GEOCHEMISTRY OF THREE KASHMIR HIMALAYAN LAKES AND ITS IMPACT ON VEGETATION DYNAMICS

THESIS

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*****CERTIFICATE*****

*This is to certify that the Ph.D. thesis entitled **"Geochemistry of Three Kashmir Himalayan Lakes and its Impact on Vegetation Dynamics"** is an original work of **Mr. Aftab Ahmad Bhat** for the award of the degree of Doctor of Philosophy in **Environmental Science** from **University of Kashmir**. This study has been carried out under our supervision and the same or any part of this thesis has not been submitted for this or any other degree so far.*

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AFTAB AHMAD BHAT

Dedicated

To My

Dear

Parents

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Chapter 1

INTRODUCTION

1. INTRODUCTION

Aquatic plants, including the macrophytes, are in close contact with the environmental conditions of a lake through the root-system as well as the shoots/leaves which are surrounded or floating in a dense chemical solution compared with terrestrial plants. It is thus expected that aquatic plants respond strongly to the particular environmental conditions within a lake. The macrophytes act as ecotones horizontally between the land and open waters and vertically between sediments and over lying waters (Wang *et al.*, 2007). Thus any change in the catchment, water column or sediments is associated with changes in aquatic vegetation.

The eutrophication, acidification, and other water chemistry changes are reflected by the changes in species composition and abundance of macrophytes in the lakes (Roelofs, 1983; Srivastana *et al*., 1995; Arts, 2002 Macmets and Friberg, 2005). The eutrophication of lakes often leads to change in species composition due to different nutrient demands and light requirements of the species and is main cause of declining of macrophyte cover, number and diversity in lakes and wetlands (Moller and Martin, 2007). However, in recent years the decline of macrophyte diversity from lakes and wetlands have been attributed to physiological stress associated with geochemical changes in sediments and overlying water column e.g. ammonium toxicity resulting from high concentration of ammonium is believed to be the main factor responsible for decline of submerged macrophytes from the lakes and wetlands (Smolders *et al*., 1996b, 2000) as it retards the growth of macrophytes by disturbing their nitrogen and phosphorous metabolism (Coa *et al*., 2004; 2009).

The excessive use of manures and fertilizers has greatly increased the concentration of nitrate in surface waters which in turn hampers the growth of macrophytes, reduces macrophyte diversity and evenness (Oertli *et al*. 2000: Boedeltje *et al*., 2005; Bella *et al*., 2008). The presence of heavy metals and phosphorous in aquatic ecosystems resulting from agricultural runoff, industrial discharge and biological decomposition process has also been related with disappearance and recession of macrophytes from lakes (Wang *et al.*, 2009; Radic *et al.,* 2010, 11). Similarly, the high concentration of phosphorous has been known to cause protein damage, decrease photosynthesis and photorespiration efficiency (Wang *et al*., 2009). For example, the species richness of submerged macrophytes in Lake Fure Sø in Denmark has declined from 33 to 10 during the last 100 years in response to a 30-fold increase in external phosphorus loading. It is therefore, important to relate aquatic macrophytes quantitatively to their environmental tolerances so that the effects of environmental changes can be predicted. The highest macrophyte diversity is observed in mesotrophic or slightly eutrophic ecosystems and lowest is recorded in oligotrophic and eutrophic lakes (Vestergaard and Sand-Jensen, 2000; Heegaard *et al.,* 2001; Murphy, 2002). The alkalinity and pH of the lakes regulates the species composition and dynamics of macrophytes. The species richness increase from acidic, poorly buffered lakes to neutral, well buffered lakes (Heegaard *et al.,* 2001).

Salinity has also been recognized as an important factor determining the composition of plant communities (Espinar *et al.,* 2002; Watt *et al*., 2007). It restricts the growth of macrophyte communities and different growth forms have different tolerances to salinity. The free floating species are highly sensitive to salinity and become chlorotic and subsequently sank to bottom; the submergeds are relatively tolerant but fail to grow in salt solution of 6.66% (Haller *et al.,* 1974; Van den Brink and Van der Velde, 1993).

Sediments have a dual importance to the rooted macrophyte species, as a source of nutrients and as a means of anchorage within the lakes. Various macrophyte species have different, preferences and tolerances for both physical conditions and sediment chemistry. The principal influence of sediments upon the growth and distribution is due to physical properties of sediments (Sculthorpe, 1967). The sediment texture effects anchorage (Denny, 1980) and determine the rooting success of macrophytes and resistance to erosion in particular conditions of water flow (Haslam, 1978).

Macrophytic species vary in their responses to sediment conditions (Barko and Smart, 1980, 1983; van Wijck *et al*., 1992; Holmer *et al*., 2005; Li *et al*., 2012), which may influence the species composition of aquatic macrophyte communities. The excessive organic matter in sediments often contains high concentration of toxic organic acids, and metabolic product which inhibit their growth (Mishra, 1938; Barko *et al*., 1986; Brenda *et al.*, 1993). The succession of aquatic plants communities (submerged to floating leaved to emergent) in lakes parallels the accumulation of organic matter in lakes and thus contribute to decline of submerged species (Wetzel, 1979; Carpenter, 1981). The decline of many macrophytes is also associated with increased sulphide concentration in surface waters and decreased iron levels in the sediments (van Wijck *et al*., 1992). The sulfate reduction generates the phototoxin, H_2S and its subsequent precipitation with iron leads to iron deficiency which seriously hampers the growth of macrophytes (Smolders and Roelofs, 1993; Smolders *et al.*, 1995). The anaerobic sediments provide favourable conditions for generation and accumulation of soluble sulfide including S, HS and H_2S which are highly toxic to plants and are considered to be main cause of disappearance and recession of macrophytes (Holmer *et al.*, 2005).

Jammu and Kashmir located in the foothills of Himalaya, abounds in fresh water natural lakes of varied ecological conditions from subtropical lowland Terai to high altitude alpine that have come into existence as a result of various geological changes. These water bodies provide an excellent opportunity for studying the structure and functional process of an aquatic ecosystem (Zutshi, 1975; Kaul, 1977; Kaul *et al*, 1978; Trisal, 1983, Khan, 2000). The high altitude lakes are fed by snow-melt, precipitation and springs, whereas lakes of lower altitudes receive water from rivers, streams, and springs. Around 44.7% of high altitude lakes of India are found in Jammu & Kashmir with 87.2% share of total area (SAC-ISRO, 2011). The Pangong Tso, Tso Morari and Tso Khar are three important high altitude (>4500m.a.s.l) saline lakes located in Ladakh region, being the only breeding grounds for migratory birds like black-necked crane and bar-headed goose in India. These habitats have been reported to be devoid of any fish species (Bhat *et al*, 2011). On the Kashmir side high altitude lakes (3000-4000 m) like Gangbal, Sheshnag, Tarsar, Marsar, Kausarnag, etc., support some fisheries. The relatively low altitude lakes of Kashmir (alt. 1587-1600 m) like Dal, Nageen, Wular, Anchar and Manasbal, lying in the flood plain of river Jhelum, have luxuriant macrophytic vegetation and support commercial fisheries.

The increasing anthropogenic pressure in recent years, in and around Himalayan aquatic ecosystems including their watersheds has contributed to the mineral enrichment of these systems, leading to accelerated eutrophication. The research studies so far carried out in the lakes and wetlands of Kashmir Himalaya have covered various aspects of limnology (Zutshi and Khan 1978: Zutshi *et al*., 1980; Zutshi and Ticku, 1990; Zutshi and Yousuf, 2004), plankton and macro-invertebrates (Pandit, 2002; Qadri and Yousuf, 2004; Reyaz and Yousuf, 2005), sediment chemistry (Trisal and Kaul, 1983; Geelani and Shah, 2007) environmental change (Gopal and Zutshi, 1998), and macrophytic diversity (Pandit, 2001: Rather and Pandit, 2005; Pandit, 2008).The earlier works on aquatic vegetation of Kashmir deal with taxonomic considerations (Zutshi and Kaul, 1963, Kaul and Zutshi, 1967; Kak, 1990) and production ecology of macrophytes (Kaul and Zutshi, 1966; Zutshi and Vass, 1971; Handoo, 1978). Some studies have included both the floral composition and water quality (Zuthsi, 1989; Pandit, 1992) Studies on seasonal change in physical and chemical parameters of lake waters have been useful in categorizing the lakes and their status (Pandit and Yousuf, 2002).

A perusal of these studies clearly indicates that not much work has been conducted on the limnology of the Ladakh waters and further no study has so far been conducted which would give a comparative limnology of Kashmir and

Ladakh lakes. The main constraints in this direction have been the extreme climatic conditions, formidable topography and high altitude of the area, where such lakes occur (Hutchison *et al*., 1943; Gopal *et al*., 2002). In the present study, therefore, an attempt has been made to investigate the ionic concentration in the water and sediments of two high-altitude lakes of Ladakh, i.e., Tso Morari and Tso Khar and evaluate the impact of water and sediment chemistry on the dynamics of macrophyte population occurring in these systems. An attempt has also been made to compare these aquatic systems in respect of water and sediment chemistry and macrophyte diversity with a typical valley lake of Kashmir, i.e., Lake Manasbal. The data obtained during the study conducted from 2004 to 2006, the observations made and the inferences made on the basis of the collected data are described in the following pages in the light of the available literature in the field.

Fig. 1.1. Map of Jammu and Kashmir showing location of Tso Morari, Tso Khar and Manasbal Lake.

Chapter 2

STUDY AREA

2. STUDY AREA

Jammu and Kashmir is located in the north-western part of the Himalaya between the geographical coordinates of 32^{o} 15' and 37^{o} 05' N latitude and 72^{o} 35' and 80^{o} 20' E longitude. Although situated in sub-tropical latitude, but owing to orographic features the climate over greater parts of the Jammu and Kashmir State resembles to that of temperate latitudes. The climate of the valley has four distinct seasons spring (March - May), summer (June - August), autumn (September - November) and winter (December - February). The precipitation in the valley is in the form of rain as well as snow with its highest occurrence in winter and spring season. Snowfall is mainly restricted to winter season and is attributed to western depressions, while rainfall occurs mainly in spring and summer seasons and is associated with western depression and southwest monsoon.

Ladakh, on the other hand, lying in the high altitude range of North West Himalayas forms the cold arid zone of the state. More than 75% of the geographical area of the state falls in this zone. Summers in Ladakh are short, although long enough to grow crops. Both cold desert of Ladakh and temperate Kashmir valley are endowed with a number of water bodies of varied depth and size. While most lakes occurring in the valley are shallower, < 15m in depth, in Ladakh several very deep water bodies (depth > 50m) are located, containing generally brackish water. Keeping in mind variability in depth and salinity it was decided to undertake a comparative study of three water bodies of the region, very deep brackish Tso Morari, shallow saline Tso Khar, and shallow (<15) fresh water Manasbal lake of Kashmir.

2.1 Tso Morari Lake

The Tso Morari Lake, located in Rupshu desert of Changthang region (32° 40'–33°15' N latitude and 78° 15' –78° 25' E longitude), lies about 220 km southeast of Leh at an altitude of 4500m above mean sea level, close to the Indus Suture Zone

(ISZ; Dubey and Shukla, 2008).The surface area of the lake is 148.8 sq km with maximum depth of 110m near the center. On the north and east sides, the lake is bounded by rolling hills of the Tibetan cold desert, whereas the western side is bordered by steeper peaks exceeding 5,500m.The Tso Morari is a land locked lake and is fed by several springs and glacial streams originating from high mountain glaciers. The major tributaries to the lake include the Gyoma in the Northern end entering the lake through pasture land at Peldo Le, Korzuk in the North western side and Phersey stream which flows in southwest into the lake, creating a wide, sloping plain or fan, crisscrossed by small rivulets which eventually drain into the lake.

The area is characterized by an arid, cold desert climate (Philip and Mazari, 2000). The summer temperature ranges from 0° to 30°C, falling between -10° and -40°C in winter (Mishra and Humbert-Droz, 1998). The lake is ice-covered from January to March. The mean annual precipitation in the region is about 100mm (Wünnemann *et al.*, 2010). Keeping in view the ecological importance of the Lake and its surroundings, the Tso Morari was notified in November 2002 under the list of Ramsar Wetland sites. Tso Morari is the only breeding ground outside China for one of the most endangered crane – Black Necked Crane and the only breeding ground of Bar Headed Geese in India.

As a closed-basin lake, the only loss of the water is mainly through evaporation and seepage. There are no industrial activities or urban development within the Tso Morari basin, except for small village at Korzuk. The basin is, however, a popular pasturing area for Champa, the local shepherd of Tibetan origin. The wetland provides rich pastures for domestic livestock. The marshes and pasturelands around the lake are grazed by domestic and nomadic livestock. These high altitude pasturelands of Changthang are historically the home of Pashmina goat and main centre for production and supply of Pashmina wool from these areas to the Indian plains and Kashmir valley. Several species of Ungulates and big herds of *Kiang* also depend on these pasturelands for grazing. A small portion on the periphery is used by the people of Korzok village for agriculture.

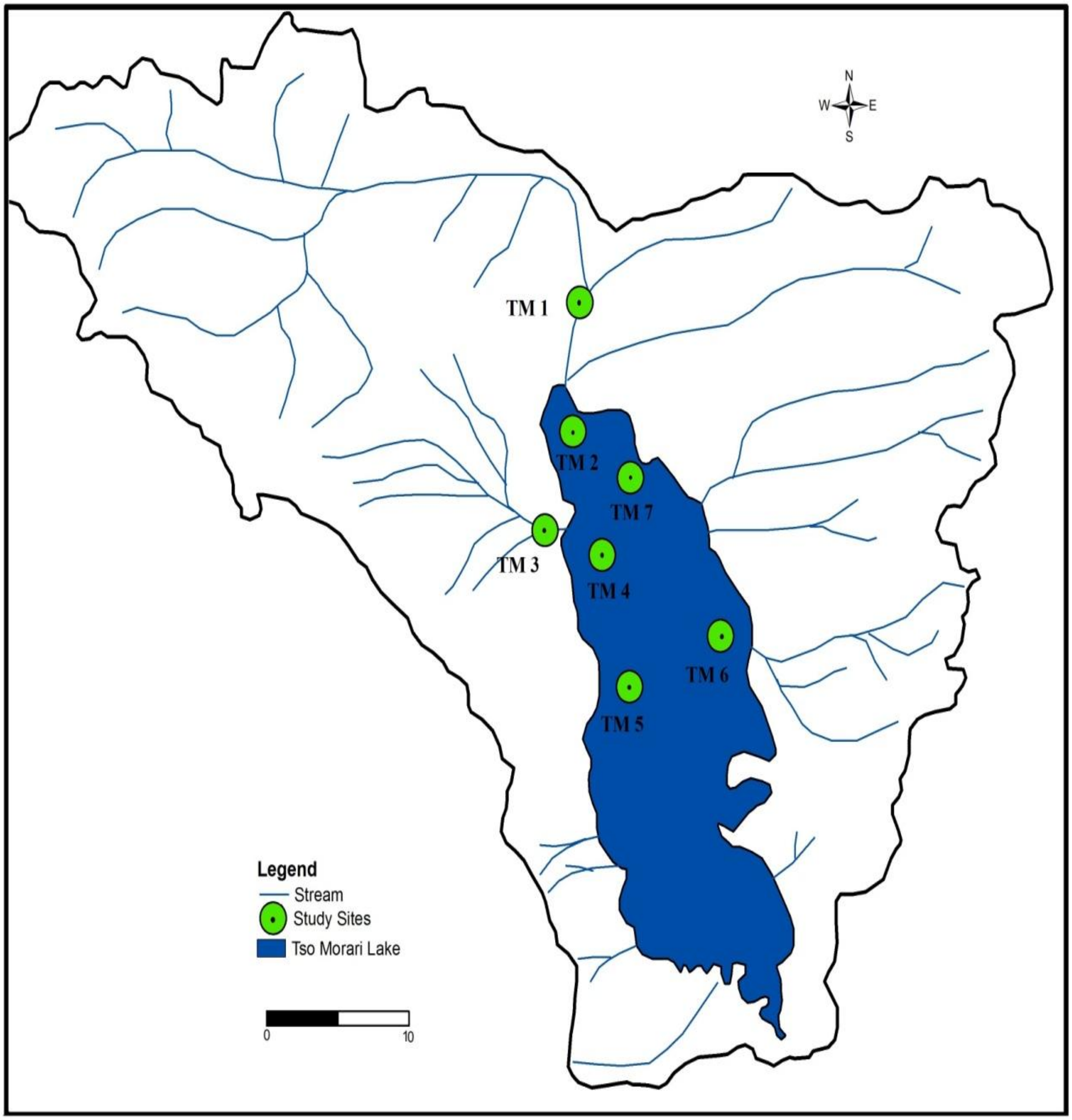


Fig. 2.1. Map of Tso Morari lake showing location of study sites

2.1.1. Study sites

A preliminary survey of the lake was conducted in December 2004 and on the basis of habitat structure in the lake seven sampling sites were selected for collecting data from the lake and tributaries (Fig. 2.1; Plate 2.1.1, 2.1.2 and 2.1.3).

Site TM1

This site was located in the Gyoma stream of the lake about 3.0 km ahead of its confluence with the lake at 33º, 04.537' N and 78º, 16.511' E. The stream drains the northern catchment of the lake and is used by the Champas (local shepherds of Tibetan origin) as a drinking water source for their Cattle. Marmot tunnels are common along both the banks of stream. The stream has a rocky bottom.

Site TM2

It was located in the lake where the Gyoma stream emptied into the lake at 33º, 00.584' N and 78º, 15.777' E. The site was relatively shallow due to deposition of silt brought by the Gyoma stream from the catchment. The site has a luxuriant growth of submerged macrophytes.

Site TM3

The site was located about 200m ahead of its confluence with the lake in the Korzok stream near Korzok village at 32º, 57.827' N and 78º, 15.554' E. The stream is used by the villagers of Korzok as a source of potable water and also for irrigating their agricultural fields lying on both the sides of the stream. During summer both the banks of the stream near its mouth are used as camping sites for tourists.

Site TM4

The site was located in the littoral zone of the lake near the confluence point of Korzok stream on the western side of the lake at 32º, 57.827' N and 78º, 15.554' E. The site was shallow with abundant macrophytic vegetation. At this site sediments were dark in color with silty texture.

Site TM5

It was located towards the western bank about six to seven kilometers from Korzok site at 32º, 58.207' N and 78º, 16.977' E. The site was deep with sparse vegetation towards the banks. The site has very high slope. The sediments at this site were dark in color with clayey texture. The bottom of this was designated as site **TM5b.**

Site TM6

The site was located towards the eastern side of the lake at 32º, 55.435' N and 78º, 21.570' E. TM5. The site is marked by a sudden steep slope having average depth of 7 meters.

Site TM7

It was located in the north eastern area of the lake just opposite to site TM2 at 32º, 00.101' N and 78º, 17.636' E. It was relatively deeper than site TM2. The site was infested with very sparse vegetation. The sediments at this site were yellowish and sandy in texture.

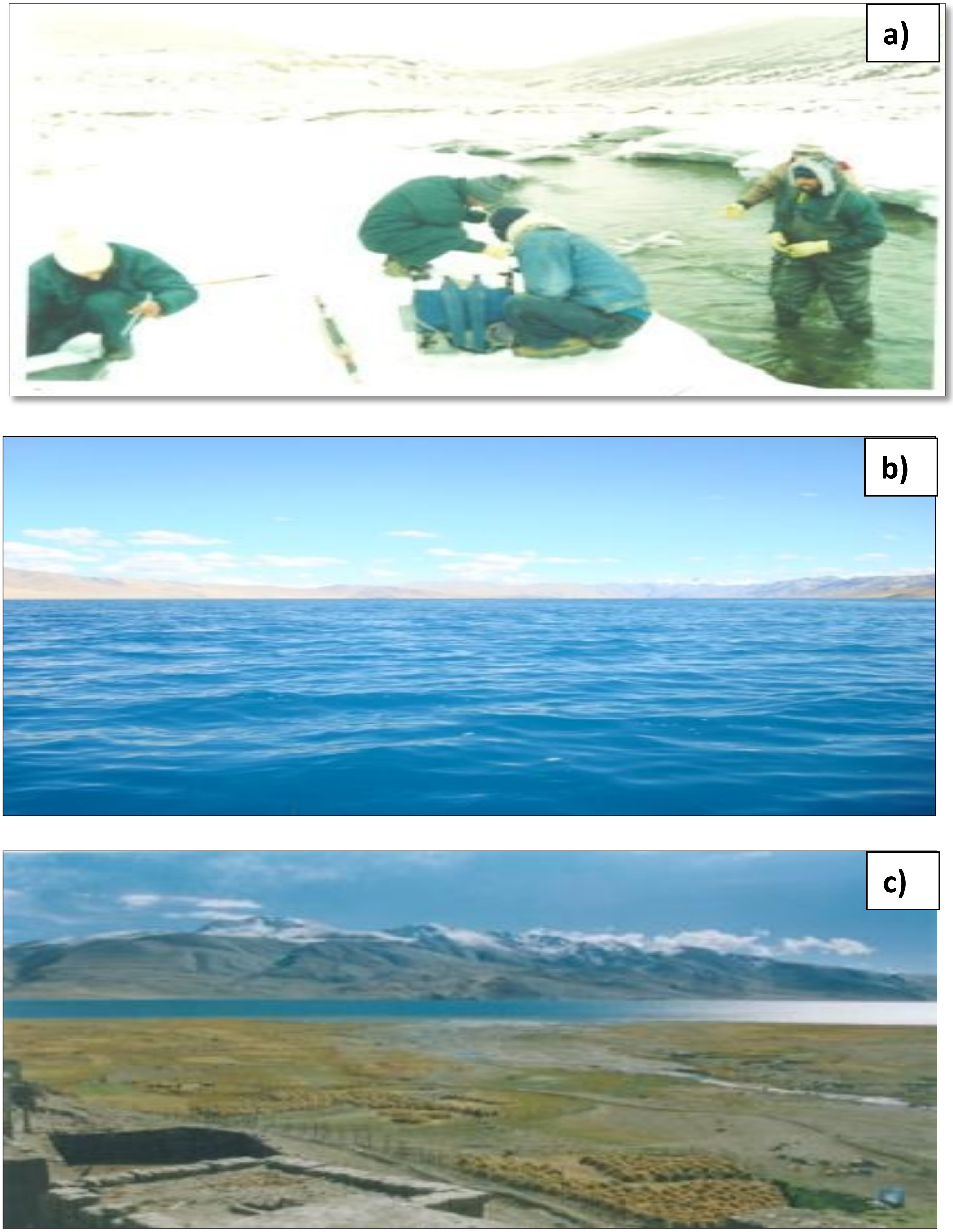


Plate 2.1.1. Location of study sites in Tso Morari lake: a) TM1; b) TM2; c) TM3

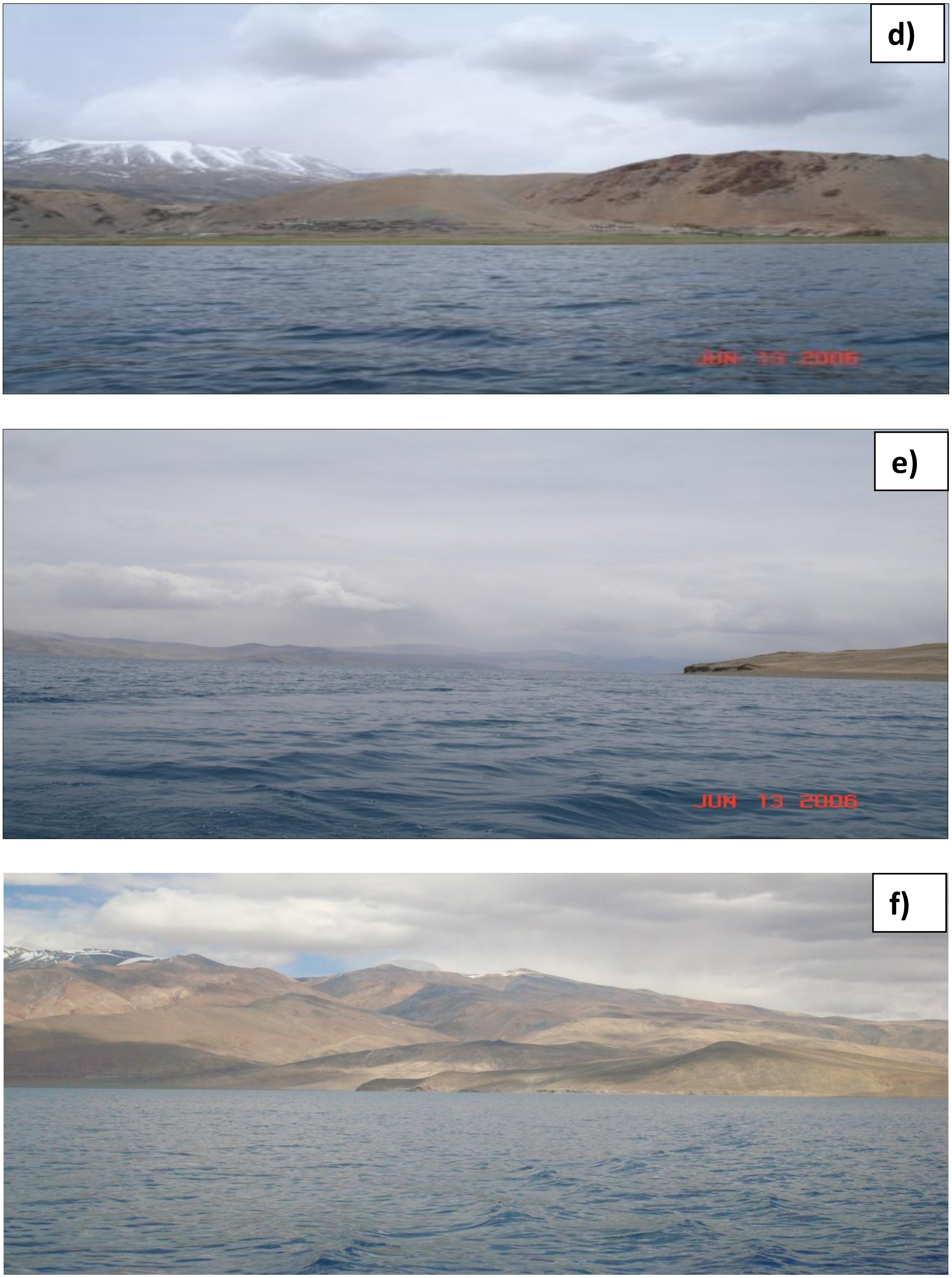


Plate 2.1.2. Location of study sites in Tso Morari lake: d) TM4; e) TM5; f) TM6.

Plate2.1.3. Location of study sites:- g) TM7; h) Bar Headed Geese; i) Motor boat

2.2 Tso Khar Lake

The Tso Khar Lake is located between 32° 40' and 33°15' N latitude and 78° 15' and 78° 25' E longitude at an altitude of 4536 meters a.m.s.l, having a surface area of 16.7 km^2. It lies between the Zanskar range in the south and Ladakh range in the north. The basin is bounded by two longitudinal faults and forms a graben structure where the central block has subsided to constitute a basin (Wünnemann *et al*., 2010). Summer temperatures range from 0°C to 30°C, winter temperatures from -5°C to as low as -40°C. The Tso Khar is a land locked lake, fed by several glacier streams originating from high mountain glaciers. The southern streams are almost dry but show well braided stream channel features, while the southern streams are almost perennial. The southern streams, however, first enter into the Startspuk Tso where from the water is drained into the Tso Khar lake through a meandering channel 6 to 8 meters in width and 2.5 km long. There are a number of freshwater and hot springs within and around the periphery of the lake basin. Geologically the catchment of the Tso Khar comprises of Puga formation (Pre Cambrian), Sondu formation (cretaceous to Paleocene) and Liyan formation (Miocene). The Puga formation contains mainly micrictic limestone and gypsum.

The basin is a popular seasonal grazing pasture for domestic livestock, mainly yaks and horses and pashmina goats for the Champas. The arid steppe vegetation of surrounding areas is dominated by species of *Astragalus* and *Caragana*. The marshes around the larger lake contain areas with extensive deposits of natron, borax, and other salts. The basin is surrounded on all sides by peaks rising to over 7000m. Five study sites were selected in the fresh and saline water parts of the lake (Fig. 2.2; Plate 2.2.1 and 2.2.2).

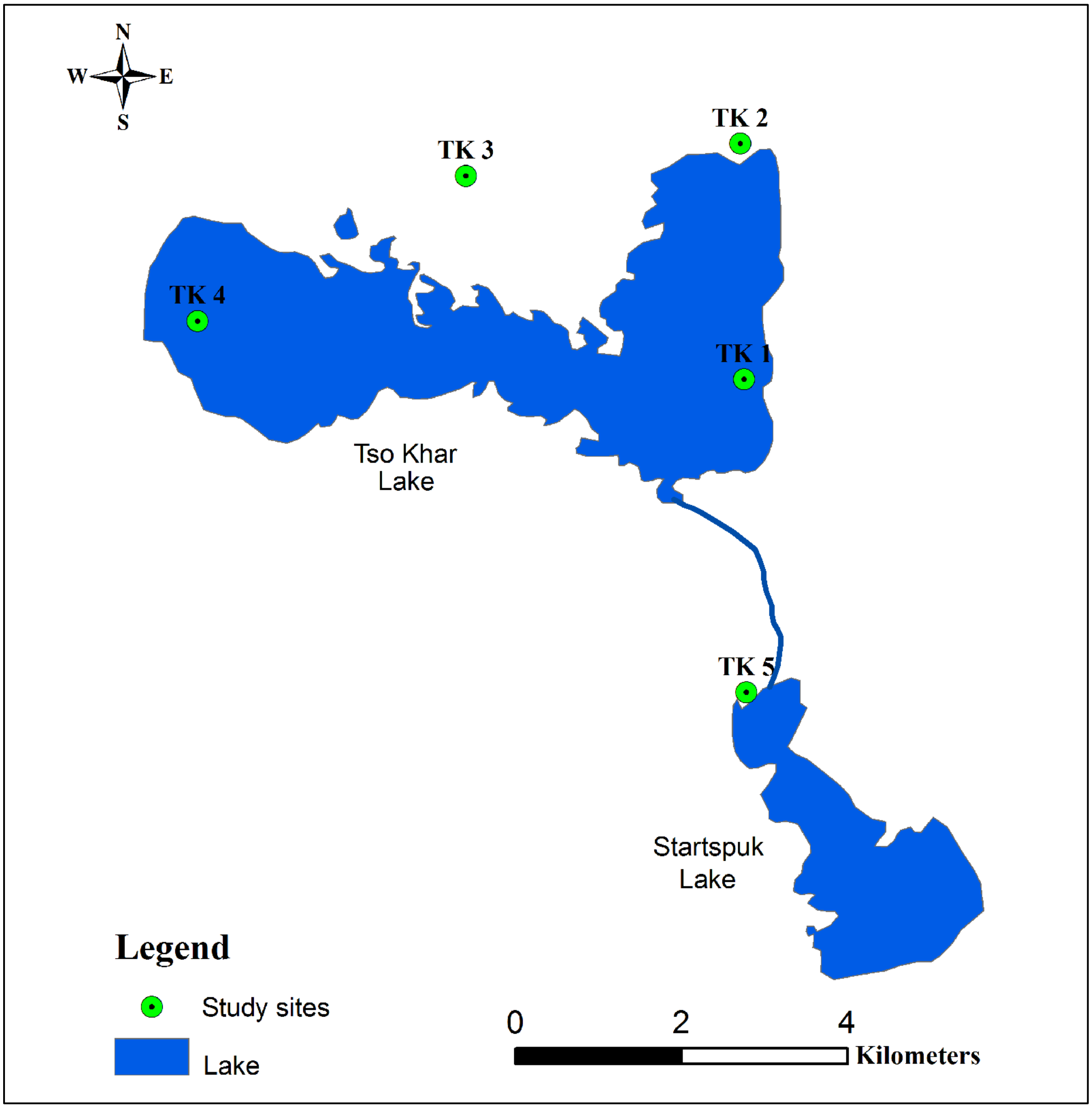


Fig. 2.2. Map of Tso Khar lake showing location of study sites

2.2.1 Study sites

Site TK1

The site was located in the northern part of the Tso Khar towards the eastern bank at 33°, 17.600' N and 78°, 03.156' E. The site was devoid of vegetation. The sediments were dark in colour with clayey texture.

Site TK2

The site was located in the Northern part near Thugji Gompa in the Tso Khar village towards the north eastern shore at 33º, 21.467' N and 78º, 01.400' E. The catchment area was covered by the green meadows.

Site TK3

This site was located in the spring adjacent to salt zone on its north western side having coordinates of 33º, 19.500' N and 77º, 55.417' E. The water of the spring is used by the people for drinking purposes. The adjacent area is used as camping site by the tourists and local shepherds.

Site TK4

It was located in the northern part of the Tso Khar on western side at 33º, 19.450' N and 77º, 57.500' E. The site was devoid of vegetation. The sediments were brown in colour with clayey texture.

Site TK5

It was located in the fresh water (southern) part of the Tso Khar in front of watching tower at 33º, 16.300' N and 78º, and 01.972' E. The site has a luxuriant growth of macrophytes. The sediments in this area were brown in colour with loamy texture.

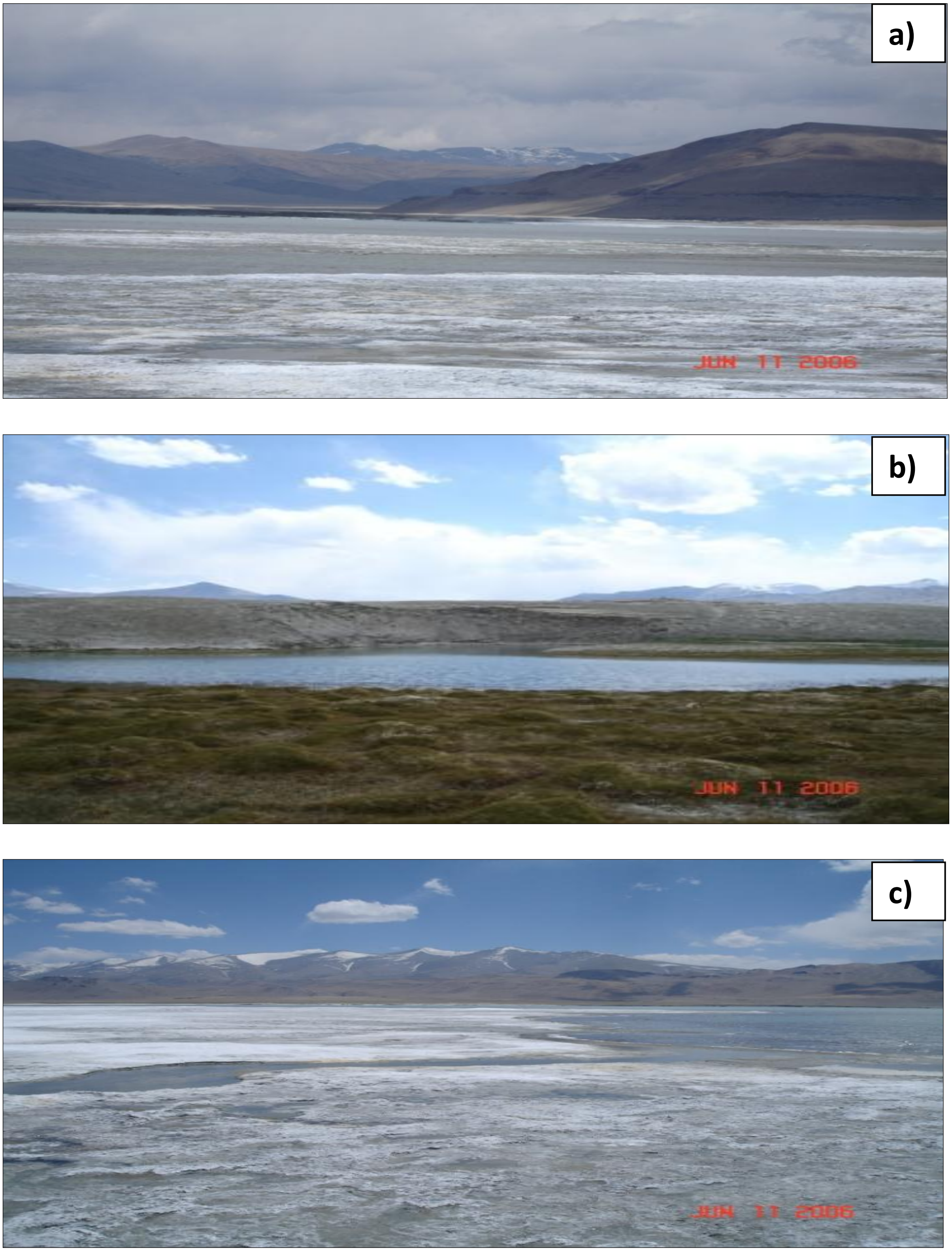


Plate 2.2.1. Location of study sites in Tso Khar Lake: a) TK1; b) TK2; c) TK4

Plate 2.2.2. Location of study sites in Tso Khar Lake: d, e and f) TK5

2.3 Manasbal Lake

Manasbal lake is the deepest freshwater valley lake of Kashmir, having an area of 2.8km^2, situated about 32km northwest of Srinagar city. The lake lies at an altitude of about 1584 a.m.s.l. between 34°15'and 34°16.534' N latitude and 74° 40' and 74° 42.530' E longitude. Almost whole of eastern part of its catchment is a range of very high mountains which are mostly rugged and bare with several limestone quarries. On the north east there is the drug research form and fisheries farm. On the southern side is a low range of hills, extending from the lofty limestone mountain in the east, with a conical peak called Ahatang about 1920 a.m.s.l.

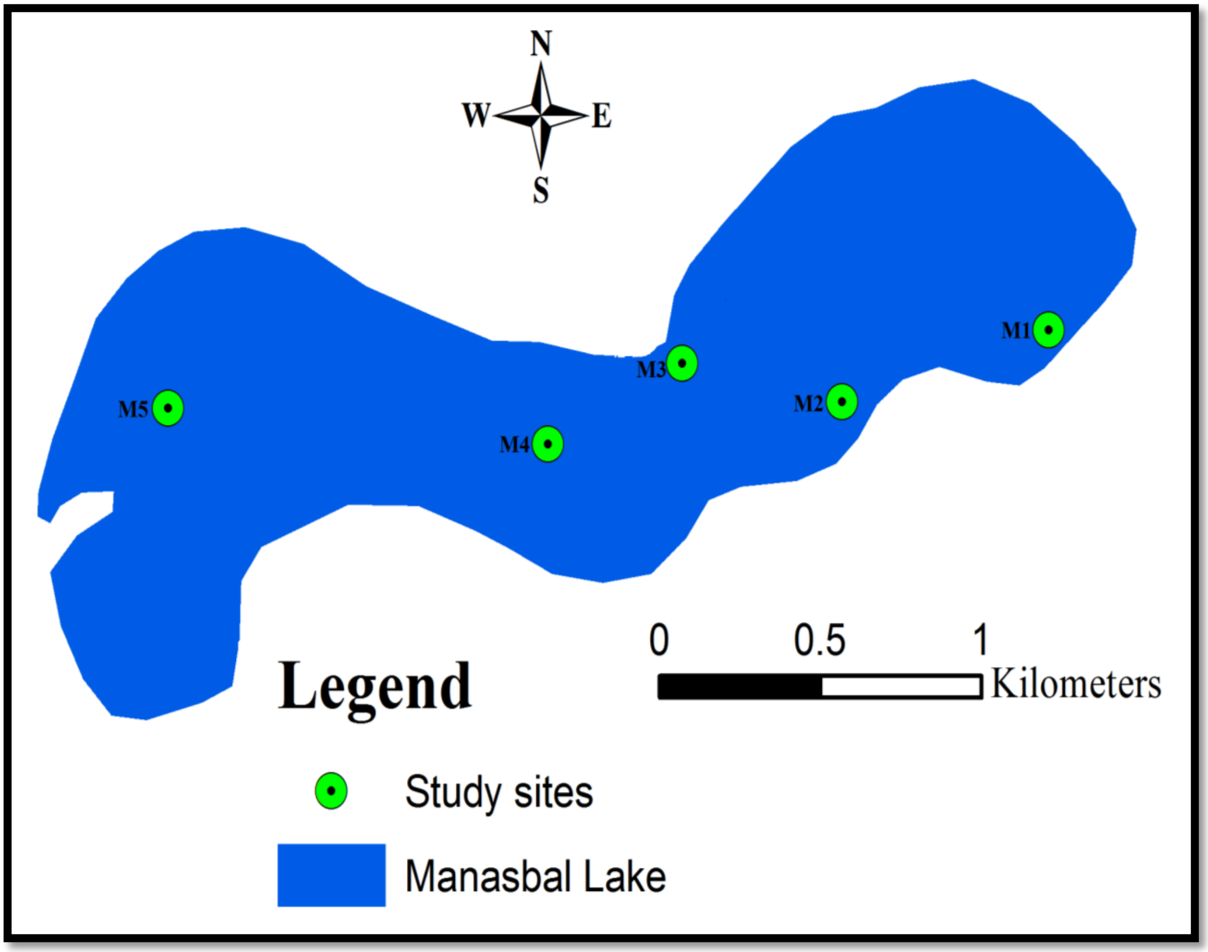


Fig 2.3. Map of Manasbal lake showing location different study sites

The water of the lake is chiefly derived from springs spread throughout the lake bed. The lake is also fed by a small irrigation stream on the eastern side of lake (called Lar kull). This cold water stream takes off from Sind nallah and irrigates the field throughout its course. A small branch of this stream drains its water into the lake from spring to autumn. The lake is connected to river Jhelum by a channel called Nunnyar Nallah which is 1.6 km long and leaves the lake on its western side and runs south direction to join the river below the village Sumbal.

2.3.1 Study sites

On the basis of habitats available in the lake six study sites were selected for collection of data (Fig. 2.3; Plate 2.3.1 and 2.3.2).

Site M1

The site was located near the inlet of the lake at 34º, 15.279' N and 74º, 41.352'E. The site has luxuriant growth of submerged macrophytes. The lake shore was covered with willow plants. The sediments were brown in colour with silty texture.

Site M2

This site was located near Koundabal village at 34º, 15.061' N and 74º, 41.057'E. The site was used by the local villagers for washing clothes and receives a drain from the village. This was most degraded site of lake. The sediments at this site were black in colour with clayey texture.

Site M3

The site was located in the littoral area near Jarogabal at 34º, 15.040' N and 74º, 40.385' E. The site was dominated by submerged macrophytes with sparsely distributed emergents like *Phragmites* and *Typa*. The sediments were brown in colour with silty texture.

Site M4

It was located near the outlet of the lake at 34º, 15.268' N and 74, 39.117' E. The site was dominated by submerged vegetation with significant population of *Phragmites australis*. The water at this site was clear. The sediments were brown in colour and were silty in texture.

Site M5

It was located in the centre of the lake at 34º, 14.916' N and 74, 40.015' E. The site was without macrophytic vegetation. This was the deepest site of the lake. The sediments were black in colour and with clayey in texture**.** The bottom of this site was designated as **TM5b**.

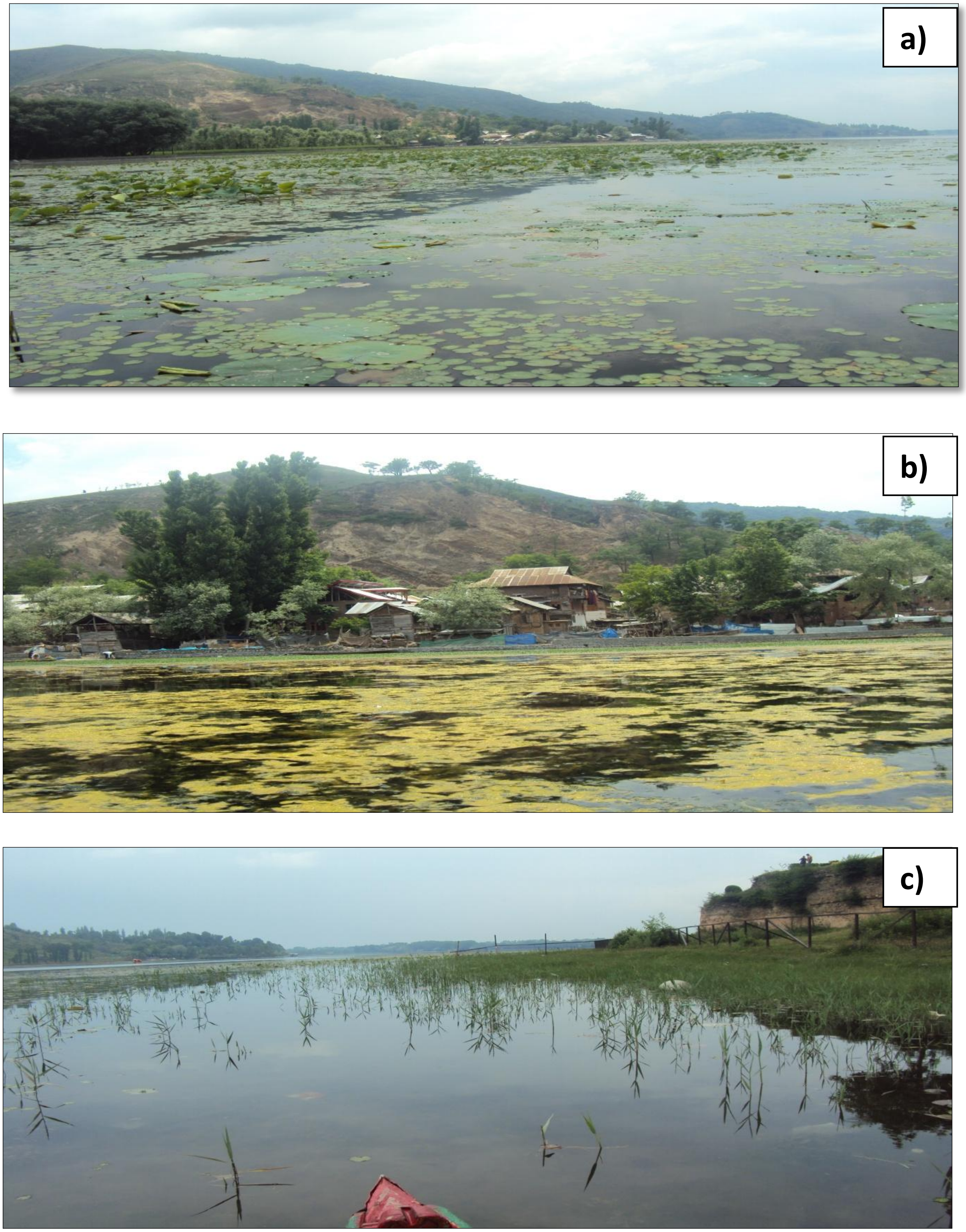


Plate 2.3.1. Location of study sites in Manasbal lake: a) M1; b) M2; c) M3

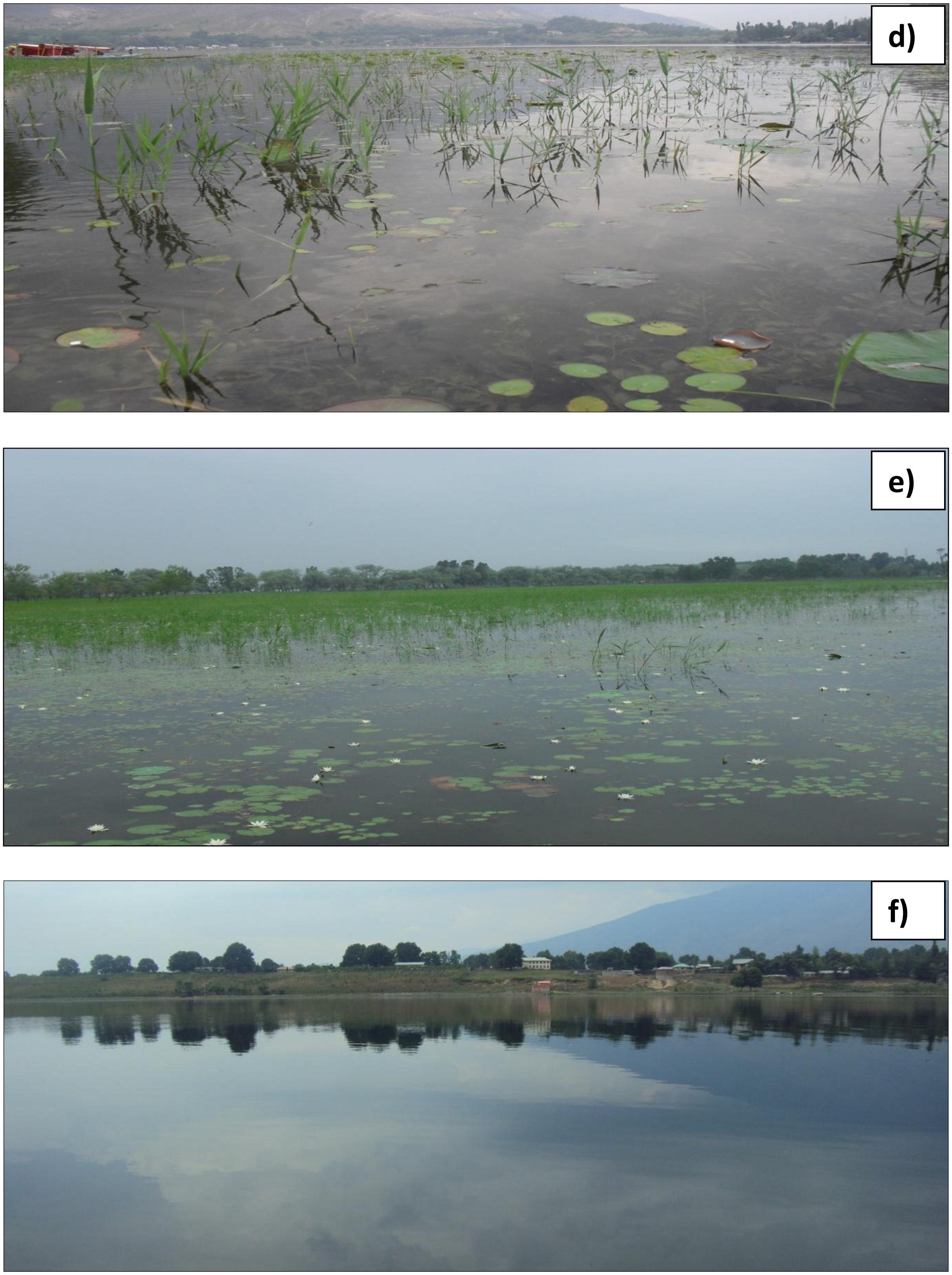


Plate 2.3.1. Location of study sites in Manasbal lake: d) M3; e) M4; f) M5

Chapter 3

REVIEW OF LITERATURE

3. REVIEW OF LITERATURE

The abundance and distribution of macrophytes in aquatic habitats are found to be influenced by myriad of factors like Depth (Spence, 1982; Anderson and Kalff, 1986: Hrivnák *et al.*, 2006), eutrophication (Moyle, 1945; Hutchinson, 1967; Pip, 1979; Lachavanne,1985 Rossette, 1991; Raven, 1998; Vestergaad and Sand–Jenson, 2000; Murphy, 2002; Nurminnen, 2003; Maemets and Freiberg, 2005), acidification (Roelof, 1983; Arts *et al.*, 1990; Nixdorf *et al.*, 2001; Arts, 2002) and sediment characteristics (Pearsall,1920, 21; Misra,1938; Denny, 1980; Barko and Smart, 1981ab; Anderson and Kalff, 1986; Koch *et at.*,1990; Van-wijck *et al.*,1992; Smolders *et al.*,1995; Holmer *et al.*, 2005). However, role of geochemistry of lakes in structuring the macrophytic community has received little attention from the researchers. Voluminous literature is also available on the characteristics of macrophytic vegetation of lakes in Kashmir valley (Zutshi and Kaul, 1963; Kaul and Zutshi, 1966; Zutshi, 1968; Kaul and Vass, 1970; Zutshi and Vass, 1971; Kaul *et al.*, 1978; Kak, 1978; Handoo, 1978; Zutshi and Wanganeo, 1979; Pandit, 1984, 1992,1996; Khan, 2000, 2008; Pandit, 2001, 2002; Rather and Pandit, 2005, 2006; Pandit and Kumar, 2006), there are only few reports from lakes of Ladakh (Hutchinson,1933; Hutchinson *et al.*, 1943; Gopal *et al.*, 2002). In the following pages important contribution made by different workers on the subject in the last 30 years has been reviewed.

Rastogi (1976) assessed the geochemical characteristics of Lake Tso Khar in the Ladakh Himalayas. He reported that diluted inflowing water gradually gets concentrated while moving westwards, however, high calcium content of inflowing waters get precipitated immediately after entering the lake. Eugster and Jones (1979) found that initial Ca+Mg/HCO_3 ratio is a key factor which regulates chemical composition of saline lakes. The high Ca+Mg/HCO_3 ratio (> 1) in water leads to evolution of chloride or sulfato-chloride lakes, whereas low ratio (1<) favours the formation of alkaline soda lakes. They reported that saline lakes are depleted in Ca due to precipitation of $CaCO_3$ and enriched in sodium and chloride ions because of their conservative nature.

Wiegleb (1981) found that vegetation samples from Lower Saxony, Germany, were more related to the physico-chemical type of the water course (acidic or base-rich) than to water quality.

Carignan (1982) while working on relative importance of roots on phosphorus uptake by aquatic macrophytes concluded that plants absorb their nutrients from interstitial water which is dependent on the concentration ratios of interstitial and overlying water column. Barko and Smart (1983) examined the growth of three submerged (*M. spicatum, H. verticillata* and *E.canadesis*) and three emergents (*M. aquaticun, P. nodosus* and *S.latifolia*) macrophytes in laboratory conditions on different sediments with varying organic matter. They found that growth of all macrophytes species was negatively correlated with organic matter. The emergents showed low growth inhibition than submerged due to greater root zone oxidizing ability.

Pokorny *et al.* (1984) studied the production ecology of *Elodea canadensis* in Czechoslovakia. He observed low values of pH, organic matter, nitrate, phosphate, and cations in water as well as in sediments colonized by *E. canadensis* as compared to open waters, however, the concentration of magnesium remain unchanged. Pomogyi *et al.* (1984) studied the nutrient leaching from dead and living plants of *Ceratophyllum demersum* in Hungry and concluded that phosphorus leached faster from dead plants than living plants whereas the leaching of carbon was equal in dead and living plants.

Agami *et al.* (1984) while investigating the seasonal variations in growth capacity of *Najas marina* as function of various water depths at the Yorkon springs in Israel reported that light attenuation limited the growth of *N. marina* in these springs. Ozimek and Kowalezewski (1984) observed that eutrophication of Lake Mikolajskic in Poland has altered the distribution and frequency of submerged macrophytes. They also found that eutrophication has altered the dominance of lake vegetation from *Chara* to *Potamogeton* type.

Toxological effects of NaCl and KCl on *Cyprus involucrate* was carried out by Hockings (1985). The author found that salinities of 50mM, NaCl, and 100mM, KCl has negligible effect on the growth, while the salinities of 100mM, NaCl and 200mM, KCl showed significant symptoms of salt toxicity. The NaCl salinity was more damaging than KCl and Cl ion was more toxic to plant growth than K ion.

Carter *et al.* (1985) while working on abundance and distribution of submerged macrophytes in tidal Potomac River suggested that nutrient enrichment and poor light were responsible for disappearance of submerged macrophytes. The nutrient dynamics in littoral sediments of lake Memphremagog, Germany colonised by *Myriophyllum spicatum* was carried out by Carignan (1985). He observed high concentration of phosphorus, exchangeable ammonia, calcium and potassium in pore water of colonised sediments as compared to un-colonised sediments.

Nichols and Shaw (1986) reviewed the ecological life histories of *Myriophyllum spicatum, Potamogeton crispus* in North America. They observed that both the species grow on variety of sediment types; however their best growth was noticed on fine sediments with 10-25 % organic matter. They also found that both the species have broad range of tolerance to varied water chemistry, but are regarded as characteristic species of hard, nutrient rich alkaline waters. Dale (1986) studied the depth distribution of aquatic macrophytes in different lakes of Ontario, Canada. He observed that under high light penetration, the maximum depth at which macrophytes occur is frequently limited by water temperature and under optimum temperature conditions plant growth is limited by turbidity, under such conditions the area is occupied by those macrophytes (*Cerotophyllum demersum, chrales* and *Utricularia*) which do not require photosynthetic oxygen for root growth.

Wilson and Keddy (1986) found that macrophytic species with low competition ability were present on nutrient poor sites while as species with high competitive ability were found in nutrient rich sites. Anderson and Kalff (1986) reported that submerged aquatic plant distribution in lake Memphremagog (Canada) was not related to sediment characteristics. However, the authors found positive relationship between biomass of macrophytes and sediment characteristics and concluded that nutrient shortage prevents the competition and allows the coexistence of many species. Barko *et al*. (1986) reviewed the effect of environmental factors on distribution, species composition and productivity of submerged macrophyte communities. They found that light was a major factor which determines the distribution of macrophytes in the lakes. The reduction in light by plankton and suspended material produced the seasonal changes in dominance and interspecific competition whereas nutrient limitation was shown to decrease the productivity of macrophytes. The study also showed that sediment properties have significant effect on macrophytic distribution. Sediment texture affect the rooting of plants, low organic matter stimulates the growth whereas high concentration of organic matter reduced the growth of plants. High concentration of soluble iron, manganese and hydrogen sulphide in sediments was found to be toxic and inhibited the growth of macrophytes.

Barko and Smart (1986) studied the growth of *Myriophyllum spicatum* and *Hydrilla verticillata* on 40 different sediments from 17 geographically widespread North American lakes. The study showed 10 to 20-fold declines in growth with increasing sediment organic matter and sand fraction in sediment. The growth inhibition of *Hydrilla* was more than *Myriophyllum* which indicated its sensitive nature.

De-Decker and Williams (1988) reported that saline lakes of western Victoria were oligotrophic on the basis of nitrate-nitrogen, however, on the basis of total phosphorus lakes are considered as eutrophic. The authors concluded that saline lakes are limited by nitrogen rather than phosphorus. Kipphut (1988) reviewed the role of the metal-rich sediments within Toolik Lake in regulating fluxes of phosphate and ammonium to the overlying waters. The oxidizing superficial sediments strongly adsorb phosphate and ammonium ions thus reduce the fluxes of ammonium and phosphate to overlying waters.

Barko *et al.* (1988) reported that *Valliseneria* out competes *Hydrilla* at lower light intensities and sediment fertility, whereas higher sediment fertility favoured *Valliseneria* over *Hydrilla.* Zutshi and Waganeo (1989) worked on nutrient dynamic and trophic status of valley lakes. They observed that net balance of phosphorus and nitrogen was much higher in urban lakes in comparison to rural lakes. Kaul *et al.* (1989) conducted studies on hydrochemistry of three Kashmir Himalayan lakes (Khanpur, Trigam and Tilwan). They observed that waters were alkaline and calcium rich with varied Ca: Mg ratios ranging from 4:1 (Khanpur) to 1:1(Trigam). Kovacs *et al*. (1989) recorded great quantities of organic matter deposited in *Phragmites* reed beds in Lake Balaton and in Lake Velence in Hungary. They found that a loose and deep organic matter layer in sediment produced permanent anoxic conditions and accumulation of hydrogen sulphide, which was injurious to the underwater parts of reeds. The author regarded acetic acid as the most harmful fatty acid and suggested that it could be responsible for reed death in lakes.

Kilham (1990) while assessing the mechanism controlling chemical composition of African waters found that rock dominance and evaporation-crystallization are main process controlling chemistry of African waters whereas atmospheric precipitation has insignificant effects on water chemistry. Yousuf *et al*. (1990) while comparing the physicochemical parameters of 1976 with 1988 of Manasbal Lake concluded that lake is progressing towards eutrophication. Last (1990) studied the paleochemistry and paleohydrology of Ceylon Lake in northern Great Plains of Canada and found that lake experience significant changes (30 ppt to greater than 300 ppt) in annual TDS concentration. The lake also exhibited dramatic fluctuations in ionic ratios on a seasonal basis and changed from Ma-(Mg)-SO_4-HCO_3 type in early spring to an Mg-(Na)-Cl-SO_4 type by winter.

Koch *et al*. (1990) studied the hydrogen sulphide induced growth limitations in wetland plants of North America. They observed that H_2S suppressed the activity of alcohol dehydrogenase in the root cells, which decreased the total adenine nucleotide pool (ATP, ADP, AMP), and adenylate energy ratio. The author attributed limited growth of macrophytes in H_2S sediments to decreased energy dependent uptake of ammonia. Grillas (1990) investigated submerged macrophyte assemblages in the marshes of the Camargue (France) and found that *Callitriche sp*. *Ranunculus sp*. and *Tolypella sp.* dominated communities in temporarily flooded oligohaline marshes whereas permanently flooded marshes are dominated by *Potamogeton sp*. and *Myriophyllum spicatum.*

Principal determinants of aquatic macrophytic richness in 641 northern European lakes were studied by Roselette (1991). He found that meso-eutrophic lakes with alkaline pH had higher species richness than oligotrophic and hyper-eutrophic lakes with low pH. Van Dijk and Vierssen (1991) reported that net growth of *P. Pectinatus* in eutrophic Lake Valwae, Netherlands was completely ceased under high levels of shading. Medson *et al.* (1991) studied the effect of *Myriophylllum spicatum* on native vegetation in lake George in U.S.A. They observed that constant expansion of *Myriophylllum spicatum* from 1987 to 1989 has reduced the number of species in $3m^2$ grid in *Myriophyllum spicatum* beds from 20 to 9 in two years,while as average number of species per quadrat decreased from 5.5 to 2.2 in the same period.

Chambers *et al.* (1992) while working on the temporal and spatial dynamics of sediment chemistry of Pembina River, Canada found the highest concentrations of exchangeable phosphorus in the finest sediments, and the lowest in sandy sediments. Carignan and Neiff (1992) studied the nutrient dynamics in *E. cressipes* meadow in Brazil. They reported that calcium, magnesium and sodium have orthograde profiles in the meadow water whereas ammonia, dissolved reactive phosphorus and potassium retained the vertical gradient. Cornwell and Kipphut (1992) studied the biogeochemistry of Mn and Fe rich sediments of Toolik lake, Alaska, U.S.A. They found that Mn and Fe geochemistry exerts strong influence on the fluxes of phosphate and metals from sediments to overlying waters which limit the organic production of lake. Rajmankova (1992) while studying the ecology of creeping macrophytes reported that decomposition rates of macrophytes are controlled by C: N ratio. He observed that creeping macrophytes with low C: N ratio (10:1) decomposes faster than macrophytes with high C: N ratio (20:1).

Stone and English (1993) investigated the geochemical composition of suspended and bed sediments of Lake Erie tributaries particles of various sizes. They found that total phosphorus concentrations decreased with increasing particle size and most of P was associated with iron and aluminium oxides, whereas calcium contents showed uniform distribution in all particle sizes. Martinova (1993) found that the main phosphorus transformation processes occur in the top 20-30cm of freshwater sediments and was related to the decomposition of organic phosphorus and its subsequent adsorption on sediments.

The growth and morphology of *Potamogeton lucens*, *Potamogeton perfoliatus*, *Potamogeton nodosus* and *Ranunculus circinatus* were studied in relation to salinity by the van den Brink and van der Velde (1993) in lower Rheine River in Netherlands. The sodium chloride level of the main channel negatively affected biomass production and growth rates for all three *Potamogeton* species. The effects of metabolic product of cellulose bacteria on the *Hydrilla verticillata* were studied by Brenda *et al*. (1993). They found that the metabolic product was inversely related to abundance of *H. verticillata.* The product was also found have inhibitory effect on photosynthesis, distorted chloroplast and increased respiration rate.

Kok and Van der Velde (1994) attributed the limitation of macrophytic decomposition to physico-chemical characteristics of water (temperature, pH and redox potential) as well as to the biochemical properties (nutrient and fibre content) of decomposing plant material.

Palmer *et al*. (1994) summarized species-occurrence data from 1124 water bodies in England, Wales, and Scotland, and related species occurrences to alkalinity, pH, and conductivity measurements. Gacia *et al.* (1994) used a multivariate ordination analysis to study the relationship between macrophytic community composition and environmental factors and found that water chemistry (TP, nitrate, and ionic content of water), altitude, vegetation cover of the catchment, and nutrient availability are the major environmental factors which determine the macrophyte distribution in the Pyrenean lakes. They also observed that isoetids were distributed in soft waters oligotrophic lakes while, as potamids were found in relatively hard water. Chambers and Prepas (1994) determined the impact of effluent loading from sewage treatment plant on sediment chemistry of Saskatchewan River, Saskatchewan, Canada. They found effluent loading and aquatic macrophytes have caused significant changes in the chemistry of riverbed sediments. The high concentrations of pore water and sediment-bound nitrogen and phosphorus were observed in vegetated sites.

Laboratory studies were conducted by Olila and Reddy (1995) to determine the pH effect on P fractions and P sorption kinetics in oxidized sediment suspensions from two subtropical lakes (Lake Apopka and Lake Okeechobee, Florida). They observed that alkaline pH increased the water soluble P concentrations in Lake Apopka sediment suspensions but no such effect was seen on Lake Okeechobee sediment suspensions and was attributed to adsorption of P to poorly crystalline Fe and Al oxyhydroxides at $pH < 7.5$. Camarero *et al.* (1995) determined the impact of acidification on alpine lakes of Alps in Central, Southwest and Southeast Europe. The multivariate analysis revealed that water chemistry of lakes was influenced by catchment lithology, biological activity of soils in the catchment, and atmospheric deposition.

Smolders *et al*. (1996b) examined the effects of $NH4^+$ on growth, accumulation of free amino acids and nutritional status of *Stratiotes aloides* and found that elevated water column $NH4^+$ concentrations and low DO reduced the growth and vitality of *Stratiotes aloides*. The growth inhibition was related to high uptake $NH4^+$ and its subsequent incorporation in N-rich free amino acids, which requires more energy and carbon that cannot be used for growth. Sulfate reduction and organic matter decompositon in wetland soils and sediments was investigated by Devaid *et al.* (1996) and observed that sulfate reduction was limited by easily decomposible organic matter. Robach *et al*. (1996) used multivariate analysis to study the relationship between vegetation and water chemistry data from the Alsace Rhine floodplain and the Northern Vosges, France. The analysis showed that the response of macrophyte communities to nutrient enrichment was different in acidic and calcareous systems.

Whitmore *et al*. (1997) studied the water quality and sediment geochemistry of 24 lakes of Yunnan province, china. They observed significant difference in water chemistry of deep tectonic origin and shallow solution lakes. The shallow lakes had high P and N concentration than deep water lakes and were more susceptible to riparian disturbances. The authors attribute high concentrations of Ca, Mg and HCO_3 in the waters to carbonate geology. Ecology of Charophytes in lake Lake Okeechobee, Florida, was carried out by Steinman *et al.* (1997). The regression analysis showed that charophytic biomass was inversely related to water depth and positively related to Secchi depth, suggesting that irradiance strongly influences Charophytes distribution in this lake. The relationships between plant growth and sediments texture was investigated through experiments with *Myriophyllum spicatum* and *Potamogeton pectinatus* by Wertz and Weisner (1997). They found no significant relationship between macrophyte biomass and sediment density and texture. Wigand *et al.* (1997) while assessing the influence of submerged macrophytes on sediment biogeochemistry in Chesapeake Bay, U.S.A found that deep-rooted *Vallisneria americana* retained greater amounts of inorganic phosphorus, Mn and Fe in the sediments than *Hydrilla verticallata* and *Myriophyllum spicatum* due to higher root oxygenation capabilities.

Williams *et al.* (1998) reported that sodium and chloride contribute 93 % and 97% of total cations and anions respectively to lake Torres (central Australia). The ionic sequence of the lake was in the order of that Na > Mg > Ca; Cl > SO_4> CO_3. Torres and Mange (1998) also reported high contents of Na, Mg and K and low values of Ca in lake Zirahuan in Mexico. Alceocer and Hammer (1998) studied the saline lake ecosystems of Mexico and found that majority of lakes were alkaline (pH 8.5-11.5), turbid, rich in sodium chloride and had high conductivity (68-112.5mS/cm). They also observed that species diversity of macrophytes decreases as salinity increased. Herbst (1998) found that hypersalinity (50- 100g/l) reduced the benthic nitrogen fixation in Lake Mono (California) which restrained the primary production and reduced species diversity.

Garcia-Ruiz *et al.* (1998) showed that denitrification rates in 31 rivers in north-east England were strongly and positively related to the water content of sediments, percentage carbon and nitrogen of the sediments, percentage of particles size and river water conductivity, alkalinity and nitrate. House and Denison (1998) indicated that spatial differences in sediment chemistry were related to differences in sediment particle size. They attributed increase in sediment total phosphorus concentrations from winter to summer to phosphorus co-precipitation with calcite. Kupper *et al.* (1998) demonstrated that substitution of Mg^{2+} in chlorophyll molecules by metal ions such as Cu, Zn, Cd, Hg, Pb or Ni was the reason for the collapse of photosynthesis in *L. minor* and other water plants.

Temple *et al.* (1998) assessed the impact of emergent macrophytes (*Phragmites australis*, *Lythrum Salicaria* and *Typha angustifolia*) on sediment chemistry of a Hudson River marsh ecosystem. They found significant depletion of ammonium in the sediments of all the three species from spring to summer suggesting that N is the limiting nutrient for these plants. The significant drop of porewater N:P ratio from spring to summer suggests that the plants or microbes are depleting DIN faster than DIP. Mensing *et al*. (1998) evaluated anthropogenic effects on the biodiversity of riparian wetlands in the United States and noticed that shrub vegetation was most influenced by agriculture activities on adjacent land. The study also noted that wet meadow vegetation was affected by local disturbances and environmental factors such as grazing, nutrient loading and pH level.

Mosello *et al.* (1999) conducted studies on hydro-chemical evolution of two alpine lakes in relation to atmospheric deposition in Italy. He attributed low concentration of sulphate in lake waters to reduction of SO_2 in acid deposition however high deposition rates of ammonium and nitrate raised nitrate concentration in lake water. Mosello (1999) reported that snow melt (acid deposition) caused sharp decline in pH, alkalinity, calcium and other major nutrients in 23 lakes, in Europe. Panday *et al.* (1999) studied the weathering and geochemical processes in Ganga head water and found that relatively high contribution of (Ca^{2+} + Mg^{2+}) to the total cations and the very low contribution of (Na^+ + K^+) to the total cations. The cation ratios suggest that carbonate weathering is the major source of the ions in water, while the silicate weathering has insignificant effect on water chemistry.

Babu *et al.* (2000) interstitial and sediment geochemistry of waters of the Ashtamudi estuary located in the southwest coast of India. They found high concentration of N, P, and Fe in interstitial waters as compared to over lying waters. They also observed positive correlation of these nutrients with sediments and organic matter which indicate that these elements are released during the early diagenetic decomposition of organic matter trapped in estuarine muds. Mander *et al*. (2000) noticed that change in land use plays a major role in releasing phosphorus and nitrogen into aquatic environments, resulting in the eutrophication of water bodies. Vestergaard and Sand-Jensen (2000) used different multivariate analysis techniques to evaluate the distribution aquatic plant with respect to alkalinity and trophic state in Danish lakes. They found that Lakes with high alkalinity were dominated by vascular plants of the elodeid growth form, lakes of intermediate alkalinity contained elodeids and isoetid growth form, while the lakes of low alkalinity and low pH dominated by isoetids and bryophytes. The eutrophic lakes were dominated by robust elodeid species which are able to compensate for turbid conditions, while as small elodeids and slow-growing isoetid species were absent from eutrophic lakes.

Bianco *et al*. (2001) in their study on some ponds in the Castelporziano Reserve (Italy) found plant communities dominated by *Callitriche sp*. and *Ranunculus aquatilis* in temporary ponds, with turbid and eutrophic waters, whereas communities rich in *Potamogeton* species were present in permanent ponds, with transparent and oxygenated waters. Effect of *Valliseneria americana* on community structure and ecosystem function in lake macrocosm was studied by Wigand *et al*. (2000) at Louis Caldera centre Armonk, New York, USA. He observed that sediments under *Valliseneria americana* had low phosphate and iron content, but high redox potential. He also reported low level of TDS and DOC in the overlying water column in *Valliseneria americana* community.

