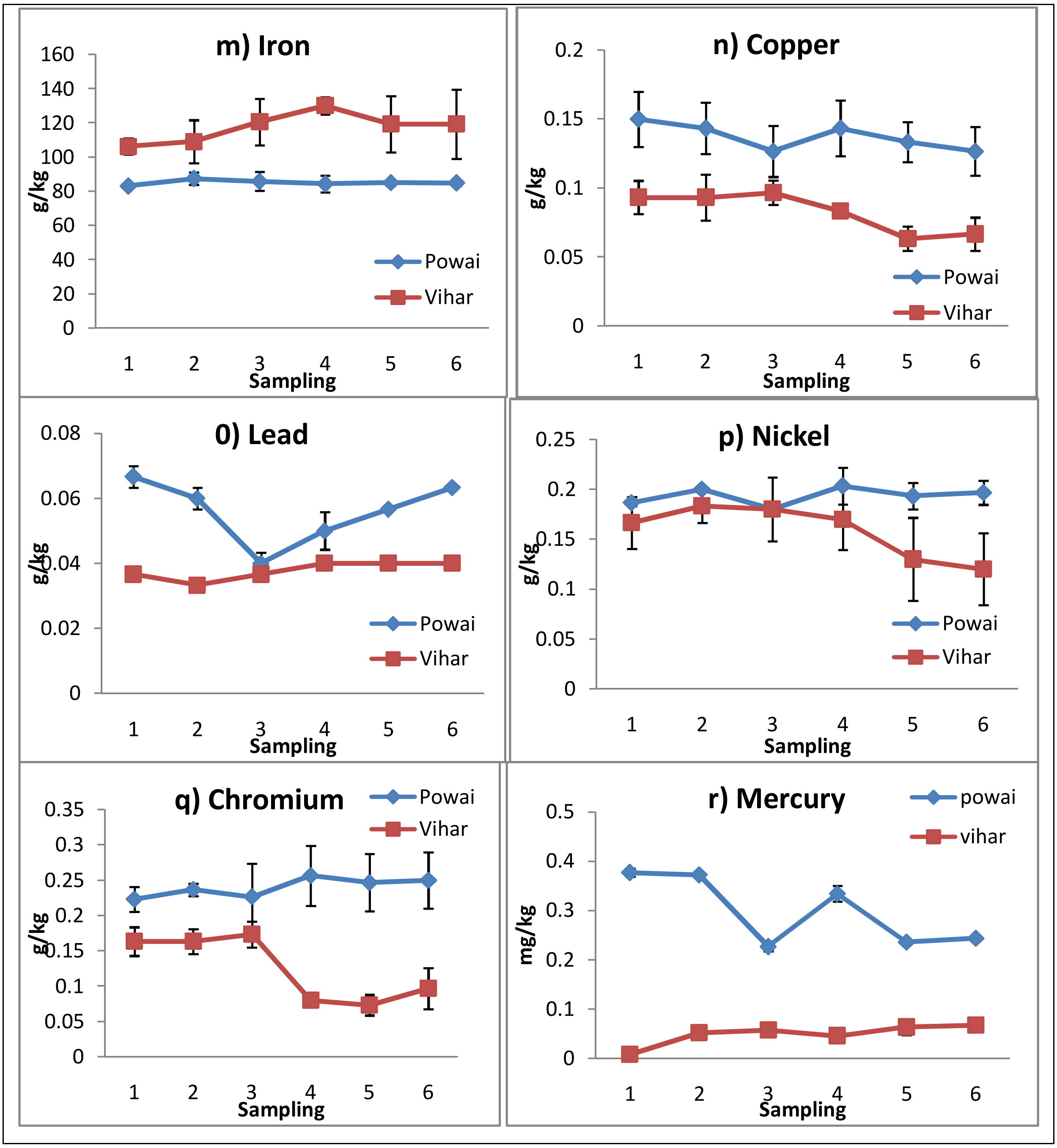

Fig. 4(contd). Differences in sediment quality parameters between Powai and Vihar lakes during different samplings

4.5. Phytoplankton diversity

A total of 34 genera of phytoplankters were observed in Powai Lake. The diversity of phytoplankton obtained from Vihar Lake was much more than that of Powai with a total of 51 genera. The most commonly occurring algae in both the lakes showed a striking similarity. All the organisms tentatively identified during the sampling period from both the lakes with their abundance are given in tables 12 - 13. Pictures of selected phytoplankters which are tentatively identified from both the lakes are also given (Fig. 8).

4.5.1. ANOVA test and percentage contribution

The mean sums of squares of plankton analyzed through the analysis of variance are presented in Table 13. The model R^2 values ranged from 0.96 to 0.99. F-test proved that there is a significant difference in phytoplankton population between the lakes and between different sampling periods (Table 11).

An increasing trend in abundance was observed for the chlorophyceans and cyanophyceans, whereas the other groups showed more or less equal abundance in consequent samplings. The variations in group-wise abundance of phytoplankton during different samplings are presented in Fig. 6. The periodic variation of different phytoplankton groups are shown in Fig. 7.

Table 11. Mean sums of squares (type 2) from analysis of variance for phytoplankters

Source	df	Bacillario	Chloro	Cyano	Dyno	Eugleno
Between lakes	1	200741669 **	791203136 **	3251470469 **	2141344 **	406022500 **
Sampling	5	618858 **	15757536 **	7983816 **	38784 **	1360513 **
Error	101	59348	815389	666996	3149	246946
R^2		0.99	0.97	0.99	0.96	0.98

(**Significance at P≤0.01;*Significance at P≤0.05; df: Degrees of freedom; Bacillario: Bacillariophyceae;Chloro: Chlorophyceae; Cyano: Cyanophyceae; Dyno: Dynophyceae; Eugleno: Euglenophyceae)

Table 12. Phytoplankters (no./l) identified from Powai Lake

A.	CHLOROPHYCEAE	Samplings S1	S2	S3	S4	S5	S6
	Volvocales						
1.	*Eudorina* sp.	440	547	413	440	663*	680
2.	*Pandorina* sp.	220	283	327*	303	320	327
3.	*Volvox* sp.	140	123	127	233*	220	210
	Ulotrichales						
4.	*Ulothrix* SPP.	2893	2297	3067	2820	3377	4113*
	Chlorococcales						
5.	*Micractinium* sp.	320	420*	410	253	310	400
6.	*Tetraedron* sp.	330	443	453	510	490	563*
7.	*Pediastrum* spp.	1493	1923	2697	2760	3023	3180*
8.	*Ankistrodesmus* sp.	260	327	330	337	297	357*
9.	*Chlorella* sp.	500	653	740	767*	513	467
10.	*Selenastrum* sp.	537	703	950	1257*	1503	1743
11.	*Scenedesmus* sp.	1493	1870	1933	1950*	1433	1720
12.	*Actinastrum* sp.	130	167	247	277	307	337*
13.	*Crucigenia* sp.	640	707	687	750	827*	780
	Zygnematales						
14.	*Staurastrum* sp.	990	1287	1607	1750	1763	1830*
15.	*Micrasterias* sp.	457	633	683	827	820	853*
16.	*Cosmarium* sp.	130	173	130	107	130	150
B.	**BACILLARIOPHYCEAE**						
	Centrales						
1.	*Melosira* sp.	3267*	2853	3160	2647	2910	2133
2.	*Cyclotella* sp.	117	120	143	220	237	260
	Pennales						
3.	*Asterionella* sp.	87	107	150	80	127	143
4.	*Synedra* sp.	1130	1063	1157*	1220	1340	1500
5.	*Navicula* sp.	1007	997	1077	1230	1273	1290*
6.	*Nitzschia* sp.	917	927	1037	1070	1297*	1240
7.	*Rhizosolenia* sp.	130	147	147	147	150	213
C.	**DINOPHYCEAE**						
1.	*Peridinium* sp.	260	320	343	323	363	403*
D.	**EUGLENOPHYCEAE**						
1.	*Euglena* spp.	4270*	3533	3830	3547	3153	2887
2.	*Phacus* sp.	3873*	3797	3620	3267	2867	2717
E.	**CYANOPHYCEAE**						
	Chroococcales						
1.	*Chroococcus* sp.	450	507	563	603	513	610*
2.	*Microcystis* sp.	4310	4507*	3713	3393	2933	2707
3.	*Merismopedia* sp.	2520	2433	2917	3070	3293	3520*
	Nostocales	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
4.	*Siprulina* sp.	40	47	47	57*	47	40
5.	*Anabaena* sp.	840	677	867	940	1263*	1303
6.	*Arthrospira* sp.	8733	9303	10337	11320	11433	12447*
7.	*Oscillatoria* sp.	1387	1443	1387	1880*	1440	1723
8.	*Nostoc* sp.	1343	1483	1227	1920	2197	2297*

(*maximum)

Table 13. Phytoplankters (no./l) identified from Vihar Lake

A.	CHLOROPHYCEAE	Samplings S1	S2	S3	S4	S5	S6
	Volvocales						
1.	*Gonium* sp.	80	67	110	113	130	137*
2.	*Pandorina* sp.	60	90	103*	93	77	87
3.	*Eudorina* sp.	133	147	170	120	180*	143
4.	*Volvox* sp.	177	190	220	253	280*	250
	Tetrasporales						
5.	*Sphaerocystis* sp.	60	63	73	107	130	133*
	Ulotrichales						
6.	*Ulothtix* sp.	253	273	283	310	343	350*
7.	*Uronema* sp.	90	127	140	200*	240	183
	Chlorococcales						
8.	*Micractinium* sp.	227	250	273*	203	233	197
9.	*Characium* sp.	57	67	100	147*	113	120
10.	*Coelastrum* sp.	40	67	40	67	67	90*
11.	*Tetraedron* sp.	100	57	80	83	103	123*
12.	*Pediastrum* spp.	453	427	567	560	653	700*
13.	*Hydrodictyon* sp.	33	37	33	33	60	73*
14.	*Selenastrum* sp.	163	217	250	307	337*	323
15.	*Scenedesmus* spp.	357	370	313	420	470	487*
16.	*Actinastrum* sp.	90	93	140	170	237	247*
17.	*Crucigenia* sp.	163	187	190	220	253*	217
18.	*Kirchneriella* sp.	70	50	107	130	153	157*
	Zygnematales						
19.	*Closterium* sp.	90	140	160*	123	153	147
20.	*Staurastrum* sp.	453	447	510	540*	493	523
21.	*Micrasterias* sp.	110	157	160	167	217*	183
22.	*Cosmarium* sp.	543	593	610	657	667*	643
23.	*Desmidium* sp.	137	170	160	217*	170	173
24.	*Xanthidium* sp.	47	77	117	140	170*	143
25.	*Arthrodesmus* sp.	73	60	103	127	160	200*
B.	**BACILLARIOPHYCEAE**						
	Centrales						
1.	*Melosira* sp.	343	333	400	397	467	453*
2.	*Cyclotella* sp.	140	170	117	147	163	180*
3.	*Coscinodiscus* sp.	90*	30	23	47	70	90
	Pennales						
4.	*Asterionella* sp.	133	113	167	150	190*	150
5.	*Synedra* sp.	267	240	237	243	303	333*
6.	*Navicula* sp.	153	103	113	133	167*	147
7.	*Gyrosigma* sp.	33	43	63*	60	47	53
8.	*Pinnularia* sp.	133	160	237	227	267	300*
9.	*Rhizosolenia* sp.	210	250	260	337	347*	343
10.	*Surirella* sp.	50	50	57	67	63	80*
11.	*Cymbella* sp.	90	73	107	150	130	167*
12.	*Gomphonema* sp.	63	77	103	127	137	163*
C.	**DINOPHYCEAE**						

1.	*Peridinium* sp.	703	650	780	830	880	943*
2.	*Gonyolax* sp.	10	27	10	30	33	43*
D.	**EUGLENOPHYCEAE**						
1.	*Phacus* sp.	160	163	200	217*	157	163
E.	**CYANOPHYCEAE**						
	Chroococcales						
1.	*Chroococcus* sp.	427	343	427	483	460	497*
2.	*Gloeocapsa* sp.	80	73	100	130	137	160*
3.	*Synechocystis* sp.	103	63	130	157	150	200*
4.	*Aphanocapsa* sp.	123	150	147	167*	110	113
5.	*Microcystis* sp.	240	257	293	303	317*	247
6.	*Merismopedia* sp.	133	113	157	210	230	260*
	Nostocales						
7.	*Spirulina* sp.	93	57	70	123	150*	133
8.	*Arthrospira* sp.	460	560	587	463	570	630*
9.	*Lyngbya* sp.	280	257	287	340	353	380*
10.	*Anabaena* sp.	340	367	287	333	383	460*
11.	*Nostoc* sp.	350	353	363	340	447	480*

(*maximum)

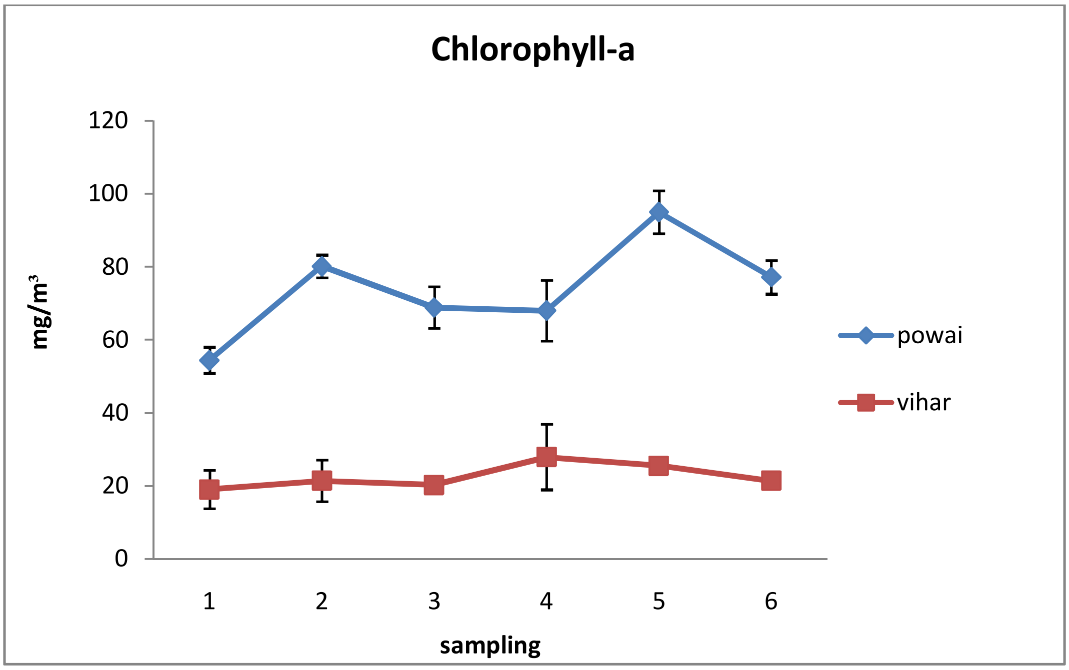

Fig. 5. Differences in chlorophyll-a content between Powai and Vihar lakes during different samplings

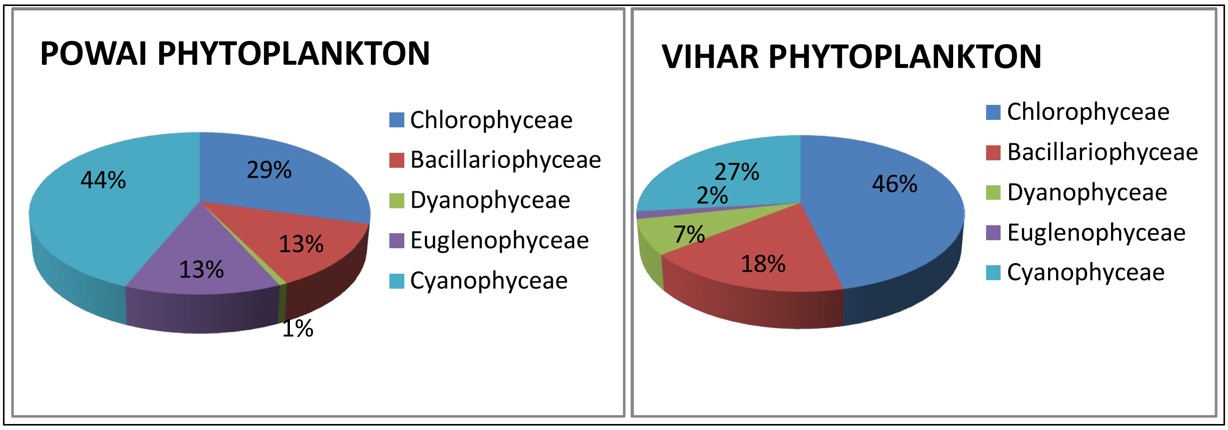

Fig. 6. Percentage contribution of phytoplankton groups in Powai and Vihar

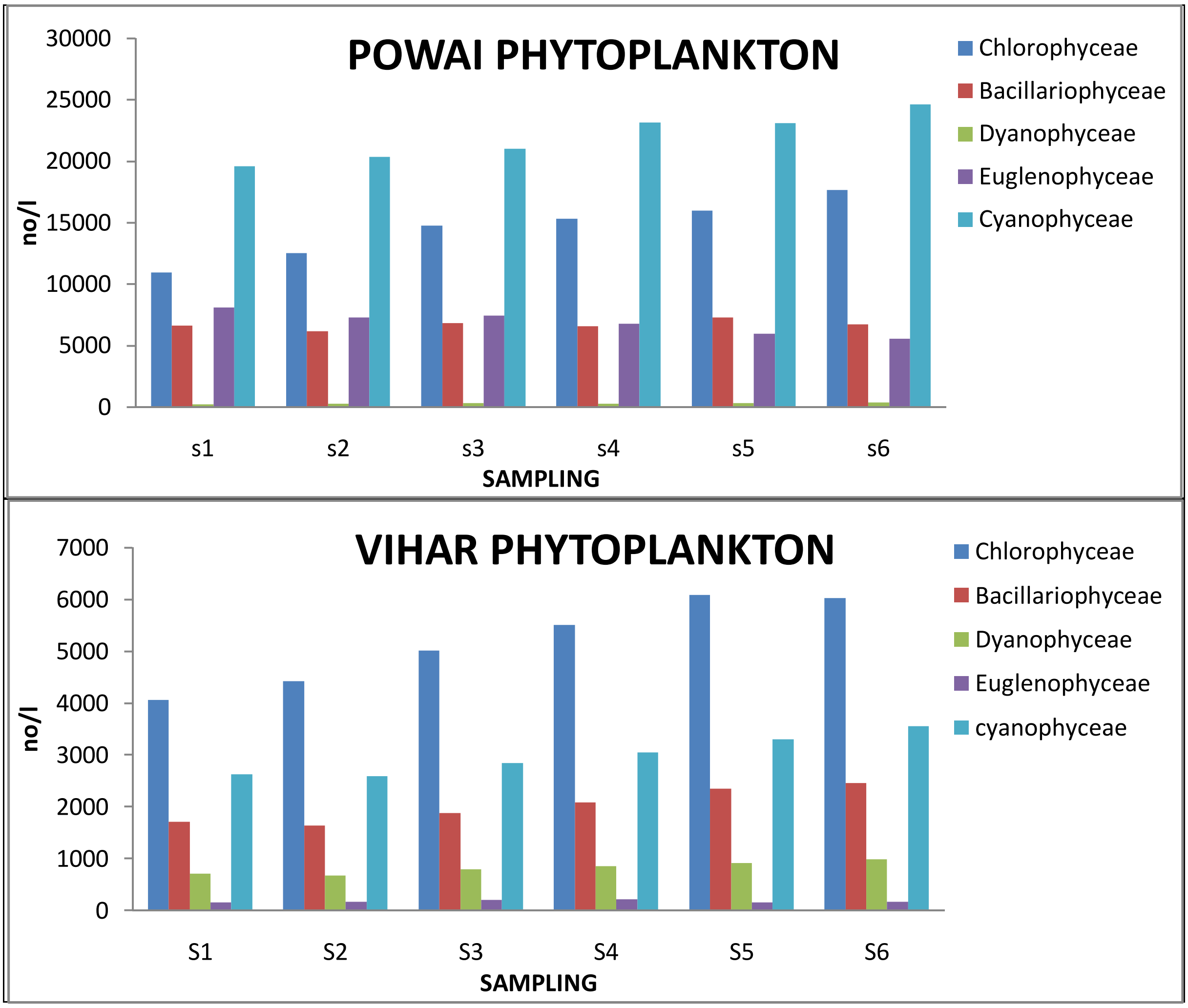

Fig. 7. Sampling - wise variation in population density (no./l) of phytoplankton groups in Powai and Vihar

