

DIATOMS AS INDICATORS OF WATER QUALITY IN KHAJIYAR LAKE, HIMACHAL PRADESH

THESIS

By

**AKANKSHA BHARDWAJ
(S-2010-30-25)**

Submitted to



**CHAUDHARY SARWAN KUMAR
HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA
PALAMPUR - 176 062 (H.P.) INDIA**

in

partial fulfillment of the requirements for the degree

of

**MASTER OF SCIENCE IN BASIC SCIENCES
(DEPARTMENT OF BIOLOGY AND ENVIRONMENTAL SCIENCES)
(ENVIRONMENTAL SCIENCES)**

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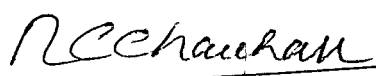
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CERTIFICATE – I

This is to certify that the thesis entitled “**Diatoms as Indicators of Water Quality in Khajiyar lake, Himachal Pradesh**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Basic Sciences)** in the discipline of **Environmental Sciences** of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, is a bonafide research work carried out by **Akanksha Bhardwaj (S-2010-30-25)** daughter of **Mr. Satish Bhardwaj** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.


The assistance and help received during the course of this investigation have been fully acknowledged.

Place: Palampur
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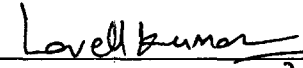

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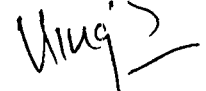
This is to certify that the thesis entitled “**Diatoms as Indicators of Water Quality in Khjiyar lake, Himachal Pradesh**” submitted by **Akanksha Bhardwaj (S-201030-25)** daughter of **Mr. Satish Bhardwaj** to Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the award of the degree of **Master of Science (Basic Sciences)** in the discipline of **Environmental Sciences**, has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.



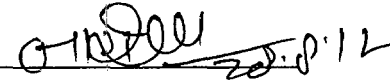
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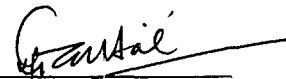
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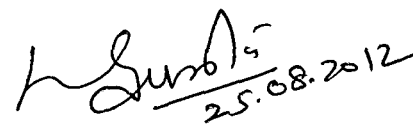
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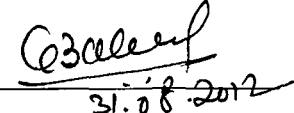
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I owe my extreme regards to the whole faculty of the Dept. of Biology and Environmental Sciences. I owe my ecstatic thanks to Dr. Neelam Sharma.

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Place: Palampur

Dated: 13/7/2012


(Akanksha Bhardwaj)

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LIST OF ABBREVIATIONS USED

<u>Abbreviation</u>	<u>Meaning</u>
%	Per cent
°C	Degree Celcius
µmhos/cm	Micro mhos per centimeter
cm	Centimeter
D.O.	Dissolved oxygen
etc.	Et. Cetera
et al.	et alii (and others)
ha	Hectare
i.e.	id est (that is)
kg	Kilogram
km	Kilometer
m	Meter
m/sec	Meter per second
mg/L	Milligram per liter
mg	Milli grams
ml	Milli litre
no./L	Number per litre
p.	Page
p.p	Pages
TDS	Total dissolved solids
TS	Total solids
TSS	Total suspended solids
viz.	videlicet (namely)

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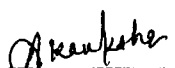
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ABSTRACT

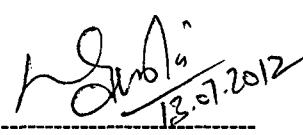
The present investigation was carried out to assess the water quality of Khajiyar lake, Himachal Pradesh using diatoms as indicators in relation to the physico-chemical characteristics. The physico-chemical characteristics such as temperature, transparency, conductivity, total solids, total dissolved solids, total suspended solids, pH, dissolved oxygen, alkalinity, free carbon dioxide, chloride, nitrate-nitrogen, total phosphate-phosphorus, silicates, sodium, potassium and diatom species were estimated and recorded at three different study sites seasonally from April 2011 to January 2012 and then average values were considered for the data interpretation. The majority of the physico-chemical characteristics showed significant relationships among themselves. The diatom species composition, presence and abundance was found greatly influenced by the physico-chemical regime of the lake. The diatom density showed highly significant and positive relationship with conductivity ($r = 0.869$, $p < 0.01$), chloride ($r = 0.857$, $p < 0.01$). Their density also revealed significant and positive relationship with nitrate nitrogen (0.362), total phosphate phosphorus (0.56) and silicates (0.942, $p < 0.01$). The higher values of free carbon dioxide (11.0-26.8 mg/L), chloride (20.2-33.1mg/L), nitrate nitrogen (0.098-0.485mg/L), total phosphate phosphorous (0.61-2.32mg/L), very low percentage of oxygen indicators species and the distribution, presence and abundance of pollution indicator diatom species such as *Diatoma vulgare* (5%), *Navicula gracilis* (24%), *Navicula gibba* (8%), *Pinnularia nobilis* (12%), *Nitzschia sigmoidea* (3%), *Gomphonema geminatum* (23%), *Frustulia rhomboides* (2%), *Tabellaria fenestrata* (2%) and *Cylinderotheca gracilis* (4%) throughout the investigation indicated highly deteriorated water quality of the lake ecosystem.



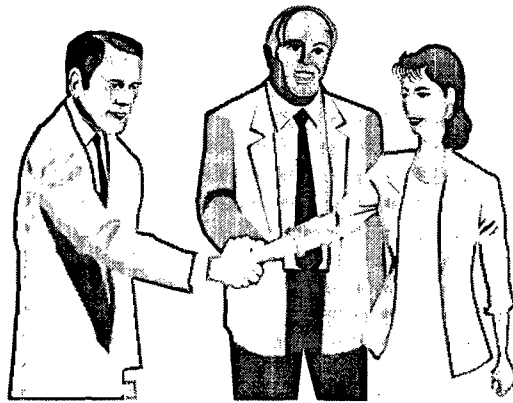
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INTRODUCTION

1. INTRODUCTION

An ecosystem is a dynamic entity composed of biotic community and its associated abiotic environment. Ecosystems are always undergoing changes in their abiotic and biotic components. Among the several types of ecosystems an aquatic ecosystem is the most diverse and productive ecosystem of the world. It is an ecosystem located in the body of water and is of two types- freshwater and marine ecosystem. Freshwater ecosystems cover 0.80% of earth's surface. Its resources include lakes, ponds, rivers, streams, reservoirs, wetlands and groundwater. Aquatic ecosystems perform many important environmental functions. A lake is a body of relatively still fresh or salt water of considerable size, localized in a basin that is surrounded by land. Lakes are inland and are larger and deeper than ponds. They can be contrasted with rivers or streams, which are usually flowing. However, most lakes are fed and drained by rivers and streams. Natural lakes are generally found in mountainous areas, rift zones, and areas with ongoing glaciations.

Natural, unpolluted aquatic ecosystems are fast disappearing around the world. Silt from poor soil management, run off from chemical intensive agriculture, urban and industrial pollution is all wreaking catastrophic damage on freshwater ecosystems. Eutrophication is the most widespread form of lake pollution on a global scale, and has many deleterious impacts on aquatic systems, Harper (1992). Eutrophication refers to enrichment of aquatic systems by inorganic plant nutrients, Wetzel (1983) and Mason (1991). This is a term used to describe the biological effects of an increase in the concentration of plant nutrients usually of nitrogen and phosphorus, but sometimes others such as potassium, calcium, iron, manganese, silicon and chloride on aquatic ecosystem. The causes of eutrophication are natural and anthropogenic. In addition to increasing overall primary production, eutrophication causes considerable changes to biochemical cycles and biological communities. The marked changes occur at all levels in the food web and entire communities can change or die out. The physico-chemical parameters of water such as temperature, pH, electrical conductivity, dissolved oxygen, free carbon dioxide, chloride, nitrate-nitrogen, phosphate-phosphorus, total hardness and total

dissolved solids determine the presence and distribution of organisms in an aquatic environment, Chauhan (1993). The changes in the ratio of N:P often results the shifting of primary production from primarily diatoms and other smaller edible algae towards larger cyanobacteria that are better competitors for N, and more resistant to grazing. It is imperative, therefore, that biological monitoring system be developed to follow environmental changes so as to protect the ecological integrity of aquatic ecosystem.

The bio-monitoring technology is a valuable tool that is receiving increased use in water quality monitoring programs of all types, Kennish (1992). It involves the use of indicators, indicator species or indicator communities. The presence or abundance of indicator species reflects environmental conditions. Bio-indicators are any biological species or group of species whose function, population, or status can be used to determine ecosystem or environmental integrity. Such organisms are monitored for changes (biochemical, physiological, or behavioural) that may indicate a problem within their ecosystem. Routine biological monitoring may be employed to assess the types of pollution and their effects on the ecosystem.

Detection of pollution or eutrophication using biotic communities including plankton or periphyton has been pursued by many workers, Stein and Danison (1967). They maintained that biological indicators are better than chemical or physical features used alone. Among planktons, the algae are ecologically important group of organisms in most aquatic ecosystems but are most ignored as an indicator of pollution. Because of their position at the base of food chain they provide relatively unique information regarding the health of aquatic ecosystem than that of commonly used animals and bacterial indicators. In terms of numbers, the most important groups of phytoplankton include the diatoms, cyanobacteria and dinoflagellates. Among these groups the diatom species in particular have received more attention and greater acceptance as an indicator species.

Diatoms are single celled stationary microscopic algae and are therefore, almost unable to avoid harmful conditions. They are highly sensitive to the changes in water chemistry, abundant in aquatic environment and largely cosmopolitan in distribution. Diatoms are considered to be one of the most opportunistic algal group in the sense that they are quite sensitive to the minor change in the environment. They allow the detection

of water quality changes, accompanied by the derivation of ecological inferences, at a scale infinitely more subtle than those possible using conventional water chemistry techniques. No other biomonitoring indicator provides a fraction of that provided by diatoms for evaluating water stress and climate change, or for benchmarking ecological condition. The ability to use diatoms to evaluate present and past conditions of water quality and environmental change in just about any aquatic environment has been recognised world-wide. No other single taxonomic group of aquatic organisms is as sensitive as diatoms to the changes both in water quality and habitats. They satisfy all the conditions to qualify for suitable indicators as they are simple, capable of quantifying changes in water quality, applicable over large geographic areas and can furnish data on background conditions and natural variability. The use of diatom-based approaches is now supported by a better understanding of the relationship between diatoms and environmental variables, Juttner *et. al.* (2003). Whilst the majority of bio monitoring tools use micro invertebrates and fish, diatoms have been increasingly recognised as an extremely an important tool for the assessment of water pollution and trophic status of aquatic ecosystems. Thus, in the present investigation an attempt has been made to assess the water quality of Khajiyar lake ecosystem using diatoms as indicators under the following objectives:-

1. Estimation of physico-chemical characteristics of the lake in relation to diatoms.
2. Assessment of water quality in fresh water lake ecosystem by using diatoms as indicators.



REVIEW
OF
LITERATURE

2. REVIEW OF LITERATURE

The concept of presence and abundance of species indicating certain conditions is practically based on observations verifiable by almost anyone who has contact with environment. The rapidly producing micro-organisms communities including algae are among the best indicators indicating organic load to the aquatic ecosystems. Thus, keeping in view the significance of diatoms as an indicator of water quality an attempt has been made in present investigation to study the diatoms in relation to physico chemical regime of the lake ecosystem. The literature related to the present piece of research work has been reviewed under the following heads:

1. Physico-chemical characteristics
2. Phytoplanktons
3. Diatoms

Physico-chemical characteristics

Tiwari *et al.* (1991) monitored physico-chemical and biological parameters of the river Alaknanda. Water quality was assessed by comparison with existing standards for important parameters. Dissolved oxygen showed positive relationships with temperature. Turbidity, total alkalinity, hardness, free carbon dioxide, chloride concentration, total dissolved solids, zooplanktons and phytoplanktons showed marked variations during monsoon and winter seasons.

Nishihara *et al.* (1998) evaluated the water quality from twelve mineral sources located in Metropolitan Region of Sao Paulo, Brazil. The samples were collected trimestrially during one year and were submitted to physicochemical measurements. Data are presented for aspect; colour; odour; turbidity; pH; alkalinity; calcium; magnesium; total hardness; chloride; iron; ammonia and albuminoid nitrogen; nitrite; nitrate; consumed oxygen; potassium; sodium; sulphate; arsenic; barium; cadmium; lead; cyanide; copper; chromium; fluoride; manganese; zinc and total dissolved solids. The observed values for each one of these parameters were similar during the studied period.

Most of the sources agree with the requirements of the Federal Brazilian Regulations, despite one of them exceeding the maximum contaminant levels for manganese and nitrate. The concentration ranges for some of the common metallic elements were 2.8 to 19 mg Na/litre; 1.3 to 3.4 mg K/litre; 0.6 to 14 mg Ca/litre and 0.8 to 11 mg Mg/litre.

Jha and Barat (2003) studied some hydrobiological features of lake Mirik, situated in the Darjeeling Himalayas (West Bengal, India), during May to October 2000. Water temperature showed abrupt fluctuations. The water pH was generally acidic. Dissolved oxygen increased steadily with increasing rainfall and recorded highest in late August ($12.6 \text{ mg litre}^{-1}$). Chlorophyta and Cyanophyta were identified among phytoplanktons. Zooplanktons were represented by cladocerans and copepods. The study revealed higher concentration of nutrients at certain pockets of the lake, which points to increasing human influences in the system, and the water cannot be an alternative for drinking purposes.

Kara *et al.* (2004) took water samples from Lake Isykii in Denizli region, Turkey, during the four seasons and analyzed for chemical and physical properties. The results were found within the acceptable limits of pollution according to Turkish standards except organic matter, phosphate, ammonia nitrogen and nitrite.

Mahar *et al.* (2005) analysed water samples of Main Nara Valley Drain entering Manchhar lake at monthly intervals between January to December 2001. The samples were analysed for temperature, secchi disc depth, conductivity, total dissolved solids, chemical oxygen demand, and total nitrogen and orthophosphate contents. It was concluded that the water quality of Main Nara Valley Drain is drastically degrading the quality of Manchhar lake along with the biotic components.

Mustapha and Omotosho (2005) studied physico-chemical factors from two stations on the surface water of Moro lake over a period of eight months and concluded that due to high nitrate and phosphate surface water quality the lake is productive and eutrophic.

Daniela *et al.* (2006) assessed the quality of three different aquatic ecosystems. Physical, chemical and microbiological parameters of water, as well as the aquatic invertebrates were studied. A comparative analysis of the characteristics of lake showed a better quality of the natural water ecosystem than the changed and created ecosystems.

Fafioye *et al.* (2006) while studying the physico-chemical parameters of Omi water body reported the range of dissolved oxygen from 1.4 to 4.8 mg/l; pH 6.7 to 7.2; temperature 26.5 to 31.5°C; alkalinity 24.2 to 25.4 ppm; conductivity 23.0 to 28.3 ohms/cm; turbidity 0.11 to 0.15 m; and free carbon dioxide from 3.5 to 4.5mg/l. Dissolved oxygen, pH and water temperature were found to serve as variables since the fluctuation of one affects the values of others.

Leghari *et al.* (2006) analysed water samples from Hanna Lake and Urak Spring for physico-chemical and biological parameters during 1999 and 2003. The water was recorded slightly alkaline in nature with electrical conductivity and total dissolved solids within the range 263-1228 micro S/cm and 165-785 mg/L respectively. It was concluded that the lake and spring waters were suitable for fish culture.

Alam *et. al* (2007) collected water samples from a part of Surma river along different points and analyzed for various water quality parameters during dry and monsoon periods. This study involved determination of physical, biological and chemical parameters of surface water at different points. The river was found to be highly turbid in the monsoon season.

Borda *et al.* (2007) evaluated the seasonal variation of the abiotic and biotic factors; three different aquatic ecosystems were investigated: a natural ecosystem, a transformed ecosystem and an artificial ecosystem. The physical, chemical and bacteriological parameters of water, as well as the aquatic invertebrates from surface and benthic zone were determined. A comparative analysis of the seasonal dynamics in the three lakes showed that the artificial ecosystem was the least stable of all and the biodiversity was highest in the natural ecosystem, followed by the transformed and artificial ecosystems.

Bria and Arsene (2007) analysed water samples obtained from different points of Tulcea district (Romania) in 2004-2007 to determine the physicochemical properties of surface waters by spectrophotometry. This method was found to be fast, efficient and has low reactive consumption.

Tiwari *et al.* (2007) studied total of 18 lakes and ponds in Bhopal District, Madhya Pradesh, India, to determine the effect of changes in the physical and chemical

parameters of the water on plankton population and distribution and concluded that due to manhandling of these water bodies, the parameters changed, which led to population fluctuation of phytoplanktons. The physical and chemical properties of the water bodies also affected the distribution of plankton.

Arain *et al.* (2008) studied the status of Manchar lake water with respect to different physico-chemical parameters (electrical conductivity, pH, chloride, phosphate, sulphate, total alkalinity, potassium, calcium, magnesium, manganese, iron, cadmium, copper, arsenic, nickel, zinc, chromium, lead and selenium) in 2005-2007. They found that among the elemental investigation of lake water except Co, Cr, Cu, Mn, and other elements (Al, As, Ca, Cd, Fe, Mg, Na, K, Ni, Pb and Se) have higher values as compared to the permissible level of these elements in drinking water.

Armagan *et al.* (2008) collected water samples from 7 different points in the Balikligol lakes (Lake Ayn-i Zeliha and Lake Halil-ur Rahman) in Sanlifura during a one-year period and analyzed monthly for 11 physico-chemical water quality parameters (temperature, pH, conductivity, chemical oxygen demand (COD), dissolved oxygen (DO), Fe, Na, Cr, Cu, Ni, and Pb). It was found that the measured parameters comply surprisingly well with the standard values.

Trisal *et al.* (2008) assessed water quality of the River Yamuna in the Delhi stretch by determining changes in the concentration levels of 19 physico-chemical parameters. It was proposed that restoration of the inundation pattern of floodplains would greatly help in re-aeration of the overlying water and re-absorption of pollutants through mud/water exchanges.

Srivastava and Athar (2008) monitored the pollution level in Jamtara station at Khirhani ghat of Narmada River in Jabalpur, Madhya Pradesh, India. Physico-chemical parameters of the river water were analysed. The study reflected that the sampling sites were polluted and pollution level increased beyond the prescribed standard limit.

Trivedi *et al.* (2009) investigated the physico-chemical parameters of water samples of Ganga, River at Kanpur. Water samples under investigations were collected from Jalsansthan Benajhwar Kanpur, sampling station during pre monsoon (April-May), monsoon (July- August) and post monsoon (October- November) seasons in the year

2008. Correlation coefficients were calculated between different pairs of parameters to identify the highly correlated and interrelated water quality parameters and t-test was applied for checking significance. It was found that significant positive correlation holds for TA with Cl^- , Mg^{+2} , Ca^{+2} , TH, TDS, fluoride. A significant negative correlation was shown by soluble solids with chloride, Mg^{+2} , TDS and fluoride.

Umamaheswari and Saravanan (2009) studied the water quality of Cauvery, river basin in Trichirappalli, India. River receives city sewage, industrial effluents, and anthropogenic wastes and is subjected to change due to seasons, climate and geochemistry of the land over which it flows and influx of waters from various tributaries. Physico-chemical parameters and bacteriological indicators of pollution were assessed and water quality index was evaluated.

Bhalla and Sekhon (2010) studied the seasonal variations (winter, summer, monsoon) of parameters like Temp, Turbidity, pH, Free CO_2 , DO, Nitrates, Phosphates, Planktonic community, along with primary production of Godavari river water at Nasik during November 2002 to October 2003 and concluded that the physico-chemical characteristics influence the planktonic population whereas primary productivity depends upon the photosynthetic activity of phytoplankton. The planktonic community showed direct correlation with primary productivity i.e. maximum in the summer and minimum in the winter.