Tait and Thaler (2000) found that acid deposition has significantly altered the water chemistry (particularly alkalinity, sulphate, nitrate and calcium content) in the lakes of Eastern Alps. Barbieri and Mosello (2000) observed that lake water chemistry is considerably affected by atmospheric loading leading to high concentration of nitrate and sulphate. Strauss and Lamberti (2000) while working on regulation of nitrification in aquatic sediments by organic carbon, found that organic carbon inhibited nitrification and that the inhibitory effect was greater when organic carbon quality was higher.

Lyons *et al.* (2001) worked on geochemistry of Issyk-Kul Lake in Kirghizstan. Their findings revealed that lake is enriched in V, Co, Cu, Mo, U, Sr, Sb, Cs, Br, Fe and Li and deficient in Mn, B, Si, and NO_3 relative to inflow rivers waters. The lake has saline water with $Na + K > Mg + Ca$ and $Cl \geq SO_4 >> HCO_3$. Hadgson *et al.* (2001) investigated the limnology of saline lakes of Raucer islands in Eastern Antarctica. They observed that waters were chloride dominated with an ionic order of Cl>Na > SO_4>K>Ca> HCO_3. The lake waters has high conductivity (3.55-131.5 mS/cm) whereas nitrate and phosphate content was very low.

Tolotti (2001) while working on trophic status of 16 high mountain lakes of Italy found that lakes had low buffering capacity, levels of mineralization and low conductive values (8-21 µS/cm). On the basis of average total phosphorus concentrations, 4 lakes were classified as ultra oligotrophic while as 12 lakes were classified as oligotrophic. Eriksson (2001) studied the effects of flow velocity and oxygen metabolism on nitrification and denitrification in macrophyte-periphyton complex and concluded that water flow and oxygen metabolism have minor effects on nitrification but have significant effects on denitrification rates in biofilms present on submerged macrophytes. Heegaard *et al*. (2001), while analyzed the relationship between occurrences of macrophytic species with Lake Environment from 574 lakes in Northern Ireland found that generalist species have wide range of tolerance to nutrients and ions (phosphorus, nitrogen, Ca, K, Si, and Mg) as compared to specialized species.

Beutel *et al.* (2001) made limnological studies on saline Walker lake, Nevada, USA. They observed that lake was well oxygenated throughout the study period, dissolved solids were dominated by sodium (31.8%), chloride (25.2%) sulphate (24.4%) and carbonate (22.3%). The lake was enriched in phosphorus and limited in nitrogen. Heijmans *et al*. (2001) carried out studies on elevated carbon dioxide and increased nitrogen deposition on bog vegetation in Netherlands and pointed out that elevated atmospheric carbon dioxide increased the height of S*phagnum magellanium* that reduces the growth of shallow rooted macrophytic species, while increased nitrogen deposition favoured the growth of shallow rooted macrophytes over *sphagnum magellanium.*

Bhat *et al.* (2001) studied the impact of effluents from SKIMS hospital, Soura on Achar lake and attributed high concentration of Na, K, P and nitrate to the draining of hospital waste into the lake. Nagid *et al.* (2001) pointed that wind induced resuspension of sediments was the main factor responsible for eutrophication in Lake Newnan in Florida. They proposed increase in water level to reduce the internal nutrient loading to lake. Rather *et al.* (2001) while working on water quality of Hokarsar wetland found low values for depth, alkalinity and pH and high values for calcium, magnesium, sodium, potassium, nitrogen and phosphorus.

Geochemistry of water and ground water in the Pantanal wetland, Brazil was studied by Barbéro *et al*. (2002). They attributed the changes in geochemical composition of waters to precipitation of calcite, Mg-calcite and the formation of Mg-silicates as waters become more saline. Roeloefs *et al.* (2002) summarised the effects of acidification on macrophytic vegetation in fresh water habitats of Norway. They found that acidification ($pH < 4.5$) ceased nitrification process, accumulate ammonia and increases CO_2 concentrations in waters which ultimately restrain the growth of macrophytic species which uptake nitrate as a dominant nitrogen source.

Pandit and Yousuf (2002) while working on six Kashmir Himalaya lakes revealed that total phosphorus and total inorganic nitrogen in epilimnetic layer are the best chemical indicators to assess trophic status of these lakes. They placed the mountain lakes, (Gangabal and Nundkuol) under oligotrophic category, rural lakes Manasbal and Malpursar, under mesotrophic while semi-urban Anchar lake under eutrophic and urban Khushhalsar Lake under hyper eutrophic category.

Translocation and growth experiments of *Potamogeton lucens* on industrial tailings in traunsee (Austria) were studied by Wychera and Humpesch (2002). The field experiments suggest that the industrial sludges are less favorable for the growth which was reflected by limited growth of *P. lucens and* less dry weight at sluges site.

Thiebaut *et al.* (2002) monitored the water quality in the Northern Vosges (NE of France) by using the diversity and trophic indices based on macrophyte communities. He found highly significant correlations between the four tested chemical variables (bicarbonate, calcium, phosphorus and ammonical nitrogen) and trophic indices, abundance and richness. Trophic indices and McIntosh's index were more effective in predicting water quality than diversity indices and provide direct information on the quality and degree of degradation of the ecosystem from which the sample was taken, whereas diversity indices did not provide such information.

Kufel and Kufel (2002) reviewed the role of charophytes as nutrients sink in shallow lakes. The charophytes indirectly affect nutrient cycling in lakes by utilizing bicarbonate ion which accompanied by precipitation of calcite during periods of intensive photosynthesis, favours immobilization of P by binding in the crystal structure or sorption on sedimenting mineral particles. Charophytes also enhance nitrification/denitrification processes in the lakes.

Khan (2003) assessed the variations in physicochemical parameters of four saline lakes in Western Victoria, Australia. He observed that lakes were alkaline (pH 8.2-9.3), turbid (30 to 659NTU), and had low values of secchi depth (7.7 - 89Cm). On the basis of nutrient status, lakes were classified as eutrophic to hyper-eutrophic and among the four lakes one lake was limited by nitrogen while the remaining three were limited by phosphorus.

Meerhoff *et al.* (2003) while studying the structural role of free floating verses submerged macrophytes in lake Podo, Southern Hemisphere (UK) observed significant difference among microhabitats of these plant communities particularly in temperature, conductivity and alkalinity, NO_3 and soluble reactive phosphorus. Temporal variations in biomass of submerged macrophytes in Lake Okeechobee, Florida were carried out by Hpson and Zimba (2003). They reported that total biomass in submerged macrophytic community was strongly influenced by water transparency and subsurface light conditions.

The geochemical study of the Dankar, Thinam and Gete lakes of the Spiti Valley was undertaken by Das and Dhiman (2003). The high (Ca+Mg): HCO_3 equivalent ratio (6.94) in Dankar lake indicated carbonate weathering, while as low (Na+K): TZ^+ ratio (0.07) showed insignificant silica dissolution in this lake. The low (Ca+Mg):HCO_3 equivalent ratio (2.09) and (Na+K): TZ^+ ratio (0.12) indicated both carbonate weathering and silicate weathering are contribution to the lake Thinam. In Lake Gete, the (Ca+Mg): HCO_3 equivalent ratio and the (Na+K): TZ^+ ratio showed dissolution of both carbonate and silicate rocks in the basin. Furthermore all the lakes were enriched in Mg and depleted in Ca. Selig and Schlungbaum (2003) compared the Phosphorus release rates from two dimictic (Dudinghausen and Tiefer) lakes during the summer stratification. They found soluble reactive phosphate (SRP) and NH_4^+were released from the anoxic sediment into the water column during stratification. The P-release was higher (15-207 mg P m^{-2} y^{-1}) in Lake Dudinghausen than Lake Tiefer (22 and 55 mg P m^{-2} y^{-1}).

Van den Berg *et al.* (2003) used Logistic regression to analyses the relationship between six submerged macrophyte taxa (*Chara* spp., *Potamogeton perfoliatus*, *Potamogeton pectinatus*, *Potamogeton pusillus*, *Myriophyllum spicatum*, *Alisma gramineu)* and four environmental variables (turbidity, effective wind fetch, and water depth and sediment silt percentage) in lake, Veluwemeer. The authors found that water depth and light extinction were the most important factors determining the occurrence of all studied species. The effective wind fetch had a moderate effect and sediment silt had an insignificant effect on the occurrence of macrophytes. Preston *et al*. (2003) studied the long term impact of urbanization on aquatic plants in Cambridge and river Cam. They observed 35% of native aquatic plant species were extinct due to pollution and transformation of riparian pastures into suburban open spaces.

Redox chemistry in the root zone of salt marsh sediments in Tagus estuary Portugal was studied by Sundby *et al*. (2003). They observed high precipitatation of Fe oxides when roots infiltrate and supply high oxygen to anoxic Fe (II) containing sediment in spring. The authors did not find such precipitation in summer due to unavailability of Fe (II) or in winter when oxygen was unavailable. The relationship between catchment characteristics and lake water chemistry of 30 upland lakes of U.K was examined by Maberly *et al*. (2003). They found that catchment vegetation characteristics (conifers, woodland, pasture and shrub) had significant on water chemistry (DON, DOC, DIN, and TDP) of the lakes.

Takamura *et al*. (2003) studied the effect of macrophytes on water quality in three shallow lakes of Japan. They reported that *Trapa japonica* had wide tolerance range to nutritional levels than *Polygonum amphibium*. The concentration of DO, nitrate, nitrite and soluble reactive phosphorus were lower in *Trapa* stands as compared to other vegetation stands. Hupfer and Dollan (2003) studied the phosphorus retention mechanisms in sediments of Lake Müggelsee Germany after re-colonisation by *Potamogeton crispus* and *Elodea canadensis* under laboratory conditions. They found a sharp redox-gradient in sediment at root surface oxidised ferrous iron to ferric iron which bound substantial portions of phosphorus.

Liikanen *et al.* (2003) studied the nutrient dynamics in the sediments of the eutrophic, boreal Lake Kevätön in Finland. The authors found high fluxes of NH_4^+ and P from the deep profundal sediments with the highest mineralization rate to overlying water column. The fluxes of NH_4^+ and P were negatively correlated with the overlying water O_2 concentration and the sediment redox potential, and positively with the carbon mineralization rate and the sediment O_2 consumption.

Kufel *et al.* (2004) studied the in situ decomposition of *Ceratophyllum demersum, Menyanthes trifoliate* and *Nuphar lutea* in three small mid-forest lakes with different pH and nutrient content in Poland. They observed that decomposition of *C. demersum* and *M. trifoliate* plants was faster in acidic waters than in alkaline waters whereas decomposition of *Nuphar lutea* was the fastest and was independent of pH.

Kundangar and Abu-Baker (2004) while comparing the past limnological data of Dal lake with present, reported a progressive increase in various chemical parameters viz specific conductivity, total conductivity, sodium and potassium while considerable increase was observed in silicate, nitrate nitrogen, ammonical nitrogen and that of total nitrogen. Dissolved oxygen showed gradual decline whereas no significant change was observed in pH.

Xie *et al.* (2004) reported that higher nutrient concentration is an important factor in controlling the decomposition rate of macrophytes. The authors observed that nutrient requirements of decomposers exceeded the nutrient supply from the decomposing plant material.

Cao *et al.* (2004) found that high water column NH_4^+–N concentrations (1–20mgL^{-1}) significantly decreased soluble carbohydrate (SC) content and increased free amino acids (FAA) content of *P. crispus* in an acute exposure experiment.

Fractionation of heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) was performed on bottom sediment of river Odra (Germany / Poland) by Głosińska *et al.* (2004). The observed the majority of heavy metals (Zn, Mn, Fe, Cr and Ni) were bound to hydrated iron and manganese oxides, whereas significant amounts Cd, Pb, Ni and Zn, were bound to carbonates. Furthermore about 85-97% of Ni, Mn, Cr and Cu were potentially bioavailable which indicated that metals are not permanently immobilized in the bottom sediments. Last and Ginn (2005) assessed the influence of seasonal variability of hydrologic cycle on saline lakes of Great Plains of western, Canada. They observed that 85% of lakes showed remarkable changes in ion concentrations and ionic ratios by seasonal fluctuations in water levels.

Boedeltje *et al.* (2005) evaluated combined effects of water column nitrate enrichment, sediment type and irradiance on *Potamogeton alpines* and observed that high water column NO_3 concentrations, low light availability and anoxic, muddy sediments are key factors hampering growth of rooted submerged plants in shallow, eutrophic fresh water lakes. Maemets and Friberg (2005) investigated long and short term changes in macrophytic vegetation in strongly stratified hyper eutrophic lake Vereni, Estonia. The study revealed that strong eutrophication has changed the vegetation from *Myriophyllu –Potamogeton* type to *Ceratophyllum-Lemma* type from1984 to 1988 due to formation of loose organic rich sediments. The decrease in water level in 1998 facilitated rapid mineralization of sediments which favoured dominance of *Ranunculus cincinnatus* in the lake. The effects of floating-leaved, submerged and emergent macrophytes on sediment resuspension and internal phosphorus loading were studied in the shallow Kirkkojarvi basin in Finland by Nurminen and Nurminen (2005). The authors observed that all the three life forms considerably reduced sediment resuspension compared with non-vegetated areas. The submerged (*Ceratophyllum demersum*, *Potamogeton obtusifolius*, *Ranunculus circinatus*) and emergent (*Typha angustifolia*) plants, showed average resuspension rate of 43% than in the adjacent open water. The floating-leaved, submerged and emergent plants reduced internal phosphorus loading by 21, 12 and 26 mg m^2 /d respectively as compared to non-vegetated area.

Saenger *et al*. (2006) surveyed the inland lakes and saline pond of Christmas Island and Teraina islands of republic of Kiribati and found that dissolved oxygen (DO) and pH values were inversely related to salinity. Hypersaline lakes were hypoxic and have neutral to alkaline pH. They also reported high precipitation rates of calcite, gypsum, halite and a variety of chlorides which reduced the Ca^{2+}, Na^+, and K^+ content of waters. The expansion and decline of Charophyte communities in 11 lakes of Sejny Lake District (north-eastern Poland), was studied by Kłosowski *et al*. (2006). They observed that Chara species disappeared completely from some lakes and were replaced by Potametea (mainly *Nupharo-Nymphaeetum albae* and *Ceratophylletum demersi*) due to high phosphorus and DIC concentration. They also found negative correlation between phosphorus, pH and turbidity in these lakes.

Kian *et al*. (2006) while working on phosphorus speciation in three submerged macrophytes found that more than 80% of total phosphorus in *Najas marina* and *Vallisnerea gigantea* was present in bioavailable form, 19% was represented by organic phosphorus and less than 1%was found as calcium bound. However, in *Chara fibrosa* major portion of total phosphorus was represented by organic phosphorus (41%), 46% was bioavailable and 15% was calcium bound. Shilla *et al.* (2006) studied the decomposition and nutrient dynamics of submerged macrophytes in Myall Lake, Australia and found that water column exhibited low nutrient concentrations during growth phase, while significant increase in water column nutrients was observed during decay period.

Guangwei *et al*. (2006) studied the geochemical forms and bioavailability of phosphorus from the sediments of 25 lakes in the middle and lower reaches of Yangtze River. They observed significantly positive relationship of sediment exchangeable phosphorus with total phosphorus (TP), dissolved total phosphorus (DTP) and soluble reactive phosphorus (SRP) contents in the lake water. The major portion of phosphorus was associated with Fe (Fe-P), detrital apatite (De-P), and occluded (Oc-P) fractions. Furthermore the bioavailable phosphorus ((Bio-P)) content was lower in macrophytic dominant sites than non macrophytic sites. Jeelani and Shah (2006) investigated geochemical characteristics of Dal Lake. Their findings revealed geochemical characteristics of lake water is influenced by weathering of carbonate and silicious rocks of catchment area. However the author attributed high concentration of Zn, Cu and Pb in sediments of Gagribal and Nigeen basins to anthropogenic sources.

Tolotti *et al.* (2006) conducted limnological study on alpine high altitude lakes in Italy. They categorised 75% of lakes as ultra oligotrophic on the basis of TP and observed low levels of mineralization and buffering capacity of in these lakes. Fureder *et al.* (2006) studied the relationship between water chemistry and geolithology in Alps, Austria. They observed that lakes with calcium carbonate catchment had high values of calcium, magnesium, conductivity, pH and alkalinity whereas lakes with siliceous geology depicted low levels of Ca, Mg, conductivity and alkalinity.

The relationship between the sediment geochemistry and phosphorus fluxes in a great lakes coastal marsh was studied by Mayer *et al*. (2006) and found that P fluxes sediments from to overlying water column vary from 0.57 to 5.03mg P m^{-2} day^{-1} which makes the marsh more resilient to restoration even after the reduction of the external phosphorus loading.

Mony *et al*. (2006) studied the ecological requirements and floristic composition of three *Ranunculus* communities in North-eastern France and concluded that water alkalinity, conductivity, and ANC were key parameters which separate *Ranunculus fluitans* community from *Ranunculus peltatus* and *Ranunculus penicillans*. *Ranunculus fluitans* community was characterised by high species richness and low evenness whereas, *Ranunculus peltatus* and *Ranunculus penicillan* communities were characterised by high evenness and low species richness.

Zak *et al.* (2006) studied the sulfate mediated phosphorus mobilization in the sediments of river Spree NE Germany. They found high sulfate content and high temperature played a key role in P mobilization from the sediments. Jin *et al.* (2006) investigated the phosphorus release kinetics from the sediments of 9 lakes in Yangtze River region, China and found that total phosphorus (TP), organic matter (OM), Al_2O_3+Fe_2O_3 and the percentage of sand particles were the most important factors affecting the ability of phosphorus sorption. Seasonal variability of dissolved and particulate P forms of two lakes in Western Pomerania (North-East Germany) was studied by Selig *et al.* (2006). They found higher concentration of total P (93-298 μg l^{-1}) and SRP (13-74 μg l^{-1}) in the surface water of Polimictic Lake Bützow than dimictic Lake Dudinghausen (TP: 19-68 μg l^{-1}; SRP; 5-28μg l^{-1}). In the former lake, the highest values were recorded in spring and autumn, whereas in the latter the values were higher in summer.

Brenner *et al.* (2006) determined the role of submersed aquatic vegetation (SAV) in the sedimentation of organic matter (OM) and phosphorus (P) in Lake Panasoffkee, Florida (USA). The study showed that in response to increased P loading from human settlement and forest clearance, SAV and associated periphyton served as temporary sinks for soluble P by promoting P burial and retention in sediments, thus maintaining relatively clear-water, low-nutrient conditions in the lake. DE-Vincet *et al.* (2006), performed field measurements and laboratory experiments to determine the contribution of physical, biological, and chemical mechanisms to nutrient dynamics in two shallow (Lake Honda and Lake Nueva) lakes in Andalusia (Spain).The study revealed wind induced resuspension of the surface sediment favoured by its morphometry, hydrologic regime, sediment granulometry and intense organic matter mineralization increased the nutrient concentrations in lake Honda. In Lake Nueva, wind-induced resuspension was limited by coarse surface sediment and development of macrophytic beds (*Najas marina, Potamogeton pectinatus*).

Rejmankova and Houdkova (2006) found that decomposition proceeds much faster at P-enriched sites due to presence of more active and diverse decomposer community. The high salinity significantly reduces the decomposition process due to low microbial activity and diversity.

Eimanifar and Mohebbi (2007) reviewed the various aspects of hypersaline Lake Urmia and found that lake belongs to sodium- chloride- sulfate type. The cations were dominated by Na^+ and K^+, whereas anions were dominated by Cl^-.The concentration of Na^+ and Cl^- in the lake was 4 times higher than seawater. Phytotoxic effect of Cd on *Eichhornia crassipes* was carried out by Mishra *et al.* (2007). They found that Cd accumulation and toxicity to plants dependent on concentration and duration of cadmium in the water medium. Phytotoxicity caused reduction of chlorophyll, protein levels and in-vivo nitrate reductase activity of plants. Joniak *et al.* (2007) reported that 12 small water bodies situated within urban and suburban areas of Pozan city in Poland have significant difference in water chemistry between vegetation and non vegetation zones.

The influence of water level and salinity on plant assemblages of a seasonally flooded Mediterranean wetland were studied by Watt *et al*. (2007). They considered water regime and salinity as the most important environmental variable which regulate vegetation composition of seasonally flooded Mediterranean wetland. Koch *et al.* (2007) studied the Synergistic effects of high temperature and sulfide on tropical sea grass (*Halodule wrightii* and *Thalassia testudinum*) in mesocosm in Florida. They concluded that sea grass has high thermal tolerance however Synergistic effect of high sediment H_2S and high temperature lead to mortality of sea grass. Boers *et al.* (2007) found that frequent flooding and nutrient enrichment in wetlands along Des Plaines River in Wadsworth, Illinois U.S.A. favours the aggressive, flood tolerant plants, *Typha*×*glauca* (hybrid cattail), which had significantly reduced and species diversity and richness of the wetland. Moller and Martin (2007) conducted studies on distribution of eelgrass (*Zostera marina*) in the coastal waters of Estonia. The author observed decrease in occurrence of eelgrass in different water due to eutrophication. Bunluesin *et al*. (2007) reported that humic acid reduced the toxicity and accumulation of heavy metals (Cd and Zn) in *C. demersum* under laboratory conditions.

Bennett *et al*. (2007) while evaluating climatic and non climatic influences on major ion chemistry in natural and man made lakes of Nebraska, USA found that Climate control the chemistry of lakes via its influence on the hydrologic cycle, thermal structure, catchment weathering and erosion. They also reported that changes in precipitation and evaporation produced significant changes in ionic composition in lakes without outlet.

Major ion chemistry of fresh water coastal lagoon (Mangueira Lagoon) in southern Brazil was studied by Santos *et al*. (2008). They observed that lake water was enriched with Na and HCO_3 ions due to ground water which supply 50-70%

of the total $Na^+$and Cl to the Lagoon. Furthermore the low K^+ concentration in Lagoon was attributed to dominance of sands (quartz) and low content of K-feldspars in the catchment. Boschila *et al*. (2008) while working on macrophyte co-occurrence in braided flood plains of River Parana in Brazil concluded that spatial segregation of macrophytes are structured by competition and habitat preferences.

Lindholm *et al*. (2008) found that water milfoil had almost excluded plants like *Potamogeton praelongus, Potamogeton gramineus* and *Chara aspera* from the lake Österträsk, Finland. They also found that *Myriophyllum sibiricum* raised the pH values of about 10, caused oxygen supersaturation near the surface and anoxic condition in deeper layers. The high productivity of *Myriophyllum sibiricum* had changed the sediment texture from sandy to muddy.

Major ion geochemistry of Nam Co Lake and its sources, in Tibetan Plateau were investigated by Zhang *et al.* (2008). They found that lake was enriched with Mg and Na and depleted in Ca. The stream water was low in Na and K but enriched with calcium, however in lake the former elements attain dominance due to evapo-concentration effect.

Comparative effects of irradiance and phosphorus on the growth of three submerged macrophytes were made by Zhu *et al.* (2008). Their findings revealed that higher irradiance (230 mmol s^{-1} m^{-2} vs. 113 mmol s^{-1} m^{-2}) had significant positive effects on submerged macrophyte growth whereas elevated sediment phosphorus (2.1–3.3 mg g^{-1} vs. 0.7 mg g^{-1}) did not have any significant impact. The co-precipitation of phosphate with calcium carbonate in the Salton Sea, California was conducted by Rodriguez *et al.* (2008). They found that the internal loading of P was controlled by calcite precipitation which gets actively precipitated due to alkalinity production via sulfate reduction reactions. Chambers *et al.* (2008), while assessing the global biodiversity of fresh water macrophytes found that vascular macrophyte generic diversity is highest in the tropics (Afrotropics, Neotropics and Orient) and lower in the Nearctic, Palaeoarctic and

Australasia and species diversity was highest in the Neotropics followed by the Orient, and Nearctic. Macrophyte distribution and species numbers decreased with latitudinal and altitudinal gain.

Bella *et al*. (2008) conducted limnological study on 21 pounds (8 permanent and 13 temporary) located in four protected areas along the Tyrrhenian coast in central Italy. They observed low species diversity in temporary ponds than permanent ones and was negatively related to nitrate concentration and depth.

Wang *et al.* (2009) found that phosphorus, Cd and Zn have antagonistic effect on two submerged macrophytes (*E. nuttallii* and *H. verticillata*). Cadmium and zinc reduced the photosynthetic efficiency and increased oxidative stress to plants. The oxidative stress induced by cadmium and zinc was partially alleviated by the addition of phosphorus. They also found that *E. nuttallii* was more sensitive than *H. verticillata* and accordingly was proposed as an indicative plant for polluted waters.

Cao *et al*. (2009) studied the carbon and nitrogen metabolism of *Potamogeton crispus*, under NH_4^+ stress and low light conditions in Lake Donghu china. They found that *P. crispus* efficiently avoid NH_4^+ accumulation in the plant tissues in short term treatment with fertile sediment, which explain its notorious abundance in eutrophic waters. However, the detoxification of NH_4^+ consumes a large amount of carbohydrates, reduces its tolerance level over an extended period and NH_4^+ induced stress was intensified under low light availability. Trolle *et al.* (2009) studied the influence of water quality and sediment geochemistry on the horizontal and vertical distribution of phosphorus and nitrogen in sediments of lake Taihu, China. A multiple stepwise linear regression revealed that the combination of sediment manganese and carbon concentrations explained 91% of the horizontal variability and 65% of the vertical variability of TP concentrations in sediment. Wang *et al.* (2009), while studying water quality of Nam Co, in Tibet found high values of pH (9.21), dissolved oxygen (8.90mg l^{-1}) and electric conductivity (1,851 $lScm^{-1}$) in surface water of the lake. Hydrochemistry of Salt

Lakes of the Qinghai-Tibet Plateau, China was studied by Zheng and Liu (2009). The pH values of the plateau lakes range from 7 to 9, indicating that the brine is neutral to alkaline and tend to decrease from the carbonate type >sodium sulfate subtype > magnesium sulfate subtype > chloride type. They also reported that geothermal springs are the major sources of the Li, B, K, Cs, and Rb in salt lakes of the Qinghai plateau.

McElarneya *et al*. (2010) evaluated the response of aquatic macrophytes in Northern Irish soft water lakes to eutrophication and dissolved organic carbon and found that large regional increase in DOC posed a threat to macrophyte abundance and diversity in these aquatic ecosystems. van Katwijk *et al*. (2010) studied the Eelgrass (*Zostera marina*) vulnerability to eutrophication in the Wadden Sea in Netherlands and concluded that sea grass is not a useful early warning bioindicator, but rather a too late bioindicator of eutrophication.

Ecotoxicological effects of aluminium and zinc on growth and antioxidants in *Lemna minor* were studied by Radic *et al.* (2010). The authors observed that metal stress increased the superoxide dismutase and peroxidases activities and decrease the catalase activity. The frond number, relative growth rates and chlorophyll were significantly decreased by Zn than by Al, which suggest high toxicity of Zn to duckweed. Hydrochemistry of lake Lago Péten Itzá,Guatemal was carried out by Perez *et al*. (2010). They found that sulfate dominated bicarbonate in anions and calcium dominates magnesium in cations. On the basis of total phosphorus the lake was assigned the meso-oligotrophic state. Furquima *et al*. (2010), while working on Pantanal Wetland, Brazil concluded that Ca, Mg, and K effectively undergo oversaturation and precipitation as the waters become more saline and are subsequently incorporated in the authigenically formed carbonates, smectites, and micas in saline lakes. The precipitation of Ca occurs as calcite and dolomite in nodules while Mg and K are mainly involved in the neoformation of Mg-smectites (stevensitic and saponitic) minerals.

Radic *et al.* (2011) studied the impact of industrial wastewater on duckweed plants in Croatia. They observed that waste waters caused reduction of duckweed growth rates, chlorophylls and carotenoid contents and peroxidase activity.

It is clear from the above literature that very little information exists on the impact of geochemistry on macrophytic vegetation dynamics in high altitude lakes. It is in this context that the present work was undertaken.

Chapter 4

MATERIALS AND METHODS

4. MATERIAL AND METHODS

4.1. Water Chemistry

The surface and bottom water samples were collected in 1liter decontaminated polyethylene bottles between 10.00 and 12.00hr from the sampling sites. Collection of water samples was started from September 2004 to November 2006. The Manasbal lake was sampled on monthly basis, whereas Tso Morari and Tso Khar lakes were sampled on seasonal basis. Prior to sample collection bottles were rinsed with the lake water to be sampled and were transported to the laboratory. The parameters like temperature, depth, and transparency were determined on spot, whereas the rest of the parameters were determined in the laboratory. The samples were stores at 4^0C till further analysis. Standard methods given in APHA (1998), Mackereth *et al*. (1978) CSIR, (1974), Golterman *et al*. (1978) were followed to assess the various physico-chemical parameters.

4.1.1. Water Temperature

Water temperature was recorded on spot by dipping the bulb of the thermometer in water sample for 1 minute under shade. The results were expressed in °C.

4.1.2. Depth

The depth was recorded by sounding the lake bottom with a standard lead weight attached to the marked rope. The results were expressed in meters.

4.1.3. Transparency

The transparency of water was recorded with the help of standard Secchi disc (diameter 20 Cm.). The mean of the depths at which the Secchi disc disappeared and reappeared was taken as water transparency. The results were expressed in meters.

4.1.4. pH

The pH was measured with the help digital pH meter (Systronics- MKVI). The pH meter was standardized against buffer solutions of pH 4 and 9.2 before used.

4.1.5. Conductivity

The digital conductivity meter (Systronics- DB-104) was employed to record the conductivity of water samples. Prior to use conductivity meter was calibrated with 0.01M KCl. The results were expressed in µScm^{-1} at 25°C.

4.1.6. Dissolved Oxygen

Winkler's method (APHA, 1998) was used for the determination of dissolved oxygen. The dissolved oxygen was fixed on spot in 300mL dissolved oxygen bottles by adding 1mL each of alkali iodide-azide and manganous sulfate. The bottle was tightly stoppered then inverted and erected for several times to mix the reagents. The precipitate formed, was dissolved by addition of 1mL of concentrated H_2SO_4 in the laboratory. 50mL of the fixed sample was titrated against 0.025N $Na_2S_2O_7$ till blue formed by addition starch disappeared. The Dissolved oxygen content was by calculated below given formula;

$$\boldsymbol{Dissoloved\ Oxygen(mgL^{-1}) = \frac{VxNxEx1000}{Volume\ of\ sample}}$$

Where, V = Volume of $Na_2S_2O_7$ used.

N = Normality of $Na_2S_2O_7$.

E = Equivalent weight of oxygen.

4.1.7. Free Carbon Dioxide

Free carbon dioxide was determined by titrating the 100ml sample against 0.02N NaOH in presence of phenolphthalein indicator (Mackereth *et al.*, 1978). The CO_2 was calculated by using formula**;**

$$\textbf{Free Carbon Dioxide (mgL}^{-1}\textbf{)} = \frac{\textbf{Tx1000}}{\textbf{Volume of sample (ml)}}$$

Where, T= Volume of NaOH used

4.1.8. Total Alkalinity

Total alkalinity was determined by titrated sample against 0.02N H_2SO_4 with phenolphthalein as indicator (pH 8.3) till colour changed from pink to colourless. Then same sample was again titrated with H_2SO_4 with methyl orange as indicator till colour changed from yellow to orange. The volume of titrant was used to estimate total alkalinity, carbonates and bicarbonates as per following formula;

$$\boldsymbol{TA\ as\ CaCO_3} = (\boldsymbol{mgL^{-1}}) = \frac{\boldsymbol{TxNx1000x50}}{\textbf{Volume of sample}}$$

$$\boldsymbol{PA\ as\ CaCO_3} = (\boldsymbol{mgL^{-1}}) = \frac{\boldsymbol{TxNx1000x50}}{\textbf{Volume of sample}}$$

Where, T = Volume of acid used in phenolphthalein and methyl orange titrations.

A = volume of acid used in phenolphthalein titration.

N = Normality (0.02) of H_2SO_4

4.1.9. Total Hardness

EDTA Titrimetric method (APHA, 1998) was followed. To 50 ml of sample 1ml ammonium buffer was added to raise its pH. Then sample was titrated against 0.01 M EDTA solution with Eriochrome black T as indicator, till colour changed from wine red to blue. Total hardness was calculated as follows;

$$\boldsymbol{Total\ Hardness\ as\ CaCO_3}\ (\boldsymbol{mgL^{-1}}) = \frac{\boldsymbol{Tx1000}}{\textbf{Volume of sample}}$$

Where, T = Volume of titrant used

4.1.10. Calcium

EDTA titrimetric method (APHA, 1998) was followed. To 50ml of sample 1ml of 2N NaOH buffer was added to raise its pH to 12. The sample was then titrated against 0.01M EDTA using murexide as indicator and the calcium content in sample was estimated by the below given formula;

$$\boldsymbol{Ca^{2+}as\ Ca\ mgL^{-1}}) = \frac{\boldsymbol{Tx400.8x1000}}{\textbf{Volume of sample}}$$

Where, T = Volume of titrant used

4.1.11. Magnesium

Magnesium was calculated as follows;

Mg^{2+} as mg/L = [Total hardness (as mg $CaCO_3$/L) –

Calcium hardness (as mg $CaCO_3$/L)] X 0.243

4.1.12. Sodium

Digital flame photometer (Systronics 130) was used to measure the concentration of sodium in samples. Instrument was calibrated against standard sodium chloride and result was expressed in mg/l after computing from known standards.

4.1.13. Potassium

Digital flame photometer (Systronics 130) was used to measure the concentration of Potassium in samples. Instrument was calibrated against standard potassium chloride and result was expressed in mg/l after computing from known standards.

4.1.14. Chloride

Argentometric method (APHA, 1998) was employed for the determination of chloride.50 ml sample was titrated against 0.0141N AgNO3 till yellow colour formed by the addition of 1ml $K_2Cr_2O_4$ indicator changed to faint brick colour. The chloride content was calculated by following formula;

$$\boldsymbol{Chloride\ (mgL^{-1}) = \frac{TxNxEx1000}{Volume\ of\ sample}}$$

Where, T = Volume of titrant ($AgNO_3$) used.

N = Normality (0.0141) of $AgNO_3$

E = Equivalent weight of Chlorine

4.1.15. Nitrate Nitrogen

Salicylate method (CSIR, 1974) was used for the estimation. 1ml of sodium Salicylate was added to 50ml of sample and subsequently evaporated to dryness on hot plate. The residue was dissolved by adding 1ml concentrated sulphuric to beaker and allowed to stand for 10 minutes. Then 6ml of distilled water and 7ml of 30% sodium hydroxide solution was added. The samples developed yellow colour and the volume of the sample solution was raised to 50 ml by adding distilled water. The absorbance of yellow colour was measured at 410nm spetrophotometrically (Systronics 106) against reagent blank and values were computed from known standards curve.

4.1.16. Ammonical Nitrogen

Phenate method (APHA, 1998) was used for the estimation of ammonia in the water samples. To 25ml sample 1ml phenol solution, 1ml sodium nitro-prusside solution, and 2.5ml oxidizing solution was added with thorough mixing. The sample was left in subdued light at room temperature for at least one hour for colour development covered with paraffin films. Colour is stable for 24 hours. Absorbance was measured at 640 nm spetrophotometrically against a reagent blank and values were computed from standards curve.

4.1.17. Total Phosphorus

The total phosphorus concentration was estimated by stannous chloride method (APHA, 1998). 50 ml sample was digested with 1 ml sulphuric acid and 5 ml nitric acid on hot plate to a volume of 1ml.The sample was then cooled and diluted with 20ml distilled water. Then sample was titrated against 1N sodium hydroxide solution with phenolphthalein as indicator, till faint pink colour appeared. Strong acid solution was used to discharge the colour and those samples which required more than 5 drops, the sample volume was reduced. The final volume was again raised to 50ml with distilled water. Then 4ml molybdate reagent and 10 drops of stannous chloride were added to sample with continuous stirring. The sample was allowed to stand for 10 minutes between 20 to 30^{o}c.After 10 minutes, but before 12 minutes, colour was measured photometrically at 690nm against reagent blank and values were computed from calibration curve.

4.1.18. Sulphate

Turbidimetric method (APHA, 1998) was used for estimation of sulphate. 20ml buffer solution was added to 100ml sample. To this barium chloride was added with continuous stirring. The absorbance was measured against reagent blank at 420nm spetrophotometrically. Values were computed from standard curve developed for each analysis separately.

4.1.19. Dissolved Silica

Molybdosilicate method (APHA, 1998) was used to determine silica in sample. In a rapid succession 1ml HCl and 2ml ammonium molybdate solution were added. Sample was then mixed and allowed to stand for 5-10 minutes, and then 2ml of oxalic acid solution was added and again mixed thoroughly. Absorbance was measured at 410nm spetro-photometrically after 2 minutes but before 15 minutes against reagent blank. Values were computed from standard curve developed for each analysis separately.

4.1.20. Total Dissolved Solids

100ml filtered sample was taken in a previously weighed china dish and evaporated to dryness at 180^{o}c in an oven for 1hour. This was followed by the cooling in a desiccator to balance the temperature and final weight of dish containing residue was taken. The increase in dish weight represented the amount of total dissolved solids and the result was expressed as;

$$\boldsymbol{TDS(mgL^{-1}) = \frac{A - B\ x\ 1000}{\text{Volume of sample}}}$$

Where, A = weight of dried residue and dish in grams.

B = weight of dish in grams.

4.2 Sediment Chemistry

Sediment samples were collected with the help of Ekman dredge from three the lakes on seasonal basis. The samples were transported to laboratory in decontaminated polyethylene bags. The analysis was carried out on wet as well dry samples. Parameters like pH, conductivity, nitrate and ammonia were immediately analyzed on wet samples whereas the rest of parameters were analyzed on air dry samples. Standard methods given in Jackson (1973) and Page *et al*. (1982) were followed to assess the chemical parameters of the sediments.

4.2.1. pH

pH was determined with the help of digital pH meter (Systronics MKVI). A 1: 2 w/v suspension was prepared from 20g of wet sediments and 40 ml of distilled water in 100ml beaker with continuous stirring. The pH of suspension was recorded by pH meter which was standardized against pH 4 and pH 9 before used.

4.2.2. Conductivity

Digital conductivity meter (DB-104) was used to record conductivity of sediment samples. A 1: 2 w/v suspension was prepared from 20g of wet sediments and 40 ml of distilled water in 100ml beaker with continuous stirring. Prior to use conductivity meter was calibrated with standard potassium chloride solution (0.01M).The results were expressed as μScm^{-1} at 25°C.

4.2.3. Organic Carbon and Organic Matter

Walkley and Black (1934) wet combustion method was used for the determination of organic carbon in sediments. 0.2g of sediments was treated with excess of standard $K_2Cr_2O_7$ in presence of concentrated sulphuric acid. The excess $K_2Cr_2O_7$, not reduced by the organic matter of the soil, was determined by back titration with standard ferrous ammonium sulphate using diphenylamine indicator. The organic carbon was calculated by below given formula:

$$\textbf{Organic carbon (\%)} \quad = \quad \frac{\mathbf{0.003 \times 10\ (B\text{-}C)}}{\mathbf{W}} \quad \mathbf{100}$$

Where w = weight of sediment.

Since it is assumed that organic carbon recovery by this method is only 77% and hence, the values obtained were multiplied by a correction factor of 1.3.

The organic matter was determined from organic carbon by assuming that organic matter contains 58% organic carbon and thus multiplying the value of organic carbon with Van Bemmelen factor of 1.724.

4.2.4. Ammonical Nitrogen

Indophenol blue method (Page *et al.*, 1982) was employed to determine exchangeable ammonia from the sediments. 2.5g of wet sediment sample was shaken for 30 minutes on mechanical shaker with 50ml 2M KCl to obtain the exchangeable ammonia. To 5ml aliquot, 1ml of EDTA, 2ml of phenol-nitroprusside and 4 ml of sodium hypochlorite were added and subsequently diluted to volume 50ml with ammonia free water. The sample was left in subdued light at room temperature for 30 minutes for colour development. After 30 minutes absorbance was measured at 640 nm spetrophotometrically (Systronics 106) against a reagent blank and values were computed from known standards.

4.2.5. Nitrate Nitrogen

Phenol-disulfonic acid method (Jackson, 1973) was used to determine the Nitrate nitrogen of sediments. 2g of sediment sample was extracted in a solution of 0.01M $CuSO_4$ containing $AgSO_4$ and was subsequently shaken on a mechanical shaker for 15 minutes. Then $Ca(OH)_2$ and $MgCO_3$ were added to precipitate AgCl and solution was further shaken for 5 minutes. Then 20 ml of the filtered extract was evaporated to dryness and allowed to cool. To this 3 ml of phenol-disulfonic acid was added and allowed to stand for 10 minutes until reaction was complete. After that 20ml of distilled water and 10ml of 6N ammonia solution was added until yellow color develops. Color intensity is measured at 420nm on a spectrophotometer (Systronics 106) against the blank solution. Concentration of nitrate was computed from standard nitrate curve.

4.2.6. Exchangeable Phosphorous

Olsen’s method was used to determine the available phosphorous in soil samples. 2.5g of soil samples were extracted with 50 ml 0.5M $NaHCO_3$ solution at pH 8.5 by shaking on a mechanical shaker for 30 minutes. 5ml aliquot was taken and adjusted to pH 5.0 with dilute H_2SO_4. Ascorbic acid method was used for color development. Intensity of the color was measured at 882nm on a spectrophotometer. The concentration of available phosphorous was obtained by comparing the absorbance with standard phosphorous curve.

4.2.7. Total Phosphorus

The total phosphorus was estimated by triacid digestion method (Jackson, 1973). A known weight of air dried sediment was digested in a mixture of three acids in the ratio of 9:4:1 (Nitric acid: Sulphuric acid: Perchloric acid) after pretreatment with nitric acid. The samples were digested till the appearance of white fumes of perchloric acid and the whiteness of the silica. The digest was allowed to cool and raised to a certain volume with distilled water and filtered through Whatman No. 1 filter paper. A suitable volume of aliquot was taken and diluted to determine the total phosphorus spectrophotometrically (Model-Systronics 106) by molybdenum blue. The concentrations were worked out from their respective standard curves and results expressed in ppm.

4.2.8. Exchangeable Calcium and Magnesium

The exchangeable calcium and magnesium were estimated by Versenate EDTA method (Jackson, 1973). The cations were extracted in 1N ammonium acetate solution by centrifugation and decantation method in a 1:10 soil extract ratio. Prior to analysis EDTA was standardized with standard Ca solution using both eriochrome black tea (EBT) and calcon as indicators.

The exchangeable calcium and magnesium were calculated by using the following formulae:

Calculation

$$\boldsymbol{Ca\ or\ Ca + Mg\ (meqL^{-1}) = \frac{V - B)xNxRx1000}{\mathrm{Wt}}}$$

$$\mathbf{Mg\ (meq/L) \quad = \quad Ca + Mg\ (meq/L) - Ca\ (meq/L)}$$

Where: V = Volume of EDTA titrated for the sample (mL)

B = Blank titration volume (mL)

R = Ratio between total vol. of the extract and extract vol. used for titration.

N = Normality of EDTA solution.

Wt= Weight of air-dry soil (g)

The concentrations were then converted and expressed in cmol(+) /kg

4.2.9. Exchangeable Sodium and Potassium

Digital flame photometer (Systronics 130) was used to measure the concentration of exchangeable sodium and potassium in samples. Instrument was calibrated against standard sodium chloride and result was expressed in mg/l after computing from known standards. The Na and K ions were extracted from sediments in 1N ammonium acetate solution by centrifuge method (Page *et al.*, 1982)

4.3 Aquatic Vegetation Analysis

The phytosociological features of macrophytes were worked out on monthly basis from January to December 2006. Quadrat method was followed for the macrophytic study. Quadrats of definite size (1m^2) were laid randomly at the fours selected sites. For the submergeds, Ekman dredge was used to collect the plants falling in the quadrat. The species were identified using standard taxonomic works (Fasset, 2002; Kak, 1978). The macrophytes occurring in each quadrat/sampling unit were listed species wise and the number of individuals of each species was counted for various community characteristics of macrophytes (Misra, 1968). For *Nymphoides peltatum* three leaves were taken to represent one individual while for *Nelumbo nucifera*, *Nymphaea alba* and *Euryale ferox* one leaf was taken to represent one individual. In case of *Ceratophyllum demersum* (a free-floating submerged species) one meter length of the plant along with branches was taken as a unit to represent one individual. The genus *Lemna* (*L. minor*, *L. major* and *L. trisulca*) was taken as single species for various phytosociological.

4.3.1. Frequency and Relative Frequency

$$\boldsymbol{Frequency\ (F)\ = \frac{No.of\ quadrats\ in\ which\ the\ species\ occured}{Total\ No.of\ quadrats\ studied} \times 100}$$

$$\boldsymbol{Relative\ Frequency\ (RF)\ = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species} \times 100}$$

4.3.2. Density and Relative Density

The density and relative density were calculated by using following methods:

$$\boldsymbol{Density\ (D)\ =\ \frac{No.of\ individuals\ of\ a\ species}{Total\ No.of\ quadrats\ studied}}$$

$$\boldsymbol{Relative\ Density\ (RD) = \frac{Density\ of\ a\ species}{Total\ density\ of\ all\ species} \times 100}$$

4.3.3. Abundance and Relative Abundance

The abundance and relative abundance were worked out by the following method:

$$\boldsymbol{Abundance\ (A) = \frac{Total\ No.of\ individuals\ of\ a\ species}{No.of\ quadrats\ in\ which\ the\ species\ occured}}$$

$$\boldsymbol{Relative\ Abundance\ (RA) = \frac{Abundance\ of\ a\ species}{Abundance\ of\ all\ species} \times 100}$$

4.3.4. Importance Value Index

The importance value index (IVI) was calculated by using the following formula:

$$\textbf{Importance Value Index (IVI)} = \boldsymbol{RF + RD + RA}$$

Where, RF = Relative Frequency; RD = Relative Density; RA = Relative Abundance

4.3.5. Species Diversity

Species diversity was determined by using information statistics index (Shannon-Weiner, 1949) given as:

$$\mathbf{H}^{/} = -\sum_{i=1}^{i=s}\left(\frac{ni}{N}\right)\log e\left(\frac{ni}{N}\right)$$

$H^{/}$ = Index of species diversity

n_i = Density of one species

N = Density of all the species

e = Base of natural logarithm $\log e\left(\frac{ni}{N}\right) = 2.303 \log_{10}\left(\frac{ni}{N}\right)$

$\sum_{i=1}^{i=s}$ = Addition of the expression for values of i from $i = 1$ to $i = S$

4.3.6. Species Richness/Variety Component

The species richness of macrophytes was determined by counting the number of species.

4.3.7. Index of Similarity

The Index of similarity (S0 was calculated according to Sorensen (1948), with the formula given below:

$$\mathbf{S = \frac{2C}{A+B} \times 100}$$

Where A and B represent the numbers of species at site A and B respectively, and C is the number of species common to both sites.

4.4 Statistical Analysis

The SPSS 12 software and Microsoft Excel was used to calculate mean, standard difference, correlation coefficient, IVI and diversity indices. The analysis of variance (ANOVA) test was used to work out whether the spatial and temporal variations in physicochemical parameters of water and sediments were statistically significant or not. Significant difference of mean values was performed by the Tukey's honest square difference test at 5% level of significance ($P \leq 0.05$). Bivariate correlations (Pearson, two tailed) were used to explore the relationships between different physical and chemical properties of water and sediments. The impact of geochemistry on macrophytic vegetation was worked out by analysis of variance between vegetated and non vegetated sites in the three lakes.

Chapter 5

RESULTS

5. RESULTS

The physico-chemical characteristics of water of the three lakes differed with each other, reflecting variation in source rock, source of inlet water, productivity, and photosynthetic activity in the lakes. The results are depicted lake wise as follows.

5.1. Physico-chemical features of water

5.1.1. Tso Morari Lake

5.1.1a. Air and Water Temperature

The minimum (-7°C) and maximum (27°C) air temperature was observed at site TM2 and TM3 in December 2005 and August 2006 respectively. The mean air temperature varied from a low of 6.6±10.6°C at site TM1 to a high of 15.2±9.2°C at site TM6 (Table 5.1.1a_1). Most of the sites (TM1, TM2, TM3, TM4, and TM7) had mean air temperature less than 10°C, except sites TM5 and TM6 (Fig. 5.1.1a). However, there was no significant difference ($F_{7,54}$=0.586; p= 0.765) in mean air temperatures observed between the sites. The water temperature of Tso Morari lake ranged from 0.0°C (TM3) in December 2004 to 19°C (TM5) in August 2006 and followed the same trend as air temperature (Table 5.1.1a_2). The mean values varied from 5.9±1.0°C (TM5b) to 10.1±4°C (TM6), although, the mean water temperature at sites TM1, TM2 and TM3 were higher than the mean air temperature (Fig. 5.1.1a_2). However, there was no significant ($F_{7,54}$=0.443; p= 0.871) difference in mean water temperatures between the study sites.

5.1.1b. Depth and Transparency

The variations in depth recorded at different selected sites in Tso Morari lake are depicted in Table 5.1.1b_1. The water depth ranged from 0.2m to 46m during the study period. There was significant difference ($F_{7,54}$= 4321; p= 0.000) among the study sites with respect to depth. Site TM1 (0.2 ±0.1m) and TM3 (0.3 ±0.1m) representing the inlet streams had significantly lower mean water depth than all other sites. Among the lake sites, TM5 (44.1 ±1.3m) had significantly higher mean water depth followed by TM6 (36.2 ±1.2m), TM7 (6.2 ±0.6m), TM4 (4.7 ±0.9m) and least was recorded at site TM2 (2.5 ±0.6m) (Fig. 5.1.1b_1). The transparency values of Tso Morari Lake varied from a low of 0.1m at site TM3 in December 2005 to a high of 23m at site TM5 in August 2006 (Table 5.1.1_2). For river sites TM1and TM3 water transparency followed the same trend as water depth throughout the study period. However, water transparency for the lake sites varied significantly during the study. The mean water transparency at TM6 (15.8 ± 2.3m) and TM5 (15.7±4.9m) was significantly higher ($F_{7,54}$= 63.709; p= 0.000) than TM7(4.9 ±0.6m), TM4 (3.5±0.9m) and TM2 (2.3±0.6m) (Fig. 5.1.1b_2).

5.1.1c. pH

The pH of water at all the sites during the study period was on the alkaline side. The minimum (7.38) and maximum (9.36) pH was recorded at site TM3 during December 2005 and October 2004 respectively (Table 5.1.1c). The mean pH ranged from 8.26±0.4 (TM1) to 8.89±0.3 (TM2). However, there was no significant variation in mean pH values observed between the study sites ($F_{7,54}$= 2.590; p=0.022) (Fig. 5.1.1c).

5.1.1d. Conductivity

The conductivity fluctuated from a low of 109 µS/cm at TM3 (October) in 2004 to a high of 2390 µS/cm at TM5 (October) in 2005 (Table 5.1.1d). A comparison of data at different sites revealed that TM1 and TM3 had significantly ($F_{7,54}$=27.346; p= 0.000) low mean values of conductivity than other sites. Site TM5 registered the highest mean values (1735±440 µS/cm) of conductivity. In general, lake water had higher conductivity values (>1000 µS/cm) than inlet stream sites (<300 µS/cm).

However, the conductivity values between the lake sites did not show any significant variation (Fig. 5.1.1d).

5.1.1e. Dissolved Oxygen

The variations in the dissolved oxygen at different sites are depicted in (Table 5.1.1e). The concentration of dissolved oxygen varied from a minimum value of 4.4mg/L (TM5b) in June 2005 to a maximum value of 11mg/L (TM4) in November 2006. The maximum mean value of 8.5±1.6mg/L was recorded at site TM1 and minimum of 6.8±1.3mg/L was recorded at site TM5b (Fig. 5.1.1e). However, there was no significant variation ($F_{7,54}$= 1.462; p= 2.00) in dissolved oxygen between the study sites.

5.1.1f. Free Carbon Dioxide

The free carbon dioxide at different sites is depicted in Table 5.1.1f and Fig. 5.1.1f. The free carbon dioxide was absent at TM2, TM4, TM5 and TM5b during the investigation, whereas at TM1 and TM3 free carbon dioxide varied from a low of 3 mg/L (TM7) in October 2005 to 20 mg/L (TM1 and TM3) in December 2005. The mean values varied from 0.5±1.2 mg/L at site TM7 to 7.1±7.4mg/L at site TM1.

5.1.1g. Alkalinity

The carbonate, bicarbonate and total alkalinity at different study sites in Tso Morari are depicted in Tables $5.1.1g_{1\text{-}3}$. Total alkalinity at most of the sites was mainly contributed by bicarbonates and followed the same trend as bicarbonate alkalinity. During the period of investigation the total alkalinity varied from 32 mg/L for TM3 in July 2005 to 520 mg/L for TM4 in December 2005. However, the highest mean value was recorded for TM7 (411±61mg/L) and the lowest for TM1 (68±18mg/L). The inlet stream sites (TM1 and TM3) were found to have significantly lower values ($F_{7,54}$=16.627; p=0.000) of total alkalinity than other sites. However, no significant difference in total alkalinity values was found between the lake sites (Fig. 5.1.1g).

5.1.1h. Total Hardness

The total hardness values are depicted in Table 5.1.1h.The lake water was found to be highly hard water type. The values in general showed wider fluctuation from a low of 46 mg/L at TM1 in August 2006 to a high of 2100 mg/L at TM5b in July 2005. On the basis of mean values of total hardness, TM1(153±100 mg/L) and TM3 (271±241 mg/L) showed significantly lower values ($F_{7,54}$ = 8.577; p=0.000) than other sites. On the other hand, the mean total hardness values at sites TM5b (1151±520 mg/L), TM5 (1051±329 mg/L), TM4 (1046±426mg/L), TM6 (928±526 mg/L), TM2 (851±460 mg/L) and TM7 (792±204 mg/L),did not show any significant variation (Fig. 5.1.1h).

5.1.1i. Calcium and Magnesium

The calcium content varied from a minimum of 5mg/L (TM2 and TM5) to a maximum of 89mg/L (TM3) in December 2005 and 2004 respectively (Table 5.1.1i_1). The mean values at different sites revealed that TM3 had highest values (44±25 mg/L), while TM7 occupied bottom position (25±13 mg/L) (Fig. 5.1.1i_1). However, mean calcium values did not show any significant ($F_{7,54}$=1.319; p=0.529) difference between the study sites. Magnesium concentration ranged from a low of 4 mg/L for TM3 in June to a high of 1560 mg/L for TM4 in the same month (Table 5.1.1i_2). On the basis of mean values, the highest magnesium content was recorded at TM5 (380±412 mg/L), while the lowest for TM1 (18±12 mg/L). The magnesium content did not show any significant variation among the lake sites, however, TM1 and TM3, which represent inlet stream sites had significantly lower values ($F_{7,54}$=8.244; p= 0.000) than TM4, TM5, TM5b and TM6 (Fig. 5.1.1i_2).

5.1.1j. Sodium and Potassium

The variations in sodium content in Tso Morari lake are depicted in Table 5.1.1j_1. The sodium content fluctuated from a low of 2 mg/L at TM1 and TM3 in December 2004 to a high of 99 mg/L at TM4 in the same month. The mean values varied from a low of 10±7mg/L at site TM1 to a high of 74±14mg/L at site TM4. All the Lake sites had significantly higher ($F_{7,54}$=19.752; p=0.000) values of sodium than TM1 and TM3 (Fig. 5.1.1j_1). The potassium content of Tso Morari varied from 1mg/L (TM1and TM4) to 77 mg/L (TM6). The mean values of potassium also followed the same trend having minimum value of 6±10 mg/L at site TM1 and maximum of 36±32mg/L at site TM6 (Table 5.1.1j_2). The data revealed that site TM1, TM3 and TM4 had significantly low ($F_{7,54}$=4.841;p= 0.000) potassium content (mean<6mg/L) than site TM6. Rest of the sites did not show any significant difference in mean potassium values (Fig. 5.1.1j_2).

5.1.1k. Chloride

The chloride content in the Lake fluctuated from a low value of 2 mg/L at site TM7 in July 2005 to a high of 54 mg/L at site TM4 in August 2006 (Table 5.1.1k). The mean values of chloride ranged from 13±9mg/L (TM1) to 32±13mg/L (TM5b) (Fig. 5.1.1k). However, analysis of variance did not show any significant difference ($F_{7,54}$ = 2.172; p= 0.051) between the study sites.

5.1.1l. Nitrate Nitrogen

The nitrate content of the lake is depicted in Table 5.1.1l. The data revealed an apparent seasonal trend in which high values of nitrate were recorded in winter and low values in summer. The nitrate content varied from 0.0 µg/L (TM5b) in August 2006 to 1638µg/L (TM5) in December 2005. Conversely, minimum mean value of

194±87µg/L was registered at site TM6 and maximum value of 619±484µg/L was registered at site TM5 (Fig. 5.1.1l).

5.1.1m. Ammonical Nitrogen

The ammonical nitrogen at different sites in Tso Morari Lake is depicted in Table 5.1.1m. The data revealed relatively uniform distribution of ammonical nitrogen at all the sites with highest values in winter and autumn season. The ammonical nitrogen ranged from a low value of 6µg/L (TM7) in June 2006 to 100µg/L (TM3) in December 2005. The ammonical nitrogen values showed insignificant ($F_{7,54}$=0.415; p=0.889) variation between the study sites. However, highest mean value of 54±27µg/L was recorded at site TM3 and lowest value of 39±23µg/L was observed at sites TM5 and TM5b (Fig. 5.1.1m).

5.1.1n. Total Phosphorus

The concentration of total phosphorus at different sites in Tso Morari Lake is shown in Table 5.1.1n. The high values of total phosphorus were reported for winter and autumn as compared to summer months. Total phosphorus varied from 76µg/L (TM3) to 1638 µg/L (TM5), whereas mean values varied from 120±29µg/L (TM3) to 647±312µg/L (TM2). Except sites TM1 and TM3 which showed significantly lower values ($F_{7,54}$=4.592; p=0.000) than sites TM2 and TM5, the total phosphorus concentration at other sites did not show any significant variation (Fig. 5.1.1n).

5.1.1o. Sulphate

Sulphate content at different selected sites in Tso Morari lake is shown in Table 5.1.1o. The data revealed high concentration of sulphate in winter months and low in summer months. The sulphate content varied from a minimum value of 8 mg/L at site TM1 to a maximum of 520 mg/L at site TM5. The minimum mean value of 34±21mg/L was observed at site TM1 and maximum value of 366±118mg/L was recorded at site TM5. The mean values of sulphate varied significantly ($F_{7,54}$=13.333; p=0.000) between the selected sites. Sites TM1 and TM3 had significantly low sulphate content than other sites. Significant difference in sulphate values was also recorded between TM4 and TM5 (Fig. 5.1.1o).

5.1.1p. Dissolved Silica

The data on silicate concentrations at Tso Morari lake are presented in Table 5.1.1p. The silicate values ranged from a minimum of 1mg/l each at site TM1and TM2 to a maximum of 28mg/l at site TM6. The mean silicate values were highest at site TM6 (10±10mg/L) and lowest at TM1 (5 ±4mg/L). However, the mean silicate values did not show any significant ($F_{7,54}$=0.799; p= 0.592) difference between the study sites (Fig. 5.1.1p).

5.1.1q. Total Dissolved Solids

The TDS ranged between 31mg/L at TM1 in 2006 and 980 mg/L at TM5 in July 2005 (Table 5.1.1q). The mean values ranged from 111±84mg/L (TM1) to 724±170mg/L, (TM5b). The mean TDS values showed significant ($F_{7,54}$=10.870; p=0.000) variation between the study sites. Sites TM5b, TM5 and TM4 had significantly higher values of TDS than TM1 and TM3 sites. Site TM5b also showed significant difference in mean TDS values with sites TM2 and TM6 (Fig. 5.1.1q).

Table 5.1.1a$_{1.}$ Spatial and temporal variations in air temperature (^{0}C) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	6.0	-6.0	2.0	20.0	5.0	-7.0	9.5	25.0	5.0	**6.6**	**10.6**
TM2	15.0	-3.7	5.0	20.0	10.0	-7.0	5.0	22.0	6.0	**8.0**	**9.9**
TM3	13.0	-4.0	7.0	12.0	7.0	-6.0	4.0	27.0	6.0	**7.3**	**9.7**
TM4	13.0	-3.5	11.0	20.0	14.0	-2.0	14.0	18.0	4.5	**9.9**	**8.4**
TM5	*	*	9.0	19.0	14.0	-3.0	11.0	21.0	3.0	**10.6**	**8.5**
TM5b	*	*	9.0	19.0	14.0	-3.0	11.0	21.0	3.0	**10.6**	**8.5**
TM6	*	*	8.0	23.0	11.0	*	26.0	20.0	3.0	**15.2**	**9.2**
TM7	*	*	*	21.0	8.0	-1.0	12.0	11.0	5.0	**9.3**	**7.4**

Table 5.1.1a$_{2}$.. Spatial and temporal variations in water temperature (^{0}C) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	9.0	0.5	5.0	12.0	9.5	1.0	8.0	16.0	6.0	**7.4**	**5.0**
TM2	11.0	2.0	7.0	16.0	14.0	2.0	10.0	17.0	3.0	**9.1**	**5.9**
TM3	9.0	0.0	9.0	11.0	10.0	2.0	7.0	17.0	7.0	**8.0**	**5.0**
TM4	13.0	2.5	5.0	17.0	12.0	2.0	8.0	14.0	4.5	**8.7**	**5.5**
TM5	*	*	5.0	12.0	12.0	2.0	6.0	19.0	6.0	**8.9**	**5.8**
TM5b	*	*	5.0	6.0	6.0	5.0	6.0	8.0	5.5	**5.9**	**1.0**
TM6	*	*	6.0	15.5	12.0	*	12.0	10.0	5.0	**10.1**	**4.0**
TM7	*	*	*	15.0	12.0	1.0	9.0	9.0	6.0	**8.7**	**4.8**

Table 5.1.1b$_{1}$. Spatial and temporal variations in depth (m) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	0.2	0.2	0.3	0.4	0.3	0.2	0.2	0.2	0.2	**0.2**	**0.1**
TM2	2.0	2.5	3.0	2.5	2.0	2.0	3.5	3.0	2.0	**2.5**	**0.6**
TM3	0.2	0.2	0.3	0.4	0.3	0.1	0.4	0.3	0.2	**0.3**	**0.1**
TM4	3.8	4.0	5.5	5.2	4.0	3.9	6.0	5.5	4.0	**4.7**	**0.9**
TM5	*	*	44.6	46.0	42.5	42.5	45.0	44.4	43.6	**44.1**	**1.3**
TM5b	*	*									
TM6	*	*	37.0	35.0	34.5	*	37.4	37.0	36.3	**36.2**	**1.2**
TM7	*	*	*	6.5	6.3	6.0	6.9	6.5	5.1	**6.2**	**0.6**

Table 5.1.1b$_2$. Spatial and temporal variations in transparency (m) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	0.2	0.2	0.3	0.4	0.3	0.2	0.2	0.2	0.2	**0.2**	**0.1**
TM2	2.0	2.5	2.0	2.1	2.0	2.0	3.5	3.0	2.0	**2.3**	**0.6**
TM3	0.2	0.2	0.3	0.3	0.2	0.1	0.4	0.3	0.2	**0.2**	**0.1**
TM4	3.8	3.0	4.0	3.2	3.0	2.0	4.4	4.8	3.0	**3.5**	**0.9**
TM5	*	*	16.0	12.0	12.0	11.2	22.0	23.0	14.0	**15.7**	**4.9**
TM5b	*	*	16.0	12.0	12.0	11.2	22.0	23.0	14.0	**15.7**	**4.9**
TM6	*	*	17.0	17.0	12.0	*	18.0	17.0	14.0	**15.8**	**2.3**
TM7	*	*	*	5.5	5.0	4.8	5.2	5.0	3.8	**4.9**	**0.6**

Table 5.1.1c. Spatial and temporal variations in pH in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	8.78	8.79	7.90	8.02	8.34	8.03	8.70	7.69	8.10	**8.26**	**0.4**
TM2	9.24	8.92	8.97	9.02	8.05	9.00	8.97	9.00	8.88	**8.89**	**0.3**
TM3	9.36	8.29	9.18	7.81	8.67	7.38	9.00	8.86	7.98	**8.50**	**0.7**
TM4	9.29	8.08	8.90	8.96	8.60	8.94	8.96	8.90	8.94	**8.84**	**0.3**
TM5	*	*	8.75	8.88	8.68	9.04	8.60	8.92	8.90	**8.82**	**0.2**
TM5b	*	*	8.76	8.80	8.73	8.90	8.73	9.00	8.87	**8.83**	**0.1**
TM6	*	*	8.86	8.87	8.45	*	8.00	8.72	8.77	**8.61**	**0.3**
TM7	*	*	*	8.91	8.15	8.94	8.89	8.06	8.95	**8.65**	**0.4**

Table 5.1.1d. Spatial and temporal variations in conductivity (µS/cm) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	160	118	240	298	270	210	227	275	230	**225**	**57**
TM2	1067	1254	1796	1310	1847	1547	1937	1314	1021	**1455**	**341**
TM3	109	146	233	336	253	213	175	139	333	**215**	**82**
TM4	1672	1063	1860	1292	1871	1573	1700	1389	1037	**1495**	**317**
TM5	*	*	1995	1843	2390	1550	1910	1420	1035	**1735**	**440**
TM5b	*	*	1990	1883	1086	1555	1910	1430	1045	**1557**	**391**
TM6	*	*	1060	1047	1915	*	1126	1422	1064	**1272**	**345**
TM7	*	*	*	1925	1227	1534	1916	488	1068	**1360**	**552**

Table 5.1.1e. Spatial and temporal variations in dissolved oxygen (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	9.2	10.0	6.0	10.0	8.6	10.0	8.6	6.0	8.0	**8.5**	**1.6**
TM2	8.0	8.0	8.0	9.0	8.0	8.0	6.8	7.0	9.2	**8.0**	**0.8**
TM3	7.0	8.0	7.0	7.0	9.0	10.0	9.0	6.0	10.0	**8.1**	**1.5**
TM4	8.0	10.0	6.0	7.0	9.0	8.0	7.0	7.0	11.0	**8.1**	**1.6**
TM5	*	*	7.0	7.0	8.4	8.0	7.0	6.0	8.0	**7.3**	**0.8**
TM5b	*	*	4.4	7.0	6.8	6.0	8.2	8.0	7.0	**6.8**	**1.3**
TM6	*	*	6.4	8.0	8.0	*	8.7	7.8	8.0	**7.8**	**0.8**
TM7	*	*	*	7.0	7.0	8.0	7.0	7.0	9.0	**7.5**	**0.8**

Table 5.1.1f. Spatial and temporal variations in free carbon dioxide (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	12.0	0.0	4.0	6.0	0.0	20.0	0.0	6.0	16.0	**7.1**	**7.4**
TM2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
TM3	0.0	0.0	0.0	9.0	0.0	20.0	0.0	0.0	18.0	**5.2**	**8.4**
TM4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
TM5	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
TM5b	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**
TM6	*	*	0.0	0.0	0.0	*	8.0	0.0	0.0	**1.3**	**3.3**
TM7	*	*	*	0.0	3.0	0.0	0.0	0.0	0.0	**0.5**	**1.2**

Table 5.1.1g$_1$. Spatial and temporal variations in total alkalinity (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	74	52	68	100	80	70	54	40	72	**68**	**18**
TM2	291	376	168	484	400	380	336	240	513	**354**	**110**
TM3	78	328	48	32	90	70	340	380	408	**197**	**161**
TM4	398	212	192	456	400	520	308	300	481	**363**	**117**
TM5	*	*	232	480	370	380	312	260	490	**361**	**100**
TM5b	*	*	212	496	410	470	217	280	485	**367**	**127**
TM6	*	*	180	484	330	*	180	280	448	**317**	**130**
TM7	*	*	*	486	380	460	366	330	446	**411**	**61**

Table 5.1.1g$_2$. Spatial and temporal variations in carbonate alkalinity (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	0	12	8	0	20	0	0	0	0	**4**	**7**
TM2	64	0	24	52	90	120	66	40	90	**61**	**37**
TM3	22	4	8	0	20	0	50	0	0	**12**	**17**
TM4	58	28	40	46	80	50	74	0	81	**51**	**26**
TM5	*	*	36	36	160	50	78	0	90	**64**	**52**
TM5b	*	*	36	28	280	50	50	48	90	**83**	**89**
TM6	*	*	32	40	20	*	280	38	104	**86**	**100**
TM7	*	*	*	46	0	80	62	0	110	**50**	**44**

Table 5.1.1g$_3$. Spatial and temporal variations in bicarbonate alkalinity (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	74	40	60	100	60	70	54	40	72	**63**	**19**
TM2	227	376	144	432	310	260	270	200	432	**295**	**102**
TM3	56	324	40	32	70	90	290	380	408	**188**	**159**
TM4	340	184	152	410	320	470	234	300	400	**312**	**107**
TM5	*	*	196	444	210	330	234	260	400	**296**	**97**
TM5b	*	*	176	468	130	330	167	240	395	**272**	**128**
TM6	*	*	148	444	310	*	44	220	389	**259**	**151**
TM7	*	*	*	440	380	380	304	330	356	**365**	**47**

Table 5.1.1h. Spatial and temporal variations in total hardness (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	70	142	340	300	107	100	132	46	144	**153**	**100**
TM2	584	904	1540	1600	1020	388	440	730	452	**851**	**460**
TM3	110	184	660	700	260	160	80	58	226	**271**	**241**
TM4	728	1220	1600	1800	890	508	826	760	1080	**1046**	**426**
TM5	*	*	1340	1400	1370	544	810	890	1000	**1051**	**329**
TM5b	*	*	1550	2100	1090	688	934	608	1090	**1151**	**520**
TM6	*	*	460	1940	1100	*	480	606	980	**928**	**562**
TM7	*	*	*	500	1070	614	868	876	826	**792**	**204**

Table 5.1.1i$_1$. Spatial and temporal variations in calcium content (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	12	25	60	50	38	19	28	8	36	**31**	**17**
TM2	15	21	40	55	40	5	28	86	32	**36**	**24**
TM3	19	89	61	65	53	33	26	10	40	**44**	**25**
TM4	10	21	40	20	24	9	27	38	22	**23**	**11**
TM5	*	*	40	20	44	5	28	48	32	**31**	**15**
TM5b	*	*	60	40	48	9	16	32	35	**34**	**18**
TM6	*	*	36	20	28	*	29	32	28	**29**	**5**
TM7	*	*	*	10	36	8	24	38	34	**25**	**13**

Table 5.1.1i$_2$. Spatial and temporal variations in magnesium content (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	10	16	40	35	16	9	21	6	13	**18**	**12**
TM2	125	207	150	355	224	91	182	125	66	**169**	**87**
TM3	13	23	20	20	43	10	4	8	31	**19**	**12**
TM4	172	121	1560	425	202	118	184	161	294	**360**	**460**
TM5	*	*	1300	330	306	129	184	187	223	**380**	**412**
TM5b	*	*	149	485	236	144	217	150	222	**229**	**119**
TM6	*	*	430	460	251	*	22	142	198	**251**	**169**
TM7	*	*	*	100	238	145	196	192	186	**176**	**48**

Table 5.1.1j$_1$. Spatial and temporal variations in sodium content (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	7	2	3	15	10	19	6	22	6	**10**	**7**
TM2	53	97	73	61	73	75	74	48	74	**70**	**14**
TM3	23	2	5	28	73	6	25	44	5	**23**	**23**
TM4	79	99	76	70	78	76	68	46	76	**74**	**14**
TM5	*	*	77	76	84	76	76	40	74	**72**	**14**
TM5b	*	*	76	76	73	76	78	48	74	**72**	**11**
TM6	*	*	77	76	73	*	89	49	74	**73**	**13**
TM7	*	*	*	75	15	75	70	38	76	**58**	**26**

Table 5.1.1j$_2$. Spatial and temporal variations in potassium content (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	1	1	2	1	31	8	2	2	3	**6**	**10**
TM2	9	37	27	13	3	24	22	22	27	**20**	**10**
TM3	8	6	2	10	15	2	2	25	3	**8**	**8**
TM4	17	1	3	16	4	29	20	22	29	**16**	**11**
TM5	*	*	28	19	2	24	14	20	29	**19**	**9**
TM5b	*	*	3	18	11	26	26	20	20	**18**	**8**
TM6	*	*	4	19	76	*	77	18	22	**36**	**32**
TM7	*	*	*	18	3	25	22	11	29	**18**	**10**