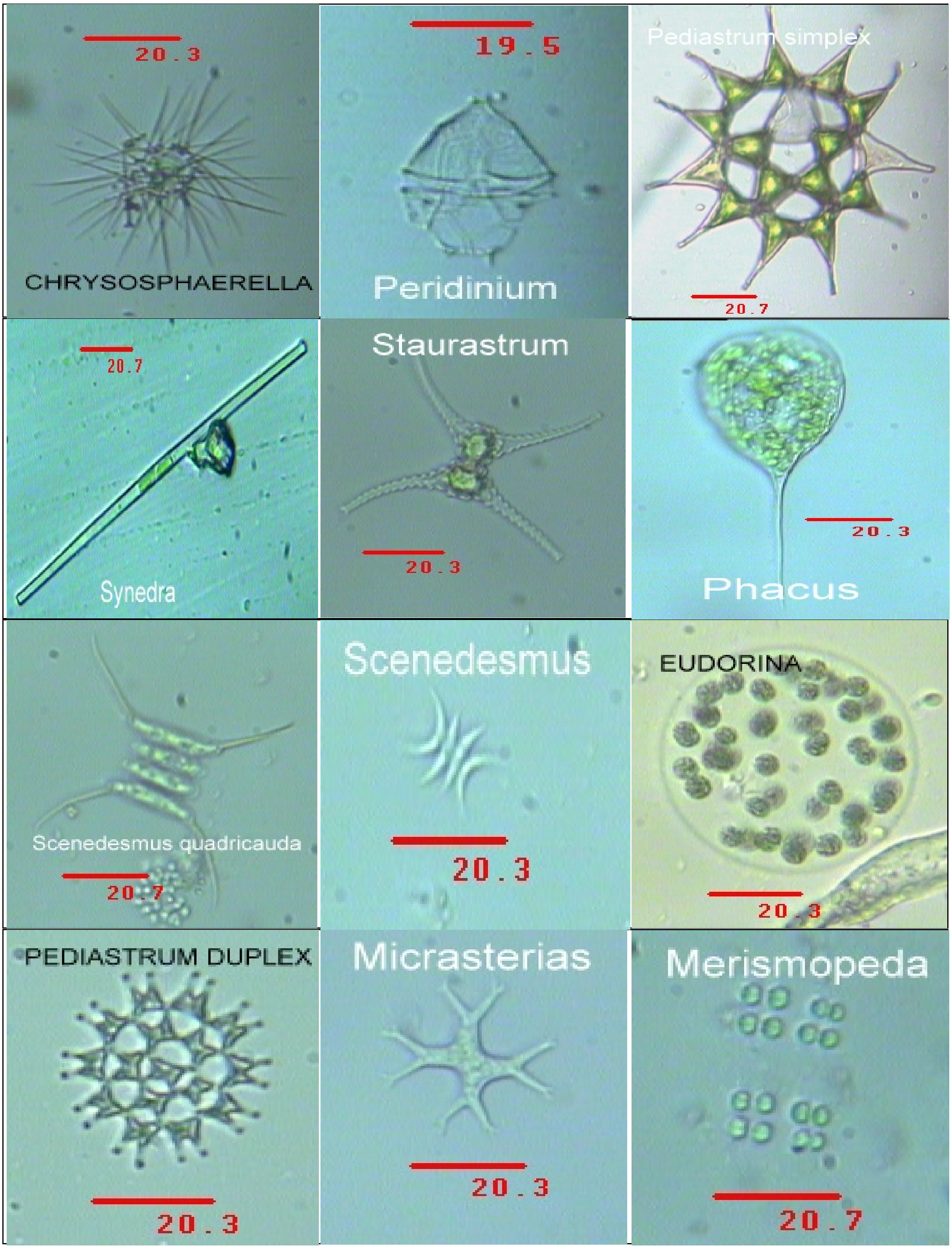

Fig. 8. Common phytoplankters observed in Powai and Vihar lakes (tentative identification)

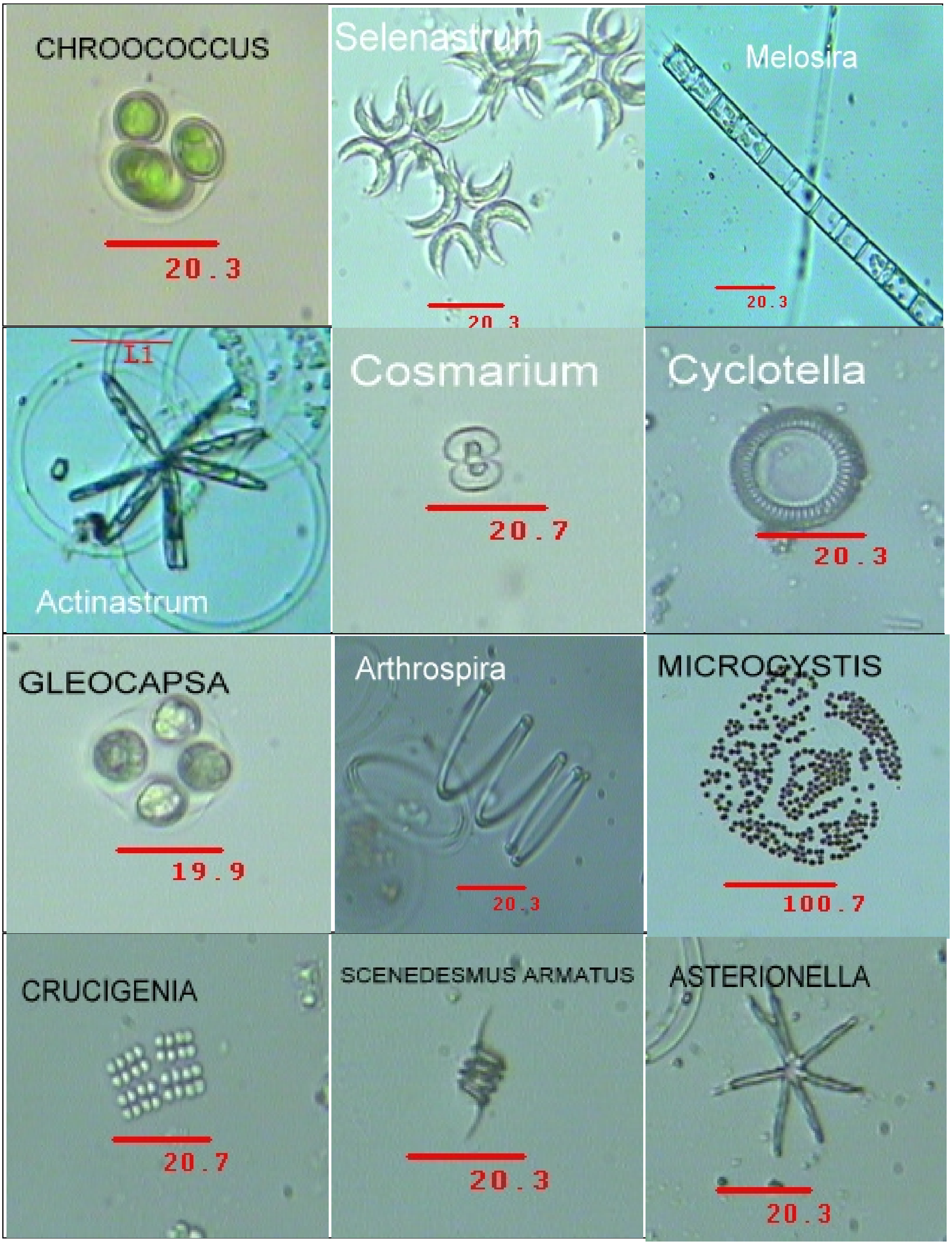

Fig. 8(contd). Common phytoplankton observed in Powai and Vihar lakes (tentative identification)

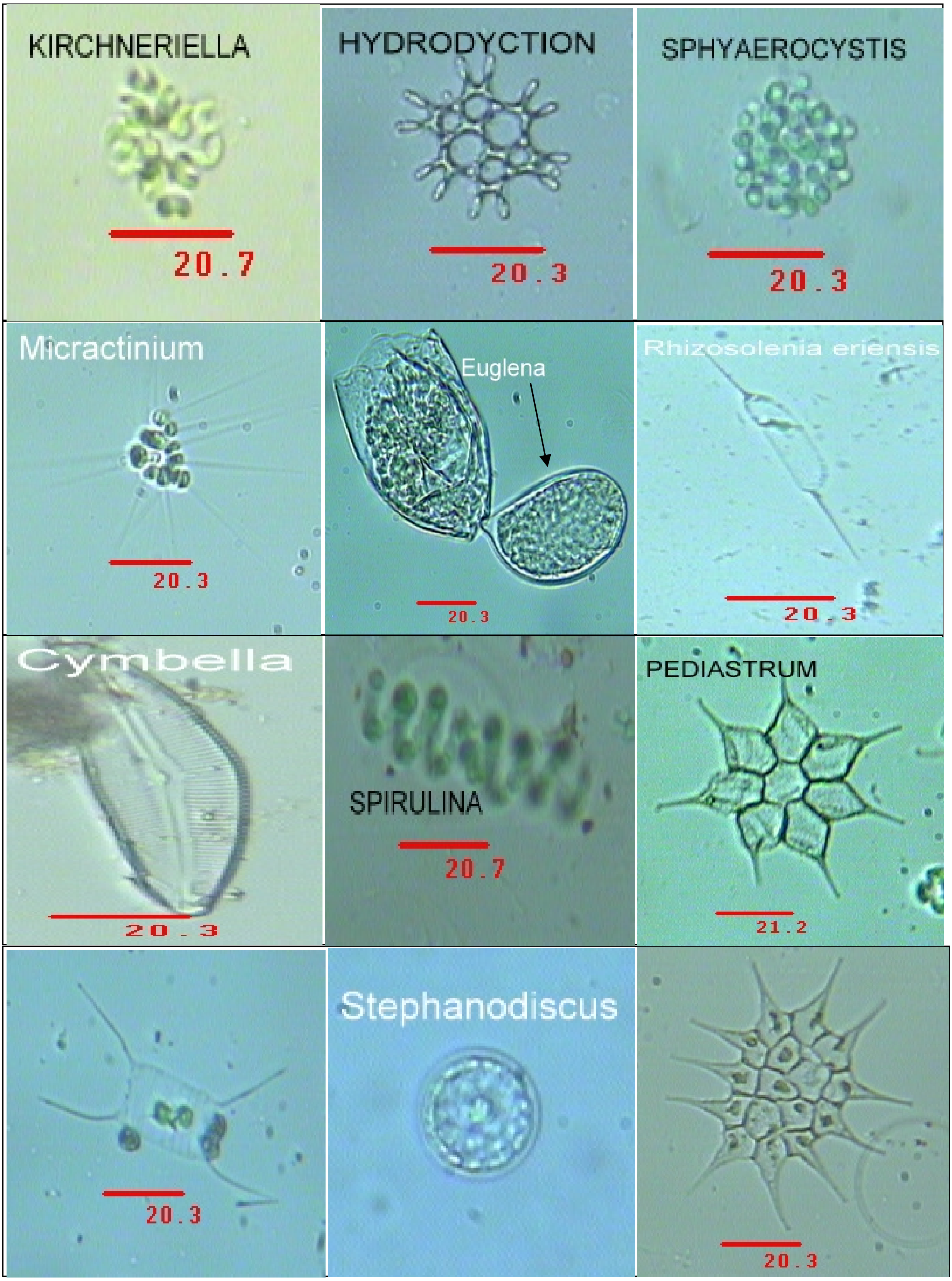

Fig. 8(contd). Common phytoplankters observed in Powai and Vihar lakes (tentative identification)

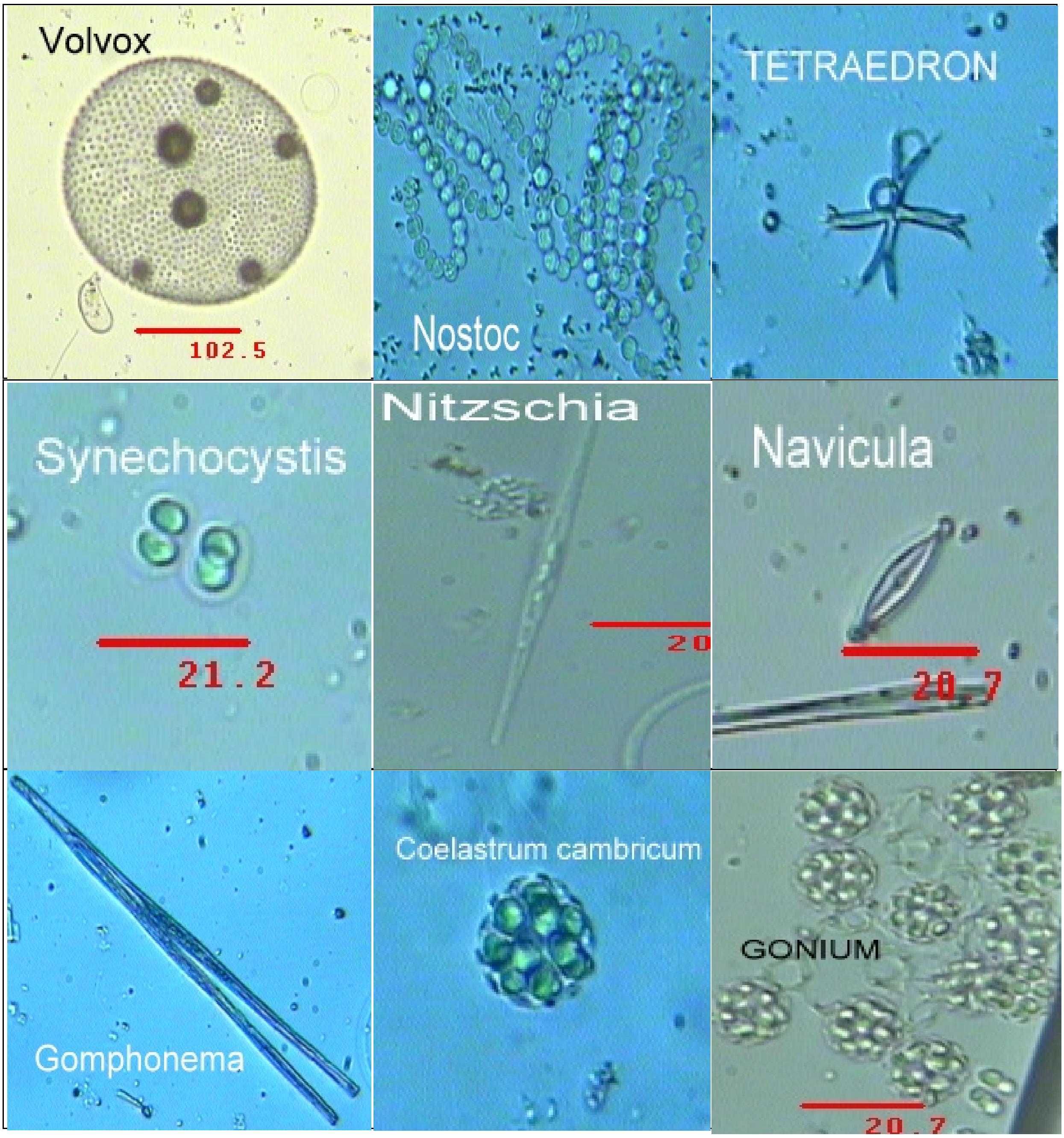

Fig. 8(contd). Common phytoplankton observed in Powai and Vihar lakes (tentative identification)

4.6. Zooplankton diversity

A total of 12 zooplankton genera were obtained from Powai Lake and 16 genera from Vihar Lake during the different samplings. All the organisms tentatively identified during the sampling period from both the lakes, with their abundance are given in Table 15. The images of selected zooplankters tentatively identified from both the lakes are given in Fig. 11.

4.6.1. ANOVA test and percentage contribution

The mean sums of squares of zooplankton analyzed, from the analysis of variance (ANOVA test) is presented in Table 15. The model R^2 values ranged from 0.95 to 0.96. F-test proved that there is significant difference in zooplankton population between the lakes and between different sampling periods (Table 14). In both the lakes, rotifers were the dominant group and group-wise distribution of zooplankters during the different samplings is shown in Fig. 9. Sample-wise variation in population density (no./l) of zooplankton groups in Powai and Vihar are shown in Fig. 10.

Table 14. Mean sums of squares (type 2) from analysis of variance for zooplankters

Source	**df**	**Rotifera**	**Cladocera**	**Copepoda**
Between lakes	1	31117802**	6010669**	3330625**
S ampling	5	324489**	193662**	20436*
Error	101	39491	8070	5725
R^2		0.96	0.96	0.95

(**Significant at P≤0.01; *Significant at P≤0.05; df: Degrees of freedom)

Table 15. Zooplankter (no./l) identified from Powai and Vihar lakes

Powai Lake							
A.	**ROTIFERA**	Samplings **S1**	**S2**	**S3**	**S4**	**S5**	**S6**
1.	*Brachionus* spp.	663	670	787	743	877	893
2.	*Keratella* spp.	1467	1543	1483	1823	2030	2093
3.	*Filina* sp.	60	80	60	100	80	117
4.	*Asplanchna* sp.	40	50	67	63	90	107
B.	**CLADOCERA**						
1.	*Daphnia* spp.	460	543	583	673	703	737
2.	*Moina* sp.	453	473	550	553	637	680
3.	*Cerodaphnia* sp.	120	217	243	250	237	263
4.	*Bosmina* sp.	63	47	70	93	100	70
C.	**COPEPODA**						
1.	*Cyclops* spp.	303	343	290	280	323	333
2.	*Diaptomus* sp.	93	63	110	133	113	130
3.	*Nauplius* sp.	673	680	570	670	710	713
4.	*Cypridopsis* sp.	80	50	30	43	60	77

Vihar Lake							
A.	**ROTIFERA**	Samplings **S1**	**S2**	**S3**	**S4**	**S5**	**S6**
1.	*Brachionus* spp.	307	340	360	323	313	397
2.	*Keratella* spp.	210	247	260	307	287	263
3.	*Filina* sp.	50	53	43	43	70	60
4.	*Asplanchna* sp.	20	17	20	20	37	37
5.	*Trichocera* sp.	10	20	3	20	33	20
6.	*Notholca* sp.	10	17	23	23	20	10
7.	*Synchaeta* sp.	40	50	47	40	30	20
8.	*Polyarthra* sp.	37	50	43	60	60	60
B.	**CLADOCERA**						
1.	*Daphnia* spp.	163	210	173	227	260	280
2.	*Moina* sp.	227	237	257	237	190	293
3.	*Ceriodaphnia* sp.	73	67	100	123	147	113
4.	*Bosmina* sp.	53	53	80	73	130	150
C.	**COPEPODA**						
1.	*Cyclops* spp.	167	150	170	173	137	163
2.	*Diaptomus* sp.	67	63	103	107	110	103
3.	*Nauplius* sp.	167	173	257	237	200	270
4.	*Cypridopsis* sp.	67	60	57	57	67	100

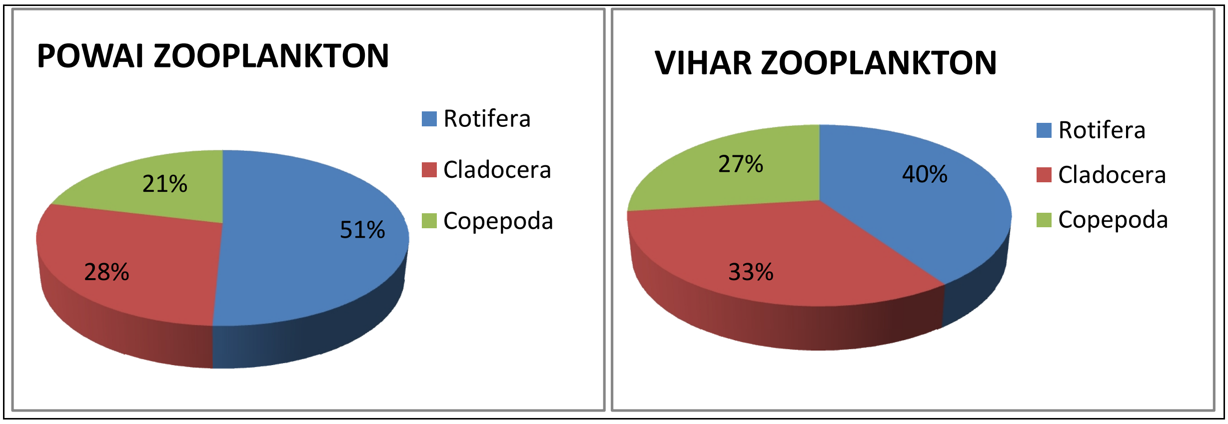

Fig. 9. Percentage contribution of zooplankton groups in Powai and Vihar lakes

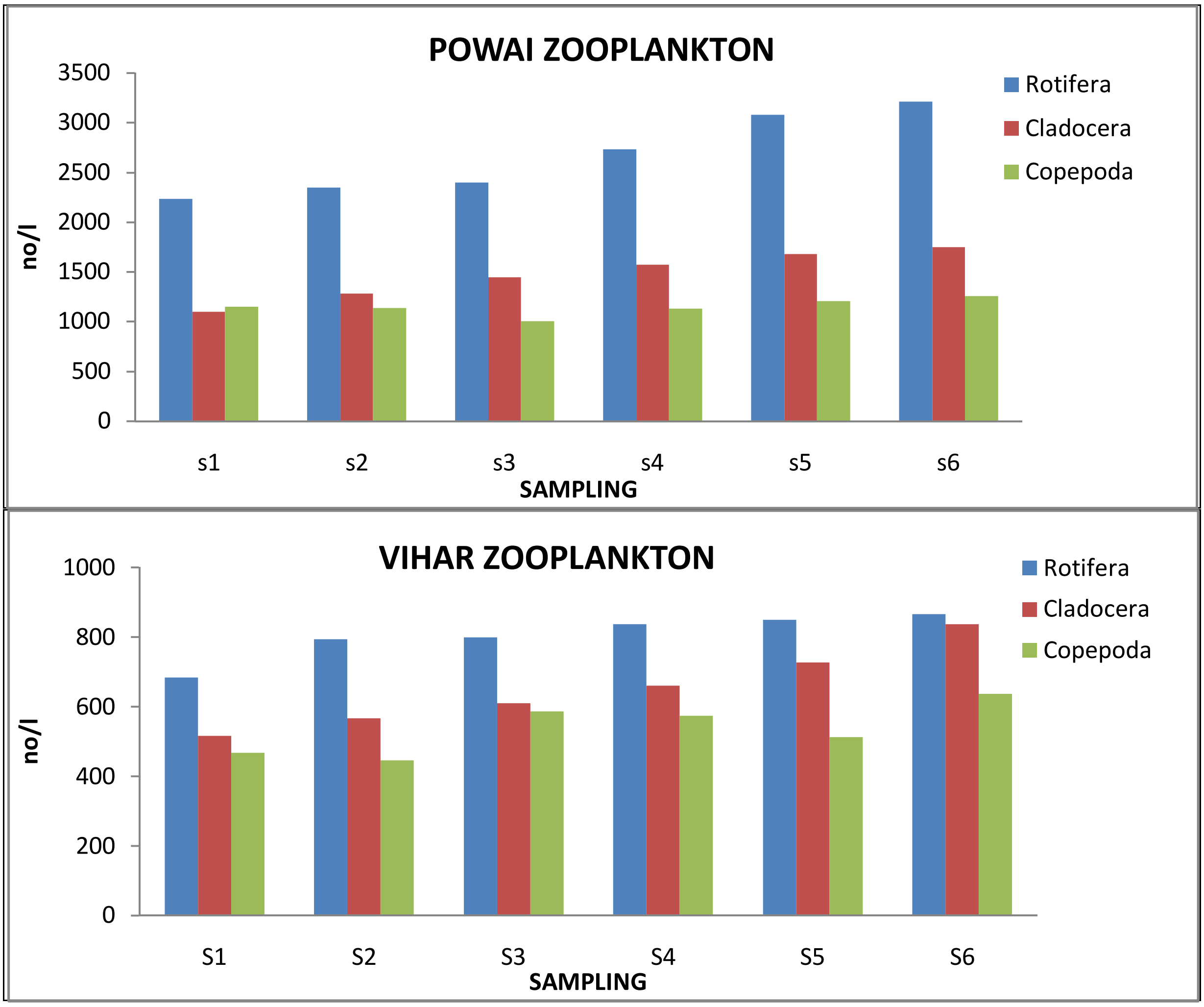

Fig. 10. Sampling - wise variation in population density (no./l) of zooplankton groups in Powai and Vihar lakes