Verma and Saksena (2010) studied the pollution status of Kalpi, river. Certain pollution parameters such as transparency, electrical conductivity, turbidity, total suspended solids, dissolved oxygen, nitrite-nitrogen, phosphates, ammonia, supplied, BOD and COD were estimated.

Andrade *et al.* (2011) analyzed the samples for the various physico-chemical parameters on the Mangalore coastal water of the Indian peninsula which revealed the alkaline condition and low dissolved oxygen concentration. The concentration of these components were compared with WHO standards and found to be deviated highly.

Gecheva *et al.* (2011) assessed bryophyte species composition and 26 common physico-chemical and inorganic chemical parameters at 23 selected sites in the

Maritsa River (BG) over a 4-year period. The data implied that the content of elements measured in bryophytes represented river contamination, while species compositional patterns reflected hydromorphology and general degradation. This study for the first time combined aquatic bryophyte occurrence, the bioaccumulation of 17 macro-and microelements in 17 species, and 26 water factors by principal components analysis (PCA) in an assessment of river pollution.

Ruggieri *et al.* (2011) presented the results of the statistical analysis of a set of physico-chemical and biological water quality parameters, monthly collected from 2000 to 2007 in the Genoa Harbour area (Ligurian Sea). Multivariate methods, such as principal component analysis (PCA) and dynamic factor analysis (DFA) for investigating the spatial and temporal variability and for providing important background information on pollution problems in the region were applied. Furthermore, meteorological variables in statistical analyses were also included because of their potential influence on the water quality parameters. These natural forcings explained part of the variability in water quality parameters that are superimposed on the dominating anthropogenic pollution factors.

Gianni *et al.* (2012) investigated temporal and spatial distribution of physico-chemical and water quality parameters and their correlation with meteorological and hydrological data, for anoxic lagoons, in Greece. Monthly variations of parameters like temperature, salinity, dissolved oxygen, chlorophyll-a, total phosphorus etc., along the Aitoliko lagoon water column, were recorded and studied at 14 stations. Meteorological conditions control temperature ($R^2=0.845$) and dissolved oxygen ($R^2=0.576$) monthly changes, in lagoon's epilimnion, while salinity seemed to be related with the salt/fresh water budget into Aitoliko lagoon. Epilimnetic chlorophyll-a (3.29-14.89 mg l⁻¹) and total phosphorus (13.33-36.31mg l⁻¹) concentrations classified Aitoliko lagoon as a mesotrophic environment. In this study, for the first time, Aitoliko lagoon was reported as seasonal anoxic basin.

Mihaiescu *et al.* (2012) presented basic chemical and physical characteristics of Ighiu lake water. The survey was carried out in 2010. Water samples were collected from two different sites covering the middle of the lake and were analyzed for a pre-defined set of physical and chemical indicators to allow the build up of a meaningful database that

can be used for comparative assessment and trend delineation. The results showed a good water quality but also showed the presence of minor traces of pesticides and heavy metals.

2.2 Phytoplanktons

Seve (1993) studied phytoplankton biomass and species composition from June to September 1991 at the mouth of four major rivers and in the freshwater (sal. 0%), the estuarine (sal. 2-10%) and the coastal (sal. 10-12%) zones of Rupert Bay, located at the southeast tip of James Bay, Canada. It was found that diatoms were dominant in the freshwater zone (30-80% abundance), with flagellates dominating in the estuarine and coastal zones (6-95% abundance). The diatom bloom was composed almost exclusively of the autochthonous planktonic diatom *Cyclotella meneghiniana* Kutz., which contributed 25-85% of the species composition, and of the subdominant benthic species *Diploneis smithii*, *Navicula lanceolata* and *Surirella robusta*. Peak abundance occurred upstream of the turbidity max., in the ideal freshwater zone.

Ibelings *et al.* (1998) carried out observations on phytoplankton in the lower reaches of the rivers Rhine and Meuse in Netherlands. Seasonal changes in density and species composition were analysed to detect the major variables and to discuss whether this monitoring meets its goals. Overall density was correlated with seasonal variation in water discharge rather than with nutrient concentrations, that are high in both rivers. It was observed that despite hydrographic and chemical differences between the two rivers, many species, predominantly diatoms and green algae, were shared and results showed that although year to year variation in phytoplankton density was mainly related to variation in water discharge, phytoplankton biomass increased as a result of eutrophication over a period of decades. However the importance of phytoplankton in trophic relationships merits its inclusion in the monitoring of riverine ecosystems.

Garg and Garg (2003) studied eutrophication-tolerant and sensitive strains of phytoplanktons from three inland lentic resources of Bhopal, Madhya Pradesh, India, i.e. Upper lake, Lower lake, and Mansarovar reservoir. Among the 59 species of phytoplanktons identified in the lake water samples, *Ankistrodesmus falcatus* exhibited high tolerance of calcium and potassium. *Chlorella vulgaris* was detected in water

samples with high nutrient contents. *Crucigenia crucifera* was highly tolerant of calcium, magnesium, potassium, and phosphorus, but was only moderately tolerant of nitrogen. *Crucigenia quadricauda* and *Crucigenia rectangularis* showed preference for calcium, magnesium, and potassium. *Pediastrum* spp. survived well in calcified and nitrated water. *Scenedesmus* survived under varying nutrient conditions. *Cosmarium granatum* was adversely affected by all nutrients, especially phosphorus. *Merismopedia punctata*, *Melosira granulata* and *Microcystis aeruginosa* were highly eutrophic.

Chakraborty *et al.* (2004) studied the water quality and plankton abundance of five beels: Paramajhdia-Magura, Bhomra, Mathura, Chandmari and Kulia, of Nadia District, West Bengal, India. The water quality parameters studied were: temperature 16.6-25.9 degrees C, dissolved oxygen 3.7-14.9 mg/litre, pH 5.9-8.2, transparency 96 cm - visible bottom, specific conductivity 67-245 micro mhos/cm and total dissolved solids 31.7-117.5 mg/litre. The depth ranged from 75 to 255 cm. The dominant phytoplanktons were Bacillariophyceae, Chlorophyceae and Euglenophyceae.

Pandey *et al.* (2004) studied the phytoplankton of the Ramjan river in Bihar, India in relation to certain physico-chemical factors. Altogether, 28 species of phytoplanktons were found comprising Chlorophyceae (37.60%), Myxophyceae (39.44%), Bacillariophyceae (15.37%) and Euglenophyceae (7.59%). The peak of the phytoplanktons was observed during summer. Bacillariophyceae showed positive correlation with dissolved oxygen, bicarbonate, nitrate and transparency. The river harbored many pollution tolerant species like *Navicula*, *Fragilaria*, and *Cyclotella*.

Ferreira *et al.* (2005) collected water samples from the Americana Reservoir in Sao Paulo, Brazil, in February, April, June and October 2004 and analysed them for the following: temperature, pH, dissolved oxygen, conductivity, total nitrogen, nitrite, nitrate, ammonia, total phosphorus, inorganic phosphate, and presence of phytoplankton. 103 taxa of phytoplanktons were detected. The species of phytoplanktons observed at high densities were *Microcystis aeruginosa*, *Anabaena spiroides*, *Microcystis* sp. and *Pseudoanabaena mucicola* [*Pseudanabaena mucicola*], with *A. spiroides* being the most abundant. In July and October, species belonging to the Cryptophyceae class comprised a large proportion of the total density.

Narayana *et al.* (2005) studied the physico-chemical properties of surface water samples from the Keladi and Kanale tanks, near Sagar Taluk, Karnataka, India, from February to July 2004 and the phytoplankton in the area were studied in relation to some environmental variables. All the parameters analysed revealed that they are within the permissible limit according to WHO and ISI. Phytoplanktons observed in the tanks belong to 4 classes: Chlorophyceae (19), Cyanophyceae (6), Bacillariophyceae (4) and Euglenophyceae (2).

Pinilla (2006) analyzed the relations between the physico-chemical variables and the vertical distribution of phytoplankton community of a clear water lake (Lake Boa). In the low water phase, the vertical distribution of *Cryptomonas* spp., *Peridinium* cf. *umbonatum* and *Chlamydomonas* spp. had significant statistical associations with the redox potential (RP), reactive phosphorus (PO₄), and hydrogen sulfide (H₂S) ($p \leq 0.05$). During the flood stage the conditions were more varied and significant associations were detected between the vertical arrangement of *Botryococcus braunii*, *Oscillatoria splendida*, *Dinobryon sertularia*, *Euglena acus*, and *Trachelomonas volvocina* with conductivity, dissolved oxygen (DO), pH, temperature, dissolved organic carbon (DOC), PO₄, RP, and ammonia (NH₄). Thus it was concluded that the vertical structure of the Lake Boa's phytoplankton responded to annual changes produced by the flood pulse, and to the vertical environmental variations, which were stronger during the high water phase.

Onyema (2007) investigated the phytoplankton composition, abundance and temporal variation of a polluted estuarine creek in Lagos for 6 months (February-July, 2003) and found strong positive correlation ($r \geq 0.73$) between physico-chemical characteristics at two stations. Higher phytoplankton diversity was recorded during the rains and also the physico-chemical characteristics and phytoplankton indicator species reflected a polluted and rapidly deteriorating estuarine environment.

Raut *et al.* (2007) collected Phytoplankton samples from four selected lakes (Ambeghosale, Rewale, Makhamali & Upavan) in the Thane City. Phytoplankton analysis was done throughout the year for these lakes. Partial Least Square regression (PLS) response (phytoplankton) to physico-chemical parameter was represented first time for Thane lakes. The study showed that calculated PLS response of phytoplankton is very near to actual response of phytoplankton in all four-study lakes.

Adesalu and Nwankwo (2008) investigated the phytoplankton of a tidal creek in Lagos, Nigeria, for six months (September 1998-February 1999). The phytoplankton was dominated by diatoms (48 pennate forms and 23 centric forms). Higher phytoplankton biomass was recorded in the dry months than wet months.

Hulyal and Kaliwal (2008) studied the limnobiologic status of Almatti reservoir from February, 2003 to January, 2005. The study revealed that, the distribution and population density of zooplankton species depend upon the physico-chemical factors of the environment.

Madihah (2008) studied spatial and temporal variation in phytoplankton communities and physico-chemical water properties in the cage culture area of Sepanggar Bay, Sabah, Malaysia based on field measurement conducted during July 2005 to January 2006. Forty phytoplankton genera, representatives of 23 families, were found in the study area with a mean abundance of $1.55 \pm 1.19 \times 10^6$ cells L⁻¹ belonging to diatoms (82.17%), Dinoflagellates (17.55%) and cyanobacteria (0.29%).

Mahadev and Ahamad (2008) studied water samples of the Dalvoii lake (Mysore, Karnataka, India) collected from different spots during May 2001 to June 2002 and phytoplanktons were studied in relation to 16 environmental variables during this period. A total of 44 phytoplankton species were identified under four classes, viz. Chlorophyceae, Bacillariophyceae, Cyanophyceae and Euglenophyceae. Maximum density was recorded under Cyanophyceae, and Chlorophyceae showed considerable fluctuations with environmental variables.

Onuoha (2008) studied the phytoplankton flora and primary productivity of the Bonny river estuary. A systematic account of the phytoplankton flora consisted mainly of diatoms and which were sparse and concluded that with the volume of effluent discharge, and possible bioaccumulation process, the environment will pose a threat to the existence of aquatic life, especially as these water bodies are known to be nursery grounds for fishes and shrimps.

Salavatian *et al.* (2009) conducted study for phytoplankton identification, density and dispersal assessment from June to October 2005 in Lar Reservoir. 34 genera of phytoplanktons consisting of 7 Phyla were distinguished. Phylum Bacillariophyta was

dominant comprising 82.83% of phytoplankton population annually. *Cyclotella*, *Navicula* and *Nitzschia* were the dominant genera. Also, in all seasons, the most dominant genus of the Phylum Bacillariophyta was *Cyclotella*.

Song and Yu (2009) investigated the species and quantity of phytoplanktons in Jingpo Lake of Mudanjiang, Heilongjiang Province during May 2006 and April 2007. A total of 103 species and varieties were recorded, belonging to 55 genera from 8 phyla and concluded that the upriver water quality is better than that of lower reaches of the river, but the water quality of the whole river is oligo-mesotrophic.

Acharya *et al.* (2010) conducted study in a tropical semi arid zone where the source of water was through sewage and rain. In this ecosystem phytoplankton of the class Bacillariophyceae, class Chlorophyceae and class Cyanophyceae were studied. Zooplanktons were obtained, less in number than phytoplanktons. The numerical of phytoplanktons showed that Bacillariophyceae dominated followed by Chlorophyceae and Cyanophyceae.

Mahadev *et al.* (2010) studied the variation in water quality with special reference to physicochemical and biological parameters in Cauvery River and its tributaries in India over a period of 1 year. 30 species of phytoplanktons were identified under five classes: viz, Chlorophyceae, Bacillariophyceae, Cyanophyceae, Euglenophyceae and Desmidiaceae. The overall diversity and density of algae at four stations was significantly different.

Sharma (2010) studied the species diversity and richness of phytoplanktons in river Damodar of Bermo sub-division. Phytoplanktons were collected regularly for a period of 12 months (Nov. 08 to Nov. 09). Altogether 51 taxa of three different classes viz., Chlorophyceae, Bacillariophyceae and Cyanophyceae, were recorded. Results indicated the wide range of seasonal fluctuations in quality and quantity of phytoplankton.

Chinnaiah *et al.* (2011) studied the correlation between the periodicity of algae in the lake with physico-chemical parameters of the water and assessed the quality of water and studied the ecological and biological concerns of the lake under various seasonal changes during September, 1999 to August, 2001 and elucidated certain aspects of phytoplanktons of selected lake of Warangal district (A.P.) with reference to its water pollution.

Sayeswara *et al.* (2011) studied the physico-chemical parameters and planktonic composition of Hosahalli pond for a period of 12 months from January to December 2010. A total of 60 species belonging to 43 genera of phytoplanktons were recorded, of which Chlorophyceae and diatoms were found to be dominant among four classes. Eleven zooplanktons were identified.

Sharma and Bhardwaj (2011) assessed the physico-chemical parameters of Mahi river, Gujarat, India during March-2006 to February-2007. Along with the physico-chemical parameters water samples were also characterized for Phytoplankton community composition and density. The dominance groups among phytoplankton community were Blue green algae and diatoms. Rise in DO and nutrient levels of nitrate, phosphate and silicate suggested favorable conditions for plankton growth. The most tolerant genera and species of four groups of algae were recorded. Thus it was concluded that phytoplankton encountered in the water body reflected the average ecological condition and therefore, they may be used as indicator of water quality.

Tavernini *et al.* (2011) analyzed the effects of water discharge, temperature and chemistry on phytoplankton dynamic and species composition in the lowland reach of the eutrophic Po river (Italy). Both taxonomical and morpho-functional methods were used. True planktonic and tychoplanktic (i.e. detached taxa of benthic origin that remain in suspension) species were found, among which only a few taxa and functional groups prevailed. Diatoms were the most abundant, with a clear dominance of species either sensitive to the onset of water stratification or well adapted to turbid waters. Phytoplankton abundance, biomass and chlorophyll-a followed similar trend, attaining the highest values in summer, at low discharge rates. Correlation and multivariate analysis revealed that the development of a stable phytoplankton community was mainly controlled by water discharge rates. The seasonal succession of phytoplankton assemblages was also related to water temperature and dissolved reactive silica availability to some extent overlapping flow effects.

Zhang *et al.* (2011) studied the characteristics of phytoplankton and its correlation with water environment and detected 57 species of phytoplankton. Additionally, it was found that Chlorophyta was the dominant phytoplankton, followed by Bacillariophyta and Cyanophyta.

Bosak *et al.* (2012) analyzed the species composition and size-structure of the phytoplankton community in the Boka Kotorska Bay (SE Adriatic Sea) with respect to abundance and carbon biomass, together with the physico-chemical parameters, with the aim of evaluating the predefined oligo-mesotrophic status of this transitional water ecosystem and concluded higher values of phytoplankton biomass and the dominance of phytoplankton species or groups with preferences for nutrient-enriched conditions appear to be consistent with the oligo-mesotrophic status of this specific ecosystem.

Sahu *et al.* (2012) carried out a comprehensive study on phytoplankton dynamics in the coastal waters of Kalpakkam which showed a considerable increase (almost 3 fold) in phytoplankton species composition (185 species) as compared to the earlier findings (60 species). The change in phytoplankton assemblages (density and species composition) during different seasons was significant and was found to be regulated by the change in water characteristics associated with monsoon. Diatoms dominated the phytoplankton assemblage followed by dinoflagellates. Salinity apparently influenced the phytoplankton density positively. Nitrate was found to be the limiting factor for phytoplankton growth during late summer and pre-monsoon periods, whereas, the role of silicate and phosphate remained insignificant in this regard.

Sitoki *et al.* (2012) investigated for environmental conditions, phytoplankton community composition, and microcystin (MC) concentrations monthly from Kisumu Bay, and bimonthly from the center of the gulf, as well as quarterly from the Rusinga Channel and the main basin of Lake Victoria between July 2008 and September 2009 in order to characterize the harmful algal bloom formation as a consequence of eutrophication, both spatially and seasonally. More than 90% of the samples obtained from the gulf were dominated by cyanobacteria, whereas diatoms only dominated in the samples obtained from Rusinga Channel and the main lake. In general, *Microcystis* accounted for the largest part (>50-90%) of cyanobacterial biovolume. The results suggested that seasonal variability did not outweigh the spatial differences in phytoplankton composition and MC production, which is seasonally persistent in Kisumu Bay.

2.3 Diatoms

Singh and Chauhan (1989) assessed the water quality of Rewalsar lake on the basis of different diatoms associations, their abundance and distribution. The water quality indicator groups viz. oxygen indicators, nitrogen heterotrophic-Naviculae, nitrogen heterotrophic-Nitzshiae and varying nitrogen level indicators have been identified as water pollution diatom indicators of the lake.

Rao (1994) studied the effects of mercury, copper, cadmium, zinc, lead, and chromium in the diatoms *Achnanthes hauckiana*, *Amphora coffeaeformis*, *Cyclotella meneghiniana*, *Fragilaria pinnata*, *Navicula confervaceae*, *Nitzschia obtusa*, *N. palea*, *Skeltonema costatum*, *Synedra tabulata*, *Thalassiosira weisflogii* and *Triceratium dubium*. It was observed that two unicellular green algae, *Scenedesmus bijugatus* and *S. dimorphus* and the filamentous *Stigeoclonium tenue* could adapt to very high concentrations of heavy metals and the algae retained the tolerance even after the metal stress was removed. The diatoms lost their tolerance immediately after the metal stress was removed.

Van-Dam and Mertens (1995) collected samples for the analysis of attached diatoms and surface water chemistry from 35 stations in 16 soft-water streams in the Netherlands in 1990. The chemical data from 16 stations were compared with data collected in 1974 and 1981. Over the same period nitrate increased significantly while alkalinity decreased significantly. The most important correlates with the distribution of diatoms were pH, nitrate, cross-sectional area of the stream and the Ca:(Ca + Cl) ratio. Diatom assemblages of upstream stations showed more acid conditions than those downstream. The diatom assemblages were diverse and contained a high proportion of filamentous diatoms, particularly *Aulacoseira crenulata* and *A. alpigena*, which are rare in Western Europe.

Gomez (1998) used epipellic diatom assemblages to evaluate water quality in the Matanza-Riachuelo river basin, N.E. Buenos Aires province, Argentina. Twenty-three sites were sampled in April, May, June and August 1995. A total number of 97 taxa were identified of which only 37 were abundant. *Navicula cryptocephala*, *Nitzschia palea* and *N. umbonata* occurred in the whole basin though more frequent downstream;

Stephanodiscus hantzschii and *Cyclotella meneghiniana* occurred where the river becomes wider and deeper. The distribution of the diatomological flora in the Matanza-Riachuelo basin was affected by the increasing concentration of organic matter. The assemblage was dominated by pollution-tolerant species, which implied strong to very strong contamination in a great portion of the basin.