Table 5.1.1k. Spatial and temporal variations in chloride content (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	21	6	12	4	32	20	8	6	10	**13**	**9**
TM2	48	36	36	12	34	28	11	34	26	**29**	**12**
TM3	15	30	10	3	36	8	10	54	10	**20**	**17**
TM4	50	8	52	15	20	28	10	38	22	**27**	**16**
TM5	*	*	32	18	22	28	11	38	38	**27**	**10**
TM5b	*	*	46	20	46	30	10	35	35	**32**	**13**
TM6	*	*	40	20	36	*	20	34	38	**31**	**9**
TM7	*	*	*	2	12	30	9	40	40	**22**	**17**

Table 5.1.1l. Spatial and temporal variations in nitrate nitrogen content (µg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	231	498	468	413	148	758	150	187	237	**343**	**206**
TM2	139	36	142	217	31	503	115	41	887	**235**	**285**
TM3	177	101	68	272	90	170	666	776	99	**269**	**265**
TM4	248	469	368	352	452	472	287	266	327	**360**	**87**
TM5	*	*	268	364	664	1638	213	664	520	**619**	**484**
TM5b	*	*	274	258	263	434	570	0	249	**293**	**176**
TM6	*	*	328	108	248	*	102	208	170	**194**	**87**
TM7	*	*	*	161	146	316	480	119	122	**224**	**145**

Table 5.1.1m. Spatial and temporal variations in ammonical nitrogen (μg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	49	82	33	53	65	20	26	18	49	**44**	**22**
TM2	60	71	35	58	65	26	12	87	33	**50**	**24**
TM3	59	69	33	43	75	100	10	60	34	**54**	**27**
TM4	44	55	54	37	57	29	12	73	34	**44**	**18**
TM5	*	*	35	38	70	30	11	69	20	**39**	**23**
TM5b	*	*	36	77	69	37	15	25	14	**39**	**25**
TM6	*	*	31	52	58	*	52	86	16	**49**	**24**
TM7	*	*	*	49	68	24	6	76	17	**40**	**29**

Table 5.1.1n. Spatial and temporal variations in total phosphorus (μg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	130	120	130	140	560	144	170	143	140	**186**	**141**
TM2	832	360	1028	720	1080	620	126	640	420	**647**	**312**
TM3	108	76	148	148	120	84	122	160	110	**120**	**29**
TM4	227	100	288	184	914	284	500	456	580	**393**	**250**
TM5	*	*	234	364	664	1638	213	664	520	**614**	**488**
TM5b	*	*	624	518	284	470	220	650	720	**498**	**188**
TM6	*	*	170	240	456	*	128	490	720	**367**	**228**
TM7	*	*	*	284	488	408	200	488	630	**416**	**155**

Table 5.1.1o. Spatial and temporal variations in sulphate (μg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	62	22	8	71	45	20	26	18	30	**34**	**21**
TM2	66	354	328	161	480	302	478	161	388	**302**	**145**
TM3	140	36	15	10	46	14	42	28	72	**45**	**41**
TM4	75	23	382	145	141	307	52	145	246	**168**	**120**
TM5	*	*	383	199	474	321	424	244	520	**366**	**118**
TM5b	*	*	360	101	458	300	359	340	380	**328**	**111**
TM6	*	*	399	167	473	*	218	378	372	**335**	**117**
TM7	*	*	*	148	224	303	126	248	363	**235**	**90**

Table 5.1.1p. Spatial and temporal variations in silicate (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	4	7	1	14	4	7	1	2	1	**5**	**4**
TM2	14	9	2	13	14	9	2	2	1	**7**	**6**
TM3	4	9	3	9	4	9	3	3	0	**5**	**3**
TM4	14	11	4	17	14	11	4	2	3	**9**	**6**
TM5	*	*	2	25	15	9	5	2	4	**9**	**8**
TM5b	*	*	3	13	14	22	6	2	0	**9**	**8**
TM6	*	*	4	10	13	*	28	2	4	**10**	**10**
TM7	*	*	*	13	14	6	6	2	6	**8**	**5**

Table 5.1.1q. Spatial and temporal variations in total dissolved solids (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM1	57	122	320	100	51	100	110	31	110	**111**	**84**
TM2	340	320	480	422	416	210	460	480	440	**396**	**90**
TM3	250	120	200	188	150	80	310	198	96	**177**	**74**
TM4	678	480	520	200	400	840	470	440	744	**530**	**195**
TM5	*	*	440	980	490	580	462	480	844	**611**	**214**
TM5b	*	*	800	460	910	710	530	790	866	**724**	**170**
TM6	*	*	640	100	470	*	190	144	876	**403**	**313**
TM7	*	*	*	100	400	780	340	420	688	**455**	**246**

*Sampling not done

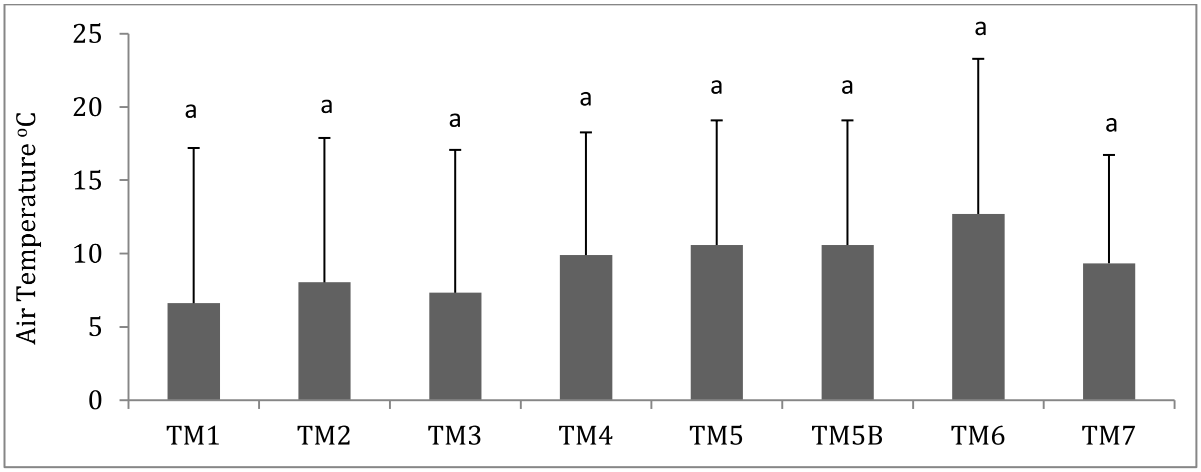


Fig. 5.1.1a$_1$. Changes in air temperature (^{0}C) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

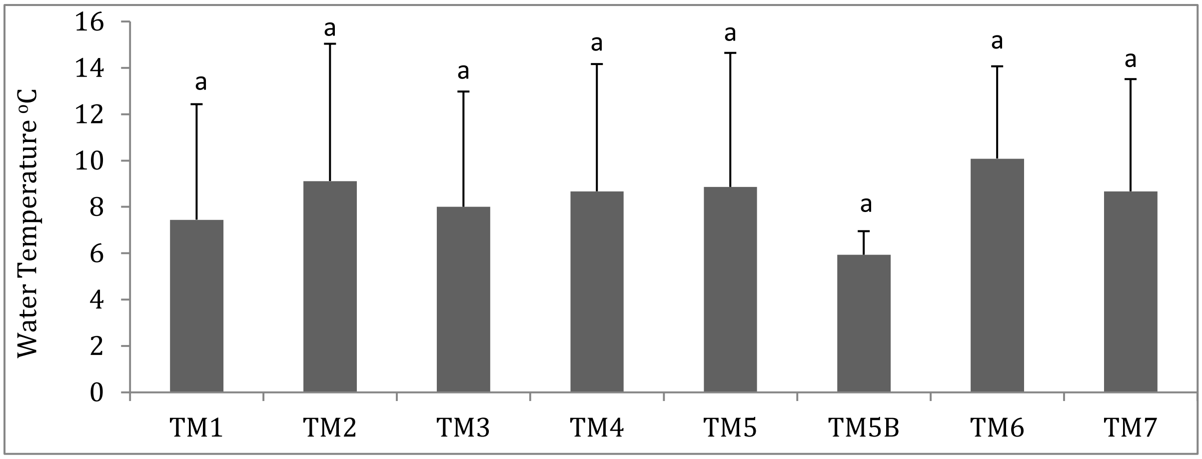


Fig. 5.1.1a$_2$. Changes in water temperature (^{o}C) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

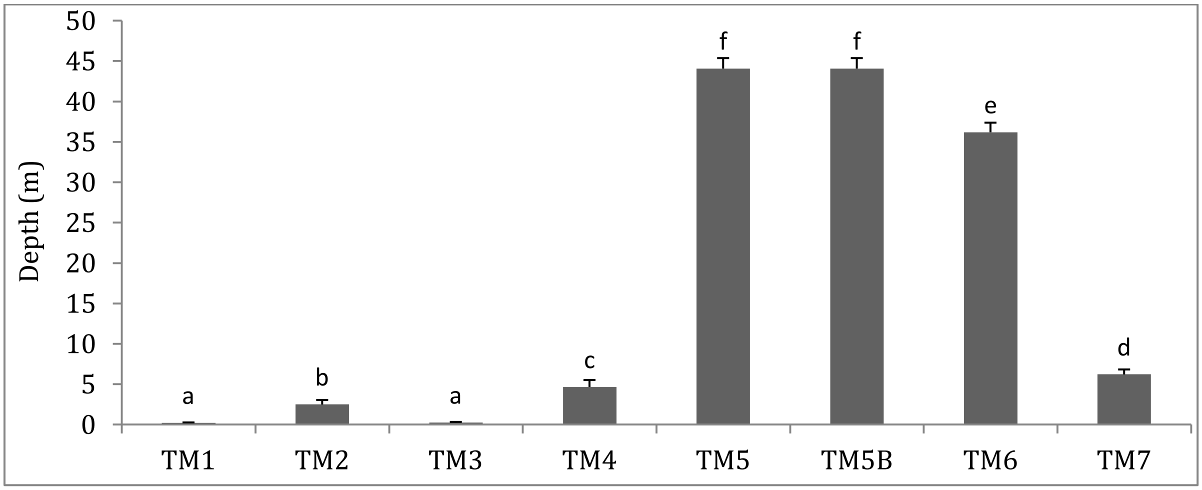


Fig. 5.1.1b$_1$. Changes in depth (m) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

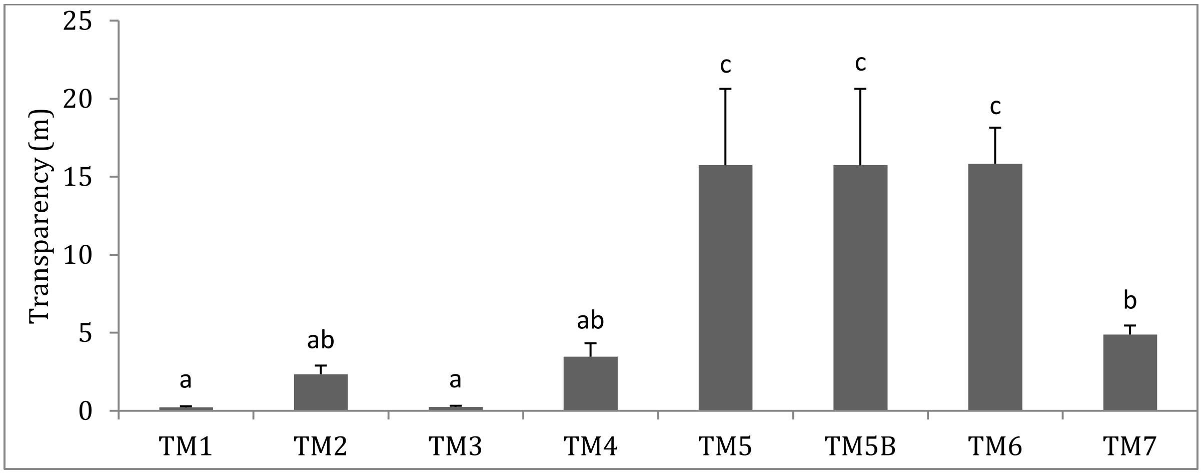


Fig. 5.1.1b$_2$. Changes in transparency (m) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

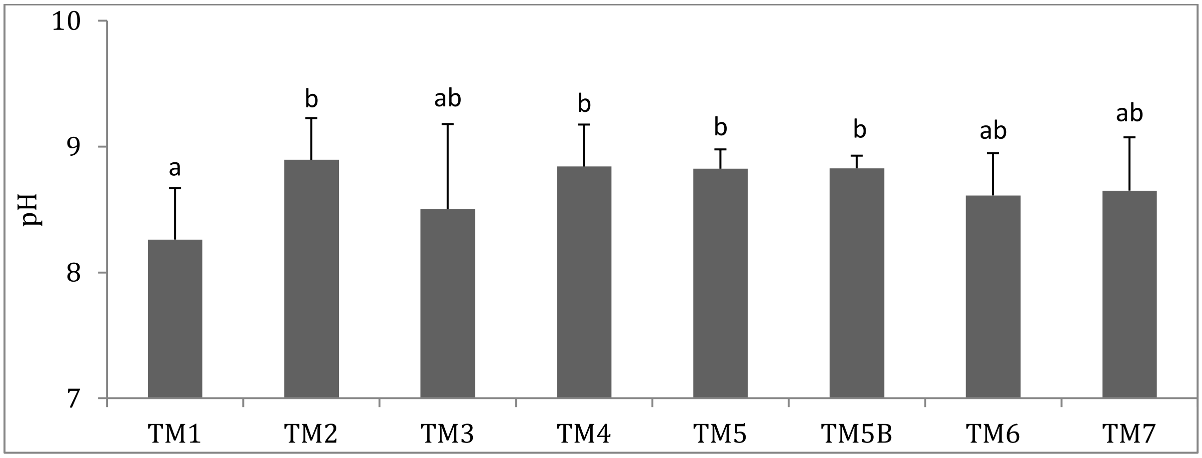


Fig. 5.1.1c. Changes in pH (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

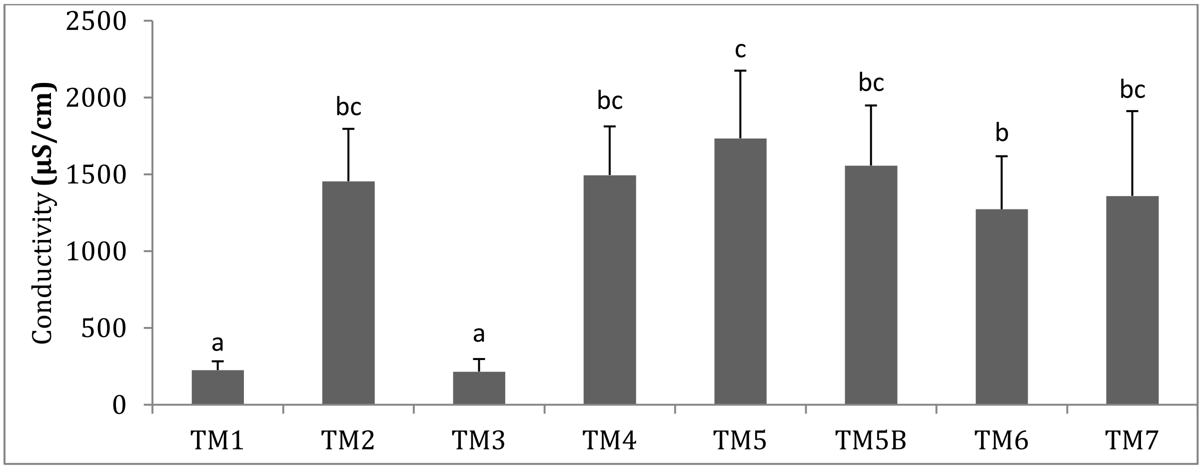


Fig. 5.1.1d. Changes in conductivity (µS/cm) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

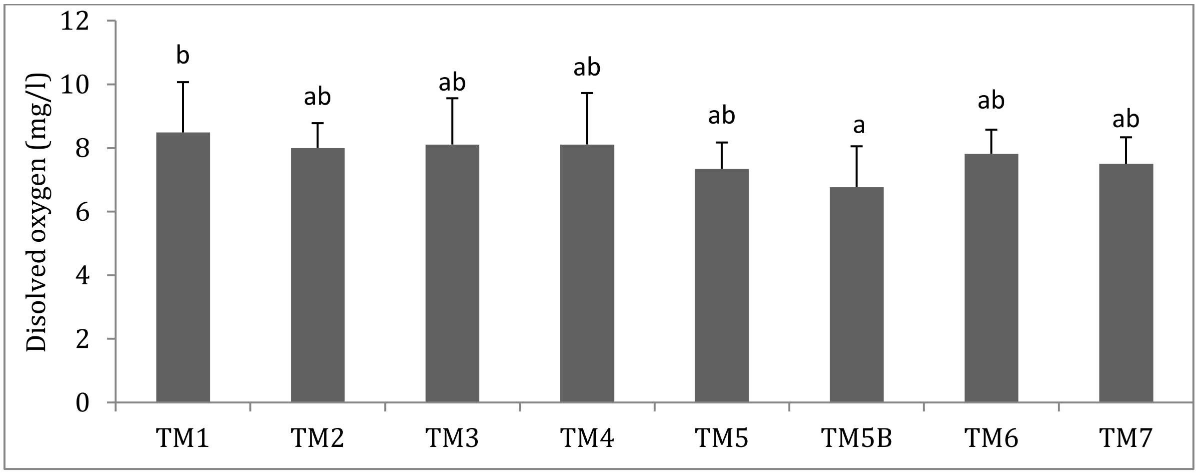


Fig. 5.1.1e. Changes in dissolved oxygen (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

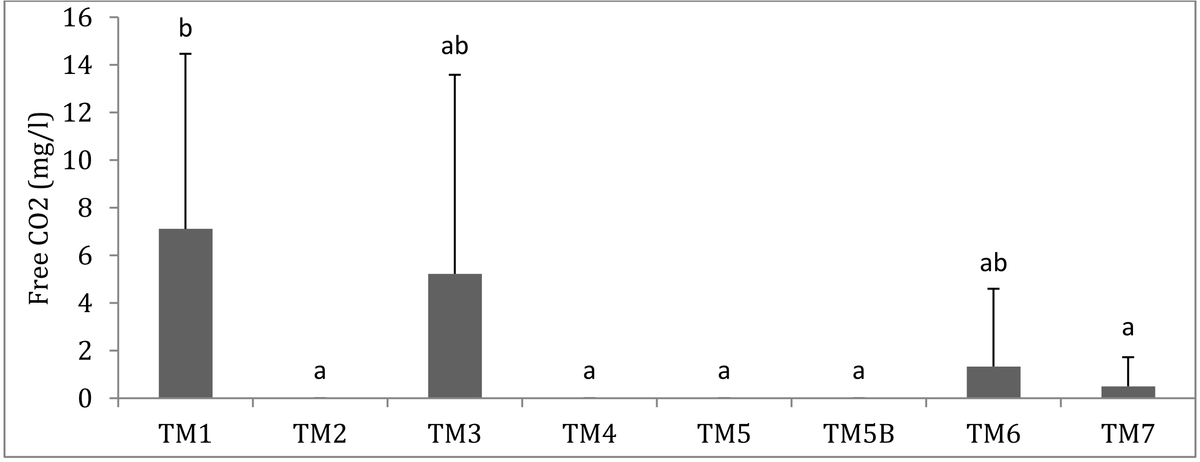


Fig. 5.1.1f. Changes in free CO_2 (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

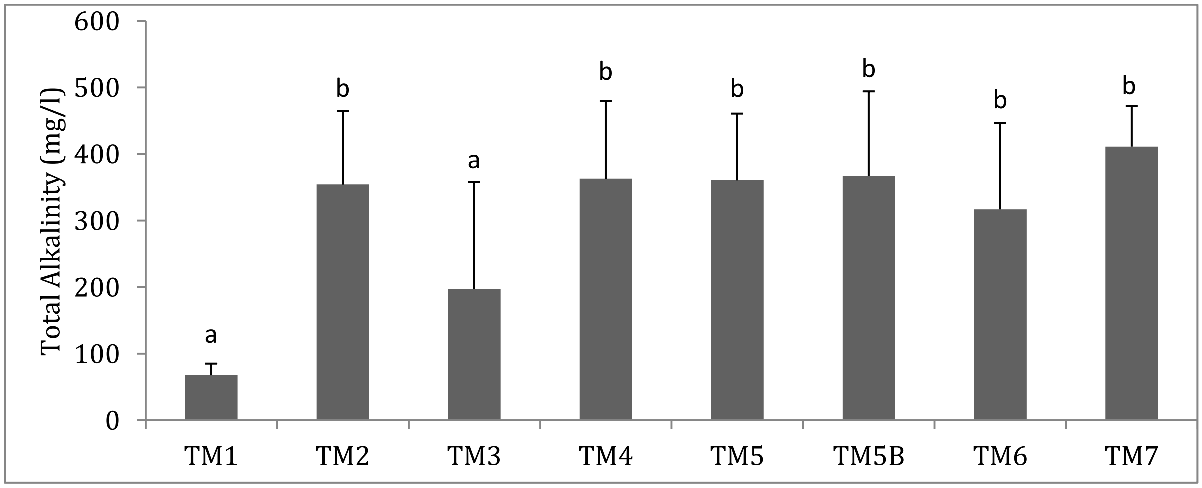


Fig. 5.1.1g. Changes in total alkalinity (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

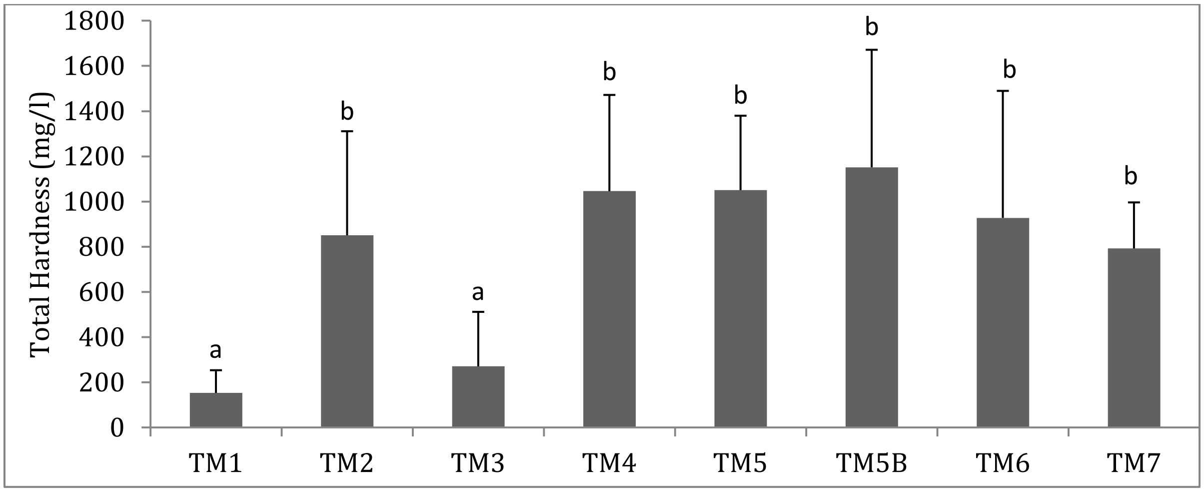


Fig. 5.1.1h. Changes in total hardness (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

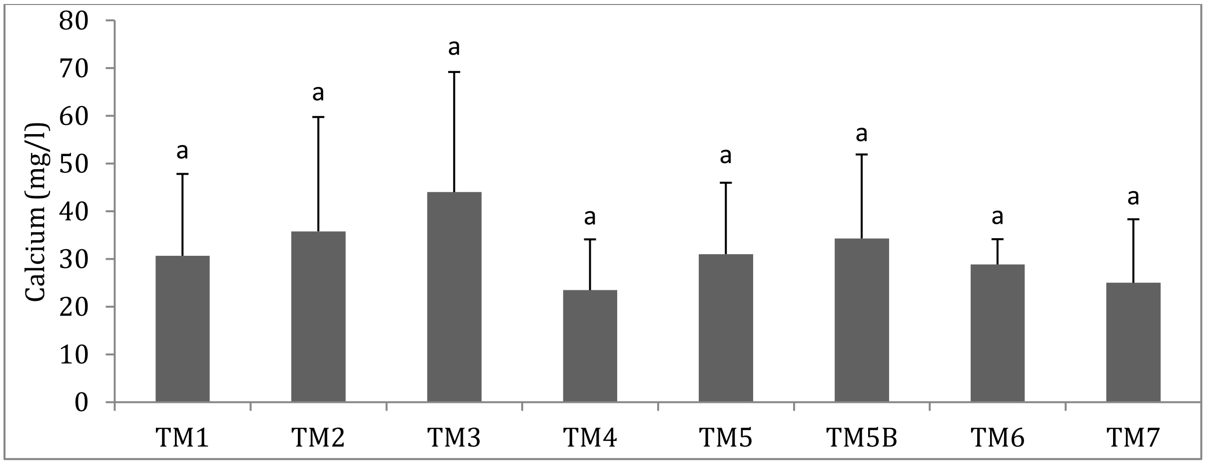


Fig. 5.1.1i$_1$. Changes in calcium (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

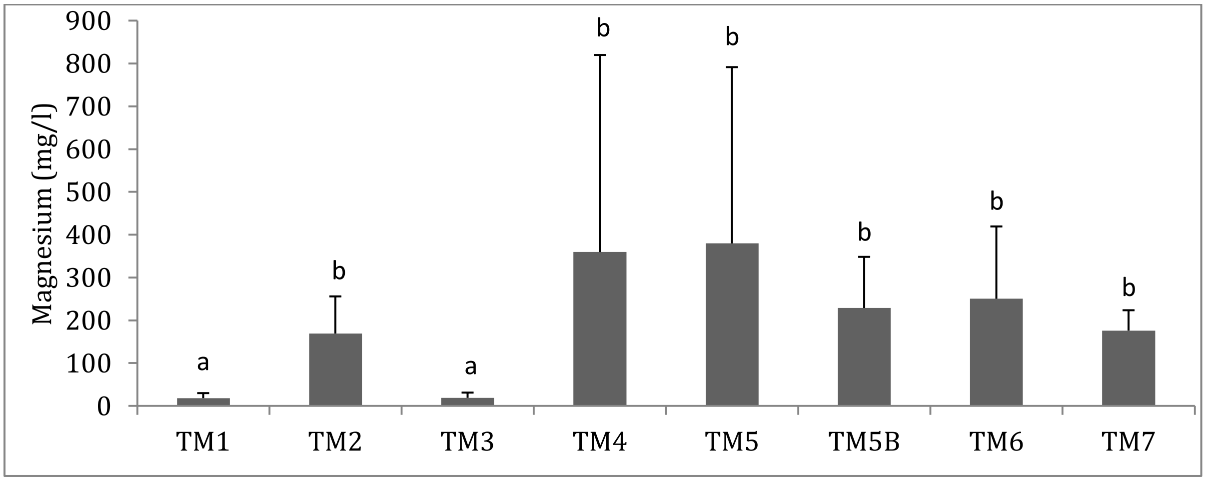


Fig. 5.1.1i$_2$. Changes in magnesium (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

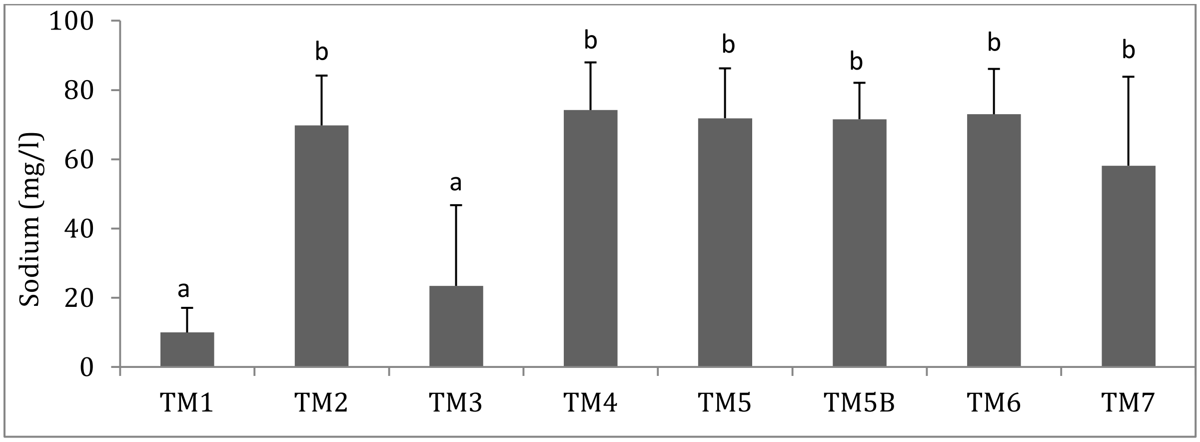


Fig. 5.1.1j$_1$. Changes in sodium (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

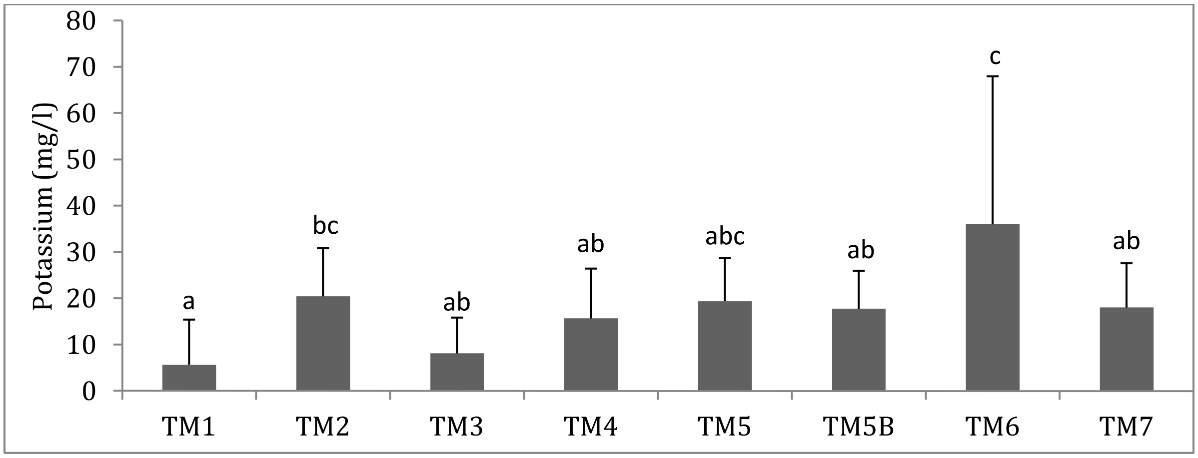


Fig. 5.1.1j$_2$. Changes in potassium (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

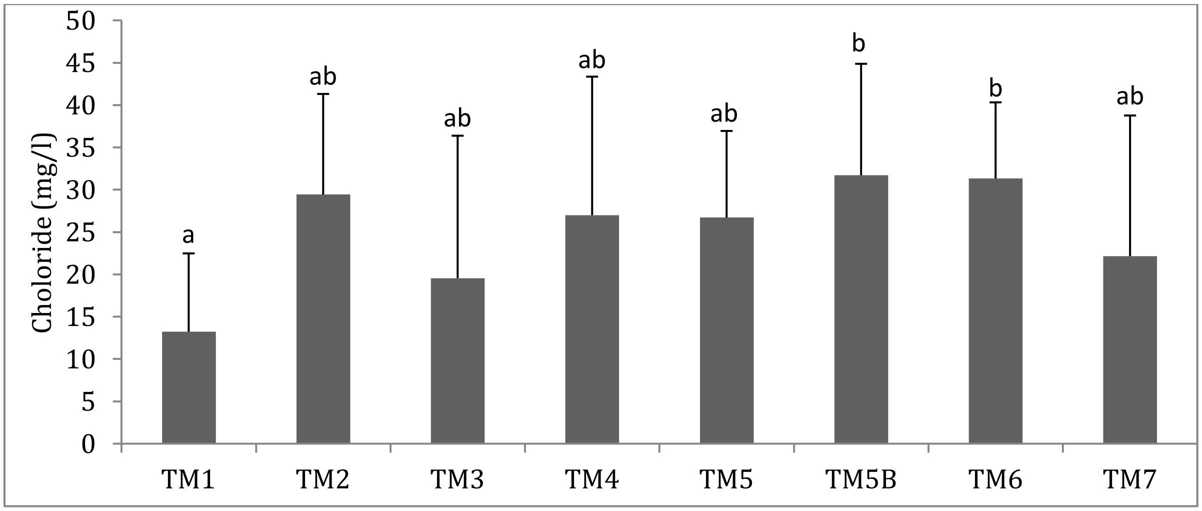


Fig. 5.1.1k. Changes in chloride (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

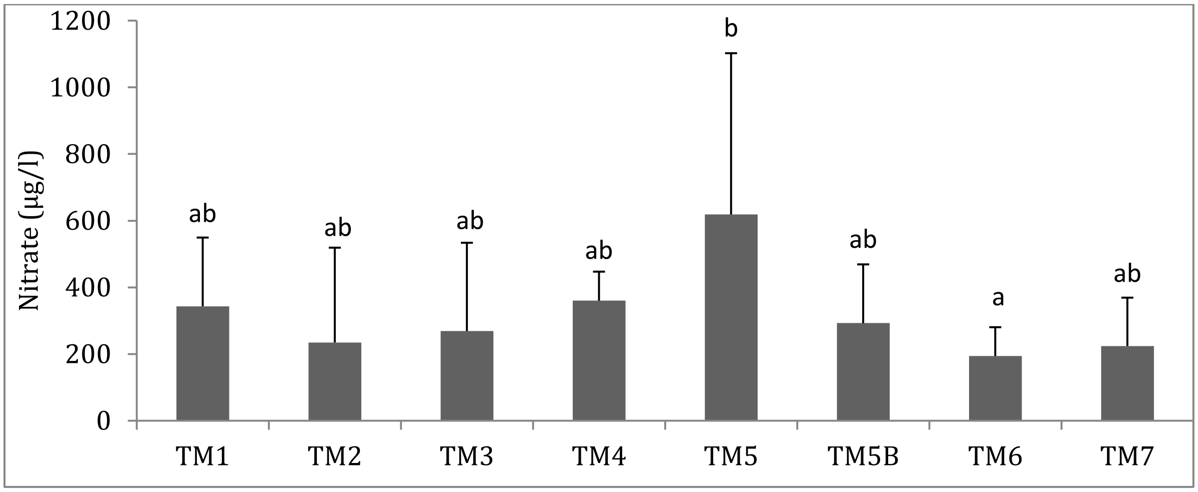


Fig. 5.1.1l. Changes in nitrate (µg /l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

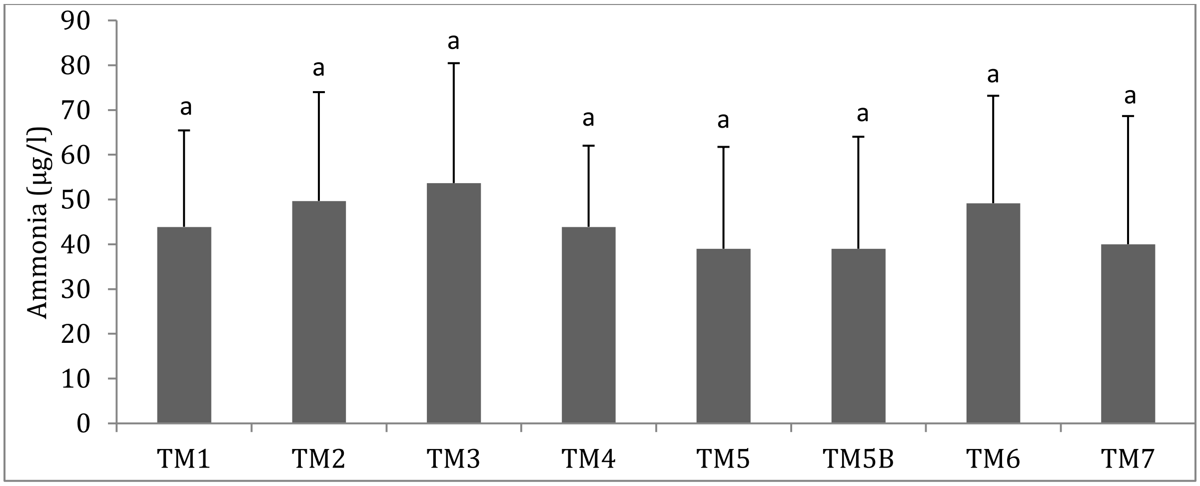


Fig. 5.1.1m. Changes in ammonia (µg /l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

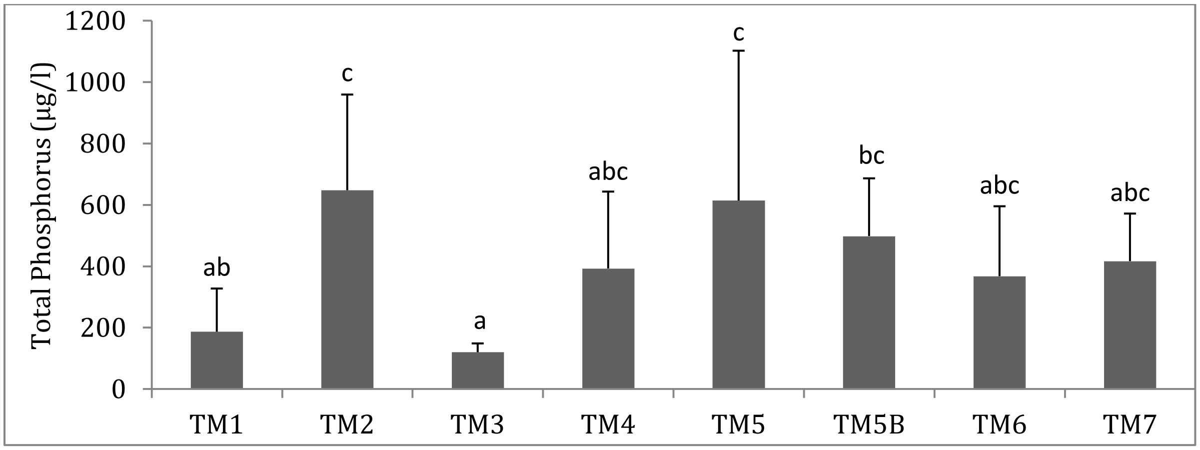


Fig. 5.1.1n. Changes in total phosphorus (µg /l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

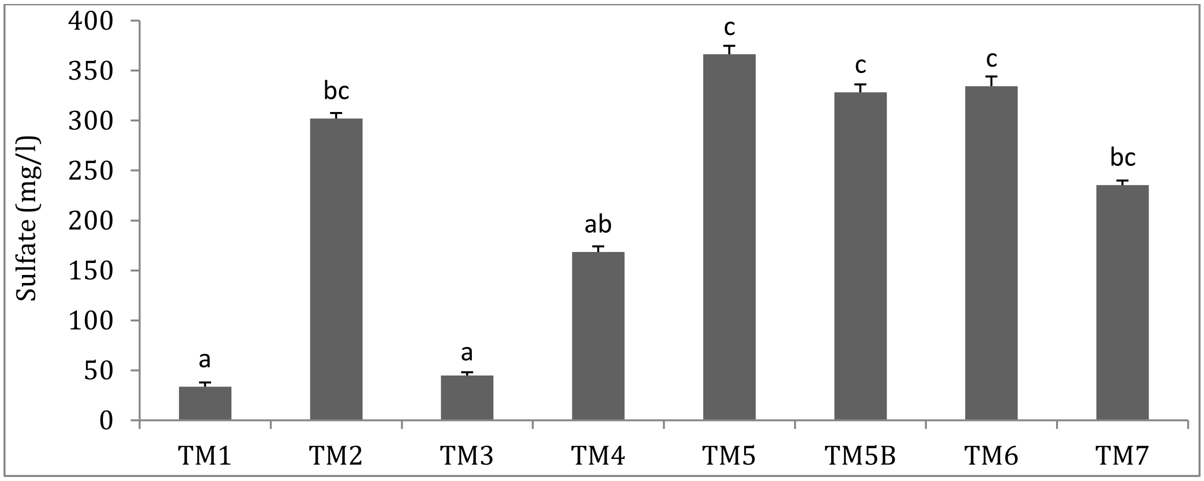


Fig. 5.1.1o. Changes in sulfate (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

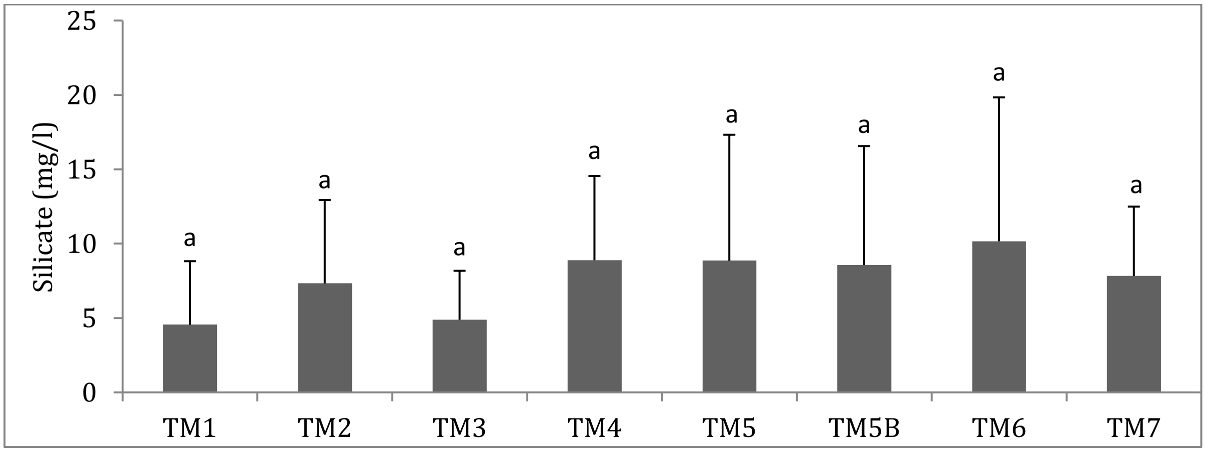


Fig. 5.1.1p. Changes in silicate (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

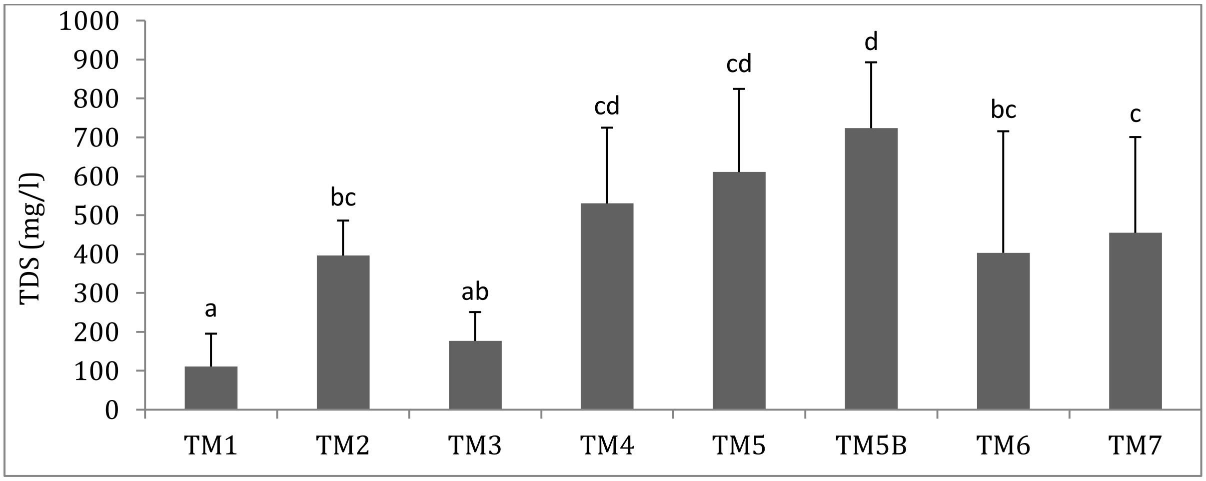


Fig. 5.1.1q. Changes in TDS (mg/l) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

5.1.2. Tso Khar Lake

5.1.2a. Air and Water temperature

The air temperature at different sites varied from a minimum of -7°C (TK3 and TK4) in December 2004 to a high of 25°C (TK1 and TK2) in July 2005 (Table 5.1.2a_1). The mean air temperature values did not show any significant variation ($F_{4,31}$=0.342; p=0.848) between the study sites. However, minimum mean air temperature was registered for site TK4 (7.0±9.3°C) and maximum was recorded at site TK1 (12.4±11.2°C) (Fig. 5.1.2a_1). The water temperature ranged from a minimum of 0°C (TK1, TK2, TK4 and TK5) in December 2004 and 2005 to a maximum value of 23°C (TK1, TK2 and TK5) in June 2005 (Table 5.1.2a_2). The highest mean values of water temperature was found at TK5 (12.6±8.2°C) followed by TK2 (11.3±8.3°C), TK1 (11.1±8.8°C), TK4 (10.0±7.5°C) and lowest was observed at TK3 (8.6±5.1°C). The mean water temperature values however, did not show any significant variation ($F_{4,31}$=0.304; p=0.873) between the study sites (Fig. 5.1.2a_2).

5.1.2b. Depth and Transparency

The depth varied from 0.2m at site TK3 to a high of 2.8m at TK4. TK1, TK2 and TK3 depicted <2m depth, while TK4 had >2m of depth throughout the study period (Table 5.1.2b_1). The mean values of depth at TK4 (1.8±1.1m) and TK5 (1.7±1.0m) were significantly higher ($F_{4,31}$=5.542; p=0.002) than TK3 (0.3±0.1m) and TK1 (0.4±0.2m), while TK2 (1.0±0.6m) showed insignificant difference with other sites with respect to depth (Fig. 5.1.2b_1). Lake transparency varied from a minimum of 0.1m at site TK1 to a maximum value of 2.2m at site TK4 (Table 5.1.2b_2). The mean values of transparency were less than 1m at all the sites, lowest being recorded at site TK1 (0.1±0.1m) and the highest at site TK5 (0.6±0.3m). However, mean transparency values did not show any significant difference ($F_{4,31}$=1.600; p=0.199) between the study sites (Fig. 5.1.2b_2).

5.1.2c. pH

The pH in this Lake varied from 7.55 at TK2 in December 2005 to 9.28 at TK5 in July 2005 (Table 5.1.2c). The maximum mean value was observed at TK4 (8.67±0.3) and the minimum at TK3 (8.25±0.4). However, pH values did not show any significant variation ($F_{4,31}$=1.064; p=0.391) between the study sites (Fig. 5.1.2c).

5.1.2d. Conductivity

Conductivity values in Tso Khar lake are depicted in Table 5.1.2d. The conductivity varied from 271 µS/cm at TK3 in October 2005 to 31000 µS/cm at TK1 in June 2005. The mean conductivity values at TK1 (23386 ±7366µS/cm and TK4 (18165±5078µS/cm) were significantly higher ($F_{4,31}$=51.667; p=0.000) than the mean conductivity values found at TK3 (463±175µS/cm), TK2 (1698±834µS/cm) and TK5 (2036±1528 µS/cm), dividing the lake into two parts one highly saline and other fresh water (Fig. 5.1.2d).

5.1.2e. Dissolve Oxygen

Variation in dissolved oxygen at different study sites is depicted in Table 5.1.2e. Due to high salinity of the lake, dissolved oxygen analysis was carried only at three sites. The dissolved oxygen fluctuated from a minimum of 2mg/L at site TK1 to a high of 9mg/L at TK2 and TK3. The mean values of dissolved oxygen also followed the same trend, being highest at site TK3 (8±1mg/L) and lowest at site TK1 (4.3±2.5mg/L) (Fig. 5.1.2e).

5.1.2f. Free Carbon Dioxide

Variation in free carbon dioxide at different study sites is presented in Table 5.1.2f. Free CO_2 content varied from 0.0 mg/L to 20 mg/L. Perusal of the data reveals that mean CO_2 values at TK3 (9.1±8.2 mg/l) were significantly higher ($F_{4,31}$=3.689;

p=0.014) than site TK4 (0.3±0.8 mg/l). Rest of the sites did not show any significant variation in free CO_2 values (Fig. 5.1.2f).

5.1.2g. Alkalinity

Considerable spatial variations were observed in total alkalinity values in Tso Khar (Table $5.1.2g_1$), ranging from a low of 68mg/L for TK5 in November 2006 to a high of 3740 mg/L for TK1 in October 2005. The maximum mean value of 2364±790mg/L was recorded at TK1 against the minimum value of 160±50mg/L recorded at TK3. However, significant variation ($F_{4,31}$=16.218; p=0.000) in total alkalinity values was observed between site TK1 with sites TK2, TK5 and TK3 and between site TK4 with sites TK5 and TK3. The total alkalinity was contributed by both carbonate (Table $5.1.2g_2$) and bicarbonate alkalinity (Table $5.1.2g_3$).

5.1.2h. Total Hardness

The hardness values in Tso Khar depicted wider fluctuations oscillating between 90 mg/L at TK5 in November 2006 and 4672 mg/L at TK4 in December 2004 (Table 5.1.2h). On the basis of hardness the lake water can be dived into hard and very hard type. Site TK1 recorded the highest mean value of 2950±908 mg/L against the lowest of 350±105 mg/L at TK3 (Fig. 5.1.2h). Similarly, the mean values of total hardness at sites TK1 and TK4 were significantly higher ($F_{4,31}$=29.325; p=0.000) than other sites.

Cationic Composition

On the basis of cation content, the study sites showed wide-ranging pattern. At site TK1 and TK4 the cationic progression was observed to be Na> K> Mg>Ca, while at site TK2 and TK3 the order was Ca>Mg>Na>K, and at site TK5, Mg>Ca>Na>K.

5.1.2i. Calcium and Magnesium

The calcium content ranged from a low of 12mg/L (TK5) to a high of 410 mg/L (TK1) (Table 5.1.2i_1). On the basis of mean calcium values site TK1 (241±107 mg/L) showed significantly higher values ($F_{4,31}$=8.896; p=0.000) than sites TK5 (41±19mg/L), TK3 (63±41mg/l) and TK2 (102±55 mg/l). However, the mean values of calcium at site TK4 did not show any significant variation with other sites except site TK5 (Fig. 5.1.2i_1). Similarly the minimum magnesium values in Tso Khar lake was found at TK5 (15mg/L) and maximum at TK4 (1452 mg/L) (Table 5.1.2i_2). The mean magnesium values were significantly higher ($F_{4,31}$=31.007; p=0.000) at TK1 (935±335mg/L) followed by TK4 (435±239 mg/l), while significantly least values were recorded at sites TK3 (38±13 mg/L), TK2 (74±44mg/l) and TK5 (98 ± 69mg/l) (Fig. 5.1.2i_2).

5.1.2j. Sodium and Potassium

Variations in sodium content at different sites are depicted in Table 5.1.2j_1. The high values of sodium were observed in summer months than winter months. It varied from 8 mg/L (TK5) to 39986 mg/L (TK1). The highest mean value of 20354±9007 mg/L was observed for TK1, followed by TK4 (17431±4936 mg/L), TK2 (124±119 mg/L), TK5 (29±12mg/L) and lowest value of 20±10 mg/L was recorded for site TK3. However, the mean values reported for sites TK1 and TK4 were significantly higher ($F_{4,31}$=42.874; p=0.000) than sites TK2, TK3 and TK5 (Fig. 5.1.2j_1). Potassium content also showed high spatial and temporal variations throughout the study period and followed almost the same trend as sodium (Table 5.1.2j_2). Potassium content ranged from a low of 1mg/L (TK3) to 7250 mg/L (TK4). The mean potassium values were significantly higher ($F_{4,31}$=18.614; p=0.000) at TK4 (3426±3102mg/L) followed by TK1 (1910±1164mg/L), and significantly least values were recorded at TK3 (7±6 mg/L), TK5 (12±9 mg/L) and TK2 (27±26 mg/L) (Fig. 5.1.2j_2).

5.1.2k. Chloride

The Lake exhibited high temporal and spatial fluctuations in chloride content throughout the study period (Table 5.1.2k). The chloride content varied 4mg/L (TK3) in December 2004 to 9990 mg/L at site TK1 in October 2004. The mean values of chloride found at TK1 (4934±2753 mg/l) and TK4 (4293±3142 mg/l) were significantly higher ($F_{4,31}$=13.426; p=0.000) than the mean values observed at sites TK3 (19±15 mg/l), TK5 (28±20 mg/l) and TK2 (34±23 mg/l) (Fig. 5.1.2k).

5.1.2l. Nitrate Nitrogen

Spatial and temporal variations in nitrate content at different sites are presented in Table 5.1.2l. The lowest (49µg/L) and highest (2988µg/L) values of nitrate were recorded in October 2005 for sites TK1 and TK5 respectively. Whereas on the basis of mean values, highest value of 2348±578µg/L was registered for TK1, followed by TK2 (406±202µg/L), TK4 (396±136µg/L), TK3 (320±254µg/L), the lowest value of 191±80µg/L was recorded at TK5. However, only site TK1 showed significant variation ($F_{4,31}$=62.238; p=0.000) in nitrate content with rest of the sites (Fig. 5.1.2l).

5.1.2m. Ammonical Nitrogen

In contrast to nitrate nitrogen, ammonical nitrogen values at all the sites were generally low, ranging from a minimum of 6µg/L (TK2) to a maximum of 681µg/L (TK3) (Table 5.1.2m). On the other hand, highest mean values of 179±89 µg/L were observed at site TK1, and lowest of 86±51µg/L was recorded for site TK5. The mean ammonical nitrogen values, however, showed insignificant variation ($F_{4,31}$=0.590; p=0.672) between the study sites (Fig. 5.1.2m).

5.1.2n. Total Phosphorus

The minimum (64µg/L) and maximum (1228µg/L) total phosphorus concentration was found at site TK4 during June and December 2005 respectively (Table 5.1.2n). The mean values ranged from 278±116µg/L (TK3) to 494±396µg/L (TK4). However, there was no significant difference ($F_{4,31}$=0.927; p=0.461) in mean total phosphorus concentration between the study sites (Fig. 5.1.2n).

5.1.2o. Sulphate

Sulphate content at various study sites is shown in Table 5.2.1o. The minimum value of 4mg/L was observed at site TK3 in December 2005 and maximum value of 787 mg/L at site TK4 in December 2004 .The minimum mean value of 18±21mg/L was reported for site TK3 and maximum mean value of 460±258mg/L was recorded for site TK4. However, the mean sulphate content at site TK4 was significantly higher ($F_{4,31}$=12.852; p=0.000) than other sites. Significant variation in sulphate content was also observed between sites TK1 and TK3 (Fig. 5.1.2o).

5.1.2p. Dissolved Silica

The silicate concentration at different study sites in Tso Khar lake during the present investigation is presented in Table 5.1.2p. It ranged from 2mg/L each at TK1 and TK4 to 28mg/L (TK5). The mean values ranged from 9±5mg/L at site TK1 to 12 ±8mg/L at site TK2 and did not show any significant variation ($F_{4,31}$=0.349; p=0.842 between the study sites (Fig. 5.1.2p).

5.1.2q. Total Dissolved Solids

The concentration of TDS showed a fluctuation from 100 mg/L at TK5 to 2284 mg/L at TK4 (Table 5.1.2q). Significant variation ($F_{4,31}$=13.042; p=0.000) in mean TDS values was observed during the present study. The mean TDS values at site TK4

(1373±579mg/L) was significantly higher than mean TDS values found at sites TK5 (138±53mg/L), TK3 (425±317mg/L) and TK2 (631±302mg/L). Site TK1 (1130±347mg/L) also showed significantly higher values than site TK5 and TK3 (Fig. 5.1.2q).

Table 5.1.2a$_1$. Spatial and temporal variations in air temperature (°C) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	17.0	-6.0	10.0	25.0	16.0	*	*	23.0	2.0	**12.4**	**11.2**
TK2	18.0	-2.0	10.0	25.0	16.0	-5.0	12.0	15.0	2.0	**10.1**	**9.9**
TK3	*	-7.0	*	14.0	20.0	-1.0	8.0	18.0	1.0	**7.6**	**10.3**
TK4	*	-7.0	4.0	16.0	12.0	-2.0	8.0	18.0	*	**7.0**	**9.3**
TK5	*	*	6.0	22.0	12.0	-3.0	10.0	*	12.0	**9.8**	**8.2**

Table 5.1.2a$_2$. Spatial and temporal variations in water temperature (°C) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	18.0	0.0	11.0	23.0	10.0	0.0	*	20.0	6.5	**11.1**	**8.8**
TK2	16.0	0.0	11.0	23.0	10.0	0.0	13.0	22.0	7.0	**11.3**	**8.3**
TK3	*	5.0	*	16.0	11.0	5.0	10.0	12.0	1.0	**8.6**	**5.1**
TK4	*	0.0	12.0	17.0	12.0	0.0	10.0	19.0	*	**10.0**	**7.5**
TK5	*	*	17.0	23.0	10.0	0.0	17.0	17.0	4.0	**12.6**	**8.2**

Table 5.1.2b$_1$. Spatial and temporal variations in depth (m) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	0.4	0.0	0.5	0.6	0.5	*	*	0.5	0.4	**0.4**	**0.2**
TK2	0.9	0.0	1.4	1.6	1.1	0.0	1.4	1.5	1.1	**1.0**	**0.6**
TK3	*	0.2	*	0.4	0.4	0.2	0.4	0.4	0.2	**0.3**	**0.1**
TK4	*	0.0	2.2	2.6	2.1	0.0	2.8	2.4	2.1	**1.8**	**1.1**
TK5	*	*	2.2	2.4	1.8	0.0	2.6	*	1.0	**1.7**	**1.0**

Table 5.1.2b$_2$. Spatial and temporal variations in transparency (m) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	0.1	0.0	0.2	0.2	0.1	*	*	0.1	0.1	**0.1**	**0.1**
TK2	0.3	0.0	0.7	0.7	0.7	0.0	0.5	0.5	0.5	**0.4**	**0.3**
TK3	*	0.2	*	0.4	0.4	0.2	0.4	0.4	0.2	**0.3**	**0.1**
TK4	*	0.0	0.2	0.2	0.3	0.0	0.2	2.2	*	**0.4**	**0.8**
TK5	*	*	0.8	0.7	0.8	0.0	0.8	*	0.8	**0.6**	**0.3**

Table 5.1.2c. Spatial and temporal variations in pH in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	8.61	8.53	8.55	8.72	8.36	*	*	8.93	8.32	**8.57**	**0.2**
TK2	8.76	8.85	8.55	8.73	8.36	7.55	8.58	8.90	8.62	**8.54**	**0.4**
TK3	*	9.06	*	8.24	8.23	8.02	8.28	7.81	8.12	**8.25**	**0.4**
TK4	*	8.92	9.03	8.57	8.25	8.33	8.98	8.62	*	**8.67**	**0.3**
TK5	*	*	8.75	9.28	7.90	7.57	8.77	*	8.58	**8.48**	**0.6**

Table 5.1.2d. Spatial and temporal variations in conductivity (µS/cm) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	25800	27720	31000	28700	13420	*	*	12690	24372	**23386**	**7366**
TK2	2250	1022	3100	2870	1342	1054	1456	1358	833	**1698**	**834**
TK3	*	315	*	466	271	533	805	421	432	**463**	**175**
TK4	*	23300	11066	11820	22390	18200	22600	17780	*	**18165**	**5078**
TK5	*	*	5140	1380	1656	1320	1478	*	1239	**2036**	**1528**

Table 5.1.2e. Spatial and temporal variations in dissolved oxygen (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	*	7.0	*	4.0	2.0	*	*	*	*	**4.3**	**2.5**
TK2	9.0	6.0	4.0	4.0	4.0	6.0	8.0	7.0	8.0	**6.2**	**1.9**
TK3	*	8.0	*	8.0	9.0	6.0	9.0	8.0	8.0	**8.0**	**1.0**
TK4	*	*	*	*	*	*	*	*	*	*	*
TK5	*	*	6.0	6.0	8.0	6.0	8.0	*	8.0	**7.0**	**1.1**

Table 5.1.2f. Spatial and temporal variations in free carbon dioxide (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	0.0	0.0	0.0	0.0	0.0	*	*	0.0	0.0	**0.0**	**0.0**
TK2	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	**2.2**	**6.7**
TK3	*	0.0	*	4.0	10.0	20.0	0.0	12.0	18.0	**9.1**	**8.2**
TK4	*	0.0	0.0	0.0	2.0	0.0	0.0	0.0	*	**0.3**	**0.8**
TK5	*	*	0.0	0.0	4.0	8.0	0.0	*	0.0	**2.0**	**3.3**

Table 5.1.2g_1. Spatial and temporal variations in total alkalinity (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	2860	2444	1576	1428	3740	*	*	2440	2060	**2364**	**790**
TK2	1110	456	1676	1284	1740	1060	580	260	446	**957**	**549**
TK3	*	240	*	88	160	150	200	120	160	**160**	**50**
TK4	*	2878	1440	2792	1840	2420	2338	1540	*	**2178**	**580**
TK5	*	*	80	144	404	180	110	*	68	**164**	**124**

Table 5.1.2g$_2$. Spatial and temporal variations in carbonate alkalinity (mg/L) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	980	722	724	324	1180	*	*	800	800	**790**	**263**
TK2	230	134	728	320	780	0	100	40	0	**259**	**300**
TK3	*	68	*	0	0	0	44	0	0	**16**	**28**
TK4	*	1278	24	320	0	700	968	720	*	**573**	**480**
TK5	*	*	16	28	0	0	54	*	0	**16**	**22**

Table 5.1.2g$_3$. Spatial and temporal variations in bicarbonate alkalinity (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	1880	1722	852	1104	2560	*	*	1640	1260	**1574**	**568**
TK2	880	322	520	1104	960	1060	480	220	446	**666**	**336**
TK3	*	172	*	88	160	150	158	120	160	**144**	**30**
TK4	*	1600	120	2472	840	1470	1470	820	*	**1256**	**746**
TK5	*	*	64	116	404	56	56	*	68	**127**	**137**

Table 5.1.2h. Spatial and temporal variations in total hardness (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	4000	2272	2130	2020	4300	*	*	3064	2866	**2950**	**908**
TK2	668	928	420	530	645	360	194	1160	382	**587**	**303**
TK3	*	444	*	390	380	120	394	360	364	**350**	**105**
TK4	*	4672	1930	3025	2300	2490	2868	2600	*	**2841**	**884**
TK5	*	*	830	800	400	640	280	*	90	**507**	**298**

Table 5.1.2i$_1$. Spatial and temporal variations in calcium content (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	90	232	190	200	210	*	*	353	410	**241**	**107**
TK2	88	196	80	100	120	42	64	180	48	**102**	**55**
TK3	*	64	*	48	120	20	36	120	32	**63**	**41**
TK4	*	152	89	135	100	60	196	315	*	**150**	**86**
TK5	*	*	40	40	68	52	36	*	12	**41**	**19**

Table 5.1.2i$_2$. Spatial and temporal variations in magnesium content (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	1452	1268	900	680	1030	*	*	644	568	**935**	**335**
TK2	58	107	85	78	54	42	38	172	33	**74**	**44**
TK3	*	48	*	56	34	17	34	44	32	**38**	**13**
TK4	*	920	430	390	330	198	259	520	*	**435**	**239**
TK5	*	*	177	170	68	124	36	*	15	**98**	**69**

Table 5.1.2j$_1$. Spatial and temporal variations in sodium content (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	15830	17608	39986	22214	14444	*	*	16720	15688	**20356**	**9007**
TK2	53	64	399	222	144	40	88	68	40	**124**	**119**
TK3		11	*	21	12	29	38	18	14	**20**	**10**
TK4	*	19760	11162	21622	13480	21100	22680	12210	*	**17431**	**4936**
TK5	*	*	28	25	44	29	38	*	8	**29**	**12**

Table 5.1.2j_2. Spatial and temporal variations in potassium content (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	1203	1230	1480	4500	1800	*	*	1436	1720	**1910**	**1164**
TK2	34	17	14	45	88	8	22	3	14	**27**	**26**
TK3	*	1	*	8	2	19	11	3	8	**7**	**6**
TK4	*	140	31	5626	5626	7250	4880	430	*	**3426**	**3102**
TK5	*	*	9	5	5	9	11	*	30	**12**	**9**

Table 5.1.2k. Spatial and temporal variations in chloride content (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	9990	3430	5850	3279	1240	*	*	5250	5500	**4934**	**2753**
TK2	39	10	58	32	24	20	10	82	28	**34**	**23**
TK3	*	4	*	10	40	38	6	20	18	**19**	**15**
TK4	*	7600	3336	2295	1488	1835	3800	9700	*	**4293**	**3142**
TK5	*	*	24	13	41	62	15	*	12	**28**	**20**

Table 5.1.2l. Spatial and temporal variations in nitrate nitrogen content (µg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	1743	2045	2777	2908	2988	*	*	2423	1552	**2348**	**578**
TK2	640	290	277	290	236	182	746	400	590	**406**	**202**
TK3	*	824	*	422	152	392	170	129	148	**320**	**254**
TK4	*	430	484	408	440	580	191	240	*	**396**	**136**
TK5	*	*	210	185	49	293	191	*	220	**191**	**80**

Table 5.1.2m. Spatial and temporal variations in ammonical nitrogen (μg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	78	345	156	168	114	*	*	153	242	**179**	**89**
TK2	140	265	156	168	114	12	6	13	30	**100**	**91**
TK3	*	681	*	40	98	29	10	65	15	**134**	**243**
TK4	*	130	121	104	180	116	125	218	*	**142**	**41**
TK5	*	*	158	128	99	38	63	*	32	**86**	**51**

Table 5.1.2n. Spatial and temporal variations in total phosphorus (μg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	242	80	356	404	807	*	*	318	485	**385**	**226**
TK2	560	234	496	404	807	408	117	210	404	**404**	**207**
TK3	*	212	*	144	441	435	273	240	202	**278**	**116**
TK4	*	404	64	664	576	1228	83	440	*	**494**	**396**
TK5	*	*	228	228	400	140	257	*	520	**296**	**139**

Table 5.1.2o. Spatial and temporal variations in sulphate (μg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	320	250	185	199	190	*	*	242	290	**239**	**52**
TK2	100	123	190	146	185	101	103	168	257	**153**	**53**
TK3	*	11	*	66	10	4	12	10	16	**18**	**21**
TK4	*	727	248	181	665	787	370	240	*	**460**	**258**
TK5	*	*	37	81	246	73	66	*	160	**111**	**78**

Table 5.1.2p. Spatial and temporal variations in silicate (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	8	9	6	15	15	*	*	2	9	**9**	**5**
TK2	16	17	14	19	19	4	4	5	14	**12**	**6**
TK3	*	11	*	10	10	4	12	10	16	**10**	**4**
TK4	*	14	12	21	14	8	5	2	*	**11**	**6**
TK5	*	*	8	28	10	6	10	*	9	**12**	**8**

Table 5.1.2q. Spatial and temporal variations in total dissolved solids (mg/L) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	960	1040	960	1900	905	*	*	1010	1133	**1130**	**347**
TK2	568	960	960	190	205	450	870	640	840	**631**	**302**
TK3	*	950	*	750	290	170	480	218	120	**425**	**317**
TK4	*	1310	920	2100	2284	980	1080	940	*	**1373**	**577**
TK5	*	*	108	100	190	100	220	*	108	**138**	**53**

*Sampling not done

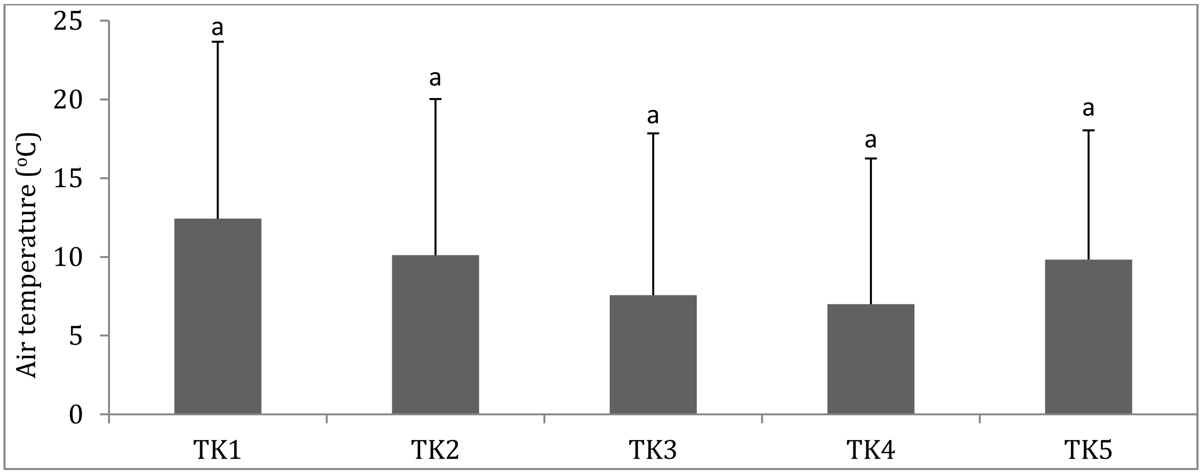


Fig. 5.1.2a$_1$. Changes in air temperature (ºC) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

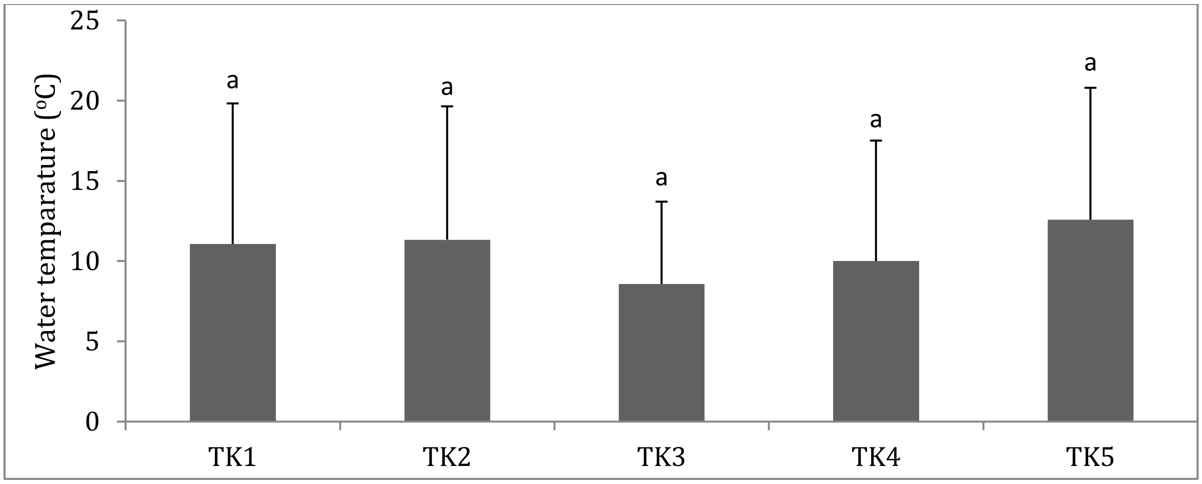


Fig. 5.1.2a$_2$. Changes in water temperature (ºC) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

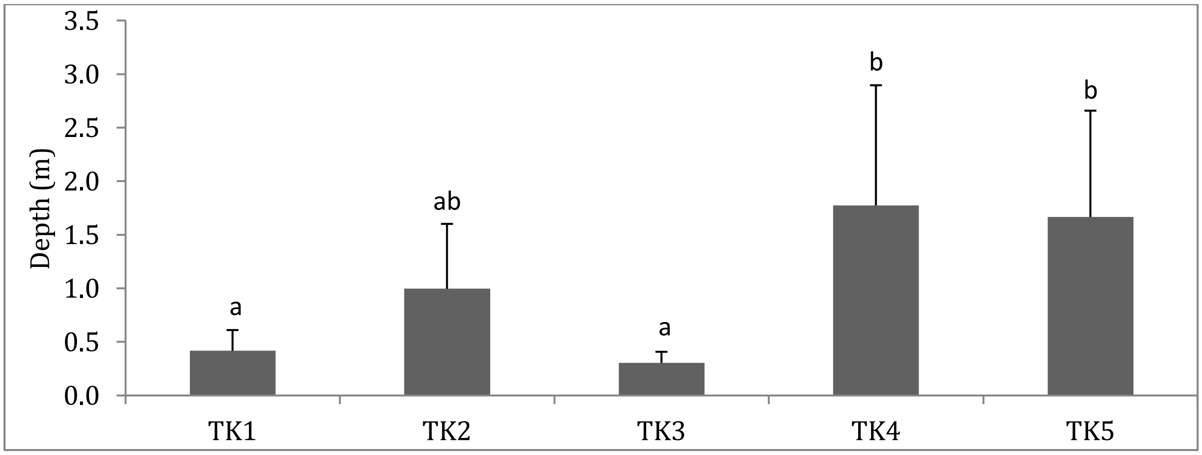


Fig. 5.1.2b$_1$. Changes in depth (m) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