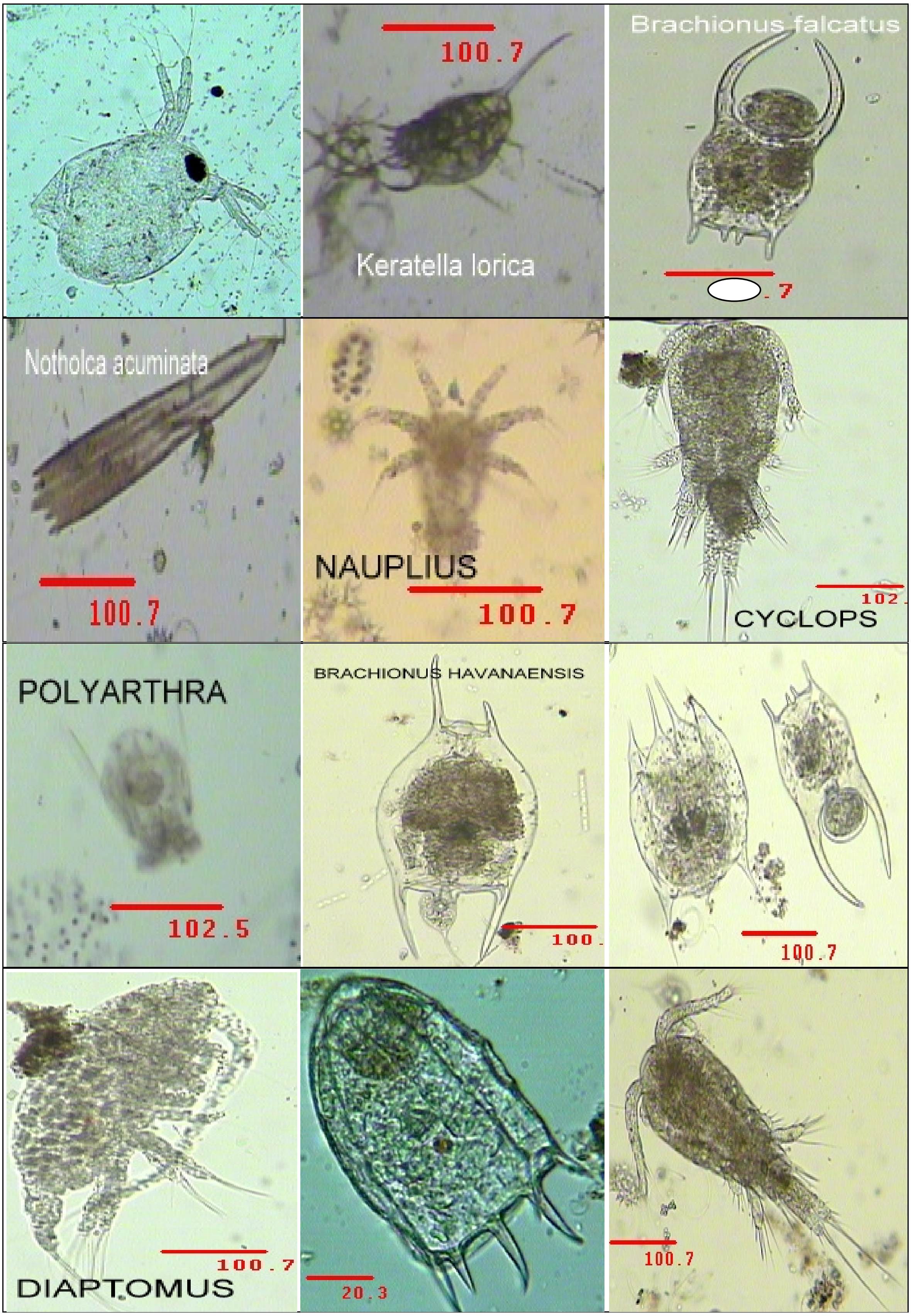

Fig. 11. Common zooplankters observed from Powai and Vihar lakes (tentative identification)

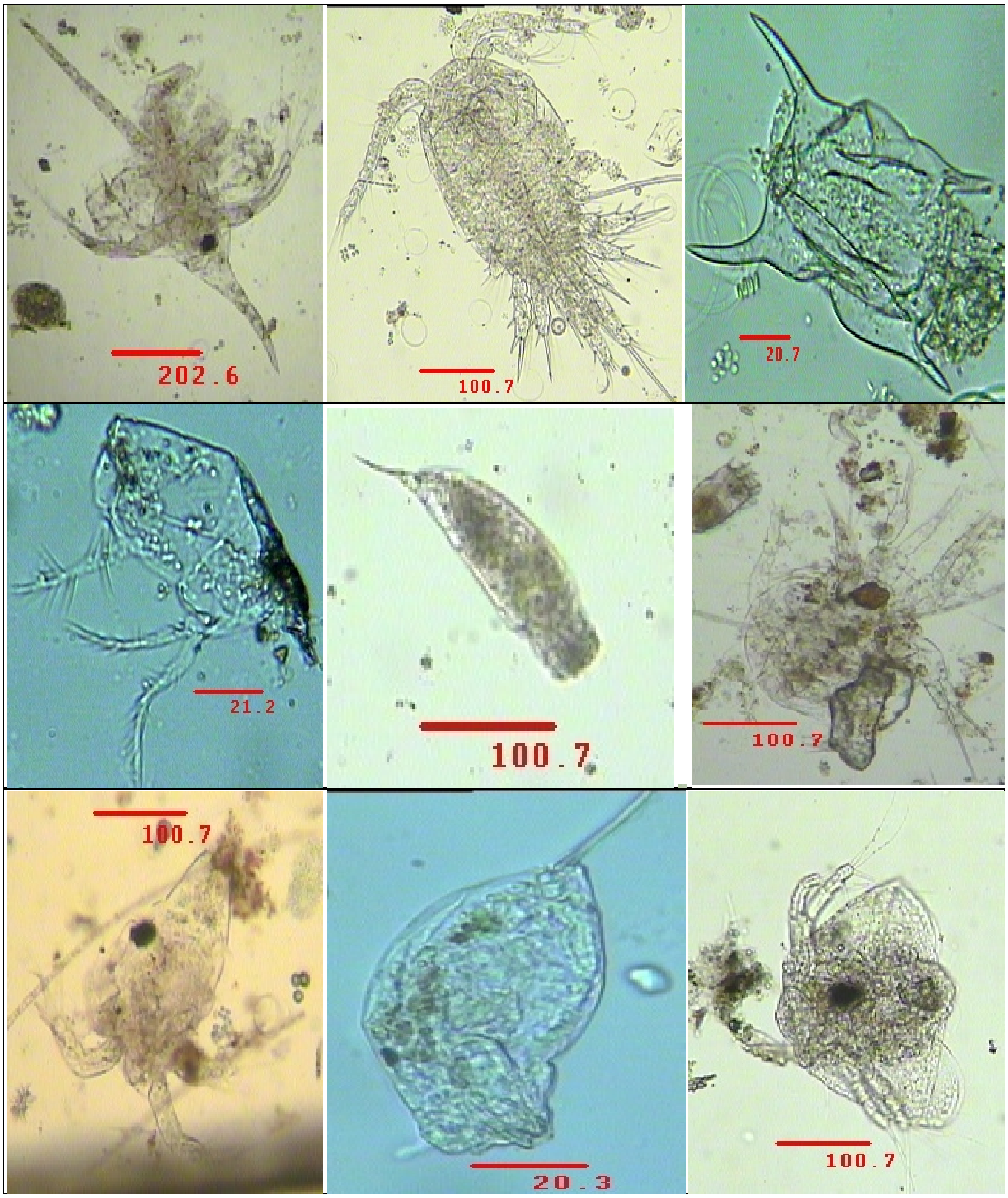

Fig.11(contd). Common zooplankters observed from Powai and Vihar lakes (not yet identified)

4.7. Macro-benthic invertebrates

A total of 11 genera of macro-benthic invertebrates were observed in Powai sediment, which consisted of three representatives from Insecta, four from Oligochaeta and four from Mollusca, whereas 19 genera observed in Vihar Lake which comprised seven from Insecta, seven from Oligochaeta and five from Mollusca throughout the period of investigation. The group-wise enumeration of different macro-benthic species is presented in Table 16.

4.7.1. ANOVA test and percentage contribution

The mean sums of squares of benthos analyzed through the analysis of variance (ANOVA test) represented in Table 16. The model R^2 values ranged from 0.33 to 065. F-test proved that there is a significant difference in benthos population between the lakes and between different sampling periods (Table 17). Group-wise distribution and periodic variation of macro-benthos during the different samplings are shown in Fig. 13. In Powai, 45% of the total benthos was contributed by Insecta, 28% by Oligochaeta and 27% by Mollusca, whereas in Vihar, Oligochaeta contributed 37%, insecta 33% and Mollusca 30% to the total (Fig. 12).

Table 17. Mean sums of squares (type 2) from analysis of variance for benthos

Source	**df**	**Insecta**	**Oligochaeta**	**Mollusca**
Between lakes	1	205847**	161484**	30949*
Sampling	5	22093**	11166	5937
Error	101	5180	6081	4196
R^2		0.678	0.55	0.33

(**Significant at P≤0.01; *Significannt at P≤0.05; df: Degrees of freedom)

Table 16. Macro-benthic invertebrates (no./m²) identified from Powai and Vihar lakes during different samplings

No.	**Powai Lake**						
		Samplings					
A.	**INSECTA**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
1.	*Chironomus* spp.	307	356	381	296	259	312
2.	*Tanypus* sp.	219	237	167	181	133	160
3.	*Polypedilus* sp.	107	74	74	126	130	110
B.	**OLIGOCHAETA**						
1.	*Chaetogaster* sp.	167	163	167	178	148	164
2.	*Tubifex* spp.	148	133	104	167	122	131
3.	*Branchiura* sp.	52	44	33	33	26	31
4.	*Limnodrilus* sp.	22	33	30	22	19	23
C.	**MOLLUSCA**						
1.	*Lymnaea* spp.	174	200	230	126	137	164
2.	*Cochliopa* sp.	70	52	85	74	52	70
3.	*Gyraulus* sp.	85	78	70	74	74	73
4.	*Viviparus* sp.	30	19	22	30	30	27
	Vihar Lake						
		Samplings					
A.	**INSECTA**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
1.	*Chironomous* spp.	104	122	115	122	104	114
2.	*Tanypus* sp.	81	104	100	96	78	91
3.	*Culicoides* sp.	81	100	70	85	78	78
4.	*Polypedilus* sp.	52	89	56	56	48	53
5.	*Orthocladius* sp.	22	56	41	30	37	36
6.	*Tipula* sp.	19	56	33	22	41	32
7.	*Monopelopia* sp.	15	33	15	22	33	23
B.	**OLIGOCHAETA**						
1.	*Chaetogastor* sp.	141	196	159	100	119	126
2.	*Tubifex* spp.	93	133	152	115	111	126
3.	*Nais* sp.	44	89	78	74	67	73
4.	*Dero* sp.	30	59	48	48	63	53
5.	*Lumbriculus* sp.	33	70	78	37	56	57
6.	*Limnodrilus* sp.	19	41	41	37	33	37
7.	*Pristina* sp.	19	37	19	19	26	21
C.	**MOLLUSCA**						
1.	*Lymnaea* sp.	137	189	100	152	159	137
2.	*Gyraulus* sp.	96	119	93	100	104	99
3.	*Indoplanorbis* sp.	78	100	78	93	74	81
4.	*Viviparus* sp.	56	56	48	63	44	52
5.	*Cochliopa* sp.	41	48	48	44	26	40

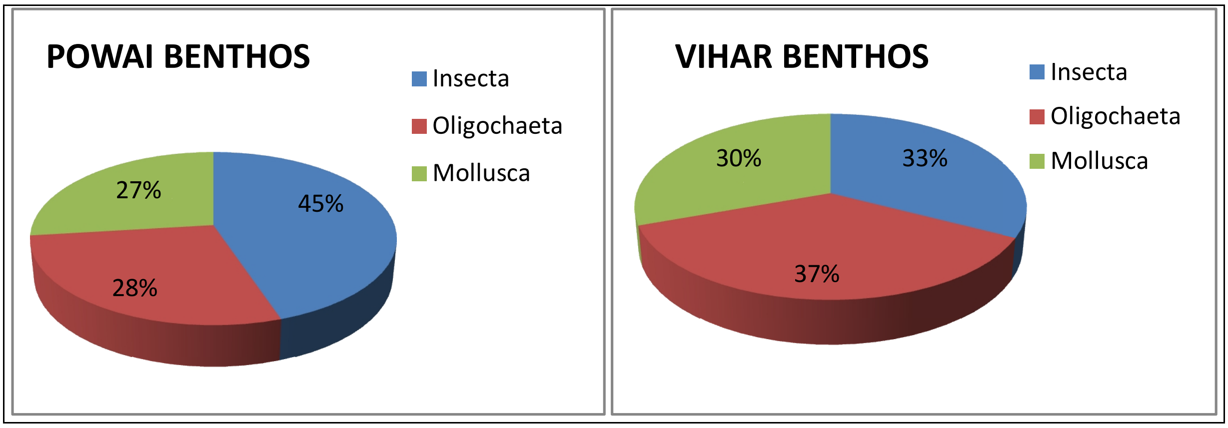

Fig. 12. Percentage contribution of macrobenthic groups in Powai and Vihar lakes

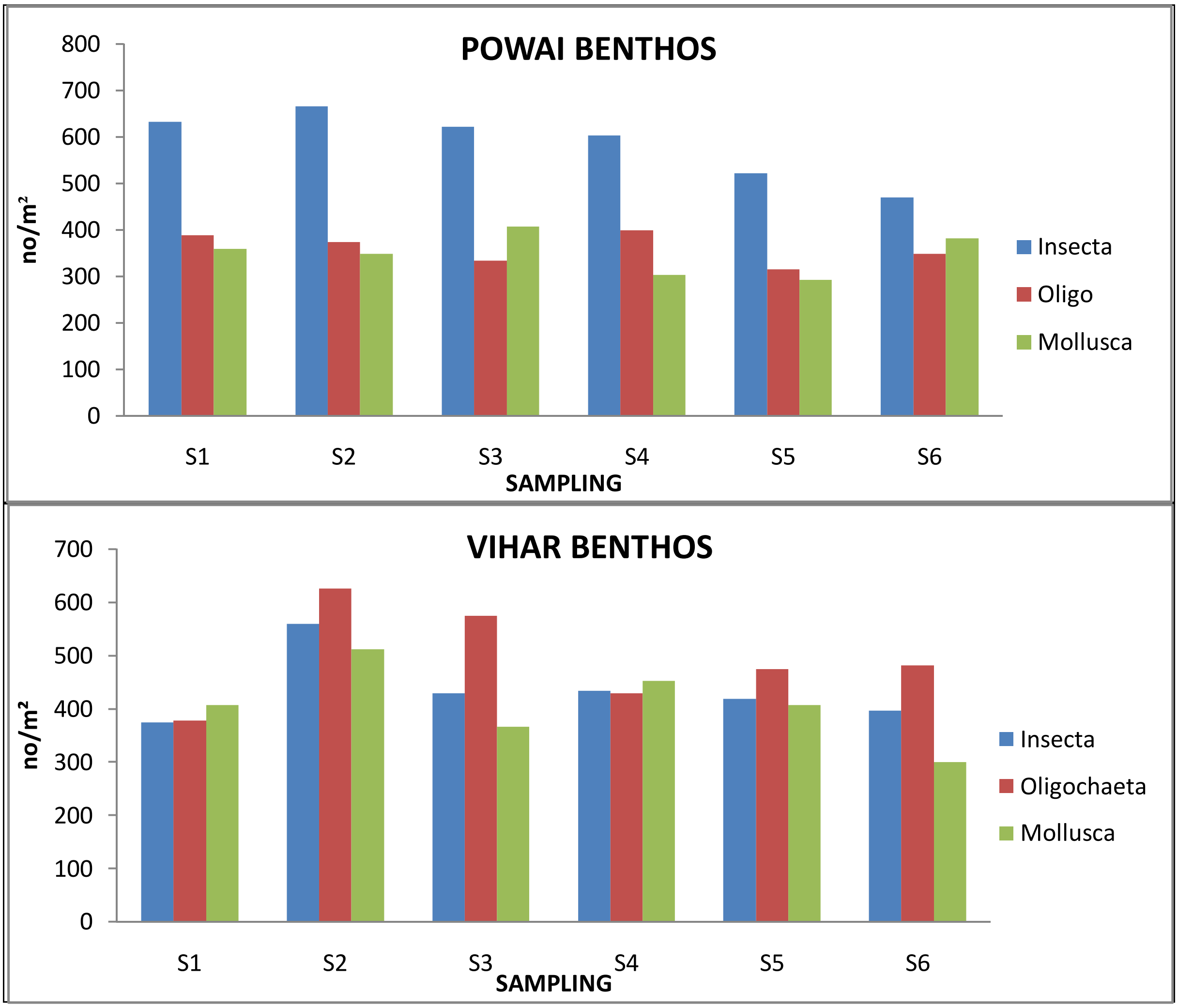

Fig. 13. Sample-wise variation in population density (no./m^2) of macro-benthic groups in Powai and Vihar lakes

4.8. Bacterial diversity

To investigate the bacterial diversity of the lakes, the genomic DNA extracted from the water and sediment samples of both the lakes were subjected to denaturing gradient gel electrophoresis (DGGE) with PCR amplified 16S rRNA gene using universal DGGE primers, BA 338F and UN 518R (Fig. 14). The gel images obtained after DGGE are presented in figures 16 to 19. The excised DGGE bands were further subjected to re-PCR and the amplification was confirmed by running agarose gel electrophoresis (Fig. 15). The PCR products were then purified and send for sequencing; 36 different sequences were obtained from Powai sediment, 30 from Vihar sediment, 40 from Powai water and 41 from Vihar water. Comparison of the the 16S rRNA gene sequence derived from the DGGE bands with those of GenBank database revealed the identity of the organisms (Table 18 - 21). The organisms which were dominant in water and sediment of both the lakes were *Pseudomonas, Bacillus, Nitrosomonas, Aeromonas, Duganella, Devosia, Enterobactor, Methylobacterium, Comomonas, Lysobactor, Actinobacterium, Paracoccus, et*c. The distinct bacterial species observed in Powai sediment were *Ferribactor*, *Klebsiella, Sulfurovum, Rhodococcus, Byssovorax, Arthrobacter, Chloroflexus, Magnetococcus, Acidobacterium, Massilia, Curvibactor, Erwinia,* etc., whereas *Herbaspirillum, Erythrobacter*, *Acinetobacter*, *Undibacteria*, *Alkanivorax*, Oxalobacteraceae, *Rickettsiella*, *Ralstonia*, Acidimicrobidae, *Blastochloris viridis, etc.* were the distinct groups in Powai water samples.