Rott *et al.* (1998) evaluated organic pollution and trophic levels in the Grand River, Ontario, Canada, using two diatom indices that showed a clear differentiation among 10 sampling sites over a distance of 214 km. Canonical correspondence analysis showed that the largest portion of the observed variability in species composition can be explained by a seasonal gradient related to temperature and by longitudinal gradients of nitrate-nitrogen, conductivity, and chloride and thus it was concluded that the Grand River showed clear signs of increased eutrophication.

Dixit *et al.* (1999) assessed historical lake water quality changes in 257 lakes in NE USA by selecting diatom assemblages as indicators of lake condition and found that the distribution of diatom species was closely related to several environmental variables, primarily lake water pH, total phosphorus, and chloride. Chloride and phosphorus levels were found to be increased, especially in lakes that currently have high concentrations and in the Coastal Lowlands/Plateau, and also there was a clear increase in eutrophic lakes, as inferred by total phosphorus. This was accompanied by a marked increase in the number of lakes with high chloride levels.

Wu (1999) studied water quality of the Keelung River (Taiwan). A generic index (GI) – the ratio of abundance of *Achnanthes*, *Cocconeis* and *Cymbella*, to that of *Cyclotella*, *Melosira* and *Nitzschia* – was used to measure changes in the diatom assemblages. GI values correlated well the saprobic index, diatom assemblage index, composite river water quality index and species richness of insects. It correlated less well with the trophic diatom index and distribution of fish in the river, suggesting that GI was more indicative of organic pollution than of eutrophication.

Winter and Duthie (2000) determined patterns of diatom [Bacillariophyta] species distribution in relation to total N (TN), total P (TP), and other environmental variables from riffle sites on 2 streams in southern Ontario, Canada, using canonical

correspondence analysis (CCA). They found that relationships with TN and TP were sufficiently strong to develop weighted-averaging (WA) regression-calibration models for inferring stream water concentrations of these nutrients and thus it was concluded that epilithic diatoms can be related to TN and TP using these methods, and that WA inference models have utility for indicating eutrophication in southern Ontario lowland streams.

Belore *et al.* (2002) compared the effectiveness of diatoms and macroinvertebrates as indicators of environmental conditions in lotic systems in a regional assessment. Benthic samples were collected during summer 2000 from 35 Provincial Water Quality Monitoring river stations in the Grand, Credit, Maitland and Upper Thames watersheds in southern Ontario. Patterns of diatom and macroinvertebrate taxon distributions in relation to environmental variables were determined using canonical correspondence analysis (CCA). Total nitrate, phosphate, conductivity and alkalinity were significant in explaining diatom data, while alkalinity, total nitrate, ammonium and total Kjeldahl nitrogen were significant in explaining invertebrate data. Regression and calibration models were developed for total nitrate. Biotic indices were also calculated. It was concluded that the invertebrate and diatom communities were similar in their abilities to predict water quality.

Gurbuz and Kivrak (2002) used epilithic diatom assemblages to evaluate water quality in the Karasu River basin (Turkey), which was polluted by industrial, agricultural and urban wastes. A total of 73 diatom taxa belonging to 22 genera were found from all seven sampling stations located in the River basin. The most pollution tolerant species *Gomphonema parvulum*, *Nitzschia palea*, *Navicula cryptocephala* were found in high densities at the polluted stations.

Juttner *et al.* (2003) assessed stream diatom assemblages in relation to water quality and habitat character in the Kathmandu Valley, and in the Middle Hills of Nepal and northern India. In total, 113 diatom taxa were found in the Kathmandu Valley streams and 106 in the Middle Hills. Most taxa found only in the Kathmandu Valley belonged to the genus *Navicula* while most taxa confined to the Middle Hills were *Achnanthes*, *Fragilaria* and *Gomphonema*.

Kitner and Poulickova (2003) studied the littoral zone of shallow water bodies in the Czech Republic. At the investigated sites, littoral periphytic diatoms were studied together with selected environmental variables (pH, conductivity, nutrients - especially total phosphorus) on three types of natural substrates (epilithon, epiphyton, epipelon). In conclusion littoral periphytic diatoms appeared to be good indicators of the fishpond water quality.

Lobo *et al.* (2004) evaluated the water quality of two urban streams, Condor and Capivara, in the Municipal District of Porto Alegre, RS, Brazil, by measuring physical, chemical and biological variables. Between May 1999 and August 2000, six field trips were taken to sample five sites distributed along the streams. *Mayamaea atomus*, *Amphora montana*, *Sellaphora pupula* and *Cyclotella meneghiniana* were extremely abundant under such conditions.

Potapova *et al.* (2004) compared two approaches for constructing diatom based indices for monitoring river eutrophication. Among several indices that use a single indicator value for each species, the best was the weighted averaging partial least square (WA-PLS) inference model. The best index that employed multiple indicator values for each species had approximately the same predictive power as the WA-PLS based index, but in addition, this index provided a sample-specific measure of uncertainty for the TP estimation.

Goma *et al.* (2005) studied epilithic diatoms of mountain rivers from the upper Segre catchment (Oriental Pyrenees) in 1998, during three different seasons: March, July and September. Four rivers, the river Segre and its three most important tributaries, Duran, Molina and Querol, were sampled in upstream and downstream stretches. The diatom communities were comparable in all upstream stretches of these mountain rivers draining siliceous substrates. Dominant taxa were *Achnanthydium subatomus*, *Diatoma mesodon*, *Encyonema cf. minutum*, *E. silesiacum*, *Fragilaria arcus*, *F. capucina*, *Gomphonema calcifugum*, *G. pumilum*, *Meridion circulare* and *Nitzschia pura*. Changes in water quality in the downstream stretches lead to the appearance of pollution tolerant taxa, such as *Eolimna minima*, *Gomphoneis minuta*, *Navicula gregaria*, and *Nitzschia inconspicua*. The diatom indices, especially the IPS, showed a good performance in these mountain rivers.

Salomoni *et al.* (2006) studied the potential use of epilithic diatoms as indicators of organic pollution in Gravatai River, RS. Epilithic diatoms were sampled eight times from September 2000 to August 2002, at six sites. Species were identified and densities and relative abundances of populations were determined. Simultaneously, physical, chemical and microbiological variables were measured. Species were classified into three groups: Group A, including species more tolerant to heavy organic pollution and eutrophication, represented by *Luticola goeppertiana*, *L. mutica*, *Eolimna subminuscula*, *Nitzschia palea* and *Sellaphora pupula*; Group B, comprised of tolerant and widely distributed species such as *Eunotia bilunaris*, *Frustulia crassinervia*, *F. saxonica*, *Navicula cryptocephala*, *N. cryptotenella*, *Nitzschia palea* var. *tenuirostris*, *Surirella angusta*, *Pinnularia microstauron* and *Ulnaria ulna* and Group C, with less pollution tolerant species represented by *Eunotia* sp. and *Gomphonema parvulum*.

Tang *et al.* (2006) studied the assessment method for ecological condition of Xiangxi River system by using 13 candidate metrics of epilithic diatom which can reflect conditions in pH, salinity, nitrogen uptake metabolism, oxygen requirements, saprobity, trophic state, morphological character and pollution tolerant capability etc. and it was concluded that multimetrics is more competent in assessment task.

Akinyemi *et al.* (2007) studied diatoms as indicator of pollution in Awon reservoir for two years. It was concluded that the presence of any of the predominated organisms in the water is an indication of water pollution.

Duong *et al.* (2007) studied periphytic diatom communities' colonization patterns at three sampling stations of the Red–Nhue–Tolich hydro system presenting different urban pollution levels by using artificial substrates for 6 weeks in dry season 2005 and concluded that the use of diatoms as a tool for water assessment appeared to be suitable for monitoring rivers in Vietnam, as it is in several other countries.

Dziengo *et al.* (2008) carried out studies of benthic diatom communities in the surface sediments of the Swarzewo area of Puck Bay during 1998 and 1999 in order to assess water quality, and in particular the organic load. Among the 192 taxa identified, teratological forms of diatoms were recorded in 17 diatom species. It was postulated that teratological diatom valves are indicative of poor water quality.

Jonge *et al.* (2008) studied the role of macro-invertebrates and diatoms as indicator for metal pollution by assessing both biota along a metal gradient in the Belgian river the Dommel. Macro-invertebrates and diatoms were sampled in summer and winter and physical-chemical characteristics of the water were measured at four different sample periods and related to sediment characteristics. In conclusion, the diatom community best reflected the metal gradient.

Tapia (2008) performed the semi-quantitative analysis of two algal samples from the Mantaro River taken few kilometres downstream from La Oroya city at Junin, Peru. The organic pollution was inferred by elevated percentages of *Nitzschia palea*, *Gomphonema parvulum* and the *Achnantheidium minutissimum* complex. It was concluded that the Mantaro River at this site contained a low water quality based on diatom bio-indicators of organic and heavy metal pollution.

Beyene *et al.* (2009) assessed the relative performance of diatoms and macro-invertebrates to measure municipal and industrial impacts on the ecological integrity of the three major rivers flowing through Addis Ababa. It was obtained that diatoms are the powerful bio-indicators for monitoring urban-impacted and seriously stressed rivers than macro-invertebrates and to examine pollution gradients and impacts of specific pollution sources.

Kalyoncu *et al.* (2009) studied the use of epilithic diatoms as indicators of river water quality in two streams of south Turkey. A total of 110 diatom taxa belonging to 32 genera were found.

Katasuki *et al.* (2009) examined diatom assemblages of the surface and in core sediment samples from Lake Saroma (Japan) for the purpose of evaluating anthropogenic effect on the coastal environmental changes. Environmental change such as increased organic loads deposited on the bottom layer in the form of excreta and the elution of nitrogen and phosphorus from the sediment, which brought about eutrophication of the surface layer, was reflected in a decrease of benthic diatom taxa and an increase of planktonic taxa, trends which have continued until today.

Bennion *et al.* (2010) studied the importance of littoral diatoms in shallow waters which makes them valuable biological indicators. Shallow lakes support a diverse range

of diatom communities. Diatom records had been successfully employed at numerous shallow lakes to assess environmental change with respect to lake development, erosion, alkalisation, acidification, Stalination, climate change, and particularly eutrophication.

Douglas and Smol (2010) reported that diatoms often dominate the benthic algal communities in high arctic environments as well and provide environmental and earth scientists with many potential applications for pale climatic and palea-environmental research and for bio-monitoring. It was concluded that considerable potential also exists for using diatoms to monitor anthropogenic disturbances, especially considering the high logistical costs of more typical monitoring programs.

Hall and Smol (2010) provided some of the many examples of how diatoms are being used as a powerful tool for eutrophication research and management as they respond rapidly to eutrophication and provide detailed information on ecological changes that occur during eutrophication and recovery, in both deep-water and near-shore habitats. Because diatoms are well preserved in most lake sediments, they can be used to generate long time series of data that track lake responses to eutrophication and recovery.

Singh *et al.* (2010) conducted seasonal studies of Mansagar lake, Jaipur and accounted for diatom diversity, density and distribution in different seasons and their correlation with physico-chemical properties of water. The study revealed the presence of 35 diatom species and also that they attain maximum growth in post monsoon and winter months and gradually declined in summer to reach its minimum during monsoon.

Snoeijs and Weckstrom (2010) studied application of diatoms as indicators of environmental change with focus on the earth's three largest brackish-water areas, the Baltic, Black, and Caspian seas. Periphyton assemblages on artificial substrata dominated by diatoms can effectively be used as pollution indicators for toxic compounds by using the selective pressure of a toxicant on sensitive species and using the capacity of diatom frustules to accumulate (radioactive) metals from the surrounding water.

Bere and Tundisi (2011) elucidated the confounding effects of eutrophication, organic pollution, ionic strength and conductivity on benthic diatom communities. Benthic diatoms and water quality sampling was done at 10 sites during summer base

flow period (2008 and 2009). The effects of ionic strength, conductivity and organic pollution, eutrophication and other environmental variables were integrated into overall resultant benthic diatom communities.

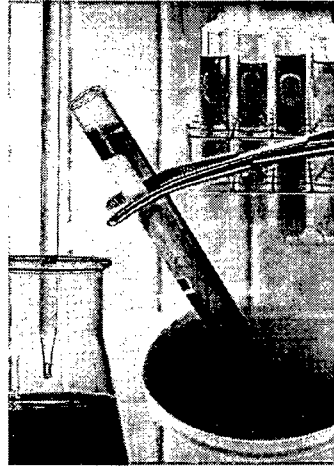
Sharma and Bhardwaj (2011) carried out study in Mahi river basin and found that diatoms are sensitive to environmental conditions in aquatic ecosystems and their distribution is mainly governed by the physicochemical composition of the water and wet sediments which are a function of regional lithology, topography, relief, climate, vegetation, tectonic activity and anthropogenic influences.

Delgado *et al.* (2012) collected water and epilithic diatom samples from 60 sites in temporary streams distributed among the three largest Balearic Islands (Majorca, Minorca and Ibiza). It was concluded that a diatom multimetrics index (DIATMIB) which was developed to assess the ecological status of temporary streams is a valuable tool for the assessment and future monitoring of temporary Mediterranean streams.

Kireta *et al.* (2012) investigated planktonic and periphytic diatom assemblages as potential biological indicators of ecological conditions in the Ohio, Missouri and Upper Mississippi rivers. The findings suggested both planktonic and periphytic diatom assemblages may be used as bio-indicators of river condition and may provide unique stressor response information.

Rishi and Awasthi (2012) conducted a study in Ganga river at Kanpur. Physicochemical characteristics of water samples revealed a varying degree of pollution. Qualitative and quantitative estimates were also made on a monthly basis and as many as 36 algal species were identified which can tolerate high degree of pollution. The dominant group also included diatoms with the genera like *Nitzschia*, *Navicula*, *Synedra*, *Gomphonema* and *Fragilaria* etc.

Timothy and McMinn (2012) applied an innovative multidisciplinary approach to a power station discharge in lake Macquarie, Australia, using benthic diatoms, water quality, satellite imagery and temperature loggers. For benthic diatoms triplicate sediment samples at five sites across a thermal gradient in one plume affected and two control bays were analysed. Study demonstrated that both benthic diatoms and satellite imagery are valuable tools for the monitoring and assessment of thermal pollution in coastal environments.



MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled “Diatoms as Indicators of Water Quality in Khajiyar lake, Himachal Pradesh” was carried out in the Department of Biology and Environmental Sciences, College of Basic Sciences, CSK Himachal Pradesh Krishi Vishva-Vidyalaya Palampur, H.P. The details of materials and methods used during the course of study are discussed under following subheads:

- 3.1 The study lake
- 3.2 Estimation of physico-chemical characteristics
- 3.3 Qualitative and quantitative estimation of diatoms.

3.1 The study lake

The Khajiyar lake of Chamba district, Himachal Pradesh was selected for the present limnological study. This little lake lies in the centre of large Khaz glade and is fed by tiny streams. It is about 26 Kms. from Dalhousie and 22 Kms. from Chamba. The lake is about 2000 m above the sea level in the foothills of the Dhauladhar ranges of Western Himalayas situated at 32° 32' 53" N and 76° 3' 34" E. The maximum area of the lake has turned to the marshy land with maximum average depth of 8 to 10 feet. However, it is of great significance from tourism point of view to attract the tourists besides to add to the beauty of the tourist place. It is surrounded by green meadows and dense forest of about 5 Kms. circumference up to the snow line. During snow fall in winter the entire lake and the surrounding Deodar trees are covered with white snow giving the name of mini Switzerland to the place.

3.2 Estimation of physico-chemical characteristics

For the estimation of physico-chemical characteristics, surface water samples were collected from the Khajiyar lake at three sites for six months over the year in the month of April-May in summer, July-August during rainy season and December-January in winter from July 2011 to May 2012. The samples thus, collected were analyzed for different physico-chemical characteristics like temperature, secchi disc transparency, conductivity, total solids, total dissolved solids and total suspended solids, pH, dissolved



Plate 1: The study lake (Khajiyar lake)

oxygen, free carbon dioxide, total alkalinity, chloride, nitrates, total phosphate-phosphorus, silicate, sodium and potassium following APHA, 2000 (American Public Health Association). Some of the parameters like temperature, pH, secchi disk transparency, dissolved oxygen and free carbon dioxide were analyzed on the spot and remaining in the laboratory with in 48 hours. The methods followed are described as under:

3.2.1 Estimation of physical parameters of the lake

3.2.1.1 Temperature

The temperature variations were recorded in degree Celsius with the help of mercury thermometer of 0 to 50°C range and with 0.2°C least count.

3.2.1.2 Transparency

The secchi disc transparency was recorded with the help of Secchi disc of 20 cm diameter painted with black and white in alternating four quadrants. The values for Secchi disc transparency were calculated by (APHA 2000).

$$\text{Transparency (cm)} = \frac{D_d - D_r}{2}$$

Where, D_d = depth of disappearance

D_r = depth of reappearance

3.2.1.3 Electrical conductivity

Electrical conductivity was recorded with Conductivity Bridge. The conductivity was calculated as under:

$$\text{Conductivity } (\mu\text{mhos/cm}) = \frac{(1000,000) (c)}{R [1+0.0191(t-25)]}$$

Where,

C = cell constant

R = measured resistance of sample

T = temperature

3.2.1.4 Total Solids (TS), Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)

TS, TDS and TSS were estimated by following (APHA 2000).

Total Solids

Total solids were determined as the residue left after evaporation of the unfiltered sample.

$$\text{Total Solids mg/l} = \frac{A-B \times 1000 \times 1000}{V}$$

Where, A = Final weight of the dish in g

B = Initial weight of the dish in g

V = Volume of sample taken in ml

Total Dissolved Solids

Total dissolved solids were determined as the residue left after evaporation of the filtered sample.

$$\text{TDS, mg/l} = \frac{A-B \times 1000 \times 1000}{V}$$

Where, A = Final weight of the dish in g

B = Initial weight of the dish in g

Total Suspended Solids

Total suspended solids were determined as the difference between the total solids and total dissolved solids.

$$\text{TSS} = \text{TS} - \text{TDS}$$

3.2.2 Estimation of chemical parameters of lake

3.2.2.1 pH

It was estimated using portable pH meter. For estimation of pH it was calibrated with standard solution having pH 7.

3.2.2.2 Dissolved oxygen (D.O.)

It was estimated by Winkler's modified method (APHA 2000). The values were calculated as follows:

$$\text{Dissolved Oxygen (mg/L)} = \frac{(8 \times N \times 1000) \times v}{V}$$

Where,

N = Normality of sodium thiosulphate solution *i.e.* 0.025

V = Volume of sample titrated

v = Volume of titrant used

3.2.2.3 Free Carbon dioxide

It was estimated following (APHA 2000) by using phenolphthalein as an indicator. The values were calculated as follows:

$$\text{Carbon dioxide (mg/L)} = \frac{A \times N \times 44,000}{\text{ml of sample taken}}$$

Where,

A = ml of titrant and

N = Normality of NaOH

3.2.2.4 Total alkalinity

The carbonate and bicarbonate alkalinity was estimated following (APHA 2000) by using phenolphthalein and methyl orange as an indicator respectively. The Values for both were calculated as under

$$\text{Alkalinity (mg/L)} = A \times 100$$

Where, A = ml of H₂SO₄ used

3.2.2.5 Chloride

It was estimated by argentometric method of (APHA 2000) by using potassium chromate as an indicator. The values were calculated as follows:

$$\text{Chloride (mg/L)} = \frac{(A-B) \times N \times 35,450}{\text{ml of sample taken}}$$

Where,

- A = ml of titration for sample
 B = ml of titration for blank
 N = Normality of Silver nitrate (AgNO₃)

3.2.2.6 Nitrate – Nitrogen

Nitrate – nitrogen was estimated by Spectrophotometric method of (APHA 2000). The amount was calculated from calibration curve prepared for it.

3.2.2.7 Total Phosphate - Phosphorus

The stannous chloride method of (APHA 2000) was used to estimate total phosphate- Phosphorus. The values were calculated from the calibration curve prepared for it.

3.2.2.8 Sodium

Sodium was estimated by Flame Photometer method of (APHA 2000) by using Syntronics - 128 Flame Photometer.