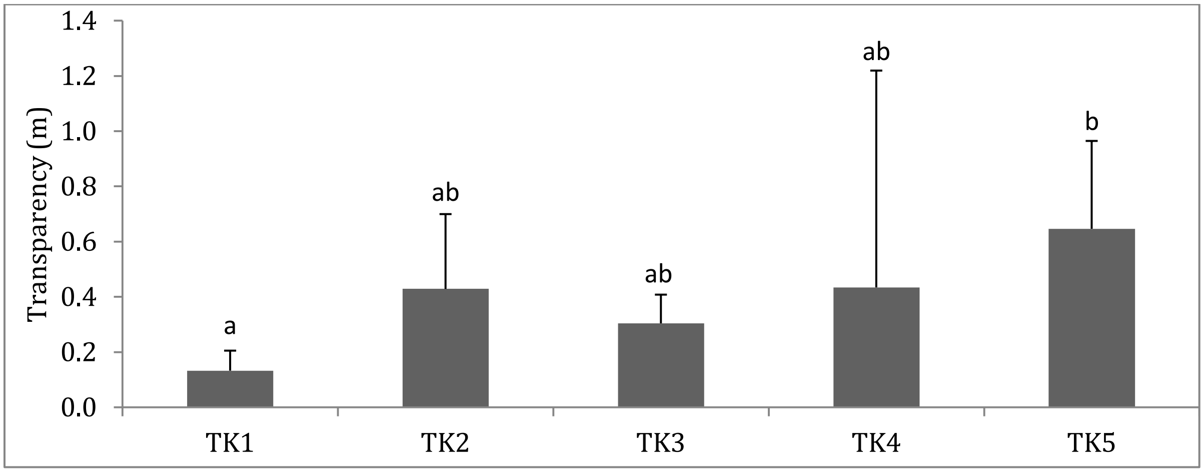


Fig. 5.1.2b$_2$. Changes in transparency (m) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

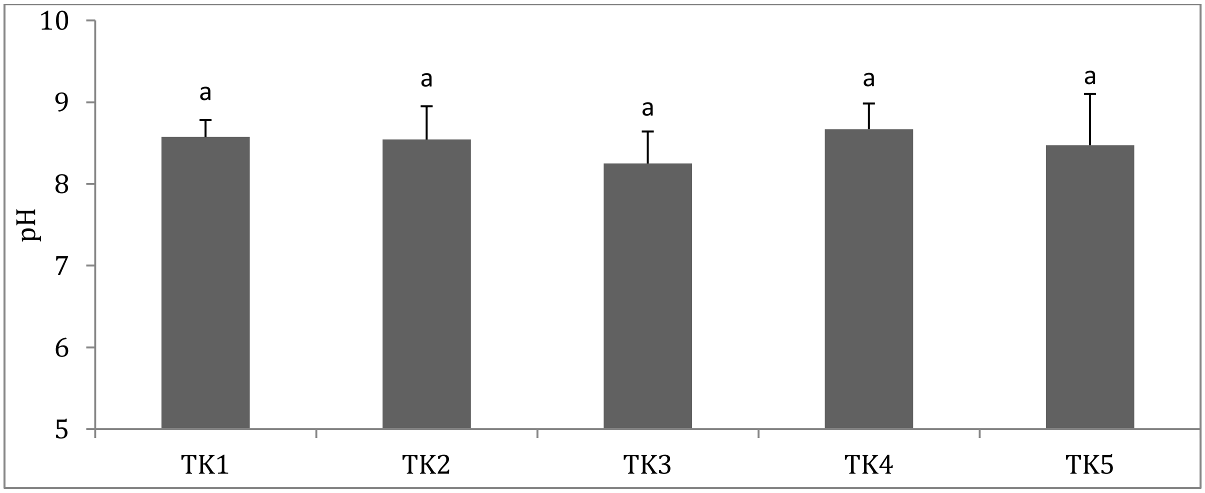


Fig. 5.1.2c. Changes in pH (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

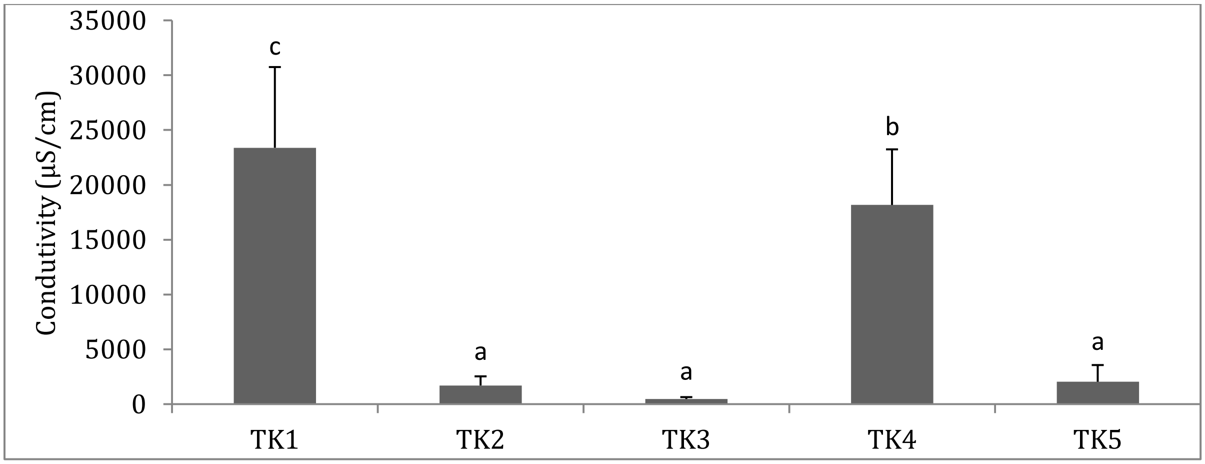


Fig. 5.1.2d. Changes in conductivity (µS/cm) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

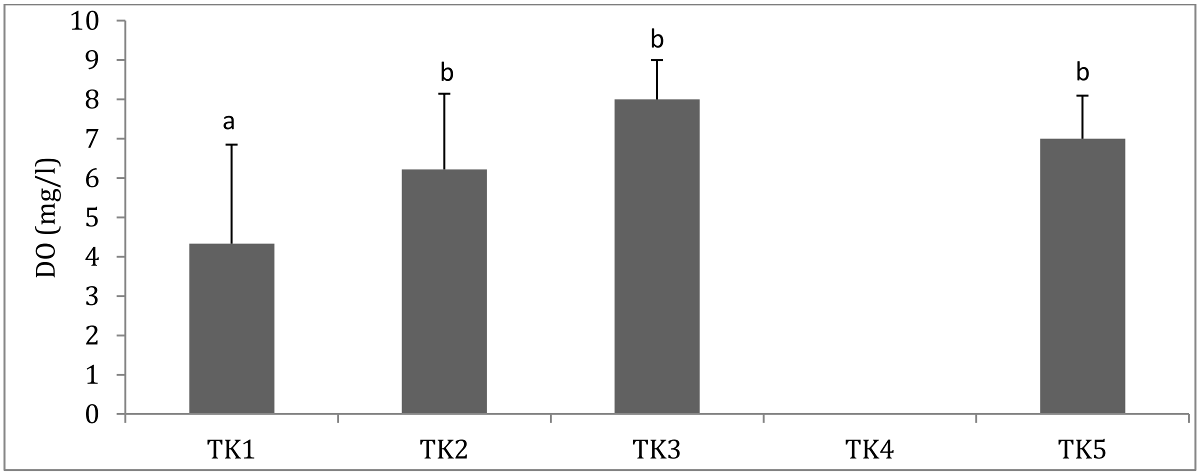


Fig. 5.1.2e. Changes in DO (mg/l)(mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

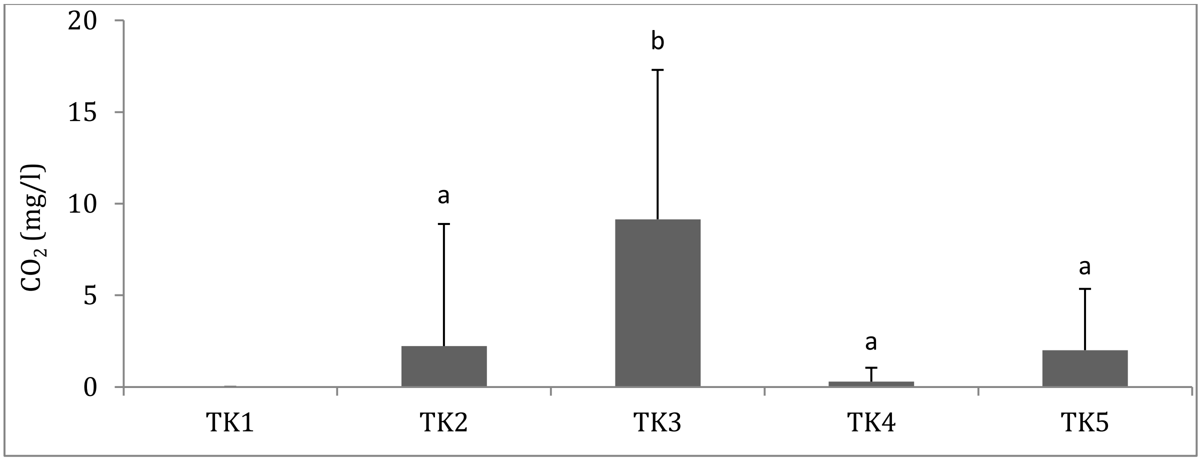


Fig. 5.1.2f. Changes in free CO_2 (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

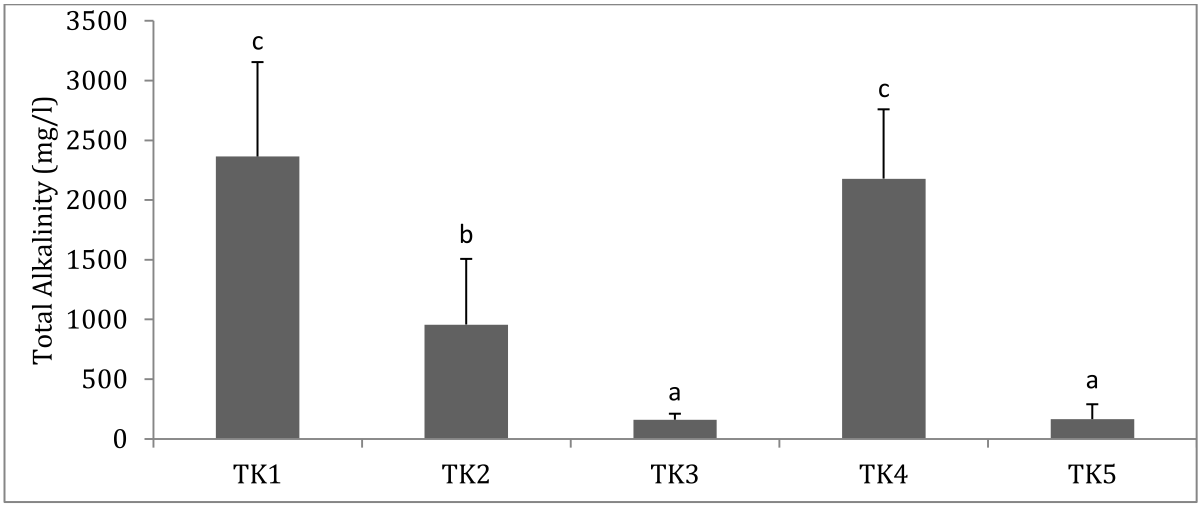


Fig. 5.1.2g. Changes in total alkalinity (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

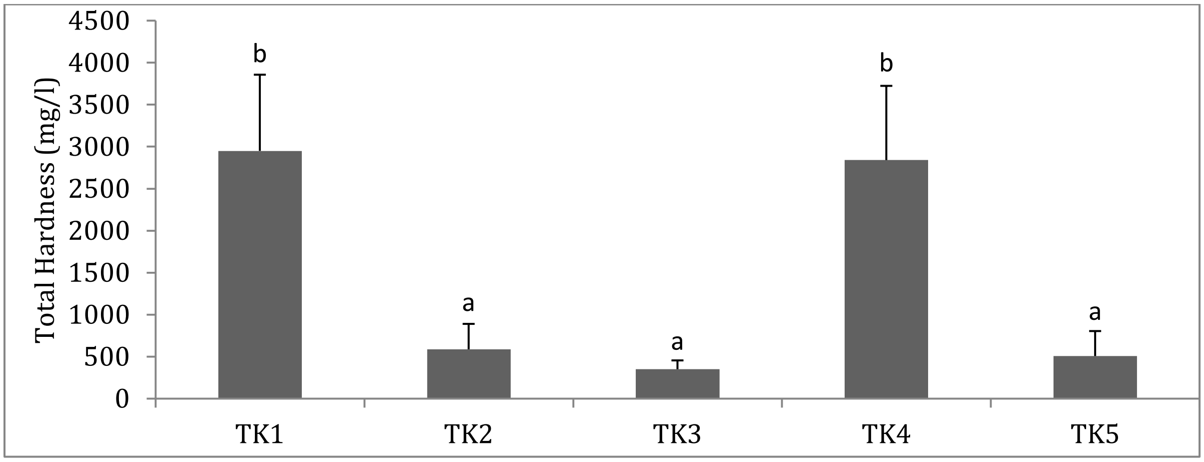


Fig. 5.1.2h. Changes in total hardness (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

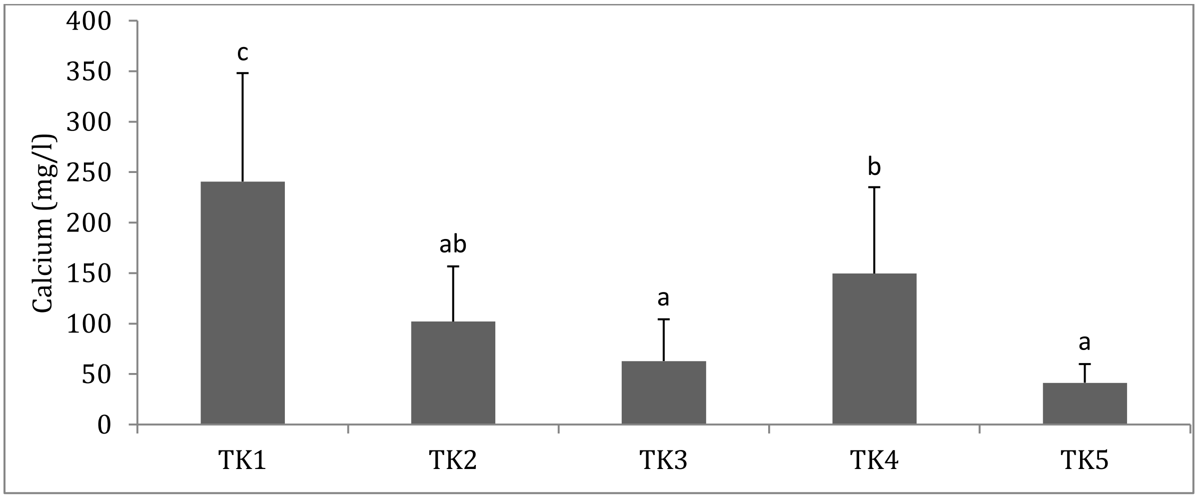


Fig. 5.1.2i$_1$. Changes in calcium (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

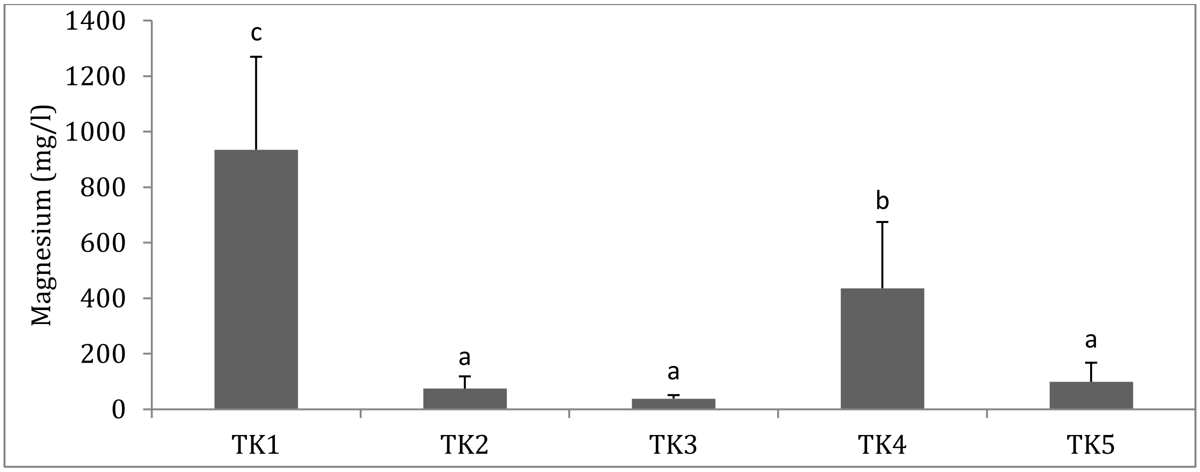


Fig. 5.1.2i$_2$ Changes in magnesium (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

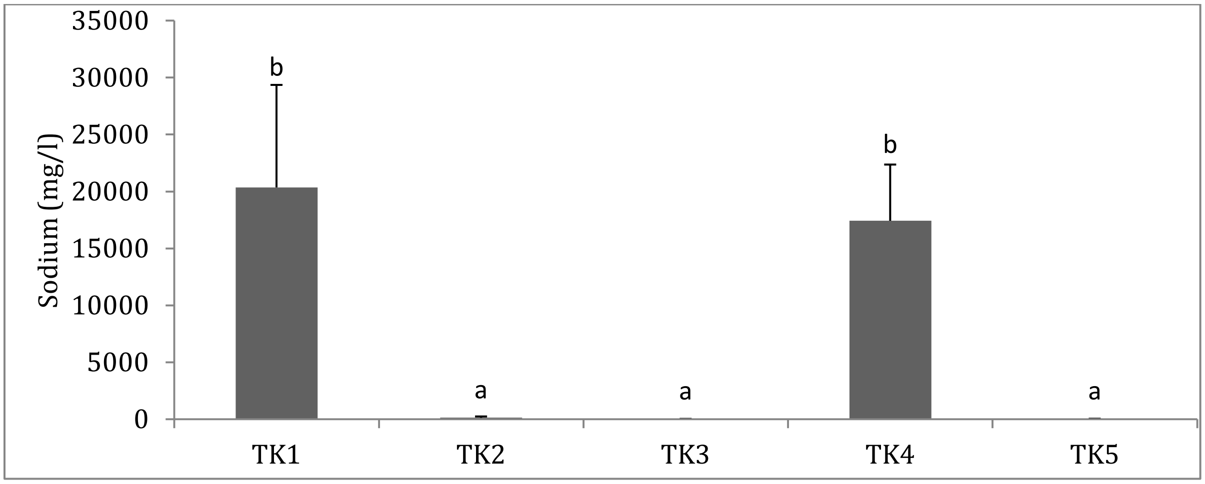


Fig. 5.1.2j$_1$. Changes in sodium (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

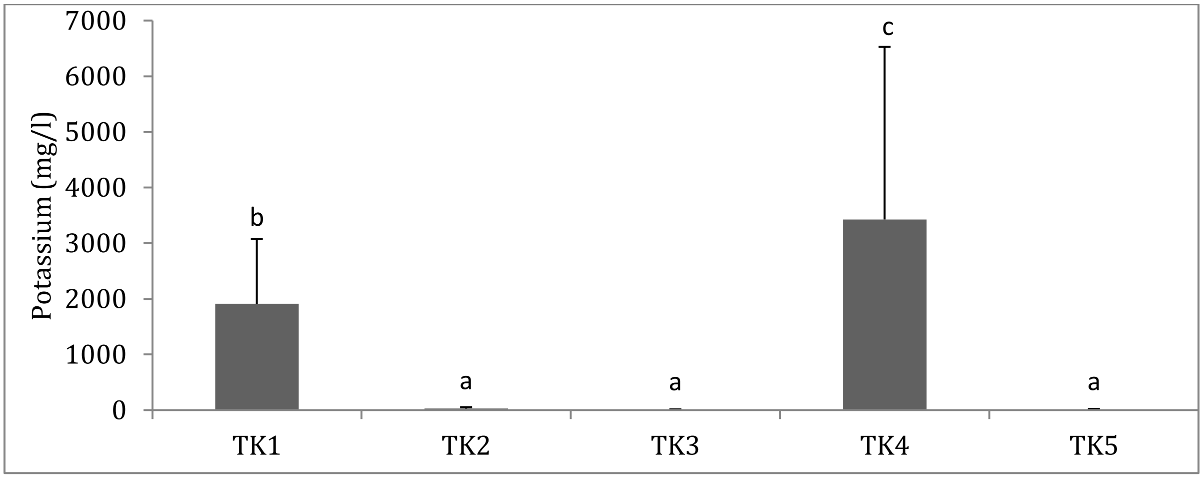


Fig. 5.1.2j$_2$. Changes in potassium (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

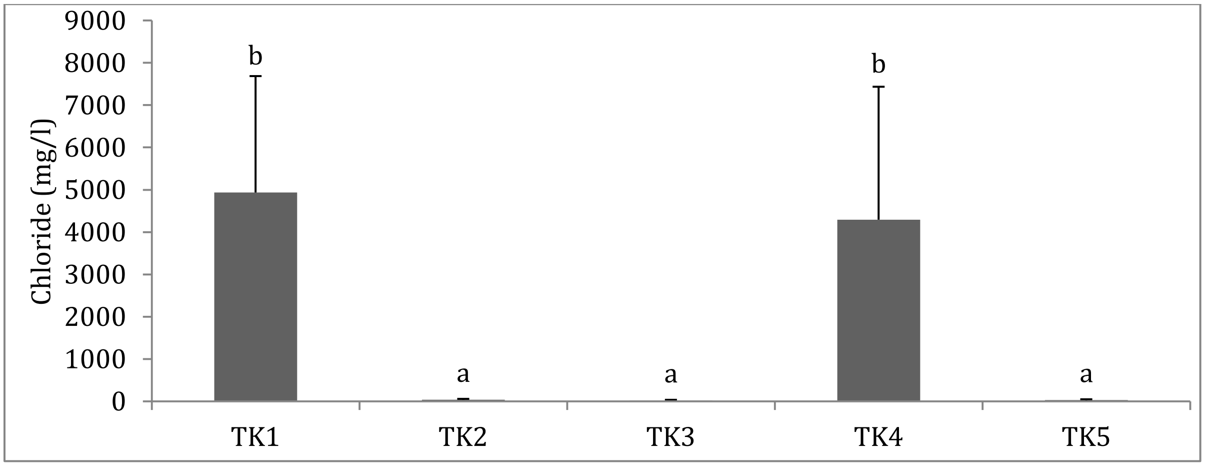


Fig. 5.1.2k. Changes in chloride (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

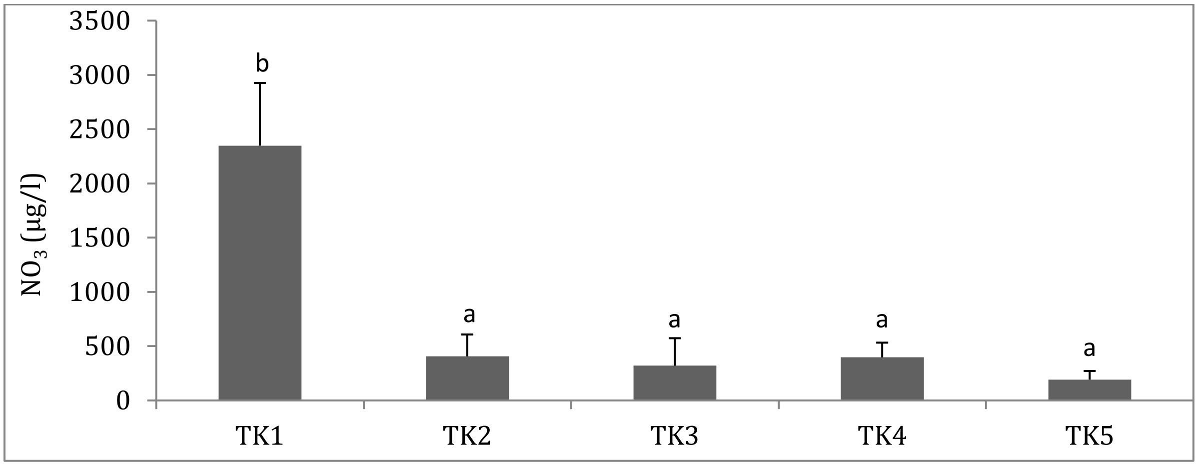


Fig. 5.1.2l. Changes in nitrate (µg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

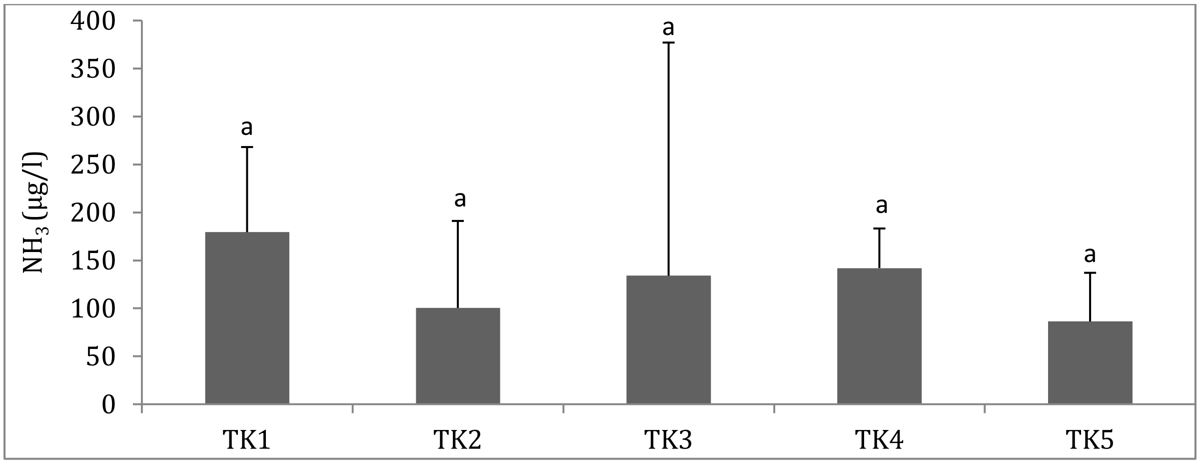


Fig. 5.1.2m. Changes in ammonia (µg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

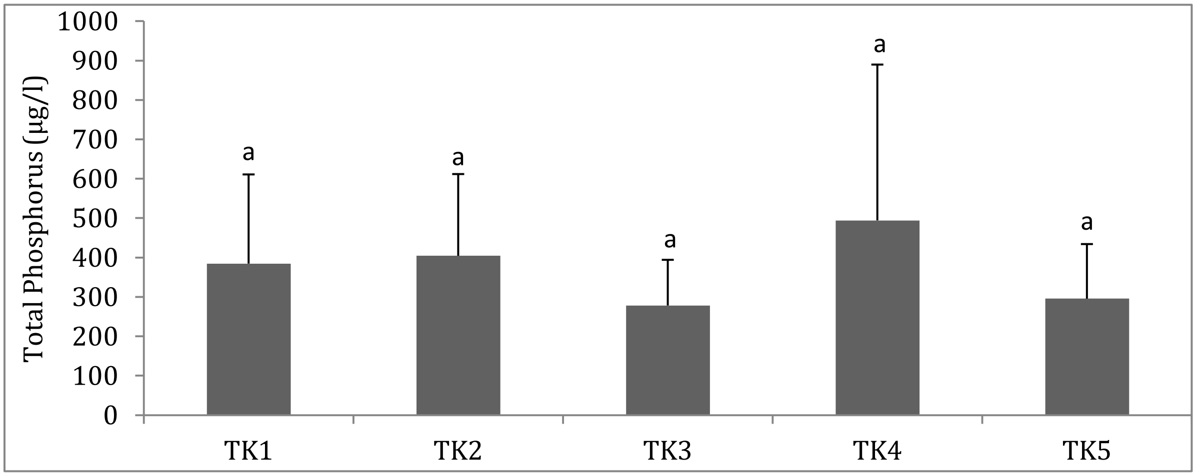


Fig. 5.1.2n. Changes in total phosphorus (µg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

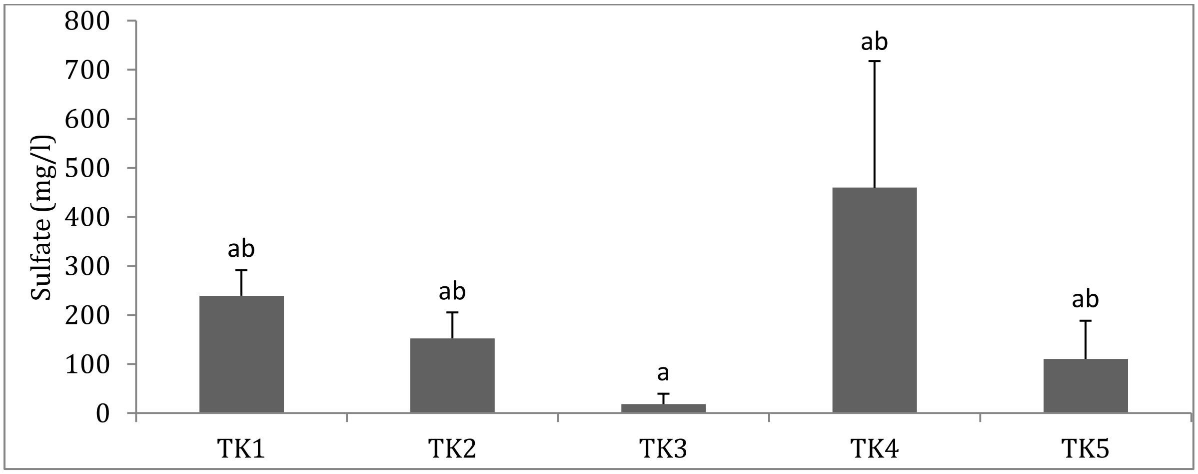


Fig. 5.1.2o. Changes in sulphate (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

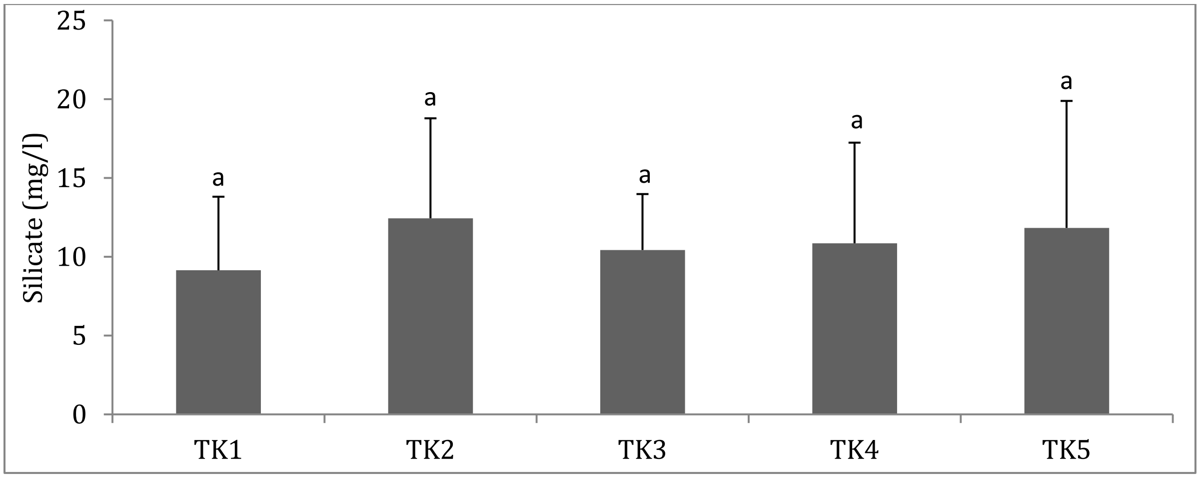


Fig. 5.1.2p. Changes in silicates (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

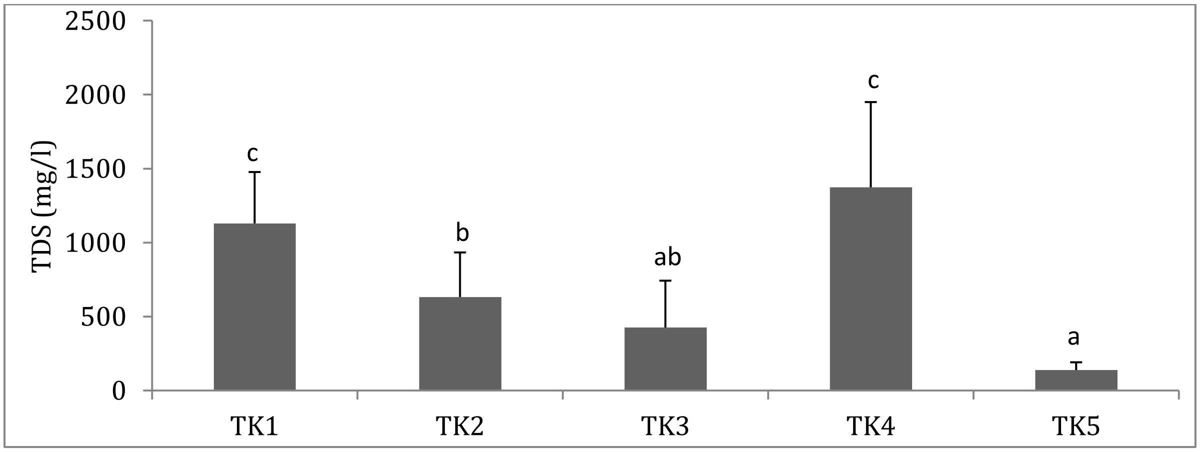


Fig. 5.1.2q. Changes in TDS (mg/l) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

5.1.3. Manasbal Lake

5.1.3a. Air and Water temperature

The air temperature at Manasbal lake fluctuated from 7°C (M1) in January to 33°C (M3 and M5) in June and July during 2005, and in 2006 from 6°C (M1) in January to 34°C (M5) in June (Table 5.1.3a_1). The highest (21.4±8°C and 21.5±8°C) and the lowest (18.1±8°C and 17.1±8°C) mean values of air temperature were recorded for sites M5 and M1 in 2005 and 2006 respectively. The mean air temperature values did not show any significant variation ($F_{5,138}$=0.924; p=0.467) between the study sites (Fig. 5.1.3a_1). The mean values of water temperature varied from 9.3±1.9°C (M5b) to 18.3±6.9°C (M5) in 2005 and from a minimum value of 9.6±2.3°C (M5b) to 18.9 ±8.1 °C (M5) in 2006 (Table 5.1.3a_2). In contrast to air temperature, mean water temperature in Manasbal lake was significantly low at site M5B than rest of the sites except site M1 (Fig. 5.1.3a_2).

5.1.3b. Depth

A clear trend was observed in depth which depicted higher values in summer and lower in winter season at all the sites. Lower values of depth were found at site M1 (0.3m) and M3 (0.5m) during 2004 and 2005 respectively, while M5 recorded highest values during the study period (Table 5.1.3b). The mean values showed significant variation ($F_{5,138}$=3365.12; p=0.000) between the study sites. Site M5 (12.24±0.3m) had significantly higher and site M1 (0.9±0.6m) had significantly lower values of mean water depth than other sites. Site M2 (1.97±0.52m) had significantly higher values than site M3 (1.56±m) during the study period (Fig. 5.1.3b).

5.1.3c. Transparency

The water transparency values at all the selected sites except M5 were below 2.5m.The highest transparencies were found in summer season. During both years of investigation minimum (0.2m) and maximum (6.0m) transparency values were found at sites M1 and M5 respectively (Table 5.1.3c). The mean transparency values showed significant difference ($F_{5,138}$= 601.29; p=0.000) between the study sites. Site M5 (5.1±0.58m) had significantly higher and site M1 (0.45±0.18m) lower mean transparency values than other sites. However, transparency values at sites M2 (0.94±0.29m), M3 (0.82±0.36m) and M4 (0.85±0.49m) did not show any significant difference (Fig. 5.1.3c).

5.1.3d. pH

The pH of water was in alkaline range, except bottom site M5b, where pH was found to be slightly acidic throughout the study period. It ranged from a minimum of 6.30 at site M5b to a maximum of 10.0 at site M2 during first year, while during 2nd year the range was 6.0 to 9.70 (Table 5.1.3d). On the basis of mean values, site M5b (6.65±0.25) had significantly lower ($F_{5,138}$= 26.033; p=0.000) pH values than other sites (Fig. 5.1.3d). Rest of the study sites did not show any significant variation in pH values.

5.1.3e. Conductivity

The conductivity revealed variations from 213 µS/cm for M4 in September to 565 µS/cm for M5b in October during the year 2004-05 while in 2005-06 it fluctuated from 259 µS/cm for M2 and M3 in August to a maximum of 596 µS/cm for M5b in June (Table 5.1.3e). The mean conductivity values were significantly different ($F_{5,138}$= 26.491; p=0.000) at site M5B (506±9 µS/cm) than other sites. Similarly, conductivity values at site M2 (409±15 µS/cm) were significantly higher than sites M5 (346±6 µS/cm) and M4 (362±11 µS/cm). Rest of the sites did not show any significant variation in mean conductivity values (Fig. 5.1.3e).

5.1.3f. Dissolved Oxygen

The highest concentration of dissolved oxygen (14mg/L) was recorded at site M1 and lowest (3mg/L and 5mg/L) at site M3 during both years of study (Table 5.1.3f). The dissolved oxygen at site M5b, which represents the bottom site was absent throughout the investigation period. The mean values of dissolved oxygen ranged from 8.6±0.6 mg/L (M3) to 10.1±0.5 mg/L (M2). Except site M5B, the mean dissolved oxygen did not show any significant difference between the study sites (Fig. 5.1.3f).

5.1.3g. Free Carbon Dioxide

Variation in free CO_2 values at different study sites in Manasbal Lake is presented in Table 5.1.3g. CO_2 values fluctuated from a minimum of 2 mg/L at site M1 to a maximum of 27 mg/L at site M5b in 2005. In 2006 free CO_2 varied from 2 mg/L at site M3 and M5 to 28 mg/L at site M5b. The mean values of free CO_2 at site M5b (21±4.21mg/L) were significantly higher ($F_{5,138}$= 45.549; p=0.000) than other sites. Similarly, the mean CO_2 values found at site M1 (7±7.17mg/L) were significantly higher than site M2 (3±3.11mg/L). Rest of the sites did not show any significant variation in mean free CO_2 values (Fig. 5.1.3g).

5.1.3h. Alkalinity

Total alkalinity was mainly contributed by bicarbonates; however, carbonate alkalinity was also recorded at some sites (Table 5.1.3h_{1-3}). Perusal of the data on total alkalinity revealed that minimum values were recorded at site M4 (46 mg/L and 86mg/L) and maximum values were found at site M5b (393mg/L and 390 mg/L) during both years of investigation (Table 5.1.3). The mean values ranged from

128±30.34 mg/L (M4) to 311±62.01 mg/L (M5b). Site M5b had significantly higher ($F_{5,138}$= 71.176; p=0.000) values than other sites. The rest of sites did not show any significant variation in total alkalinity (Fig. 5.1.3h_1).

5.1.3i. Total Hardness

The total hardness of Manasbal ranged from 57mg/L at M5 in July to 298 mg/L at M5b in August during 2004-05 and in 2005-06, the values varied between 75 each at M3 and M4 (May and June) to 288mg /L at M5b (June) (Table 5.1.3i). The mean values of total hardness ranged from 111±27.93 mg/L (M4) to 258±23.97mg/L (M5b). Comparing the sites on the basis of mean values, M5b had significantly higher ($F_{5,138}$= 85.871; p=0.000) values than other sites. Rest of the sites showed insignificant variation in total hardness values (Fig. 5.1.3i).

5.1.3j. Calcium and Magnesium

The cations at all the study sites revealed the following order Ca>Mg>Na>K. The calcium content varied between 18 mg/L (M3 and M5) to 79 mg/L (M5b) in 2004-05, while in 2005-06, the values varied from 20 mg/L (M4) to 78 mg/L (M5b) (Table 5.1.3j_1). The mean values of calcium did not show any significant difference between the study sites, except site M5b (57±12.25mg/L) which showed significantly higher ($F_{5,138}$= 17.823; p=0.000) values of calcium (Fig. 5.1.3j_1). The minimum (3 and 5mg/L) and maximum (22 and 20 mg/L) magnesium values were recorded at sites M3 and M5b respectively, during both years of investigation (Table 5.1.3j_2). The mean values of magnesium at site M5b (15±3.36µg/L) were significantly higher ($F_{5,138}$= 19.669; p=0.000) than other sites (Fig. 5.1.3j_2).

5.1.3k. Sodium and Potassium

The sodium content was below 20 mg/L throughout the study period (Table 5.1.3k_1). The sodium content varied from 2 mg/L (M1 and M3) to 18 mg/L (M2 and

M5b) during 2004-04 and from 3mg/L (M3 and M4) to 17 mg/L (M5b) during 2005-06. The mean values of sodium at site M5b (14±2.55µg/L) were significantly higher ($F_{5,138}$= 37.623; p=0.000) than other sites. Site M2 (9±3.70µg/L) also had significantly higher values than other sites (Fig. 5.1.3k_1). The potassium concentration varied from a minimum of 1 mg/L at most of the study sites, while maximum values of 7 mg/L were observed at site M5b during the study period (Table 5.1.3k_2). The mean values of potassium showed significant variation ($F_{5,138}$= 13.783; p=0.000) between the study sites. The mean concentration of potassium at site M5b (4±1.48µg/L) was significantly higher than other sites except site M2 (3±1.58µg/L). Site M2 also had higher values than sites M5 (2±0.71µg/L), M4 (2±0.65µg/L) and M3 (2±0.83µg/L). Significant difference in potassium was also observed between sites M1 (3±1.26µg/L) and M5 (Fig. 5.1.3k_2).

5.1.3l. Chloride

The chloride content at various study sites in Manasbal Lake are depicted in Table 5.1.3l. The chloride fluctuated from 10mg/L at M5 to 50mg/L at M5b during the study period. The sites M3, M4 and M5 depicted low values of chloride and sites M1, M2 and M5b recorded slightly higher values of chloride content. The mean value of chloride at site M5 (15±3.09mg/L) were significantly lower ($F_{5,138}$= 18.552; p=0.000) than other sites except site M3 (18±3.99mg/L),while at M5B (29±9.79mg/L) it was significantly higher than other sites (Fig. 5.1.3l).

5.1.3m. Nitrate Nitrogen

The nitrate content at different study sites in Manasbal Lake are shown in Table 5.1.3m. Nitrate content varied from a minimum of 110µg/L at site M5 to a maximum of 408µg/L at site M2 in 2004-05 and from 109 µg/L at site M4 to 380 µg/L at site M5b in 2005-06. The mean values of nitrate nitrogen showed significant variation ($F_{5,138}$= 16.834; p=0.000) between the study sites. The mean nitrate values at site M5b

(274±50.20µg/L) and M2 (272±63.86µg/L) were significantly higher than other sites, except site M1 (228±69.01µg/L). M1 and M4 (221±58.98µg/L) also had significantly higher values than site M5 (149±31.37µg/L) (Fig. 5.1.3m).

5.1.3n. Ammonical Nitrogen

The Manasbal Lake showed high fluctuations in ammonical nitrogen. The minimum (15µg/L and 16µg/L) and maximum (660µg/L and 680µg/L) values of ammonical nitrogen were recorded at site M5 and M5b respectively, during study period (Table 5.1.3n). The mean ammonical nitrogen was significantly higher ($F_{5,138}$= 730.06; p=0.000) at site M5b (559±77.84 µg/L) than other sites. The mean values at site M2 (73±35.51 µg/L) were also significantly higher than site M5 (32±13.38 µg/L) and M3 (41±22.48µg/L) (Fig. 5.1.3n).

5.1.3o. Total Phosphorus

The total phosphorus of the lake ranged from 56 µg/L (M5) in June to 485µg/L (M5b) in July 2004-05. While in 2005-06 it varied from 68µg/L (M3 and M4) in May to 532µg/L (M5b) in June (Table 5.1.3o). The mean nitrate content was significantly higher ($F_{5,138}$= 36.587; p=0.000) at site M5B (377±80.59 µg/L) than other sites. The mean values of total phosphorus at site M2 (233±89.02 µg/L) were also significantly higher than sites M5 (127±36.57 µg/L), M3 (151±68.50 µg/L) and M4 (166±85.39 µg/L) (Fig. 5.1.3o).

5.1.3p. Sulphate

Variation in sulphate content at different study sites in Manasbal Lake are depicted in Table 5.1.3p. Maximum sulphate content of 8 and 10 mg/L was recorded at site M5b and minimum of 1 mg/L was recorded at most of the sites during both years of study. The mean sulphate values ranged between 2.45±1.14mg/L (M4) to

6±2.70mg/L (M5b). However, mean values of sulphate at site M5b were significantly higher ($F_{5,138}$= 17.654; p=0.000) than other sites (Fig. 5.1.3p).

5.1.3q. Dissolved Silica

The silicate content of the lake ranged from 1mg/L at most of the sites to a maximum of 18 mg/L at site M5b during the investigation period (Table 5.1.3q). The mean values ranged from a minimum of 1.33±mg/L at site M2 to a maximum of 13.41±3.32mg/L at site M5b. However, analysis of variance showed significantly higher ($F_{4,31}$=128.477; p=0.000) mean value of silicate at M5b than other sites. Site M5 also showed significant difference in mean silicate values with sites M2, M4 and M3 (Fig. 5.1.3q).

5.1.3r. Total Dissolved Solids

The silicate concentration at different sites in Manasbal Lake is depicted in Table 5.1.3r. The highest (183mg/L) and lowest (21mg/L) TDS values were recorded at M2 in 2004-05 and in 2005-06 the highest concentration of TDS was recorded at M5 (185 mg/L) and lowest at M4 (30 mg/L). The mean values of TDS showed significant variation ($F_{5,138}$= 14.490; p=0.000) between the study sites. The mean value of TDS was significantly higher at site M5b (127±32mg/L) than other sites. Sites M2 (82±47mg/L) and M3 (78±28mg/L) also had significantly higher TDS values than site M4 (50±13mg/L) (Fig. 5.1.3r).

Table 5.1.3a$_1$. Spatial and temporal variations in air temperature (°C) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	9.0	7.0	10.0	14.0	17.0	20.0	30.0	32.0	25.0	22.0	18.0	13.0	**18.1**	**7.8**
	M2	9.0	9.0	10.0	16.0	18.0	22.0	32.0	32.0	28.0	27.0	20.0	13.0	**19.7**	**7.2**
	M3	11.0	10.0	11.0	17.0	22.0	24.0	33.0	33.0	27.0	28.0	20.0	16.0	**21.0**	**7.9**
	M4	10.0	8.0	12.0	13.0	19.0	27.0	31.0	31.0	28.0	26.0	31.0	15.0	**20.9**	**8.5**
	M5	13.0	10.0	12.0	18.0	20.0	26.0	31.0	33.0	28.0	26.0	22.0	18.0	**21.4**	**8.0**
	M5b														
2005-2006	**M1**	8.0	6.0	13.0	10.0	13.0	19.0	24.0	29.0	28.0	23.0	20.0	12.0	**17.1**	**7.8**
	M2	9.0	8.0	11.0	14.0	18.0	20.0	26.0	29.0	26.0	23.0	20.0	12.0	**18.0**	**7.2**
	M3	11.0	10.0	12.0	15.0	20.0	22.0	30.0	30.0	30.0	29.0	22.0	14.0	**20.4**	**7.9**
	M4	10.0	8.0	14.0	12.0	14.0	24.0	26.0	32.0	33.0	26.0	20.0	15.0	**19.5**	**8.5**
	M5	12.0	11.0	13.0	17.0	21.0	26.0	30.0	34.0	32.0	26.0	20.0	16.0	**21.5**	**8.0**
	M5b														

Table 5.1.3a$_2$. Spatial and temporal variations in water temperature (°C) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	7.0	5.0	7.0	10.3	12.0	17.0	26.0	28.0	23.0	20.0	15.0	10.0	**15.0**	**7.8**
	M2	7.8	7.0	7.0	13.5	16.0	18.0	29.0	32.0	26.0	25.0	16.0	12.0	**17.4**	**8.7**
	M3	9.0	7.5	8.0	16.0	19.0	21.0	31.0	30.0	25.0	24.0	16.0	11.0	**18.1**	**8.3**
	M4	9.0	5.0	8.4	11.0	15.0	24.0	29.0	28.0	25.0	24.0	18.0	13.0	**17.5**	**8.3**
	M5	9.2	8.4	8.6	16.0	18.0	22.0	26.0	29.0	25.0	20.0	20.0	17.0	**18.3**	**6.9**
	M5b	7.0	7.5	7.5	8.0	8.0	8.0	10.0	12.0	11.0	10.0	12.0	11.0	**9.3**	**1.9**
2005-2006	**M1**	5.0	5.0	7.0	8.4	9.0	15.0	20.0	24.0	25.0	20.0	17.0	9.0	**13.7**	**7.4**
	M2	7.0	6.8	7.0	12.0	15.0	15.0	22.0	23.0	22.0	20.0	18.0	10.0	**14.8**	**6.2**
	M3	8.5	7.2	8.0	12.0	15.0	20.0	26.0	26.0	25.0	24.0	19.0	12.4	**16.9**	**7.3**
	M4	5.8	5.9	9.0	10.0	11.0	21.0	24.0	27.0	29.0	24.0	17.0	12.4	**16.3**	**8.4**
	M5	10.0	8.0	9.0	14.0	18.0	25.0	28.0	29.0	30.0	24.0	18.0	14.0	**18.9**	**8.1**
	M5b	6.8	6.9	7.8	8.2	8.0	10.0	12.0	12.0	13.0	13.0	10.0	8.0	**9.6**	**2.3**

Table 5.1.3b. Spatial and temporal variations in depth (m) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	0.3	0.4	0.4	0.7	0.8	1.8	1.5	1.8	1.3	0.5	0.5	0.4	**0.9**	**0.6**
	M2	1.5	1.3	1.7	2.2	2.0	2.5	2.7	2.7	2.5	1.5	1.8	1.0	**2.0**	**0.6**
	M3	1.5	1.7	1.9	1.7	1.4	2.0	2.2	2.5	2.6	1.7	1.6	1.5	**1.9**	**0.4**
	M4	1.5	1.5	1.5	1.8	1.8	1.8	2.5	2.5	2.5	1.7	1.5	1.5	**1.8**	**0.4**
	M5	12.0	12.0	12.0	12.5	12.5	12.5	12.5	12.5	12.5	12.0	12.0	12.5	**12.3**	**0.3**
	M5b														
2005-2006	**M1**	1.0	0.9	1.0	0.9	1.0	1.5	1.5	1.7	1.2	0.8	1.0	0.9	**1.1**	**0.3**
	M2	1.0	1.5	2.5	2.5	2.0	2.0	2.5	2.3	2.5	1.7	1.8	1.6	**2.0**	**0.5**
	M3	1.5	1.7	0.5	0.9	1.3	1.7	1.6	1.7	0.9	1.4	1.0	1.0	**1.3**	**0.4**
	M4	1.7	1.0	0.6	0.8	1.2	1.7	2.5	2.5	3.2	2.2	1.0	0.8	**1.6**	**0.8**
	M5	12.0	12.0	12.0	12.0	12.5	12.5	12.5	12.5	12.5	12.0	11.7	12.2	**12.2**	**0.3**
	M5b														

Table 5.1.3c. Spatial and temporal variations in transparency (m) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	0.2	0.4	0.4	0.4	0.2	0.2	0.3	0.3	0.5	0.4	0.3	0.3	**0.3**	**0.1**
	M2	0.7	0.8	0.5	1.0	0.9	1.5	1.5	1.0	1.2	0.7	0.7	0.7	**0.9**	**0.3**
	M3	1.0	1.0	1.0	0.4	0.7	0.7	0.7	1.5	2.0	0.5	0.7	0.4	**0.9**	**0.5**
	M4	1.4	1.5	1.5	0.3	0.6	0.5	0.6	2.2	1.7	0.5	0.5	0.4	**1.0**	**0.6**
	M5	5.6	6.0	5.7	4.3	4.2	5.0	4.2	5.6	5.1	5.7	5.5	5.6	**5.2**	**0.6**
	M5b														
2005-2006	**M1**	0.4	0.4	0.5	0.2	0.6	0.9	0.7	0.6	0.7	0.6	0.6	0.6	**0.6**	**0.2**
	M2	0.7	0.9	0.7	1.2	0.9	0.8	1.5	1.3	0.9	0.6	0.8	1.0	**0.9**	**0.3**
	M3	1.0	1.0	1.0	0.4	0.7	0.9	1.0	0.8	0.5	0.5	0.8	0.5	**0.8**	**0.2**
	M4	0.4	1.0	0.6	0.5	0.9	0.7	1.2	1.0	1.0	0.6	0.6	0.4	**0.7**	**0.3**
	M5	5.8	5.9	5.6	4.7	4.5	4.2	4.8	4.5	5.0	5.2	5.1	5.1	**5.0**	**0.5**
	M5b														

Table 5.1.3d. Spatial and temporal variations in pH in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	7.90	7.40	7.70	8.40	9.20	8.20	9.20	9.70	9.10	7.80	7.70	7.40	**8.31**	**0.80**
	M2	7.60	7.90	7.80	8.60	8.70	8.60	10.00	10.00	9.50	8.00	7.80	7.60	**8.51**	**0.89**
	M3	7.50	7.50	7.80	8.30	8.60	8.60	9.40	9.70	8.70	7.70	7.90	7.80	**8.29**	**0.73**
	M4	7.60	7.30	7.90	8.10	7.70	8.10	9.20	9.60	8.50	7.50	7.40	7.20	**8.01**	**0.75**
	M5	7.90	7.70	7.70	8.10	8.40	8.30	9.10	9.00	8.00	7.50	7.70	8.40	**8.15**	**0.51**
	M5b	6.90	6.70	6.80	6.70	6.30	6.40	6.80	6.90	6.50	7.00	6.80	6.90	**6.75**	**0.20**
2005-2006	**M1**	7.90	7.90	7.90	7.70	8.30	7.90	8.10	8.20	8.80	8.00	7.30	7.40	**7.95**	**0.40**
	M2	7.90	7.90	7.40	7.40	9.50	9.50	9.30	9.40	9.70	8.40	8.30	8.50	**8.60**	**0.85**
	M3	7.70	7.80	7.80	8.00	8.40	9.30	9.70	9.40	9.00	8.10	7.80	7.50	**8.38**	**0.77**
	M4	7.40	7.50	7.90	7.20	7.60	8.30	9.40	9.50	8.60	8.20	7.60	7.40	**8.05**	**0.78**
	M5	7.90	7.70	8.00	8.20	8.00	9.20	9.40	8.90	8.30	8.20	7.60	7.90	**8.28**	**0.58**
	M5b	6.90	6.80	6.60	6.40	6.30	6.60	6.40	6.30	6.80	6.70	6.00	6.70	**6.54**	**0.26**

Table 5.1.3e. Spatial and temporal variations in conductivity (µS/cm) in Manasbal lake during 2004-2006

Year	sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	394	400	385	370	485	330	327	333	354	456	390	420	**387**	**49**
	M2	415	487	333	412	539	341	339	379	372	465	441	445	**414**	**64**
	M3	384	351	307	363	546	331	323	312	379	331	365	463	**371**	**69**
	M4	383	381	376	363	311	453	333	391	363	213	330	485	**365**	**69**
	M5	322	312	345	315	345	323	344	354	329	364	358	425	**345**	**31**
	M5b	464	515	455	477	563	522	522	563	542	518	565	496	**517**	**38**
2005-2006	**M1**	346	425	387	390	520	324	345	351	360	365	380	396	**382**	**51**
	M2	419	319	480	485	563	412	313	385	259	395	432	385	**404**	**83**
	M3	347	323	381	355	563	319	313	354	259	372	367	442	**366**	**76**
	M4	361	391	375	342	308	306	375	320	396	335	389	404	**359**	**35**
	M5	349	330	361	351	295	324	355	349	332	364	375	388	**348**	**25**
	M5b	459	481	499	417	479	524	596	525	510	488	464	492	**495**	**44**

Table 5.1.3f. Spatial and temporal variations in dissolved oxygen (mg/L) in Manasbal lake during 2004-2006

Year	sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	12.0	14.0	11.0	10.0	9.0	11.0	8.0	8.0	5.0	8.0	8.0	8.5	**9.4**	**2.4**
	M2	10.0	13.0	12.0	10.0	12.0	13.0	10.0	9.0	10.0	6.0	5.0	9.0	**9.9**	**2.5**
	M3	10.0	10.0	10.0	12.0	11.0	12.0	8.0	4.0	3.0	4.0	4.0	8.0	**8.0**	**3.4**
	M4	10.0	12.0	11.0	10.0	11.0	12.0	7.0	8.0	4.0	4.0	4.0	6.0	**8.3**	**3.2**
	M5	11.0	13.0	12.0	10.0	12.0	12.0	8.0	8.0	7.0	7.0	8.0	9.0	**9.8**	**2.2**
	M5b	a	a	a	a	a	a	a	a	a	a	A	a	**a**	**A**
2005-2006	**M1**	12.0	14.0	11.0	12.0	10.0	11.0	7.0	8.0	9.0	8.0	8.0	10.0	**10.0**	**2.1**
	M2	12.0	13.0	12.0	13.0	10.0	13.0	10.0	9.0	9.0	7.0	6.0	9.0	**10.3**	**2.4**
	M3	10.0	10.0	11.0	12.0	10.0	13.0	8.0	7.0	8.0	8.0	5.0	9.0	**9.3**	**2.2**
	M4	10.0	11.0	12.0	10.0	10.0	10.0	10.0	8.0	7.0	8.0	9.0	9.0	**9.5**	**1.4**
	M5	10.0	12.0	12.0	10.0	10.0	10.0	10.0	8.0	8.0	6.0	9.0	9.0	**9.5**	**1.7**
	M5b	a	a	a	a	a	a	a	a	a	a	A	a	a	A

Table 5.1.3g. Spatial and temporal variations in free carbon dioxide (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	4.0	4.0	4.0	2.0	2.0	6.0	a	a	a	4.0	6.0	4.0	**4.0**	**1.4**
	M2	4.0	6.0	8.0	7.0	a	a	a	a	a	5.0	6.0	4.0	**5.7**	**1.5**
	M3	5.0	8.0	4.0	6.0	a	a	a	a	a	5.0	6.0	6.0	**5.7**	**1.3**
	M4	6.0	4.0	10.0	8.0	6.0	6.0	a	a	a	5.0	6.0	6.0	**6.3**	**1.7**
	M5	4.0	8.0	8.0	6.0	4.0	2.0	a	a	9.0	5.0	6.0	8.0	**6.0**	**2.3**
	M5b	15.0	18.0	21.0	17.0	15.0	17.0	18.0	21.0	27.0	27.0	21.0	24.0	**20.1**	**4.2**
2005-2006	**M1**	4.0	4.0	4.0	6.0	6.0	5.0	19.0	15.0	14.0	17.0	22.0	25.0	**11.8**	**7.8**
	M2	6.0	6.0	4.0	8.0	a	a	a	a	a	a	A	a	**6.0**	**1.6**
	M3	4.0	5.0	2.0	4.0	a	a	a	a	12.0	18.0	20.0	18.0	**10.4**	**7.5**
	M4	5.0	6.0	4.0	3.0	6.0	a	a	a	a	8.0	6.0	10.0	**6.0**	**2.2**
	M5	4.0	4.0	4.0	2.0	6.0	a	a	a	4.0	10.0	14.0	16.0	**7.1**	**5.0**
	M5b	25.0	20.0	18.0	16.0	19.0	21.0	17.0	26.0	25.0	28.0	24.0	27.0	**22.2**	**4.2**

Table 5.1.3h$_1$. Spatial and temporal variations in total alkalinity (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	136	196	104	193	132	128	96	51	110	175	196	214	**144**	**50**
	M2	142	136	122	186	163	121	104	85	94	156	204	160	**139**	**36**
	M3	159	142	186	146	139	100	96	71	140	188	175	172	**143**	**37**
	M4	146	132	149	136	124	172	76	46	120	108	156	172	**128**	**37**
	M5	164	184	115	139	144	132	58	63	124	180	199	212	**143**	**49**
	M5b	256	366	393	312	303	286	258	275	292	352	216	300	**301**	**50**
2005-2006	**M1**	184	136	172	186	252	210	190	155	122	132	148	136	**169**	**38**
	M2	156	148	120	148	100	118	125	136	164	134	115	125	**132**	**19**
	M3	168	126	140	154	164	144	108	100	100	135	120	131	**133**	**23**
	M4	168	110	132	162	130	121	104	135	86	125	108	151	**128**	**24**
	M5	168	173	132	150	124	104	114	103	96	102	102	153	**127**	**28**
	M5b	216	225	196	356	354	390	390	355	296	389	384	300	**321**	**73**

Table 5.1.3h$_2$. Spatial and temporal variations in carbonate alkalinity (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	a	a	a	a	a	a	26	18	8	a	A	a	**17**	**9**
	M2	a	a	a	a	20	12	32	25	10	a	A	a	**20**	**9**
	M3	a	a	a	a	11	16	16	20	8	a	A	a	**14**	**5**
	M4	a	a	a	a	a	a	20	24	5	a	A	a	**16**	**10**
	M5	a	a	a	a	a	a	16	18	a	a	A	a	**17**	**1**
	M5b	a	a	a	a	a	a	a	a	a	a	A	a	**a**	**A**
2005-2006	**M1**	a	a	a	a	a	a	a	a	a	a	A	a	**a**	**A**
	M2	a	a	a	a	26	22	22	10	10	2	A	2	**13**	**10**
	M3	a	a	a	a	8	26	28	15	a	a	A	a	**19**	**9**
	M4	a	a	a	a	a	18	22	5	6	a	A	a	**13**	**9**
	M5	a	a	a	a	a	14	12	10	a	a	A	a	**12**	**2**
	M5b	a	a	a	a	a	a	a	a	a	a	A	a	**a**	**A**

Table 5.1.3h_3. Spatial and temporal variations in bicarbonate alkalinity (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	136	196	104	193	132	128	70	33	102	175	196	214	**140**	**56**
	M2	142	136	122	186	163	109	72	60	84	156	204	160	**133**	**45**
	M3	159	142	186	146	139	84	80	51	132	188	175	172	**138**	**44**
	M4	146	132	149	136	124	172	56	22	115	108	156	172	**124**	**45**
	M5	164	184	115	139	133	132	42	45	124	180	199	212	**139**	**54**
	M5b	256	366	393	312	303	286	258	275	292	352	216	300	**301**	**50**
2005-2006	**M1**	184	136	172	186	252	210	190	155	122	132	148	136	**169**	**38**
	M2	156	148	120	148	74	96	103	126	154	132	113	133	**125**	**25**
	M3	168	126	140	154	156	118	80	75	100	135	120	131	**125**	**29**
	M4	168	110	132	162	130	103	82	130	80	125	108	161	**124**	**29**
	M5	173	132	150	124	90	102	93	96	102	102	153	131	**121**	**27**
	M5b	168	173	132	150	124	90	102	93	96	102	102	153	**124**	**31**

Table 5.1.3i. Spatial and temporal variations in total hardness (mg/L) in Manasbal lake during 2004-2006

Year	sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	125	147	134	102	110	96	85	76	89	110	125	134	**111**	**22**
	M2	139	137	148	117	111	97	68	68	60	98	112	106	**105**	**29**
	M3	125	136	128	112	105	84	62	62	87	116	93	108	**102**	**24**
	M4	136	124	132	114	125	110	89	67	72	76	96	100	**103**	**24**
	M5	158	139	161	128	113	94	77	57	90	132	149	158	**121**	**35**
	M5b	210	245	269	260	257	282	274	268	298	216	266	247	**258**	**25**
2005-2006	**M1**	125	130	156	148	151	138	126	125	142	184	194	179	**150**	**24**
	M2	127	142	147	127	141	120	90	96	124	135	148	156	**129**	**20**
	M3	132	101	126	128	99	94	75	88	107	163	200	184	**125**	**39**
	M4	117	144	124	88	94	75	90	104	120	132	162	174	**119**	**31**
	M5	144	164	154	130	156	154	110	95	100	162	178	202	**146**	**32**
	M5b	233	217	269	276	251	288	276	284	271	223	264	254	**259**	**24**

Table 5.1.3j_1. Spatial and temporal variations in calcium content (mg/L) in Manasbal lake during 2004-2006

Year	sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	M1	42	46	54	30	32	28	25	22	25	31	32	38	34	10
	M2	41	40	42	31	31	20	19	19	19	22	33	29	29	9
	M3	38	39	46	32	31	26	18	19	18	20	28	30	29	9
	M4	39	34	37	30	35	31	31	19	22	21	27	29	30	6
	M5	45	38	43	39	37	25	21	18	27	22	25	27	31	9
	M5b	58	69	79	47	53	37	30	40	44	60	52	69	53	15
2005-2006	M1	34	35	42	57	41	46	42	35	37	52	62	52	45	9
	M2	32	45	56	50	44	34	25	27	34	28	53	57	40	12
	M3	27	30	34	45	37	26	22	26	27	43	58	56	36	12
	M4	31	40	30	26	24	20	25	29	34	37	55	57	34	12
	M5	35	46	44	38	51	43	30	26	27	42	51	55	41	10
	M5b	66	60	75	78	55	54	54	54	55	61	63	57	61	8

Table 5.1.3j_2.Spatial and temporal variations in magnesium content (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	M1	12	10	12	9	7	7	8	5	5	8	7	9	8	2
	M2	11	9	10	10	8	5	6	5	4	6	7	8	7	2
	M3	7	9	9	11	8	5	4	4	3	7	8	7	7	2
	M4	9	9	10	9	9	8	7	5	4	6	8	7	8	2
	M5	10	11	13	10	9	8	6	13	5	5	6	10	9	3
	M5b	16	18	22	11	13	11	9	10	13	16	16	18	14	4
2005-2006	M1	10	10	12	12	14	10	13	9	9	13	18	12	12	3
	M2	11	11	13	11	12	8	7	7	9	10	13	16	11	3
	M3	7	6	10	13	9	7	5	6	10	13	13	11	9	3
	M4	10	11	9	6	6	6	7	8	9	10	13	14	9	3
	M5	12	11	9	14	11	9	7	8	14	14	10	16	11	3
	M5b	17	16	20	20	14	13	12	14	16	16	19	17	16	3

Table 5.1.3k$_1$. Spatial and temporal variations in sodium content (mg/L) in Manasbal lake during 2004-2006

Year	sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	8	10	11	9	6	4	4	2	5	6	7	8	**7**	**3**
	M2	8	12	18	8	5	3	8	5	8	7	6	7	**8**	**4**
	M3	6	5	4	3	5	2	3	4	5	6	6	7	**5**	**1**
	M4	7	7	6	9	6	4	5	3	7	6	5	8	**6**	**2**
	M5	6	6	7	5	5	4	5	6	9	7	8	9	**6**	**2**
	M5b	17	15	14	10	13	10	9	13	14	15	18	17	**14**	**3**
2005-2006	**M1**	9	7	10	8	7	5	4	4	9	7	8	10	**7**	**2**
	M2	13	10	14	6	12	10	6	8	10	13	10	16	**11**	**3**
	M3	5	6	8	9	5	6	4	3	7	7	9	10	**7**	**2**
	M4	8	8	4	5	3	5	3	4	8	7	8	8	**6**	**2**
	M5	9	7	5	8	4	6	5	5	6	9	10	7	**7**	**2**
	M5b	14	13	15	16	17	14	10	10	12	14	16	15	**14**	**2**

Table 5.1.3k$_2$. Spatial and temporal variations in potassium content (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	3.0	5.0	3.0	2.0	1.6	1.0	1.0	1.0	2.0	3.0	3.0	4.0	2.5	1.3
	M2	4.0	4.0	6.0	2.0	2.0	3.0	1.0	1.6	3.0	4.0	5.0	6.0	3.5	1.7
	M3	2.0	3.0	3.0	2.0	1.0	1.4	1.5	1.0	1.0	2.0	2.5	2.5	1.9	0.7
	M4	1.0	1.2	1.5	2.0	1.0	1.5	1.6	1.0	2.0	2.0	2.3	2.6	1.6	0.5
	M5	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.3	0.5
	M5b	5.0	7.0	4.0	3.0	2.0	2.0	2.0	3.0	3.0	4.0	4.0	5.0	3.7	1.5
2005-2006	**M1**	4.0	3.0	3.0	3.0	1.5	1.4	1.6	1.0	1.0	4.0	3.0	5.0	2.6	1.3
	M2	5.0	3.0	4.0	2.0	1.6	1.3	1.0	1.0	1.0	3.0	4.0	4.0	2.6	1.4
	M3	3.0	3.5	2.0	2.5	1.0	1.0	1.0	1.0	1.5	2.3	3.0	3.0	2.1	0.9
	M4	2.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	2.6	3.0	3.0	1.9	0.8
	M5	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	3.0	3.0	3.0	1.8	0.8
	M5b	7.0	3.0	4.0	3.0	4.0	4.0	5.0	2.0	2.0	4.0	5.0	6.0	4.1	1.5

Table 5.1.3l. Spatial and temporal variations in chloride content (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	19	20	24	15	16	22	26	29	23	26	28	22	**23**	**4**
	M2	21	20	17	18	16	23	22	16	30	22	29	26	**22**	**5**
	M3	27	15	17	16	12	14	18	14	20	14	12	10	**16**	**4**
	M4	20	18	13	19	16	18	18	18	21	21	24	24	**19**	**3**
	M5	16	21	13	15	16	14	10	11	19	10	15	12	**14**	**3**
	M5b	34	50	42	31	24	27	20	26	25	20	21	18	**28**	**10**
2005-2006	**M1**	15	17	16	19	19	19	20	26	26	27	20	29	**21**	**5**
	M2	25	19	15	15	20	28	23	26	26	24	25	23	**22**	**4**
	M3	15	21	17	21	20	20	20	16	20	16	20	24	**19**	**3**
	M4	22	20	19	20	18	18	14	20	26	20	35	28	**22**	**6**
	M5	17	20	16	12	16	12	12	16	18	14	14	19	**16**	**3**
	M5b	36	45	40	16	18	14	22	32	33	40	31	34	**30**	**10**

Table 5.1.3m. Spatial and temporal variations in nitrate nitrogen content (µg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	200	189	182	220	260	195	108	129	150	235	372	300	**212**	**74**
	M2	235	210	240	283	340	252	203	192	290	304	408	390	**279**	**71**
	M3	180	130	120	280	230	290	200	170	130	170	180	160	**187**	**55**
	M4	270	160	118	250	280	159	253	200	190	139	170	290	**207**	**59**
	M5	110	156	133	153	164	128	140	120	140	136	170	112	**139**	**19**
	M5b	270	332	278	345	296	215	208	246	313	324	220	235	**274**	**49**
2005-2006	**M1**	230	176	225	245	308	220	136	180	270	262	350	321	**244**	**63**
	M2	220	205	245	270	320	236	213	182	263	340	358	320	**264**	**58**
	M3	188	100	162	213	160	140	120	140	130	340	290	283	**189**	**77**
	M4	278	200	220	212	251	185	109	226	290	243	286	324	**235**	**57**
	M5	200	137	180	190	147	160	118	100	124	136	206	213	**159**	**38**
	M5b	330	260	300	287	380	270	245	330	196	247	200	257	**275**	**54**

Table 5.1.3n. Spatial and temporal variations in ammonical nitrogen (μg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	63	57	30	64	23	20	26	19	30	45	65	72	**43**	**20**
	M2	121	103	96	66	35	36	53	42	50	73	68	89	**69**	**28**
	M3	38	45	36	44	20	23	25	38	60	42	63	35	**39**	**13**
	M4	40	28	41	60	30	18	26	30	50	43	60	42	**39**	**13**
	M5	32	24	18	32	20	25	24	15	20	40	42	35	**27**	**9**
	M5b	432	464	426	632	500	486	450	660	600	640	535	506	**528**	**85**
2005-2006	**M1**	38	50	64	56	32	29	20	25	45	69	68	52	**46**	**17**
	M2	59	86	75	80	30	43	48	40	63	100	120	184	**77**	**43**
	M3	60	52	43	40	30	24	18	22	58	92	48	67	**46**	**21**
	M4	28	30	25	40	20	16	20	18	60	80	74	105	**43**	**30**
	M5	54	43	35	26	16	20	25	24	26	56	60	53	**37**	**16**
	M5b	630	525	650	548	523	635	680	632	547	530	635	542	**590**	**58**