Peptococcaceae bacterium, *Burkholderia*, *Duganella*, *Asticcacaulis*, *Dechloromonas*, Desulfobulboceae, *Enterobacter*, Chloroflexi bacterium, *Methylobacterium,* Myxococcales, *Actinoplanes, Leptospirillum,* etc. were the distinct groups in Vihar sediment and *Stenotrophomonas*, *Chryseobacterium*, *Exiguobacterium*, *Polaromonas*, *Flavobacterium*, *Propioni vibrio*, *Alishewanella,* Rhizobiales, *Flexibacter*, Firmicutes bacterium, *Eubacterium*, etc. were the distinct groups observed in Vihar water samples.

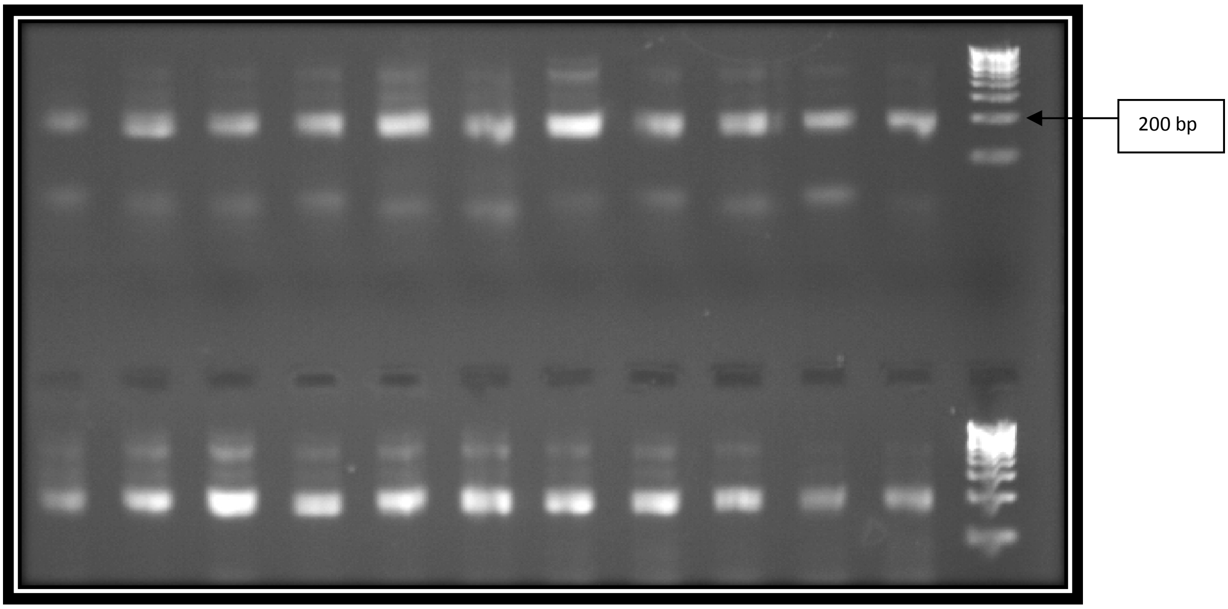

Fig. 14. Agarose gel electrophoresis picture of 230 bp DGGE amplicon obtained using BA 338F and UN 518R

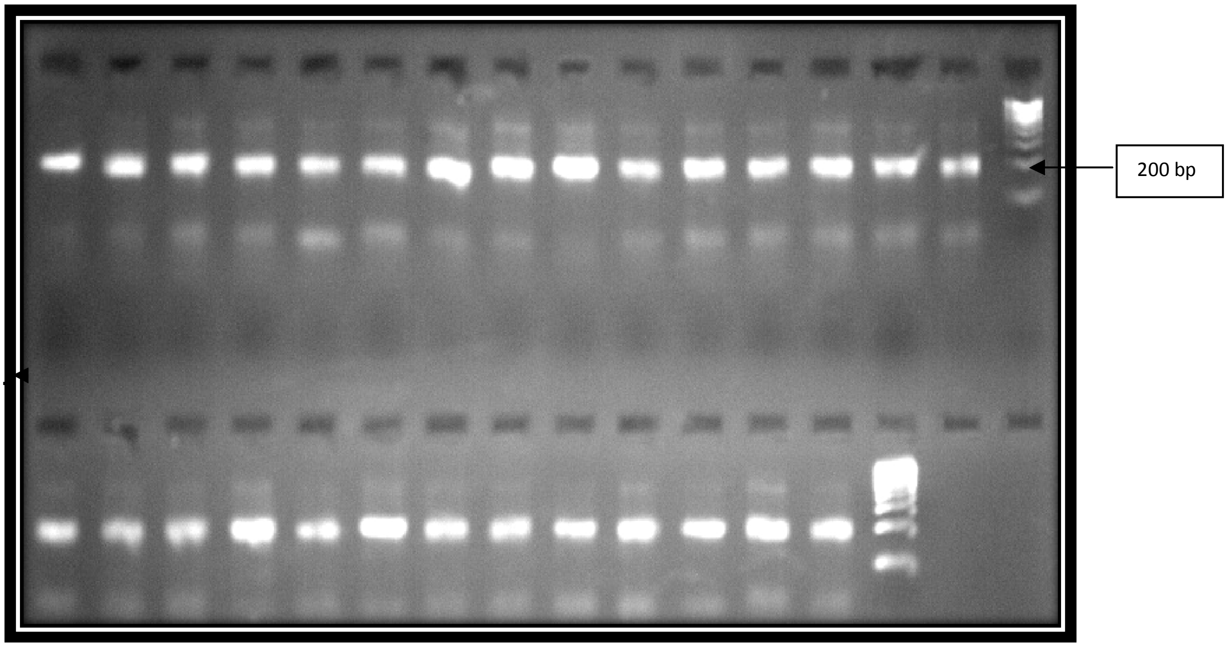

Fig. 15. Agarose gel electrophoresis picture of 180bp amplicon obtained after re-PCR of excised DGGE bands

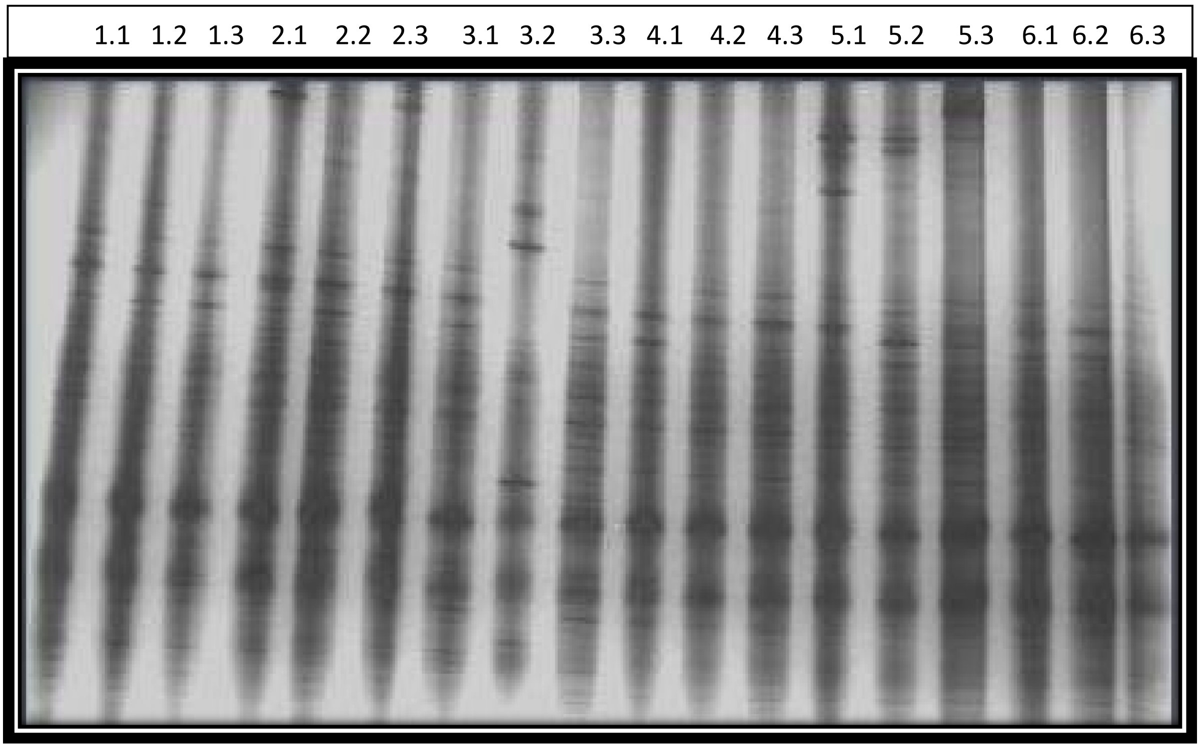

Fig. 16. 10% DGGE gel showing the microbial diversity in Powai Lake sediment (1.1 = Sampling 1, Station1; 36 different bands obtained from this gel)

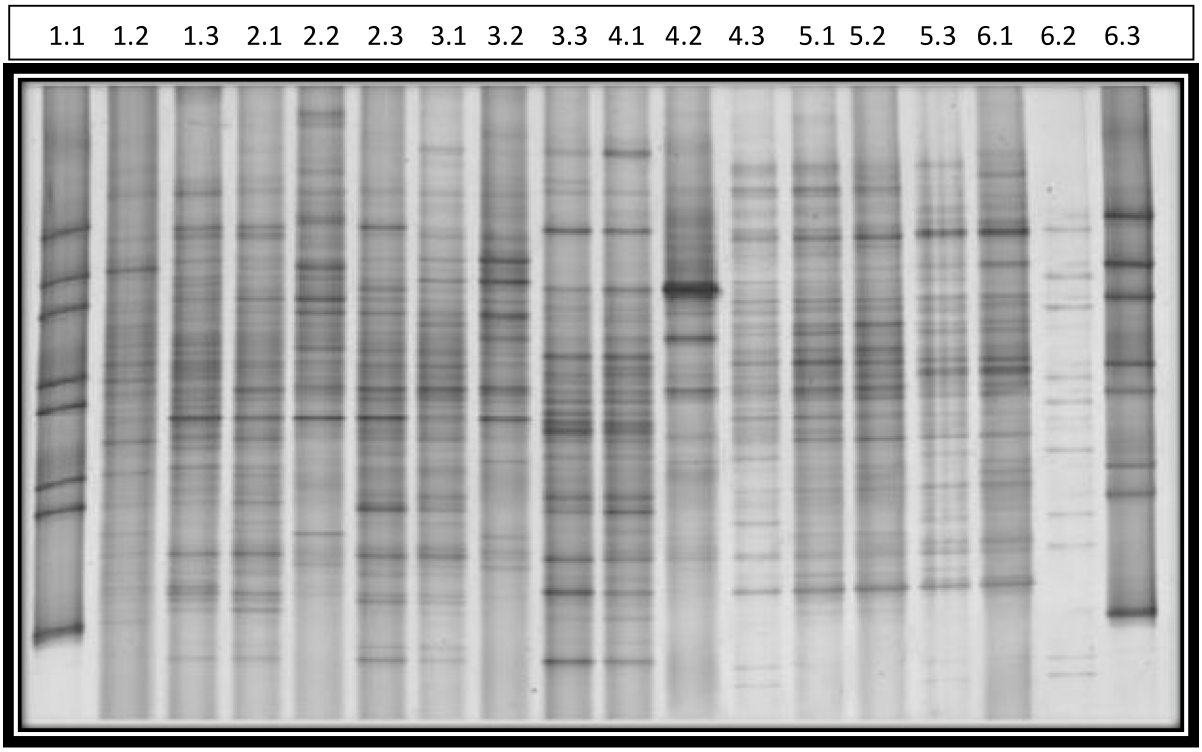

Fig. 17. 10% DGGE gel, showing the microbial diversity in Powai water (1.1 = Sampling 1, Station1; 40 different bands obtained from this gel)

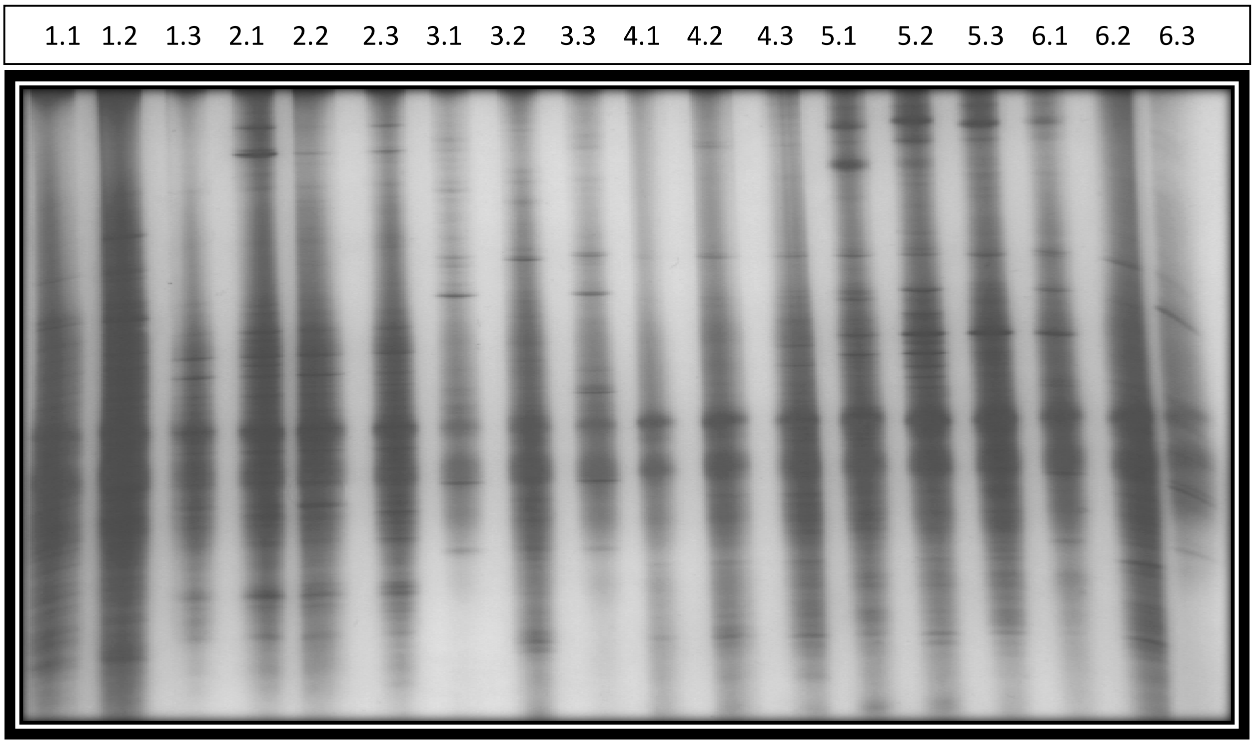

Fig. 18. 10% DGGE gel showing the microbial diversity in Vihar Sediment
(1.1 = Sampling 1, Station1; 30 different bands obtained from this gel)

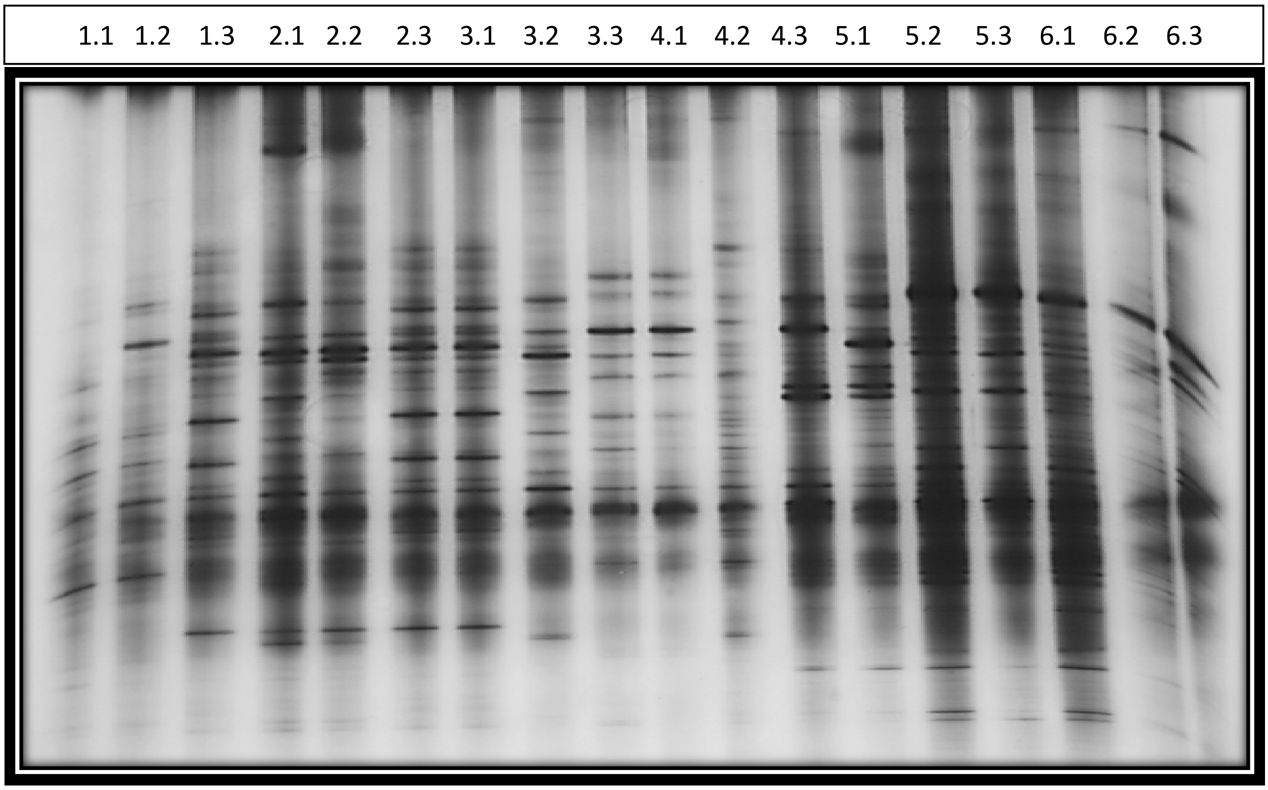

Fig. 19. 10% DGGE gel, showing the microbial diversity in Vihar water
(1.1 = Sampling 1, Station1; 41 different bands obtained from this gel)

Table 18. Bacteria identified from Powai Lake sediment
(1 = presence and 0 = absence of organism)

Sl. No	Closest match in GenBank database	Match (%)	Accession number	Sampling S1	S2	S3	S4	S5	S6
1.	*Duganella* sp.	97	HQ 891977.1	0	1	0	0	1	0
2.	*Pseudomonas jessenii*	97	EU 019982.1	0	0	0	0	1	0
3.	*Ferribactor* sp.	97	AF 282252.1	1	1	0	0	1	0
4.	*Klebsiella* sp.	97	HQ 332537.1	0	1	1	1	1	0
5.	*Pseudomonas* sp.	97	FR 692012.1	0	0	0	0	1	1
6.	*Pseudomonas putida*	97	AB 539808.1	0	1	1	1	1	0
7.	*Bacillus subtilis*	96	EU 257698.1	0	1	1	1	1	0
8.	*Pseudomonas* sp.	90	EU 482915.1	0	0	0	1	1	0
9.	*Bacillus pumilus*	86	JF 388813.1	1	1	1	1	1	1
10.	*Bacillus megaterium*	96	HM 216582.1	1	1	1	1	1	1
11.	*Bacillus amyloliquefaciens*	97	HQ 670596.1	0	0	1	1	1	0
12.	*Sulfurovum* sp.	90	GU113070.1	1	1	1	1	1	1
13.	*Rhodococcus* sp.	74	GQ 289431.1	1	1	1	1	1	1
14.	GQ 463185.1	81	GQ 463185.1	1	1	1	1	1	1
15.	*Rhodococcus opacus*	69	AP 011115.1	1	1	1	1	1	1
16.	*Byssovorax* sp.	59	FJ 933351.1	1	1	1	1	1	1
17.	*Actinobacterium* sp.	74	AY 629333.1	1	1	1	1	1	1
18.	Bacteroidates bacterium	68	CU 923149.1	1	1	1	1	1	1
19.	*Methylocystis* sp.	79	GU 227561.1	1	1	1	1	1	1
20.	*Arthrobacter* sp.	89	GQ 289414.1	1	1	1	1	1	1
21.	*Chloroflexus* sp.	75	FJ 481370.1	1	1	1	1	1	1
22.	DQ 909526.1	82	DQ 909526.1	1	1	1	1	1	1
23.	Nitrospirae bacterium	94	EU186400.1	1	1	1	1	1	1
24.	*Nitrosovibrio sp*	86	AM 773591.1	1	1	1	1	1	1
25.	Actinomycetales bacterium	96	EU 699482.1	0	1	1	0	0	1
26.	Nitrospirales bacterium	74	FJ 753184.1	1	1	1	1	1	1
27.	*Methylocystis* sp.	83	GU 227561.1	1	1	1	1	1	1
28.	Proteobacterium	84	GQ 242574.1	0	0	0	1	1	1
29.	*Magnetococcus* sp.	66	HQ 437500.1	1	1	1	1	1	1
30.	Acidobacteria bacterium	89	HQ 329075.1	1	1	1	1	1	1
31.	*Massilia* sp.	74	AJ 871238.1	1	1	1	1	1	1
32.	*Curvibactor* sp.	84	GQ 351481.1	1	1	1	1	1	1
33.	*Erwinia* sp.	69	GQ 351489.1	0	0	0	0	1	1
34.	*Methylobacterium* sp.	78	GU 430671.1	0	1	0	1	1	1