3.2.2.9 Potassium

Potassium was estimated by Flame Photometer method of (APHA 2000) by using Syntronics - 128 Flame Photometer.

3.2.2.10 Silicates

The molybdo silicate method of (APHA 2000) was used to estimate silicates. The values were calculated from the calibration curve prepared for it.

3.3 Qualitative and Quantitative enumeration of diatoms

For qualitative analysis, diatoms were collected by filtering 5 litre of water through bolting silk net having 75 meshes per cm. The sample was preserved in 4% formalin and was observed for diatom species composition under plankton invertoscope. For quantitative analysis 50 ml of water sample was fixed with Lugol's solution and drop

of glycerine was added. The fixed sample was allowed to settle overnight and decanted gently to reduce the volume to 10 ml and after uniform stirring 1 ml of the final volume was enumerated for diatoms per litre following APHA 2000 as under:

$$\text{Diatoms (no. / litre)} = \frac{C \times A_t \times 1000}{A_f \times F \times V}$$

Where,

C = no. of organisms counted

A_t = total area of bottom of counting chamber (mm²)

A_f = area of the fields counted

V = volume of the sample settled

F = no. of fields counted



RESULTS
AND
DISCUSSION

4. RESULTS AND DISCUSSION

The results of present investigation entitled “**Diatoms as Indicators of Water Quality in Khajiyar Lake, Himachal Pradesh**” have been presented and discussed in this chapter under ensuing headings :--

Physico-chemical characteristics

The seasonal variation in qualitative and quantitative presence and abundance of phytoplankton in general and diatoms in particular differ from environment to environment depending upon the physico-chemical regime of aquatic ecosystem. Physico-chemical characteristics not only reflect the quality of an aquatic ecosystem but also its biological diversity.

4.1 Physical parameters

4.1.1 Air temperature

Temperature is an important factor which regulates the biogeochemical activities in the aquatic environment. No other single factor has so many profound influences on the aquatic environments as temperature, Welch (1952). Air temperature controls the water temperature. The maxima and minima of air temperature were 24.5°C (July) and 0.7°C (January) (Fig. 4.1.1) (Appendix I). Air and water temperature revealed highly significant and positive correlation with each other ($r = 0.989$, $p < 0.01$) (Table 4.1). The highly positive and significant relationship of atmospheric temperature with water temperature showed that it regulates water temperature in an aquatic environment. Whereas a very less difference between the two during winter season in the month of December and January may be attributed to the increased humidity which decreases the heat loss through evaporation.

4.1.2 Water temperature

The water temperature value is an important index of limnology, which controls the physiological behaviour and distribution of organisms. It contributes to the solubility of H₂, N₂, CO₂ and O₂ which play vital roles in aquatic ecosystems Gillooly *et al.* (2002). Maximum water temperature 22.5°C was recorded.

Table 4.1 Correlation coefficient among physico-chemical parameters and Diatom no./L of the Lake

	A.Temp.	W.Temp	Trans.	pH	EC	TS	TDS	TSS	DO	free CO ₂	TA	Cl ⁻	NO ₃	PO ₄	SiO ₄ ⁻	Na	K	No./L	
A.Temp.	1																		
W.Temp	0.989**	1																	
Trans.	-0.995	-0.971	1																
pH	-0.881	-0.884	0.882**	1															
EC	0.677*	0.765**	-0.615	-0.742	1														
TS	0.734**	0.804**	-0.674	-0.708	0.964**	1													
TDS	0.727**	0.799**	-0.667	-0.707	0.966**	0.999**	1												
TSS	0.767**	0.832**	-0.71	-0.714	0.951**	0.997**	0.996**	1											
DO	-0.993	-0.974	0.996	0.896**	-0.636	-0.675	-0.668	-0.71	1										
free CO ₂	0.980**	0.943**	-0.989	-0.822	0.551	0.635*	0.627*	0.678*	-0.981	1									
TA	0.875**	0.879**	-0.85	-0.702	0.741**	0.832**	0.825**	0.866**	-0.85	0.877**	1								
Cl ⁻	0.722**	0.809**	-0.663	-0.783	0.984**	0.927**	0.928**	0.916**	-0.69	0.587*	0.716**	1							
NO ₃	0.995**	0.994**	-0.984	-0.907	0.742**	0.703*	0.777**	0.811**	-0.987	0.962**	0.889**	0.781**	1						
PO ₄	0.948**	0.976**	-0.923	-0.928	0.861**	0.860**	0.856**	0.875**	-0.937	0.879**	0.866**	0.896**	0.974**	1					
Silicates	0.162	0.296	-0.192	-0.305	0.822**	0.740**	0.748**	0.697*	-0.101	-0.008	0.294	0.784**	0.246	0.436	1				
Na	-0.009	0.129	0.092	-0.166	0.710**	0.578*	0.586*	0.531	-0.048	-0.174	0.154	0.681*	0.081	0.293	0.959**	1			
K	0.543	0.608*	-0.499	-0.651	0.841**	0.736**	0.737**	0.731**	-0.556	0.465	0.68	0.834**	0.617*	0.745**	0.635*	0.655*	1		
No./L	0.272	0.394	-0.306	-0.471	0.869**	0.727**	0.727**	0.668*	-0.246	0.107	0.36	0.857**	0.362	0.56	0.942**	0.946**	0.816**	1	

EC: Electrical conductivity; DO: Dissolved oxygen; oxygen; Cl: Chloride; NO₃: Nitrate; PO₄: Phosphate;
TDS: Total dissolved solids; TSS: Total suspended solids; TS: Total solids; TA: Total alkalinity; TH: total hardness
Significance, **: 1%=0.708 *: 5%=0.576

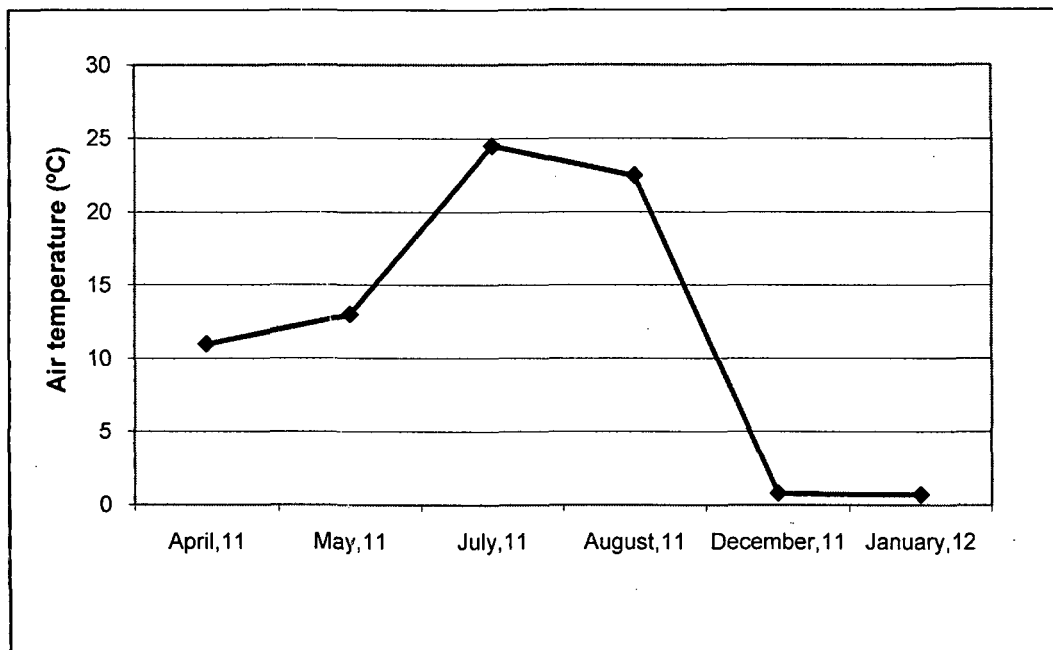


Fig. 4.1.1 Monthly variations during different Seasons in air temperature of Khajiyar Lake from April 2011 to January 2012

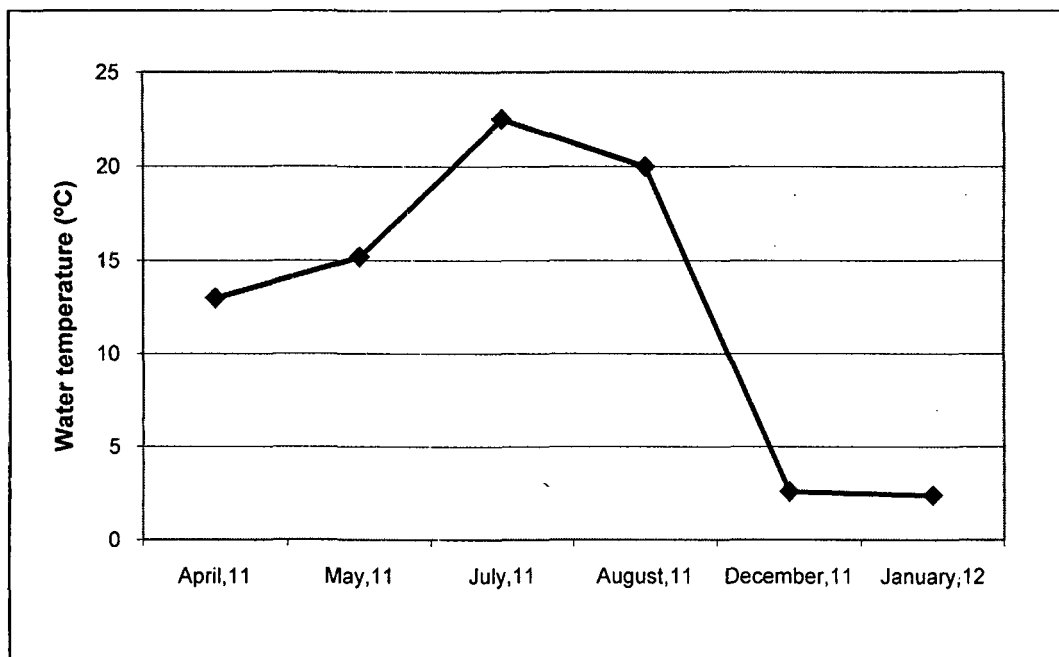


Fig. 4.1.2 Monthly variations during different Seasons in water temperature of Khajiyar Lake from April 2011 to January 2012

in the month of July whereas the minimum 2.4°C was obtained in the month of January (Fig. 4.1.2) (Appendix I). As depicted earlier it showed highly positive and significant correlation with air temperature ($r = 0.989$, $p < 0.01$) (Table 4.1.). Water temperature also showed highly significant and negative relationship with secchi transparency ($r = -0.971$, $p < 0.01$). This significant relationship of water temperature with secchi transparency may be ascribed to the planktonic population and total suspended particles, as at higher temperature there is more formation of plankton which reduces light intensity. Similar findings have been reported by Chauhan (1995) while working on the fresh water ecosystem of Rewalsar lake, Himachal Pradesh. Temperature directly and indirectly affects the vertical distribution of plankton as phytoplankton move vertically to protect themselves from intensity of heat and light at the surface layer. The variation in water temperature may be due to different timing of collection and the influence of season Jayaraman *et al.* (2003).

4.1.3 Transparency

Transparency indicates the quality of water. It is a scale of turbidity. Transparency varied significantly during different seasons. It was minimum during rainy season and maximum during winter season (Fig. 4.1.3). It was found in the range of 10cm (July) to 40cm (January) (Appendix I). Transparency showed highly significant and negative relationship ($r = -0.972$, $p < 0.01$) with water temperature and also with air temperature ($r = -0.995$, $p < 0.01$) (Table 4.1). In the present study the low transparency or high turbidity in monsoon may be ascribed to the accumulation of sand, silt, mud and other solid and semi solid particles from the catchment area primarily due to natural causes and anthropogenic activities. Whereas high transparency during winter season may be attributed to low planktonic population at low water temperature. The similar observations were recorded by Nautiyal *et al.* (1998) and Shaikh and Mandre (2009).

4.1.4 Electrical conductivity

Electrical conductivity is a measure of water capability to transmit electric current Prakash and Somesekar (2006) and it was found in the range of 120.0 μ mhos/cm to 230.0 μ mhos/cm (Appendix I). Rawson (1960) categorized eutrophic water having electrical conductance above 0.20mS. The maximum was recorded in the month of May

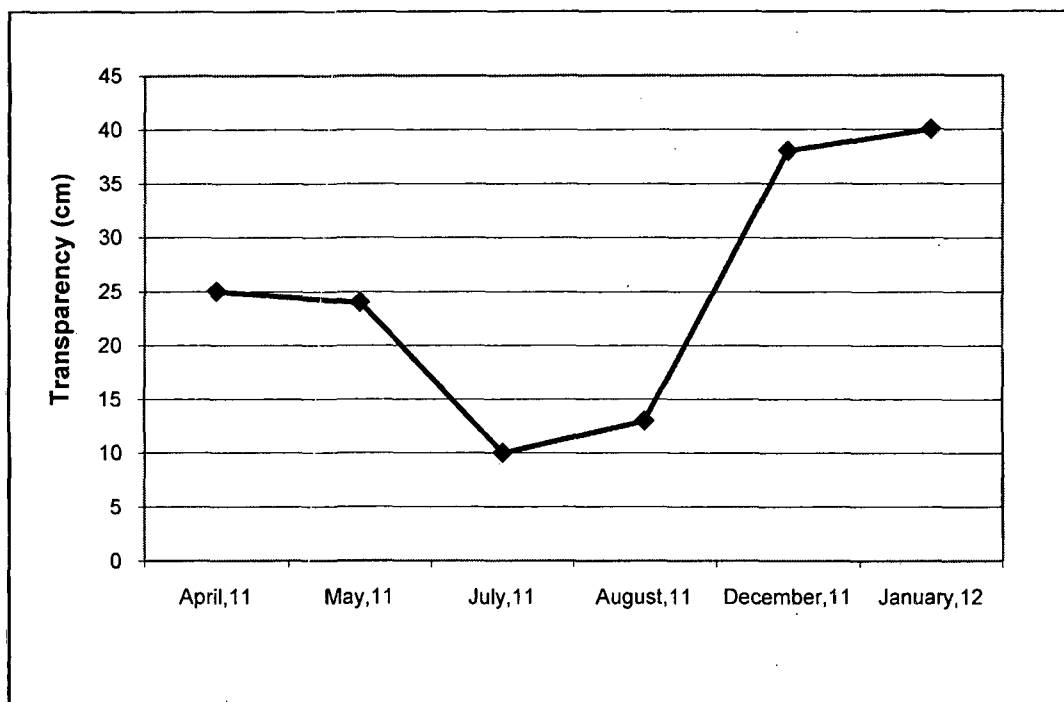


Fig. 4.1.3 Monthly variations during different Seasons in transparency of Khajiyar Lake from April 2011 to January 2012

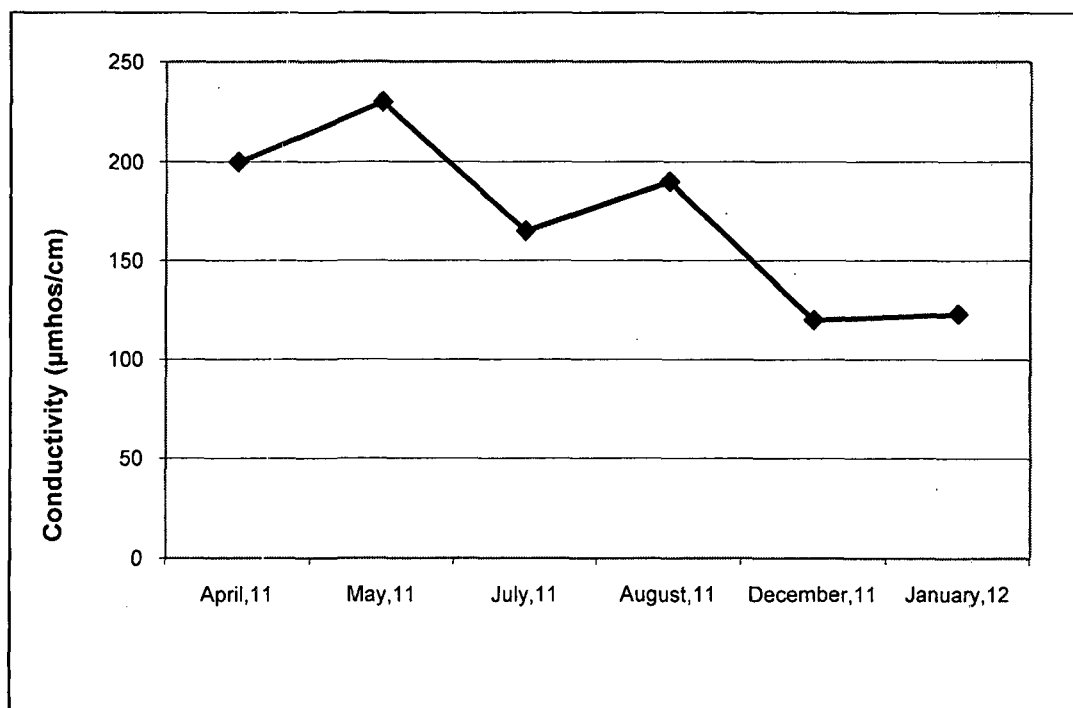


Fig. 4.1.4 Monthly variations during different Seasons in electrical conductivity of Khajiyar Lake from April 2011 to January 2012

whereas the minimum was recorded in the month of December (Fig. 4.1.4). Conductivity showed highly significant and positive relationship ($r = 0.966$, $p < 0.01$) with total dissolved solids. There was also a highly significant and positive relationship ($r = 0.984$, $p < 0.01$) with chloride and significant and positive relationship ($r = 0.869$, $p < 0.01$) with number of diatoms per litre (Table 4.1). There was a fluctuating trend in electrical conductivity due to fluctuation of dissolved solids and salinity. Higher values during the summer season can be attributed to the liberation of ions from the decomposed organic matter and also due to more leaching of ions from the catchment soils or bottom sediments. Whereas minimum values in December during winter season may be due to the adsorption of ions into the surfaces of suspended particles. High and low conductivity values due to these factors were also reported by Hall et al. (1970).

4.1.5 Total solids (TS)

Total solids are the combined weight of both total dissolved solids and suspended solids. All natural waters contain dissolved and suspended organic and inorganic substances. The low levels of total solids indicate the good quality of water. In the present study the total solids varied from 198.81 mg/L to 389.0mg/L (Appendix I). The maximum concentration of total solids was obtained in the month of May and the minimum in the month of December (Fig.4.1.5). Total solids showed highly significant and positive relationship ($r = 0.997$, $p < 0.01$) with total suspended solids. Also it showed highly significant and positive relationship ($r = 0.999$, $p < 0.01$) with total dissolved solids (Table 4.1). Such type of relationship indicated that total suspended solids are regulated by the total solids in an aquatic environment. The higher value of total solids during monsoon may be attributed to an increased load of soluble salts from the catchment area due to the surface runoff. Marker (1977) also recorded similar observations.