Table 5.1.3o. Spatial and temporal variations in total phosphorus (μg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	200	242	160	120	76	103	83	70	150	230	263	270	**164**	**75**
	M2	322	290	309	202	169	136	110	86	220	268	285	320	**226**	**85**
	M3	162	182	200	105	60	138	70	52	65	192	230	210	**139**	**66**
	M4	285	235	230	125	72	60	56	90	70	150	240	250	**155**	**87**
	M5	152	136	170	105	60	72	92	100	112	162	150	200	**126**	**42**
	M5b	382	420	318	280	320	389	453	485	423	293	356	368	**374**	**64**
2005-2006	**M1**	240	225	182	129	120	92	106	122	192	234	270	296	**184**	**69**
	M2	336	265	240	190	120	110	136	149	270	350	322	380	**239**	**96**
	M3	190	208	180	76	80	68	109	130	159	230	245	286	**163**	**72**
	M4	230	240	261	123	73	68	70	110	160	263	230	302	**178**	**86**
	M5	136	140	112	92	124	105	120	106	110	160	130	210	**129**	**32**
	M5b	484	432	300	247	280	456	532	483	402	297	362	284	**380**	**97**

Table 5.1.3p. Spatial and temporal variations in sulphate (µg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	3	3	3	2	2	2	2	2	2	1	1	2	**2**	**1**
	M2	1	3	3	2	2	2	1	1	2	2	1	2	**2**	**1**
	M3	3	3	3	2	1	2	2	2	1	1	2	2	**2**	**1**
	M4	3	2	2	3	4	2	1	2	2	2	2	2	**2**	**1**
	M5	2	2	2	2	2	2	2	2	2	2	1	2	**2**	**0**
	M5b	6	7	8	4	5	3	3	2	2	2	2	3	**4**	**2**
2005-2006	**M1**	3	4	3	3	3	3	5	3	4	5	6	6	**4**	**1**
	M2	2	2	3	3	2	2	4	2	3	4	5	5	**3**	**1**
	M3	1	4	3	4	4	2	2	3	4	5	5	2	**3**	**1**
	M4	3	2	3	3	1	2	2	2	3	3	5	1	**3**	**1**
	M5	4	1	3	3	2	4	2	3	3	5	5	1	**3**	**1**
	M5b	6	7	10	4	5	7	8	10	9	8	8	9	**8**	**2**

Table 5.1.3q. Spatial and temporal variations in silicate (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	6	7	3	1	7	9	1	1	2	1	3	3	**4**	**3**
	M2	1	2	1	2	1	1	1	1	0	1	1	2	**1**	**1**
	M3	5	4	1	1	2	1	1	1	2	4	4	4	**2**	**2**
	M4	5	2	2	1	2	1	1	0	6	4	4	2	**2**	**2**
	M5	2	3	6	5	3	5	1	1	2	6	6	4	**4**	**2**
	M5b	12	15	13	9	10	10	9	9	10	18	13	9	**11**	**3**
2005-2006	**M1**	2	3	2	4	2	1	2	1	1	1	2	3	**2**	**1**
	M2	3	3	2	1	1	1	0	1	1	1	2	2	**1**	**1**
	M3	3	2	3	1	1	0	1	1	1	1	2	3	**2**	**1**
	M4	3	2	3	1	1	1	0	1	1	2	1	2	**1**	**1**
	M5	4	5	3	5	2	4	4	3	2	3	4	7	**4**	**1**
	M5b	14	15	21	12	14	13	17	15	14	17	15	18	**15**	**2**

Table 5.1.3r. Spatial and temporal variations in total dissolved solids (mg/L) in Manasbal lake during 2004-2006

Year	Sites	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean	SD
2004-2005	**M1**	54	44	64	134	128	164	132	72	84	92	78	86	**94**	**37**
	M2	40	21	44	82	180	124	140	140	183	146	125	49	**106**	**57**
	M3	40	42	62	100	82	120	126	124	140	94	82	59	**89**	**34**
	M4	48	54	62	84	74	44	48	42	36	34	44	48	**52**	**15**
	M5	46	54	58	68	72	78	56	54	47	52	48	50	**57**	**10**
	M5b	84	126	92	104	124	158	96	164	52	90	166	84	**112**	**36**
2005-2006	**M1**	84	48	44	60	68	62	54	46	44	50	42	84	**57**	**15**
	M2	70	50	66	44	58	48	54	46	52	64	68	70	**58**	**10**
	M3	82	68	52	56	68	44	84	52	64	84	88	68	**68**	**15**
	M4	54	44	36	48	30	44	48	64	58	42	61	48	**48**	**10**
	M5	42	48	64	92	42	128	104	46	91	98	185	44	**82**	**44**
	M5b	123	129	136	115	154	178	135	129	163	152	148	136	**142**	**18**

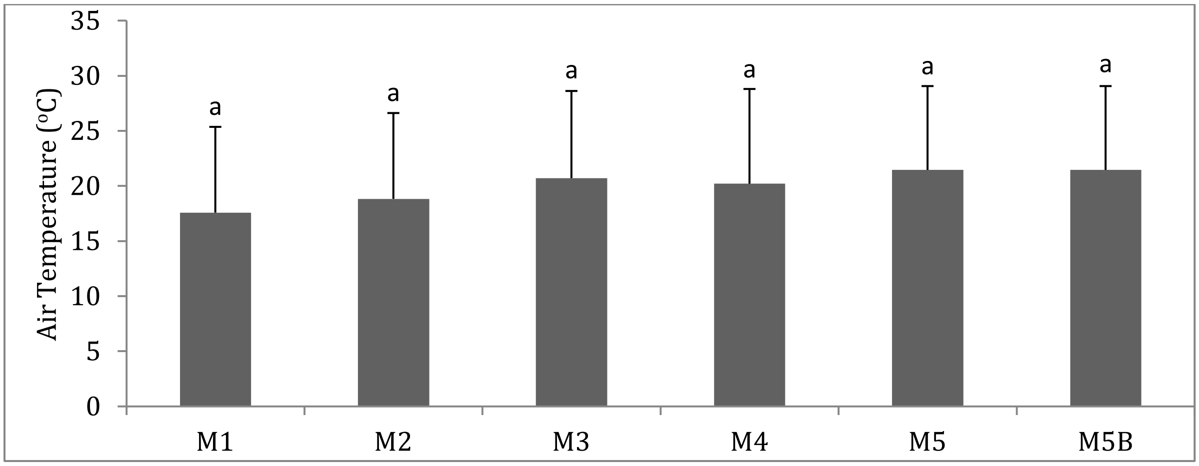


Fig. 5.1.3a$_1$. Changes in air temperature (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

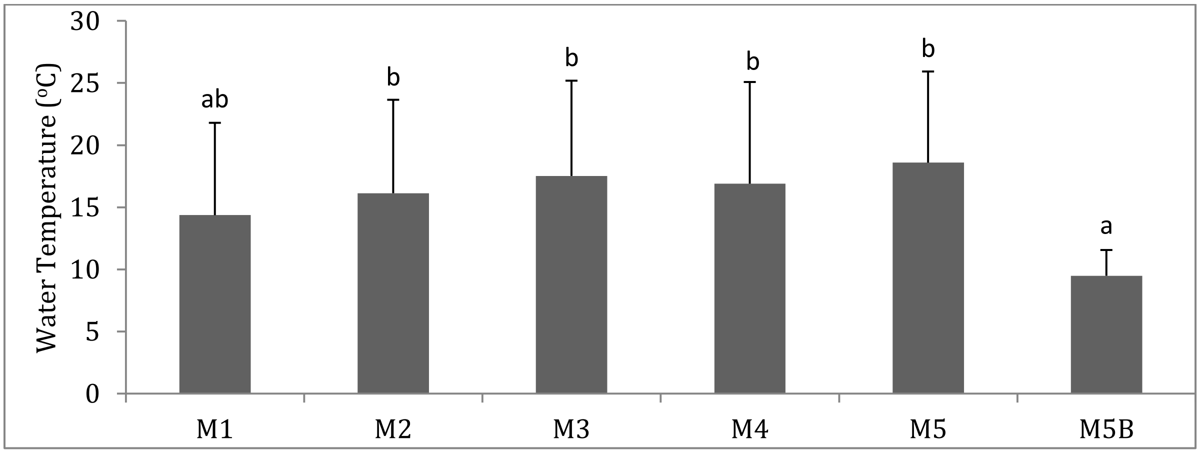


Fig. 5.1.3a$_2$. Changes in water temperature (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

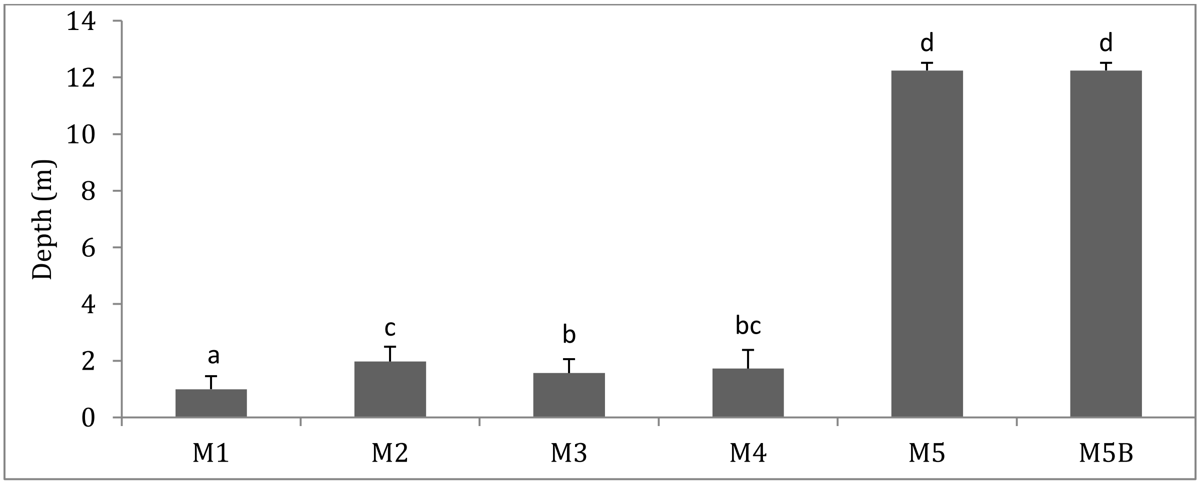
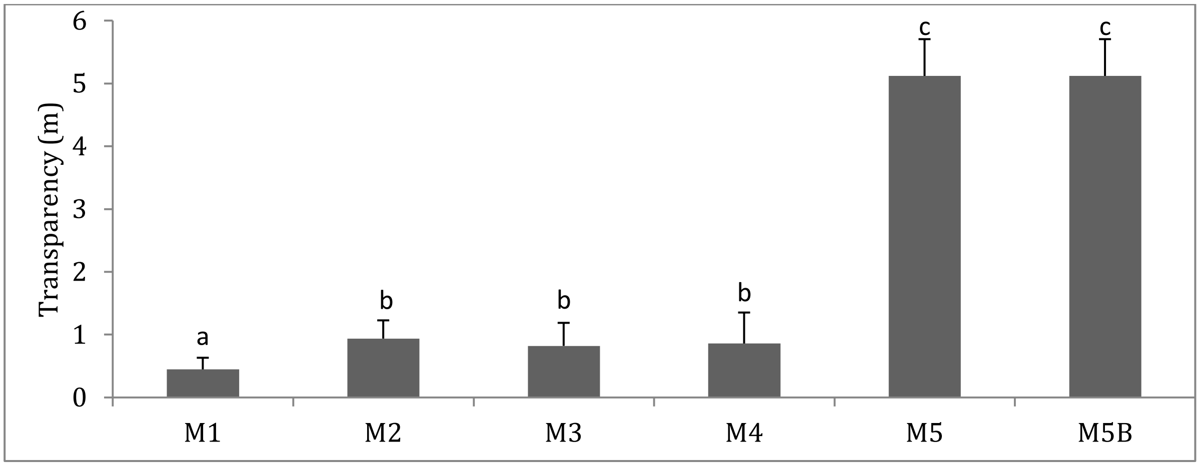


Fig. 5.1.3b. Changes in depth (m) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).



F **Fig. 5.1.3c.** Changes in transparency (m) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

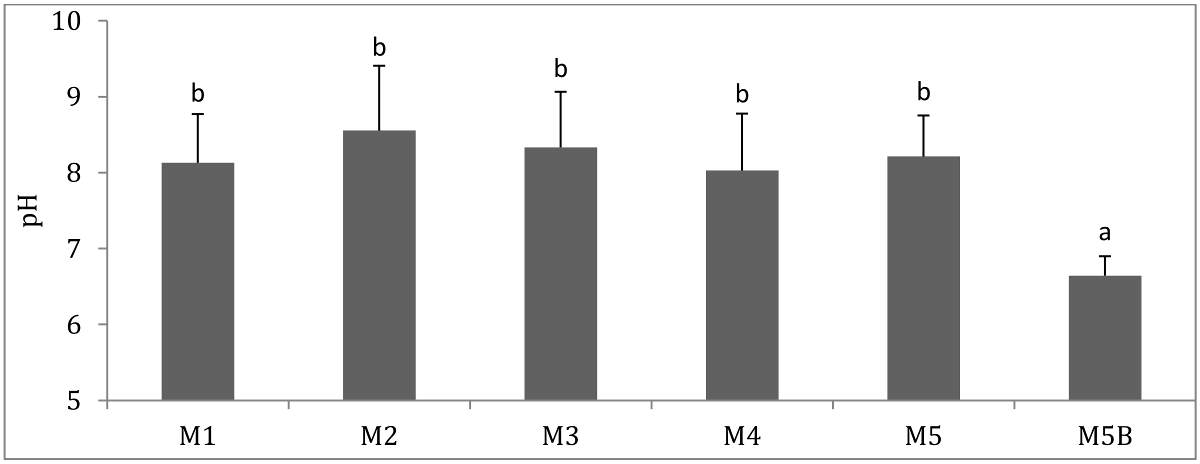


Fig. 5.1.3d. Changes in pH (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

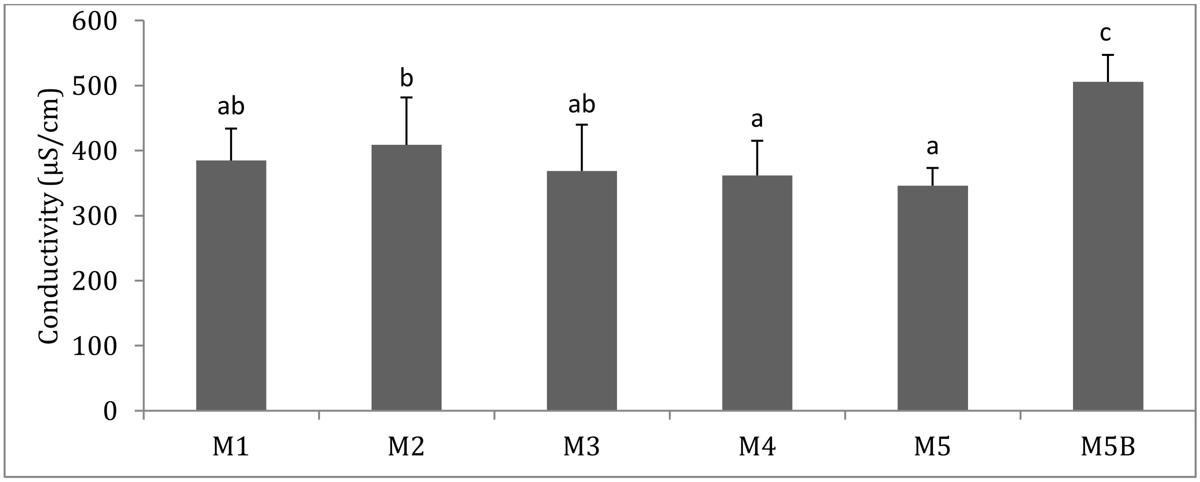


Fig. 5.1.3e. Changes in conductivity (µS/cm) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

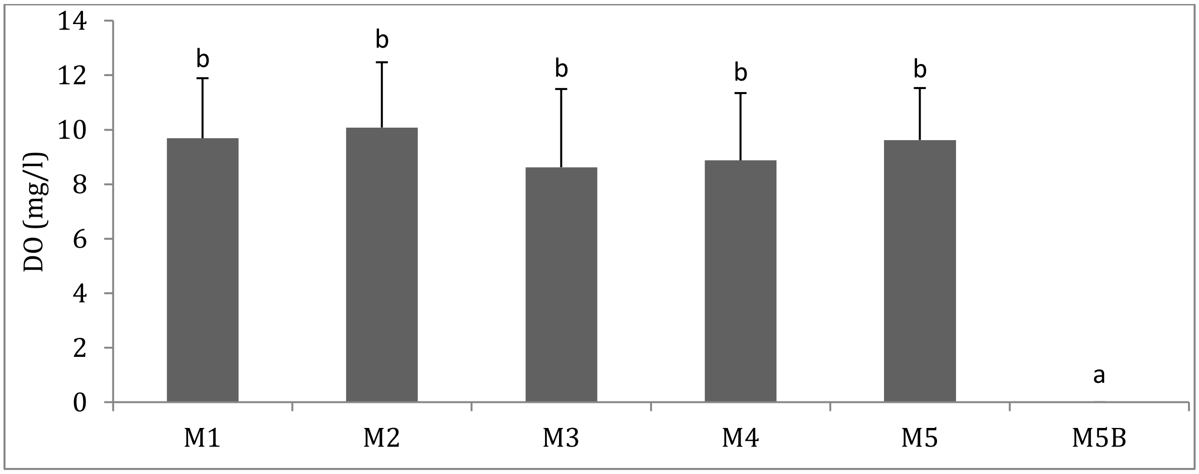


Fig. 5.1.3f. Changes in dissolved oxygen (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

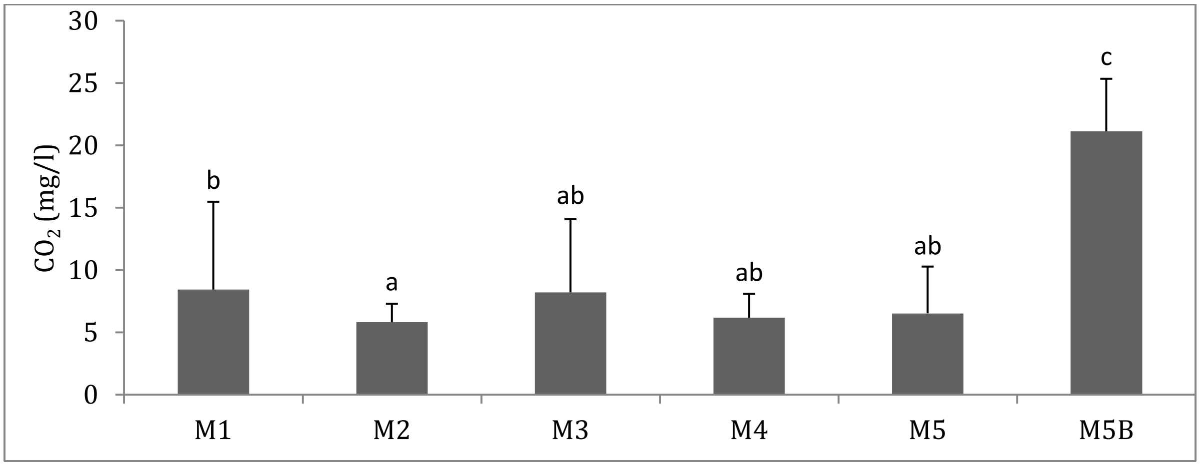


Fig. 5.1.3g. Changes in free CO_2 (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

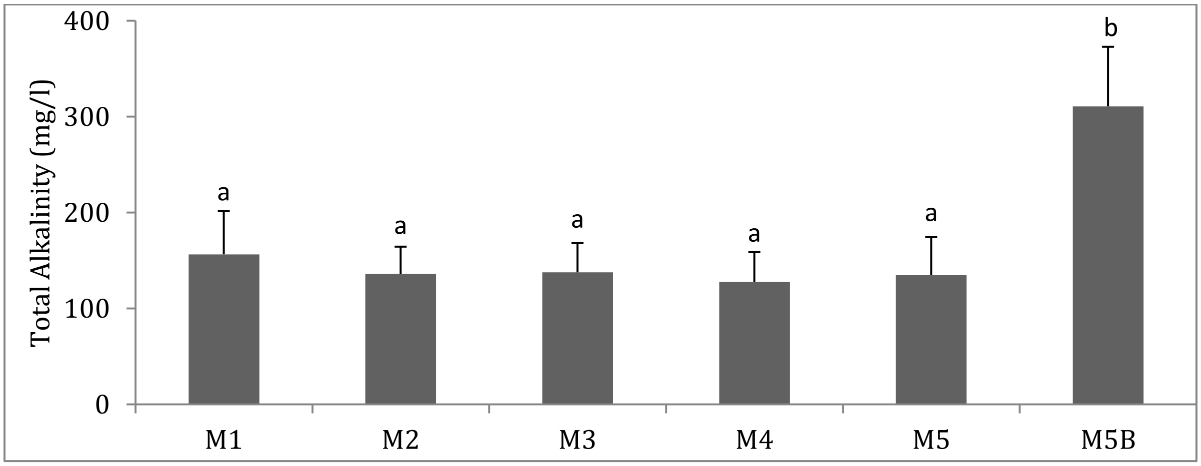


Fig. 5.1.3h. Changes in total alkalinity (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

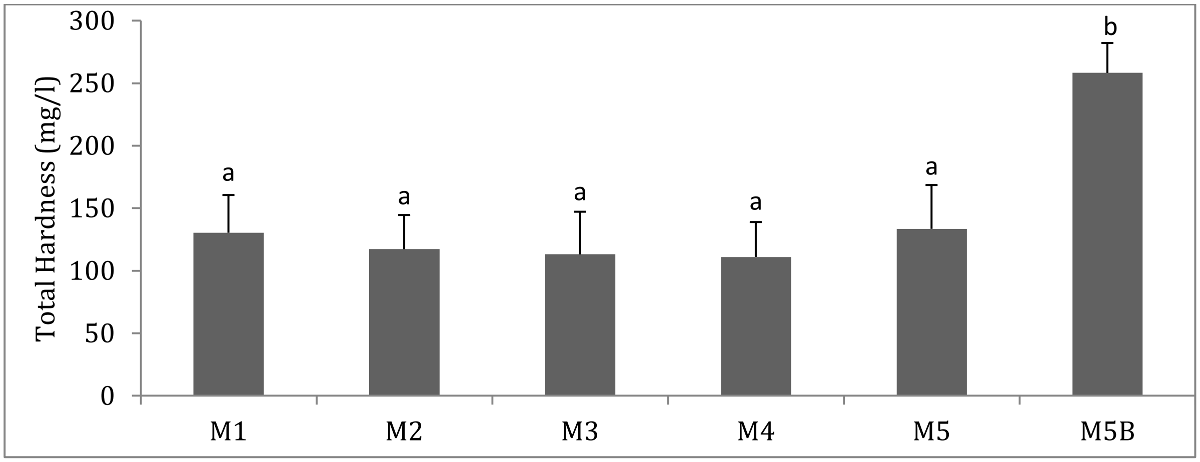


Fig. 5.1.3i. Changes in total hardness (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

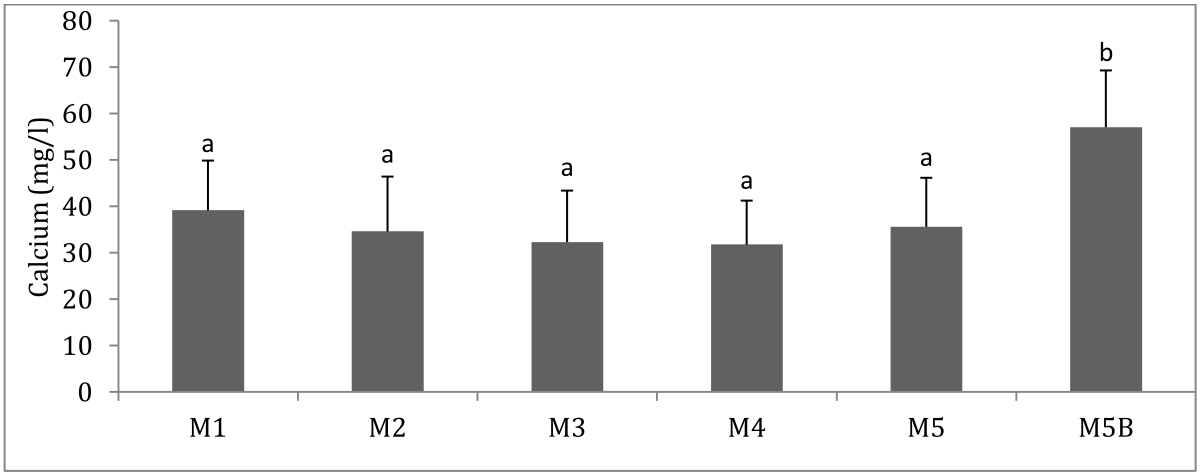


Fig. 5.1.3j$_1$. Changes in calcium (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

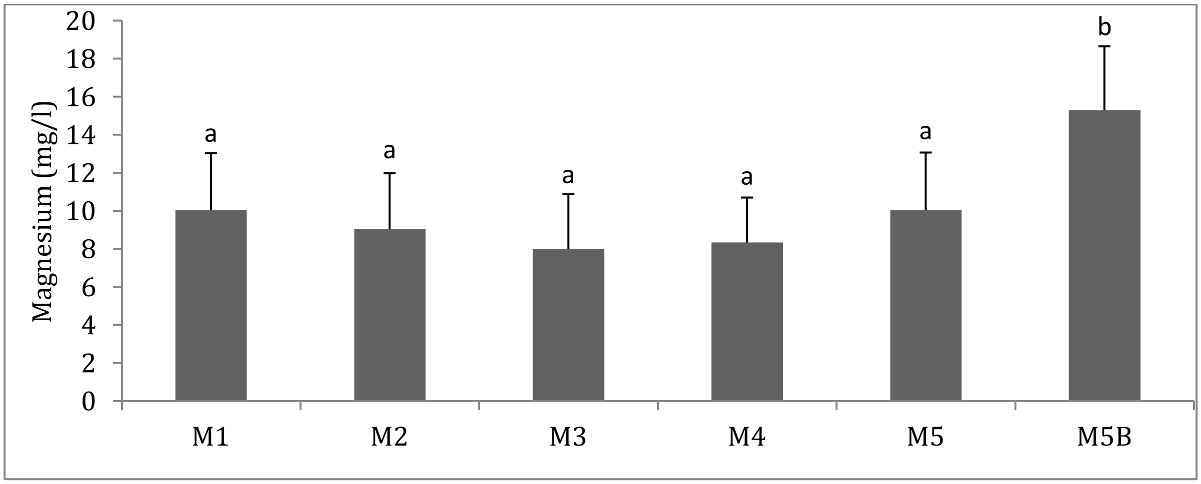


Fig. 5.1.3j$_2$. Changes in magnesium (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

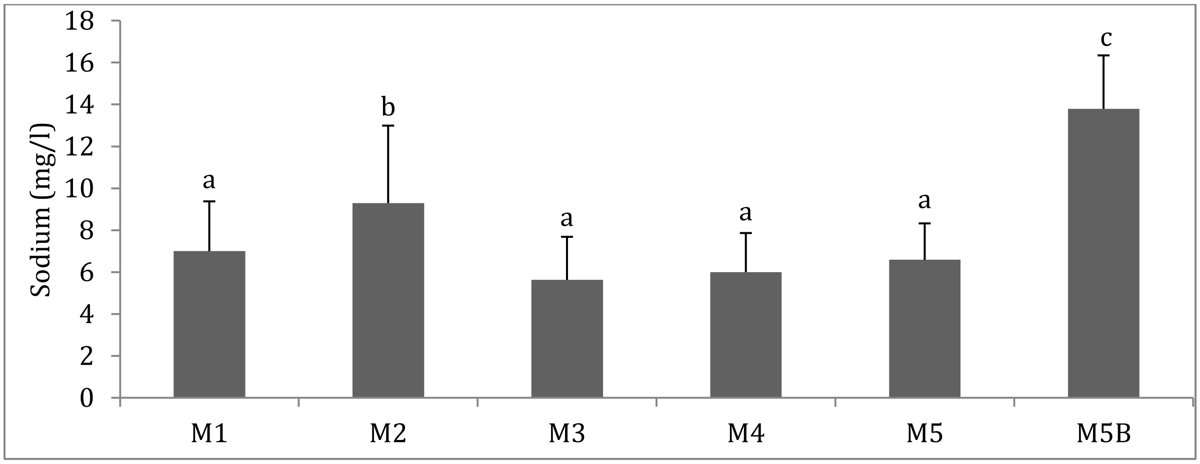


Fig. 5.1.3k$_1$. Changes in sodium (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

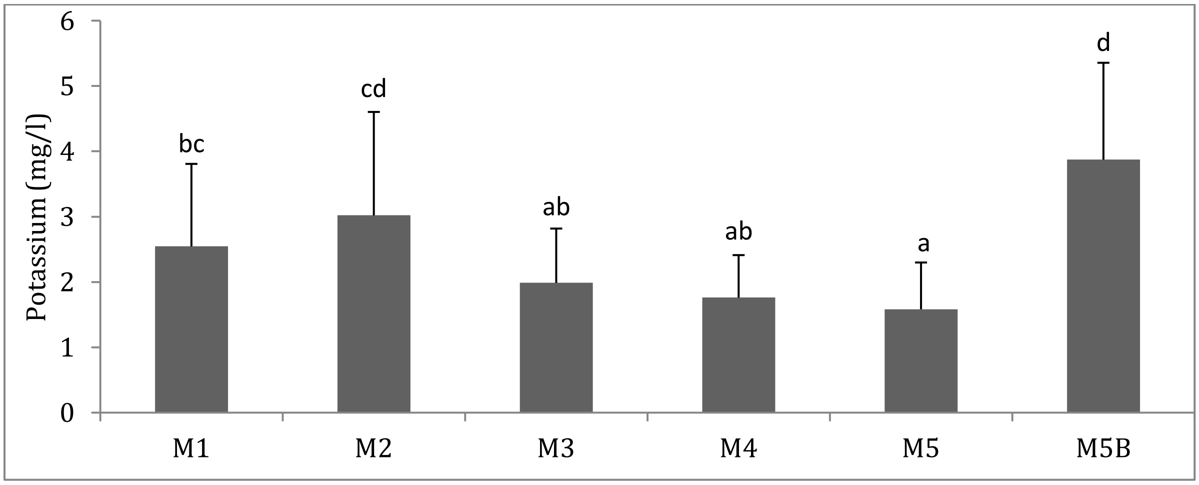


Fig. 5.1.3k$_2$. Changes in potassium (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

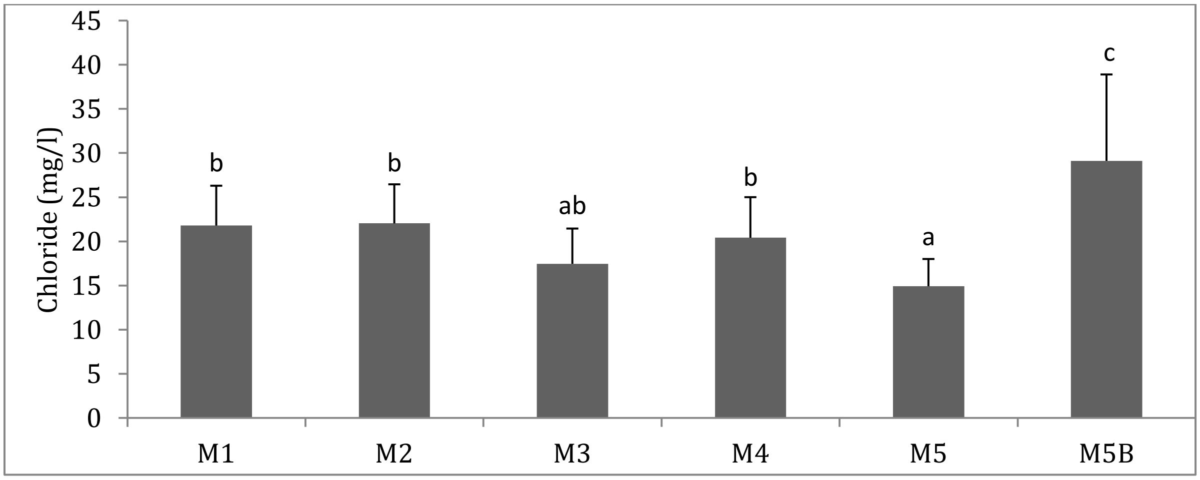


Fig. 5.1.3l. Changes in chloride (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p < 0.001$) between the sites (Tukey HSD).

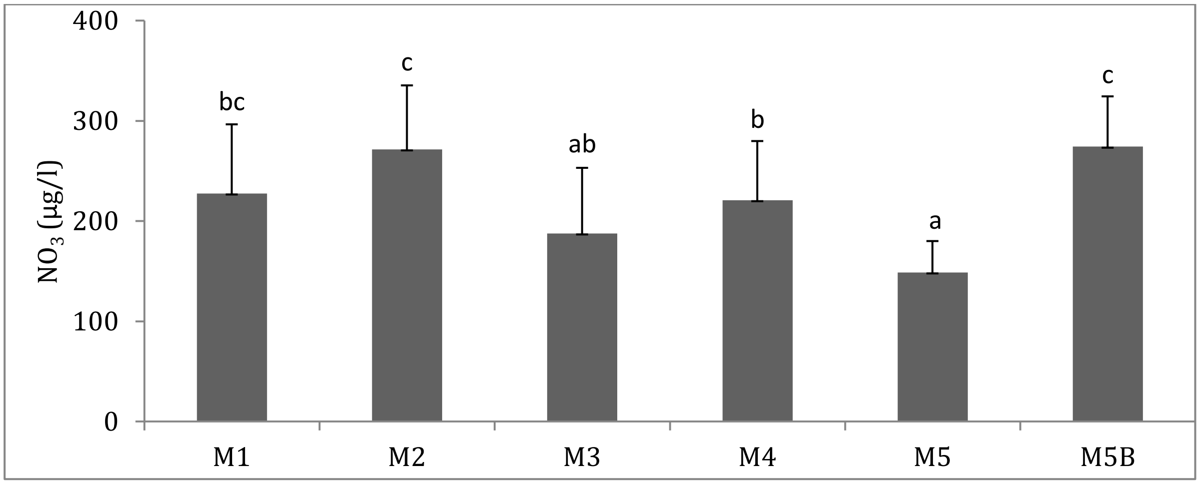


Fig. 5.1.3m. Changes in nitrate (µg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

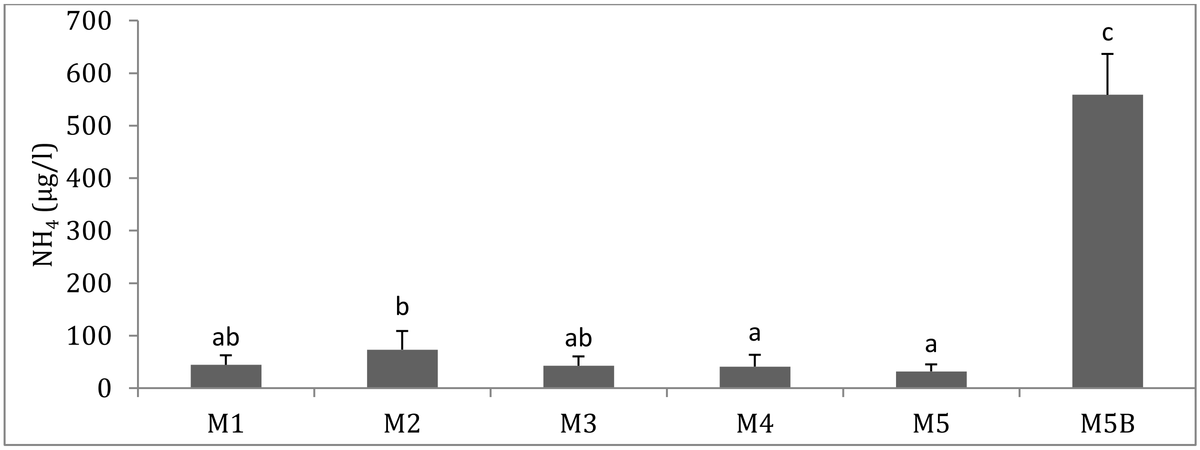


Fig. 5.1.3n. Changes in ammonia (µg /l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

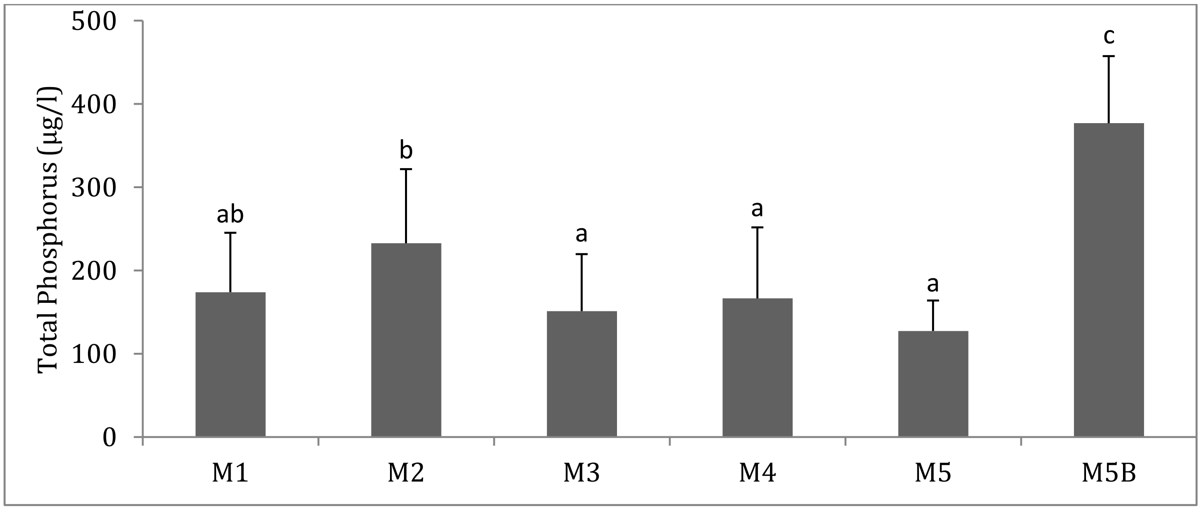


Fig. 5.1.3o. Changes in total phosphorus (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different ($p< 0.001$) between the sites (Tukey HSD).

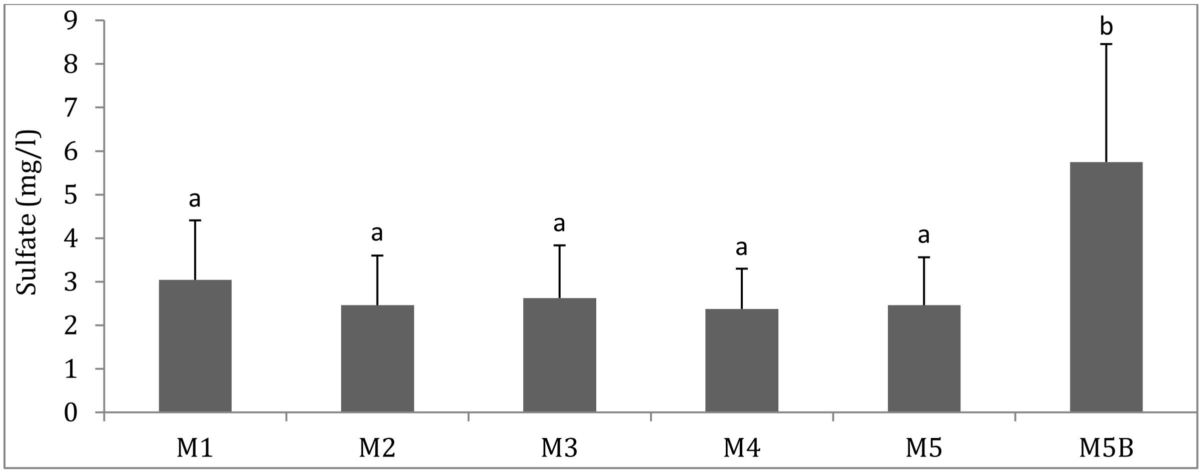


Fig. 5.1.3p. Changes in sulfate (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

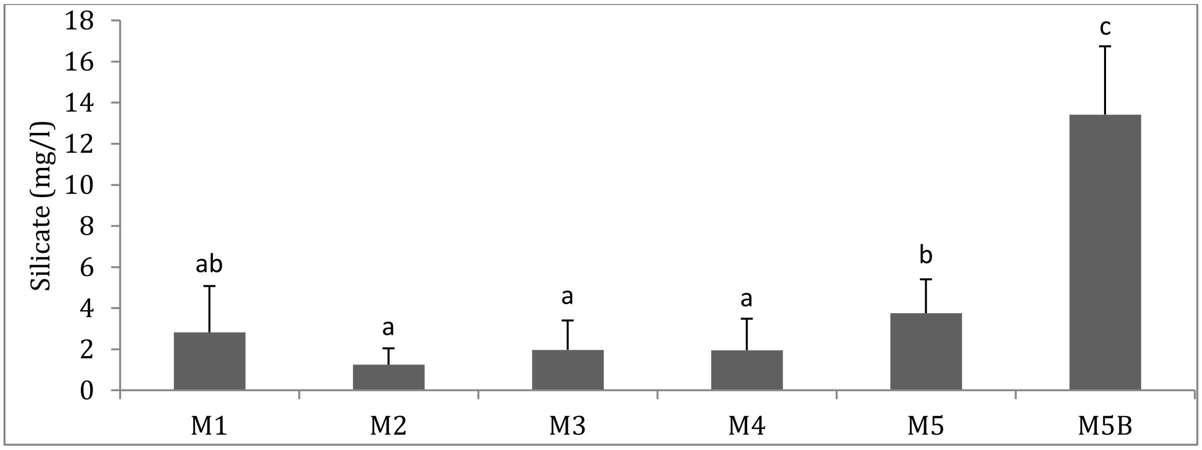


Fig. 5.1.3q. Changes in silicate (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

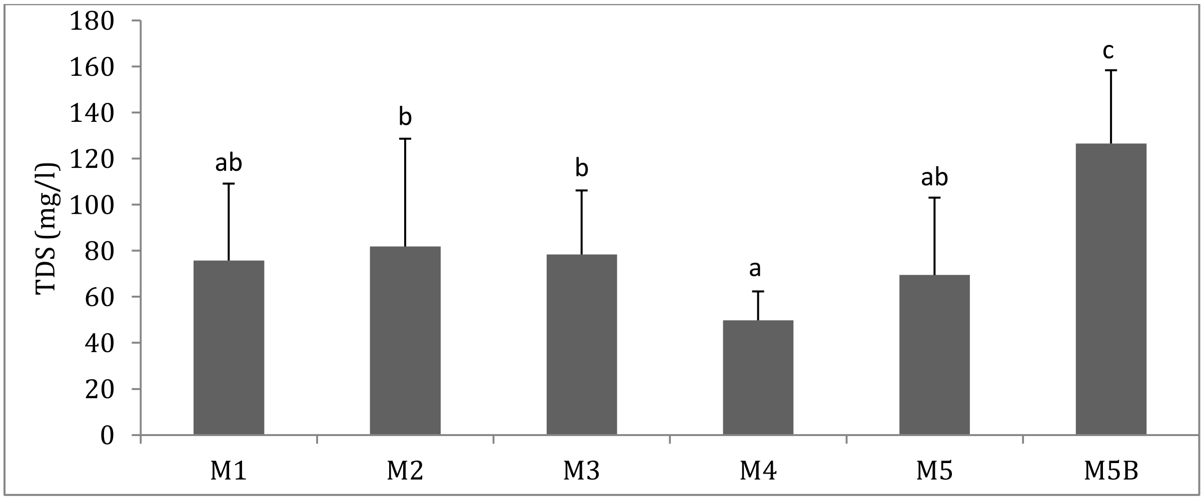


Fig. 5.1.3r. Changes in TDS (mg/l) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly different (p< 0.001) between the sites (Tukey HSD).

5.2. SEDIMENT CHEMISTRY

5.2.1. Tso Morari Lake

5.2.1a. pH

The variations in pH values of sediment from 2004 to 2006 at different study sites in Tso Morari lake are shown in Table 5.2.1a. The pH value at all the sites was in alkaline range. The minimum (7.80) and maximum (8.90) pH was recorded at site TM2 and TM7 in the month of December 2004 and June 2005 respectively. The mean values of pH ranged from a high of 8.55±0.3 at site TM7 to a low of 8.23±0.4 at site TM2. No significant differences ($F_{4,\ 35}$ = 1.213; p = 0.323) were observed in mean pH values between the study sites (Fig. 5.2.1a).

5.2.1b. Conductivity

The conductivity values of sediments at different sites in the lake during 2004 to 2006 are shown in Table 5.2.1b. The conductivity values of sediments at all the study sites were generally > 1000 µS/cm. The minimum (930 µS/cm) and maximum (2700 µS/cm) values were observed at sites TM7 and TM5 respectively. Higher values at most of the sites were recorded in winter season and lower values in summer season. The mean conductivity values showed significant difference ($F_{4,\ 35}$ = 26.543; p = 0.000) between the study sites. TM5 (2344±242µS/cm) had significantly higher values, while TM7 (1201±265µS/cm) had significantly lower values than other sites. There were no significant differences in conductivity values between sites TM2 (1841±205µS/cm) TM4 (1934±164µS/cm) and TM6 (1753±102µS/cm) (Fig. 5.2.1b).

5.2.1c. Organic Carbon and Organic Matter

The organic carbon in the lake sediments varied from 0.28% at site TM7 to 6.7% at site TM4 during the study period (Table and Fig. 5.2.1c_1). The study revealed higher concentration of organic carbon during winter months at all the study sites. The mean values of sediment organic carbon at site TM7 (0.45±0.2%) were significantly lower ($F_{4,35}$=17.49; p =0.000) than other sites. Further, site TM4 (3.72±1.3%) had significantly higher concentration of organic carbon than sites TM6 (2.37±0.7%) and TM5 (2.58±0.8%). However, sites TM2, TM5 and TM6 showed insignificant variation in the mean organic carbon values. Organic matter also followed the same trend as sediment organic carbon (Table 5.2.1c_2). The highest mean values were recorded at site TM4 (6.22±2.2%), followed by TM2 (5.86±1.4%), TM5 (4.44±1.4%), TM6 (4.07±1.0%) and significantly lower ($F_{4,35}$=15.9; p = 0.000) values were recorded at site TM7 (0.76±0.3%) (Fig. 5.2.1c_2).

5.2.1d. Ammonical Nitrogen

The HN_3-N values in the sediments varied from 25µg/g at site TM7 in June 2005 to 203µg/g at site TM4 in December 2004 (Table and Fig. 5.2.1d). Generally higher values at all the sites were observed in winter months. The mean values of NH_3-N also showed significant variation ($F_{4,35}$ =13.97; p =0.000) between the study sites. The mean concentration ranged from 44±18 µg/g (TM7) to 158±42µg/g (TM4), with TM4 having significantly higher values than other sites. TM2 (105±35µg/g) showed significantly higher values than sites TM6 (59±19µg/g) and TM7 (44±19µg/g). Site TM5 (99±41µg/g) showed significantly higher values than site TM7.

5.2.1e. Nitrate Nitrogen

The NO_3-N values of the sediments ranged from 30µg/g at site TM7 to 134µg/g at site TM4 (Table and Fig. 5.2.1e), with relatively higher concentrations in warmer months at all the sites. The highest mean value of NO_3-N was recorded for TM4 (99±24µg/g) followed by TM6 (84±17µg/g), TM5 (70±22µg/g), TM2 (64±19µg/g) and at site TM7 (61±28µg/g). Site TM4 showed significantly higher ($F_{4, 35}$ =4.12; p =0.008) values than other sites, except site TM6 where difference was not significant.

5.2.1f. Exchangeable Phosphorus

Variations in exchangeable phosphorus at different study sites are depicted in Table 5.2.1f. Its concentration ranged from 50µg/g at TM7 in June 2006 to 480µg/g at TM2 in December 2004. Site TM7 had low values of exchangeable phosphorus throughout the study period as compared to other sites. The mean values of exchangeable phosphorus were significantly lower ($F_{4,35}$=31.74; p= 0.000) at TM7 (70±15µg/g) and TM6 (127±37µg/g) than other sites. Significant difference in mean values was also observed between sites TM2 (386±65µg/g) and TM5 (257±75µg/g) (Fig. 5.2.1f).

5.2.1g. Total Phosphorus

The total phosphorus in the lake sediments ranged from 420µg/g at site TM7 in August 2006 to 1630µg/g at site TM2 in December 2005 (Table and Fig. 5.2.1g). TM2 and TM4 had high concentration of total phosphorus, while TM7 had the lowest values throughout the study period. The mean total phosphorus were significantly higher ($F_{4,35}$=20.29; p=0.000) at TM2 (1223±275µg/g) and TM4 (1164±196µg/g) than other sites. Site TM5 (807±149µg/g) also had significantly higher values than site TM7 (527±89µg/g).

5.2.1h. Exchangeable Calcium

The study revealed that exchangeable calcium of sediments varied from 7.2 cmoles (+)/kg at site TM7 in June 2006 to 27.6 cmoles (+)/kg at site TM4 in December 2005 (Table and Fig. 5.2.1h).The mean values at TM7 (11.39±3.2 cmoles (+)/kg) were significantly lower ($F_{4,35}$= 6.540; p =0.000) as compared to TM2 (18.79±3.5 cmoles(+)/kg), TM4 (20.16±4.8 cmoles(+)/kg) and TM5 (20.26±3.8

cmoles (+)/kg). However, there was no significant difference in mean exchangeable Ca values between other sites.

5.2.1i. Exchangeable Magnesium

Variations in exchangeable magnesium of sediments at different study sites are depicted in Table 5.2.1i. It ranged from 10 cmoles (+)/kg at site TM7 in June 2006 to 39 cmoles (+)/kg at site M4 in December 2005. The highest mean value was observed at site TM4 (30.59±6.9 cmoles (+)/kg), followed by TM5 (29.95±4.5 cmoles (+)/kg), and the lowest at site TM7 (13.73±7.7 cmoles (+)/kg). However, there was no significant difference in mean values between the study sites except site TM7, which showed significantly lower ($F_{4,\ 35}$ =299.43; p = 0.000) values than other sites (Fig. 5.2.1i).

5.2.1j. Exchangeable Sodium

Spatial and temporal variations in exchangeable Na at various sites lake are presented in Table 5.2.1j. It varied from 1.20 cmoles (+)/kg at TM7 to 4.3 cmoles (+)/kg at site TM4. There was significant difference ($F_{4,35}$ = 6.895; p =0.000) in the mean exchangeable Na values between the study sites. Site TM4 (2.98±0.7 cmoles (+)/kg) and TM5 (2.76±0.7 cmoles (+)/kg) had significantly higher values than site TM6 (1.91±0.6 cmoles (+)/kg), and TM7 (1.47±0.3 cmoles (+)/kg). Further, TM2 (2.64±0.8 cmoles (+)/kg) also had significantly high values of exchangeable Na than TM7. Rest of the sites did not show any significant difference in mean values (Fig. 5.2.1j).

5.2.1k. Exchangeable Potassium

The exchangeable K in the lake varied from 0.10 cmoles (+)/kg at site TM5 to 1.80 cmoles (+)/kg at site TM4 (Table 5.2.1k). Higher values of exchangeable K were recorded in winter months. The mean values at site TM4 (1.24±0.3 cmoles (+)/kg) were significantly higher ($F_{4,\ 35}$=5.87; p=0.001) than TM7 (0.63±0.1 cmoles (+)/kg) and TM6 (0.90±0.2 cmoles (+)/kg). Site TM2 (0.94±0.3 cmoles (+)/kg) also had significantly higher values than site TM7. Rest of the sites did not show any significant difference in mean exchangeable K values (Fig. 5.2.1k).

Table 5.2.1a. Spatial and temporal variation in sediment pH in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	7.84	7.80	8.74	8.70	7.86	7.82	8.60	8.50	8.20	**8.23**	**0.4**
TM4	8.23	8.13	8.65	8.73	8.20	8.30	8.60	8.74	8.40	**8.44**	**0.2**
TM5	-	8.20	8.60	8.40	8.30	8.42	8.20	8.70	8.20	**8.38**	**0.2**
TM6	-	-	8.70	8.82	8.10	8.88	8.70	8.30	7.85	**8.48**	**0.4**
TM7	-	-	8.70	8.82	8.30	8.15	8.90	8.70	8.30	**8.55**	**0.3**

Table 5.2.1b. Spatial and temporal variation in sediment conductivity (µS/cm) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	1830	2200	1800	1920	1800	2080	1630	1470	1840	**1841**	**205**
TM4	1970	2090	1870	1780	1900	2190	1630	1880	2100	**1934**	**164**
TM5	-	2600	2300	2300	2400	2450	2100	1900	2700	**2344**	**242**
TM6	-	-	1630	1700	1960	1680	1730	1830	1740	**1753**	**102**
TM7	-	-	980	1030	1400	1500	970	930	1600	**1201**	**265**

Table 5.2.1c$_1$. Spatial and temporal variation in sediment organic carbon (%) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	2.60	4.30	2.80	2.60	3.50	4.60	2.90	3.20	4.30	**3.42**	**0.8**
TM4	2.20	4.00	3.10	2.80	3.70	3.60	3.20	4.20	6.70	**3.72**	**1.3**
TM5	-	2.60	1.20	2.00	3.00	3.60	2.30	2.50	3.40	**2.58**	**0.8**
TM6	-	-	1.30	2.20	2.60	3.00	1.80	2.50	3.20	**2.37**	**0.7**
TM7	-	-	0.36	0.28	0.37	0.83	0.43	0.28	0.58	**0.45**	**0.2**

Table 5.2.1c$_2$. Spatial and temporal variation in sediment organic matter (%) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	4.50	7.40	4.50	4.40	6.00	8.00	5.00	5.50	7.40	**5.86**	**1.4**
TM4	3.70	6.80	5.30	4.80	5.00	6.20	5.50	7.20	11.50	**6.22**	**2.2**
TM5	-	4.50	2.00	3.40	5.10	6.20	4.00	4.30	6.00	**4.44**	**1.4**
TM6	-	-	2.20	3.80	4.50	5.10	3.10	4.30	5.50	**4.07**	**1.1**
TM7	-	-	0.62	0.48	0.63	1.40	0.74	0.48	1.00	**0.76**	**0.3**

Table 5.2.1d. Spatial and temporal variation in sediment NH_3-N (µg/g) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	136	160	89	73	93	120	70	62	139	**105**	**35**
TM4	176	203	98	120	135	190	109	200	187	**158**	**42**
TM5	-	94	60	62	108	130	50	120	168	**99**	**41**
TM6	-	-	40	32	67	82	50	62	80	**59**	**19**
TM7	-	-	38	29	50	62	25	30	74	**44**	**18**

Table 5.2.1e. Spatial and temporal variation in sediment NO_3-N (µg/g) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	79	64	49	38	76	90	62	40	82	**64**	**19**
TM4	89	134	65	88	120	98	78	130	85	**99**	**24**
TM5	-	73	52	48	73	92	38	102	78	**70**	**22**
TM6	-	-	56	92	86	90	63	96	102	**84**	**17**
TM7	-	-	43	47	82	98	30	36	88	**61**	**28**

Table 5.2.1f. Spatial and temporal variation in sediment exchangeable phosphorus (µg/g) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	394	480	360	281	439	460	318	380	363	**386**	**65**
TM4	364	396	260	187	430	320	180	386	360	**320**	**91**
TM5	-	386	200	260	320	282	153	196	260	**257**	**75**
TM6	-	-	132	138	160	184	106	80	92	**127**	**37**
TM7	-	-	68	56	82	96	50	68	70	**70**	**15**

Table 5.2.1g. Spatial and temporal variation in sediment total phosphorus (µg/g) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	1352	1520	1150	930	985	1630	1030	932	1480	**1223**	**275**
TM4	1079	1338	980	870	1030	1480	1280	1130	1290	**1164**	**196**
TM5	-	936	727	690	840	990	860	532	880	**807**	**149**
TM6	-	-	730	538	860	830	740	630	834	**737**	**119**
TM7	-	-	630	436	530	540	480	420	650	**527**	**89**

Table 5.2.1h. Spatial and temporal variation in sediment exchangeable calcium (cmoles (+)/kg) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	16.8	20.0	17.6	15.6	20.8	24.0	13.3	18.0	23.0	**18.79**	**3.5**
TM4	18.0	26.0	13.8	15.8	22.0	27.6	16.2	19.0	23.0	**20.16**	**4.8**
TM5	-	23.0	16.3	14.5	20.0	26.0	18.3	21.0	23.0	**20.26**	**3.8**
TM6	-	-	10.6	13.6	16.2	19.3	12.5	18.0	23.0	**16.17**	**4.3**
TM7	-	-	8.6	10.6	13.3	16.0	7.2	10.0	14.0	**11.39**	**3.2**

Table 5.2.1i. Spatial and temporal variation in sediment exchangeable magnesium (cmoles (+)/kg) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	19.2	33.0	25.0	23.3	36.0	37.0	15.6	26.0	35.0	**27.79**	**7.8**
TM4	26.4	38.6	20.3	27.0	35.0	39.0	23.0	30.0	36.0	**30.59**	**6.9**
TM5	-	32.3	25.2	23.0	35.0	32.0	26.0	32.6	33.5	**29.95**	**4.5**
TM6	-	-	15.2	18.8	20.6	26.8	20.0	30.0	32.0	**23.34**	**6.3**
TM7	-	-	12	15.0	20.0	25.0	10.0	14.6	10.3	**13.73**	**7.7**

Table 5.2.1j. Spatial and temporal variation in sediment exchangeable sodium (cmoles (+)/kg) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	3.1	3.4	2.3	1.2	1.6	3.2	2.6	3.4	3.0	**2.64**	**0.8**
TM4	3.6	4.3	3.0	2.0	2.6	3.0	2.2	2.8	3.3	**2.98**	**0.7**
TM5	-	3.3	2.5	2.0	2.5	3.6	1.8	2.7	3.7	**2.76**	**0.7**
TM6	-	-	1.4	1.4	1.6	2.6	1.3	2.8	2.3	**1.91**	**0.6**
TM7	-	-	1.3	1.2	1.8	2.0	1.2	1.3	1.5	**1.47**	**0.3**

Table 5.2.1k. Spatial and temporal variation in sediment exchangeable potassium (cmoles (+)/kg) in Tso Morari lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TM2	1.0	1.4	0.5	0.9	0.8	1.0	0.7	1.1	1.3	**0.94**	**0.3**
TM4	1.5	1.8	1.2	0.8	1.0	1.3	1.2	1.0	1.4	**1.24**	**0.3**
TM5	-	1.3	1.0	0.1	0.7	1.0	0.5	1.0	1.3	**0.86**	**0.4**
TM6	-	-	0.6	0.7	0.9	1.0	0.8	0.9	1.3	**0.90**	**0.2**
TM7	-	-	0.5	0.5	0.7	0.8	0.6	0.6	0.7	**0.63**	**0.1**

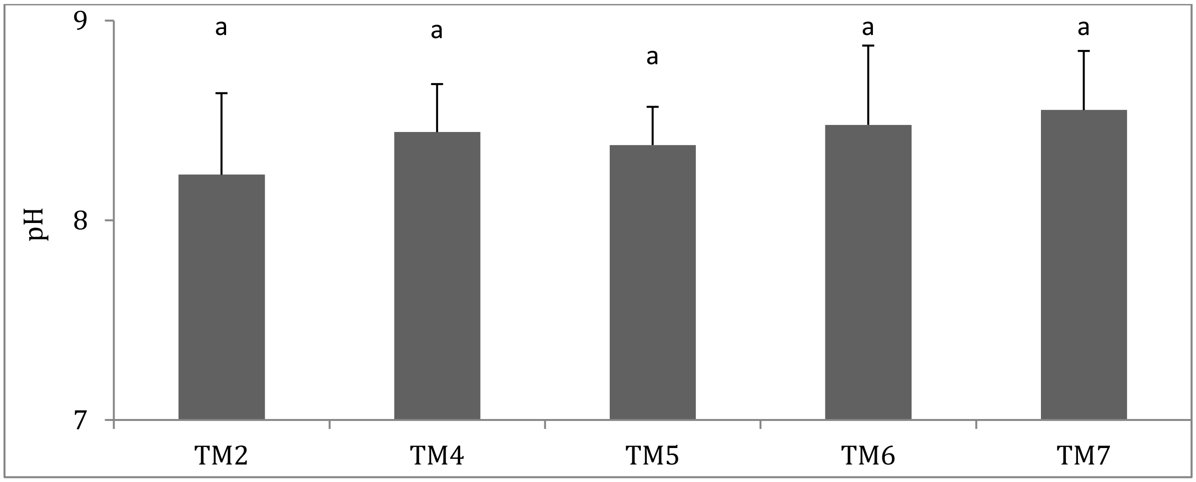


Fig. 5.2.1a. Changes in sediment pH (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

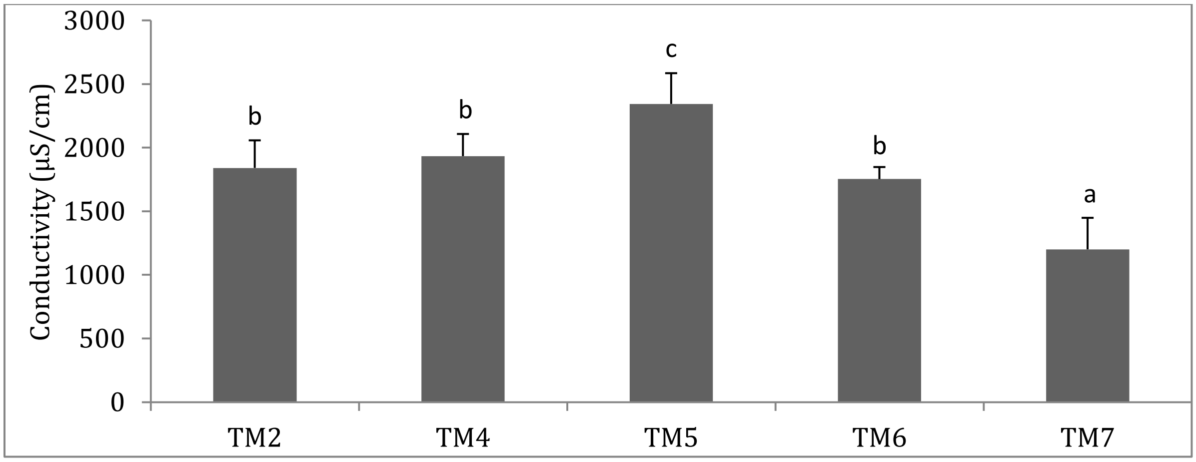


Fig. 5.2.1b. Changes in sediment conductivity (µS/cm) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

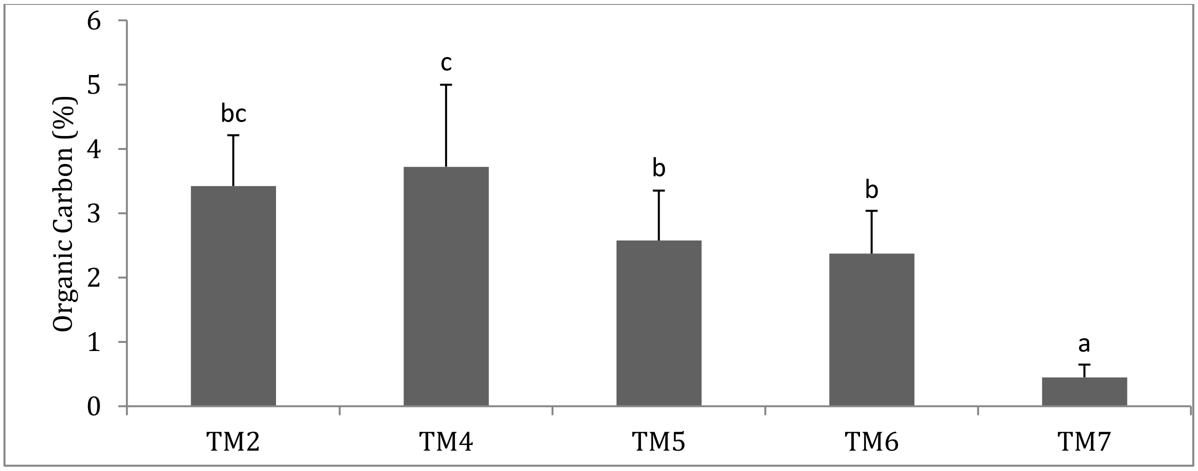


Fig. 5.2.1c$_1$. Changes in sediment carbon (%) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

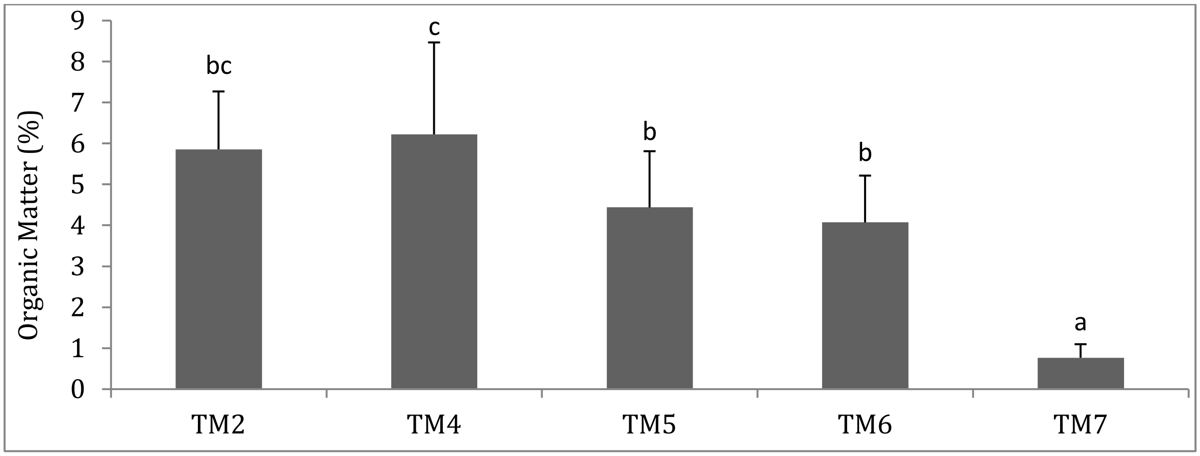


Fig. 5.2.1c$_2$. Changes in sediment organic matter (%) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

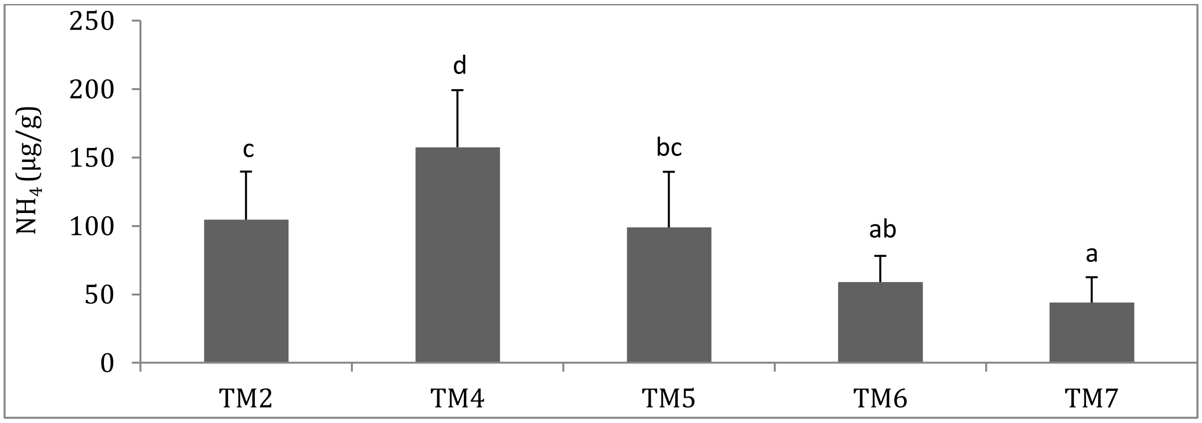


Fig. 5.2.1d. Changes in sediment ammonia (µg/g) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

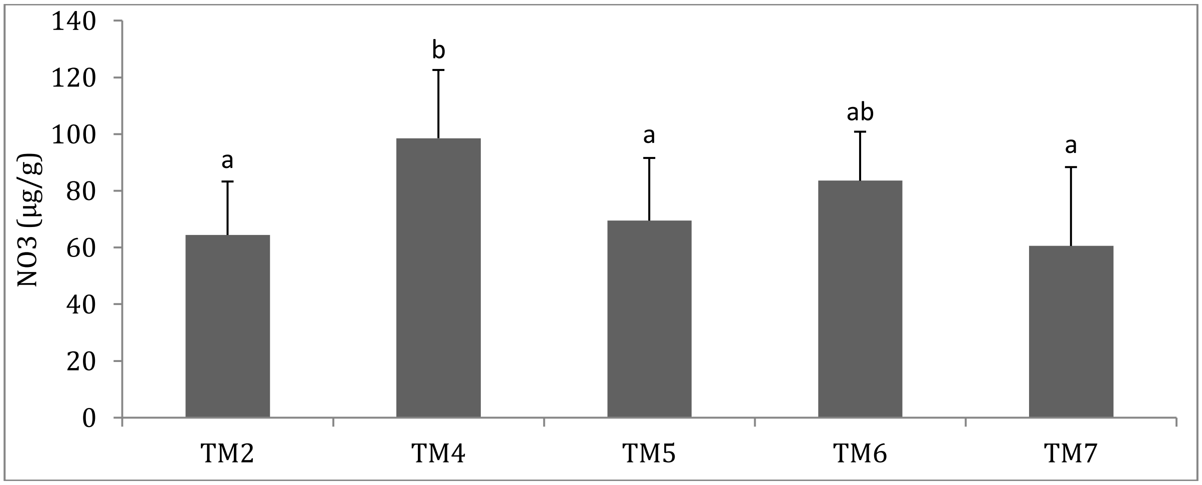


Fig. 5.2.1e. Changes in sediment nitrate (µg/g) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

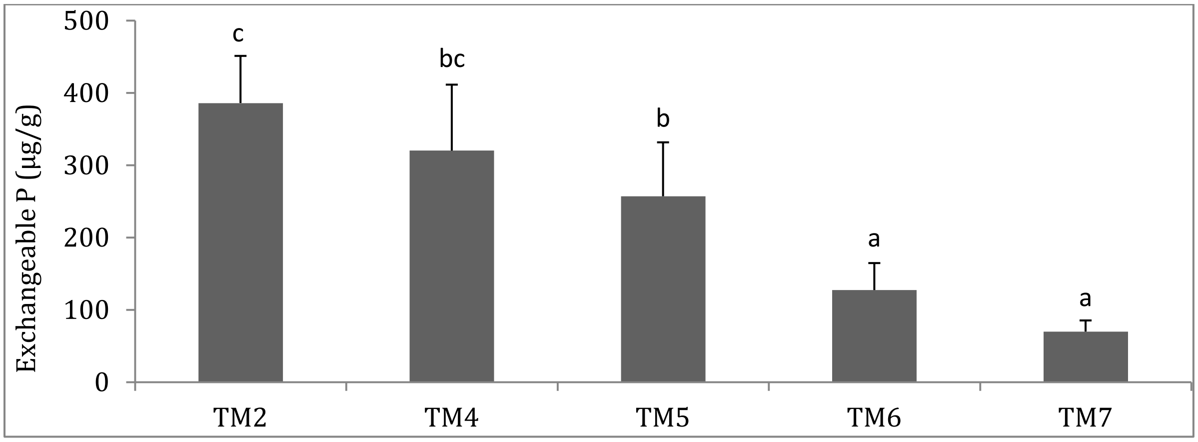


Fig. 5.2.1f. Changes in exchangeable phosphorous (µg/g) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

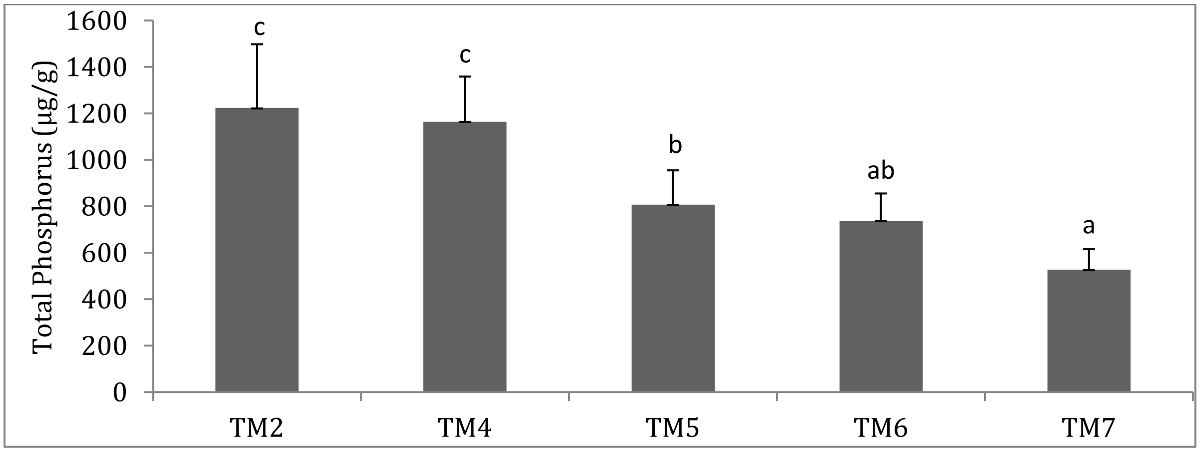


Fig. 5.2.1g. Changes in total phosphorous (µg/g) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

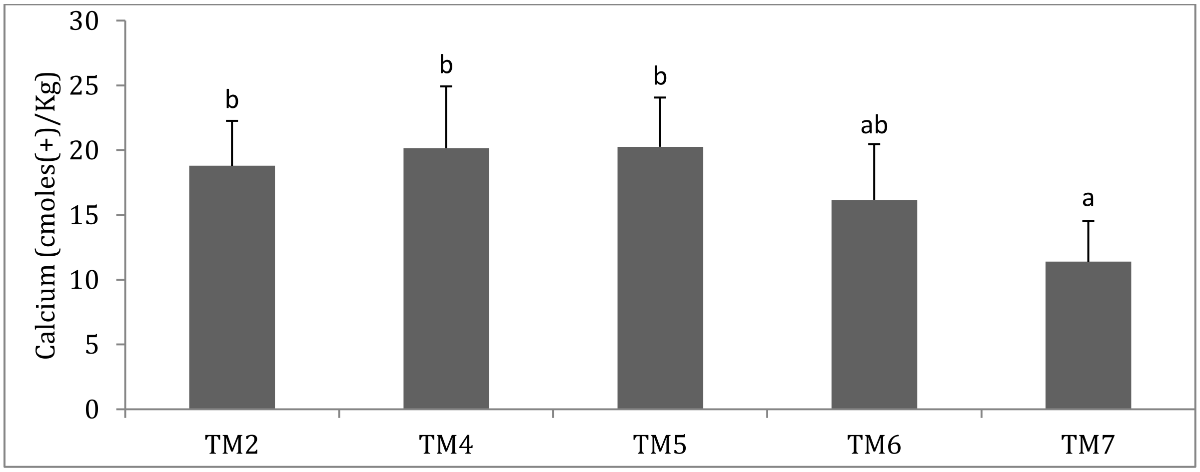


Fig. 5.2.1h. Changes in exchangeable calcium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

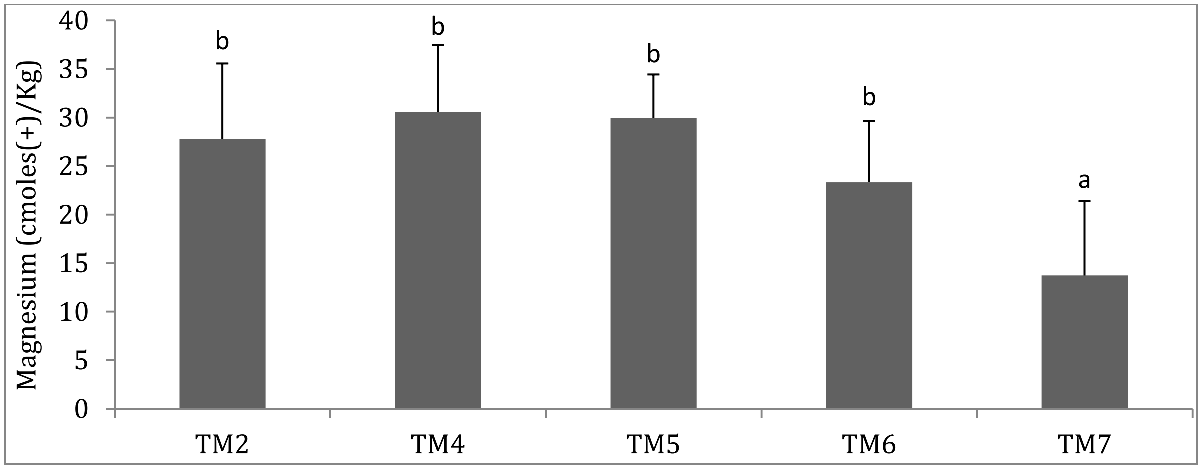


Fig. 5.2.1i. Changes in exchangeable magnesium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

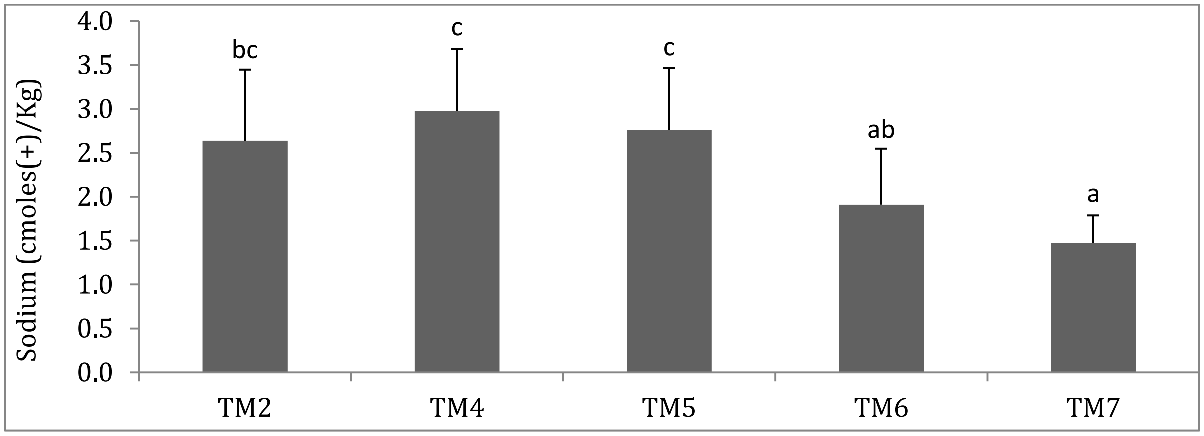


Fig. 5.2.1j. Changes in exchangeable sodium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p<0.001$) different between the sites (Tukey HSD).