Table 19. Bacteria identified from Powai Lake water
(1 = presence and 0 = absence of organism)

Sl. No.	Closest match in GenBank database	Match (%)	Accession number	Sampling S1	S2	S3	S4	S5	S6
1.	*Herbaspirillum* sp.	76	EU 665087.5	0	0	0	0	0	0
2.	*Pseudomonas* sp.	98	GU 000145.1	0	0	1	1	0	0
3.	Bacteroidetes bacterium	82	AB 254266.1	0	1	0	0	1	0
4.	*Lysobacter* sp.	78	GQ 497921.1	1	1	1	1	1	1
5.	*Pedobacter* sp.	87	AM 921635.1	0	0	1	1	1	0
6.	*Erythrobacter* sp.	93	HQ 871850.1	0	1	0	1	1	1
7.	*Flectobacillus lacus*	98	DQ 112352.1	1	1	0	0	0	1
8.	*Candidatus pelagibactor*	79	CP 002511.1	1	1	1	1	1	1
9.	*Acinetobacter baumannii*	98	EU 661701.1	1	1	1	0	1	1
10.	*Caulobacter* sp.	67	EF 619185.1	1	1	1	0	1	0
11.	*Paracoccus* sp.	83	HM 452408.1	1	1	1	1	1	0
12.	*Rickettsiella* sp.	92	AM 490939.1	0	1	1	1	1	1
13.	*Acinetobacter* sp.	84	HQ 852405.1	1	1	1	1	1	1
14.	Xanthomonadaceae bacterium	56	HM 438407.1	1	1	1	1	1	1
15.	Aeromonadeceae bacterium	96	JF 733229.1	1	1	1	1	1	1
16.	*Pseudomonas* sp.	96	FM 955865.1	1	1	1	1	1	1
17.	*Pseudomonas mendocina*	78	GQ 849483.1	1	1	1	1	1	1
18.	Hyphomicrobacteriaceae	62	GQ 351484.1	1	1	1	1	1	1
19.	*Undibacteria* sp.	90	JF 327651.1	1	1	1	1	1	1
20.	*Alkanivorax* sp.	95	GU 593634.1	1	1	1	1	1	1
21.	Pseudomonadales bacterium	58	EU 635485.1	0	1	1	1	1	1
22.	*Bacillus amyloliquefaciens*	97	HM 161864.1	1	1	1	1	1	1
23.	*Bacillus subtilis*	95	EU 736102.1	0	1	1	1	1	1
24.	*Aeromonas veronii*	56	JF 490062.1	1	1	1	1	1	1
25.	Oxalobacteraceae bacterium	77	AB 545766.1	1	1	1	1	1	1
26.	*Rickettsiella* sp.	75	EU 430249.1	1	1	1	1	1	1
27.	*Pseudomonas* sp.	89	AY 510010.1	1	1	1	1	1	1
28.	*Hypomicrobium* sp.	80	GU 479686.1	1	1	1	1	1	1
29.	*Hypomicrobium* sp.	95	JF 506020.1	0	0	1	1	1	0
30.	*Parvibaculum* sp.	87	GQ 351495.1	1	1	0	0	0	0
31.	*Pseudomonas fluorescens*	95	EF 428995.1	0	1	1	1	1	1
32.	*Ralstonia* sp.	70	GQ 351461.1	1	1	1	1	1	1
33.	*Marinomonas* sp.	97	DQ 659764.1	1	1	1	1	1	0
34.	Chloroflexi bacterium	61	FJ 901605.1	1	1	0	0	0	0
35.	AY 592175.1	95	AY 592175.1	1	1	1	1	1	1
36.	*Blastochloris viridis* sp.	68	AF 084509.1	1	1	1	0	0	0
37.	Acidimicrobidae bacterium	78	AB 360346.1	0	1	0	1	0	1
38.	*Pseudomonas* sp.	89	AY 510010.1	1	0	0	0	0	1
39.	*Pseudonocardia* sp.	66	GQ 351464.1	1	1	1	1	0	0
40.	*Pseudomonas* sp.	91	GU 429506.1	1	1	1	1	0	0

Table 20. Bacteria identified from Vihar lake sediment
(1 = presence and 0 = absence of organism)

Sl No.	Closest match in GenBank database	Match (%)	Accession number	Sampling S1	S2	S3	S4	S5	S6
1.	GQ 871703.1	96	GQ 871703.1	0	1	0	0	1	1
2.	*Pseudomonas* sp.	96	AY 510010.1	0	0	1	1	1	1
3.	*Actinobacterium* sp.	92	JF 712645.1	0	1	1	1	1	1
4.	*Pseudomonas* sp.	79	FR 751006.1	0	0	0	0	1	0
5.	EU 255863.1	90	EU 255863.1	1	1	1	0	1	1
6.	*Burkholderia* sp.	96	HM 063923.1	1	1	1	0	1	1
7.	*Bacillus* sp.	88	EU 360150.1	1	0	0	1	1	1
8.	GQ 289450.1	85	GQ 289450.1	0	0	1	1	1	1
9.	Peptococcaceae bacterium	74	EU 016425.1	1	1	1	1	1	1
10.	*Duganella* sp.	79	AM 711889.1	1	1	1	1	1	1
11.	*Bacillus* sp.	97	EF 074834.1	1	1	0	1	1	1
12.	EU 790119.1	63	EU 790119.1	1	1	1	0	0	0
13.	*Asticcacaulis* sp.	74	AB 594305.1	1	1	0	0	1	1
14.	*Aeromonas veronii*	86	GQ 374263.1	1	1	0	0	1	1
15.	HM 566395.1	95	HM 566395.1	0	0	0	0	1	1
16.	*Dechloromonas* sp.	78	DQ 351492.1	1	1	1	1	1	1
17.	Desulfobulboceae bacterium	83	FN 687052.1	1	1	1	1	1	1
18.	*Enterobacter* sp.	89	HQ 439419.1	1	1	1	1	1	1
19.	Chloroflexi bacterium	7	FJ 517059.1	1	1	0	0	0	0
20.	Nitrospirae bacterium	48	FJ 178593	1	1	1	1	1	1
21.	*Actinoplanes* sp.	92	EU 547834.1	1	1	1	1	1	1
22.	Myxococcales bacterium	88	GQ 421120.1	1	1	1	1	1	1
23.	Acidobacteriacea bacterium	79	FM 175948.1	1	1	0	0	0	0
24.	Hyphomicrobiceae bacterium	88	EF 019540.1	1	1	0	0	0	0
25.	*Methylobacterium extorquens*	87	GQ 281068.1	0	0	0	1	1	1
26.	*Methylocapsa* sp.	68	FM 175819.1	0	0	1	1	0	1
27.	*Paracoccus* sp.	78	HM 452498.1	1	1	1	1	1	1
28.	*Duganella* sp.	68	HM 149214.1	1	1	1	1	1	1
29.	Rhodacyclaceae bacterium	86	HQ 658779.1	0	1	1	1	1	1
30.	*Leptospirillum sp.*	90	GQ 289449.1	1	0	1	1	1	1

Table 21. Bacteria identified from Vihar Lake water
(1 = presence and 0 = absence of organism)

No.	Closest match in GenBank database	Match (%)	Accession number	S1	S2	S3	S4	S5	S6
1.	*Lysobacter* sp.	89	GU 217698.1	1	1	1	1	1	1
2.	*Pseudomonas* sp.	97	JF 833723.1	0	1	1	1	1	1
3.	Xanthomonadaceae bacterium	76	GU 300327.1	0	1	1	1	1	1
4.	*Pseudomonas* sp.	74	HM 011731.1	0	0	0	0	1	1
5.	*Pedobacter* sp.	76	GU 300396.1	0	1	1	0	0	0
6.	*Pseudomonas fluorescens*	95	FJ 477101.1	0	0	1	1	0	0
7.	*Stenotrophomonas* sp.	97	EU 374965.1	0	0	1	1	0	0
8.	*Pseudomonas corrugata*	93	HQ 407237.1	0	0	0	1	1	1
9.	*Pseudomonas taetrolens*	97	NR 036909.1	0	0	0	1	1	1
10.	Sphingobacteriales bacterium	79	EF 663864.1	1	1	1	1	1	1
11.	*Pseudomonas jessenii*	95	GU 391518.1	1	1	1	1	1	1
12.	*Chryseobacterium* sp.	96	FJ 932652.1	0	1	1	1	1	1
13.	*Exiguobacterium* sp.	92	EU 026414.1	1	1	1	1	1	1
14.	*Bacillus* sp.	80	EU 281635.1	1	1	1	1	1	1
15.	*Pseudomonas* sp.	95	JF 163614.1	1	1	1	1	1	1
16.	*Pseudomonas* sp.	98	EU 770404.1	1	1	1	1	1	1
17.	Pseudomonadaceae bacterium	84	AB 545755.1	1	1	1	1	1	1
18.	Methylophilates bacterium	77	EF 636167.1	1	1	1	1	1	1
19.	EU 255858.1	79	EU 255858.1	1	1	1	1	1	1
20.	Bacteroidetes bacterium	92	FJ 828283.1	0	1	1	1	1	1
21.	*Polaromonas* sp.	89	FJ 946540.1	0	0	0	0	1	1
22.	*Flavobacterium* sp.	89	HQ 917652.1	1	1	1	1	1	1
23.	*Propioni vibrio* sp.	76	FJ 976321.1	0	1	1	0	1	1
24.	*Nitrosomonas* sp.	78	AJ 275891.1	1	1	1	1	1	1
25.	*Rhodoferax* sp.	96	HQ 111172.1	1	1	1	1	1	1
26.	*Alishewanella* sp.	98	GQ 505294.1	1	1	1	1	1	1
27.	Xanthomonadaceae bacterium	93	GU 300408.1	1	1	1	1	1	1
28.	*lysobactor* sp.	93	HM 438527.1	1	1	1	1	1	1
29.	Rhizobiales bacterium	69	AB 174822.1	1	1	1	1	1	1
30.	*Paracoccus* sp.	89	HM 452408.1	1	1	1	1	1	1
31.	*Methylophega* sp.	65	HQ 268014.1	1	1	1	1	1	1
32.	*Devosia* sp.	59	DQ 780547.1	1	1	1	1	1	1
33.	*Flexibacter* sp.	79	GQ 420909.1	0	0	0	0	1	1
34.	*Arthrobacter sulfonivorans*	75	AJ 585372.1	0	1	1	1	1	1
35.	*Paracoccus* sp.	73	HM 452408.1	0	1	0	1	0	0
36.	Firmicutes bacterium	91	HQ 444233.1	0	1	0	0	1	1
37.	*Eubacterium* sp.	94	AM 085791.1	1	0	0	0	1	1
38.	*Actinobacterium* sp.	90	FJ 64245.1	1	1	1	1	1	1
39.	*Comomonas* sp.	83	EF 471961.1	1	1	1	1	1	1
40.	*Actinobacterium* sp.	78	FJ 646341.1	0	0	0	0	1	1
41.	*Actinobacterium* sp.	81	EU 715953.1	0	0	0	0	1	1

4.9. Diversity indices

The indices calculated for the present study are Margalef species richness index (d), Pielou's evenness index (j'), Simpson's index of diversity (1-λ) and Shannon index (H'). All the diversity indices were calculated using the basic software Primer Version 6. Richness gives the number of species in a population and evenness measures the relative abundance of different species making richness of the area. Simpson index measures diversity by taking into account both richness and evenness. Simpson index of diversity measures the probability that two individuals randomly selected from a sample belong to different species, whereas Shannon index gives the average degree of uncertainty in predicting to what species an individual chosen at random belongs to. The sampling-wise quantitative data of plankton and benthos in Powai and Vihar were used to calculate the diversity indices.

4.9.1. Phytoplankton

All the four diversity indices calculated such as richness (d), evenness (j'), Shannon (H') and Simpson (1-λ) showed higher values during all the samplings in Vihar Lake than Powai (Table 22).

Table 22. Diversity indices calculated for phytoplankton from Powai and Vihar lakes

Smp	S		N		d		j'		H'(loge)		1-λ	
	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	Vihar
S1	34	51	45654	9266	3.08	5.47	0.82	0.92	2.89	3.64	0.92	0.97
S2	34	51	46820	9498	3.07	5.46	0.83	0.93	2.94	3.64	0.92	0.97
S3	34	51	50523	10734	3.05	5.39	0.83	0.93	2.94	3.66	0.92	0.97
S4	34	51	52275	11718	3.04	5.34	0.84	0.94	2.96	3.70	0.92	0.97
S5	34	51	52832	12817	3.03	5.29	0.84	0.94	2.97	3.71	0.92	0.97
S6	34	51	55143	13197	3.02	5.27	0.84	0.94	2.96	3.71	0.92	0.97

(S = Total species; N = Total individuals; d = Margalef richness index; j' = Pielou's evenness index; H' = Shannon's index; 1-λ = Simpson's index of diversity; Smp = Sampling)

4.9.2. Zooplankton

All the four diversity indices calculated as richness (d), evenness (j'), Shannon (H') and Simpson (1-λ) showed higher values in Vihar Lake than Powai during all the samplings (Table 23).

Table 23. Diversity indices calculated for zooplankton from Powai and Vihar lakes

smp	S		N		d		j'		H'(loge)		1-λ	
	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	Vihar
S1	12	16	4475	1668	1.31	2.02	0.80	0.88	1.99	2.43	0.82	0.89
S2	12	16	4759	1807	1.30	2.00	0.80	0.88	1.99	2.43	0.82	0.89
S3	12	16	4843	1996	1.30	1.97	0.81	0.87	2.02	2.42	0.83	0.89
S4	12	16	5424	2070	1.28	1.96	0.81	0.89	2.01	2.46	0.82	0.90
S5	12	16	5960	2091	1.27	1.96	0.80	0.91	1.99	2.52	0.82	0.91
S6	12	16	6213	2339	1.26	1.93	0.81	0.88	2.01	2.45	0.82	0.90

(S = Total species; N = Total individuals; d = Margalef richness index; j' = Pielou's evenness index; H' = Shannon's index; 1-λ = Simpson's index of diversity; Smp = Sampling)

4.9.3. Benthos

All the four diversity indices calculated as richness (d), evenness (j'), Shannon (H') and Simpson (1-λ) showed higher values in Vihar Lake than Powai during all the samplings (Table 24).

Table 24.Diversity indices calculated for benthos from Powai and Vihar lakes

Sampling	S		d		j'		H'(loge)		i-λ	
	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	Vihar	Powai	vihar
S1	11	19	0.92	1.06	0.71	0.81	1.71	1.95	0.76	0.81
S2	11	19	0.92	1.06	0.71	0.83	1.70	1.99	0.76	0.81
S3	11	19	0.91	1.05	0.70	0.81	1.69	1.94	0.76	0.80
S4	11	19	0.91	1.04	0.69	0.80	1.66	1.92	0.75	0.79
S5	11	19	0.91	1.03	0.69	0.78	1.66	1.87	0.75	0.78
S6	11	19	0.91	1.03	0.68	0.78	1.64	1.88	0.74	0.79

(S = Total species; d = Margalef richness index; j' = Pielou's evenness index; H' = Shannon's index; 1-λ = Simpson's index of diversity)

4.10. Pollution indices

In the present study, Nygaard's algal index (compound quotient) and Palmer's index were calculated for both the lakes using the data given in tables 11, 12, 15 and 17. The pollution-tolerant algal communities are used as bioindicators of organic pollution. The indices were calculated using the formulae given in Material and Methods and the results obtained are given in Table 25. It was found that organic pollution is much more in Powai Lake compared to Vihar.

Table 25. Algal pollution indices of Powai and Vihar lakes

Attribute	**Algal pollution index**	
	Nygaard's Index (CQ)	**Palmer's index**
Powai Lake	**9** (>6 is eutrophic)	**32** (>20 means high organic pollution)
Vihar Lake	**4.85** (2 to 6 is weakly eutrophic)	**15** (>15 means probable organic pollution)

4.11. Factor analysis

The score plots between the factors proved significant separation of Powai and Vihar lakes based on different parameters namely, sediment, water and biological (phytoplankton, zooplankton, and benthos). In fact, most of the parameters have shown higher values for Powai Lake compared to Vihar. Water and sediment parameters have shown significant coefficients on the Factor 1 with high weights for the Powai samples compared to Vihar. It is evident from the score plot that there is a clear separation of Powai and Vihar lakes with respect to biological and physicochemical parameters. Thus, factor analysis successfully discriminated Powai and Vihar lakes on this background (Fig. 20 - 25).

4.11.1. Sediment parameters

The sediment parameters analyzed were subjected to factor analysis to explain total variation between the lakes. Two factors were extracted with preliminary factor pattern, which explained the cumulative variation of 86.93% in which the first factor contributed 81.34% and Factor 2 contributed 5.59% to the variation. Rotated factor pattern using the varimax rotation was used for the discrimination of the class effects. Excellent sampling adequacy has been observed with respect to the Kaiser-Meyer-Oilkin measure of 0.82 for factor procedure. Rotated-factor pattern explained cumulative variation of 100% (unweighted) in which, the first factor contributed 84.2% and the second factor contributed 15.8% to the variation (Fig. 20). The rotated factor pattern has shown significant loadings of electrical conductivity, total nitrogen, total carbon, hydrogen, sulphur, CH ratio, available nitrogen, available phosphorus, copper, magnesium, lead, potassium and mercury on Factor 1, and nickel on Factor 2 (Table 26).

Table 26. Rotated factor pattern of Factor 1 and Factor 2 with significant loadings for sediment quality parameters (dark ones show significant loadings)

Parameter	Factor 1	Factor 2
pH	-0.08557	0.35764
EC	**0.84164**	0.38907
Total nitrogen	**0.90003**	0.09716
Total carbon	**0.98446**	-0.03183
Hydrogen	**0.84166**	0.15374
Sulfur	**0.91571**	-0.07335
CN ratio	0.10786	-0.32899
CH ratio	**0.96438**	-0.07334
Available nitrogen	**0.86462**	0.34889
Total phosphorus	-0.24384	-0.51808
Available phosphorus	**0.73720**	0.33701
Copper	**0.76216**	0.24181
Iron	-0.70325	-0.24565
Magnesium	**0.84346**	0.08412
Lead	**0.75679**	-0.17443
Nickel	0.37929	**0.49196**
Chromium	0.61650	0.63892
Sodium	0.63444	0.53620
Potassium	**0.75658**	0.04567
Calcium	-0.21784	-0.10528
Mercury	**0.91656**	0.18982

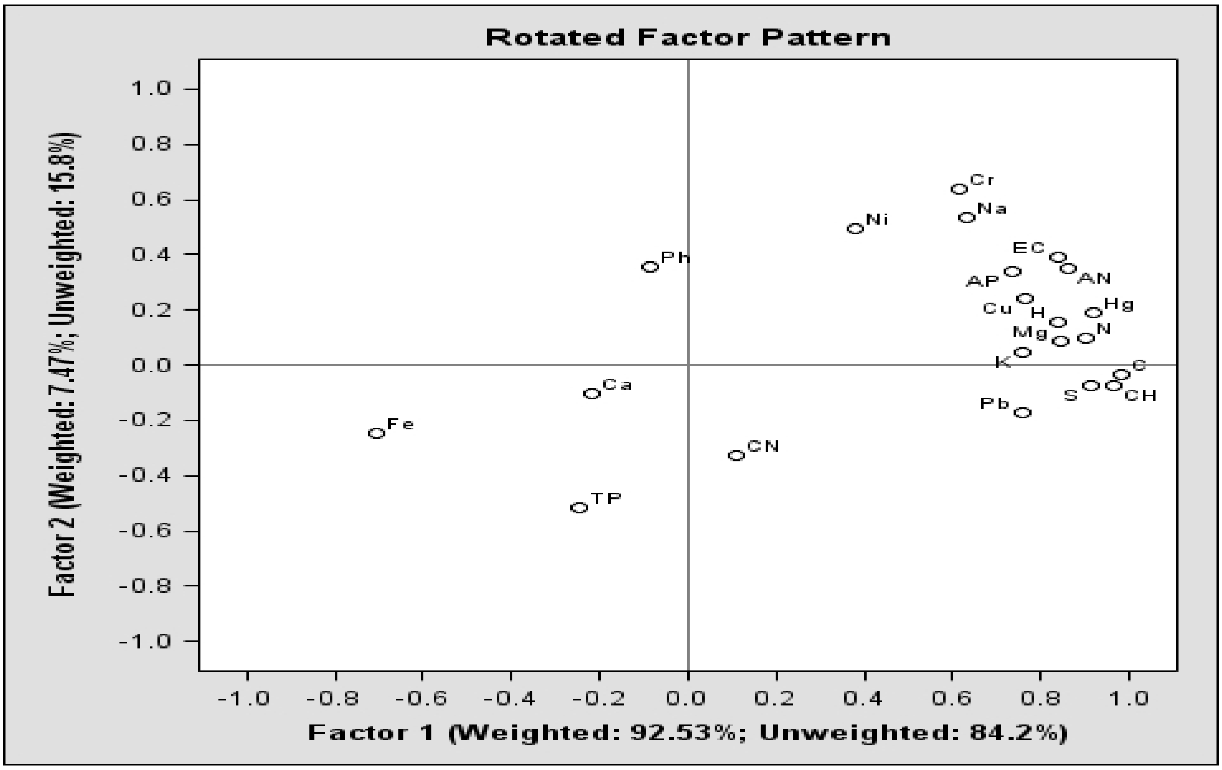

Fig. 20. Factor plot showing significant loadings of different sediment parameters