4.1.6 Total dissolved solids (TDS)

Total dissolved solids (TDS) of the water are probably the most used criterion of its quality. The values of total dissolved solids ranged from 168.81mg/L to 330mg/L (Appendix I) where maxima was found in May and minima in December (Fig. 4.1.6). It showed highly significant and positive relationship ($r = 0.966$, $p < 0.01$) with

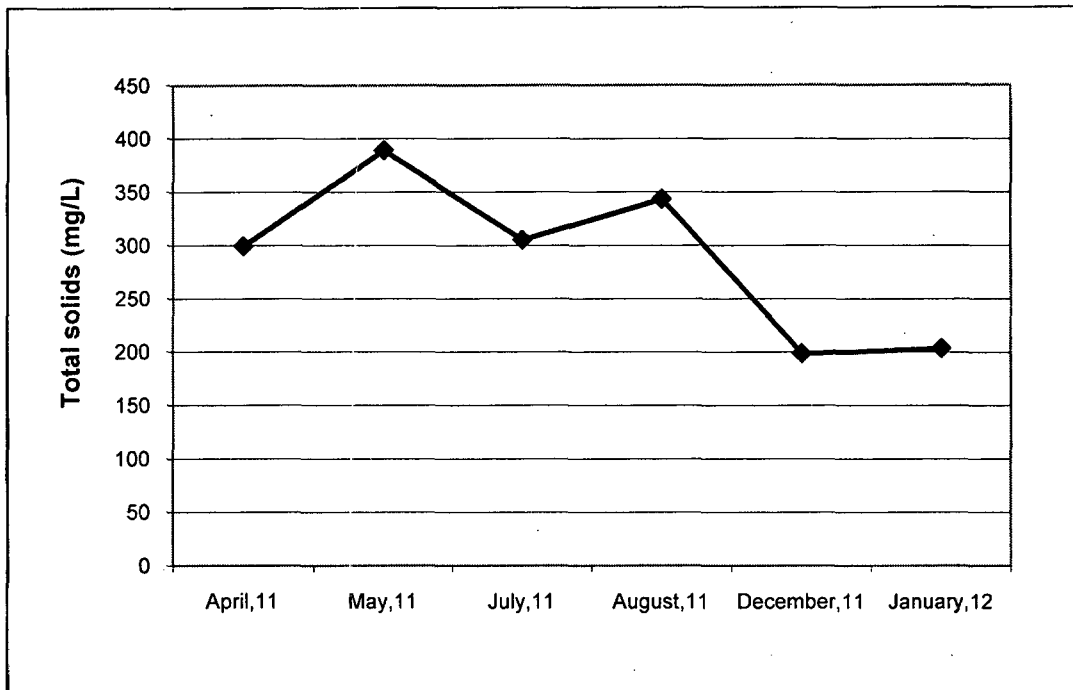


Fig. 4.1.5 Monthly variations during different Seasons in Total solids of Khajiyar Lake from April 2011 to January 2012

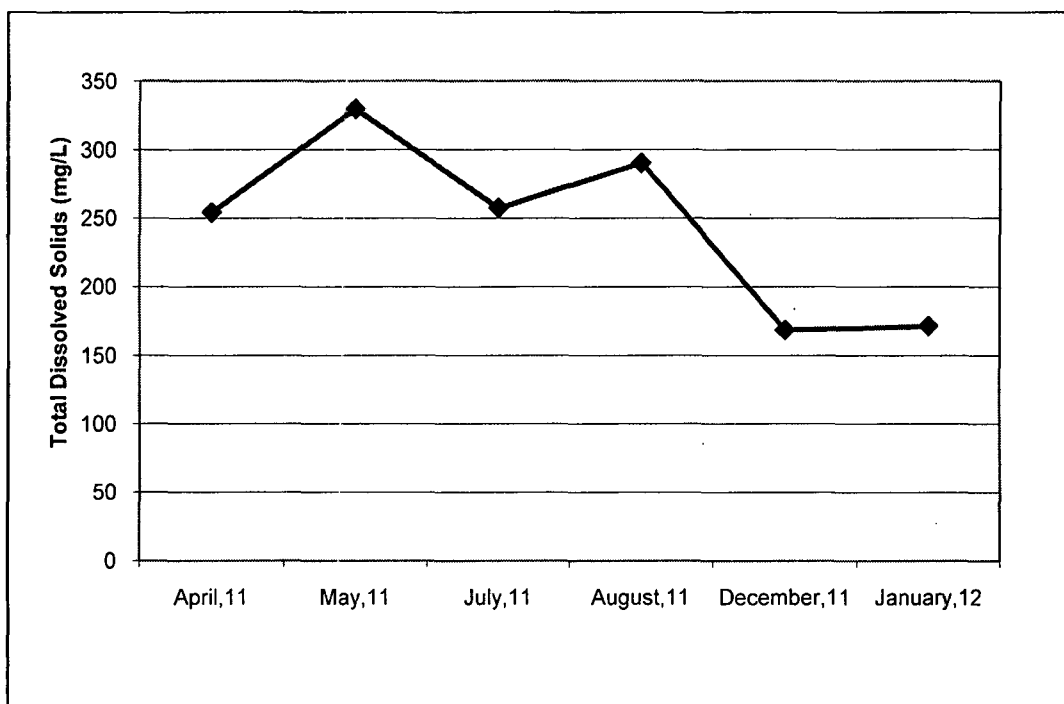


Fig. 4.1.6 Monthly variations during different Seasons in Total dissolved solids of Khajiyar Lake from April 2011 to January 2012

conductivity (Table 4.1). The concentration of TDS is proportional to the electrical conductivity of the water. It also showed highly significant and positive correlation ($r = 0.929$, $p < 0.01$), ($r = 0.825$, $p < 0.01$) and ($r = 0.754$, $p < 0.01$) with chloride, total alkalinity and number of diatoms per litre respectively (Table 4.1). Such an association of total dissolved solids and its higher values indicated deterioration in the water quality of lake ecosystem.

4.1.7 Total suspended solids (TSS)

The suspended matter in water consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton and other microscopic organisms. The values of total suspended solids varied from 30.0 mg/L to 59.0 mg/L (Appendix I). The maximum concentration was recorded in the month of May and minimum in December (Fig. 4.1.7). TSS showed significant and positive relationship ($r = -0.710$, $p < 0.01$) with transparency (Table 4.1). The effect of presence of total suspended solids is the turbidity due to silt and organic matter. Light scattering results from the suspended matter, Dallas and Day (2004). It also showed highly significant and positive correlation ($r = 0.916$, $p < 0.01$) and ($r = 0.866$, $p < 0.01$) with chloride and total alkalinity. TSS was found to prevent the penetration of sunlight into the water column causing a negative effect on the primary production of phytoplankton.

4.2 Chemical parameters

4.2.1 pH

pH is one of the important factors that serves as an index of the pollution. The pH value is a measure of the balance of positive hydrogen ions and negative hydroxide ions in water and thus assesses its acidic or basic nature, Dallas and Day (2004). The pH values did not show significant variations throughout the study period (Fig. 4.2.1). It varied from 6.0 (August) to 6.4 (January) thereby reflecting acidic conditions of the lake (Appendix I). It showed a significant and negative relationship ($r = -0.783$, $p < 0.01$) with chloride. It also showed highly significant and positive relationship ($r = 0.896$, $p < 0.01$) with dissolved oxygen (Table 4.1). Similar observations were also reported by Shiddamallayya and Pratima (2008).

4.1.2 Dissolved oxygen (D.O.)

Dissolved oxygen is essential to all forms of aquatic life. Oxygen is not readily soluble in water, and its solubility relies on temperature, salinity and atmospheric pressure. The dissolved oxygen was higher in winter whereas lower values were observed in monsoon and summer. The minimum dissolved oxygen was found in the month of July, whereas, maximum was recorded in the month of December (Fig. 4.2.2). The dissolved oxygen ranged from 4.6 mg/L to 7.9 mg/L (Appendix I). It showed oxygen highly significant and positive correlation ($r = 0.996$, $p < 0.01$) with transparency and highly significant and negative relationship with air temperature ($r = -0.993$, $p < 0.01$) and significant relationship with pH (Table 4.1). Lower dissolved oxygen in the lake coincided with higher free carbon dioxide. The low value of dissolved oxygen during monsoon month was found due to heavy influx of surrounding areas resulting high turbidity which retarded the photosynthetic activities of the algae which ultimately decreased dissolved oxygen concentration in the lake. The similar findings regarding dissolved oxygen concentration has been reported by (Khan and Siddique 1978). The low rate of diffusion and higher biochemical oxygen demand at increased temperature may also be ascribed to the low dissolved oxygen concentration during summer and rainy season. Welch (1952), Verghee *et al.* (1992), Chauhan (1995) and Hassan *et al.* (2008) also found these factors responsible for the depletion of oxygen. The highly significant and negative relationship of dissolved oxygen with temperature further supports this. Similarly, the highly significant and positive relationship of dissolved oxygen with secchi transparency also support the reasoning that the maximum concentration of dissolved oxygen during winter season may be attributed to the high secchi transparency and low chemical oxygen demand at low temperature. The lower values of dissolved oxygen during post winter months can also be attributed to the fact that the rise in temperature leads to the warming of water and ultimately helps in the increase of mineralization of non living matter which demands oxygen. The similar observations have been recorded by Kumar *et al.* (2005) while working on the fresh water ecosystems.

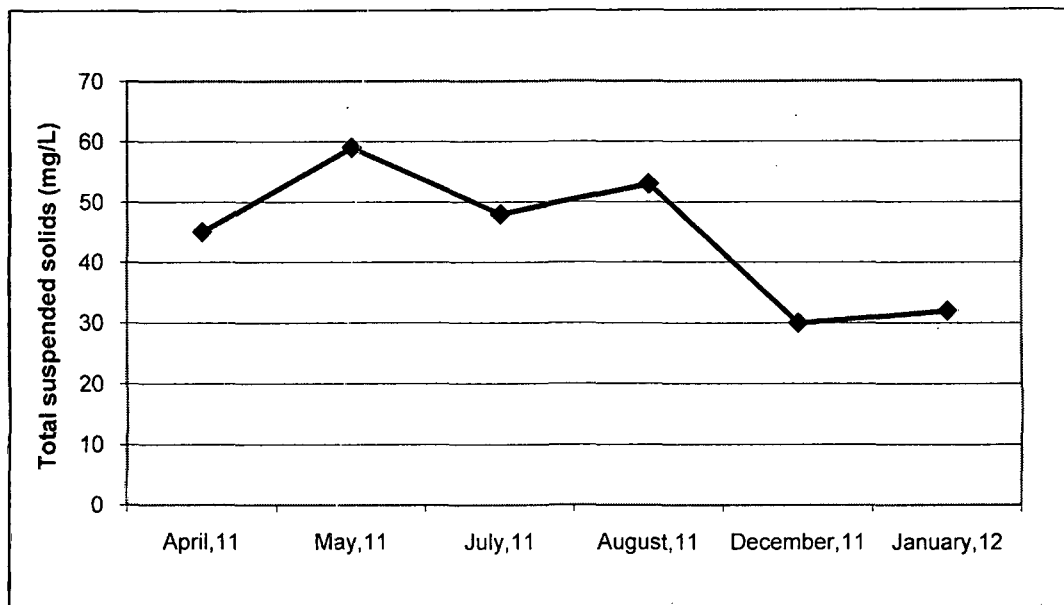


Fig. 4.1.7 Monthly variations during different Seasons in Total suspended solids of Khajiyar Lake from April 2011 to January 2012

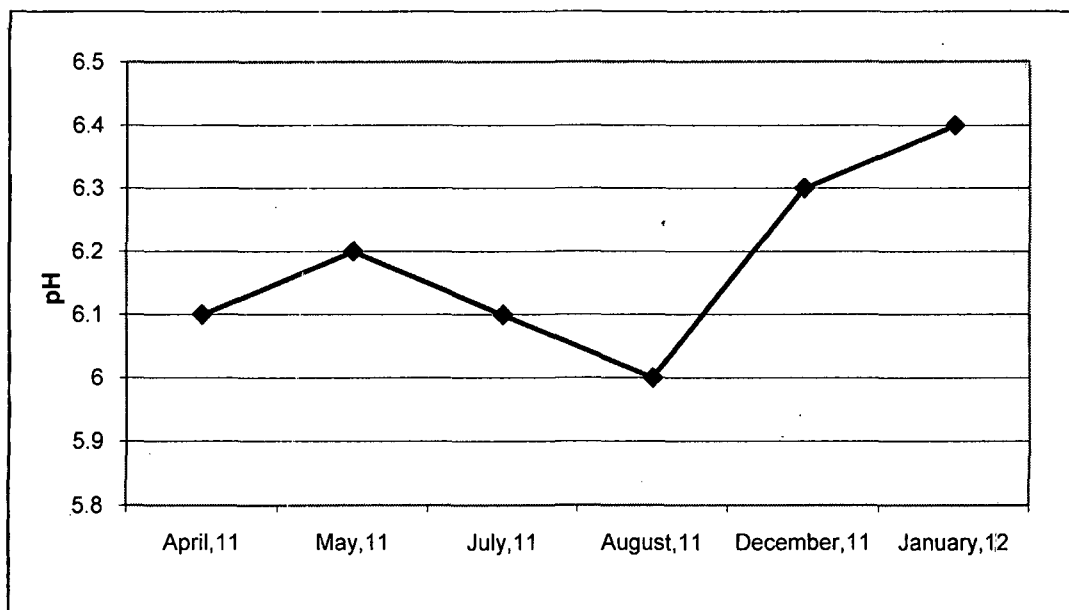


Fig. 4.2.1 Monthly variations during different Seasons in pH of Khajiyar Lake from April 2011 to January 2012

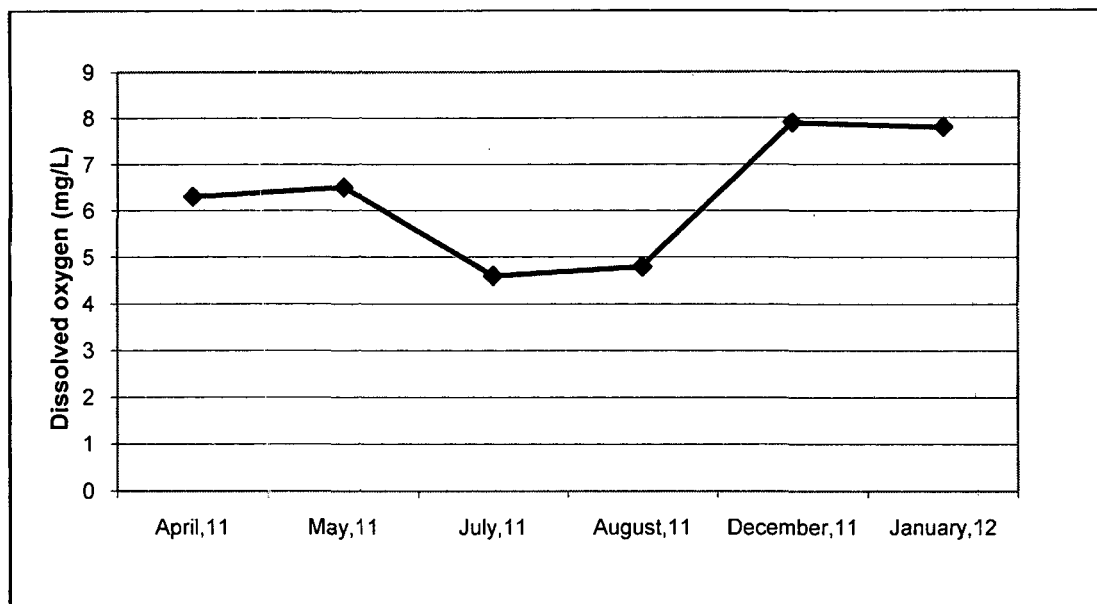


Fig. 4.2.2 Monthly variations during different Seasons in Dissolved oxygen of Khajiyar Lake from April 2011 to January 2012

4.2.3 Free carbon dioxide

Free carbon dioxide was present throughout the study period. It varied from 11.0mg/L to 26.8mg/L (Appendix I). Maximum value was recorded in the month of August and minimum in the month of December (Fig. 4.2.3). Similar results were obtained by Rao and Govind (1964). The highly significant and negative relationship ($r = -0.981$, $p < 0.01$) with dissolved oxygen (Table 4.1) indicated that it is inversely proportional to the dissolved oxygen. High concentration of free carbon dioxide during rainy season in the month of August may be due to the rise in temperature and humidity, which enhance the microbial activities and increases biochemical oxygen demand. The similar factors were also found responsible for the higher concentration of free carbon dioxide by Khan and Khan (1985) and Narayani (1990).

4.2.4 Total alkalinity

Total alkalinity is a measure of carbonate and bicarbonate concentration that shift the pH to alkaline side from neutrality. It is very useful factor for predicting the productivity of an aquatic ecosystem. The value of alkalinity slightly varied with season (Fig. 4.2.4). The phenolphthalein alkalinity was found absent throughout the study

period. The maximum concentration of alkalinity was observed in August and minimum was found during winter season. Its values varied from 95.0 mg/L to 132.0 mg/L (Appendix I). Alkalinity values >100mg/L suggested that a lake is is nutritionally rich. The same results have been reported by Phillipose (1960). The higher concentration of total alkalinity in August during rainy season may be ascribed to the higher bicarbonate ions and low dissolved oxygen concentration. It showed a highly significant and positive relationship ($r = 0.877$, $p < 0.01$) with free carbon dioxide (Table 4.1). High total alkalinity values of the lake indicated its high trophic status. Ganpati (1940) attributed the increase in bicarbonate to lowering of oxygen content which matches with the observation of the present study.

4.2.5 Chloride

The higher concentration of chloride in an aquatic environment is an index of water pollution. Chloride increases with the increasing degree of eutrophication. The chloride ion had no definite pattern of variations throughout the course of present investigation. Its values ranged from 20.2mg/L to 33.1mg/L (Appendix I). It was recorded more than 18.0mg/L throughout the study period. Thus, it can be said that the lake ecosystem is at an advanced stage of eutrophication. This can be strengthened by the findings of Hickel (1973) and Rao (1971). The maximum concentration of chloride was recorded in the month of May and the minimum was recorded during the month of January (Fig. 4.2.5) Such variations could be due to decomposition of benthic deposits resulting in recycling of nutrients due to bottom water interactions, increased concentration of organic matter presumably of animal matter and increased utilization of chlorides by aquatic vegetation. Similar factors have been found responsible for the fluctuating chloride concentration by Zuber (2007) in Lake Mansar. Chloride showed highly significant and positive relationship with ($r = 0.984$, $p < 0.01$) electrical conductivity (Table 4.1). It also showed highly significant and positive relationship with nitrate-nitrogen and total phosphate phosphorous. The higher content of chloride may be attributed to the activities animal and human origin.