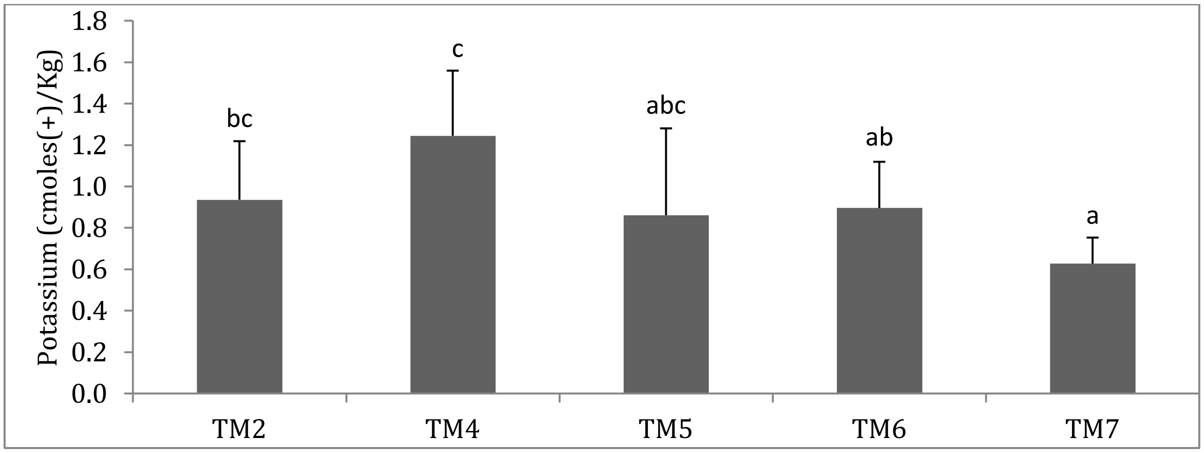


Fig. 5.2.1k. Changes in exchangeable potassium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Morari lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

5.2.2. Tso Khar Lake

5.2.2a. pH

The changes in pH value of sediment at different sites in the lake are shown in Table 5.2.2a. The pH was alkaline at all the study sites and showed wide variations. The saline zones of the lake had higher pH values. The pH ranged from 10.4 at TK1 in July 2005 to 7.8 at TK2 and TK5 in December 2004 and 2005. The mean values were significantly higher ($F_{3,32}$= 135.1; p = 0.000) at TK1 (10.11±0.20) and TK4 (9.92±0.20) than at sites TK2 (8.27±0.31) and TK5 (8.30±0.40) during the study period (Fig. 5.2.2a). Relatively higher pH values were observed in summer at all the study sites.

5.2.2b. Conductivity

The conductivity of lake sediments varied from 890µS/cm at TK2 in July 2005 to 58600µS/cm at TK1 in December 2005 (Table and Fig. 5.2.2b), with values above 35000µS/cm at saline sites (TK1 and TK4). The mean values showed significant variation ($F_{3,32}$= 407.6; p = 0.000) between the study sites. The mean conductivity values were significantly higher at TK4 (47325±6432 µS/cm) followed by TK1 (41082±3591 µS/cm) and significantly low values were recorded at TK2 (1352±252 µS/cm) and TK5 (1566±151 µS/cm).

5.2.2c. Organic Carbon and Organic Matter

The organic carbon in Tso Khar varied from 0.13% at TK1 and TK4 in November 2006 to 5.2% at TK2 in December 2004 (Table and Fig. 5.2.2c_1). The organic carbon content at saline sites (TK1and TK4) was less than fresh water sites (TK2 and TK5) throughout the study period. Significant variation ($F_{3,\ 32}$=120.4; p = 0.000) was observed in the mean values between the study sites, with TK2 having significantly higher concentration of organic carbon (3.5±0.9%) followed by TK5

(2.8%). Organic matter also followed a same trend as in case of organic carbon (Table 5.2.2c$_2$), being significantly ($F_{3,32}$=120.7; p = 0.000) high at TK2 (6.1±1.5%) followed by TK5 (4.8±1%) (Fig. 5.2.2c$_2$). The organic matter values ranged from a maximum of 8.9% (TK2) in December 2004 to a minimum of 0.22% (TK1 and TK4) in November 2006.

5.2.2d. Ammonical Nitrogen

Spatial and temporal variations in exchangeable HN_3-N concentration during the study period are presented in Table 5.2.2d. The highest (206 µg/g) and the lowest (48 µg/g) value of HN_3-N was observed at site TK2 in December (2004) and July (2005) respectively. The highest mean value of HN_3-N was recorded at TK4 (119±40 µg/g) followed by TK2 (94±49 µg/g), and lowest at TK5 (88±51 µg/g). However, the mean values did not show any significant variation ($F_{3,32}$ = .055; p =0.983) between the study sites (Fig. 5.2.2d).

5.2.2e. Nitrate Nitrogen

The NO_3-N values varied from 32µg/g at TK2 in July 2005 to 380µg/g at TK4 in December 2004 (Table 5.2.2e). There was no distinct seasonal trend in NO_3-N values at TK1 and TK4, whereas TK2 and TK5 had high NO_3-N concentration in winter months and low values in summer months. The mean values of NO_3-N found at TK1 (308±28 µg/g) and TK4 (306±40 µg/g) were significantly higher ($F_{3,32}$ = 157.3; p = 0.000) than mean values of TK2 (81±40 µg/g) and TK5 (84±25 µg/g) (Fig. 5.2.2e).

5.2.2f. Exchangeable Phosphorus

The exchangeable phosphorus ranged from 25µg/g (TK1) to 420µg/g (TK2 and TK5) (Table 5.2.2f). In contrast to other parameters, the mean values were significantly higher ($F_{3, 32}$ = 131.7; p = 0.000) at fresh water sites TK5 (364±63 µg/g) and TK2 (314±71 µg/g) than saline sites TK1 (42±13µg/g) and TK4 (68±25µg/g) (Fig. 5.2.2f).

5.2.2g. Total Phosphorus

Variations in total phosphorus at different study sites are depicted in Table 5.2.2g. The concentration varied from 236µg/g at TK1 in June 2006 to 1038 µg/g at TK5 in October 2005. Like exchangeable phosphorus, low concentration of total phosphorus was observed at saline sites (TK1 and TK2) and high values at fresh water sites (TK2 and TK5), the variations being statistically significant (TK1 :365±80µg/g and TK4:366± 65µg/g were significantly lower ($F_{3,32}$ = 74.1; p = 0.000) than fresh water sites TK2:850±110 µg/g and TK5 :836±165 µg/g) (Fig. 5.2.2g).

5.2.2h. Exchangeable Calcium

Changes in exchangeable Ca at different study sites are depicted in Table 5.2.2h. The exchangeable Ca concentration at saline sites (TK1 and TK4) was almost twice that at TK2 and TK5. Exchangeable Ca values varied from a minimum of 9.30 cmoles (+)/kg at TK2 in June 2006 to a maximum of 38.20 cmoles (+)/kg at site TK4 in December 2005. The study also revealed that exchangeable Ca at all the sites was higher in winter months. The mean values were significantly higher ($F_{3,32}$ = 38.8; p = 0.000) at sites TK1 (30.9±4.5 cmoles (+)/kg) and TK4 (30.1±5.7 cmoles (+)/kg) than sites TK2 (15.4±5.4 cmoles (+)/kg) and TK5 (14.0±3.1 cmoles (+)/kg) (Fig. 5.2.2h).

5.2.2i. Exchangeable Magnesium

Like exchangeable Ca, relatively higher values of exchangeable Mg at all the sites were registered in winter months (Table 5.2.2i). The concentration ranged from 7.8 cmoles (+)/kg) at TK2 in November 2006 to 30.2 cmoles (+)/kg) at TK1 in December 2004. The mean values of exchangeable Mg were significantly lower ($F_{3,32}$= 9.504; p = 0.000) (11.4±3.3 cmoles (+)/kg) at TK2 as compared to TK1

(21.7±4.0 cmoles (+)/kg), TK4 (20.1±4.9 cmoles (+)/kg) and TK5 (17.7±4.4 cmoles (+)/kg). The mean values of exchangeable Mg at TK1, TK4 and TK5 did not show any significant differences (Fig. 5.2.2i).

5.2.2j. Exchangeable Sodium

Spatial and temporal changes in exchangeable Na at different study sites are presented in Table 5.2.2j. The saline sites (TK1 and TK4) registered higher (>500 cmoles (+)/kg) values of exchangeable Na than fresh water sites (TK2 and TK5) throughout the study period. It ranged from 1.92 cmoles (+)/kg at sites TK2 in June (2006) to 947 cmoles (+)/kg at site TK1 in December 2005. The mean values of exchangeable Na varied from 2.71±0.6 cmoles (+)/kg (TK2) to 810.4±164.7 cmoles (+)/kg (TK1). Saline sites (TK1 and TK4) had significantly higher ($F_{3,32}$ = 194.69; p = 0.000) mean values of exchangeable Na than that of fresh water sites(TK2 and TK5) (Fig. 5.2.2j).

5.2.2k. Exchangeable Potassium

Spatial and temporal variations in exchangeable K at different selected sites are presented in Table 5.2.2k. Its concentration varied from 0.6 cmoles (+)/kg at site TK2 to 302 cmoles (+)/kg at site TK1. The mean values of exchangeable K were significantly higher ($F_{3,32}$ = 217.5; p = 0.000) at TK1 (218.3±42.2 cmoles (+)/kg) and TK4 (188.5±28.8 cmoles (+)/kg) than TK2 (1.0±0.2 cmoles (+)/kg) and TK5 (1.1±0.2 cmoles (+)/kg)((Fig. 5.2.2k).

Table 5.2.2a. Spatial and temporal variation in sediment pH in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	10.20	9.96	10.30	10.40	9.93	9.92	10.20	-	10.00	**10.11**	**0.20**
TK2	7.82	7.80	8.60	8.30	8.60	8.20	8.60	-	8.20	**8.27**	**0.31**
TK4	9.90	9.80	10.20	10.00	9.90	9.70	10.20	-	9.70	**9.92**	**0.20**
TK5	-	-	8.60	8.90	8.20	7.80	8.40	-	7.90	**8.30**	**0.40**

Table 5.2.2b. Spatial and temporal variation in sediment conductivity (mS/cm) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	47.2	51.8	39.0	45.2	52.5	58.6	38.3	-	46.0	**47.3**	**6.9**
TK2	1.4	1.6	1.0	0.9	1.5	1.6	1.4	-	1.4	**1.4**	**0.3**
TK4	38.4	42.8	41.2	38.9	43.5	39.8	35.7	-	48.3	**41.1**	**3.8**
TK5	-	-	1.7	1.4	1.7	1.8	1.3	-	1.6	**1.6**	**0.2**

Table 5.2.2c$_1$. Spatial and temporal variation in sediment organic carbon (%) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	0.23	0.19	0.21	0.26	0.38	0.30	0.15	-	0.13	**0.2**	**0.1**
TK2	3.20	5.20	2.60	2.83	3.60	4.32	2.90	-	3.60	**3.5**	**0.9**
TK4	0.23	0.24	0.21	0.20	0.38	0.40	0.15	-	0.13	**0.2**	**0.1**
TK5	-	-	2.10	2.80	2.60	3.40	2.30	-	3.50	**2.8**	**0.6**

Table 5.2.2c$_2$. Spatial and temporal variation in sediment organic matter (%) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	0.39	0.32	0.36	0.44	0.65	0.51	0.25	-	0.22	**0.4**	**0.1**
TK2	5.50	8.90	4.48	4.87	6.20	7.40	4.90	-	6.20	**6.1**	**1.5**
TK4	0.40	0.41	0.36	0.34	0.65	0.70	0.25	-	0.22	**0.4**	**0.2**
TK5	-	-	3.60	4.80	4.50	5.80	3.90	-	6.00	**4.8**	**1.0**

Table 5.2.2d. Spatial and temporal variation in sediment NH_3-N (μg/g) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	140	130	106	96	80	136	92	-	1.4	**98**	**45**
TK2	160	206	63	48	106	142	83	-	130	**94**	**49**
TK4	160	176	82	96	130	150	72	-	84	**119**	**40**
TK5	-	-	120	98	114	138	54	-	1.5	**88**	**51**

Table 5.2.2e. Spatial and temporal variation in sediment NO_3-N (μg/g) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	302	290	320	260	345	290	316	-	340	**308**	**28**
TK2	140	103	40	32	80	102	39	-	112	**81**	**40**
TK4	323	380	260	280	306	316	262	-	324	**306**	**40**
TK5	-	-	89	72	102	106	40	-	96	**84**	**25**

Table 5.2.2f. Spatial and temporal variation in sediment exchangeable phosphorus (µg/g) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	38	63	25	36	43	60	32	-	38	**42**	**13**
TK2	262	302	232	250	390	372	286	-	420	**314**	**71**
TK4	42	70	36	43	90	103	72	-	84	**68**	**25**
TK5	-	-	382	376	380	420	240	-	387	**364**	**63**

Table 5.2.2g. Spatial and temporal variation in sediment total phosphorus (µg/g) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	332	480	280	360	410	392	236	-	430	**365**	**80**
TK2	820	1035	732	720	860	960	780	-	896	**850**	**110**
TK4	430	413	380	290	384	439	270	-	320	**366**	**65**
TK5	-	-	706	740	1038	930	630	-	970	**836**	**165**

Table 5.2.2h. Spatial and temporal variation in sediment exchangeable calcium (cmoles (+)/Kg) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	26.0	30.0	26.0	27.0	32.0	36.0	32.0	-	38.0	**30.9**	**4.5**
TK2	20.4	24.6	12.3	11.3	18.2	16.3	9.3	-	10.8	**15.4**	**5.4**
TK4	30.0	33.0	26.0	19.6	32.0	38.2	28.0	-	34.0	**30.1**	**5.7**
TK5	-	-	10.6	11.2	15.0	18.0	17.0	-	12.4	**14.0**	**3.1**

Table 5.2.2i. Spatial and temporal variation in sediment exchangeable magnesium (cmoles (+)/Kg) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	20.0	18.0	23.0	20.0	23.6	30.2	20.2	-	18.2	**21.7**	**4.0**
TK2	16.5	15.8	11.0	9.2	9.7	12.3	8.5	-	7.8	**11.4**	**3.3**
TK4	23.0	20.3	15.2	11.2	24.6	18.6	23.0	-	25.0	**20.1**	**4.9**
TK5	-	-	15.3	10.6	20.3	20.0	23.0	-	17.0	**17.7**	**4.4**

Table 5.2.2j. Spatial and temporal variation in sediment exchangeable sodium (cmoles (+)/Kg) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	630.0	920.0	913.0	939.0	513.0	947.0	736.0	-	885.0	**810.4**	**164.7**
TK2	2.5	3.2	2.0	2.4	3.0	3.3	1.9	-	3.4	**2.7**	**0.6**
TK4	538.0	830.0	729.0	630.0	890.0	896.0	730.0	-	820.0	**757.9**	**126.4**
TK5	-	-	2.3	2.0	3.1	3.2	2.5	-	3.5	**2.8**	**0.6**

Table 5.2.2k. Spatial and temporal variation in sediment exchangeable potassium (cmoles (+)/Kg) in Tso Khar lake during 2004-2006

Sites	2004		2005				2006			Mean	SD
	Oct	Dec	Jun	Jul	Oct	Dec	Jun	Aug	Nov		
TK1	160.0	202.0	240.0	210.0	236.0	190.0	206.0	-	302.0	**218.3**	**42.2**
TK2	0.9	1.2	0.9	1.1	1.0	1.3	0.6	-	1.3	**1.0**	**0.2**
TK4	138.0	190.0	182.0	172.0	203.0	240.0	196.0	-	187.0	**188.5**	**28.8**
TK5	-	-	0.9	1.0	1.0	1.2	1.0	-	1.3	**1.1**	**0.2**

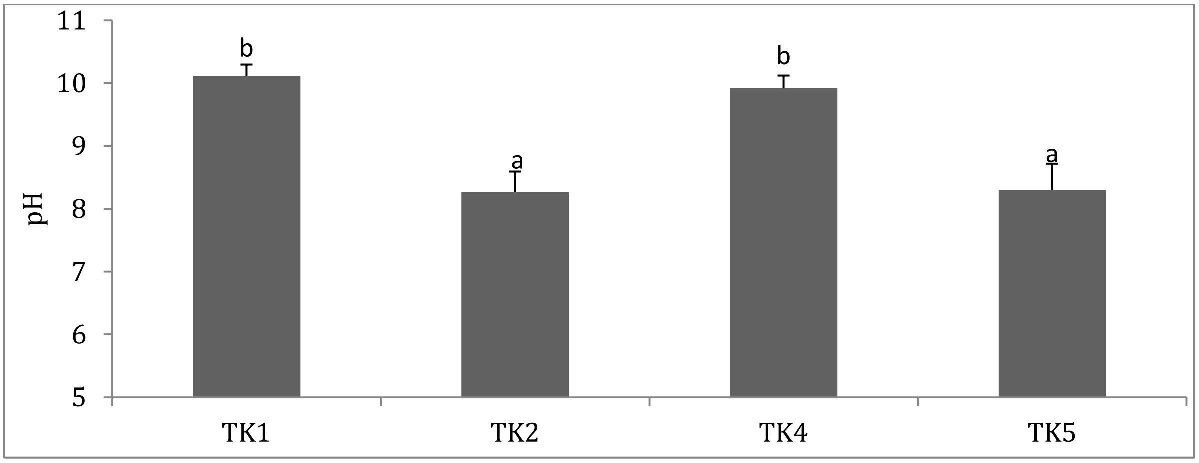


Fig. 5.2.2a. Changes in pH (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

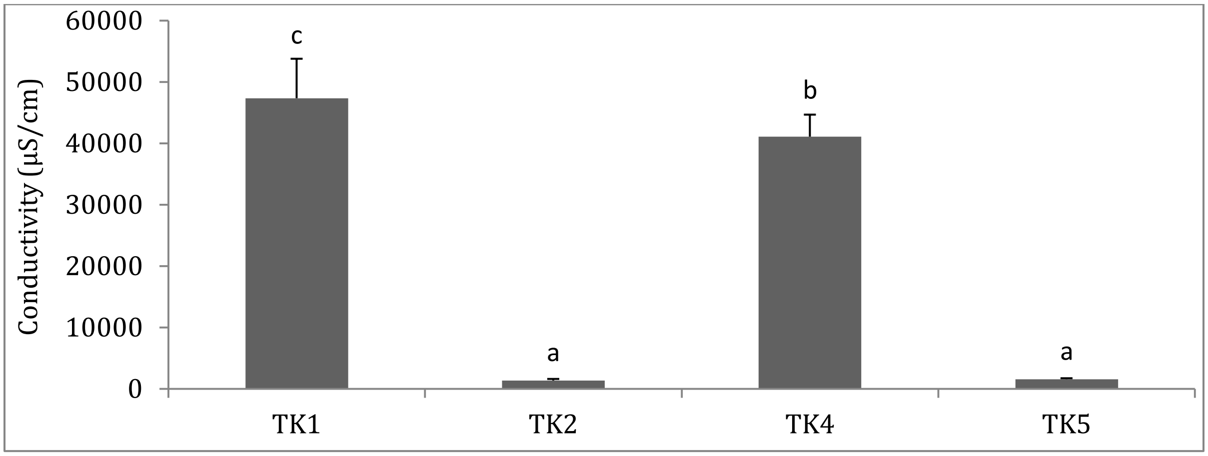


Fig. 5.2.2b. Changes in conductivity (µS/cm) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

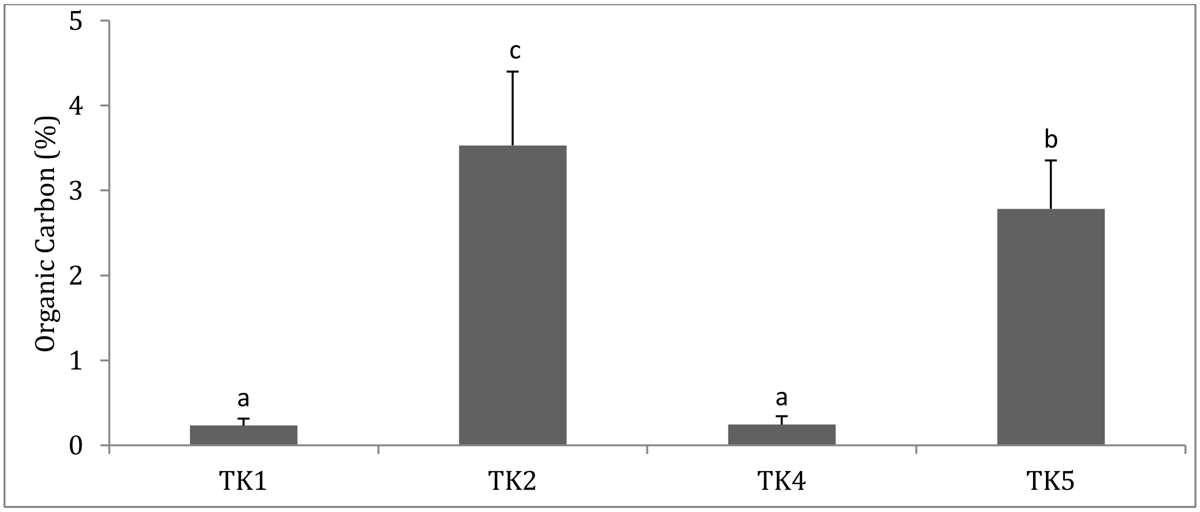


Fig. 5.2.2c$_1$. Changes in organic carbon (%) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

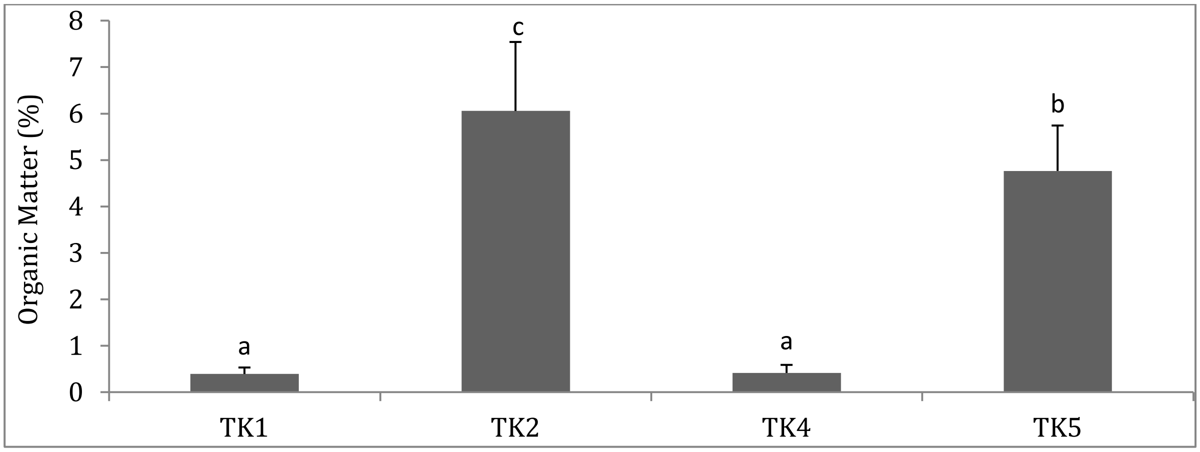


Fig. 5.2.2c$_2$. Changes in organic matter (%) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

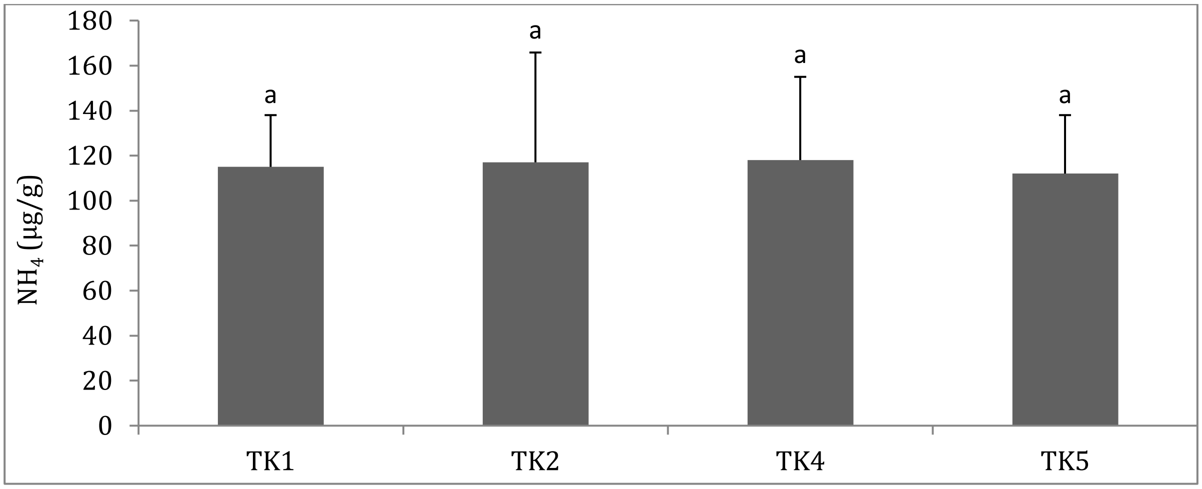


Fig. 5.2.2d. Changes in ammonia (µg/g) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

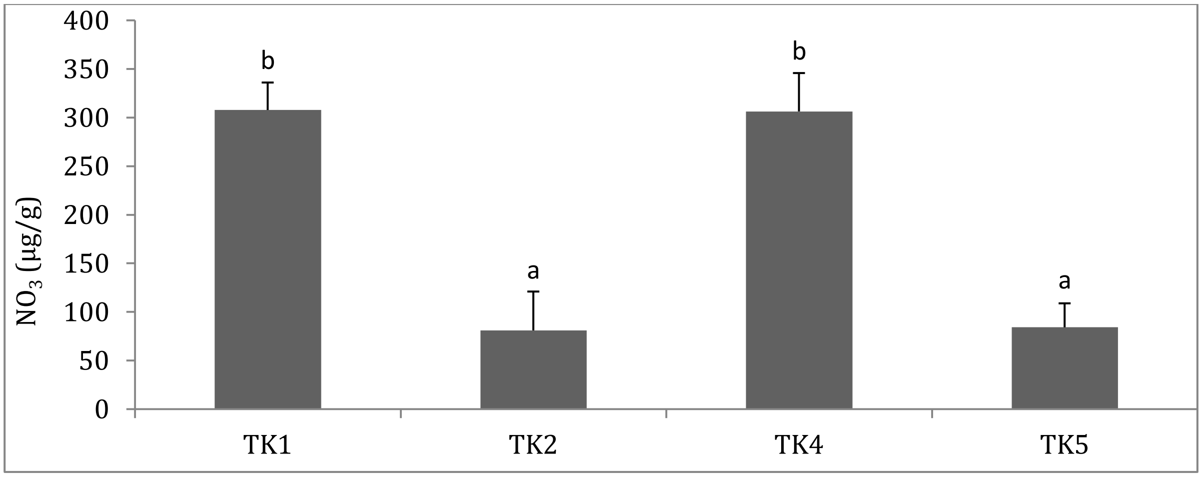


Fig. 5.2.2e. Changes in nitrate (µg/g) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

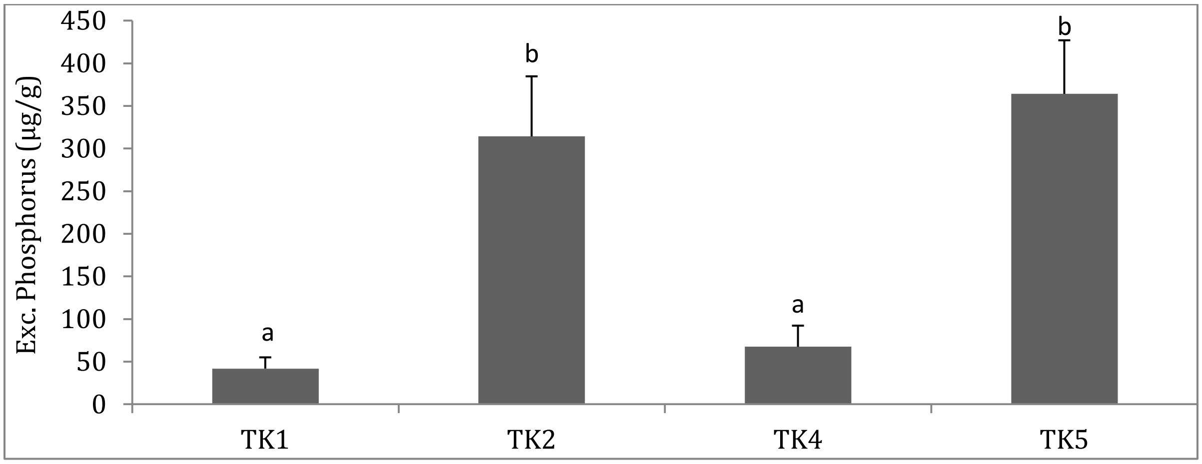


Fig. 5.2.2f.. Changes in exchangeable phosphorous (µg/g) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

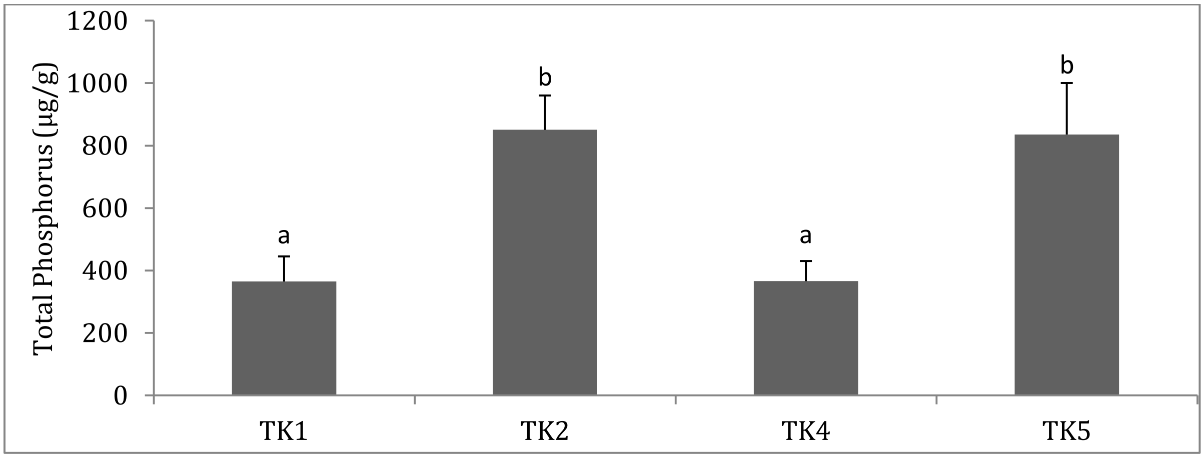


Fig. 5.2.2g. Changes in total phosphorous (µg/g) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

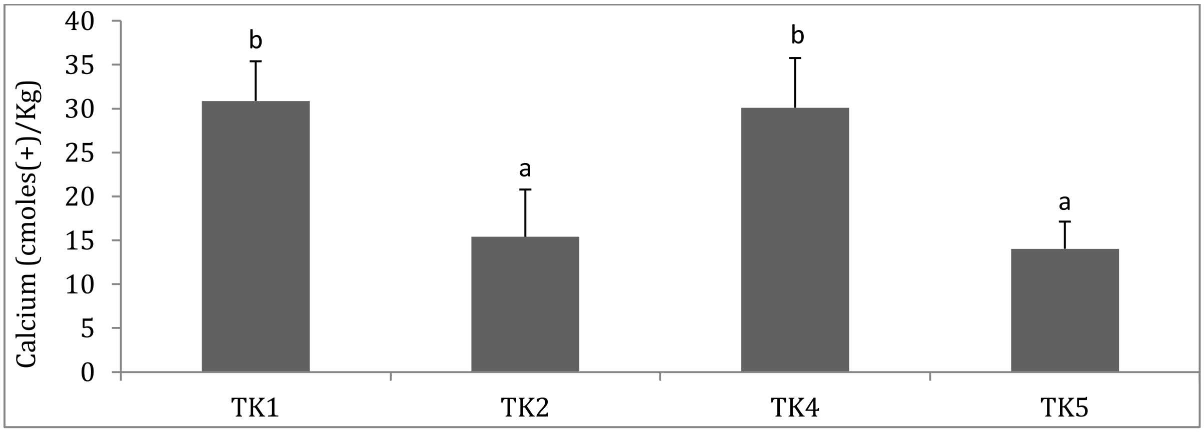


Fig. 5.2.2h. Changes in exchangeable calcium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

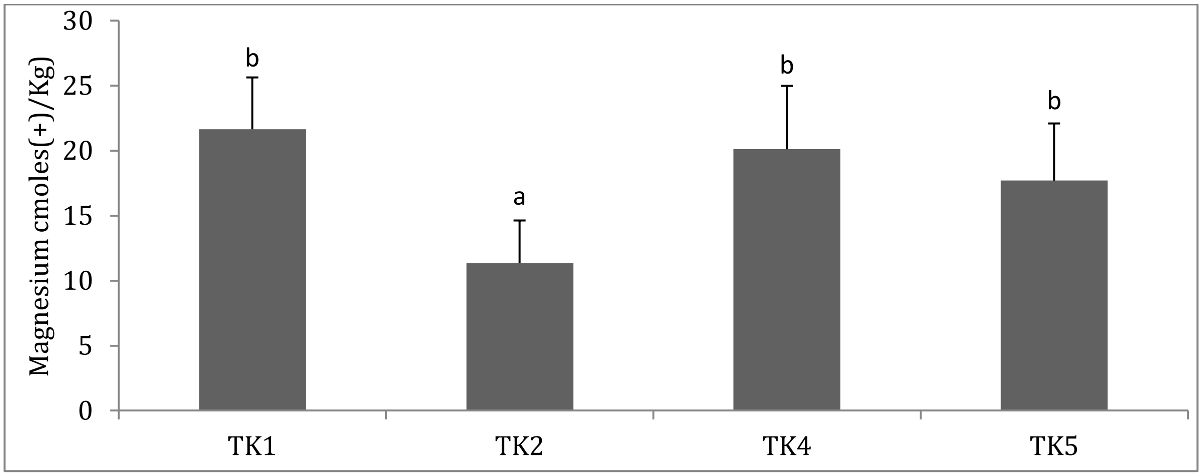


Fig. 5.2.2i. Changes in exchangeable magnesium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

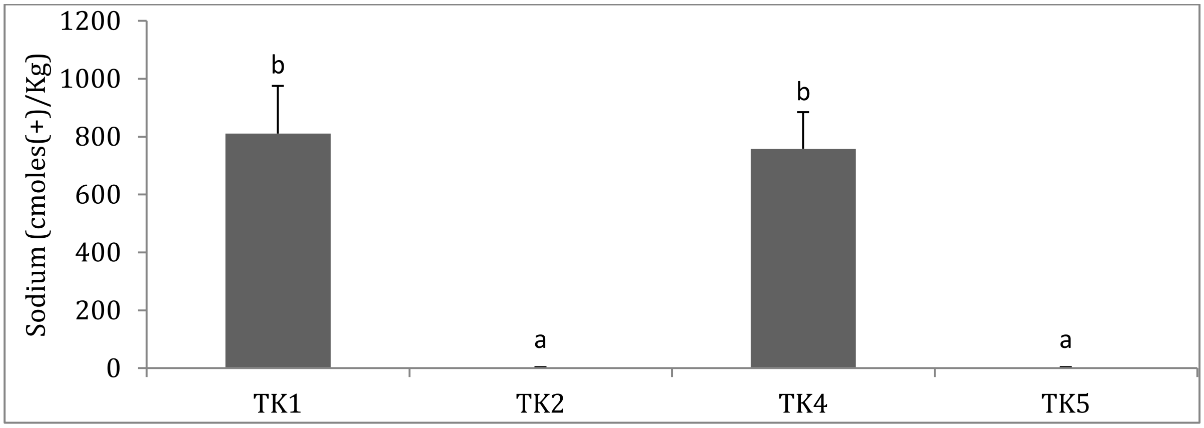


Fig. 5.2.2j. Changes in exchangeable sodium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

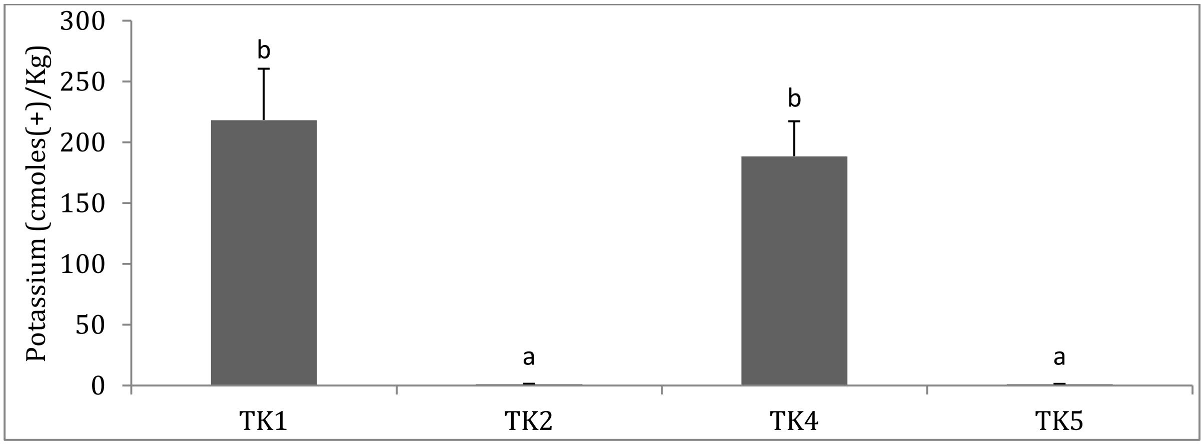


Fig. 5.2.2k. Changes in exchangeable potassium (cmoles (+)/Kg) (mean ± SD) at different study sites in Tso Khar lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

5.2.3. Manasbal Lake

5.2.3a. pH

The seasonal variations in pH values of sediment at different study sites in Manasbal Lake during 2004 to 2006 are depicted in Table 5.2.3a. The pH value at all study sites was alkaline, except M5 which had slightly acidic pH throughout study period, range being 8.00 at site M3 in winter 2005 to 6.80 at site M5 in summer 2006. Generally, higher pH values were observed in winter and autumn and lower in spring and summer. The mean values at site M5 (6.91±0.08) were significantly lower ($F_{4, 35}$ = 33.5; p = 0.000) than other sites. Furthermore, site M3 (7.72±0.19) had significantly higher pH values than site M2 (7.44±0.16) (Fig. 5.2.3a). The mean pH values at other sites did not show any significant difference.

5.2.3b. Conductivity

The conductivity values of the lake ranged from 346 µS/cm at site M4 to 910 µS/cm at site M5 (Table 5.2.3b). Conductivity values were higher at M5 and M2 and lower at M3 and M4 in all the seasons during study period. The mean conductivity values were significantly higher ($F_{4, 35}$ = 13.8; P = 0.000) at site M5 (766±113µS/cm) than other sites except site M2 (635±165µS/cm). The mean conductivity values at site M2 were significantly higher than site M3 (441±54µS/cm) and M4 (454±67µS/cm). However there was no significant difference in mean conductivity values between M1 (511±86 µS/cm), M3 and M4 sites (Fig. 5.2.3b).

5.2.3c. Organic Carbon and Organic Matter

The organic carbon ranged from 5% at site M3 to 11.60% at site M2 (Table and Fig. 5.2.3c_1). Most of the sites recorded higher value of organic carbon in winter and lower in summer season. There was significant difference ($F_{4, 35}$ =13.7; P = 0.000) in the mean values of organic carbon between the study sites. Site M2 (9.80±1.29%) and

M5 (9.40±1.00%) had significantly higher concentration of organic carbon as compared to M3 (6.65±0.83%), M4 (7.29±1.04%) and M1 (7.73±0.99%) sites. The organic matter followed the same trend as organic carbon at all the study sites (Table 5.2.3c_2). The minimum (8.60%) and maximum (20.0%) values of organic matter were observed at site M3 and M2 respectively. The mean values of organic matter were significantly higher ($F_{4,35}$=13.49; p=0.000) at M2 (16.78±2.32%) and M5 (16.11±1.74%) as compared to M1 (13.25±1.66%), M3 (11.40±1.40%) and M4 (12.34±1.84%) (Fig. 5.2.3c_2).

5.2.3d. Ammonical Nitrogen

The ammonical nitrogen of the sediments varied from 115µg/g (M3) to 400µg/g (M5) during 2005 and from 126µg/g (M4) to 360µg/g (M5) in 2006 (Table and Fig. 5.2.3d). Most of the sites showed higher values of NH_3-N in winter season, and lower in summer season. The mean values of NH3-N at site M5 (323±57µg/g) were significantly higher ($F_{4,\ 35}$= 12.7; p = 0.000) than other sites except site M2. Site M2 (254±68µg/g) also had significantly higher values than M3 (173±37µg/g) and M4 (167±38µg/g) sites. However, no significant difference in mean NH_3-N values was observed within sites M1, M4 and M3.

5.2.3e. Nitrate Nitrogen

Seasonal variations in the sediment NO_3-N at different sites are depicted in Table 5.2.3e. The lowest concentration NO_3-N was recorded for sites M4 (63 µg/g) and M5 (56µg/g), while the highest values of 204µg/g and 230µg/g was observed for site M2 during 2005 and 2006 respectively. Except site M5, all the study sites recorded highest value of nitrate in winter season followed by autumn and lowest in summer during the study period. The highest mean value of NO_3-N was found at M2 (170±50 µg/g) followed by M1 (145±37 µg/g), and lowest at M5 (88±21µg/g).

However, the mean values of NO_3-N showed significant variation ($F_{4,35} = 4.36$; p = 0.006) only between sites M2 and M5(Fig. 5.2.3e).

5.2.3f. Exchangeable Phosphorus

Variation in exchangeable phosphorus at different study of the lake are depicted in Table 5.2.3f. The exchangeable phosphorus varied from a minimum of 306µg/g at site M1 to a maximum of 573µg/g at site M5 in 2005 and from 323µg/g at site M1 to 610 µg/g at site M2 in 2006. The mean values of exchangeable phosphorus were significantly higher ($F_{4,35}$ =8.9; p = 0.000) at site M5 (532±48 µg/g) when compared with sites M3 (386±27 µg/g), M1 (418±80 µg/g) and M4 (422±30 µg/g). Further, site M2 (481±69 µg/g) also had significantly higher values than site M3. Rest of the sites did not show any significant difference in mean exchangeable phosphorus (Fig. 5.2.3f).

5.2.3g. Total Phosphorus

Total phosphorus of the sediments varied from minimum value of 860µg/g at M3 in summer 2005 to a maximum of 1730 µg/g at site M2 in winter 2006 (Table and Fig. 5.2.3g). Significant variations (F4, 35 = 19.9; p =0.000) in mean values of total phosphorus were observed between the study sites. Site M5 (1592±150 µg/g) had significantly highest values of mean total phosphorus when compared to other sites. Site M2 (1340±258µg/g), also had significantly higher values than sites M3 (979±92µg/g) and M4 (1026±86 µg/g). The analysis of variance did not show any significant differences in the mean values of total phosphorus between the sites M3, M4 and M1.

5.2.3h. Exchangeable Calcium

The seasonal variations in exchangeable calcium at different sites are presented in Table 5.2.3h. The exchangeable calcium varied from 15 cmoles (+)/kg at site M4 to

56 cmoles (+)/kg at site M5 during the study period. The highest values of exchangeable Ca were reported in winter and the lowest in summer at all the study sites. The mean values of exchangeable calcium were highest at site M5 (30.80±12.61 cmoles (+)/kg) followed by M1 (23.95±3.61 cmoles (+)/kg), M3 (23.93±6.89 cmoles (+)/kg), M4 (22.75±9.39 cmoles(+)/kg) and least at site M2 (20.75±2.60 cmoles (+)/kg). However, there was no significant difference ($F_{4,35}$ = 1.826; p = 0.146) in the mean values of exchangeable Ca between the study sites (Fig. 5.2.3h).

5.2.3i. Exchangeable Magnesium

Variation in exchangeable magnesium values at different study sites are presented in Table 5.2.3i. It ranged from 5.6 cmoles (+)/kg at site M4 to 16.6 cmoles (+)/kg at site M5 during the study period. The results depicted that low values of exchangeable Mg at all the sites were recorded in summer while the rest of seasons did not reveal any definite trend. The mean values of exchangeable Mg ranged from a minimum of 8.28±3.15 cmoles (+)/kg at site M4 to the maximum of 10.28±3.69 cmoles (+)/kg at site M5. The mean values of exchangeable Mg did not show any significant variation ($F_{4,35}$ = .079; p = 0.536) between the study sites(Fig. 5.2.3i).

5.2.3j. Exchangeable Sodium

The exchangeable Na varied from 0.30cmoles (+)/kg at site M1 and M4 to 1.39cmoles (+)/kg at site M5 during the study period (Table and Fig. 5.2.3j). Higher values of exchangeable Na were recorded in winter and spring seasons followed by autumn and lowest values in summer. The mean values of exchangeable Na ranged from 0.43±0.09cmoles (+)/kg (M3) to 0.89±0.28cmoles (+)/kg (M5). However, the mean values of exchangeable Na were significantly higher ($F_{4,35}$ = 12.25; p = 0.000) at site M5 than other sites. Rest of the sites showed insignificant variation in mean exchangeable Na values.

5.2.3k. Exchangeable Potassium

The seasonal values of exchangeable K ranged from 0.10 cmoles (+)/kg) at site M3 to 0.51cmoles (+)/kg at site M5 during the study period (Tables and Fig. 5.2.3k). Like exchangeable Na, higher values of exchangeable K were found in winter and the lower in summer at all the study sites. The mean values of exchangeable K were significantly highest ($F_{4, 35} = 8.53$; p =0.000) at M5 (0.32 ± 0.09cmoles (+)/kg) than other sites except site M2. Site M2 (0.27 ± 0.06cmoles (+)/kg) also had significantly higher values than site M3 (0.16 ±0.05 cmoles (+)/kg). Rest of the sites did not show any significant variation in exchangeable potassium.

Table 5.2.3a. Spatial and temporal variation in sediment pH in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	7.82	7.60	7.40	7.72	7.70	7.50	7.42	7.46	**7.58**	**0.16**
M2	7.45	7.50	7.20	7.35	7.60	7.68	7.30	7.40	**7.44**	**0.16**
M3	8.00	7.62	7.54	7.83	7.96	7.70	7.53	7.60	**7.72**	**0.19**
M4	7.73	7.60	7.32	7.60	7.82	7.86	7.50	7.50	**7.62**	**0.18**
M5	6.92	6.90	6.83	6.90	7.03	6.90	6.80	7.00	**6.91**	**0.08**

Table 5.2.3b. Spatial and temporal variation in sediment conductivity (µS/cm) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	642	530	380	538	584	520	410	486	**511**	**86**
M2	853	685	436	525	875	623	460	624	**635**	**165**
M3	520	456	395	485	483	383	375	433	**441**	**54**
M4	545	432	346	503	526	460	403	420	**454**	**67**
M5	910	762	640	820	842	655	624	876	**766**	**113**

Table 5.2.3c$_1$. Spatial and temporal variation in sediment organic carbon (%) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	8.50	8.30	6.40	7.00	9.00	8.60	6.70	7.30	**7.73**	**0.99**
M2	11.00	9.40	7.60	9.70	11.60	10.00	8.60	10.50	**9.80**	**1.29**
M3	7.60	7.20	5.00	6.70	7.00	7.20	6.00	6.50	**6.65**	**0.83**
M4	8.20	8.00	5.40	6.80	8.50	7.70	6.40	7.30	**7.29**	**1.04**
M5	10.00	9.00	8.60	10.60	9.80	9.20	7.60	10.40	**9.40**	**1.00**

Table 5.2.3c$_2$. Spatial and temporal variation in sediment organic matter (%) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	14.60	14.20	11.08	12.00	15.40	14.70	11.50	12.50	**13.25**	**1.66**
M2	19.00	16.00	13.00	16.60	20.00	17.20	14.40	18.00	**16.78**	**2.32**
M3	13.00	12.30	8.60	11.50	12.00	12.30	10.30	11.20	**11.40**	**1.40**
M4	14.10	13.70	9.28	11.60	14.60	13.20	11.00	11.20	**12.34**	**1.84**
M5	17.20	15.40	14.70	18.20	16.80	15.80	13.00	17.80	**16.11**	**1.74**

Table 5.2.3d. Spatial and temporal variation in sediment NH_3-N (µg/g) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	250	185	140	200	284	193	145	235	**204**	**50**
M2	340	208	185	294	325	195	178	305	**254**	**68**
M3	195	173	115	180	220	155	132	210	**173**	**37**
M4	190	132	115	203	210	173	126	190	**167**	**38**
M5	400	265	280	375	360	240	350	310	**323**	**57**

Table 5.2.3e. Spatial and temporal variation in sediment NO_3-N (µg/g) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	160	125	100	172	190	132	95	185	**145**	**37**
M2	204	143	95	187	230	165	110	222	**170**	**50**
M3	145	120	75	168	180	130	87	180	**136**	**40**
M4	150	106	63	118	195	94	75	176	**122**	**48**
M5	72	90	68	104	56	120	96	100	**88**	**21**

Table 5.2.3f. Spatial and temporal variation in sediment exchangeable phosphorus (µg/g) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	460	403	306	432	540	390	323	492	**418**	**80**
M2	535	442	395	486	610	486	415	476	**481**	**69**
M3	385	400	367	410	426	375	337	386	**386**	**27**
M4	456	416	382	430	465	425	385	420	**422**	**30**
M5	558	485	573	486	521	470	600	560	**532**	**48**

Table 5.2.3g. Spatial and temporal variation in sediment total phosphorus (µg/g) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	1405	1140	896	1084	1306	1060	920	1100	**1114**	**174**
M2	1680	1364	1057	1125	1730	1430	1170	1160	**1340**	**258**
M3	1150	936	860	1020	1030	985	885	965	**979**	**92**
M4	1144	1013	945	976	1160	1013	925	1034	**1026**	**86**
M5	1453	1500	1842	1430	1650	1500	1760	1600	**1592**	**150**

Table 5.2.3h. Spatial and temporal variation in sediment exchangeable calcium (cmoles (+)/Kg) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	21.0	28.0	20.0	21.0	30.0	25.0	22.0	24.6	**23.95**	**3.61**
M2	23.0	22.0	16.4	20.0	23.6	20.0	18.0	23.0	**20.75**	**2.60**
M3	36.0	21.4	17.0	22.0	33.0	20.0	18.4	23.6	**23.93**	**6.89**
M4	39.0	15.0	17.0	20.0	36.0	19.0	15.0	21.0	**22.75**	**9.39**
M5	56.0	28.0	15.8	32.0	40.6	26.0	20.0	28.0	**30.80**	**12.61**

Table 5.2.3i. Spatial and temporal variation in sediment exchangeable magnesium (cmoles (+)/Kg) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	9.0	10.4	7.0	8.0	8.6	7.2	8.0	10.6	**8.60**	**1.34**
M2	10.0	9.2	6.8	8.6	9.2	8.0	7.2	9.6	**8.58**	**1.15**
M3	12.4	7.6	8.0	10.6	10.8	7.0	6.6	8.0	**8.88**	**2.10**
M4	14.0	6.4	6.8	8.0	12.4	6.0	5.6	7.0	**8.28**	**3.15**
M5	16.6	9.2	6.0	9.2	15.2	9.0	7.4	9.6	**10.28**	**3.69**

Table 5.2.3j. Spatial and temporal variation in sediment exchangeable sodium (cmoles (+)/Kg) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	0.56	0.34	0.30	0.39	0.63	0.57	0.39	0.46	**0.45**	**0.12**
M2	0.62	0.52	0.39	0.56	0.78	0.52	0.43	0.43	**0.53**	**0.13**
M3	0.47	0.47	0.34	0.30	0.52	0.43	0.39	0.54	**0.43**	**0.09**
M4	0.56	0.39	0.30	0.39	0.57	0.39	0.35	0.50	**0.43**	**0.10**
M5	1.39	1.00	0.63	0.60	1.13	0.87	0.65	0.83	**0.89**	**0.28**

Table 5.2.3k. Spatial and temporal variation in sediment exchangeable potassium (cmoles (+)/Kg) in Manasbal lake during 2004-2006

Sites	2005				2006				Mean	SD
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn		
M1	0.26	0.21	0.15	0.19	0.26	0.28	0.18	0.21	**0.22**	**0.04**
M2	0.31	0.33	0.19	0.23	0.36	0.26	0.23	0.26	**0.27**	**0.06**
M3	0.21	0.21	0.10	0.13	0.25	0.15	0.10	0.15	**0.16**	**0.05**
M4	0.28	0.18	0.13	0.18	0.23	0.21	0.15	0.20	**0.19**	**0.05**
M5	0.51	0.26	0.23	0.36	0.38	0.31	0.23	0.32	**0.32**	**0.09**

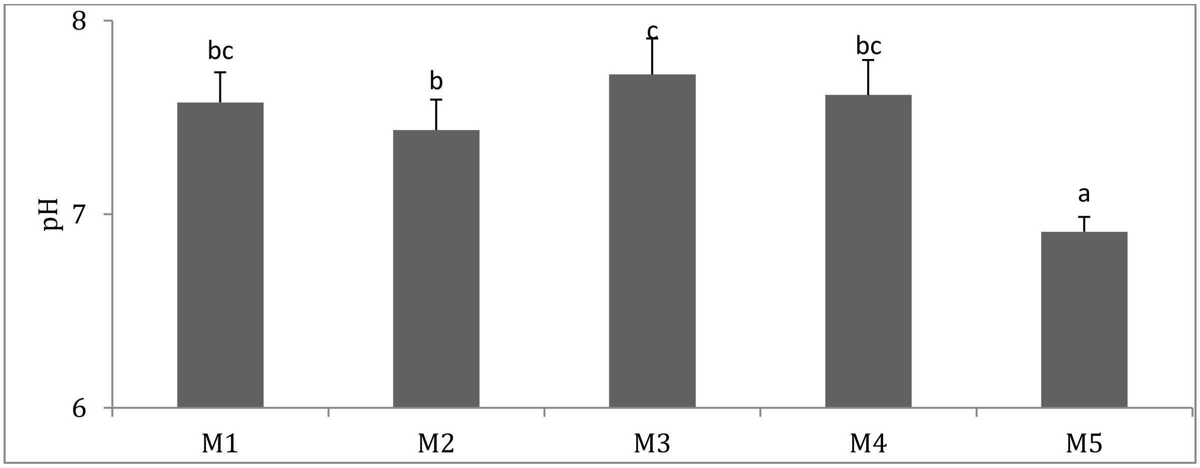


Fig. 5.2.3a. Changes in pH (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

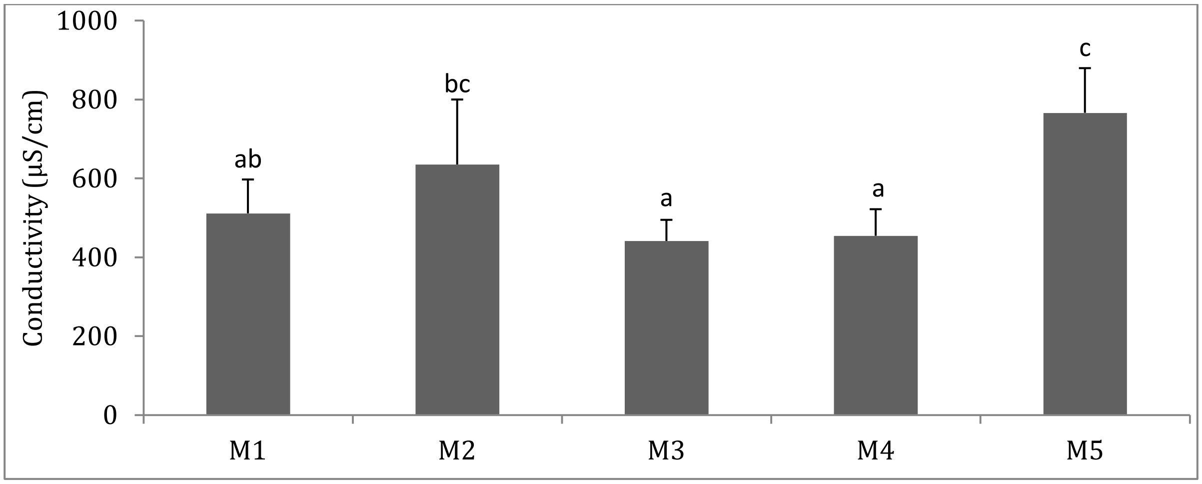


Fig. 5.2.3b. Changes in conductivity (μS/cm) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

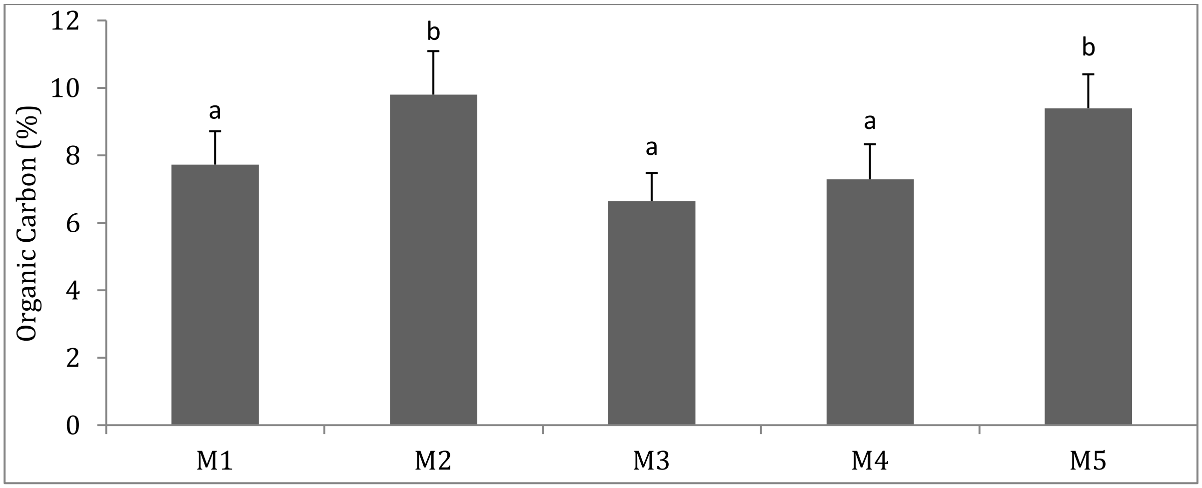


Fig. 5.2.3c$_1$. Changes in organic carbon (%) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

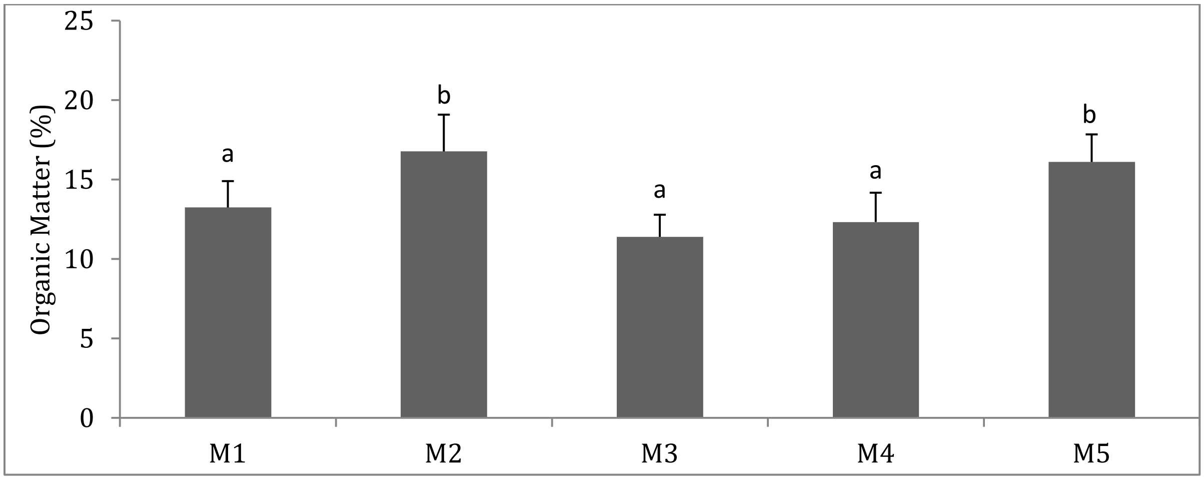


Fig. 5.2.3c$_2$. Changes in organic matter (%) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

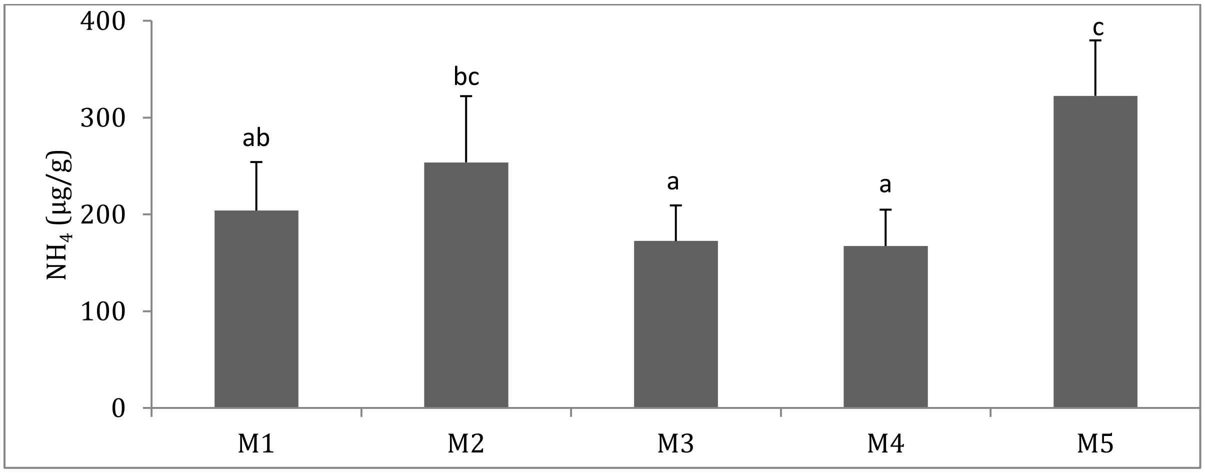


Fig. 5.2.3d. Changes in ammonia (µg/g) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

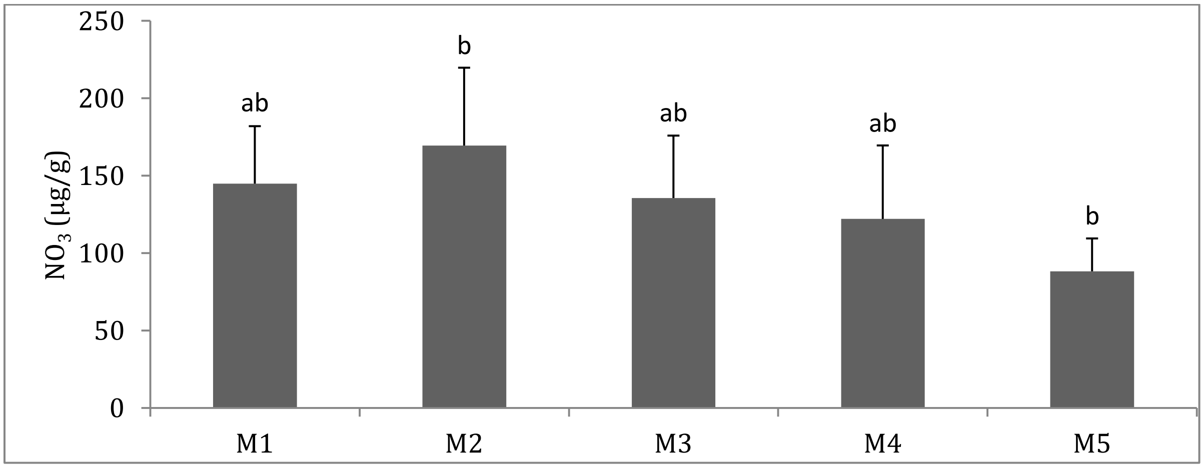


Fig. 5.2.3e. Changes in nitrate (µg/g) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

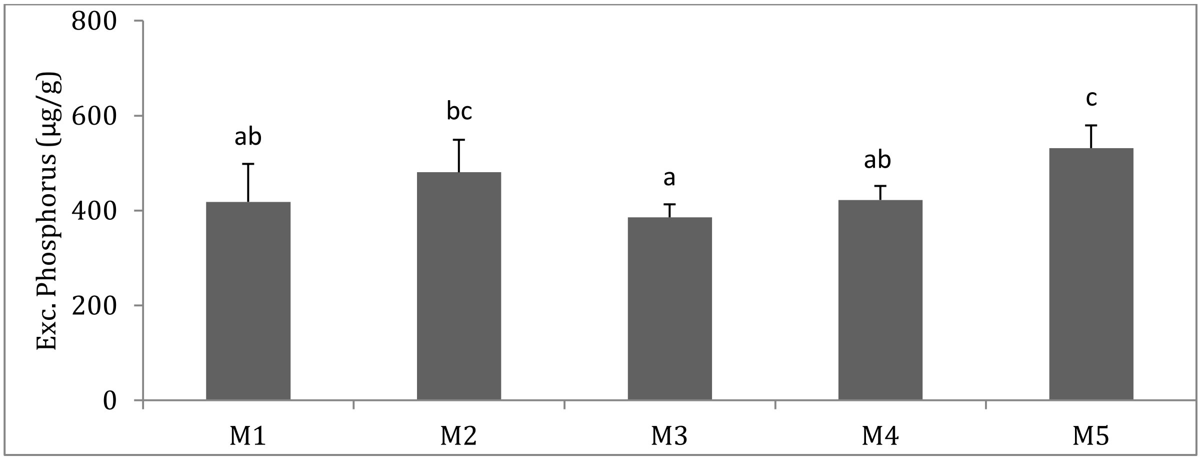


Fig. 5.2.3f. Changes in exchangeable phosphorus (µg/g) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

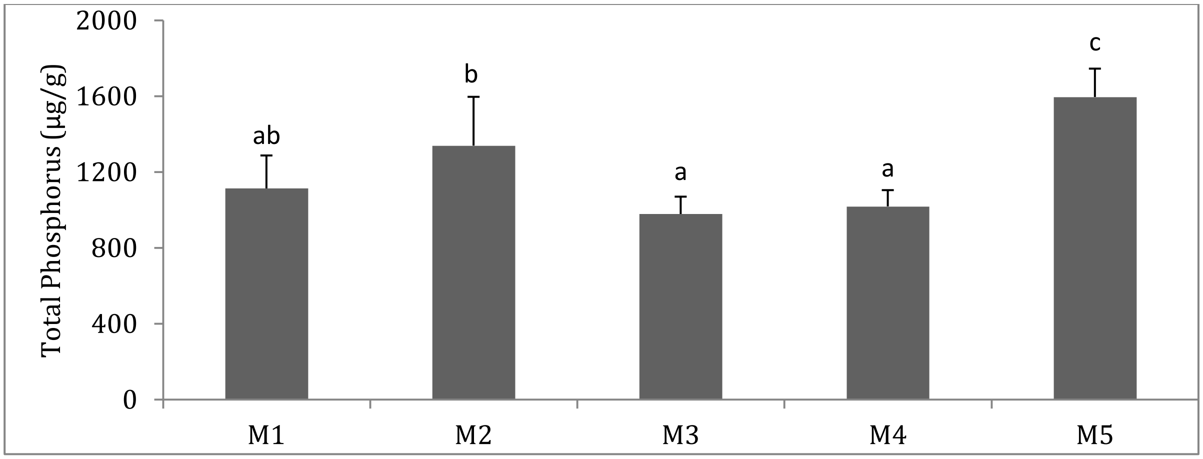


Fig. 5.2.3g. Changes in total phosphorus (µg/g) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites. (Tukey HSD)

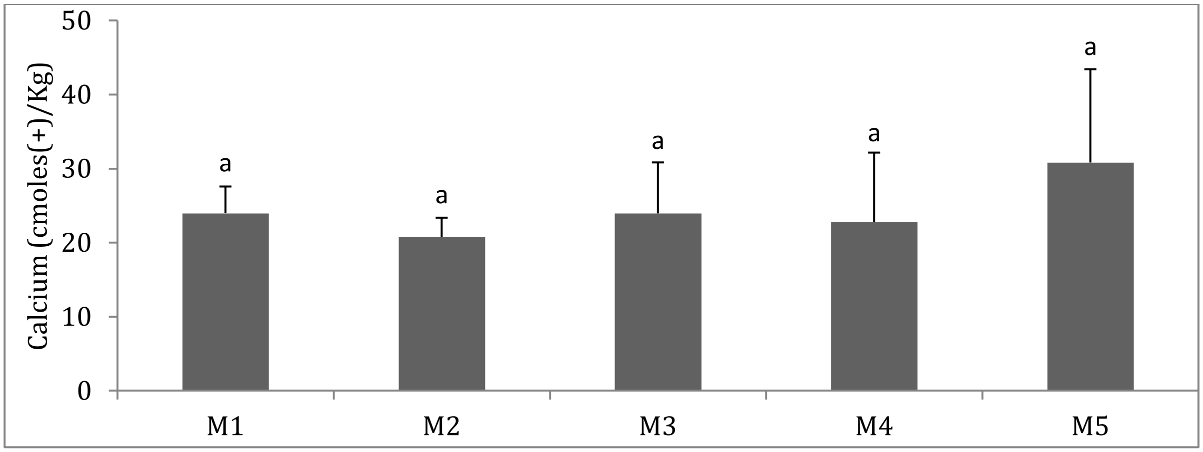


Fig. 5.2.3h. Changes in exchangeable calcium (cmoles (+)/Kg) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p< 0.001$) different between the sites (Tukey HSD).