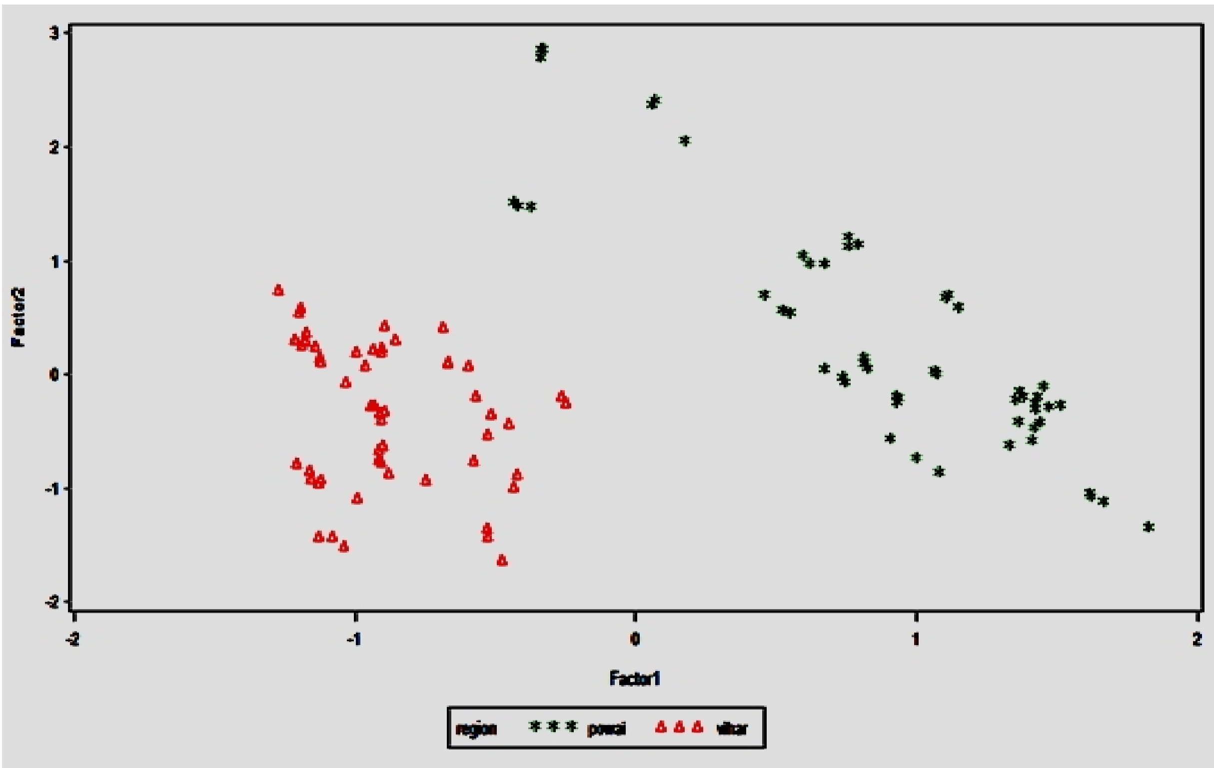

Fig. 21. Score plot between Factor 1 and Factor 2 for different sediment parameters

4.11.2. Water parameters

The water quality parameters analyzed were subjected to factor analysis to explain total variation between the lakes. Two factors were extracted which explained the cumulative variation of 90.21%, where the first factor contributed 79.34% and Factor 2 contributed 10.87% to the variation. Rotated-factor pattern using the varimax rotation was used for the discrimination of the class effects. Excellent sampling adequacy has been observed with respect to the Kaiser-Meyer-Oilkin measure of 0.86 for factor procedure. Rotated-factor pattern explained cumulative variation of 100% (unweighted) in which, the first factor contributed 61.43% and the second factor contributed 38.57% to the variation (Fig. 22). The rotated-factor pattern has shown significant loadings of BOD, total carbon, total nitrogen, total organic carbon and pH on Factor 1, and ammonia and on Factor 2.

Table 27. Rotated-factor pattern of Factor 1 and Factor 2 with significant loadings for water quality parameters (dark ones show significant loadings)

Parameters	Factor 1	Factor 2
Available phosphorus	0.38068	0.10342
Ammonia	0.21331	**0.49260**
BOD	**0.80710**	0.06451
Chlorophyll a	0.64135	0.64263
Calcium	0.65119	0.69553
Chromium	-0.59657	-0.23914
Copper	-0.28531	-0.13720
Dissolved oxygen	-0.24306	-0.78534
Electrical conductivity	0.54849	0.77176
Iron	-0.41705	-0.01501
Potassium	-0.64289	-0.69505
Magnesium	-0.00712	0.16607
Sodium	0.59911	0.76947
Nickel	0.01780	0.42288
pH	**0.74059**	0.25963
Lead	-0.74333	0.52103
Total carbon	**0.92972**	0.34560
Total nitrogen	**0.70624**	0.25303
Total organic carbon	**0.97925**	-0.00148
Total alkalinity	0.81210	0.55485
Depth	0.74168	0.54168
Nitrate-nitrogen	0.66272	0.59448
Transparency	-0.75032	-0.26272
Water temperature	-0.01361	-0.46098

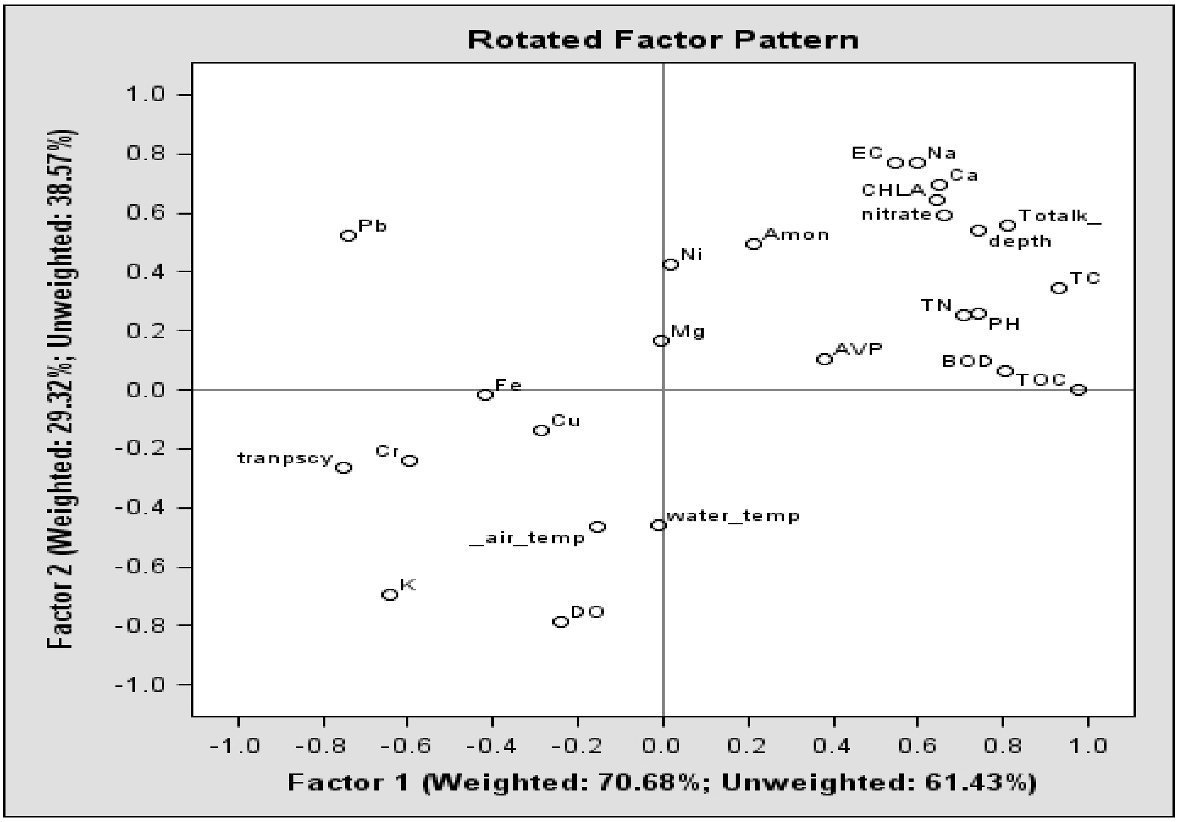

Fig. 22. Factor plot showing significant loadings of different water parameters

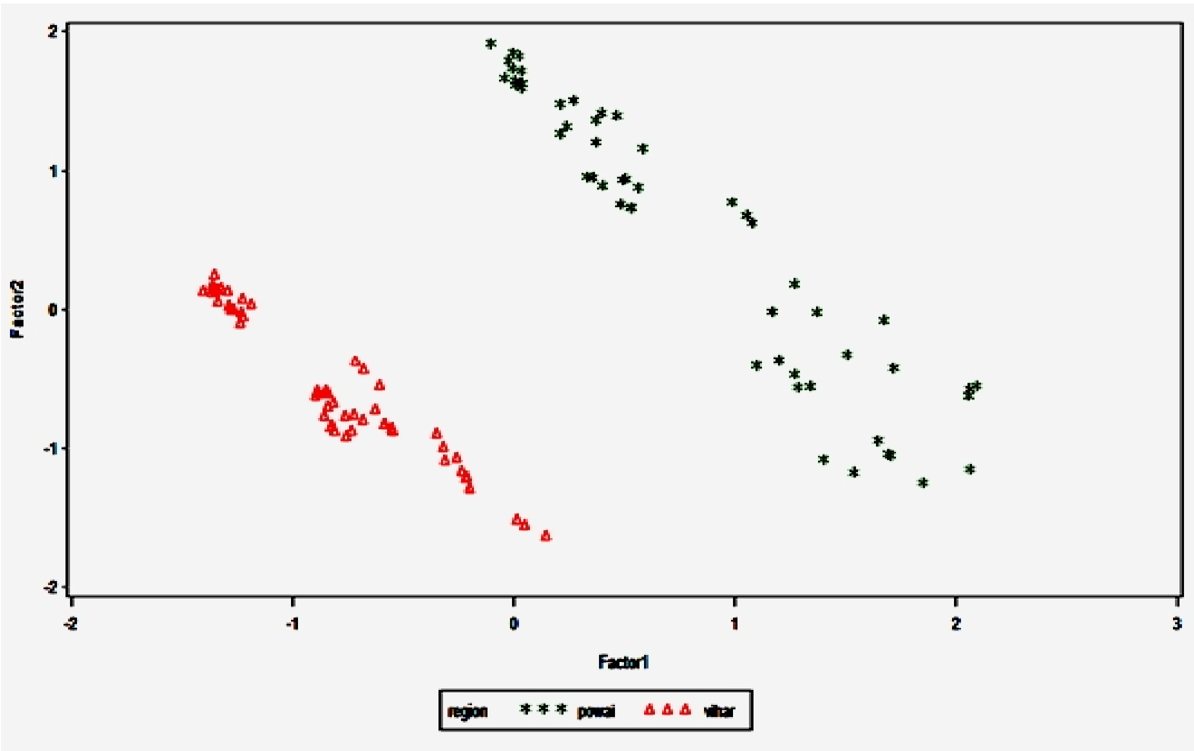

Fig. 23. Score plot between Factor 1 and Factor 2 for different water parameters

4.11.3. Plankton and benthos

The biological parameters as plankton and benthos analyzed were subjected to factor analysis to explain total variation between the lakes. Two factors were extracted which explained cumulative variation of 99.43%, where the first factor contributed 96.53% and Factor 2 contributed 2.90% to the variation. Rotated-factor pattern using the varimax rotation was used for the discrimination of the class effects. Excellent sampling adequacy has been observed with respect to the Kaiser-Meyer-Oilkin measure of 0.82 for factor procedure. Rotated-factor pattern explained cumulative variation of 100% (unweighted) in which, the first factor contributed 61.6% and the second factor contributed 38.4% to the variation (Fig. 24). The rotated-factor pattern has shown significant loadings of Chlorophyceae, Rotifera and Cladocera on Factor 1, and insects on Factor 2 (Table 28).

Table. 28. Rotated-factor pattern of Factor 1 and Factor 2 with significant loadings for plankton and benthos (dark ones show significant loadings)

Attribute	Factor 1	Factor 2
Insecta	0.21356	**0.72782**
Oligochaeta	-0.58262	-0.30340
Mollusca	-0.41640	-0.16167
Chlorophyceae	**0.90946**	0.40940
Bacillariophyceae	0.78746	0.59695
Dynophyceae	-0.52192	-0.82347
Euglenophyceae	0.61305	0.77270
Cyanophyceae	0.80414	0.59444
Rotifera	**0.86861**	0.43202
Cladocera	**0.94021**	0.33391
Copepoda	0.78804	0.56658

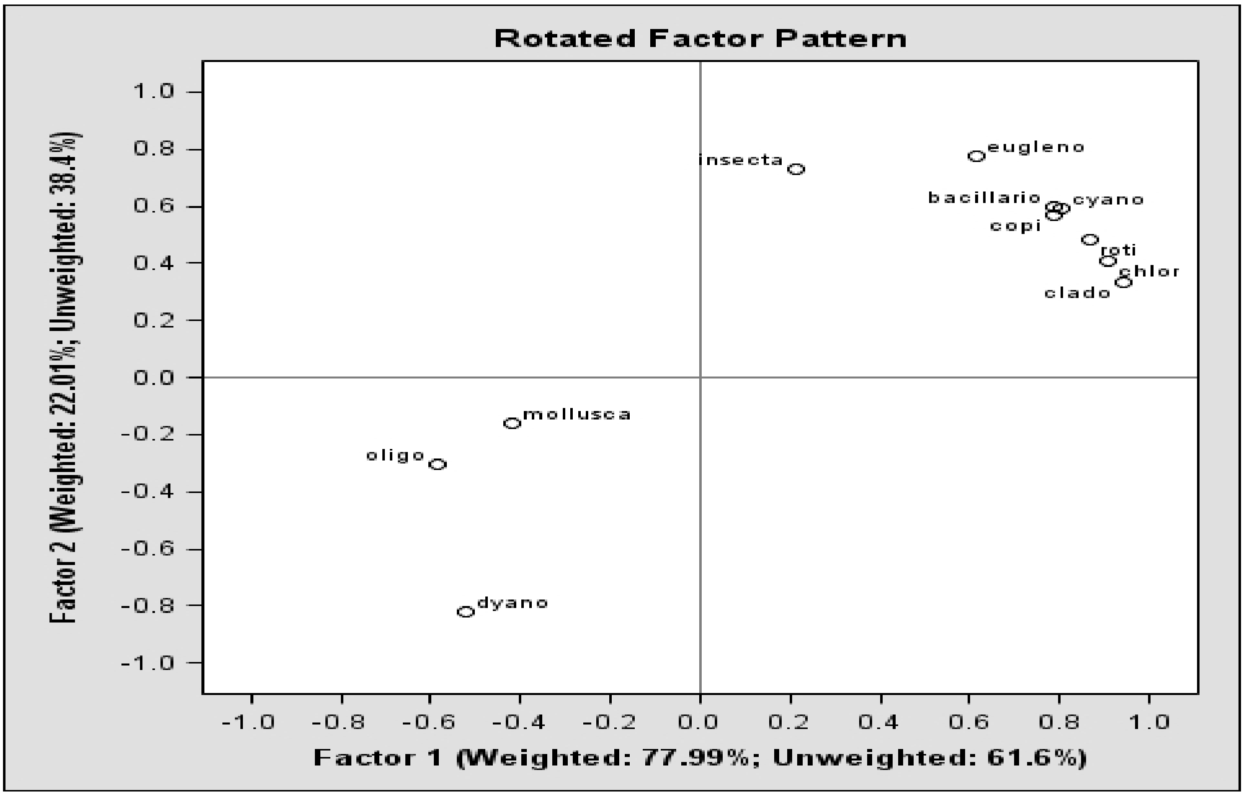

Fig. 24. Factor plot showing significant loadings of different biological parameters

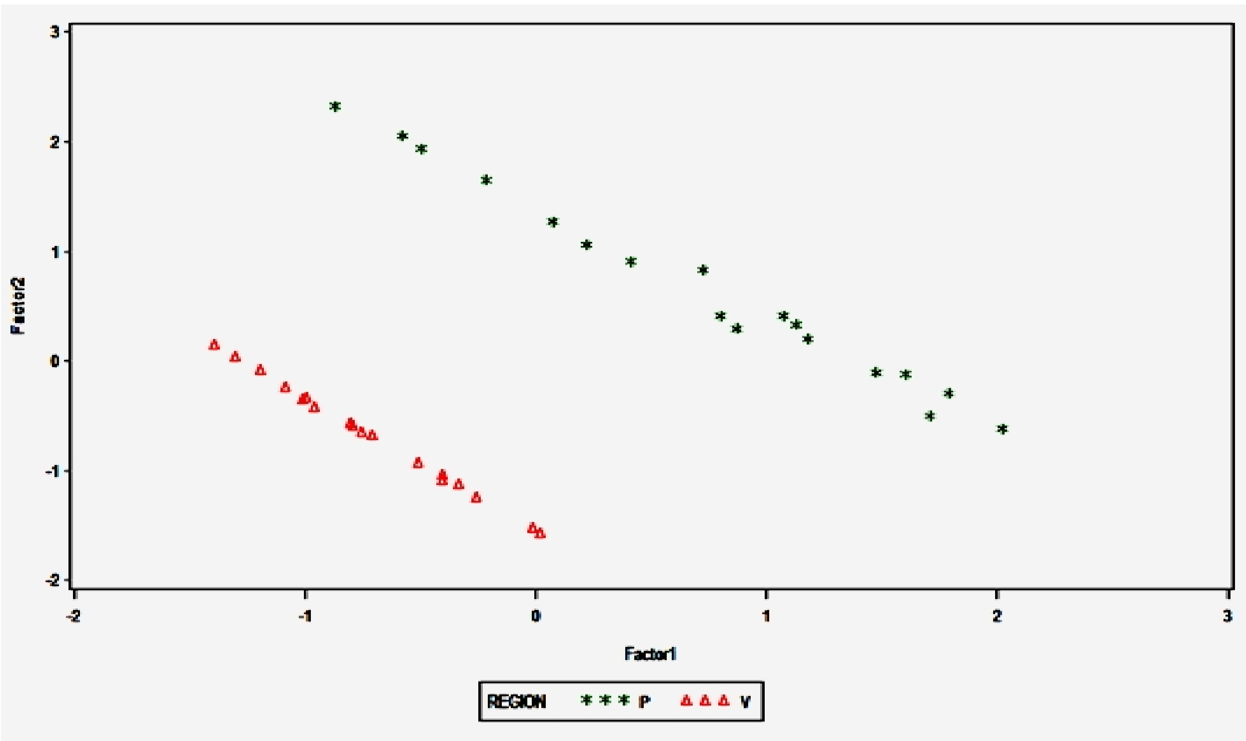

Fig. 25. Score plot between Factor 1 and Factor 2 for different biological parameters

4.12. Interaction between important biological and physicochemical parameters

The correlation matrix between plankton and physicochemical parameters of the two lakes showed many significant correlations (Table 29 - 30). In Powai, significant positive correlation was obtained between chlorophyll-a and plankton. Nitrate also showed a significant positive correlation with Chlorophyceae and Bacillariophyceae, whereas some significant negative correlations were observed for the planktonic groups with available phosphorus, biochemical oxygen demand, dissolved oxygen, total carbon, total organic carbon and water temperature.

In Vihar, significant positive correlations were obtained between ammonia and euglenophyceans, and between transparency and most of the plankters, whereas some significant negative correlations were observed for the planktonic groups with biochemical oxygen demand, total carbon, total organic carbon and total alkalinity.