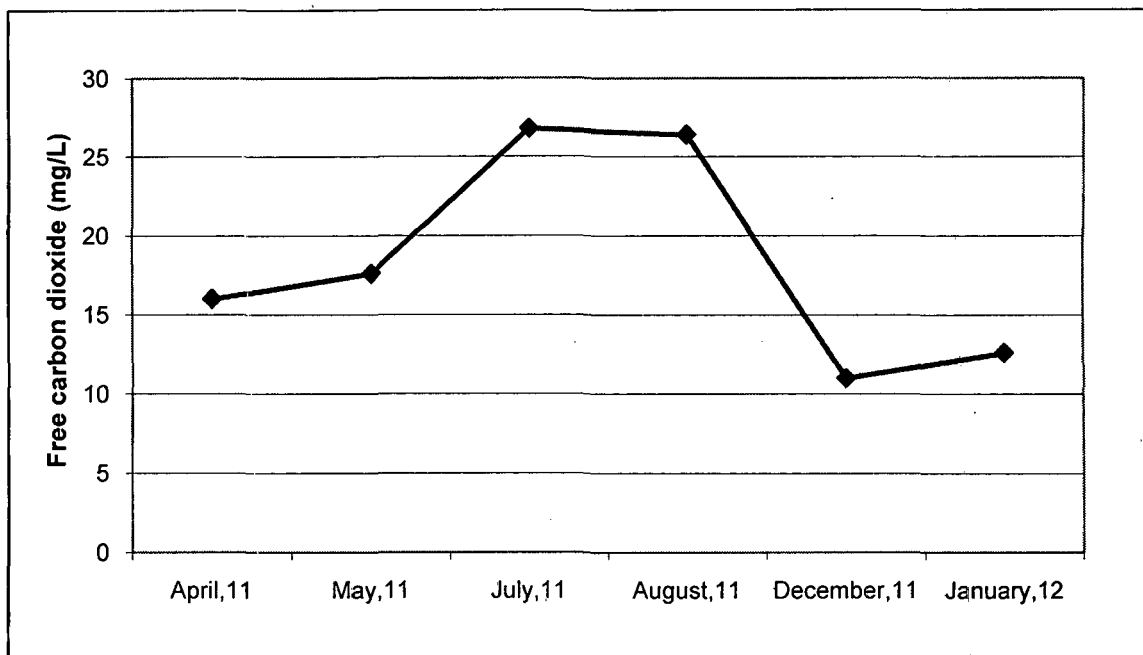


Fig. 4.2.2 Monthly variations during different Seasons in free carbon dioxide of Khajiyar Lake from April 2011 to January 2012

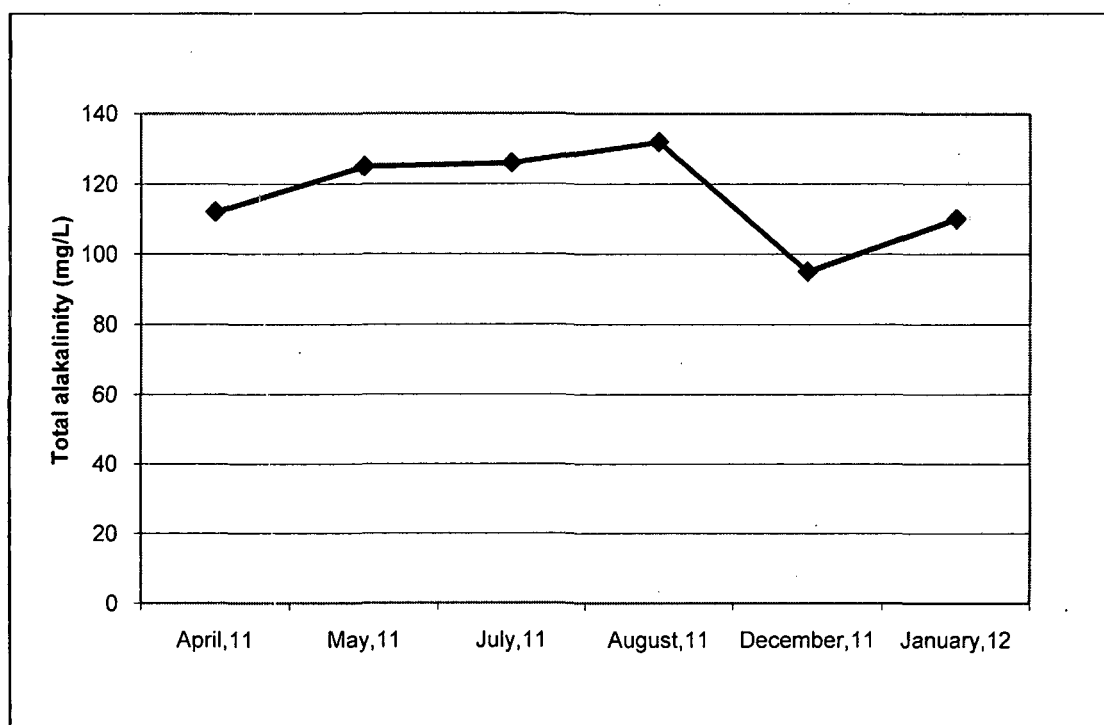


Fig. 4.2.4 Monthly variations during different Seasons in total alkalinity of Khajiyar Lake from April 2011 to January 2012

4.2.6 Nitrate –Nitrogen

Nitrate generally occurs in trace quantities which is essential for many photosynthetic autotrophs and in some has also been identified as growth limiting nutrient (Prakash 1994). The concentration of nitrate nitrogen during the present study varied between 0.098mg/L to 0.485mg/L (Appendix I). This wide variability in the nitrate concentration may be ascribed to the leachate from leaf fall, influx of nitrates along with rain/ snow water, variation in decomposition rate at diverse temperature regimes and contamination of wetland water with sewage washed away by surface run off. The similar factors were found responsible by Wetzel (2001) and Zuber (2007) for the wide fluctuation of nitrate- nitrogen. It was recorded minimum during winter season in the month of December and maximum in the month of July during rainy season (Fig. 4.2.6). It showed highly significant and positive correlation ($r = 0.995$, $p < 0.01$), ($r = 0.995$, $p < 0.01$) with air temperature and water temperature. It also showed negative correlation ($r = -0.984$, $p < 0.01$), ($r = -0.907$, $p < 0.01$) and ($r = -0.987$, $p < 0.01$) with transparency, pH and dissolved oxygen (Table 4.1).

4.2.7 Total phosphate phosphorous

Total phosphate-phosphorus is represented by organic and inorganic dissolved phosphorous and phosphate which is attached to particulate matter. It is generally the limiting nutrient for algal growth. The minimum concentration of total phosphate – phosphorus was recorded during winter season in the month of January (Fig. 4.2.7). Whereas its maximum values were obtained in the month of August during rainy season. Its values varied from 0.61 mg/L to 2.32 mg/L (Appendix I). Maximum phosphate concentration is observed in water which interferes with chemical coagulation of turbid water. It showed highly significant and positive correlation ($r = 0.974$, $p < 0.01$) with nitrate nitrogen. Its values were found increased during monsoon which can attributed to the heavy influx of inorganic phosphate from surrounding areas due to heavy rains and growth of filamentous algae. Parvateasam *et al.* (1991) also reported the higher values of phosphate during monsoon due to the same factors. The high concentration of phosphate phosphorus is always indicative of eutrophy. It also showed significant and positive relationship with conductivity, alkalinity and chlorides and highly significant and negative relationship ($r = -0.923$, $p < 0.01$) with transparency (Table 4.1). In the present

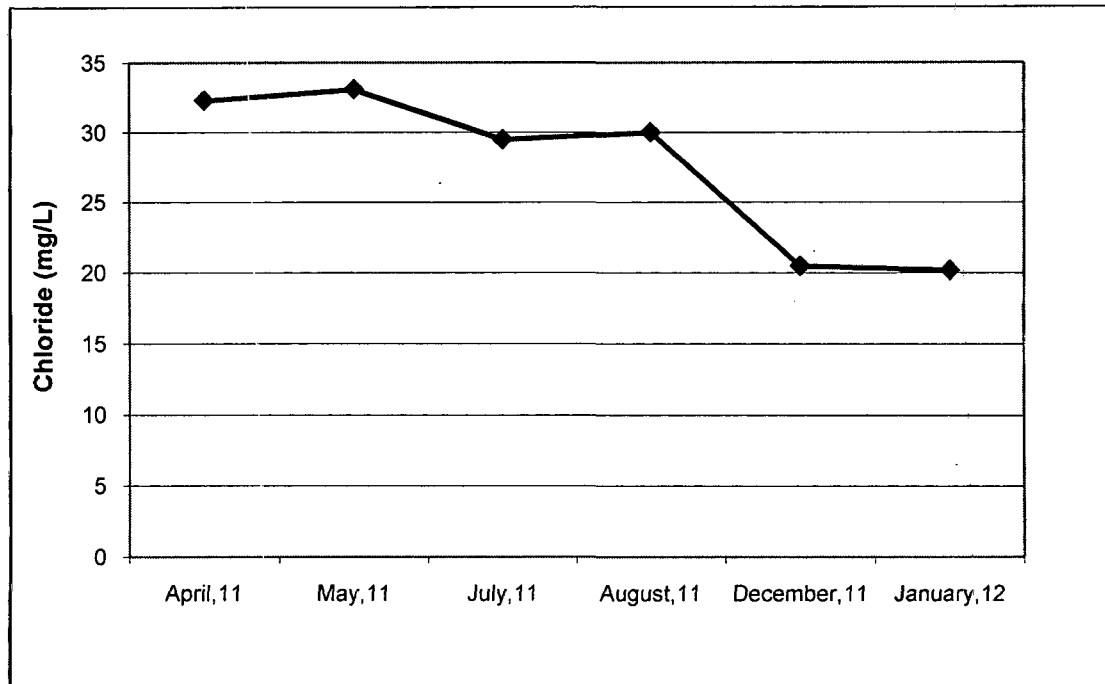


Fig. 4.2.5 Monthly variations during different Seasons in Chloride of Khajiyar Lake from April 2011 to January 2012

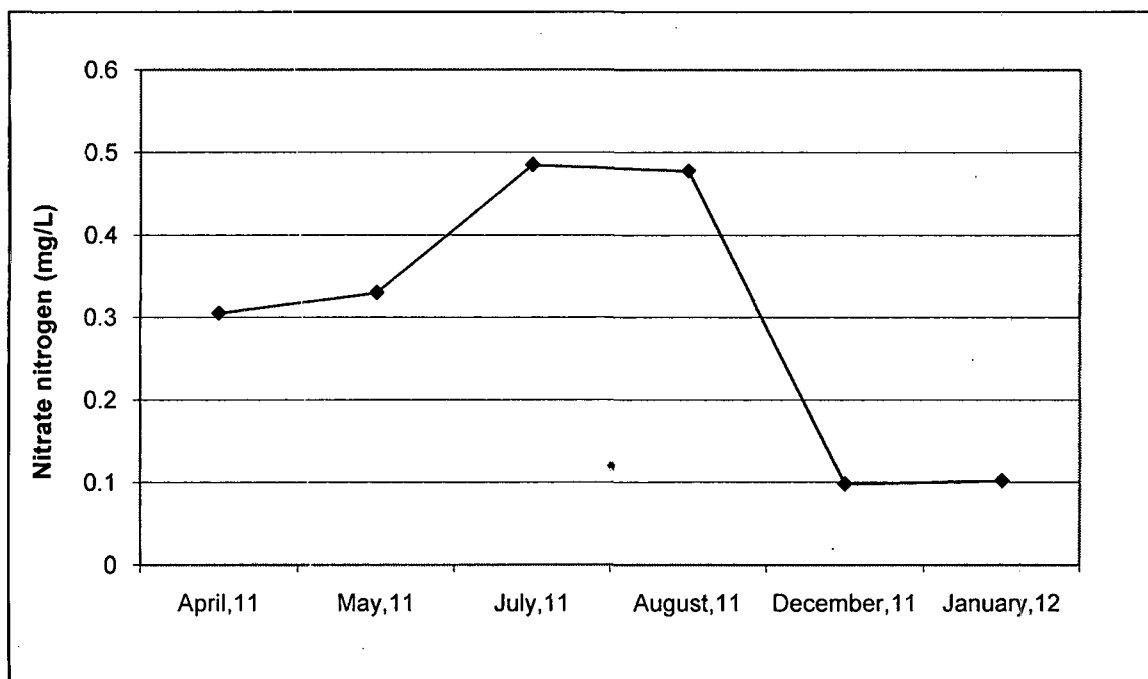


Fig. 4.2.6 Monthly variations during different Seasons in nitrate-nitrogen of Khajiyar Lake from April 2011 to January 2012

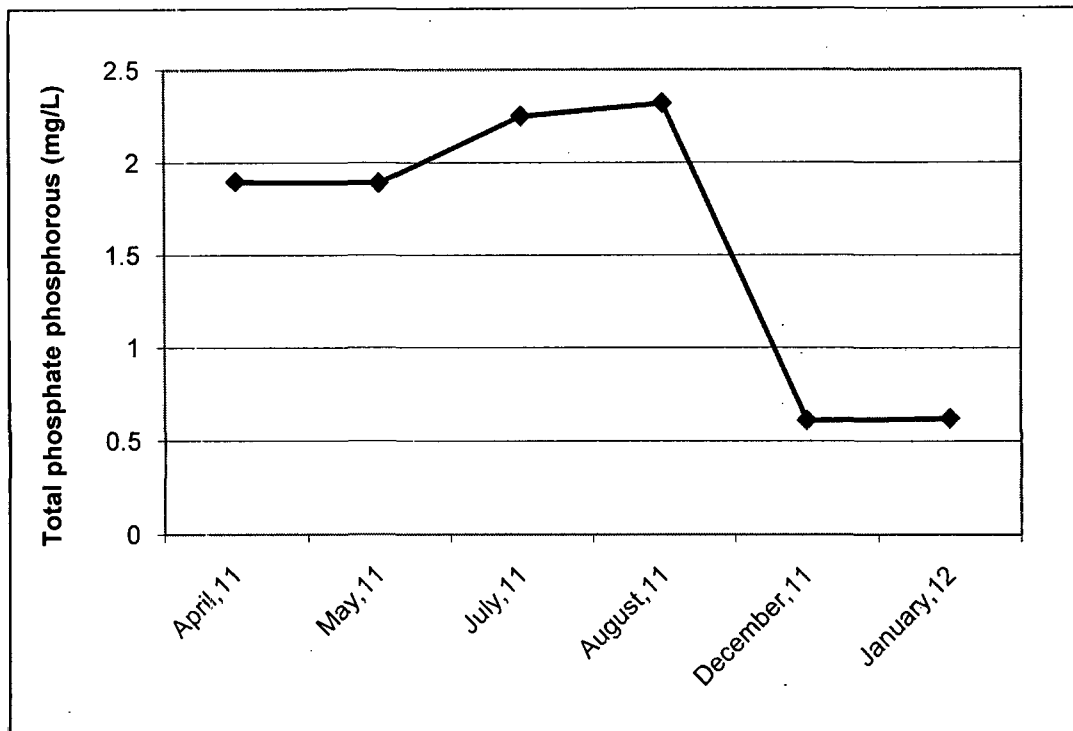


Fig. 4.2.7 Monthly variations during different Seasons in Total phosphate phosphorous of Khajiyar Lake from April 2011 to January 2012

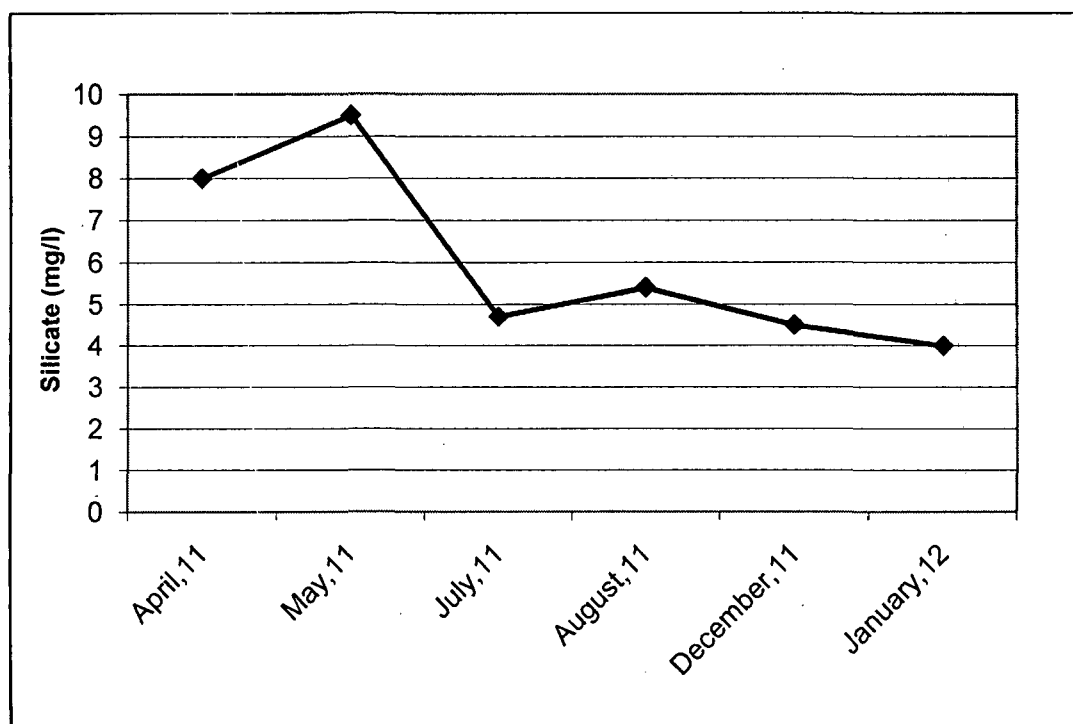
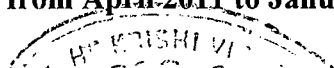


Fig. 4.2.8 Monthly variations during different Seasons in Silicates of Khajiyar Lake from April 2011 to January 2012



study concentration of phosphate phosphorous was recorded more than 0.025mg/L which resulted in decreased species diversity, increased productivity, growth of nuisance aquatic plants and algal blooms causing eutrophication in the lake ecosystem. The similar findings have been reported by Camargo *et al.* (2007).

4.2.8 Silicates

Silica in water is present as silicates. The main source of silica in a water body is leaching of silicates by rainwater from the catchment and partly also by the death and decay of diatoms. Its concentration during the present study varied from 4.0 mg/L (January) to 9.5mg/L (May) (Appendix I) (Fig. 4.2.8). Silicate concentration was higher in summer and the similar results were obtained by Naik *et al.* (2009). It showed highly significant and positive correlation ($r = 0.942$, $p < 0.01$) with number of diatoms per litre. It also showed significant and positive relationship with conductivity and chlorides (Table 4.1). The positive and significant association of silicates with diatoms revealed that it is an important major nutrient which plays an important role in the presence and abundance of diatoms in an aquatic ecosystems.

4.2.9 Sodium

In surface water the sodium concentration varies depending upon the geographical area. The sodium content of the study lake ranged from a minimum of 4.8mg/L to a maximum of 6.5mg /L (Appendix I). The maximum concentration was observed in the month of May and minimum in the months of July and December (Fig. 4.2.9). The minimum value can be explained on the basis of lower microbial activity whereas the maximum value might be due to high rate of mineralization in the sediments, increasing sodium into the nutrient pool thereby making more sodium to solubilise. It showed significant and positive relationship ($r = 0.635$, $p < 0.05$) with potassium. It also showed highly significant and positive relationship ($r = 0.959$, $p < 0.01$), ($r = 0.942$, $p < 0.01$) with silicates and number of diatoms per litre (Table 4.1) showing that it also determines the water quality.