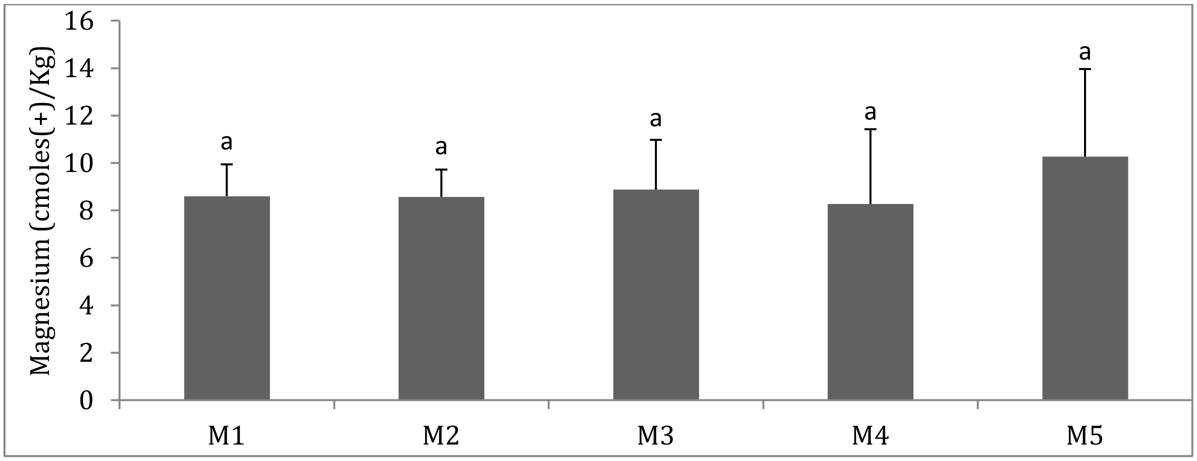


Fig. 5.2.3i. Changes in exchangeable magnesium (cmoles (+)/Kg) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

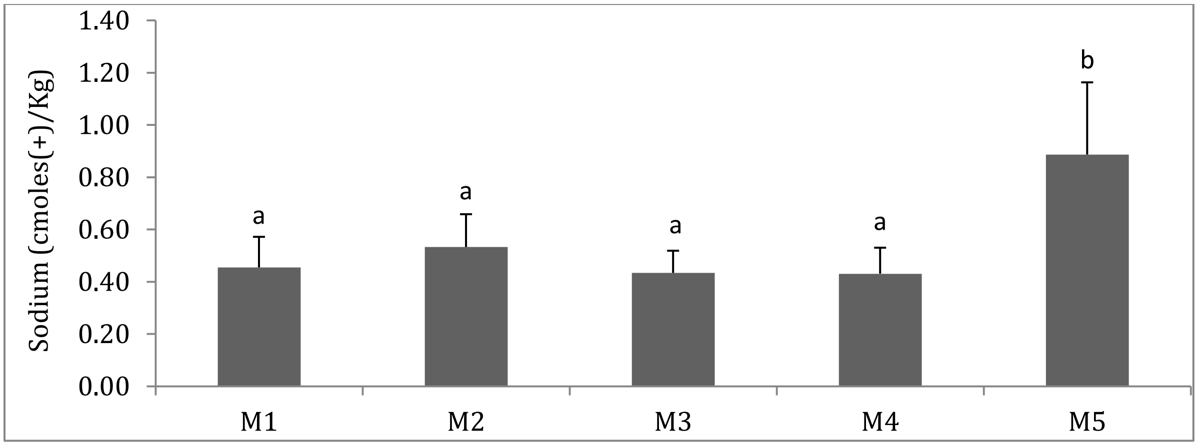


Fig. 5.2.3j. Changes in exchangeable sodium (cmoles (+)/Kg) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

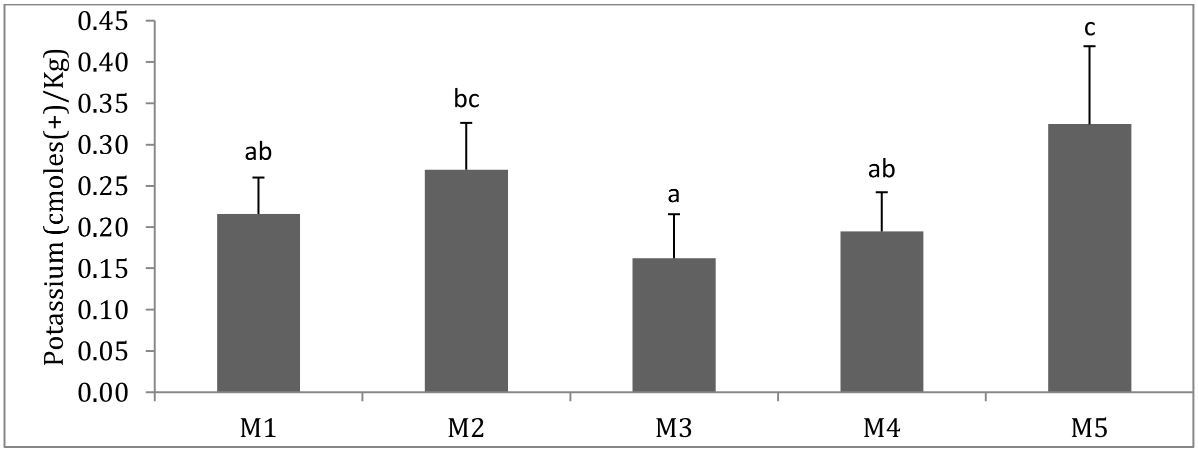


Fig. 5.2.3k. Changes in exchangeable potassium (cmoles (+)/Kg) (mean ± SD) at different study sites in Manasbal lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD).

5.3. MACROPHYTES

A survey of macrophytic vegetation revealed the presence of 38 macrophytic species, belonging to 29 genera and 23 families. The three lakes were located in different altitudinal and climatic zones. The three water bodies also differed in their salinity level, with some parts of Tso Khar being hyper-saline and devoid of any macrophytic vegetation. The Tso Morari Lake was slightly brackish and deep which with the macrophytic vegetation restricted to littoral zone only. The Manasbal Lake was typical fresh water and had a wide diversity of macrophytes. Only one macrophyte species, *Potamogeton pectinatus* was found to be present in all the three lakes

5.3.1. Tso Morari Lake

5.3.1a. Species Composition

The macrophytic community of Tso Morari was represented by mono-specific stands of submerged plant *Potamogeton pectinatus* belonging to family Potamogetonaceae. All other forms of macrophytes like free floating, emergents and rooted floating were absent in the lake. Among the study sites *P. pectinatus* was found only at TM2, TM4 and TM7 (Table 5.3.1a).

5.3.1b. Density, Frequency and Abundance

The density of *P. pectinatus* ranged from 215 to 560 indi./m^2, 340 to 886 indi./m^2 and 13 to 30 indi./m^2 at sites TM2, TM4 and TM7 respectively. Its density was highest in summer months (June, July and August) and lowest was recorded in winter months (November and December). The highest mean density was observed at site TM4 (618.9±207 indi./m^2), while lowest was recorded at site TM7 (19.6±6.3 indi./m^2) (Table 5.3.1b$_1$).

The frequency of *P. pectinatus* ranged from a minimum of 10% at site TM7 to a maximum of 100% at site TM2 and TM4 (Table 5.3.b_2). The mean frequency ranged from 30±14.7 % (TM7) to 77.8±21.5% (TM4), while the abundance varied from 17 at site TM7 to 886 at site TM4. The mean abundance was highest for site TM4 (643±188) followed by TM2 (429±119) and least abundance was recorded at site TM7 (29±10) (Table 5.3.b_3). Higher values of both frequency and abundance were recorded in summer months and least in winter months.

5.3.1c. Importance Value Index

As only one species, *P. pectinatus* was present at all the sites, the IVI values could not be calculated.

5.3.1d. Similarity and Diversity Indices

P. pectinatus showed luxuriant growth at TM2 and TM4 where fresh water enters into the lake. However, the macrophytic vegetation was absent in inlet river sites TM1 and TM2. As only one macrophytic species was recorded the similarity index was 100% between sites TM2, TM4 and TM7 (Table 5.3.c). Further, the diversity index was equal to zero, which is a characteristic of mono-species stands.

Table 5.3.1a Conspectus of growth forms at different sites in Tso Morari Lake.

Sites---->	**TM2**			**TM4**			**TM7**			**Total**		
Life forms	**F**	**G**	**S**	**F**	**G**	**S**	**F**	**G**	**S**	**F**	**G**	**S**
Emergents	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Rooted-floating	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Submerged	1	1	1	1	1	1	1	1	1	**1**	**1**	**1**
Free-Floating	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**
Total	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

F= Family; G= Genera; S= Species

Table 5.3.1b$_1$. Density of *Potamogeton pectinatus* at various study sites in Tso Morari Lake

Sites	**Oct-04**	**Dec-04**	**June-05**	**July-05**	**Oct-05**	**Dec-05**	**June-06**	**Aug-06**	**Nov-06**	**Mean**	**SD**
TM2	380	270	482	560	230	215	540	490	328	**388.2**	**134.4**
TM4	564	420	886	872	628	468	860	532	340	**618.9**	**207.5**
TM7	Ns	Ns	20	26	15	15	18	30	13	**19.6**	**6.3**

Table 5.3.1b$_2$. Frequency of *Potamogeton pectinatus* at various study sites in Tso Morari lake

Sites	**Oct-04**	**Dec-04**	**June-05**	**July-05**	**Oct-05**	**Dec-05**	**June-06**	**Aug-06**	**Nov-06**	**Mean**	**SD**
TM2	65	45	90	100	50	35	90	100	55	**70.0**	**25.2**
TM4	70	60	100	100	85	60	100	85	40	**77.8**	**21.5**
TM7	Ns	ns	35	40	20	10	45	45	15	**30.0**	**14.7**

Ns; Not Sampled

Table 5.3.1b$_3$. Abundance of *Potamogeton pectinatus* at various study sites in Tso Morari lake

Sites	Oct-04	Dec-04	June-05	July-05	Oct-05	Dec-05	June-06	Aug-06	Nov-06	Mean	SD
TM2	436	342	532	560	323	236	575	490	365	**429**	**119**
TM4	586	465	886	872	652	522	860	563	384	**643**	**188**
TM7	Ns	33	46	25	23	19	27	40	17	**29**	**10**

Ns; Not sampled

Table 5.3.1.c. Macrophytic similarity between different study sites based on Sorenson's similarity index in Tso Morari lake

Sites	TM2	TM3	TM4	TM5	TM6	TM7
TM1	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
TM2		**0%**	**100%**	**0%**	**0%**	**100%**
TM3				**0%**	**0%**	**0%**
TM4					**0%**	**100%**
TM5						**0%**
TM6						**0%**

5.3.2. Tso Khar Lake

5.3.2a. Species Composition

A total of 2 species, belonging to 2 genera of 2 families (Potamogetonaceae and Ranuncluaceae) were recorded from Lake, *P. pectinatus* and *Ranunculus aquatalis*. Both the species belonged to submerged vegetation class and were observed only at sites TK2 and TK5 (Table 5.3.2a). The macrophytic vegetation was absent at site TK1 and TK4 due to their hyper saline nature and at site TK3 which represents spring site.

5.3.2b. Density, Frequency and Abundance

The density of *P. pectinatus* ranged from 420 to 1790 indi./m^2 at site TK2 and from 780 to 1632 indi./m^2 at site TK5. However, the mean density was higher at site TK5 (1228±375 indi./m^2) than TK2 (1079±578 indi./m^2). The density of *R. aquaticus* ranged from 3 indi./m^2 at both the sites to a maximum of 25 indi./m^2 at site TK2 and 22 indi./m^2 at site TK5. The mean density of *R. aquaticus* at TK2 (13±10 indi./m^2) and TK5 (13±7 indi./m^2) did not show any significant difference. Both the species showed the highest density values in July. The lowest density was recorded in December for *P. pectinatus*, while *R. aquaticus* showed lowest density in November (Table 5.3.2b$_1$ & b$_2$).

At site TK2, frequency varied from 20% for *R. aquatalis* to 100% for *P. pectinatus*. At site TK5, lower values of frequency were again recorded for *R. aquatalis (25%)*, while *P. pectinatus* (100%) had high values of frequency. Similarly the mean frequency ranged from 45.8±16.9% to 76.7±25.6% at site TK2 and from 46±15.2% to 86±12.9% at site TK5 for *R. aquatalis* and *P. pectinatus* respectively (Table 5.3.2b$_3$ & b$_4$). The lowest abundance values were recorded for *R. aquatalis*, while highest abundance values were recorded for *P. pectinatus* at both the sites during the study period. Similarly, the mean values ranged from a minimum of 21±16 for *R. aquatalis* at site TK2 to a maximum of 1278±342 for *P. pectinatus* at site TK5 (Table 5.3.2b$_5$ & b$_6$).

5.3.2c. Importance Value Index

The highest IVI values were recorded for *P. pectinatus,* while lower IVI values were recorded for *R. aquatalis* at both the study sites. The mean IVI values ranged from 36±16 to 264±16 at site TK2 and from 30±15 to 270±15 at site TK5 for *R. aquatalis* and *P. pectinatus* respectively (Table 5.3.c$_1$ & c$_2$.)

5.3.2d. Similarity and Diversity Indices

The Sorenson's similarity index showed 100% similarity between TK2 and TK5, as macrophytic vegetation was formed by only two species and was restricted to these two sites only (Table 5.3.2d$_1$). Other sites did not show any similarity based on macrophytic vegetation. The diversity values were also generally in the lower range and ranged from 0.0 to 0.045 at site TK2 and from 0.011 to 0.309 at site TK5. However, the mean diversity values were higher at site TK5 (0.028±0.011) than site TK2 (0.025±0.014) (Table 5.3.2d$_2$).

Table 5.3.2a. Conspectus of growth forms at different sites in Tso Khar Lake

Sites----->	**TK2**			**TK5**			**Total**		
Life forms	**F**	**G**	**S**	F	**G**	**S**	**F**	**G**	**S**
Emergents	0	0	0	0	0	0	**0**	**0**	**0**
Rooted floating	0	0	0	0	6	0	**0**	**0**	**0**
Submerged	2	2	2	2	2	2	**2**	**2**	**2**
Free Floating	0	0	0	0	0	0	**0**	**0**	**0**
Total	2	2	2	2	2	2	**2**	**2**	**2**

F= Family; G= Genera; S= Species

Table 5.3.2b$_1$. Density of macrophytes at site TK2 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P. pectinatus	420	1538	1790	938	1360	430	**1079**	**578**
R. aquatalis	4	15	23	8	25	3	**13**	**10**

Table 5.3.2b$_2$. Density of macrophytes at site TK5 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P. pectinatus	ns	1238	1632	780	1560	930	**1228**	**375**
R. aquatilis	ns	10	18	12	22	3	**13**	**7**

Table 5.3.2b$_3$. Frequency of macrophytes at site TK2 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P. pectinatus	40	95	100	70	100	55	**76.7**	**25.6**
R. aquatalis	30	55	60	50	60	20	**45.8**	**16.9**

Table 5.3.2b4. Frequency of macrophytes at site TK5 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P. pectinatus	Ns	80	100	75	100	75	**86**	**12.9**
R. aquatilis	Ns	40	65	45	55	25	**46**	**15.2**

Ns; Not sampled

Table 5.3.2b$_5$. Abundance of macrophytes at site TK2 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P. pectinatus	525	1708	1790	1042	1360	477	**1150**	**569**
R. aquatalis	6.6	18.7	35	12.5	45	5	**21**	**16**

Table 5.3.2b$_6$. Abundance of macrophytes at site TK5 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P.pectinatus	ns	1345	1632	850	1560	1005	**1278**	**342**
R. aquatilis	ns	15	35.5	18	35	7	**22**	**13**

Ns; Not sampled

Table 5.3.2c$_1$. Important value index (IVI) of macrophytes at site TK2 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P. pectinatus	254.96	261.28	259.31	256.30	257.49	297.6	**264**	**16**
R. aquatalis	45.04	38.72	40.69	43.70	42.51	2.4	**36**	**16**

Table 5.3.2c$_2$. Important value index (IVI) of macrophytes at site TK5 in Tso Khar lake

Species	Oct-04	June-05	July-05	Oct-05	June-06	Nov-06	Mean	SD
P. pectinatus	ns	264.76	257.39	58.91	295.02	273.99	**270**	**15**
R. aquatalis	ns	35.24	42.61	41.09	4.98	26.01	**30**	**15**

Ns; Not sampled

Table 5.3.2d$_1$. Macrophytic similarity between different study sites based on Sorenson's similarity index in Tso Khar lake

Sites	TK2	TK3	TK4	TK5
TK1	0%	0%	0%	0%
TK2		0%	0%	**100%**
TK3			0%	0%
TK4				0%

Table 5.3.2d$_2$. Diversity (Shannon Wiener) index of species at different study sites in Tso Khar lake

Sites	Oct-04	Dec-04	June-05	July-05	Oct-05	Dec-05	June-06	Nov-06	Mean	SD
TK2	0.027	-	0.027	0.034	0.024	0	0.045	0.021	**0.025**	**0.014**
TK5	-	-	0.023	0.030	0.039	-	0.037	0.011	**0.028**	**0.011**

5.3.3. Manasbal Lake

5.3.3a. Species Composition

The macrophytic community of Manasbal Lake was represented by all the four life form-classes, i.e. belonging to emergents, rooted floating leaf type, submerged and free floating. 37 macrophytic species were recorded from this water body, which belonged to 28 genera of 22 families. A total of 29, 21, 22 and 29 species were recorded at sites M1, M2, M3 and M4 respectively (Table 5.3.3a). The minimum numbers of species were recorded during January and December and maximum number in July and August at all the study sites. The emergents, rooted floating, submerged and free floating contributed about 40.54%, 21.62%, 27.02% and 10.81% to macrophytic community respectively. Among the life forms site M1 (12) and site M4 (11) had highest number of species belonging to emergent group, while site M4 had highest number of species (10) of submerged class. The least number of species at all the sites belonged to free floating class. The emergents were represented by 15 species, namely *Alisma plantago aquatica, Carex sp, Cyperus difformis, Echinocloa crusgali, Lycopus europus, Myriophyllum verticillatum, Nasturtium officinale, Polygonum amphibium, Sium latijugum, Bidens cernua, Nasturtium sp., Sagittaria sagittifolia, Phragmites australis, Typha latifolia* and *Eleocharis palustris.* The submergeds were represented by 10 species including *Ceratophyllum demersum, Chara fragiles, Hydrilla verticillata, M. spicatum, Potamogeton crispus, P. lucens, P. pectinatus, P. perfoliatus, P. pusillus and Utricularia aurea.* The Rooted floating leaf types were represented by viz. *Hydrocharis dubia, Nelumbo nucifera, Nymphaea alba, Nymphoides peltatum, P. natans, Trapa natans,* and *Euryale ferox* and free floating include 4 species, *Lemna minor, L. major, L. triscula and Salvinia natans* belonging to 2 families and 2 genera. The maximum number of species belonged to family Potamogetonaceae,(6), followed by Lemnaceae (3) and Cyperaceae (3), while

Nymphaeaceae, Alismataceae, Poaceae, Haloragaceae, Brassicaceae and Hydrocharitaceae, were represented by 2 species each.

5.3.3b Frequency, Density and Abundance

At site M1 the highest mean frequency was reported for *C. demersum* (36.7%) followed by *N. peltatum* (23.75%), *H. vericillata (23.3%)*, *P. lucens* (22.1%), *M. spicatum* (20.8%) *and N. nucifera* (20.0%), while lowest value was obtained for *A. plantago-aquatica* (0.83%) (Table 5.3.3b_1). However, *Lemna spp.* recorded highest mean density (6.0 indi./m^2) and abundance (30.64) values followed by *C. demersum* (3.83 indi./m^2 and 8.33), *N. peltatum* (2.30 indi./m^2 and 7.98) and *H. vericillata* (1.29 indi./m^2 and 4.61). The minimum mean density (0.01 indi./m^2) and abundance (0.27) values were recorded for *A. plantago aquatic* and *C. fragile* respectively (Table 5.3.3b_{2-3}).

At site M2, the highest mean frequency value was recorded for *C demersum* (58.83) followed by *N. peltatum* (28.33), *P. pectinatus* (22.92) and *N. nucifera* (20.0), whereas lowest value of 0.42 was recorded for *E. crusgali* (Table 5.3.3b_4). The data showed that frequency of macrophytes decreased in the order of submerged > rooted floating > free floating > Emergents. The mean density values of macrophytic species fluctuated from 0.01 indi./m^2 (*E. crusgali*) to 5.65 indi./m^2 (*C. demersum*)(Table 5.3.3b_5). The highest value of density was exhibited by submerged followed by free floating, rooted floating and lowest was recorded for emergents. However, the highest mean values of abundance were recorded for *Lemna spp.* (18.67) followed by *C. demersum* (9.41), *S. natans* (5.92) and *N. peltatum* (5.58), whereas lowest value was recorded for *E. crusgali* (0.02)(Table 5.3.3b_6).

At site M3 the highest mean frequency values were observed for *M. spicatum* (32.92), *P. crispus* (29.58), *N. peltatum* (27.08), *C. demersum* (25.42) and *N. nucifera* (19.58), while lowest mean frequency value of 1.67 was reported for *H. dubia* (Table

5.3.3b$_7$). On the other hand, maximum mean annual density was obtained for *C. demersum* (2.99 indi./m^2), followed by *M. spicatum* (2.63 indi./m^2), *N. peltatum* (2.40 indi./m^2), and *Lemna spp.* (2.37 indi./m^2) and least density value of 0.03 indi./m^2 was recorded for *M. verticellatum* and *H. dubia* (Table 5.3.3b$_8$). The mean values of abundance fluctuated from 0.45 (*N. officinale*) to 10.10 (*C. demersum*). The other species with high values of abundance included *N. peltatum* (7.09), *M. spicatum* (6.95) and *P. crisps* (5.43)(Table 5.3.3b$_9$).

At site M4, the highest values of frequency were observed for *M. spicatum* (35.42) followed by *C. demersum* (25.83), *N. peltatum* (24.17), *P. crispus* and *P. natans* (22.92) and least value was observed for *N. alba* (0.83)(Table 5.3.3b$_{10}$). However, the mean density values of macrophytic species ranged from a minimum of 0.02 indi./m^2 (*N. alba*) to a maximum of 4.22 indi./m^2 (*Lemna spp.*). The other species with appreciable density include *C. demersum, N. peltatum, and M. spicatum* (Table 5.3.3b$_{11}$). The highest mean abundance values were recorded for Lemna *spp.* (16.54), *C. demersum* (12.58), *N. peltatum* (9.20), *M. spicatum* (7.75) and *P. crispus* (6.78) respectively. Whereas, *E. crusgali, C. difformis, E. palustris, P. amphibium, S. sagittifolia and N. alba* recorded less than 1.0 abundance values (Table 5.3.3b$_{12}$).

5.3.3c. Importance Value Index

On the basis of important value index (IVI), *C. demersum* was the most dominant species at all the study sites except at site M4, where *M. spicatum* was the most dominant species followed by *C. demersum*. At site M1 the other co-dominant species were *M. spicatum* (36.41), *Lemna* spp. (32.50), *H. verticillata* (29.86) and *N. peltatum* (26.68). The least dominant species having IVI values of less than 1.0 were *Carex* sp, *A. plantago aquatic, E. crusgali M. verticillatum, C. fragiles and P. pusillus* (Table 5.3.3c$_1$). Similarly, at site M2 the species with high IVI values were *P. pectinatus* (33.4), *Lemna spp.* (31.02), *N. peltatum* (29.85) and *P. crispus* (15.4), while low IVI values were recorded for *E. crusgali* (0.10), *S. sagittifolia* (0.44) and *C. difformis* (0.74) (Table 5.3.3c$_2$). At site M3, *M. spicatum* (54.6), *P. crispus* (33.6), *N. peltatum* (27.56), *P. pectinatus* (17.6) also contributed significantly to dominance values, whereas *E. crusgali, N. officinale and H. dubia* showed least dominance having IVI value of < 1.0 (Table 5.3.3c$_3$). The highest mean values of IVI at site M4 was recorded for *M. spicatum* (50.31), followed by *C. demersum* (46.19), *P. crispus* (24.47), *N. peltatum* (22.81) and *P. pectinatus* (20.61), while least IVI value of 0.12 was recorded for *Lycopus europus* (Table 5.3.3c$_4$).

5.3.3d. Similarity and Diversity Indices

The Sorenson's similarity index based on species composition generally showed good similarity between all sites except site M5, which was devoid of any macrophytic vegetation. However, the results indicate that site M1 had high degree of similarity with site M4 (71%), M3 (67%) and M2 (66%), while least degree of similarity (52%) was observed between site M2 and M4 (Table 5.3.3d$_1$). *E. crusgali, M. verticillatum, P. amphibium, H. dubia, N. nucifera, N. peltatum, C. demersum, M. spicatum, P. crispus, P. lucens, P. pectinatus, L. minor, L. major and S. natans* were common at all the four sites. The number of species common to any two sites was 10, and for any three sites were 7. Whereas, *L. triscula, U. aurea, P. perfoliatus, T. latifolia and N. alba* were restricted in their distribution, being present at only one site.

Species diversity ranged from a minimum of 0.41 at site M3 in February to a maximum of 2.65 at site M4 in September. All the sites showed low species diversity in winter months and high in summer months. The mean annual diversity was highest at site M4 (2.14±0.55) and lowest at site M2 (1.53± 0.59) (Table 5.3.3d$_2$).

Table 5.3.3a. Conspectus of growth forms at different sites in Manasbal Lake

Sites---->	**M1**			**M2**			**M3**			**M4**			**Total**		
Life forms	**F**	**G**	**S**	**F**	**G**	**S**	**F**	**G**	**S**	**F**	**G**	**S**	**F**	**G**	**S**
Emergents	9	11	12	8	8	8	6	7	8	8	11	11	**10**	**10**	**15**
Rooted floating	7	7	7	6	6	6	6	6	6	6	6	6	**7**	**8**	**8**
Submerged	5	5	8	3	3	5	4	4	7	6	6	10	**4**	**6**	**10**
Free Floating	2	2	3	2	2	3	2	2	3	2	2	4	**2**	**2**	**4**
Total	**20**	**23**	**30**	**17**	**18**	**22**	**15**	**18**	**24**	**20**	**24**	**31**	**22**	**28**	**37**

F= Family; G= Genera; S= Species

Table 5.3.3b$_1$. Monthly variations in frequency of macrophyte species at site I in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	5.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	**0.83**	**1.9**
2	*Bidens cernua*	0.0	0.0	0.0	5.0	0.0	5.0	0.0	10.0	0.0	0.0	5.0	0.0	**2.08**	**3.3**
3	*Carex sp.*	0.0	0.0	0.0	0.0	0.0	5.0	0.0	10.0	0.0	0.0	0.0	0.0	**1.25**	**3.1**
4	*Cyperus difformis*	0.0	0.0	0.0	5.0	0.0	10.0	0.0	15.0	0.0	0.0	5.0	0.0	**2.92**	**5.0**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	15.0	0.0	0.0	0.0	**1.67**	**4.4**
6	*Eleocharis palustris*	0.0	0.0	0.0	10.0	0.0	0.0	15.0	0.0	10.0	5.00	0.0	0.0	**3.33**	**5.4**
7	*Lycopus europus*	0.0	0.0	0.0	10.0	0.0	0.0	15.0	0.0	10.0	10.0	0.0	0.0	**3.75**	**5.7**
8	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	5.0	0.0	**1.25**	**3.1**
9	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	10.0	10.0	20.0	15.0	0.0	0.0	0.0	**4.58**	**7.2**
10	*Nasturtium sp.*	0.0	5.0	0.0	10.0	15.0	10.0	20.0	20.0	15.0	10.0	0.0	5.0	**9.17**	**7.3**
11	*Polygonum amphibium*	0.0	0.0	0.0	5.0	0.0	0.0	5.0	0.0	10.0	0.0	0.0	0.0	**1.67**	**3.3**
12	*Sium latijugum*	0.0	0.0	0.0	0.0	5.0	10.0	25.0	15.0	15.0	15.0	0.0	0.0	**7.08**	**8.6**
Rooted floating															
13	*Euryale ferox*	0.0	0.0	0.0	0.0	10.0	25.0	35.0	40.0	25.0	15.0	0.0	0.0	**12.50**	**15.2**
14	*Marsilia quadrifolia*	0.0	0.0	0.0	5.0	0.0	10.0	0.0	15.0	0.0	0.0	0.0	0.0	**2.50**	**5.0**
15	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	5.0	0.0	25.0	0.0	25.0	0.0	0.0	0.0	**4.58**	**9.6**
16	*Nelumbo nucifera*	0.0	0.0	0.0	10.0	15.0	25.0	40.0	45.0	45.0	35.0	25.0	0.0	**20.00**	**18.2**
17	*Nymphoides peltatum*	0.0	0.0	5.0	15.0	20.0	35.0	45.0	50.0	45.0	40.0	30.0	0.0	**23.75**	**19.4**
18	*Potamogeton natans*	0.0	0.0	0.0	0.0	5.0	15.0	35.0	40.0	15.0	0.0	15.0	0.0	**10.42**	**14.2**
19	*Trapa natans*	0.0	0.0	0.0	0.0	0.0	15.0	20.0	30.0	20.0	10.0	0.0	0.0	**7.92**	**10.8**
Submerged															
20	*Ceratophyllum demersum*	10.0	15.0	10.0	15.0	25.0	40.0	50.0	80.0	80.0	60.0	45.0	10.0	**36.7**	**26.6**
21	*Chara fragiles*	0.0	0.0	0.0	0.0	0.0	5.0	5.0	0.0	10.0	0.0	0.0	0.0	**1.7**	**3.3**
22	*Hydrilla verticillata*	0.0	10.0	15.0	20.0	25.0	35.0	40.0	45.0	40.0	25.0	25.0	0.0	**23.3**	**15.1**
23	*Myriophyllum spicatum*	10.0	10.0	20.0	0.0	10.0	40.0	40.0	45.0	45.0	20.0	0.0	10.0	**20.8**	**17.2**
24	*Potamogeton crispus*	0.0	5.0	0.0	10.0	10.0	15.0	25.0	40.0	35.0	30.0	20.0	0.0	**15.8**	**14.1**
25	*Potamogeton lucens*	5.0	5.0	0.0	15.0	20.0	40.0	45.0	40.0	40.0	35.0	20.0	0.0	**22.1**	**17.2**
26	*Potamogeton pectinatus*	5.0	0.0	5.0	5.0	15.0	15.0	15.0	25.0	30.0	20.0	10.0	0.0	**12.1**	**9.6**
27	*Potamogeton pucilus*	0.0	0.0	0.0	0.0	0.0	10.0	0.0	10.0	0.0	0.0	0.0	0.0	**1.7**	**3.9**
Free floating															
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	30.0	40.0	20.0	25.0	25.0	35.0	0.0	**14.58**	**16.0**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.0	20.0	30.0	25.0	35.0	10.0	0.0	**10.00**	**13.7**

Table 5.3.3b$_2$. Monthly variations in density of macrophyte species at site I in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
	Emergents														
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	**0.01**	**0.03**
2	*Bidens cernua*	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.3	0.0	0.0	0.1	0.0	**0.05**	**0.09**
3	*Carex sp.*	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	**0.03**	**0.06**
4	*Cyperus difformis*	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.2	0.0	0.0	0.1	0.0	**0.05**	**0.08**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	**0.03**	**0.07**
6	*Eleocharis palustris*	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	**0.04**	**0.08**
7	*Lycopus europus*	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.2	0.1	0.0	0.0	**0.05**	**0.09**
8	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	**0.02**	**0.04**
9	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	0.5	0.6	0.8	0.6	0.0	0.0	0.0	**0.21**	**0.31**
10	*Nasturtium sp.*	0.0	0.1	0.0	0.3	0.4	0.3	0.8	0.8	0.5	0.3	0.0	0.1	**0.30**	**0.29**
11	*Polygonum amphibium*	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	**0.04**	**0.08**
12	*Sium latijugum*	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.6	0.8	0.6	0.0	0.0	**0.25**	**0.28**
	Rooted floating-leaf type														
13	*Euryale ferox*	0.0	0.0	0.0	0.0	0.3	0.6	0.8	1.4	0.9	0.7	0.0	0.0	**0.39**	**0.48**
14	*Marsilia quadrifolia*	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.3	0.0	0.0	0.0	0.0	**0.05**	**0.10**
15	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.8	0.0	0.0	0.0	**0.11**	**0.25**
16	*Nelumbo nucifera*	0.0	0.0	0.0	0.2	0.3	0.5	0.6	1.8	3.5	2.8	0.4	0.0	**0.84**	**1.19**
17	*Nymphoides peltatum*	0.0	0.0	0.1	0.8	1.3	2.0	4.6	6.0	8.0	3.0	1.8	0.0	**2.30**	**2.63**
18	*Potamogeton natans*	0.0	0.0	0.0	0.0	0.2	0.4	0.8	1.6	0.6	0.0	0.4	0.0	**0.33**	**0.48**
19	*Trapa natans*	0.0	0.0	0.0	0.0	0.0	0.5	0.7	1.3	1.6	0.4	0.0	0.0	**0.38**	**0.56**
	Submerged														
20	*Ceratophyllum demersum*	0.2	0.3	0.2	0.4	2.2	4.0	5.8	10.0	14.5	5.0	3.0	0.3	**3.83**	**4.51**
21	*Chara fragiles*	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	**0.03**	**0.05**
22	*Hydrilla verticillata*	0.0	0.2	0.2	0.3	0.5	0.7	3.2	3.5	3.6	2.0	1.0	0.3	**1.29**	**1.39**
23	*Myriophyllum spicatum*	0.3	0.2	0.4	0.0	0.8	0.8	1.0	1.5	2.7	1.4	0.0	0.5	**0.80**	**0.78**
24	*Potamogeton crispus*	0.0	0.0	0.0	0.1	0.2	0.4	0.6	1.8	1.2	0.9	0.2	0.0	**0.45**	**0.58**
25	*Potamogeton lucens*	0.1	0.0	0.0	0.2	1.3	2.5	1.4	2.0	2.6	1.0	0.5	0.2	**0.98**	**0.97**
26	*Potamogeton pectinatus*	0.2	0.0	0.0	0.1	0.2	0.4	0.6	0.3	1.6	0.6	0.3	0.0	**0.36**	**0.44**
27	*Potamogeton pucilus*	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	**0.03**	**0.06**
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	2.0	15.0	6.0	35.0	10.0	4.0	0.0	**6.00**	**10.33**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.0	4.0	3.0	0.6	0.0	**0.84**	**1.39**

Table 5.3.3b$_3$. Monthly variations in abundance of macrophyte species at site I in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	1.5	0.0	2.3	0.0	0.0	0.0	0.0	0.0	**0.32**	**0.8**
2	*Bidens cernua*	0.0	0.0	0.0	1.3	0.0	2.0	0.0	3.4	0.0	0.0	1.0	0.0	**0.64**	**1.1**
3	*Carex sp.*	0.0	0.0	0.0	0.0	0.0	2.3	0.0	3.5	0.0	0.0	0.0	0.0	**0.48**	**1.2**
4	*Cyperus difformis*	0.0	0.0	0.0	1.3	0.0	1.2	0.0	2.0	0.0	0.0	2.0	0.0	**0.54**	**0.8**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	2.0	0.0	0.0	0.0	**0.42**	**1.0**
6	*Eleocharis palustris*	0.0	0.0	0.0	2.4	0.0	0.0	3.5	0.0	1.3	0.0	0.0	0.0	**0.60**	**1.2**
7	*Lycopus europus*	0.0	0.0	0.0	1.5	0.0	0.0	2.6	0.0	3.0	2.5	0.0	0.0	**0.80**	**1.2**
8	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	1.0	0.0	**0.30**	**0.8**
9	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	8.2	4.5	6.0	3.7	0.0	0.0	0.0	**1.87**	**2.9**
10	*Nasturtium sp.*	0.0	1.3	0.0	3.4	5.6	5.0	6.3	6.5	6.0	3.0	0.0	1.3	**3.20**	**2.6**
11	*Polygonum amphibium*	0.0	0.0	0.0	2.2	0.0	0.0	2.0	0.0	3.3	0.0	0.0	0.0	**0.63**	**1.2**
12	*Sium latijugum*	0.0	0.0	0.0	0.0	2.5	2.0	3.6	5.3	8.0	5.6	0.0	0.0	**2.25**	**2.8**
Rooted floating-leaf type															
13	*Euryale ferox*	0.0	0.0	0.0	0.0	2.0	3.0	4.0	6.2	5.8	4.0	0.0	0.0	**2.08**	**2.4**
14	*Marsilia quadrifolia*	0.0	0.0	0.0	4.0	0.0	11.0	0.0	14.4	0.0	0.0	0.0	0.0	**2.45**	**5.0**
15	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	2.0	0.0	3.0	0.0	5.0	0.0	0.0	0.0	**0.83**	**1.6**
16	*Nelumbo nucifera*	0.0	0.0	0.0	3.2	3.0	2.0	1.6	3.4	10.0	13.0	2.0	0.0	**3.18**	**4.1**
17	*Nymphoides peltatum*	0.0	0.0	3.0	7.0	10.0	7.3	11.5	15.0	22.0	14.0	6.0	0.0	**7.98**	**6.9**
18	*Potamogeton natans*	0.0	0.0	0.0	0.0	2.7	4.5	3.0	5.6	4.6	0.0	2.5	0.0	**1.91**	**2.2**
19	*Trapa natans*	0.0	0.0	0.0	0.0	0.0	2.8	5.0	6.5	8.0	5.0	0.0	0.0	**2.28**	**3.0**
Submerged															
20	*Ceratophyllum demersum*	2.3	3.0	3.0	5.0	9.0	13.0	10.5	14.0	18.3	10.0	7.5	4.4	**8.33**	**5.1**
21	*Chara fragiles*	0.0	0.0	0.0	0.0	0.0	1.0	1.2	0.0	1.0	0.0	0.0	0.0	**0.27**	**0.5**
22	*Hydrilla verticillata*	0.0	1.2	1.5	2.4	2.0	3.0	6.0	12.2	11.0	7.0	6.0	3.0	**4.61**	**3.9**
23	*Myriophyllum spicatum*	2.0	2.0	3.0	0.0	4.0	3.5	2.6	4.0	10.0	7.0	0.0	2.2	**3.36**	**2.8**
24	*Potamogeton crispus*	0.0	1.0	0.0	1.5	2.3	3.3	3.0	4.5	3.8	2.5	2.0	0.0	**1.99**	**1.5**
25	*Potamogeton lucens*	1.0	1.2	1.5	2.5	4.6	7.3	5.0	6.0	8.0	3.8	3.2	2.0	**3.84**	**2.4**
26	*Potamogeton pectinatus*	1.3	0.0	1.0	2.6	3.0	3.0	3.5	2.0	5.0	3.5	2.0	0.0	**2.24**	**1.5**
27	*Potamogeton pucilus*	0.0	0.0	0.0	0.0	0.0	2.0	2.5	0.0	0.0	0.0	0.0	0.0	**0.38**	**0.9**
Free-floating															
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	10.0	35.0	22.7	220.0	65.0	15.0	0.0	**30.64**	**62.8**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.0	7.0	12.0	11.0	15.0	5.0	0.0	**4.17**	**5.7**

Table 5.3.3b$_4$. Monthly variations in frequency of macrophyte species at site II in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Bidens cernua*	0.0	0.0	0.0	0.0	5.0	0.0	10.0	0.0	10.0	5.0	0.0	0.0	**2.50**	**4.0**
2	*Cyperus difformis*	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	10.0	0.0	0.0	0.0	**1.25**	**3.1**
3	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	**0.42**	**1.4**
4	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	5.0	0.0	15.0	10.0	5.0	5.0	0.0	**3.33**	**4.9**
5	*Nasturtium sp.*	0.0	0.0	0.0	5.0	0.0	10.0	0.0	0.0	15.0	0.0	0.0	0.0	**2.50**	**5.0**
6	*Polygonum amphibium*	0.0	0.0	0.0	0.0	10.0	0.0	15.0	0.0	0.0	10.0	0.0	0.0	**2.92**	**5.4**
7	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	5.0	0.0	0.0	0.0	**1.25**	**3.1**
8	*Sium latijugum*	0.0	0.0	0.0	5.0	15.0	10.0	0.0	10.0	0.0	0.0	0.0	0.0	**3.33**	**5.4**
Rooted floating-leaf type															
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	15.0	20.0	35.0	20.0	0.0	0.0	0.0	**7.50**	**12.0**
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	5.0	10.0	25.0	30.0	30.0	20.0	10.0	0.0	**10.83**	**12.2**
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	30.0	40.0	35.0	50.0	55.0	30.0	0.0	0.0	**20.00**	**22.1**
12	*Nymphoides peltatum*	0.0	0.0	10.0	25.0	40.0	45.0	40.0	55.0	50.0	40.0	35.0	0.0	**28.33**	**20.6**
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	0.0	15.0	15.0	20.0	0.0	30.0	10.0	0.0	**7.50**	**10.3**
14	*Trapa natans*	0.0	0.0	0.0	0.0	10.0	0.0	20.0	35.0	30.0	20.0	10.0	0.0	**10.42**	**12.9**
Submerged															
15	*Ceratophyllum demersum*	20.0	20.0	40.0	50.0	50.0	65.0	80.0	85.0	65.0	55.0	50.0	30.0	**50.83**	**21.1**
16	*Myriophyllum spicatum*	0.0	5.0	0.0	5.0	20.0	15.0	20.0	25.0	20.0	15.0	0.0	5.0	**10.83**	**9.3**
17	*Potamogeton crispus*	10.0	5.0	0.0	5.0	15.0	15.0	0.0	20.0	30.0	25.0	15.0	0.0	**11.67**	**10.1**
18	*Potamogeton lucens*	0.0	0.0	10.0	0.0	15.0	20.0	30.0	40.0	15.0	25.0	20.0	0.0	**14.58**	**13.2**
19	*Potamogeton pectinatus*	10.0	10.0	20.0	15.0	25.0	10.0	30.0	55.0	45.0	25.0	20.0	10.0	**22.92**	**14.5**
Free-floating															
20	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	25.0	40.0	45.0	30.0	35.0	20.0	0.0	**16.25**	**18.1**
21	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	25.0	35.0	35.0	45.0	35.0	10.0	0.0	**15.42**	**18.0**

Table 5.3.3b$_{5.}$ Monthly variations in density of macrophyte species at site II in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Bidens cernua*	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.1	0.0	0.0	**0.04**	**0.08**
2	*Cyperus difformis*	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	**0.03**	**0.06**
3	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	**0.01**	**0.03**
4	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.3	0.2	0.1	0.0	**0.08**	**0.12**
5	*Nasturtium sp.*	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.3	0.0	0.0	0.0	**0.05**	**0.10**
6	*Polygonum amphibium*	0.0	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.3	0.0	0.0	**0.07**	**0.14**
7	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	**0.02**	**0.06**
8	*Sium latijugum*	0.0	0.0	0.0	0.1	0.5	0.4	0.0	0.6	0.0	0.0	0.0	0.0	**0.14**	**0.23**
Rooted floating-leaf type															
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	0.5	0.8	1.3	0.7	0.0	0.0	0.0	**0.28**	**0.45**
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.2	0.2	0.4	0.9	0.7	0.4	0.3	0.0	**0.26**	**0.30**
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	0.5	1.0	1.4	2.3	3.0	2.0	0.0	0.0	**0.85**	**1.08**
12	*Nymphoides peltatum*	0.0	0.0	0.5	0.6	1.7	2.0	4.6	7.2	4.6	4.0	1.3	0.0	**2.21**	**2.35**
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.5	0.0	0.8	0.3	0.0	**0.23**	**0.30**
14	*Trapa natans*	0.0	0.0	0.0	0.0	0.2	0.4	0.0	1.4	1.4	0.5	0.2	0.0	**0.35**	**0.52**
Submerged															
15	*Ceratophyllum demersum*	1.0	1.3	1.6	3.3	5.0	7.7	12.6	13.2	8.5	7.0	3.6	3.0	**5.65**	**4.19**
16	*Myriophyllum spicatum*	0.0	0.0	0.0	0.0	0.7	1.5	0.6	1.0	2.0	1.5	0.0	0.1	**0.62**	**0.73**
17	*Potamogeton crispus*	0.1	0.0	0.0	0.1	0.1	0.3	0.0	0.5	0.9	0.4	0.3	0.0	**0.23**	**0.27**
18	*Potamogeton lucens*	0.0	0.0	0.1	0.0	0.6	0.6	0.7	0.8	0.5	0.6	0.3	0.0	**0.35**	**0.31**
19	*Potamogeton pectinatus*	0.2	0.3	0.4	0.2	0.7	0.6	1.0	4.0	4.5	1.0	0.4	0.4	**1.14**	**1.48**
Free-floating															
20	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	2.0	8.0	14.0	22.0	8.0	2.0	0.0	**4.67**	**7.10**
21	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.5	0.8	8.0	4.0	4.0	1.0	0.0	**1.53**	**2.52**

Table 5.3.3b$_{6.}$ Monthly variations in abundance of macrophyte species at site II in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Bidens cernua*	0.0	0.0	0.0	0.0	1.0	0.0	1.8	0.0	2.2	2.6	0.0	0.0	**0.63**	**1.0**
2	*Cyperus difformis*	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	2.3	0.0	0.0	0.0	**0.48**	**1.1**
3	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	**0.02**	**0.1**
4	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	2.3	0.0	4.0	3.2	2.6	1.5	0.0	**1.13**	**1.5**
5	*Nasturtium sp.*	0.0	0.0	0.0	1.2	0.0	2.0	0.0	0.0	3.0	0.0	0.0	0.0	**0.52**	**1.0**
6	*Polygonum amphibium*	0.0	0.0	0.0	0.0	1.0	0.0	2.4	0.0	0.0	2.0	0.0	0.0	**0.45**	**0.9**
7	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.0	0.0	0.0	0.0	**0.27**	**0.7**
8	*Sium latijugum*	0.0	0.0	0.0	2.3	4.0	5.0	0.0	5.6	0.0	0.0	0.0	0.0	**1.41**	**2.2**
Rooted floating-leaf type															
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	2.4	4.0	4.4	2.0	0.0	0.0	0.0	**1.07**	**1.7**
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	2.0	2.0	3.0	3.4	2.6	3.0	2.0	0.0	**1.50**	**1.4**
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	1.0	4.0	3.0	4.2	6.0	7.0	0.0	0.0	**2.10**	**2.6**
12	*Nymphoides peltatum*	0.0	0.0	2.0	4.0	6.0	5.6	12.0	16.4	9.0	8.0	4.0	0.0	**5.58**	**5.1**
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	0.0	4.0	5.5	3.8	0.0	4.0	3.0	0.0	**1.69**	**2.2**
14	*Trapa natans*	0.0	0.0	0.0	0.0	0.0	2.0	7.0	6.0	3.0	3.6	2.0	0.0	**1.97**	**2.5**
Submerged															
15	*Ceratophyllum demersum*	2.0	2.3	4.0	7.0	10.0	13.0	16.0	18.0	13.6	13.0	9.0	5.0	**9.41**	**5.4**
16	*Myriophyllum spicatum*	0.0	1.0	0.0	0.0	3.0	7.0	4.0	8.0	7.0	6.0	0.0	1.4	**3.12**	**3.2**
17	*Potamogeton crispus*	1.3	1.2	0.0	2.0	2.5	2.0	3.6	4.0	3.3	3.0	4.0	0.0	**2.24**	**1.4**
18	*Potamogeton lucens*	0.0	0.0	1.0	0.0	4.0	6.0	3.6	2.0	4.0	4.0	2.0	0.0	**2.22**	**2.1**
19	*Potamogeton pectinatus*	1.2	1.3	1.0	1.7	3.0	5.0	4.0	8.0	7.0	5.0	3.0	2.0	**3.52**	**2.3**
Free-floating															
20	*Lemna spp.*	0.0	0.0	0.0	0.0	3.0	8.0	15.0	30.0	105.0	50.0	13.0	0.0	**18.67**	**31.2**
21	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	4.0	4.0	12.0	15.0	32.0	4.0	0.0	**5.92**	**9.6**

Table 5.3.3b$_7$. Monthly variations in frequency of macrophyte species at site III in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Carex sp.*	0.0	0.0	0.0	0.0	5.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	**1.25**	**3.1**
2	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	5.0	0.0	20.0	0.0	0.0	0.0	0.0	**2.08**	**5.8**
3	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	5.0	0.0	20.0	0.0	15.0	0.0	0.0	0.0	**3.33**	**6.9**
4	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	15.0	0.0	10.0	0.0	0.0	0.0	0.0	**2.08**	**5.0**
5	*Nasturtium sp.*	0.0	0.0	5.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	**1.25**	**3.1**
6	*Phragmites australis*	0.0	0.0	25.0	30.0	20.0	30.0	35.0	35.0	35.0	0.0	20.0	0.0	**19.17**	**15.1**
7	*Polygonum amphibium*	0.0	0.0	0.0	0.0	10.0	0.0	15.0	0.0	0.0	0.0	0.0	0.0	**2.08**	**5.0**
8	*Typha latifolia*	0.0	0.0	0.0	15.0	0.0	20.0	25.0	0.0	20.0	20.0	15.0	0.0	**9.58**	**10.3**
Rooted floating-leaf type															
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	5.0	15.0	40.0	30.0	15.0	10.0	0.0	**9.58**	**13.4**
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	5.0	15.0	0.0	0.0	0.0	0.0	**1.67**	**4.4**
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	20.0	30.0	40.0	45.0	40.0	40.0	20.0	0.0	**19.58**	**18.9**
12	*Nymphoides peltatum*	0.0	0.0	15.0	25.0	35.0	40.0	50.0	45.0	45.0	40.0	30.0	0.0	**27.08**	**18.9**
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	15.0	20.0	0.0	20.0	25.0	20.0	0.0	0.0	**8.33**	**10.5**
14	*Trapa natans*	0.0	0.0	0.0	0.0	0.0	15.0	35.0	40.0	50.0	35.0	20.0	0.0	**16.25**	**19.1**
Submerged															
15	*Ceratophyllum demersum*	10.0	15.0	10.0	10.0	20.0	25.0	40.0	40.0	35.0	40.0	35.0	25.0	**25.42**	**12.3**
16	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	5.0	10.0	20.0	35.0	25.0	30.0	20.0	10.0	**12.92**	**12.7**
17	*Myriophyllum spicatum*	5.0	10.0	25.0	40.0	45.0	50.0	50.0	55.0	40.0	35.0	30.0	10.0	**32.92**	**17.1**
18	*Potamogeton crispus*	0.0	5.0	25.0	40.0	35.0	55.0	50.0	45.0	40.0	20.0	25.0	15.0	**29.58**	**17.5**
19	*Potamogeton lucens*	0.0	0.0	0.0	0.0	35.0	25.0	30.0	20.0	15.0	20.0	0.0	0.0	**12.08**	**13.6**
20	*Potamogeton pectinatus*	10.0	0.0	0.0	15.0	20.0	40.0	30.0	40.0	35.0	30.0	0.0	0.0	**18.33**	**16.3**
21	*Potamogeton pucilus*	0.0	0.0	0.0	5.0	0.0	0.0	10.0	0.0	15.0	0.0	0.0	0.0	**2.50**	**5.0**
Free-floating															
22	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	0.0	10.0	25.0	20.0	20.0	5.0	0.0	**6.67**	**9.6**
23	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	5.0	5.0	15.0	10.0	15.0	5.0	0.0	**4.58**	**5.8**

Table 5.3.3b$_{8.}$ Monthly variations in density of macrophyte species at site III in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Carex sp.*	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.0	0.0	**0.03**	**0.1**
2	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.0	0.0	0.0	0.0	**0.05**	**0.1**
3	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.1	0.0	0.0	0.0	**0.03**	**0.1**
4	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	**0.04**	**0.1**
5	*Nasturtium sp.*	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	**0.03**	**0.1**
6	*Phragmites australis*	0.0	0.0	0.4	0.7	2.1	1.3	2.0	3.6	3.0	0.0	2.0	0.0	**1.26**	**1.3**
7	*Polygonum amphibium*	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	**0.04**	**0.1**
8	*Typha latifolia*	0.0	0.0	0.0	0.4	0.0	1.0	1.6	2.0	0.0	0.6	0.2	0.0	**0.48**	**0.7**
Rooted floating-leaf type															
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.7	1.5	0.2	0.0	0.0	**0.26**	**0.5**
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	**0.03**	**0.1**
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	0.4	0.6	1.4	2.0	4.0	2.0	0.4	0.0	**0.90**	**1.2**
12	*Nymphoides peltatum*	0.0	0.0	0.6	1.6	2.0	3.6	4.0	4.0	9.0	3.0	1.0	0.0	**2.40**	**2.6**
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	0.3	0.0	0.7	0.8	0.5	0.3	0.0	0.0	**0.22**	**0.3**
14	*Trapa natans*	0.0	0.0	0.0	0.0	0.2	0.8	2.0	5.0	4.0	2.0	1.0	0.0	**1.25**	**1.7**
Submerged															
15	*Ceratophyllum demersum*	0.3	0.2	0.4	1.0	3.0	3.2	5.0	8.2	4.0	4.8	3.5	2.3	**2.99**	**2.4**
16	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	0.1	0.3	1.0	2.0	2.0	1.6	1.0	0.5	**0.71**	**0.8**
17	*Myriophyllum spicatum*	0.0	1.2	1.0	2.3	4.6	6.0	7.0	3.0	2.4	2.0	1.0	1.0	**2.63**	**2.2**
18	*Potamogeton crispus*	0.0	0.0	0.8	1.5	2.0	3.4	4.0	3.0	2.5	1.4	1.3	1.2	**1.76**	**1.3**
19	*Potamogeton lucens*	0.0	0.0	0.0	0.0	1.5	1.0	1.2	0.8	0.8	0.4	0.0	0.0	**0.48**	**0.6**
20	*Potamogeton pectinatus*	0.4	0.0	0.0	0.6	2.0	2.0	1.4	1.7	3.0	1.0	0.0	0.0	**1.01**	**1.0**
21	*Potamogeton pucilus*	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.4	0.0	0.0	0.0	**0.06**	**0.1**
Free-floating															
22	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	0.0	0.4	6.0	15.0	4.0	3.0	0.0	**2.37**	**4.5**
23	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.1	0.8	3.0	4.0	2.8	0.5	0.0	**0.93**	**1.5**

Table 5.3.3b$_9$. Monthly variations in abundance of macrophyte species at site III in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
	Emergents														
1	*Carex sp.*	0.0	0.0	0.0	0.0	1.3	0.0	0.0	3.2	0.0	0.0	0.0	0.0	**0.38**	**1.0**
2	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	1.5	0.0	4.3	0.0	0.0	0.0	0.0	**0.48**	**1.3**
3	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	2.6	0.0	3.0	0.0	2.2	0.0	0.5	0.0	**0.69**	**1.2**
4	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	2.0	0.0	3.4	0.0	0.0	0.0	0.0	**0.45**	**1.1**
5	*Nasturtium sp.*	0.0	0.0	2.3	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	**0.44**	**1.0**
6	*Phragmites australis*	0.0	0.0	3.0	6.0	7.0	6.7	7.9	9.2	11.3	6.0	4.6	0.0	**5.14**	**3.7**
7	*Polygonum amphibium*	0.0	0.0	0.0	0.0	3.2	0.0	3.6	0.0	0.0	0.0	0.0	0.0	**0.57**	**1.3**
8	*Typha latifolia*	0.0	0.0	0.0	3.5	0.0	0.0	5.7	8.0	0.0	3.2	3.4	0.0	**1.98**	**2.8**
	Rooted floating-leaf type														
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	3.2	2.0	2.5	6.2	3.0	0.0	0.0	**1.41**	**2.0**
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	2.5	5.2	0.0	0.0	0.0	0.0	**0.64**	**1.6**
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	1.7	3.6	4.3	5.0	10.0	7.4	3.0	0.0	**2.92**	**3.3**
12	*Nymphoides peltatum*	0.0	0.0	6.2	7.4	9.0	10.0	8.5	18.0	12.0	10.0	4.0	0.0	**7.09**	**5.5**
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	2.5	0.0	4.2	3.5	5.0	3.0	0.0	0.0	**1.52**	**2.0**
14	*Trapa natans*	0.0	0.0	0.0	0.0	3.4	7.3	7.0	10.0	12.0	9.0	6.0	0.0	**4.56**	**4.5**
	Submerged														
15	*Ceratophyllum demersum*	1.3	2.0	2.0	8.2	15.0	14.0	15.3	20.0	14.0	11.4	10.0	8.0	**10.10**	**6.0**
16	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	2.0	2.5	3.8	6.5	6.0	5.8	4.3	3.5	**2.87**	**2.5**
17	*Myriophyllum spicatum*	1.2	2.2	5.3	6.2	13.6	16.0	12.0	7.0	8.3	5.0	4.6	2.0	**6.95**	**4.7**
18	*Potamogeton crispus*	0.0	1.0	3.6	5.0	5.7	8.0	8.4	7.0	7.5	9.0	7.0	3.0	**5.43**	**3.0**
19	*Potamogeton lucens*	0.0	0.0	0.0	0.0	5.0	3.2	5.5	4.2	5.0	3.2	0.0	0.0	**2.18**	**2.4**
20	*Potamogeton pectinatus*	2.2	0.0	0.0	3.4	6.0	5.6	4.0	6.8	6.0	5.0	0.0	0.0	**3.25**	**2.7**
21	*Potamogeton pucilus*	0.0	0.0	0.0	2.3	0.0	0.0	2.0	0.0	4.2	0.0	0.0	0.0	**0.71**	**1.4**
	Free-floating														
22	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	2.0	6.0	25.0	53.0	41.0	10.0	0.0	**11.42**	**18.3**
23	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.0	4.0	11.0	18.0	15.0	4.0	0.0	**4.33**	**6.6**

Table 5.3.3b$_{10}$. Monthly variations in frequency of macrophyte species at site IV in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	5.0	0.0	0.0	**0.8**	**1.9**
2	*Bidens cernua*	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	**1.3**	**3.1**
3	*Carex sp.*	0.0	0.0	0.0	5.0	10.0	15.0	0.0	20.0	0.0	15.0	10.0	0.0	**6.3**	**7.4**
4	*Cyperus difformis*	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	15.0	15.0	0.0	0.0	**3.3**	**6.2**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	5.0	5.0	0.0	10.0	0.0	0.0	0.0	0.0	**1.7**	**3.3**
6	*Eleocharis palustris*	0.0	0.0	0.0	5.0	0.0	0.0	10.0	0.0	10.0	0.0	5.0	0.0	**2.5**	**4.0**
7	*Lycopus europus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	**0.4**	**1.4**
8	*Nasturtium sp.*	0.0	0.0	0.0	5.0	0.0	15.0	0.0	0.0	15.0	10.0	10.0	0.0	**4.6**	**6.2**
9	*Phragmites australis*	0.0	0.0	20.0	25.0	35.0	15.0	40.0	40.0	40.0	30.0	25.0	0.0	**22.5**	**15.7**
10	*Polygonum amphibium*	0.0	0.0	0.0	5.0	0.0	0.0	10.0	15.0	20.0	0.0	0.0	0.0	**4.2**	**7.0**
11	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	5.0	0.0	0.0	15.0	0.0	0.0	0.0	0.0	**1.7**	**4.4**
Rooted floating-leaf type															
12	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	20.0	0.0	0.0	0.0	**3.3**	**6.5**
13	*Marsilea quadrifolia*	0.0	0.0	0.0	10.0	0.0	0.0	15.0	0.0	10.0	0.0	0.0	0.0	**2.9**	**5.4**
14	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	20.0	30.0	50.0	55.0	45.0	30.0	25.0	0.0	**21.3**	**21.2**
15	*Nymphaea alba*	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	5.0	0.0	0.0	0.0	**0.8**	**1.9**
16	*Nymphoides peltatum*	0.0	0.0	20.0	30.0	30.0	40.0	35.0	45.0	40.0	30.0	20.0	0.0	**24.2**	**16.4**
17	*Potamogeton natans*	0.0	0.0	25.0	30.0	40.0	30.0	40.0	35.0	30.0	25.0	20.0	0.0	**22.9**	**15.0**
Submerged															
18	*Ceratophyllum demersum*	10.0	15.0	10.0	20.0	20.0	35.0	35.0	40.0	40.0	30.0	35.0	20.0	**25.8**	**11.2**
19	*Chara fragiles*	0.0	0.0	0.0	0.0	20.0	20.0	25.0	30.0	30.0	25.0	20.0	0.0	**14.2**	**12.9**
20	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	15.0	10.0	15.0	10.0	20.0	20.0	0.0	0.0	**7.5**	**8.4**
21	*Myriophyllum spicatum*	15.0	20.0	40.0	45.0	35.0	40.0	40.0	50.0	55.0	35.0	30.0	20.0	**35.4**	**12.3**
22	*Potamogeton crispus*	0.0	10.0	10.0	25.0	30.0	40.0	45.0	40.0	35.0	20.0	15.0	5.0	**22.9**	**15.1**
23	*Potamogeton lucens*	0.0	5.0	10.0	20.0	10.0	25.0	30.0	35.0	30.0	20.0	15.0	5.0	**17.1**	**11.4**
24	*Potamogeton pectinatus*	10.0	0.0	15.0	15.0	20.0	30.0	20.0	35.0	40.0	30.0	20.0	15.0	**20.8**	**11.2**
25	*Potamogeton perfoliatus*	0.0	0.0	0.0	10.0	0.0	10.0	0.0	15.0	15.0	20.0	0.0	0.0	**5.8**	**7.6**
26	*Potamogeton pucilus*	0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	0.0	0.0	0.0	0.0	**1.7**	**3.9**
27	*Utricularia aurea*	0.0	0.0	10.0	0.0	20.0	30.0	25.0	20.0	30.0	30.0	20.0	0.0	**15.4**	**12.7**
Free-floating															
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	25.0	30.0	35.0	20.0	15.0	10.0	0.0	**11.3**	**13.3**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	10.0	15.0	20.0	25.0	20.0	15.0	0.0	**8.8**	**9.8**

Table 5.3.3b$_{11}$. Monthly variations in density of macrophyte species at site IV in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
	Emergents														
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	**0.01**	**0.03**
2	*Bidens cernua*	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	**0.03**	**0.06**
3	*Carex sp.*	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0	0.4	0.1	0.0	**0.11**	**0.18**
4	*Cyperus difformis*	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.3	0.0	0.0	**0.06**	**0.12**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.0	0.0	0.0	0.0	**0.05**	**0.10**
6	*Eleocharis palustris*	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.0	0.3	0.0	0.1	0.0	**0.07**	**0.11**
7	*Lycopus europus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	**0.01**	**0.03**
8	*Nasturtium sp.*	0.0	0.0	0.0	0.1	0.0	0.4	0.0	0.0	0.3	0.2	0.1	0.0	**0.10**	**0.15**
9	*Phragmites australis*	0.6	0.6	0.6	0.5	2.3	2.0	3.5	6.0	3.0	2.4	1.0	0.6	**1.93**	**1.67**
10	*Polygonum amphibium*	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.3	0.5	0.0	0.0	0.0	**0.09**	**0.16**
11	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.0	0.1	0.0	0.0	**0.05**	**0.10**
	Rooted floating-leaf type														
12	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.8	0.0	0.0	0.0	**0.13**	**0.25**
13	*Marsilea quadrifolia*	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.0	0.4	0.0	0.0	0.0	**0.10**	**0.19**
14	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	0.5	1.4	3.6	5.0	4.0	3.0	2.0	0.0	**1.63**	**1.85**
15	*Nymphaea alba*	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	**0.02**	**0.06**
16	*Nymphoides peltatum*	0.0	0.0	0.5	1.5	2.0	4.0	6.0	8.3	7.0	5.2	3.4	0.0	**3.16**	**2.94**
17	*Potamogeton natans*	0.0	0.0	0.4	0.8	2.4	3.2	3.5	4.0	1.3	1.0	0.5	0.0	**1.43**	**1.47**
	Submerged														
18	*Ceratophyllum demersum*	0.3	0.5	0.5	1.0	2.5	5.4	6.3	8.0	9.3	3.0	1.5	1.0	**3.28**	**3.17**
19	*Chara fragiles*	0.0	0.0	0.0	0.0	0.4	0.6	1.2	2.5	5.2	3.0	1.3	0.0	**1.18**	**1.63**
20	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	0.3	0.6	0.6	0.8	0.5	0.6	0.0	0.0	**0.28**	**0.32**
21	*Myriophyllum spicatum*	0.6	0.8	1.0	2.5	4.0	4.0	6.0	5.3	6.0	2.6	2.0	1.6	**3.03**	**1.98**
22	*Potamogeton crispus*	0.0	0.4	0.5	1.3	2.0	3.0	4.0	3.6	3.0	2.5	1.0	0.0	**1.78**	**1.43**
23	*Potamogeton lucens*	0.0	0.0	0.2	0.4	0.7	0.8	1.5	1.8	1.6	1.0	0.6	0.0	**0.72**	**0.65**
24	*Potamogeton pectinatus*	0.1	0.0	0.2	0.4	0.5	1.0	1.3	2.7	2.5	2.0	1.0	0.4	**1.01**	**0.94**
25	*Potamogeton perfoliatus*	0.0	0.0	0.0	0.2	0.0	0.5	0.0	0.6	0.7	0.9	0.2	0.0	**0.26**	**0.33**
26	*Potamogeton pucilus*	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	**0.03**	**0.06**
27	*Utricularia aurea*	0.0	0.0	0.6	0.0	1.0	1.4	2.3	3.5	3.0	2.0	1.5	0.0	**1.28**	**1.23**
	Free-floating														
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	5.0	13.0	15.0	7.0	6.0	4.6	0.0	**4.22**	**5.32**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.2	3.0	2.0	2.0	0.0	**0.73**	**1.06**

Table 5.3.3b$_{12}$. Monthly variations in abundance of macrophyte species at site IV in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	1.0	0.0	0.0	**0.21**	**0.50**
2	*Bidens cernua*	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.4	0.0	0.0	0.0	**0.31**	**0.76**
3	*Carex sp.*	0.0	0.0	0.0	0.0	1.0	3.0	0.0	4.4	0.0	4.2	1.0	0.0	**1.13**	**1.72**
4	*Cyperus difformis*	0.0	0.0	0.0	0.0	1.7	2.7	0.0	0.0	2.0	2.5	0.0	0.0	**0.74**	**1.12**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	2.4	2.3	0.0	6.3	0.0	0.0	0.0	0.0	**0.92**	**1.92**
6	*Eleocharis palustris*	0.0	0.0	0.0	1.8	0.0	0.0	2.6	0.0	3.0	0.0	2.3	0.0	**0.81**	**1.22**
7	*Lycopus europus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	**0.11**	**0.38**
8	*Nasturtium sp.*	0.0	0.0	0.0	3.0	0.0	4.5	0.0	0.0	4.2	3.2	2.4	0.0	**1.44**	**1.86**
9	*Phragmites australis*	0.0	0.0	0.0	4.0	6.0	6.0	8.3	15.0	8.0	9.5	3.0	0.0	**4.98**	**4.74**
10	*Polygonum amphibium*	0.0	0.0	0.0	3.2	0.0	0.0	3.0	2.0	2.0	0.0	0.0	0.0	**0.85**	**1.30**
11	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	1.8	0.0	0.0	2.2	0.0	3.4	0.0	0.0	**0.62**	**1.17**
Rooted floating-leaf type															
12	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	3.6	6.0	5.0	0.0	0.0	0.0	**1.22**	**2.26**
13	*Marsilea quadrifolia*	0.0	0.0	0.0	3.0	0.0	0.0	4.3	0.0	5.0	0.0	0.0	0.0	**1.03**	**1.90**
14	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	2.0	6.0	8.6	9.0	10.0	8.0	4.0	0.0	**3.97**	**4.11**
15	*Nymphaea alba*	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	1.0	0.0	0.0	0.0	**0.33**	**0.89**
16	*Nymphoides peltatum*	0.0	0.0	4.3	5.0	11.3	9.8	15.0	24.0	16.0	13.0	12.0	0.0	**9.20**	**7.52**
17	*Potamogeton natans*	0.0	0.0	4.0	6.3	5.5	8.0	11.0	13.0	4.0	6.0	3.5	0.0	**5.11**	**4.17**
Submerged															
18	*Ceratophyllum demersum*	4.0	6.0	8.0	11.5	13.0	18.5	20.0	23.4	24.0	12.0	6.0	4.5	**12.58**	**7.30**
19	*Chara fragiles*	0.0	0.0	0.0	0.0	3.3	7.0	5.3	9.8	14.0	10.0	6.7	0.0	**4.68**	**4.89**
20	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	5.0	8.0	6.4	11.0	6.3	3.8	2.6	0.0	**3.59**	**3.78**
21	*Myriophyllum spicatum*	2.3	3.0	5.0	7.8	9.0	14.5	10.4	13.0	12.3	8.0	5.0	2.7	**7.75**	**4.21**
22	*Potamogeton crispus*	0.0	4.3	7.6	4.0	9.4	7.0	11.6	8.6	11.3	8.0	8.0	1.6	**6.78**	**3.62**
23	*Potamogeton lucens*	0.0	1.5	4.0	4.0	8.5	3.4	6.6	5.3	8.0	6.8	4.3	1.2	**4.47**	**2.70**
24	*Potamogeton pectinatus*	2.0	0.0	2.0	2.6	4.0	3.6	7.0	9.0	7.0	5.5	5.0	3.5	**4.27**	**2.55**
25	*Potamogeton perfoliatus*	0.0	0.0	0.0	2.0	0.0	4.3	0.0	6.4	3.8	4.8	4.5	0.0	**2.15**	**2.44**
26	*Potamogeton pucilus*	0.0	0.0	0.0	2.3	0.0	2.5	0.0	2.5	3.4	4.3	2.3	0.0	**1.44**	**1.61**
27	*Utricularia aurea*	0.0	0.0	5.0	0.0	7.4	5.5	13.0	15.0	9.6	5.0	6.0	0.0	**5.54**	**5.12**
Free-floating															
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	14.5	25.0	65.0	42.0	30.0	22.0	0.0	**16.54**	**21.16**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	2.0	5.0	5.0	14.0	8.6	8.6	0.0	**3.60**	**4.69**