Table 29. Correlation matrix of some important water parameters with plankton of Powai Lake

	Amon	AVP	BOD	CHLA	DO	nitrate	PH	trsp	TC	TOC	Totalk	TN	wt tp	chlor	bacill	dyno	eugle	cyano	roti	clado
AVP	0.54																			
BOD	-0.02	0.47																		
CHLA	0.12	0.01	-0.15																	
DO	-0.40	-0.08	0.56	-0.47																
nitrate	0.31	0.10	-0.49	-0.14	-0.31															
PH	-0.38	-0.09	-0.14	-0.05	0.32	0.11														
trsp	-0.33	-0.28	-0.28	-0.26	0.05	-0.17	0.10													
TC	-0.13	0.15	0.52	-0.21	0.51	-0.53	-0.01	-0.02												
TOC	-0.43	0.02	0.53	-0.44	0.76	-0.48	0.25	-0.02	0.83											
Totalk	0.35	0.31	0.21	0.33	-0.09	-0.33	-0.36	0.02	0.19	-0.19										
TN	-0.08	-0.11	-0.34	-0.58	0.20	0.19	0.25	0.43	0.10	0.23	-0.18									
wt tp	0.13	0.79	0.60	-0.33	0.34	0.03	0.05	0.01	0.30	0.30	0.09	0.04								
chlor	0.31	-0.41	-0.59	0.46	-0.80	0.41	-0.41	0.23	-0.59	-0.87	0.31	-0.21	-0.47							
bacilla	0.37	-0.16	-0.46	0.39	-0.55	0.66	-0.03	-0.28	-0.63	-0.70	0.00	-0.17	-0.22	0.51						
dyano	-0.03	-0.32	-0.46	0.55	-0.62	0.21	-0.23	0.19	-0.61	-0.81	0.21	-0.37	-0.33	0.87	0.54					
eugle	-0.17	0.30	0.29	0.57	0.31	-0.07	0.34	-0.11	0.36	0.38	-0.28	0.34	0.69	-0.31	-0.44	-0.80				
cyano	0.20	-0.46	-0.73	0.47	-0.75	0.15	-0.28	0.29	-0.54	-0.77	0.25	-0.05	-0.68	0.94	0.41	0.76	-0.92			
roti	0.16	-0.44	-0.68	0.55	-0.72	0.17	-0.27	0.09	-0.57	-0.76	0.14	-0.23	-0.77	0.89	0.55	0.79	-0.95	0.94		
clado	0.34	-0.22	-0.62	0.54	-0.81	0.25	-0.33	0.18	-0.60	-0.87	0.29	-0.23	-0.54	0.98	0.56	0.86	-0.92	0.94	0.92	
cope	-0.43	-0.67	-0.47	0.32	-0.21	-0.13	0.20	0.03	-0.38	-0.24	-0.11	-0.01	-0.83	0.36	0.23	0.38	-0.54	0.52	0.63	0.43

(figures in red show significant correlations; Amon = Ammonia; AVP = Available phosphorus; CHLA = Chlorophyll-a; nitra = Nitrate; trns = Transperency; TC = Total carbo;, TOC = Total organic carbon; Totalk = Total alkalinity; TN = Total nitrogen; Wt tp = water temperature; Chlor = Chlorophyceae; bacilli = Bacillariophyceae; dyno= Dinophyceae; eugle = Euglenophyceae; cope = Copepoda; cyano = Cyanophyceae; clado = Cladocera)

Table 30. Correlation matrix of some important water parameters with plankton of Vihar Lake

	Amon	AVP	BOD	CHLA	DO	nitra	PH	trns	TC	TOC	Totalk	TN	wt tp	Chlor	bacilla	dyno	eugle	cyano	roti	clado
Amon																				
AVP	0.78																			
BOD	0.02	0.39																		
CHLA	-0.01	-0.09	-0.23																	
DO	0.66	0.53	0.22	-0.21																
nitrate	0.26	-0.05	-0.20	0.20	0.29															
PH	-0.41	-0.27	0.10	0.02	-0.28	-0.25														
trns	-0.14	-0.31	-0.66	0.20	-0.42	0.28	-0.41													
TC	-0.09	0.02	0.67	0.07	0.21	-0.06	0.49	-0.75												
TOC	-0.22	-0.12	0.62	0.01	0.14	-0.16	0.52	-0.74	0.97											
Totalk	0.01	0.18	0.37	-0.24	0.41	-0.25	0.48	-0.59	0.49	0.49										
TN	-0.14	-0.55	-0.21	0.28	-0.01	0.06	0.34	-0.18	0.44	0.51	0.05									
wt tp	0.83	0.80	0.32	0.01	0.61	-0.12	-0.28	-0.44	0.19	0.08	0.14	-0.06								
chlor	0.03	-0.17	-0.72	0.35	-0.36	0.17	-0.41	0.82	-0.89	-0.87	-0.69	-0.19	-0.25							
bacilla	-0.09	-0.29	-0.72	0.25	-0.44	0.10	-0.18	0.71	-0.79	-0.74	-0.57	-0.12	-0.35	0.93						
dyano	-0.02	-0.27	-0.73	0.11	-0.41	0.17	-0.27	0.79	-0.79	-0.75	-0.58	-0.04	-0.28	0.92	0.94					
eugle	0.52	0.34	-0.02	0.23	0.32	0.02	-0.42	-0.08	0.01	-0.05	-0.29	0.06	0.62	0.06	-0.01	0.01				
cyano	-0.09	-0.32	-0.80	0.11	-0.44	0.19	-0.18	0.80	-0.82	-0.80	-0.53	-0.08	-0.41	0.94	0.95	0.96	-0.04			
roti	0.07	0.08	-0.42	0.01	-0.31	-0.31	-0.06	0.36	-0.67	-0.64	-0.39	-0.19	0.01	0.71	0.67	0.62	-0.05	0.64		
clado	-0.13	-0.26	-0.64	-0.11	-0.45	0.02	-0.19	0.67	-0.86	-0.82	-0.59	-0.21	-0.34	0.90	0.91	0.91	-0.06	0.93	0.71	
cope	0.42	0.16	-0.44	0.03	-0.01	0.07	-0.09	0.30	-0.55	-0.57	-0.12	-0.04	0.17	0.62	0.66	0.65	0.25	0.66	0.59	0.66

(figures in red show significant correlations; Amon = Ammonia; AVP = Available phosphorus; CHLA = Chlorophyll-a; nitra = Nitrate; trns = Transperency; TC = Total carbon; TOC = Total organic carbon; Totalk = Total alkalinity; TN = Total nitrogen; Wt tp = water temperature; Chlor = Chlorophyceae; bacilli = Bacillariophyceae; dyno = Dinophyceae; eugle = Euglenophyceae; cope = Copepoda; cyano = Cyanophyceae; clado = Cladocera)

5. DISCUSSION

5.1. Water quality parameters

According to Wetzel (1975), Jhingran (1991) and Sharma (2000), water temperature, transparency, conductivity, pH, alkalinity, dissolved gases and nutrients (ammoniacal nitrogen, nitrate-nitrogen, phosphorus, iron, calcium, magnesium, etc.) influence the productivity of an aquatic ecosystem. Salaskar *et al.* (2007) studied the environmental status of Powai Lake (Mumbai), and concluded that the productivity of an aquatic ecosystem fully depends on the physicochemical factors and that the physicochemical factors never remain stable for a long period, but show fluctuation from region to region. In the present study, 23 important water quality parameters were analysed periodically and compared between the two lakes.

Relatively narrow ranges of variations were observed in the temperature of the upper mixed layer of tropical waters (Lewis, 1987). In Powai and Vihar lakes also, the temperature variation was narrow during the study period (20.3 to 27.7ºC). A close relationship between air and surface water temperature has been recorded by several workers, *viz.,* Choudhary and Mazumdar (1981), Sharma (2000), etc. In the present study also, the water temperature fluctuated in accordance with atmospheric temperature in both the lakes as expected.

There are seasonal and regional variations of water transparency due to the differential quantities of suspended solids, algae, silt and illumination (Salim and Ahmed, 1985; Sharma, 2000). The low value of transparency in Powai compared to Vihar may be due to the high plankton density and silt load observed in Powai, which is the result of human activity in and around the lake unlike Vihar, which is isolated and protected inside the Sanjay Gandhi National Park.

With respect to electrical conductivity, Powai seems to be eutrophic with its value of more than 0.2 mS/cm, whereas Vihar seems to be oligotrophic with its EC values less than 0.2 mS/cm when we consider the interpretations by Olson (1950) and Rawson (1960). The level of dissolved oxygen also indicated the same fact with lower dissolved oxygen in Powai compared to Vihar. Dissolved oxygen level in water depends on factors like temperature of water, the concentration of dissolved salts, biological activity and geology of basins of river (Goldman and Horne, 1983). The lower dissolved oxygen value in Powai than in Vihar also may be due to the high biological activity in Powai, especially the respiration of plankters at night. The plankton density was higher in Powai than in Vihar and the sampling was done in early morning.

BOD values were found higher in Powai than in Vihar. Higher values of BOD indicate a higher level of consumption of oxygen and a higher pollution load. The increase in BOD and decrease in dissolved oxygen in Powai Lake compared to Vihar Lake may be attributed to the discharge of agricultural runoff and domestic sewage from the surrounding area and oxygen consumption due to high growth and activities of microorganisms. Similar to the above observation, the impact of urbanization on Bellandur Lake (Bangalore) also showed higher values of alkalinity, BOD and COD, and low levels of DO, which are indicators of the polluted nature of the lake (Chandrasekhar *et al*., 2003).

Bell (1971) has stated that pH range between 6.5 and 9.0 provides adequate protection to the life of freshwater fishes, bottom-dwelling invertebrates and other aquatic organisms. Mishra *et al.* (2003) have reported that a pH range of 7.2 to 8.5 favours the growth of plankton. The pH observed in both the lakes was within the range of 7.5 to 8.4. According to Reynolds *et al.* (1968), pH is the most important factor regulating plankton density. In the present study, a higher pH was observed in Powai than in Vihar, and the plankton density was also observed to be quite higher in Powai compared to Vihar.

Total alkalinity in Indian waters ranges between 40 and over 1000 mg/l of $CaCO_3$ (Jhingran, 1982). Total alkalinity in Powai (around 150 mg/l of $CaCO_3$) was found to be much higher than that in Vihar (around 50 mg/l of $CaCO_3$). It is reported that alkaline pH is favourable for good plankton growth (Mahajan and Kanhere, 1995). In the present study also, high plankton density was observed in Powai Lake were the alkalinity was comparatively higher. Khatavkar (1986), while studying two eutrophic polluted water bodies, observed alkalinity value above 150 ppm in two water bodies and reported that pollution of waters can increase the level of total alkalinity. While comparing with his report, it could be concluded that Powai Lake is eutrophic wereas Vihar lake is not eutrophic.

Nitrate represents the end-product of oxidation of nitrogenous matters and its concentration may depend on the nitrification and de-nitrification activities of microorganisms. It is one of the most important nutrients in an aquatic ecosystem and generally, water bodies polluted by organic matter exhibit higher values of nitrate (Shanti *et al*., 2002). In the present study, the concentration of nitrate-nitrogen ranged from a minimum of 0.12 to 0.58 mg/l in the two lakes; however, quite higher concentrations were observed in Powai than in Vihar, indicating more organic pollution in Powai than in Vihar.

Phosphate determination is useful in measuring water quality since it is an important plant nutrient and may play a role of limiting factor among all other essential plant nutrients, especially in fresh waters (Thirumala *et al.,* 2006). Wetzel (1983) concluded that phosphorus is the most important limiting factor responsible for th eutrophication of water all over the world. Comparatively lower levels of phosphorus are capable of causing eutrophication as indicated by Reid (1961). In the present study, the concentration of reactive phosphorus in the lakes ranged from 0.01 to 0.21 mg/l, which are low values and it may be due to the limiting nature of phosphorus in the two lakes. In the case of Powai, it could be due to the higher utilization of phosphorus in biological production that results in lower concentrations in water.

Organically polluted waters have normally higher concentrations of ammonia which is a product of ammonification of organic matter (Rybak and Sikorska, 1976). Ellis *et al.* (1946) stated that the quantity of ammonia in unmodified natural waters is very small, being less than 0.1 mg/l. The concentration of ammonia-nitrogen in Powai Lake during the present study remained quite above the oligotrophic limit of 0.1 mg/l reflecting the level of pollution in Powai Lake, whereas in Vihar Lake, the ammonia-nitrogen concentration observed was below the 0.1 mg/l level.

The higher concentrations of nutrients, particularly nitrogen and carbon, are naturally to be expected in polluted waters (Munawar, 1970). Total nitrogen, total carbon and total organic carbon were quite high in Powai waters indicating substantial quantities of organic matter both in the form of living algal mass and detritus. So, from the observations on the above nutrients, it is concluded that Powai

Lake is polluted organically, whereas Vihar Lake is comparatively unpolluted organically. This can also be substantiated with the result of the algal pollution indices used in the present study which reflected the higher organic pollution in Powai Lake compared to Vihar.

High concentrations of calcium, magnesium, sodium and potassium in water bodies are entirely due to pollution (Beaton, 1968; Munawar, 1970). The hardness of water is also mainly contributed by calcium and magnesium ions. In the present study, high concentrations of sodium and calcium were observed in Powai Lake indicating its polluted nature. However, potassium and magnesium concentrations in both the lakes were found to be in similar lower range.

The maximum permissible limit of copper and iron in drinking water is 1.0 ppm and that of lead is 0.1 ppm, whereas for zinc, it is 15.0 ppm as prescribed by WHO (1984). The maximum permissible limit of copper, chromium and arsenic in drinking water is 0.05 mg/l (Awashthi, 2000). In the present study, it was found that the concentrations of copper, iron, chromium and nickel were within the permissible limits given by WHO in both the lakes. Similar studies were made by Wadhwani *et al.* (1991), Mule and Patil (2000), and Bhosle and Patil (2001) in drinking water for various trace elements. Therefore, it can be concluded that the two lakes studied are devoid of any heavy metal pollution.

5.2. Sediment quality parameters

The chemical characteristics of bottom sediment greatly influence the supply of nutrients through mineralization of decomposing organic debris, creating suitable conditions for the existence of aquatic life. The sediment texture in Powai Lake was found to be silty-loam and that of Vihar was claey-loam. According to Kaul and Handoo (1989), silty-loam sediment originates from the deposition of autochthonous and allochthonous particulate matter in the basin. It can be concluded that the sediment in Powai is the result of organic deposition.

Jhingran (1988, 1991) has reported that the moderately alkaline nature of basin soil is good for aquatic productivity. The pH in both the lakes ranged from 6.37 to 7.92. Vihar Lake sediment showed slightly higher pH value than that of Powai during the study period.

Sediments, in general, are rich in mineral nutrients. According to Ishaq and Kaul (1989), the nutrient pools in different compartments of the lake indicate that about 96% of the total calcium capital and 99% of the phosphorus pool are locked up within the sediments; whereas the remaining 4 and 1% of calcium and phosphorus, respectively, are distributed between macrophytic and water compartments. The higher concentrations of nutrients, particularly nitrogen and carbon, are naturally to be expected in polluted waters (Munawar, 1970). Total nitrogen, total carbon, total organic carbon, available phosphorus and total sulphur were quite high in Powai sediment than in Vihar indicating a substantial level of organic pollution in Powai sediment.

Higher concentrations of calcium, magnesium, sodium and potassium in water bodies are entirely due to pollution (Beaton, 1968; Munawar, 1970). High calcium and magnesium contents in sediment are an indication of eutrophic water as opined by Sahai and Sinha (1969). Sodium, potassium and magnesium concentrations were found to be quite high in Powai sediment indicating its polluted nature, whereas all these elements were quite low in Vihar Lake.

Sediment has aptly been called as 'Trace element trap' (Chesyter and Stoner, 1975) because these eventually receive almost all the heavy metals, which enter the aquatic environment (Greig and McGrath, 1977). Generally, more than 90% of the heavy metal load in aquatic systems is bound to particulates like suspended matter and sediments. The type and stability of the heavy metal bonding on these solid compounds are the decisive factors for potential mobility and bioavailability (Calmano *et al.,* 1993). Iron, copper, lead, chromium, nickel and mercury were analysed in the sediment of both the lakes and copper, lead, chromium, nickel and mercury concentrations were found to be quite higher in Powai sediments than in Vihar. All the heavy metals analysed were within the critical limits in both the lakes. The common range of various elements given by Clarke and Washington (1924), Bowen (1966) and Mitchell (1964) were referred to draw this conclusion. It is recorded that alkaline conditions of the sediments cause very low rate of diffusion regarding certain metals (Reimann and de Caritat, 1998). That may be the reason for the very low concentrations of heavy metals in the water samples of both the lakes compared to the high concentrations in sediment.

5.3. Chlorophyll-a

The microscopic elaboration of phytoplankton samples including subsequent calculation of algal biomass are labour-intensive and require sound taxonomic skills of the investigator (Hillebrand *et al.,* 1999). Consequently, chlorophyll-a concentration began to be used as a quick and easy-to-measure surrogate of phytoplankton biomass (Kamoto, 1966; Dillon and Rigler, 1974) besides the fact that chlorophyll-a measurements lack any information on phytoplankton community structure. Chlorophyll-a content was found to be higher in Powai Lake than in Vihar. The values ranged from 8.90 mg/m^3 in Vihar to 103.24 mg/m^3 in Powai, which indirectly indicates the high phytoplankton density, eutrophic nature and high plankton productivity of Powai Lake.

5.4. Phytoplankton

Phytoplankton is the base of most of the lake food-webs and fish production is linked to phytoplankton production. Moreover, the number and species of phytoplankters serve to determine the quality of a water body (Ryder *et al.,* 1974). A total of 34 genera of phytoplankters belonging to Chlorophyceae (16 genera), Bacillariophyceae (7 genera), Dinophyceae (1 genus), Euglenophyceae (2 genera) and Cyanophyceae (8 genera) were observed in Powai Lake. The diversity of phytoplankton obtained from Vihar Lake was much more than that of Powai with a total of 51 genera belonging to Chlorophyceae (25), Bacillariophyceae (12), Dinophyceae (2), Euglenophyceae (1) and Cyanophyceae (11). It was noticed that even though the plankton diversity is more in Vihar Lake, the plankton density was found to be more in Powai and the most dominant species in Powai were the pollution-tolerant ones. Lewis (1972) had emphasized that species richness is lower in tropical waters than temperate ones. In terms of species composition, Powai and Vihar lakes represent the tropical water bodies with comparatively less diversity than temperate lakes.

In Powai Lake, the major groups observed were cyanophyceans with a contribution of 44%, chlorophyceans with 29%, bacillariophyceans with 13%, euglenophyceans with 13% and dinophyceans with 1% contribution to the total. But in Vihar, the major groups were chlorophyceans with 46%, cyanophyceans with 27%, bacillariophyceans with 18%, dinophyceans with 7% and euglenophyceans with 2% contribution to the total. Lewis (1979) considered it logical that a quantitatively-dominating class should have more number of species as the ecological differences are larger between than within the classes. Thus, Chlorophyceae appears to be ecologically suitable for the environment of Lake Vihar and Cyanophyceae for Powai. Hence, these groups are quantitatively dominant with the representation of the maximum number of genera in the respective lakes.

The seasonal variations in water quality parameters of a water body have a marked influence on the numerical abundance of plankton. The relation between these parameters and plankton diversity has been studied by Hedge (1985), Pollinger *et al.* (1988), Kulshreshtha *et al.* (1989), Adholia (1991) and Narasimha *et al.* (2001). In the present study also, an increasing trend in phytoplankton density was observed from November to February. However, during the present study, no significant direct relationship was seen between phytoplankton and nutrients, though an inverse relationship for phytoplankton was observed with reactive phosphorus, total carbon and total organic carbon, which are supported by the works of Round (1957), Singh (1960), Vollenweider (1968), Lund (1969), and Das and Singh (1993).

The most commonly occurring green algae in both the lakes during the present study were *Ulothrix, Pediastrum, Scenedesmus* and *Staurastrum.* The dominant diatoms observed were *Melosira, Synedra, Navicula* and *Nitzschia.* Dinoflagellates were represented only by a single genus *(Peridinium)* in Powai and by two genera *(Peridinium* and *Gonyaulax)* in Vihar. Euglenophyceae was represented by two genera in Powai *(Euglena* and *Phacus)* and by a single genus in Vihar *(Phacus).* The euglenophycean density of Powai Lake was very high indicating its polluted nature. The most commonly recorded blue-green algae were *Arthrospira, Microcystis (Anacystis), Merismopedia* and *Ocillatoria* in both the lakes.

From the study of phytoplankters in both the lakes, it can be concluded that the number of species (diversity) was found more in Vihar, whereas the total number of individuals (density) was quite higher in Powai than in Vihar. The phytoplankters, which were most abundant in Powai, were mostly pollution tolerant, indicating the polluted nature of the lake. It is reported that the study of plankton serves as an index of water quality in respect of industrial pollution, and municipal and domestic sewage pollution (Pati and Sahu, 1993; Acharjee *et al.,* 1995; Baruah *et al.,* 1997). Pollution load was more in Powai which was confirmed by the presence of pollution indicator species as per Palmer (1969) comprising different groups like cyanophyceans (*Anabaena* and *Microcystis*), chlorophyceans (*Spirogyra, Closteridium* and *Scenedesmus*) diatoms (*Navicula, Nitzschia* and *Pinnularia*), euglenophyceans *(Euglena* and *Phacus),* etc. in considerably higher numbers in Powai Lake than in Vihar Lake.

5.5. Zooplankton

The zooplankton occupy a central position between the autotrophs and other heterotrophs, and form an important link in the food-web of a freshwater ecosystem. The occurrence and abundance of zooplankton depend on its productivity, which in turn, is influenced by physicochemical parameters and the level of nutrients in the water **(**Pawar and Pulle, 2005). Marked variations were observed in the species composition and population density of zooplankton in both the lakes. A total of 12 zooplankton genera were obtained from Powai Lake during different samplings. This consisted of four cladocerans, four copepods and four rotifers; whereas in Vihar, a total of 16 genera were observed with eight rotifers, four cladocerans and four copepods. The most dominant rotifers obtained were *Brachionus* spp. and *Keratella* spp. Total zooplankton diversity was observed to be low in both Powai and Vihar lakes. According to Dumount and Tundisi (1984), the species diversity of limnetic copepods and cladocerans seems to decrease progressively towards the equator. The reduction in the number of genera may also be due to predation (Jhingran, 1982). Latha and Thanga (2010) studied the macroinvertebrate diversity of Veli and Kadinamkulam lakes (South Kerala), and concluded that the diversity and distribution patterns of certain species are clearly related to water quality.