4.2.10 Potassium

Sodium and potassium are closely related to each other. The occurrence of potassium is less widespread in nature and in an aquatic environment it is found always in lower concentration than sodium due to more chloride values. The potassium

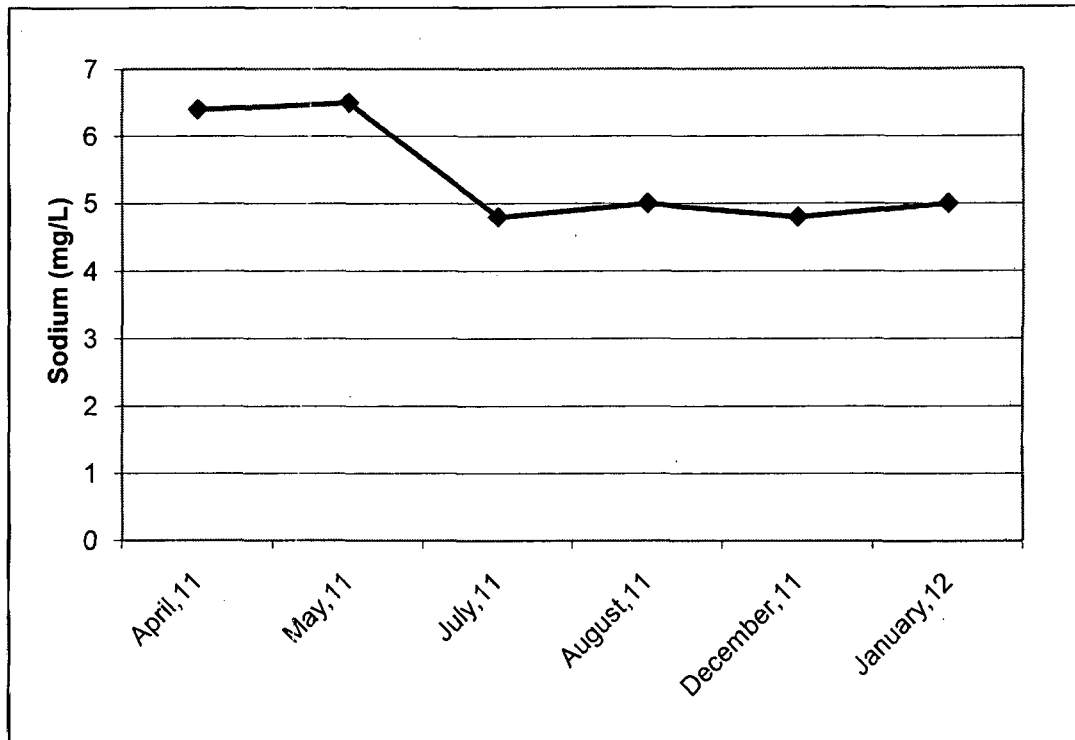


Fig. 4.2.9 Monthly variations during different Seasons in Sodium of Khajiyar Lake from April 2011 to January 2012

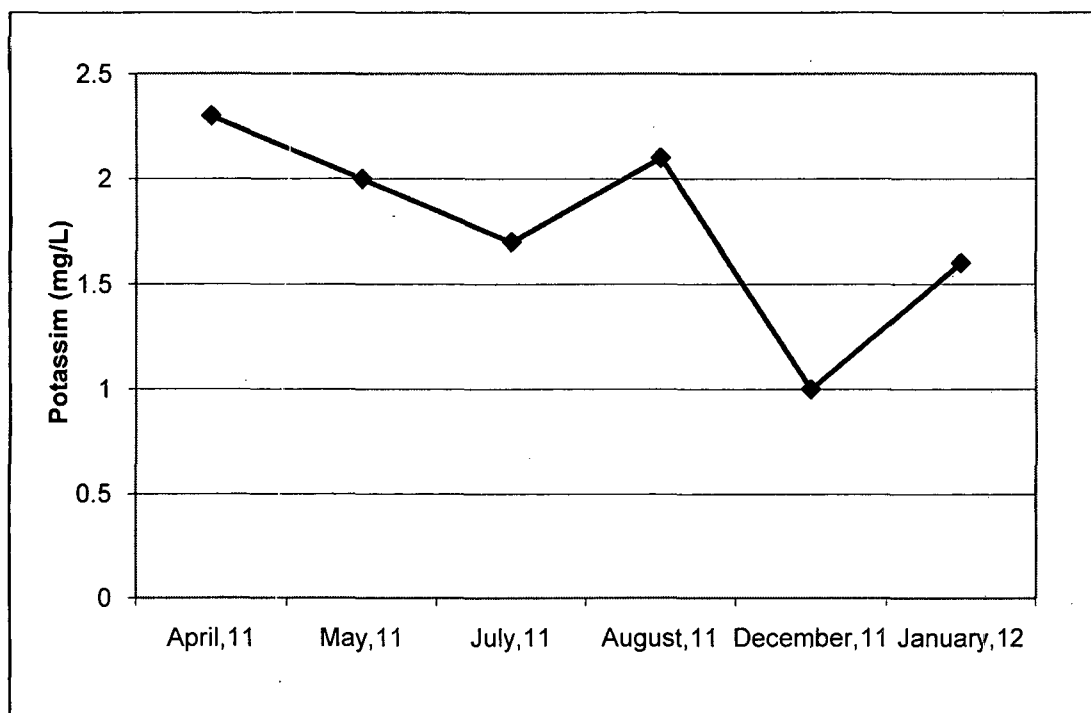


Fig. 4.2.10 Monthly variations during different Seasons in Potassium of Khajiyar Lake from April 2011 to January 2012

concentration varied from 1.0 mg/L to 2.3 mg/L (Appendix I) where maxima was found in the month of April and minima in the month of December (Fig. 4.2.10). It showed highly significant and positive relationship ($r = 0.834$, $p < 0.01$) with chloride (Table 4.1). The major source of potassium in natural fresh water is weathering of rocks but the quantity was found slightly increased in the present investigation due to the inflows of waste water to the lake.

4.3 Ecology of Diatoms in relation to Physico-chemical regime

Diatoms are photosynthetic algae with a distinct silica cell wall called frustules. They constitute the fundamental link between primary (autotrophic) and secondary (heterotrophic) production and form a vital component of aquatic ecosystems. During the course of present investigation twelve species of diatoms were recorded from the lake under study. The diatom flora was found to be composed of *Cyclotella stelligera*, *Diatoma vulgare*, *Navicula gracilis*, *Navicula gibba*, *Pinnularia nobilis*, *Nitzschia sigmoidea*, *Gomphonema geminatum*, *Cylinderotheca gracilis*, *Fragilaria capucina*, *Frustulia rhomboides*, *Synedra ulna* and *Tabellaria fenestrata*. All the above species were recorded throughout the study period. However, their abundance varied significantly during different seasons. Diatom richness was recorded maximum during summer followed by rainy season and minimum during the winter season. The maximum richness of diatoms in summer and rainy season revealed that temperature determines the presence and abundance of diatoms which has further been strengthened by the significant and positive correlation (0.394) between temperature with diatom's population.

The diatom number per litre varied significantly during different seasons. The number was recorded minimum (28684) in the month of December and maximum (58359) in the month of April during the course of study. The diatom population was found dominated by *Navicula gracilis* (60904) and co dominated by *Gomphonema geminatum* (55839) during the entire study period except for the month of July when *Gomphonema geminatum* dominated the population. The lowest count (2880) was obtained for *Synedra ulna* followed by *Tabellaria fenestrata* (3830). Diatom density showed significant and positive correlation with total solids, total dissolved solids and total suspended solids (Table 4.1). During winter the hydrological and meteorological

regimes were unstable and so the diatoms were poorly developed. Similar results were obtained by Rakaj (2010). The diatom density also showed highly significant and positive relationship ($r = 0.869$, $p < 0.01$), ($r = 0.857$, $p < 0.01$) with conductivity and chloride respectively (Table 4.1). Such association is an indication of eutrophication as during the course of present investigation chloride values were always more than 18.0mg/L.

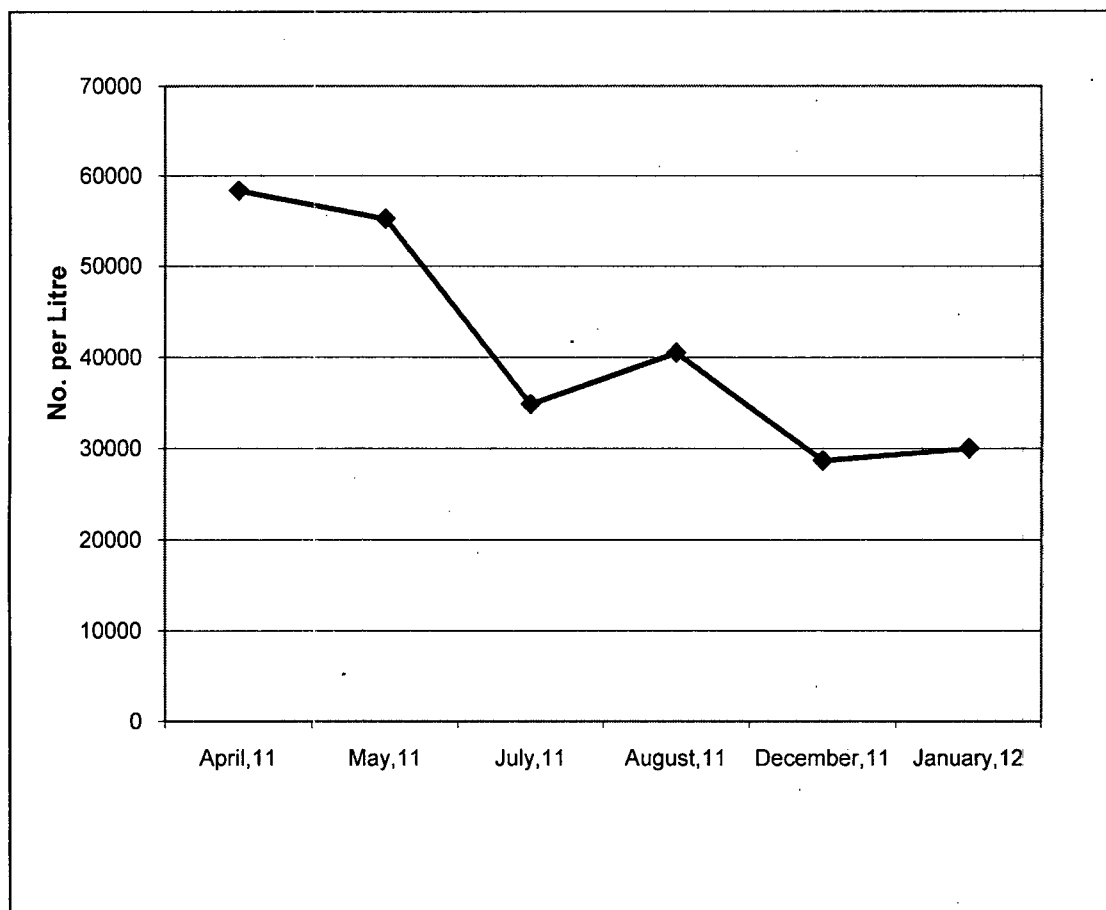


Fig.4.3.1. Monthly variations during different Seasons in diatom no. per litre from April 2011 to January 2012

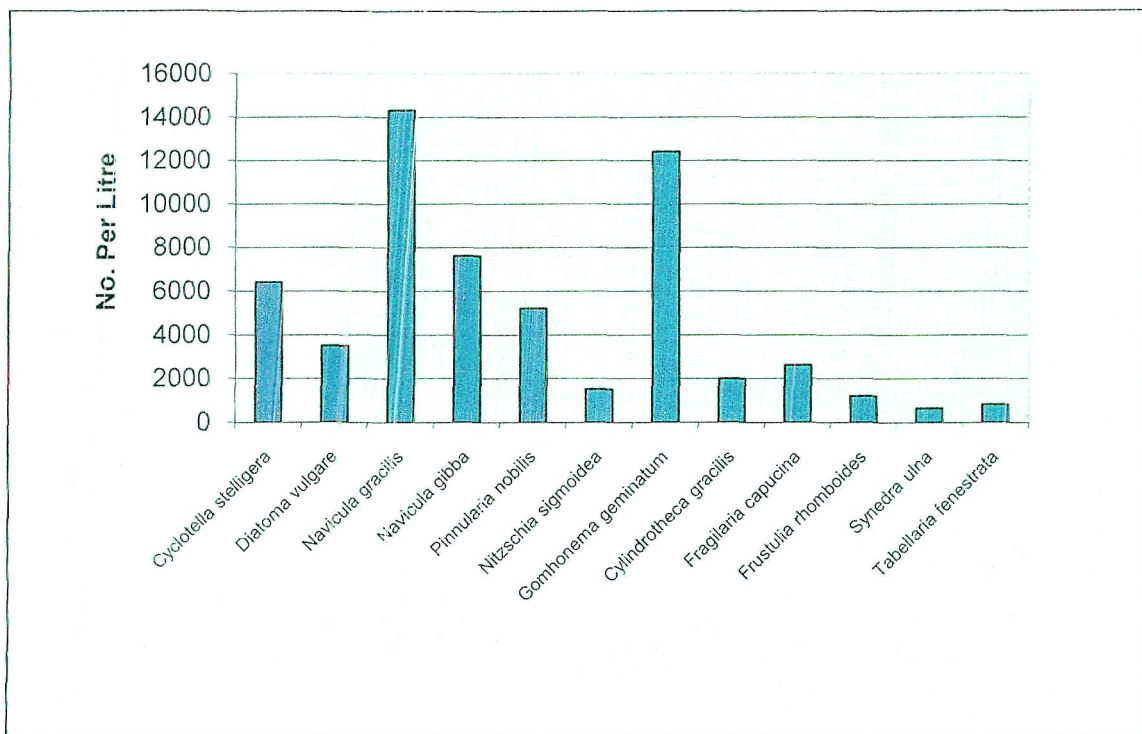


Fig. 4.3.2 Variations in Diatom no./L in the month of April

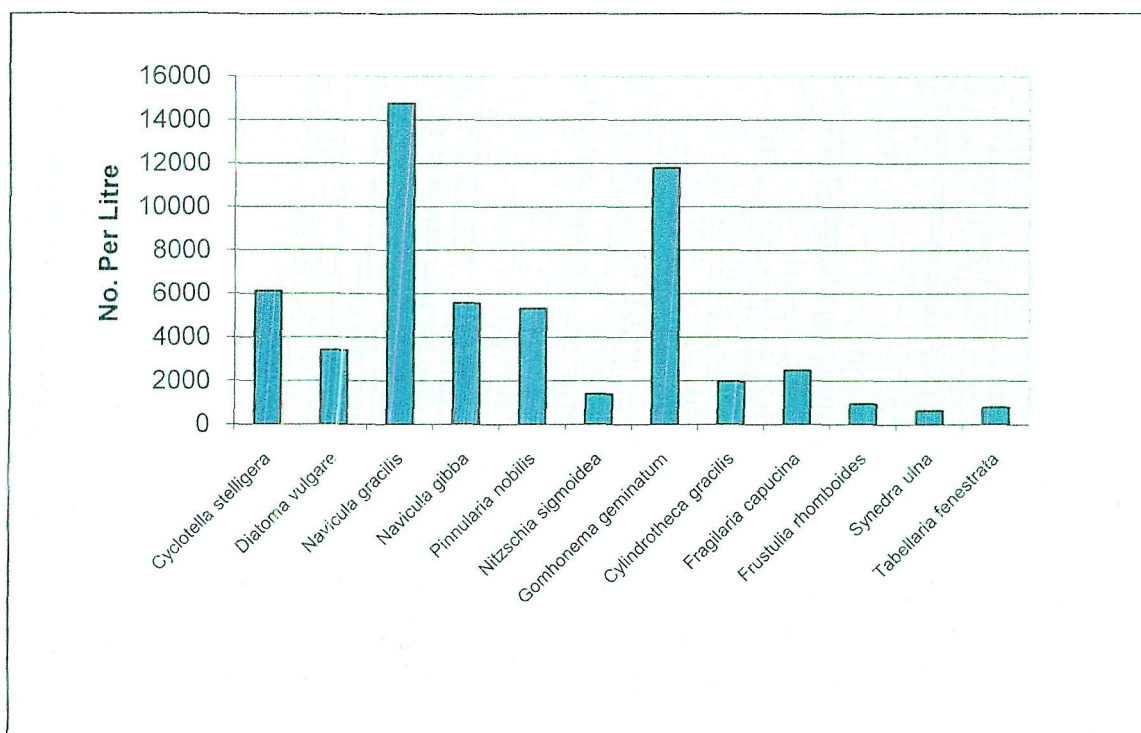


Fig. 4.3.3 Variations in Diatom no./L in the month of May

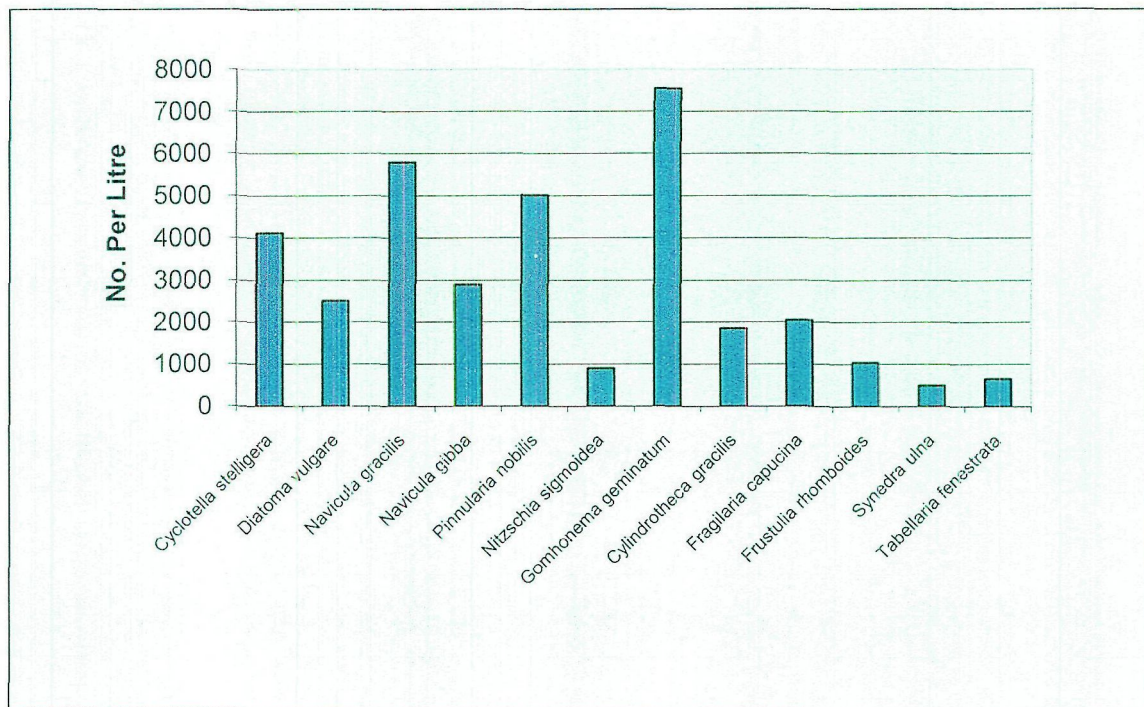


Fig. 4.3.4 Variations in Diatom no./L in the month of July

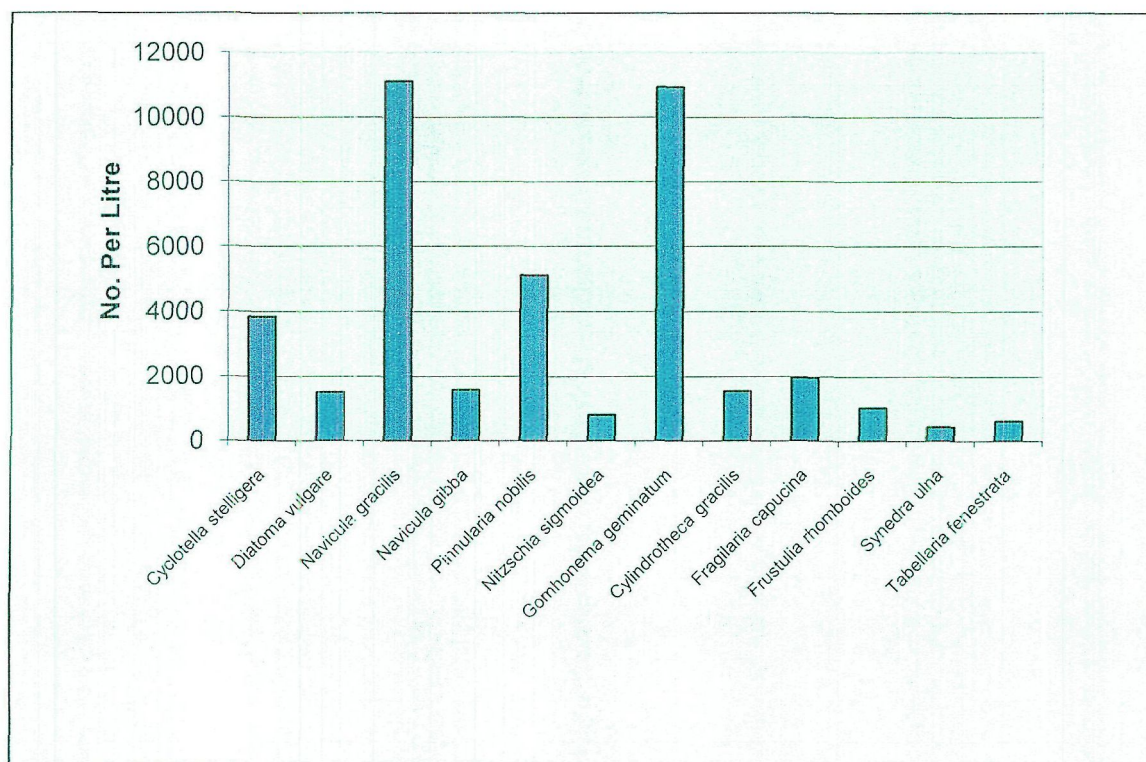


Fig. 4.3.5 Variations in Diatom no./L in the month of August

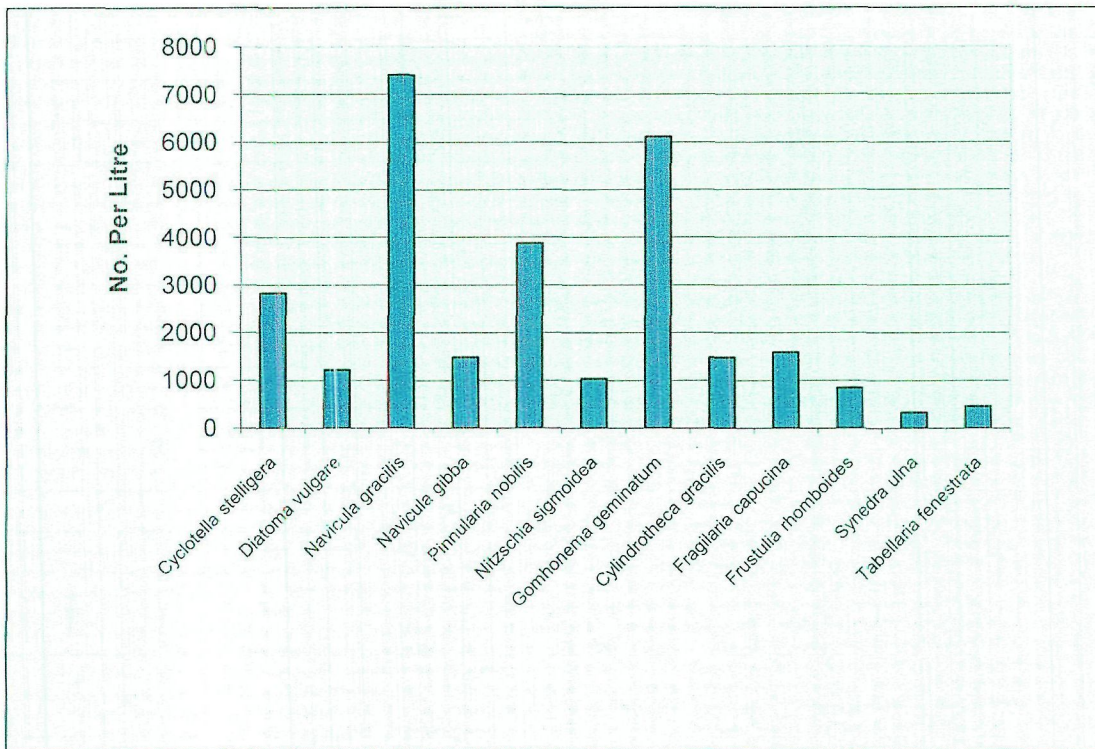


Fig. 4.3.6 Variations in Diatom no./L in the month of December

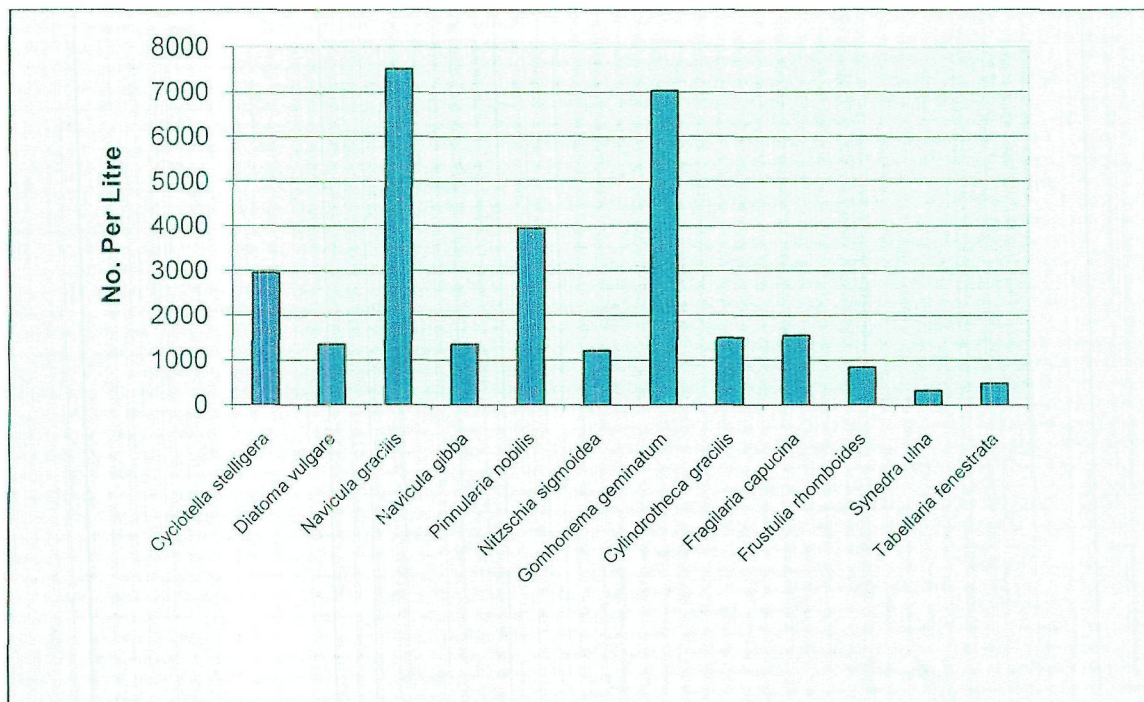


Fig. 4.3.7 Variations in Diatom no./L in the month of January

The oxygen indicator species were found in low percentage which indicated that water of Khajiyar lake is polluted and poor in oxygen concentration. This group was represented by *Synedrea ulna* and *Fragilaria capucina*. This condition can be related to the allochthonous material entering through run-off from the catchment area resulting in higher oxygen consumption for its decaying and decomposition. Similar observations were reported by Singh and Chauhan (1992). *Gomohonema geminatum* indicates varying nitrogen level. These species are heterotrophic in nature. The presence of Nitrogen heterotrophic- Naviculaes group which is represented by *Navicula gracilis* (24%), *Navicula gibba* (8%) and *Pinnularia nobilis* (12%) (Fig. 4.3.8) indicated pollution in the lake. The abundance of these species has also been reported in polluted lake system by Shashikant (1979). The diatom species of Nitrogen heterotrophic- Nitzschiae dominate mostly in nitrogen rich water which has further been strengthened by the positive correlation (0.362) of diatoms with total nitrate nitrogen. This group in the present investigation was represented by *Nitzschia sigmoidea* and *Cylindrotheca gracilis*.

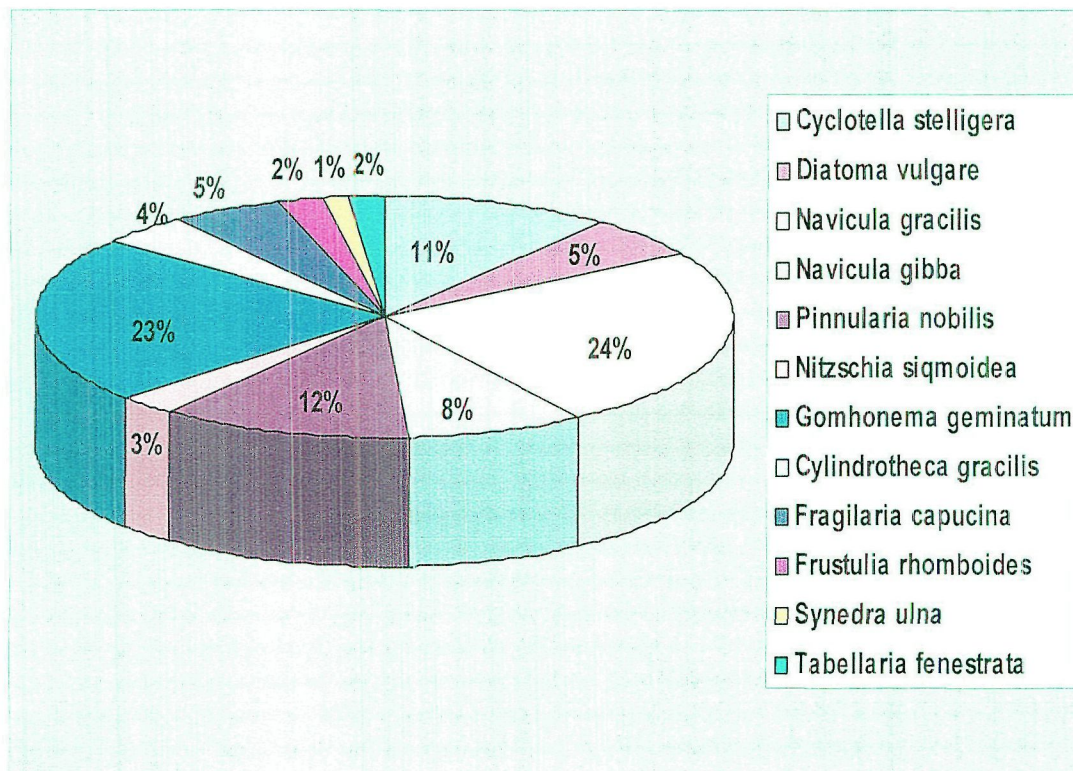


Fig 4.3.8 An annual average abundance of Diatom's species

Thus, the very low percentage of oxygen indicator, abundance of Nitrogen heterotrophic- Naviculae, and Nitzschiae and presence of varying nitrogen level indicators diatoms species during the present study indicated the deteriorated water quality of the lake.



SUMMARY
AND
CONCLUSIONS

5. SUMMARY AND CONCLUSIONS

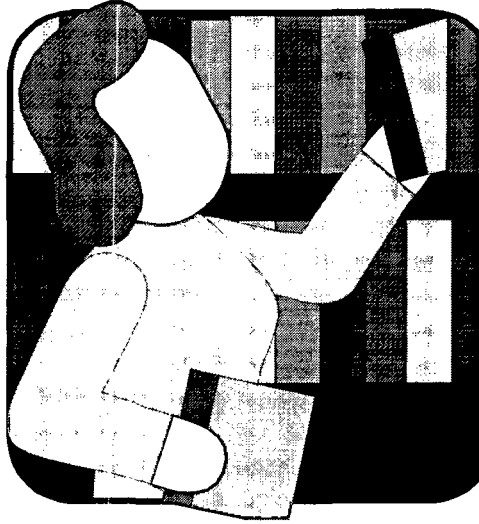
An aquatic ecosystem is the most diverse and productive ecosystem of the world. A lake is a body of relatively still fresh or salt water of considerable size, localized in a basin that is surrounded by land. A variety of environmental goods and services provided by lakes make them vulnerable to human demand. Society's demand for economic gains has contributed to the deterioration of water quality and aesthetic values of lakes. Eutrophication is the most widespread form of lake pollution on a global scale, and has many deleterious impacts on aquatic systems. The causes of eutrophication are natural and anthropogenic. The estimation of water quality using biotic communities is better than chemical or physical features alone and has significant role to play in assessing water quality quickly. Among algae periphytic species in general and diatom species in particular are used as indicator of water quality. Diatoms are considered to be of the opportunistic algal group in bio-monitoring in the sense that they are quite sensitive to the minor change in the environment. Thus, in the present investigation two prime concerns- estimation of physico-chemical characteristics of the Khajiyar lake of Chamba district, Himachal Pradesh in relation to diatoms and assessment of water quality of lake ecosystem by using diatoms as indicators have been addressed. The main results and conclusions that emerged out of the present study are summerized below:

The atmospheric temperature ranged from 0.7°C to 24.5°C and water temperature from 2.4°C to 22.5°C (Appendix I). The atmospheric temperature showed highly positive and significant relationship with water temperature and revealed that it regulates water temperature in an aquatic environment. Transparency was found in the range of 10cm to 40cm. It showed highly significant and negative relationship with water temperature and also with air temperature (Appendix I and Table 4.1). Electrical conductivity was found in the range of 120.0µmhos/cm to 230.0µmhos/cm. It showed highly significant and positive relationship with total dissolved solids. There was also a highly significant and positive relationship ($r = 0.984$, $p < 0.01$) of conductivity with chloride and ($r = 0.869$, $p < 0.01$) with number of diatoms per litre (Appendix I and Table 4.1). Total solids, total dissolved solids and total suspended solids ranged from 198.81mg/L to 389.0 mg/L,

168.81mg/L to 330.0 mg/L and 30.0mg/L to 59.0 mg/L during the investigation. Total solids showed positive and significant relationship with total suspended solids (Appendix I and Table 4.1). Such type of relationship indicated that total suspended solids are regulated by the total solids in an aquatic environment. TSS showed significant and positive relationship ($r = -0.710$, $p < 0.01$) with transparency as the effect of presence of total suspended solids is the turbidity due to silt and organic matter.

pH values showed variations from 6.0 to 6.4 which revealed the acidic nature of the lake water throughout the study. Dissolved oxygen of the lake ranged from 4.6mg/L to 7.9 mg/L and it showed highly positive and significant relationship with transparency and such a type of associations revealed that dissolved oxygen is directly proportional to secchi transparency (Appendix I and Table 4.1). Low values of dissolved oxygen in the lake coincided with higher free carbon dioxide. Free carbon dioxide values showed variations from 11.0mg/L to 26.8mg/L and showed highly significant and negative relationship with dissolved oxygen which indicated that it is inversely proportional to the dissolved oxygen. Total alkalinity was found ranging from 95.0mg/L to 132.0 mg/L. High total alkalinity values of the lake indicated its high trophic status. Chloride varied from 20.1mg/L to 33.1 mg/L. It was recorded more than 18.0mg/L throughout the study period which revealed that the lake ecosystem is at an advanced stage of eutrophication. Chloride showed highly significant and positive relationship with ($r = 0.984$, $p < 0.01$) electrical conductivity (Table 4.1). The concentration of nitrate-nitrogen and total phosphate-phosphorus in the lake ranged from 0.098mg/L to 0.485mg/L and 0.61 mg/L to 2.32mg/L. Total phosphate phosphorous showed highly significant and positive relation with nitrate-nitrogen. This relationship revealed more activities of organic origin in the catchment area. The concentration of silicates varied from 4.0mg/L to 9.5mg/L. It showed highly significant and positive correlation with number of diatoms per litre which showed their direct relationship with each other. It also showed significant and positive relationship with conductivity and chlorides. The sodium content of the lake ranged from 4.8mg/L to 6.5mg /L and the potassium concentration varied from 1.0 mg/L to 2.3 mg/L. Both showed significant and positive relationship with one another as they are quite closely related to each other in an aquatic ecosystem.

Diatoms are photosynthetic algae with a distinct silica cell wall called frustules. They constitute the fundamental link between primary (autotrophic) and secondary (heterotrophic) production and form a vital component of aquatic ecosystems. The present investigation recorded twelve species of diatoms from the lake. The diatom flora consisted of *Cyclotella stelligera*, *Diatoma vulgare*, *Navicula gracilis*, *Navicula gibba*, *Pinnularia nobilis*, *Nitzschia sigmaidea*, *Gomphonema geminatum*, *Cylinderotheca gracilis*, *Fragilaria capucina*, *Frustulia rhomboides*, *Synedra ulna* and *Tabellaria fenestrata*. Diatom richness was recorded maximum during summer and rainy season and minimum during the winter season. The diatom number per litre varied from 28684 to 58359. Their density showed significant and positive correlation with total solids, total dissolved solids and total suspended solids. The highly significant and positive relationship of diatom density with conductivity and chloride indicated deteriorated water quality of the lake ecosystem. The diatom's species composition, presence and abundance was found greatly influenced by the physico-chemical regime of the lake. The oxygen indicator species i.e. *Fragilaria capucina* and *Synedra ulna* were found in very low percentage which also revealed that water of Khajiyar lake is polluted and poor in oxygen concentration. This condition can be related to the allochthonous material entering through run-off from the catchment area resulting in higher oxygen consumption for decaying and decomposition. The higher values of free carbon dioxide (11.0-26.8 mg/L), chloride (20.2-33.1mg/L), nitrate nitrogen (0.098-0.485mg/L), total phosphate phosphorous (0.61-2.32mg/L) and the distribution, presence and abundance of pollution indicator diatom species such as *Diatoma vulgare*, *Navicula gracilis*, *Navicula gibba*, *Pinnularia nobilis*, *Nitzschia sigmaidea*, *Gomphonema geminatum*, *Frustulia rhomboides*, *Tabellaria fenestrata* and *Cylinderotheca gracilis* throughout the investigation indicated highly deteriorated water quality of the lake ecosystem.



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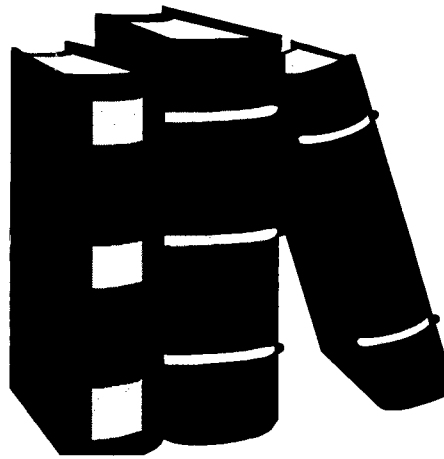
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APPENDICES

Appendix-I

Monthly variation during different seasons in various physico-chemical characteristics and Diatom count of Khajiyar lake

	Air temp (°C)	Water temp. (°C)	Secchi transparency (cm)	pH	Conductivity (µmhos/cm)	TS (mg/l)	TDS (mg/l)	TSS (mg/l)	DO (mg/l)	Free CO ₂ (mg/l)	Total Alkalinity (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)	Silicates (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Diatoms (no./l)
April	11	13	25	6.1	200	299.18	254.18	45	6.3	16	112	32.3	0.305	1.898	8	6.4	2.3	58359
May	13	15.2	24	6.2	230	389	330	59	6.5	17.6	125	33.1	0.33	1.89	9.5	6.5	2	55225
July	24.5	22.5	10	6.1	165	305.4	257.4	48	4.6	26.8	126	29.5	0.485	2.25	4.7	4.8	1.7	34880
August	22.5	20	13	6	190	343.4	290.4	53	4.8	26.4	132	30	0.478	2.32	5.4	5	2.1	40501
December	0.8	2.6	38	6.3	120	198.81	168.81	30	7.9	11	95	20.5	0.098	0.61	4.5	4.8	1	28684
January	0.7	2.4	40	6.4	123	203.6	171.6	32	7.8	12.6	110	20.2	0.102	0.62	4	5	1.6	30014

Appendix-II

Monthly variation during different seasons in presence and abundance of Diatoms species from April 2011 to January 2012 in Khajiyar lake

	<i>Cyclotella stelligera</i>	<i>Diatoma vulgare</i>	<i>Navicula gracilis</i>	<i>Navicula gibba</i>	<i>Pinnularia nobilis</i>	<i>Nitzschia sigmaidea</i>
April,11	6415	3515	14316	7625	5226	1520
May,11	6125	3410	14750	5580	5330	1400
July,11	4112	2512	5790	2896	5020	900
August,11	3841	1510	11120	1575	5125	800
December,11	2832	1220	7413	1488	3875	1041
January,12	2944	1345	7515	1350	3940	1210

Appendix-III

Monthly variation during different seasons in presence and abundance of Diatoms species from April 2011 to January 2012 in Khajiyar lake

	<i>Gomphonema geminatum</i>	<i>Cylindrotheca gracilis</i>	<i>Fragilaria capucina</i>	<i>Frustulia rhomboides</i>	<i>Synedra ulna</i>	<i>Tabellaria fenestrata</i>	Total
April, 11	12420	2012	2630	1210	650	820	58359
May, 11	11790	1980	2480	940	640	800	55225
July, 11	7550	1850	2050	1040	500	660	34880
August, 11	10940	1540	1970	1025	440	615	40501
December, 11	6114	1480	1590	846	330	455	28684
January, 12	7025	1495	1550	840	320	480	30014

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Class	Month, Year	School	Board/University	Marks (%)	Division
10 th	March 2005	DAVPS Palampur	Central Board of Secondary Education, Delhi	77.2%	1st
12 th	March 2007	DAVPS Palampur	Central Board of Secondary Education, Delhi	76.4%	1st
B.Sc. Basic Sciences	July 2010	CSK HP Krishi Vishvavidyalaya, Palampur	CSK HPKV, Palampur	73.0%	1st
M.Sc. (Env.Sc.)	July 2012	CSK HP Krishi Vishvavidyalaya, Palampur	CSK HPKV, Palampur	81.5%	1st