In both the lakes, rotifers were the dominant group. Between the two lakes, rotifers contributed more to the total zooplankton abundance in Powai than in Vihar. In Powai, 51% of the total zooplankton was contributed by rotifers, 28% by cladocerans and 21% by copepods, whereas in Vihar, rotifers contributed 40%, cladocerans 33% and copepods 27% to the total. Rotifers are abundant in polluted waters and so, rotifer populations are very useful in indicating water quality, particularly in pollution studies (Shadecek, 1983). Many pollution indicator species of rotifers and *Cyclops* were found more in number in Powai than in Vihar. The dominance of Rotifera may be attributed to their dependence on abundant particulate organic matter (Sarwar and Praveen, 1995). The high abundance of rotifers in Powai Lake indicates its polluted nature. From the study of zooplankters in both the lakes, it can be concluded that the number of species (diversity) was found more in Vihar, whereas the total number of individuals (density) was higher in Powai than in Vihar. The zooplankters, which were most abundant in Powai, are mostly pollution-tolerant organisms, indicting the polluted nature of the lake. A direct corelation is observed between the zooplankton and the phytoplankton. This indicates that zooplankton is dependent mainly for food on phytoplankton which was also reported by Hazelwood and Parker (1961).

5.5. Macro-benthos

In the productivity of a water body, the importance of bottom fauna as a link in the energy flow from primary production to fish yield has been stressed by many workers (Krishnamurthy, 1966; Bose and Lakra, 1994; Anitha *et al.,* 2004). The bottom fauna play an important role in the mineralization and recycling of organic matter. They also serve as good indicators of water pollution since they form an important food item for fishes.

Marked variation was observed in the species composition and population number of macro-benthos in both the lakes. Michael (1964) observed that the difference in the total number of benthic organisms relates to the nutrient condition of the bottom mud. In the present study, a total of 11 genera of macro-benthic invertebrates were observed in Powai sediment, which consisted of three representatives from Insecta, four from Oligochaeta and four from Mollusca, whereas 19 genera were observed in Vihar Lake, which comprised seven from Insecta, seven from Oligochaeta and five from Mollusca throughout the investigation period. The most dominant organisms under Insecta were *Chironomus, Tanipus, Polypedilus* and *Culicoides*. The dominant oligochaetes were *Chaetogaster* and *Tubifex,* and the common molluscans included *Lymnaea, Gyraulus* and *Viviparus* in both the lakes. The pollution-tolerant organisms like *Chironomus, Tubifex,* etc. were found in very high numbers in Powai Lake compared to Vihar, but the total diversity of benthic invertebrates was found less in Powai than in Vihar. Jonasson and Brinkhurst (1969) noted that the tubificids are well adapted to low oxygen content. Das (1978) suggested that some oligochaetes such as Tubifex sp. and *Limnodrilus* sp. are biological indicators of pollution. Vass *et al.* (1977) recognized red *Chironomus* as pollution indicator in Dal Lake. Das (1978) recorded high population of *Chironomus* larvae in Nainital Lake even in polluted region and suggested that these larvae may be considered as pollution indicators. High population of *Chironomus* larvae observed throughout in the different zones of Powai Lake under the present study supports the findings of Vass *et al.* (1977) and Das (1978).

From the study, it could be concluded that like those of phytoplankton and zooplankton, the macro-benthic invertebrate density was more in Powai, but the diversity was more in Vihar. The benthos diversity is greatly reduced below the thermocline in mesotrophic to eutrophic lakes, but may be found at depths up to hundreds of metres in oligotrophic lakes (Martin *et al.*, 2005). The reduction in benthos diversity of Powai Lake may also be due to its eurtophic nature, which has already been proved using the pollution indices in the present study.

In Powai Lake, Insecta was the dominant group and in Vihar, it was Oligochaeta. In Powai, 45% of the total benthos was contributed by Insecta, 28% by Oligochaeta and 27% by Mollusca, whereas in Vihar, Oligochaeta contributed 37%, Insecta 33% and Mollusca contributed 30% to the total.

5.6. Microbial community

To investigate the bacterial diversity from water and sediment samples of both the lakes, the respective samples were subjected to DGGE analysis with PCR amplified 16s rRNA gene using universal DGGE primers (BA 338F and UN 518R). DGGE has proved to be an exceptional tool to study species diversity and bacterial community dynamics. Analysis of DGGE bands from the lakes' sediment and water revealed the existence of a fairly diverse bacterial community. The total number of bands visualized in a DGGE gel also provides an estimate of the genetic diversity found within a given environment (Muyzer *et al.,* 1993). During the present study, 36 different sequences were obtained from Powai sediment, 30 from Vihar sediment, 40 from Powai water and 41 from Vihar water. The comparison of the of the 16S rRNA gene sequence derived from the DGGE bands with those of GenBank database revealed the identity of the organisms. The microorganisms identified from Powai sediment, Vihar sediment, Powai water and Vihar water have been presented in tables 18 to 21. DGGE method can clearly indicate the existence of common groups of microorganisms in natural environment, but it does not permit the precise identification of these microbes to the species or sub-species level. The phylotypes belonging to Beta- and Gamma- Proteobacteria were the predominant group obtained throughout the sampling from both the lakes. The microorganisms in both the lakes' sediment and water include methane producers, sulphate reducers, ammonia oxidizers, dechlorinators, etc. The increase in the concentration of metal elements such as iron might also be related to the presence of bacteria belonging to the genus *Leptospirillum.* The organisms which were dominant in water and sediment of both the lakes were *Pseudomonas, Bacillus, Aeromonas, Duganella, Devosia, Enterobacter, Nitrosomonas, Nitrobacter, Methylobacterium, Methylocystis, Methylocapsa, Methylophilates, Methylophaga, Comomonas,* members of Desulfobulbaceae, *Dechloromonas,* etc.

The distinct bacterial species observed in Powai sediment were *Ferribactor*, *Klebsiella, Sulfurovum, Rhodococcus, Byssovorax, Arthrobacter, Chloroflexus, Magnetococcus, Acidobacterium, Massilia, Curvibactor, Erwinia*, etc., whereas *Herbaspirillum, Erythrobacter*, *Acinetobacter*, *Undibacteria*, *Alkanivorax*, Oxalobacteraceae, *Rickettsiella*, *Ralstonia*, Acidimicrobidae, *Blastochloris viridis, etc.* were the distinct groups in Powai water samples.

Peptococcaceae bacterium, *Burkholderia*, *Duganella*, *Asticcacaulis*, *Dechloromonas*, Desulfobulboceae, *Enterobacter*, Chloroflexi bacterium, *Methylobacterium*, Myxococcales, *Actinoplanes, Leptospirillum,* etc. were the distinct groups in Vihar sediment, and *Stenotrophomonas*, *Chryseobacterium, Exiguobacterium, Polaromonas*, *Flavobacterium, Propioni vibrio*, *Alishewanella,* Rhizobiales, *Flexibacter*, Firmicutes bacterium, *Eubacterium,* etc. were the distinct groups observed in Vihar water samples.

The important roles of microorganisms in nutrient cycles such as methane production (Chan *et al.,* 2005), sulphate reduction (Li *et al.,* 1999) and ammonia oxidation (Hastings *et al.,* 1998), etc. are well documented. Many bacterial species which are involved in these types of biogeochemical cycles were observed from both the lakes during the study period *(Nitrosomonas, Nitrobacter, Methylobacterium, Methylocystis, Methylocapsa, Methylophilates, Methylophaga, Leptospirillum* members of Desulfobulbaceae, *Dechloromonas,* etc). No prominent indicator organisms other than *Enterobactor* and *Klebsiella* were observed during the sampling from both the lakes.

Similar type of works for profiling microbial communities from soil, marine environments, hydrothermal vents, gastrointestinal tract of humans and even the study of a microbial community resident in a medieval wall painting (Felske *et al.,* 1997; Hold *et al.,* 2001; Zoetendal *et al.,* 2002; Nicol *et al.,* 2003) have already been done using the DGGE technique.

5.7. Diversity indices

Diversity indices are mathematical functions which explain the number of species in a biological community (Tiwari and Chauhan, 2006). In the present study, an attempt was made to calculate different diversity indices to compare the diversity between the two lakes. The indices calculated were Simpson's index of diversity (1949), Shannon index (1949), Margalef species richness index (1958) and Pielou's evenness index (1977).

In the case of phytoplankton, a total of 34 genera with high density were observed in Powai Lake, wheres Vihar Lake showed a higher diversity of 51 genera, but with lower number of individuals. A total of 12 genera of zooplankters were observed in Powai Lake, whereas Vihar Lake showed a comparatively higher diversity of 16 genera, but the total number of individuals was less. A total of 11 genera of macro-benthic invertebrates were observed in Powai Lake and 16 genera in Vihar. All the indices calculated for phytoplankton, zooplankton and benthos of both the lakes proved that the organisms in Vihar Lake are more diverse than in Powai, indicated by the higher value of the richness, evenness and overall indices for phytoplankton, zooplankton and benthos studied during the period. From the values obtained for different diversity indices, it can be concluded that Powai Lake is having medium diversity and Vihar Lake a comparatively higher diversity. The results of the respective indices for respective groups between the lakes are given in tables 22 -

24. The lesser diversity in Powai Lake may be due to turbidity, pollution or over-utilization of upper trophic levels. The higher diversity in Vihar may be due to the favourable conditions such as sufficient nutrient availability, low pollution level and low utilization by upper trophic levels. Similar types of works which support the above results have been carried out by Caley and Schluter (1997), Oriole (1999), and Santhanam and Perumal (2003).

5.8. Pollution indices

Naganandini and Hosmani (1990) reported pollution-tolerant algae and suggested the use of algae as indicators of organic pollution. The study of plankton serves as an index of water quality in respect of industrial pollution, and municipal and domestic sewage pollution (Pati and Sahu, 1993; Acharjee *et al.,* 1995; Baruah *et al.,* 1997). In the present study also, an attempt was made to evaluate the water quality of both the lakes using Nygaard's (1949) algal index and Palmer's (1969) index. According to Nyggard, certain algal groups are indicative of the levels of nutrient enrichment. Palmer's index is based on the presence or absence of selected taxa of algae in the water sample. A definite score is assigned to each taxon and depending upon the total score, the water bodies are classified as oligotrophic, mesotrophic or eutrophic. Palmer (1969) opined that the continuous presence and dominance of chlorococcales indicates the presence of organic pollution as *Scenedesmus* is a pollution-tolerant genus.

Both the indices calculated yielded higher value for Powai Lake than Vihar Lake. Hence, it can be concluded that organic pollution is much more in Powai Lake compared to Vihar. A value above 6 for Nyggard's index and above 20 for Palmer's index represents eutrophication in the lake. In Powai, both the index values crossed the eutrophication limit revealing the polluted nature of the lake, whereas in Vihar, both the index values were on the margin of eutrophication limit given, suggesting the need of proper management. Similar type of wok has been done by many ecologists to evaluate the polluted nature of different water bodies (Ragothaman, 1981; Pandey and Habeeb, 1989; Vaishali *et al.,* 2003; Nandan and Aher, 2003; Sreelatha and Rajalekshmi, 2005; Devidar *et al.,* 2006).

5.9. Statistical analyses

Different interpretations were generated from the data using different statistical tools and techniques. They comprise analysis of variance, factor analysis, correlation plots, score plots, trend graphs, pie diagrams and bar diagrams. These statistical reports were used to compare the two lakes with respect to physicochemical and biological parameters. Analysis of variance test showed that majority of the physicochemical and biological parameters analyzed showed significant difference between the lakes except magnesium in water. Powai Lake showed significantly higher values for most of the physicochemical and biological parameters studied except transparency, potassium, iron, chromium and lead in water, and pH, total phosphorus and iron in sediment parameters, which were significantly higher in Vihar Lake. Thus, the analysis of variance test successfully seperated the Powai and Vihar lakes based on all the parameters analyzed.

All the parameters analyzed were subjected to factor analysis to explain the total variation between the lakes. Factor analysis also proved significant separation of Powai and Vihar lakes based on different physicochemical and biological parameters. Water, sediment and biological parameters have shown significant loadings on Factor 1 with high weights for the Powai samples compared to those of Vihar. Excellent sampling adequacy has been observed with respect to the Kaiser-Meyer-Oilkin measure with higher than 0.82 for factor procedures of all the parameters. Based on the the score plot obtained from factor analysis, it is evident that there is a clear separation of Powai and Vihar lakes with respect to biological and physicochemical parameters. All the parameters showed higher values for Powai Lake compared to Vihar. Thus, factor analysis successfully demarcated Powai and Vihar lakes on this background.

The correlation matrix between plankton and physicochemical parameters of the two lakes showed many significant correlations. With all the phytoplankton samples studied, the zooplankton samples showed a positive correlation in both the lakes during all the samplings. This indicates that zooplankton is dependent mainly for food on phytoplankton which was also reported by Hazelwood and Parker (1961). Prasad (1956) also observed a direct relationship between phytoplankton and zooplankton. In Powai, significant positive correlations were obtained between chlorophyll-a and plankters. Chlorophyll-a, the active photosynthetic pigment, gives an idea with regard to phytoplankton biomass (Yeragi and Yeragi, 2003). Chlorophyll-a concentration is being used as a quick and easy-to-measure surrogate of phytoplankton biomass (Kamoto, 1966; Dillon and Rigler, 1974). So, normally when phytoplankton density increases, chlorophyll-content also increases with it.

Nitrate also showed a significant positive correlation with Chlorophyceae and Bacillariophyceae. Excess concentration of nitrates brings eutrophication and is considered sufficient to stimulate algal bloom (Bahura, 1998). Singh (1986) also observed direct relation of phytoplankton with nitrate and inverse relation with phosphates. Some significant negative correlations were observed for the planktonic groups with available phosphorus, biochemical oxygen demand, dissolved oxygen, total carbon, total organic carbon and water temperature. These types of inverse relationships between phytoplankton and nutrients were observed by Round (1957), Singh (1960), Vollenweider (1968), Lund (1969), and Das and Singh (1993). Phosphorus is an important plant nutrient and may play a role of limiting factor among all other essential plant nutrients (Thirumala *et al.,* 2006). In Powai also, the negative relation of phosphate with plankton density may be due to the complete utilisation of the nutrient by the dense plankton. The phytoplankton production of Lake Wadali exhibited a negative relationship with temperature and total alkalinity, thereby indicating the polluted nature of the zones in the lake (Meshram and Dhande, 2000).

SUMMARY

Since time immemorial, human beings have been depending directly or indirectly on the surrounding biodiversity for food, clothing, shelter, medicine, fuel, etc. and thus, biodiversity is an important contributing factor for the existence of mankind on this planet. This diversity, a product of billions of years of evolution, has been rapidly declining in recent years by demographic and developmental pressures, and climate change is exacerbating the rapid loss. Because of our intimate association with biodiversity, the loss of which is threatening our survival, it is high time to curtail the loss. Reducing the loss of our precious biodiversity requires a comprehensive programme of documentation, monitoring and a people-oriented conservation paradigm that extends beyond the protected areas. We, therefore, urgently need to document life and at the same time, assess the changes in biodiversity and the factors influencing these changes. Cataloguing the life forms and analysing the factors influencing it form the basis of conservation. Freshwater systems are estimated to contain about 10% of all animal species on earth. But community and species diversity estimates mostly refer to the macro-biological level of fishes, and it is likely that the species richness of microorganisms, which greatly contribute to the functional biodiversity of freshwater ecosystems, has been underestimated.

A study was conducted to compare the physicochemical parameters and the biodiversity with respect to phytoplankton, zooplankton, benthos and bacteria between two freshwater lakes in Mumbai. The lakes selected for the present study were Vihar Lake (inside Sanjay Gandhi National Park and thus, protected) and Powai Lake (in the urban area of Mumbai). Fortnightly sampling was conducted in these two lakes from 30 November 2010 to 01 February 2011.

A total of 23 important water quality parameters (water temperature, depth, transparency, hydrogen ion concentration, electrical conductivity, dissolved oxygen concentration, biochemical oxygen demand, total alkalinity, reactive phosphorus, total nitrogen, nitrate-nitrogen, ammonia-nitrogen, total carbon, total organic carbon, sodium, potassium, calcium, and heavy metals like copper, chromium, nickel, iron, magnesium and lead) and 19 important soil quality

parameters (hydrogen ion concentration, electrical conductivity, total nitrogen, available nitrogen, total carbon, total sulphur, carbon:nitrogen ratio, total phosphorus, available phosphorus, sodium, potassium, calcium, and heavy metals like copper, iron, lead, mercury, magnesium and nickel) were analyzed and compared between the two lakes. Among the 42 physicochemical parameters analyzed from water and sediment of both the lakes, 39 parameters showed significant difference ($p<0.05$) between the two lakes and 34 parameters showed significant difference between the different samplings ($p<0.05$). Most of the parameters analyzed showed higher values in Powai Lake compared to Vihar. The heavy metal concentrations in both the lakes were within the permissible limits prescribed by the World Health Organisation. The sediment texture in Powai Lake was found to be silty-loam and that of Vihar was claey-loam. Chlorophyll-a content was found to be higher in Powai Lake than in Vihar. The values ranged from 8.90 mg/m³ in Vihar to 103.24 mg/m³ in Powai, which indirectly indicates the high phytoplankton density, eutrophic nature and high plankton productivity of Powai Lake compared to Vihar.

A total of 34 genera of phytoplankters belonging to Chlorophyceae (16), Bacillariophyceae (7), Dinophyceae (1), Euglenophyceae (2) and Cyanophyceae (8) were observed in Powai Lake. The diversity of phytoplankton obtained from Vihar Lake was much more than that of Powai with a total of 51 genera belonging to Chlorophyceae (25), Bacillariophyceae (12), Dinophyceae (2), Euglenophyceae (1) and Cyanophyceae (11). From the study of phytoplankters in both the lakes, it can be concluded that the number of species (diversity) is more in Vihar, whereas the total number of individuals (density) is quite higher in Powai than in Vihar. The phytoplankters, which were most abundant in Powai, were mostly pollution tolerant, indicating the polluted nature of the lake.

A total of 12 zooplankton genera were obtained from Powai Lake during different samplings. This consisted of four cladocerans, four copepods and four rotifers; whereas in Vihar, a total of 16 genera were observed with eight rotifers, four cladocerans and four copepods. From the study of zooplankters in both the lakes, it can be concluded that the number of species (diversity) is more in Vihar, whereas the total number of individuals (density) is higher in Powai than in Vihar. The zooplankters, which were most abundant in Powai, are mostly pollution-tolerant organisms, indicating the polluted nature of the lake.

In the present study, a total of 11 genera of macro-benthic invertebrates were observed in Powai sediment, which consisted of three representatives from Insecta, four from Oligochaeta and four from Mollusca, whereas 19 genera were observed in Vihar Lake, which comprised seven each from Insecta and Oligochaeta and five from Mollusca throughout the period of investigation. The pollution-tolerant organisms like *Chironomus, Tubifex,* etc. were found in very high numbers in Powai Lake compared to Vihar; but the total diversity of benthic invertebrates was found to be less in Powai than in Vihar.

DGGE analysis with PCR-amplified 16s rRNA gene using universal DGGE primers (BA 338F and UN 518R) and further sequencing of excised band obtained from polyacrylamide gel, revealed the nearest identity of 145 microorganisms from water and sediment of both the lakes, which included 34 microorganisms from Powai sediment, 30 from Vihar sediment, 40 from Powai water and 41 from Vihar water. The phylotypes belonging to Beta- and Gamma-Proteobacteria were the predominant group obtained throughout the sampling from both the lakes. The microorganisms in both the lakes' sediment and water included methane producers, sulphate reducers, ammonia oxidizers, dechlorinators, etc. The increase in the concentration of metal elements such as iron might also be related to the presence of bacteria belonging to the genus *Leptospirillum.*

All the biodiversity indices calculated (Simpson's index of diversity Shannon index, Margalef species richness index and Pielou's evenness index) for phytoplankton, zooplankton and benthos using PRIMER software gave higher values for Vihar Lake compared to Powai, indicating higher species diversity in Vihar compared to Powai. The algal pollution indices showed higher value for Powai Lake than Vihar Lake indicating the eutrophic nature of Powai Lake.

The following conclusions were drawn from the present study:

- Distinct variations in all the physicochemical and biological parameters are evident between the two lakes.
- Powai Lake showed higher values for most of the physicochemical parameters analyzed.
- Heavy metal concentrations in both the lakes were found to be within the critical limits.
- Physicochemical and biological evaluation showed that Powai Lake is organically polluted, whereas Vihar Lake is comparatively unpolluted and is suitable for public water supply.
- However, Vihar Lake has reached the threshold level of water quality and unless and until corrective steps are undertaken, it will be difficult to maintain the same quality and biodiversity.
- Biodiversity was observed to be more in Vihar Lake than in Powai with respect to phytoplankton, zooplankton and benthos.
- Density of organisms is more in Powai Lake than in Vihar, but most of them are pollution-tolerant organisms.

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