Table 5.3.3c_1. Monthly variations in IVI of macrophyte species at site I in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
	Emergents														
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	6.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	**0.74**	**1.8**
2	*Bidens cernua*	0.0	0.0	0.0	10.0	0.0	3.9	0.0	4.4	0.0	0.0	4.6	0.0	**1.91**	**3.2**
3	*Carex sp.*	0.0	0.0	0.0	0.0	0.0	4.2	0.0	4.2	0.0	0.0	0.0	0.0	**0.70**	**1.6**
4	*Cyperus difformis*	0.0	0.0	0.0	10.0	0.0	4.9	0.0	4.0	0.0	0.0	6.3	0.0	**2.10**	**3.4**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	3.3	0.0	0.0	0.0	**0.56**	**1.3**
6	*Eleocharis palustris*	0.0	0.0	0.0	19.5	0.0	0.0	5.7	0.0	2.2	1.3	0.0	0.0	**2.39**	**5.7**
7	*Lycopus europus*	0.0	0.0	0.0	14.1	0.0	0.0	5.1	0.0	2.8	4.4	0.0	0.0	**2.19**	**4.2**
8	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	4.8	0.0	**0.68**	**1.6**
9	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	13.9	6.7	8.7	4.2	0.0	0.0	0.0	**2.79**	**4.6**
10	*Nasturtium sp.*	0.0	35.9	0.0	25.3	23.5	9.4	10.3	9.1	4.7	5.4	0.0	17.2	**11.73**	**11.5**
11	*Polygonum amphibium*	0.0	0.0	0.0	11.6	0.0	0.0	2.9	0.0	2.8	0.0	0.0	0.0	**1.44**	**3.4**
12	*Sium latijugum*	0.0	0.0	4.0	0.0	8.8	6.3	8.1	7.1	5.6	9.2	0.0	0.0	**4.09**	**3.9**
	Rooted floating-leaf type														
13	*Euryale ferox*	0.0	0.0	0.0	0.0	12.9	12.8	11.1	13.3	6.8	8.5	0.0	0.0	**5.46**	**6.0**
14	*Marsilia quadrifolia*	0.0	0.0	0.0	16.7	0.0	15.0	0.0	12.1	0.0	0.0	0.0	0.0	**3.65**	**6.7**
15	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	7.4	0.0	7.6	0.0	6.5	0.0	0.0	0.0	**1.79**	**3.3**
16	*Nelumbo nucifera*	0.0	0.0	0.0	21.5	17.7	11.2	9.6	13.3	14.5	25.9	16.8	0.0	**10.87**	**9.1**
17	*Nymphoides peltatum*	0.0	0.0	44.2	53.9	45.7	28.0	28.3	31.3	23.1	28.4	37.3	0.0	**26.68**	**18.3**
18	*Potamogeton natans*	0.0	0.0	0.0	0.0	10.2	10.7	10.4	13.4	4.5	0.0	13.7	0.0	**5.24**	**5.9**
19	*Trapa natans*	0.0	0.0	0.0	0.0	0.0	9.6	9.0	11.8	7.4	6.9	0.0	0.0	**3.73**	**4.7**
	Submerged														
20	*Ceratophyllum demersum*	93.2	98.4	61.3	36.0	58.0	47.0	31.5	44.6	35.8	37.3	55.6	80.5	**56.60**	**22.9**
21	*Chara fragiles*	0.0	0.0	0.0	0.0	0.0	2.9	2.0	0.0	2.1	0.0	0.0	0.0	**0.58**	**1.1**
22	*Hydrilla verticellata*	0.0	57.4	58.8	30.6	23.5	15.9	19.7	22.8	14.0	17.1	28.9	69.7	**29.86**	**21.1**
23	*Myriophyllum spicatum*	101.1	65.6	99.4	0.0	22.9	18.2	11.5	12.9	13.5	13.9	0.0	77.8	**36.41**	**38.2**
24	*Potamogeton crispus*	0.0	20.3	0.0	14.7	11.7	9.5	8.1	13.2	8.3	12.1	13.2	0.0	**9.26**	**6.4**
25	*Potamogeton lucens*	44.3	22.4	11.5	23.4	35.8	32.3	15.1	14.6	12.0	14.5	17.8	54.8	**24.87**	**14.0**
26	*Potamogeton pectinatus*	61.4	0.0	20.8	12.6	16.2	9.2	6.8	5.8	8.3	9.2	10.0	0.0	**13.35**	**16.2**
27	*potamogeton pucilus*	0.0	0.0	0.0	0.0	0.0	5.2	2.4	1.5	0.0	0.0	0.0	0.0	**0.76**	**1.6**
	Free-floating														
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	29.6	71.9	31.6	105.5	78.3	73.2	0.0	**32.50**	**39.3**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	0.0	10.0	16.9	12.0	27.7	17.9	0.0	**7.04**	**9.6**

Table 5.3.3c$_2$. Monthly variations in IVI of macrophyte species at site II in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Bidens cernua*	0.0	0.0	0.0	0.0	4.6	0.0	4.9	0.0	3.6	3.5	0.0	0.0	**1.38**	2.1
2	*Cyperus difformis*	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	3.6	0.0	0.0	0.0	**0.74**	1.8
3	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	**0.10**	0.3
4	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	0.0	5.3	0.0	6.2	4.3	3.6	6.4	0.0	**2.15**	2.8
5	*Nasturtium sp.*	0.0	0.0	0.0	13.4	0.0	6.9	0.0	0.0	5.2	0.0	0.0	0.0	**2.12**	4.3
6	*Polygonum amphibium*	0.0	0.0	0.0	0.0	7.4	0.0	7.4	0.0	0.0	5.0	0.0	0.0	**1.65**	3.0
7	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	1.5	0.0	0.0	0.0	**0.44**	1.1
8	*Sium latijugum*	0.0	0.0	0.0	19.9	20.8	12.0	0.0	7.1	0.0	0.0	0.0	0.0	**4.98**	8.1
Rooted floating-leaf type															
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	10.6	11.7	11.8	8.7	0.0	0.0	0.0	**3.56**	5.3
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	9.0	6.9	10.4	9.4	8.7	8.7	12.1	0.0	**5.44**	5.0
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	19.8	23.1	15.9	16.0	19.8	19.3	0.0	0.0	**9.50**	10.1
12	*Nymphoides peltatum*	0.0	0.0	56.7	58.3	48.0	32.2	36.7	34.9	23.4	29.1	38.8	0.0	**29.85**	20.8
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	0.0	12.2	11.7	7.2	0.0	13.3	14.3	0.0	**4.89**	6.3
14	*Trapa natans*	0.0	0.0	0.0	0.0	6.1	4.9	12.3	13.2	10.2	9.4	11.5	0.0	**5.64**	5.5
Submerged															
15	*Ceratophyllum demersum*	171.4	170.9	161.5	158.9	94.1	79.3	75.3	52.1	36.1	46.3	80.1	211.9	**111.5**	59.6
16	*Myriophyllum spicatum*	0.0	29.7	0.0	4.5	22.5	22.2	10.9	12.2	11.4	13.0	0.0	30.6	**13.1**	11.1
17	*Potamogeton crispus*	61.6	33.2	0.0	18.3	13.4	8.9	3.9	7.4	9.5	10.0	18.8	0.0	**15.4**	17.2
18	*Potamogeton lucens*	0.0	0.0	29.6	0.0	22.0	17.5	13.2	10.0	6.1	11.4	17.0	0.0	**10.6**	9.8
19	*Potamogeton pectinatus*	67.1	66.2	52.9	27.5	24.6	13.1	14.6	22.8	21.1	13.3	20.2	57.5	**33.4**	21.1
Free-floating															
21	*Lemna spp.*	0.0	0.0	0.0	0.0	7.4	29.3	50.5	55.6	102.3	69.6	57.5	0.0	**31.02**	35.2
22	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	15.8	15.1	29.5	24.4	44.3	23.5	0.0	**12.72**	15.1

Table 5.3.3c$_3$. Monthly variations in IVI of macrophyte species at site III in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Carex sp.*	0.0	0.0	0.0	0.0	4.1	0.0	0.0	4.5	0.0	0.0	0.0	0.0	**0.72**	**1.7**
2	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	0.0	3.5	0.0	7.4	0.0	0.0	0.0	0.0	**0.91**	**2.3**
3	*Myriophyllum verticillatum*	0.0	0.0	0.0	0.0	5.9	0.0	7.2	0.0	4.4	0.0	0.8	0.0	**1.53**	**2.7**
4	*Nasturtium officinale*	0.0	0.0	0.0	0.0	0.0	7.2	0.0	4.5	0.0	0.0	0.0	0.0	**0.97**	**2.4**
5	*Nasturtium sp.*	0.0	0.0	18.1	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	**1.97**	**5.3**
6	*Phragmites australis*	0.0	0.0	49.3	40.1	28.0	21.5	20.0	19.7	18.8	4.4	29.4	0.0	**19.26**	**16.1**
7	*Polygonum amphibium*	0.0	0.0	0.0	0.0	9.5	0.0	6.8	0.0	0.0	0.0	0.0	0.0	**1.36**	**3.2**
8	*Typha latifolia*	0.0	0.0	0.0	21.9	0.0	9.6	14.8	9.3	4.0	10.1	13.3	0.0	**6.92**	**7.4**
Rooted floating-leaf type															
9	*Euryale ferox*	0.0	0.0	0.0	0.0	0.0	6.4	6.0	10.3	12.2	7.0	4.3	0.0	**3.85**	**4.5**
10	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	3.5	6.6	0.0	0.0	0.0	0.0	**0.85**	**2.1**
11	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	11.8	14.8	16.0	15.5	20.8	23.9	16.1	0.0	**9.92**	**9.2**
12	*Nymphoides peltatum*	0.0	0.0	60.1	52.0	35.6	38.0	29.5	27.9	32.0	29.6	26.0	0.0	**27.56**	**19.4**
13	*Potamogeton natans*	0.0	0.0	0.0	0.0	10.5	5.3	5.8	7.5	8.7	8.8	0.0	0.0	**3.88**	**4.3**
14	*Trapa natans*	0.0	0.0	0.0	0.0	5.5	16.1	19.2	24.1	24.0	23.7	25.0	0.0	**11.47**	**11.4**
Submerged															
15	*Ceratophyllum demersum*	144.2	102.7	30.6	38.1	43.3	37.0	36.4	37.2	22.1	37.6	54.7	136.2	**60.0**	**42.6**
16	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	5.0	6.9	10.4	14.6	12.0	18.5	22.2	47.9	**11.5**	**13.8**
17	*Myriophyllum spicatum*	56.6	161.4	77.8	66.1	59.4	58.0	41.4	20.7	17.0	20.8	27.0	48.8	**54.6**	**39.1**
18	*Potamogeton crispus*	0.0	35.9	64.1	53.2	31.3	38.7	29.4	18.9	16.8	17.4	30.8	67.2	**33.6**	**20.0**
19	*Potamogeton lucens*	0.0	0.0	0.0	0.0	27.7	14.7	14.5	8.0	7.3	9.3	0.0	0.0	**6.8**	**8.8**
20	*Potamogeton pectinatus*	99.2	0.0	0.0	19.0	22.5	17.8	13.5	12.4	14.2	12.4	0.0	0.0	**17.6**	**27.0**
21	*Potamogeton pucilus*	0.0	0.0	0.0	9.4	0.0	0.0	4.4	0.0	6.1	0.0	0.0	0.0	**1.7**	**3.2**
Free-floating															
22	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	2.4	8.5	33.0	60.5	50.8	38.5	0.0	**16.15**	**22.9**
23	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	1.7	6.9	16.0	19.2	25.8	12.0	0.0	**6.80**	**9.2**

Table 5.3.3c$_4$. Monthly variations in IVI of macrophyte species at site IV in Lake Manasbal

S.No.	Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
Emergents															
1	*Alisma plantago aquatica*	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	1.8	0.0	0.0	**0.36**	**0.85**
2	*Bidens cernua*	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	3.1	0.0	0.0	0.0	**0.55**	**1.29**
3	*Carex sp.*	0.0	0.0	0.0	2.0	4.2	6.4	0.0	5.8	0.0	7.2	4.8	0.0	**2.54**	**2.94**
4	*Cyperus difformis*	0.0	0.0	0.0	0.0	1.8	4.8	0.0	0.0	3.8	6.0	0.0	0.0	**1.37**	**2.21**
5	*Echinocloa crusgali*	0.0	0.0	0.0	0.0	4.7	3.2	0.0	4.6	0.0	0.0	0.0	0.0	**1.04**	**1.91**
6	*Eleocharis palustris*	0.0	0.0	0.0	6.3	0.0	0.0	3.9	0.0	3.6	0.0	4.4	0.0	**1.52**	**2.33**
7	*Lycopus europus*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	**0.12**	**0.43**
8	*Nasturtium sp.*	0.0	0.0	0.0	8.0	0.0	7.9	0.0	0.0	5.0	4.9	6.2	0.0	**2.67**	**3.42**
9	*Phragmites australis*	37.5	26.1	25.8	22.0	29.5	13.5	19.4	21.1	15.3	19.4	15.6	16.7	**21.83**	**6.93**
10	*Polygonum amphibium*	0.0	0.0	0.0	8.2	0.0	0.0	4.2	3.7	5.1	0.0	0.0	0.0	**1.76**	**2.80**
11	*Sagittaria sagittifolia*	0.0	0.0	0.0	0.0	4.6	0.0	0.0	3.9	0.0	2.4	0.0	0.0	**0.90**	**1.70**
Rooted floating-leaf type															
12	*Hydrocharis dubia*	0.0	0.0	0.0	0.0	0.0	0.0	4.7	4.6	7.0	0.0	0.0	0.0	**1.36**	**2.52**
13	*Marsilea quadrifolia*	0.0	0.0	0.0	12.2	0.0	0.0	6.5	0.0	4.6	0.0	0.0	0.0	**1.95**	**3.90**
14	*Nelumbo nucifera*	0.0	0.0	0.0	0.0	11.0	15.2	21.8	19.9	18.8	20.0	20.8	0.0	**10.62**	**9.79**
15	*Nymphaea alba*	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	1.3	0.0	0.0	0.0	**0.44**	**1.17**
16	*Nymphoides peltatum*	0.0	0.0	34.4	36.6	32.1	27.7	27.0	28.7	25.7	28.9	32.6	0.0	**22.81**	**14.10**
17	*Potamogeton natans*	0.0	0.0	34.5	31.1	31.1	21.9	21.0	16.7	9.0	12.3	12.2	0.0	**15.81**	**12.45**
Submerged															
18	*Ceratophyllum demersum*	95.5	92.3	37.4	37.9	33.4	37.0	30.6	27.2	33.2	22.5	23.9	91.9	**46.90**	**28.38**
19	*Chara fragiles*	0.0	0.0	0.0	0.0	11.9	11.3	10.4	12.4	20.1	20.1	18.6	0.0	**8.73**	**8.36**
20	*Hydrilla verticillata*	0.0	0.0	0.0	0.0	11.7	9.8	7.9	7.1	7.1	8.7	2.4	0.0	**4.55**	**4.55**
21	*Myriophyllum spicatum*	108.1	95.1	59.8	58.1	41.7	31.2	25.2	21.1	24.8	20.1	23.4	95.2	**50.31**	**32.63**
22	*Potamogeton crispus*	0.0	66.4	36.4	30.7	30.1	22.8	23.3	15.2	16.0	16.3	16.8	19.5	**24.47**	**16.19**
23	*Potamogeton lucens*	0.0	20.1	20.7	19.0	16.1	10.4	12.7	10.5	11.3	11.6	11.6	16.6	**13.40**	**5.68**
24	*Potamogeton pectinatus*	58.9	0.0	18.8	14.6	13.2	12.3	10.6	13.3	14.0	15.8	15.7	60.1	**20.61**	**18.73**
25	*Potamogeton perfoliatus*	0.0	0.0	0.0	9.5	0.0	6.8	0.0	5.9	5.4	10.1	5.0	0.0	**3.56**	**3.99**
26	*Potamogeton pucilus*	0.0	0.0	0.0	3.8	0.0	1.8	2.2	3.0	1.6	2.7	2.1	0.0	**1.43**	**1.38**
27	*Utricularia aurea*	0.0	0.0	32.1	0.0	19.5	14.8	17.0	14.2	14.4	15.5	18.8	0.0	**12.19**	**10.17**
Free-floating															
28	*Lemna spp.*	0.0	0.0	0.0	0.0	0.0	30.7	44.9	52.5	34.3	38.3	43.5	0.0	**20.34**	**21.91**
29	*Salvinia natans*	0.0	0.0	0.0	0.0	0.0	4.0	6.7	7.0	15.6	15.4	21.7	0.0	**5.87**	**7.67**

Table 5.3.3d$_{1.}$ Macrophytic similarity between different study sites based on Sorenson's similarity index in Manasbal lake

Sites	M2	M3	M4	M5
M1	66%	67%	71%	0%
M2		61%	52%	0%
M3			53%	0%
M4				0%

Table 5.3.3d$_{2.}$ Diversity (Shanon Wiever) index of species at different study sites in Manasbal lake

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	SD
M1	1.47	1.47	1.52	2.36	2.14	2.49	2.20	2.49	2.05	2.18	1.95	1.60	**1.99**	**0.39**
M2	0.69	0.48	1.05	0.91	1.70	2.08	1.82	2.12	1.97	2.10	1.88	1.53	**1.53**	**0.59**
M3	0.67	0.41	1.63	1.81	2.15	2.20	2.49	2.60	2.34	2.37	2.14	1.25	**1.84**	**0.72**
M4	1.22	1.35	2.10	2.15	2.31	2.54	2.42	2.55	2.65	2.64	2.48	1.26	**2.14**	**0.55**
M5	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**

Chapter 6

DISCUSSION

6. DISCUSSION

6.1. Water Chemistry

The basic aim of the present study was to compare the geochemistry of three completely different water bodies of Jammu and Kashmir State. Two of the water bodies are located in the cold desert of Ladakh, while the third one is in the main valley of Kashmir. While lake Tso Morari is a large and very deep (Z_m>72m) brackish water body, the Tso Khar is very shallow (Z_m< 5m) water expanse divided into two distinct parts, one fresh and the other salt water. Both these water bodies are without any outlet and are as such completely isolated in nature and the loss of water is mainly through evapotranspiration. Both these water bodies remain ice covered for three to four months during winter when the atmospheric temperature may dip down to as low as -40^{o}C. The Tso Morari being very deep can be easily classified as cold monomictic water body (Hutchinson, 1967) as it did not record any significant stratification during the warmer summer in spite of intense solar radiation during day time which may be related to the fast winds regularly in the afternoon which mixed the water column very often.

The Tso Khar, being shallow, could not be assigned to any category on the basis of thermal stratification. The third water body, viz Manasbal lake has the maximum depth of 12.5m.While the first two water bodies have distinct tributaries bringing in water, the Manasbal does not have any permanent and distinct inlet and the source of its water is mainly the springs spread over its basin as well as in its neighborhood. This water body has, however, an outlet, Nunnyar Nallah and as such forms a part of the Jhelum river system. In contrast to Tso Morari and Tso Khar, the Manasbal lake remains stratified for a period of 8 to 9 months from March to November and mixes up only during the winter months of December to February. While the other two water bodies remain completely ice covered during winter, this lake recorded a temperature of 4 to 5 °C throughout the water column at this time of the year. Accordingly this water body is categorized as warm monomictic lake (Qadri and Yousuf, 1978).

The three water bodies also showed significant differences in the transparency. The secchi disc transparency is essentially a function of reflection of light from its surface and is influenced by the absorption characteristics of water and its dissolved and particulate matter. Aquatic macrophytes serve as impediment to re-suspension of sediments and facilitate in improving transparency by reducing the concentration of inorganic suspended solids in the water (Jackson and Starret, 1959; Dieter, 1990; James and Barko, 1990; Horppila and Nurminen, 2001; Nurminen and Nurminen 2005). The water in Tso Morari Lake appeared blue with silty particles in suspension, recording significantly high values of transparency in deeper areas (15m), especially during the calm weather conditions, probably due to low plankton populations and suspended particles (Mitamura *et al.*, 2003). In case of Tso Khar lake, the re-suspension of sediments by turbulent winds substantially reduced the transparency in areas devoid of any vegetation (Maceina and Soballe, 1990; Khan, 2003). However, in vegetated areas the dense submerged macrophytic association of *Potamogeton pectinatus* and *Ranunculus aquatalis* acted as effective barrier for sediment re-suspension resulting in improving the transparency (Barko and James, 1998; Nagid *et al.*, 2001; De-Vicente *et al.*, 2006; Huang *et al.*, 2007). In Manasbal Lake the littoral macrophytes acted as sinks and filter for nutrients and suspended particles and helped in maintaining relatively clear water in the limnetic areas (Lindholm *et al.*, 2008). In order to understand the influence of the catchment on the geochemistry of the three water bodies, it was decided to have detailed study of the chemistry of the overlying water column as the sediment chemistry is greatly influenced by the water chemistry.

The water chemistry in lake ecosystems is controlled mainly by three important factors viz. precipitation, evaporation and rock dominance in the catchment (Gibbs, 1970; Whitefield, 1983; Kilham, 1990; Catalan *et al.,* 1993). Evaporation-crystallization in saline lakes has been found to play a key role in hydrochemistry (Gibbs, 1970). The pH of natural water is governed to a large extent by the interaction of H^+ generated by dissociation of H_2CO_3 and from OH^- produced during the hydrolysis of HCO_3 (Wetzel, 2001). The pH of water in Tso Morari, which is a typical endorheic lake, was always alkaline due to high concentration of soda (Na_2CO_3), (Hammer and parker, 1984; Bowman and Sachs, 2008). Moreover high concentration of bicarbonates and carbonates of calcium and magnesium also contributed to the alkalinity of water which is depicted by significant positive correlation ($r= 0.441$; $p > 0.01$) of pH with alkalinity. The alkaline pH in Tso Khar Lake could be due to alkalinity generated by sulfate reduction (Lamers *et al.,* 1998: Last and Ginn, 2009). Though the photosynthetic activity of macrophytes increases the pH of the water, macrophytic infested fresh water sites in Tso Khar had low pH than saline sites. The high pH at saline sites may be due to high concentration of soda (Na_2CO_3), and bicarbonates and carbonates of calcium and magnesium (Wetzel, 2001). Saenger *et al.* (2006) as well as Zheng and Liu. (2009) also reported similar results from some inland saline lakes. The pH value of Manasbal lake was alkaline at all the study sites, only the bottom water had slight acidic pH which may be attributed to high CO_2 and other organic acids generated by the decomposition of organic matter in hypoliminion (Reimer *et al*., 2008). The littoral area, which is infested with macrophytes had high pH values due to photosynthetic activity of macrophytes and epiphytic algae (Otsuki and Wetzel, 1972; Olila and Reddy, 1995; Wetzel, 2001).

The conductivity of lake is influenced by incoming waters, seasonal rainfall pattern, evaporation rates, drainage type and trophic status (Kinnear and Garnett, 1999). The higher conductivity values in Tso Morari lake sites was due to high values of Na^+, K^+ Cl^- and Mg^{2+} which get concentrated in lake waters due to evaporation (Zhang *et al*., 2008). Both Tso Morari and Tso Khar being land locked and without any outlet the loss of the water is chiefly through evapotranspiration which has resulted in the higher concentration of dissolved salts in the lake over the geological period of time (Oduor *et al*., 2003). The conductivity of Tso Khar was significantly higher than the Tso Morari and could be related to much higher contents of Na^{+}, K$^{+,}$ Cl^{-}, Mg^{2+} and Ca^{2+} (Rastogi, 1976; Eimanifar and Mohebbi, 2007). The ionic rich geothermal springs located in and around the lake also influence the conductivity (Alonso, 1999; Zang, 2001ab; Rimmer and Gal, 2003: Santos *et al*., 2008). This was substantiated by significant positive correlation of conductivity with these major ions (Table I and II). In comparison to Tso Morari and Tso Khar lakes, the conductivity values recorded at Manasbal lake were very low and could be attributed to rapid uptake of nutrients by macrophytes and their attached micro flora (Vymazal, 2002). Furthermore the continuous flushing of nutrients from the lake through outlet and low evaporation rate maintain low value of conductivity in the lake (Whitmore *et al.,* 1997).

The mean oxygen concentration of Manasbal (9.4mg/l)) was higher than Tso Morari (7.8mg/l) and Tso Khar (6.4mg/l). The dynamics of oxygen distribution in inland waters is governed by a balance between inputs from atmosphere, photosynthesis and losses from respiration and chemical oxidation (Wetzel, 2001). Variability in DO is related to the combined effects of salinity, basin morphometry, daily sampling time and nutrient loading (Saenger *et al*., 2006). The solubility of dissolved oxygen decreases with increase in temperature, salinity and with low atmospheric pressure at high altitudes (Wetzel, 2001). The DO was uniformly distributed in Tso Morari and could be related to turbulent mixing of lake water by high velocity winds (Mitamura *et al.,* 2003; Wang *et al*., 2009) and diurnal thermal convection. The dissolved oxygen concentration of saline sites was significantly lower than fresh water sites in Tso Khar lake. Hypersalinity is known to partially inhibit photosynthesis (Pinckney and Paerl, 1995; Saenger *et al*., 2006) and thus leads to low dissolved oxygen production at saline sites. Similar observations were also made by Bowman and Sachs (2008) from the saline lakes in Alberta and

Saskatchewan. This is also substantiated by significant negative correlation of DO with conductivity (r= -0.601; p= 0.01), TDS (r= -0.440; p= 0.01), Na^+ (r= -0.595; p= 0.01), K^+ (r=-0.601; p= 0.01) and Cl^- (r= 0.549; p= 0.01) in this lake (Table III). The littoral sites of Manasbal lake had high concentration of dissolved oxygen due to luxuriant growth of submerged macrophytes which act as main sources of aeration for the lake (Srivastava *et al.*, 2008) due to photosynthesis. The bottom water (M5b) of the limnetic zone in the lake was anoxic throughout the study period, which seems to be related to oxygen consumption by microbial and chemical oxidation, especially during thermal stratification (Wetzel, 2001).

The free CO_2 is highly soluble in water and is hydrated to form carbonic acid. The free CO_2 was almost absent from Tso Morari lake, except stream sites. The absence of free CO_2 may be due to high pH, low primary production and low pollution load. In Tso Khar lake the mean values of free CO_2 were significantly higher at TK3 which represents the spring site which may be due to dissolution of carbonate rocks. Presence of free CO_2 at TK2 and TK5 could be related to decomposition of organic matter (Yousuf *et al.*, 1983). In contrast to Tso Morari (1.8mg/l) and Tso Khar (2.7mg/l), the free CO_2 (9.3 mg/l) was present throughout the study period in lake Manasbal except during summer months when carbonates were present.

The major source of alkalinity in lakes is the dissolution of carbonate rocks and aluminosilicates (Das and Dhiman, 2003). The formation of carbonic acid by the reaction of CO_2 and H_2O in soil accelerates the dissolution of carbonate rocks in the catchment and produces calcium bicarbonate which is soluble in water and increases the alkalinity of the water (Wetzel, 2001). The water of the Tso Morari Lake as well as its streams was alkaline throughout study period. The $Ca^{2+} + Mg^{2+}$**:** HCO_3 ratio of the Tso Morari is 0.8 indicating that carbonate weathering is main source of alkalinity in the lake. Zhang *et al.* (2008) also reported similar results from Nam Co lake in

Tibetan plateau. The saline sites of Tso Khar lake had significantly high alkalinity than the fresh water sites as a result of high concentration of both bicarbonates and carbonates. In saline lakes presence of Na_2CO_3 (Cole, 1983 and Zheng and Liu, 2009) and the high sulfate content and its subsequent reduction by sulfur reducing bacteria (SBR), generate HCO_3which is found to significantly increase the alkalinity of lake water (Lamers *et al*., 1998; Rodriguez *et al*., 2008; Reimer *et al.*, 2008; Last and Ginn, 2009).

The mean alkalinity values of Mansbal lake (167mg/l) were relatively low as compared to Tso Morari (305mg/l) and Tso Khar (1165mg /l). Being a typical marl lake alkalinity was chiefly due to bicarbonate ions. However, carbonates were found only in summer season in minor quantities and could be attributed to high photosynthetic rate of macrophytes and periphyton (Wetzel, 2001). The low values of alkalinity at rest of the sites could be attributed to dense macrophytic vegetation which use bicarbonate as a carbon source, thus increases pH and consequently shift the chemical equilibrium towards the formation of carbonate ions (Stumm and Morgan, 1970, 1996) which then precipitate with calcium in the form of calcite that significantly leads to decline of alkalinity (Kufel and Kufel, 2002).

The hardness of water which is mostly governed by the carbonates and bicarbonates of calcium and magnesium but in saline lakes other ions like $Cl^-$and SO_4^{2-} also contribute to hardness significantly (Cole, 1983). The stream sites of Tso Morari Lake had significantly low values of hardness than Lake Sites. The high values of hardness in lake could be due to high concentration of carbonates of calcium, magnesium, sulfate and chlorides over the geological period of time due to evapotranspiration of the lake water. The hardness was significantly higher in winter months as compared to summer months. This may be due to high photosynthetic activity of macrophytes and plankton in summer which increases the pH of water and accelerates the de-calcification, resulting in decrease of hardness. The hardness of the saline sites of Tso Khar was significantly higher (2691.8 to 2950 mg/l) than fresh water and spring sites which is also attributable to high values of magnesium, calcium carbonates, Cl^- and sulfate at these sites. This is substantiated by significant positive correlation of hardness with Ca (r=0.676; p<0.01), Mg (r=0.858; p<0.01) chloride (r =0.831; p<0.01) and sulfate (r= 0.631; p<0.01) in this lake (Table II). Compared to Ladakh lakes (Tso Morari and Tso Khar), the hardness of Manasbal Lake was much less (111 to 256 mg /l), mainly contributed by Ca and Mg bicarbonates. The low values are due to well flushing of water as well as due to high density of macrophytes which use the most of the salts for their growth and life processes.

The relatively high contribution of Ca^{2+} + Mg^{2+} and low contribution of Na^+ + K^+ to the total cations in Tso Morari lake suggest that carbonate weathering is the major source of ions, while the contribution from silicate weathering is minor (Sarin *et al*., 1989; Pandey *et al*., 1999). The geochemical evolution in evaporative lakes without river outlets is primarily controlled by inflow composition, selective removal processes of dissolved species, and concentration processes in the lake basin (Yan *et al*., 2002). Inflow streams around Tso Morari are the major supply of the lake water and thus contribute most of the ionic load. Calcium concentration in Tso Morari is depleted because of chemical precipitation and biological activities (Reimer *et al*., 2008), while enrichment of magnesium and sodium is due to evapo-concentration effect (Zang *et al*., 2008). In Tso Khar lake significant differences were observed in mean calcium and magnesium content among the study sites. The cationic progression found at saline sites TK1 and TK4 was in the order of Na> K> Mg>Ca, while at sites TK2 and TK3- Ca>Mg>Na>K. The saline sites were dominated by magnesium ion, whereas fresh water sites were dominated by calcium. The high content of Mg at saline sites could be attributed to Mg enrichment due to evaporation and selective removal of Ca by precipitation under high pH (Jones and Weir, 1983; Kilham and Cloke, 1990). In Manasbal lake the cationic progression was in the order of Ca>Mg>Na>K which reflected the dominance of Ca over Mg and could be attributable to Ca rich lime rocks in the catchment (Zutshi, *et al*., 1980; Jeelani and Shah, 2006).

Sodium and potassium are conservative ions and show little spatial and temporal variation (Wetzel, 2001). The high concentration of sodium (mean, 452mg/l) and potassium (mean, 141mg/l) in the Tso Morari lake could be due to enrichment of these salts by evaporation. Furthermore, the high concentration of sodium in the lake could also be related to high rate of weathering of sodium rich metamorphic rocks (biotite, kaolinite, actiolite and albite) in its catchment (Steck and Epard, 2008). In Tso Khar mean values of Na and K were significantly high at saline sites TK1 (20356mg/l and 1910 mg/l) and TK4 (17431mg/l and 3426m/l) than fresh water sites. The high sodium and potassium content at TK1 and TK4 could be related to enrichment by evaporation as has also been observed in many evaporative lakes in Tibetan Plateau (Wang and Dou, 1998; Yang *et al*., 2003). Further, the basin is located to geothermally active region and contains number of geothermal springs which add large quantities of Na and K ions (Zheng and Liu, 2009). The Manasbal lake had low values of sodium (8mg/l) and potassium (2.5mg/l) which could be related to low inputs from the rocks in the catchment, low pollution load, continuous flushing of water through outlet and lockup in dense macrophytic vegetation (Pandit, 2002).

Concentration of chloride in an aquatic system is an index, not only of eutrophication, but also of pollution caused by sewage and other waste waters (Munawar, 1970; Hasalan, 1991; Berzas-Nevado *et al.*, 2009). The major sources of chloride are dissolution of rock minerals, pollution and run off from deicing roads. The Tso Morari lake located at high altitude, where human activity in and around the lake is negligible and contribution of Cl^- by sewage and deicing is a remote possibility. Therefore the primary source for Cl^- in these habitats is rock weathering and enrichment by evaporation as is depicted by high values of Cl^- in streams

(33mg/l) and lake (168mg/l). The fresh water sites of Tso Khar had significantly low concentration of Cl^- (81mg/l) than saline water sites (9227mg/l). The sodium and chloride perfectly behave as conserved species that remain in solution throughout the concentration process of brine, whereas other ions are selectively removed (Eugster and Jones, 1979) which leads to Cl^- enrichment (Kilham, 1971; Eugster and Jones, 1979). Furthermore, the re-dissolution of precipitated salts at saline sites is also a significant source of Cl^- (Friedricha and Oberhanslib, 2004). The Manasbal lake recorded low values of Cl^- (15mg/l to 29mg/l) with respect to other two lakes. The high Cl^- content at bottom site is related with decomposition of organic matter and infiltration of ground water (Santos, *et al.*, 2008). The littoral zone of Manasbal has higher amount of Cl^- than limnitic area which is directly attributable to be due to runoff from the catchment and decomposition of macrophytes.

Nitrification rates are regulated by many factors like NH_4 availability (Triska *et al.*, 1990; Jones *et al.*, 1995; Strauss, 1995), pH (Sarathchandra, 1978), temperature (Strauss and Lamberti, 2000), oxygen concentration (Stenstrom and Poduska, 1980; Triska *et al.*, 1990; Verhagen and Laanbroek 1991; Strauss and Dodds, 1997), and organic carbon availability (Verhagen and Laanbroek, 1991; Strauss and Dodds 1997). The principal source of nitrate in Tso Morari lake is the leaching from the catchment which is popular grazing ground for the domestic and nomadic livestock. The stream sites had high nitrate content (375µg/l) during summer months which may be due to high nitrification rates at high temperatures and its subsequent leaching, while lake sites had high nitrate content during winter (334 µg/l) as compared to summer (287 µg/l) which could be attributed to uptake by phytoplankton and macrophytes in summer and their release back into lake water after senescence (Lander, 1982; Goldshalk and Barko, 1985; Xie, *et al.*, 2004; Shilla *et al.*, 2006). Although, salinity and sulfides are reported to limit the nitrification in saline lakes, high concentration of nitrate was observed in saline zone of Tso Khar lake. The high concentration of nitrate may be due to ground water discharge by springs within and around periphery of the lake, and thus provides a direct conduit for nutrient-enriched ground water to move from the aquifer to surface waters (De- Brabandere *et al.*, 2007) as is also reflected from higher concentration of nitrate at spring site. The nitrate content of Manasbal Lake varied from 139µg/l to 279 µg/l. In Manasbal, the high nitrate content was observed in anoxic hypolimnion, a favorable condition for de-nitrification process (Eriksson, 2001; Wetzel, 2001; Schaller *et al*, 2004) and could be attributed to ground water discharge via springs spread along the bottom of lake which act as conduit for nutrient-enriched ground water to move from the aquifer to surface waters (Bacchus and Barile 2005; De- Brabandere *et al.*, 2007). Kennedy *et al*. (2009) also attributed rising nitrate concentration in Florida's oligotrophic freshwater ecosystems to Floridian aquifer. The low nitrate content in littoral zones may be due to rapid uptake and assimilation by macrophytes and their associated flora (Frazer *et al*., 2001; Notestein *et al.*, 2003 and Hoyer *et al*., 2004).

The distribution of ammonia in water is highly variable in lakes and depends upon the level of productivity, sewage inflow, decomposition, nitrogen fertilizers and organic loading (Bowden, 1987; Heathwaite and Johnes, 1995; Ogato, 2007; Lumbreras, *et al.*, 2009). As Tso Morari lake is located in remote area with least human interference and very limited agricultural activity, it seems that decomposition of organic matter within the lake and ammonia leaching from the catchment is the main source of ammonia. In Tso Khar, the saline sites had relatively high concentration of ammonia although these sites were least productive and had high pH which favors the volatilization of ammonia from the lake (Panigatti and Maine, 2003). The high concentration of ammonia at these sites may be linked to ground water discharge from the springs to the lake. This was also depicted by high concentration of NH_3 at spring site (TK3). Similar observations have also been reported by Kazanci *et al*. (2004) from saline Salda lake of Turkey. In Manasbal lake the mean values of NH_3 were significantly higher at bottom site (M5b) than other sites. The high concentration at M5b is due to result of loss of oxidized micro zone at the sediment-water interface under anoxic conditions in hypoliminion which releases significant ammonia in overlying waters (Wetzel, 2001). Furthermore, the development of thermal stratification in lake resulted in anoxic conditions which retards nitrification rate (Strauss and Lamberti, 2000), thus leading to high concentration of ammonia in hypolimnion.

Phosphorus is the key nutrient which limits the plant growth in the surface waters (Wetzel, 2001; Søndergaard, *et al.*, 2003ab; Mehner *et al.*, 2008). The phosphorus content of fresh water mountainous lakes with crystalline bed rock is generally low in comparison to lowland lakes with sedimentary rock deposits. The mean value of total phosphorus for Tso Morari varied from 120µg/l to 647µg/l. According to Smolders *et al*. (2003) the reduction of sulfate and subsequent formation of H_2S lead to Fe reduction, which mobilizes large quantities of phosphorus, promoting release of phosphate (Lamers *et al*., 1998; Smolders *et al*., 2000; Wetzel, 2001). The sulfate reduction also stimulates the mineralization of organic matter by acting as oxidative agent which may further enhance the internal phosphorus loading in Tso Morari Lake. This is the main reason why saline lakes are limited by nitrogen rather than phosphorus (De Decker and Williams, 1988; Herbst, 1998; Khan, 2003). The high total phosphorus content in saline area in Tso Khar may be due to re-suspension of sediments by strong wave action (Maceina and Soballe, 1990; Bengtsson and Hellström, 1992; Kristensen *et al*., 1992). Søndergaard, *et al*. (1992) also observed that internal phosphorus loading through wind-induced sediment re-suspension dominated the shallow Lake Arreso, in Denmark. In Manasbal lake, the large macrophytic cover and phytoplankton facilitate co-precipitation of phosphorus with calcium (Wetzel, 2001; Dittrich *et al*., 2004) and significantly enhance the phosphorous sorption ability of sediments by affecting the contents of organic matter, CEC, Ca, Fe, Al, exchangeable Ca, and oxygen supply, (Vincet, 2001; Liu *et al*., 2004; Jin *et al*., 2005 and Wang *et al*., 2007), thus maintains relatively low total phosphorus concentration in the lake.

The sulfate content in lakes originates from weathering of sulfate containing rocks in the catchment, oxidation of organic sulfur from the terrestrial sources (Holmer and Storkholm, 2001) and recycling of reduced sulfur compounds through re-oxidation (Bak and Pfennig, 1991 and Urban *et al*., 1994). The study revealed that lake sites of Tso Morari had high concentration of sulfate (289mg/l) than incoming streams (39mg/l). The sulfate in incoming stream water subsequently gets enriched in the lake waters by evaporation (Zang *et al*., 2008; Kohfahl *et al.*, 2008). Similarly, high concentration of sulfate (196mg/l) in Tso Khar lake could be attributed to sulfate enrichment by evaporation and high contribution of sulfate through sulfur springs (Zang and Liu, 2009) located within and the periphery of the lake. Furthermore significant amount of sulfate is re-dissolved and released from the sediments into water column from saline lakes which may have also have raised the sulfate content of Tso Khar (Friedrich and Oberhansli, 2004). The low concentration of sulfate in Manasbal Lake is related to low concentration of sulfate in the rocks of the catchment area and short renewal time of the water in open drainage type lakes which prevents the sulfate enrichment (Jeelani and Shah, 2006).

Aluminosilicate minerals are the most abundant in the earth's crust (Schlesinger, 1997) but, owing to their limited solubility, silicates are not the major dissolved ion in water (Stumm and Morgan, 1981). The low silicate values in Tso Morari and Tso Khar lakes contrary to other elements could be due to locking up of silicates in the sediments by the phenomenon of reverse weathering, a major process in closed basins resulting in the reduction of silica through time (Von Damm and Edmond, 1984; Drever, 1988). However, the littoral and limnitic area of Manasbal lake had significantly low silicate content, as compared to hypolimnion. The high concentration in hypolimnion may be due to dissolution of silica from the sediments (Ryves *et al.,* 2006; Reimer *et al*., 2008) and reduced uptake due to low diatom populations.

Concentration of total dissolved solids (TDS) in water varies owing to different mineral solubility's in different geological regions (Connolly *et al.*, 1990). The TDS values in Tso Morari lake ranged from 111 to 724 mg/l. The high TDS values in the lake could be related to evapo-concentration effect (Zhang *et al.*, 2008), which is substantiated by low values of TDS in the tributaries feeding the lake. The TDS values showed significant positive correlation with all the cations, conductivity, Cl^-, and SO_4^{2}in Tso Morari (Table I). In Tso Khar lake, significantly higher (1373mg/L and 1130mg/L) values of TDS were reported at saline sites because of high ionic enrichment at these sites (Herbst, 1998; Kohfahl *et al*., 2008). Similar results were observed by Bowman and Sachs (2008) from saline lakes in Alberta and Saskatchewan. Generally, lakes with higher TDS have Na^+ and Cl^- as the dominant ions, while Ca^{2+} and SO_4^{2-} are the major ions in lakes with lower TDS (Zhang *et al*., 2008) which is also confirmed by the present study. The Manasbal Lake has very high macrophytic cover which enhances sedimentation and counteracts resuspension of sediment particles, and therefore restricts the return of nutrients from sediments (Sóndergaard *et al*., 1992; Kufel and Kufel, 2002) thus maintaining the low TDS values in the lake.

6.2 Sediment Chemistry

The influence of sediment composition on the productivity and distribution of aquatic macrophytes was recognized many years ago in the studies of Pond (1905), Pearsall (1920) and Misra (1938). The studies conducted in a broad variety of aquatic systems have confirmed that sediment composition does exert a major influence on the growth of submersed aquatic vegetation (Moeller, 1975; Sand-Jensen and Sondergaard, 1979; Kiorboe, 1980; Danell and Sjoberg, 1979; Carignan, 1984; Fritz *et al*., 2004; Xiao *et al*., 2007; Li *et al*., 2012). Macrophyte species vary in their response to sediment conditions (Barko and Smart, 1983, 1986) which may influence the species composition of macrophytic communities. It has been reported that changes in water quality due to increased nutrient levels (Roselette, 1991; Coops *et al.,* 2007) and high salinity and sulfide content (Haller *et al.*, 1974; Kovacs *et al*., 1989; Koch *et al.*, 1990; Lathrop *et al*., 2003) has a strong negative impact on the abundance and species composition of the aquatic vegetation in lakes. During the present study, all the three lakes showed variation in sediment characteristics owing to their different geological location and lake features.

The pH is the master variable which determines the availability and mobility of nutrients in sediments (Miao *et al.,* 2006; Urban *et al.*, 2009). The high pH (>8) in the sediments of Tso Morari and Tso Khar could be attributed to high precipitation rates of calcium and magnesium carbonates due to alkalinity production via sulphate reduction reactions from saline water (Kilham and Cloke, 1990; Zang *et al.,* 2008; Rodriguez *et al.,* 2008). Ryves *et al.* (2006) also reported that preferential precipitation of calcium carbonate with increase in salinity leads to increase in pH. The pH of sediments in Manasbal lake was slightly alkaline, except M5 which showed significant decrease in pH. The alkaline nature of sediments could be attributed to calcium rich rocks in the catchment (Zutshi *et al*., 1980; Zutshi and Wanganeo, 1984) and high precipitation of $CaCO_3$ induced by photosynthetic activity of submerged macrophytes (Otsuki and Wetzel, 1972; Wetzel 2001). Conductivity is influenced by a variety of factors like catchment geology, weathering rate, mineralization, lake type and trophic structure of the lake. In Tso Morari lake, higher conductivity values may be related to high concentration of cations and other dissolved ions. This is also supported by the significantly positive correlation of conductivity with exchangeable cations during the present study (Table IV). In Tso Khar lake the conductivity values of saline sites (TK1 and TK4) was significantly higher than fresh water sites (TK2 and TK5), which may be due to high concentration of Na and K, which are precipitated as halite and carnalite from hypersaline lakes (Xhenhao and Wenxuan, 2001). Besides, higher values of Ca, Mg and other soluble ions may have also led to the increase in conductivity values which is also substantiated by significant positive correlation with exchangeable cations (Table V). The low values of conductivity in Manasbal lake could be related to low amount of exchangeable cations in the sediments. Furthermore, the rapid mineralization aided by macrophytes and subsequent uptake of released nutrients by the macrophytes may have decreased the conductivity value of sediments in Manasbal lake.

The organic matter content of sediments is dependent on supply of organic matter via primary productivity, its subsequent retention in sediments and the rate of microbial decomposition (Bianchini, 2006; Rejmankova and Houdkova, 2006). The decomposition of organic matter in aerobic sediments is almost complete and therefore unlikely to accumulate in lakes like Tso Morari which have fairly high dissolved oxygen concentration (Goldshalk and Wetzel, 1976; Farajlla *et al.*, 2000 Peret and Bianchini, 2004). The low concentration of organic carbon could also be attributed to sparse cover and low productivity of macrophytes and other primary producers (Last and Ginn, 2009) and short growing season. The hypersaline zone (TK1 and TK4) of Tso Khar restricted the growth of macrophytes (Haller *et al.*, 1974) which are the major source of organic matter in the lakes (Wetzel, 2001), thus responsible for low levels of organic carbon and matter. The decreases in biodiversity with increase in salinity (Alceocer and Hammer, 1998; Last and Ginn, 2009) may also have decreased the organic matter at saline area of the Tso Khar. In contrast to Tso Morari and Tso Khar, the Manasbal lake had significantly high concentration of organic carbon and organic matter. The high values of organic carbon in Manasbal are attributable to high primary productivity of macrophytes which cover 90% of the lake and high organic loading from the catchment. However, the low value of organic matter at littoral sites could be related to low depth, high oxygen concentration and high temperature which may have accelerated the mineralization rate of organic matter at these sites (Heyer and Kalff, 1988; Kucinskiene and Krevs, 2006).

Nitrogen and phosphorus are considered two most important elements in the functioning of aquatic ecosystems (Ramiez-Olvera *et al.,* 2009). The fresh waters are often limited by phosphorus, however, in estuarine saline and other marine ecosystems, nitrogen has been identified as a key nutrient limiting primary production (De Deckker and William, 1988; Herbst, 1998; Khan, 2003; Carin, 2007). The present study revealed low values of NH_4-N and NO_3-N in Tso Morari which seems to be an important factor responsible for patchy distribution of macrophytes in the lake. The vegetated sites of the lake had relatively high concentration of NH_4-N and NO_3-N (Roman *et al.,* 2001; Kufel and Kufel, 2002). Exchangeable ammonia and nitrate of saline area of Tso Khar lake were higher than fresh water area. The high concentration NO_3-N at saline area might be due to diffusion of nitrate into the sediments from the overlying water column (Revsbech *et al*., 2005) and from groundwater (Reddy and D'Angelo, 1997; Wetzel, 2001). Further, the saline zone has high density of arthropods whose decomposition may also have contributed to increased levels of NH_4-N and NO_3-N. The Manasbal lake had relatively high concentration of exchangeable NH_4-N and NO_3-N in comparison to Tso Morari and Tso Khar which is related to organic loading and high inputs of autochthonous organic matter from the macrophytic vegetation of the lake (Lander, 1982). The hypolimnion has significantly high concentration of NH_4-N and low concentration of NO_3-N which could be due to denitrification process and inhibition of nitrification rate by organic matter especially lignin (White 1988; Strauss and lamberti, 2000; Wetzel, 2001). The high concentration of NO_3-N and low NH_4-N in littoral area could be attributed to high nitrification rate under oxic conditions (Shilla *et al.,* 2006; MaCarthy *et al*., 2007).

Phosphorus is a key element which limits the growth of macrophytes. Sediments are considered as sinks for phosphorus in lakes. The phosphorus retention ability of sediments is regulated to various interacting factors like adsorption to clay minerals, co-precipitation with calcium, Mn and Fe; adsorbed to metal oxide (Al, Mn, and Fe), oxygen and organic carbon (Olila and Reddy, 1995; Wetzel, 2001; Wang *et al*., 2009).

During the present study both exchangeable and total phosphorus in Tso Morari lake was low, however the macrophytic sites had relatively high concentration due to the sedimentation of suspended load carried by the streams from the catchment (Kłosowski *et al*., 2006). The high productivity of macrophytes adds high amounts of organic matter at their seasonal decay, releasing organic phosphorus and nitrogen under rapid bacterial degradation (McCormick and Laing, 2003; Palomo *et al*, 2004) which binds to inorganic particles (Krom and Berner, 1981). This fact is also depicted by significant positive correlation of phosphorus with organic carbon ($r=0.807$; $p<0.01$) and organic matter ($r=0.805$; $p<0.01$) in Tso Morari lake (Table IV). Similar observations were also made by Clark and Watson (2001) from lowland rivers of England. In Tso Khar lake, saline sites had significantly low concentration of both exchangeable and total phosphorus than fresh water sites. The lowest concentration of total phosphorus at saline sites could be attributed to low primary productivity (Khan 2003) which in turn leads to low inputs of organic matter to sediments. This fact is revealed by significant positive correlation of total phosphorus with organic matter (Table V).

The Manasbal lake had high concentration of exchangeable phosphorus and total phosphorus than Tso Morari and Tso Khar. The high concentration of phosphorus in Manasbal lake could be related to high organic matter by macrophytic production (Wang *et al*., 2007). The relatively low phosphorus in the littoral zone could be related to rapid mineralization of organic matter under oxic conditions and subsequent uptake of the phosphorus by the macrophytes (Palomo *et al.*, 2004; Srivastava *et al.*, 2008). Guangwei *et al*., (2006) also attributed low phosphorus in vegetated sites to active assimilation of phosphorus by macrophytes.

The nature of rocks in the catchment and the weathering rates are major source of source of exchangeable cations in the sediments. The exchangeable cations at all the sites in Tso Morari were dominated by magnesium followed by calcium, sodium and least values were observed for potassium. The low concentration of Mg and Ca could be related to sandy nature of sediments, which retain low quantity of nutrients (Chambers *et al.*, 1992; Stone and English, 1993; Clark and Wharton, 2001). In Tso Khar lake, the results indicated that saline area had significantly higher values of Na, K, Ca and Mg than freshwater sites. Kilham and Cloke (1990) reported significant precipitation of $CaCO_3$ and $MgCaCO_3$ in the saline lakes of Tanzania at high pH. Almost similar conditions were present at saline sites of Tso Khar lake. The major mechanism controlling the water chemistry of the Tso Khar lake is the evapo-precipitation (TDS: 1251 mg/l and weight ratio of Na/(Na+Ca) **:** 0.99) where different mineral get precipitated from water column increasing the concentration of different cations in the sediments (Gibbs, 1970). The sodium and potassium may be attributed to chemical precipitation of halite and crossnite (Xhenhao and Wenxuan, 2001) during the evolution process of the brine, while the high content of Ca at saline sites could be attributed to selective precipitation of Ca under high pH (Jones and Weir, 1983) which is reflected by different ionic progression of saline (Na > K >Ca>Mg,) and fresh water (Ca> Mg >Na >K) areas of Tso Khar lake.

The exchangeable cations at all the sites in Manasbal lake were dominated by calcium followed by magnesium and sodium and least was recorded for potassium. The valley lakes have calcium rich rocks in the catchment and could be possible cause of high concentration of calcium in the lake sediments (Zuthsi, *et al.,* 1980; Geelani and Shah, 2006). The high concentration of Na and K is found in eutrophic and hypereutrophic lakes receiving high sewage load (Bhat, *et al.,* 2001), however, low sewage load in Manasbal are possible reasons of low values of Na and K in sediments. However, significant positive correlation was found between cations (Table VI).

6.3 Macrophytes

The distribution and diversity of macrophytes is influenced by geographical factors like altitude (Lacoul, 2004; Lacoul and Freedman, 2006ab), latitude (Chambers *et al.*, 2008), size of water body (Ronal and Maltchik, 2006), transparency, depth, light (Spence, 1982; Dale, 1986; Wetzel, 2001; Hopson and Zimba, 2003), nutrient enrichment (Gacia, 1994; Moller and Martin, 2003; Macmets and Friberg, 2005) and salinity (Haller *et al.*,1974; Harper *et al.*,2003). The influence of water chemistry on aquatic plant richness has been described as major predictor of species distributions and the highest macrophyte diversity is observed in mesotrophic or slightly eutrophic ecosystems (Rørslett, 1991; Vestergaard and Sand-Jensen, 2000, Heegaard *et al.*, 2001; Murphy, 2002). As the three lakes were located in different altitudinal and climatic zones and has contrasting geochemistry, only one species *Potamogeton pectinatus* was found to be common in all the three lakes. Further, the lakes also differed in their salinity content with some parts of Tso Khar lake being hyper-saline which was devoid of any macrophytic vegetation. The Tso Morari lake was slightly brackish and deep which restricted the macrophytic vegetation to littoral zone only. However, the Manasbal lake belongs to fresh water mesotrophic category and thus had highest diversity of macrophytes.

The macrophytic community of Tso Morari was represented by the mono-specific stands of *Potamogeton pectinatus* (family Potamogetonaceae). *P. pectinatus* is one the most cosmopolitan submerged macrophytic species (Sculthorpe, 1967) and grows in dense stands with an extensive rootstocks in a wide range of salinity (Van Dijk *et al*., 1992) and altitude (Seimon *et al*., 2007). The high density of *P. pectinatus* at confluence points of tributaries seems to be due to high nutrient content and loamy texture of sediments which are favorable for its optimum growth. The low density and abundance of the species at site TM7 could be attributed to sandy texture which has low fertility status (Barko *et al.*, 1991). The low macrophytic diversity in the lake is attributable to high altitude of the lake and salinity (Harper *et al.*, 2003; Chambers *et al*., 2008).

In Tso Khar lake the macrophytic vegetation was represented by association of *P. pectinatus* and *R. aquatalis*. Both the species belonged to submerged vegetation class and were observed only at fresh water area. The high salinity and sulfide content restrict the growth of macrophytes in saline area of the Tso Khar and thus renders the area without vegetation (Haller *et al*., 1974; Kovacs *et al*., 1989; Koch *et al.*, 1990 Lathrop *et al*., 2003). Further, the low diversity in the fresh water zone seems to be attributable to high altitude of the lake. The IVI of macrophytic community revealed the dominance of *P. pectinatus* over *R. aquatalis*, which seems to be its strong competitive strategy (Grime, 1979), cosmopolitan nature (Sculthorpe, 1967) and ability to tolerate wide range of salinity (Van Dijk *et al*., 1992; Spinke, 1993).

Manasbal lake belonging to fresh water category and having mesotrophic status had highest number of macrophytic species. A total of 37 macrophytic species were recorded in the lake which represented all the four life form-classes i.e., emergents (40%), rooted floating leaf type (22%), submerged (27%) and free floating (11%). The submerged macrophytes cover significant area of the lake, while the emergent floating and rooted floating types together constituted less than 20% of the lake area. The Sorenson’s similarity index based on species composition indicate that site M1 had high degree of similarity with site M4 (71%), M3 (67%) and M2 (66%), which may be due to their littoral nature and similarity in their sediment and water characteristics as was observed during the present study. Further, all the sites have almost similar dominance pattern of macrophytes which may also have resulted in high similarity between the sites. The central site (M5) which was devoid of any macrophytic vegetation did not show any similarity with other sites.

The study of IVI values revealed that *C. demersum* was the dominant species at M1, M2 M3 and co-dominant at M4 indicating its absolute dominance over other species in the Manasbal lake. At site M4, *M. spicatum* was most dominant species followed by *C. demersum*. The dominance of *C. demersum* over other species is attributed to variety of life strategies under different environmental condition like it grows as free floating mats in polluted lakes (Melzer, 1999; Lombardo and Cooke, 2003) and descends to greater depths in oligotrophic and mesotrophic lakes (Trapp, 1995). In the present study the species was growing as free floating at site M2 indicating the high pollution load, while at rest of sites it grows as submerged. Moreover, dominance of *C. demersum* is due to its high vegetative propagation, cosmopolitan nature (Foroughi *et al*., 2010), lack of true roots, and high surface area: volume ratio, which makes it a strong competitor for nutrients (Hernández *et al.*, 1999). The dominance of *M. spicatum* at site M4 could be attributed to relatively low nutrient status at this site.

The Shannon’s diversity index showed high diversity of macrophytes at site M4 (2.14±0.55) and lowest at site M2 (1.53± 0.59). The low diversity at M2 may be related to high organic matter concentration (Walker, 1972, Wetzel, 1979, Carpenter, 1981), high concentration of ammonia and low transparency (Kufel and Kufel, 2002). Thiebaut *et al*. (2002) found that at low phosphate concentrations, species sensitive to phosphate enrichment and cosmopolitan species coexist in macrophyte community, but at high phosphate concentrations macrophytic community lacks sensitive species and are dominated by tolerant species. The present study also confirmed the fact that sensitive species like *Chara spp* and *Hydrilla sp*. were absent at site M2 due to high concentration of phosphorus. However, the reasons for high diversity at site M4 may be due to low organic matter, nitrate and phosphate concentration and relatively high transparency (Oertli *et al*., 2000).

In the present study it was found that macrophytic species richness in the lakes decreased with increase in altitude (Gacia *et al.,* 1994) and salinity. Lacoul and Freedman (2006a) also reported linear decrease in species diversity with increase in altitude in Nepal Himalayas and has been related to low speciation at high altitudes (Jacobsen and Terneus, 2001). Similarly, Harper *et al.* (2003) reported that the hypersalinity of inland waters restrict the growth of macrophytes. Similar results were found in saline area of Tso Khar which supports no macrophytic vegetation. As Manasbal lake is situated at slightly lower altitude (1580m) it recorded highest species richness. Furthermore, the high species richness may be also related to its mesotrophic status (Murphy, 2002).

6.4 Impact of geochemistry on vegetation dynamics in the lakes

A variety of environmental factors interact, in affecting the species composition, distribution and productivity of macrophytic communities. Foremost among these are light, water temperature, sediment composition and inorganic carbon availability. Light, depth and temperature are important in determining morphology and distribution (with altitude, season and depth), thereby influencing productivity and species composition as well. Sediments provide an important source of nutrients, principally N, P, and micronutrients, which are relatively less available in the upper layers of water column of most aquatic systems (Barko *et al*., 1986). In order to study whether geochemistry of the lakes influenced macrophytic vegetation directly or through the overlying water column the study sites within each lake were categorized into two types.

1. Vegetative sites:- Sites where macrophytic vegetation was present were grouped together under this category.

2. Non vegetative sites:- Sites where macrophytic vegetation was absent were grouped together under this category.

Analysis of variation was carried out to see if there was any significant variation in the water and sediment characteristics between the two categories (Table VII to Table XX).

6.4.1. Tso Morari Lake

As only one species of macrophyte (*Potamogeton pectinatus*) was present in the lake the sites could be easily grouped into vegetative and non vegetative sites. Site TM2, TM4, TM7 represented macrophytic sites, while site TM6, TM5 and TM5b represented non-macrophytic sites. Perusal of the data revealed that the mean values of depth, transparency and sulphate showed significant difference between the vegetative and non-vegetative sites (Table XIII). Mean depth was significantly ($F_{1,\ 42}$ = 1832.45; p = 0.000) lower at macrophytic sites (4.24±0.34m) than that of non-macrophytic sites (41.72±0.87m). Although mean water transparency was significantly ($F_{1,\ 42}$ = 201.846; p = 0.000) higher at non-macrophytic sites (15.77±0.91m) than macrophytic sites (3.40±0.25m), the ratio of depth to transparency was however, lower for macrophytic sites. As macrophytic vegetation of Tso Morari was restricted to littoral zones it appears that macrophytic distribution was regulated by the depth, rather than chemistry of water. Water depth is regarded as a major factor structuring vegetation (Wetzel, 1979; Spence, 1982), while light is a primary factor determining distribution of submerged plants in lakes (Duarte *et al*. 1986). This is because submerged plants are able to assimilate nutrients from sediment and water (Denny, 1972; Barko and Smart, 1981a) but low transparency values may have reduced the light necessary for photosynthesis (Boedeltje et al., 2005). Similarly, mean sulphate concentration at non-macrophytic sites (344±25mg/l) was significantly ($F_{1,42}$=8.416; p = 0.006) higher than macrophytic sites (235±27mg/l). The data revealed that among the water parameters, conductivity, CO_2, TP, total hardness, Ca, Mg, Na, K, Cl, NO_3, Si and TDS had lower mean values at macrophytic sites than non-macrophytic sites. Similarly, water temperature, pH, DO, total alkalinity and NH_4 had slightly higher mean values at macrophytic sites than those of non-macrophytic sites. However, the above parameters did not show any significant variation between macrophytic and non macrophytic sites.

The data on sediment chemistry revealed that the mean values of sediment organic carbon, organic matter, NH_3-N, exchangeable phosphorus, total phosphorus and exchangeable K, were significantly ($p < 0.05$) higher at vegetative sites when compared to non-vegetative sites. The mean values of sediment conductivity, NO_3, exchangeable Ca, Mg, and Na were statistically insignificant between the vegetative non-vegetative sites. Thus the results indicate that sediment nutrient status has significant effect on distribution of macrophytes, however, macrophytic vegetation inturn also alters the sediment chemistry for their continued existence.

6.4.2. Tso Khar Lake

In Tso Khar lake two species of macrophytes (*P. pectinatus and R. aquatalis*) were recorded during the study period. In this Lake, site TK2 and TK5 represented vegetative sites, while TK1 and TK4 represented non-vegetative sites. The results depicted that the mean values of conductivity, total alkalinity, total hardness, Ca, Mg, Na, K, Cl, NO_3, NH_4, SO_4, and TDS were significantly ($p < 0.05$) higher at non-vegetative sites when compared with vegetative sites (Table XV). However, the mean values of DO were significantly ($F_{1,34} = 15.57$; $p = 0.000$) lower at non-vegetative sites than that of vegetative sites. The mean values of air and water temperature, depth, transparency, CO_2 and silicate were higher, while pH and TP were lower at vegetative sites than that of non-vegetative sites, although the difference was not significant ($p > 0.05$). The results indicate that the macrophytic community of Tso Khar is limited by high salt content (Haller, *et al*, 1974). Further high sulphide content which is well known phototoxic compound may have also limited the growth of macrophytes (Kovacs *et al.* 1989; Koch *et al.*, 1990; Lathrop *et al.*, 2003). High concentration of SO_4, Na, Cl and other elements in saline environments can directly limit the growth and distribution of submerged macrophytes (Barko *et al*., 1986).

The sediment chemistry of the Tso Khar lake showed that the mean values of OC, OM exchangeable P and total P were significantly higher at vegetative sites than that of non-vegetative sites. Similarly, the mean values of pH, conductivity, NO_3, exchangeable Ca, Mg, Na and K were significantly higher at non-vegetative sites when compared with vegetative sites. The results showed that macrophytic vegetation was limited due to high salinity and low organic matter content which may have changed the nutrient concentration necessary for macrophytes.

6.4.3 Manasbal Lake

In case of Manasbal lake only one site M5, was without any vegetation, while all other sites having diverse vegetation. At sites M1, M2 and M3 *C. demersum* was dominant species; while at site M4 *M. spicatum* was the dominant species. However, on comparing the non-vegetative site M5 with other sites the mean values of depth and transparency were significantly ($p < 0.05$) higher than other vegetative sites. The mean values of Cl and NO_3 were significantly ($p < 0.05$) lower than other sites except site M3, while mean values of silicate were significantly ($p < 0.05$) higher except site M1. The results indicate that macrophytic distribution was mainly limited by depth (Spence, 1982; Hpson and Zimba, 2003), while nutrient concentrations had no effect on vegetation but they may have altered the composition of different macrophytes as was depicted by distribution of macrophytes at different sites.

As most of the sites in Manasbal lake were covered with macrophytic vegetation except site M5 which was located in the centre of the lake, all the sites were analyzed separately for sediment chemistry due to variation in the vegetation cover at these sites. The non-vegetative site M5 was compared with other vegetative sites (M1, M2, M3 and M4). Perusal of the data indicated that except exchangeable Ca and Mg all the parameters showed significant ($p < 0.05$) variation between the study sites. The mean values of total P and exchangeable Na were significantly higher at non-vegetative site M5 than other vegetative sites. Similarly, the mean values of conductivity, OC, OM, NH_3, exchangeable P and exchangeable K were significantly higher at non vegetative site M5 when compared to other vegetative sites except site M2. However, the mean pH value was significantly ($p < 0.05$) lower at non-vegetative sites as compared to other sites. Many aspects of the sediment type including nutrient availability, organic content and redox potential may additionally affect macrophytic plants. For example, organic matter additions to sediments negatively influenced the growth of *M. spicatum*. (Barko and Smart, 1983). Similarly, high organic matter at non vegetative site which was significantly deep and more transparent than other vegetative sites may be due to transport from littoral vegetative sites. Low light availability and anoxic, muddy sediments may be key factors hampering growth of macrophytes (Boedeltje *et al*., 2005).

Overall the results of present study indicate that the structure and composition of macrophytes in the three lakes is regulated mainly by altitude and salinity, however, changes in depth, transparency, light, texture and nutrient availability especially organic matter, N and P, in sediments as well as overlying water column also has a major influence on their distribution.

Chapter 7

CONCLUSIONS

7. Conclusions

It can be concluded that the differences observed in geochemistry of the studied lakes are apparently due to differences in climatic condition, rock dominance in catchment, land use, drainage, geothermal springs and evapo-crystallization processes. Tso Morari and Tso Khar are high altitude (>4500m a.m.s.l) land locked lakes located in an arid cold desert of Ladakh which favors the development of saline lakes, while the Manasbal is low altitude(1600m a.m.s.l) open drainage lake situated in the temperate valley of Kashmir which retards salinisation process. The Tso Morari is fed by glacial streams, Tso Khar is fed by glacial streams as well as geothermal springs and the loss of water is only through evapotranspiration and seepage, while the Manasbal is mainly fed by fresh water springs and forms a part of the Jhelum river system. Tso Morari is a large and very deep (Z_m >110m) brackish water body, Tso Khar is very shallow (Z_m < 5m) water expanse divided into two distinct parts, one fresh and the other salt water and the Manasbal is deep (Z_m =12.5m) fresh water body. Both Tso Morari and Tso Khar remain ice covered for three to four months during winter when the atmospheric temperature may dip down to as low as -40 ^{o}C, while in case of Manasbal lake the temperature never dipped below 4°C. Accordingly Tso Morari can be classified as cold monomictic water body and Manasbal lake as warm monomictic lake.

The high alkaline pH of Tso Khar and Tso Morari was due to enrichment of incoming waters as a result of evapo-concentration effect and alkalinity generated by sulfate reduction, while in case of Manasbal lake, pH fluctuations were mainly influenced by the photosynthetic activity of submerged macrophytes and calcareous catchment. The higher conductivity values in Tso Morari and Tso Khar lakes were related to the presence of high Na^{+}, $K^{+,}$ Cl^{-} and Mg^{2+} content, which was got concentrated in lake waters due to evaporation, the much higher ionic content in Tso Khar lake being influenced by inflow from by geothermal springs and enrichment process. Turbulent mixing of lake water by high velocity winds and diurnal thermal convection maintained the uniform distributed of DO in Tso Morari, whereas partial inhibition of photosynthesis by hypersalinity led to very low dissolved oxygen production at saline sites of Tso Khar. In case of Manasbal lake the luxuriant growth of submerged macrophytes acted as the main source of aeration for the lake.

The water of the Tso Morari Lake as well as its streams was alkaline as a result of carbonate weathering as depicted by $Ca^{2+} + Mg^{2+}$**:** HCO_3 ratio in the Tso Morari. The high alkalinity of saline area of Tso Khar was attributable to the sulfate reduction and high concentration of soda. The alkalinity of Manasbal lake was chiefly due to bicarbonate ions. However, carbonates were found only in summer season in minor quantities and could be attributed to high photosynthetic rate of macrophytes and periphyton, which use bicarbonate as a carbon source, thus increases pH and consequently shifts the chemical equilibrium towards the formation of carbonate ions which then precipitate with calcium in the form of calcite that significantly leads to decline of alkalinity.

The geochemical evolution in evaporative lakes without river outlets is primarily controlled by inflow composition, selective removal processes of dissolved species, and concentration processes in the lake basin. Inflow streams around Tso Morari are the major supply of the lake water and thus contribute most of the ionic load. The cation composition of the three lakes showed significant difference which reflects their catchment characteristics and evapo-crystallization processes. The cation progression of Tso Morari was Mg> Ca >Na >K which suggests the lake water to be depleted in Ca and enriched with Mg due to selective precipitation of Ca at high pH. The cation progression of saline area of Tso Khar was Na> K> Mg>Ca which showed that the lake is enriched with Na and K as they behave as perfectly conserved species. Further, the basin of this water body is located in geothermally active region and contains number of geothermal springs which add large quantities of Na and K ions.

The cation progression of Manasbal lake was Ca > Mg > Na > K which reflect dominance of Ca over other cations which is relate with the Ca rich lime rocks in the catchment and low pollution load.

The principal source of nitrate and ammonia in Tso Morari lake is the leaching from the catchment which is popular grazing ground for the domestic and nomadic livestock. The stream sites had high nitrate content during summer months which may be due to high nitrification rates at high temperatures and its subsequent leaching. The high concentration of nitrate and ammonia in saline zone of Tso Khar lake may be linked to ground water discharge from springs within and around periphery of the lake, while the low nitrate and ammonia content in Manasbal is due to rapid uptake and assimilation by macrophytes and their associated flora.

The high phosphorus content in Tso Morari and Tso Khar was related to internal phosphorus loading enhanced by sulfate reduction in sediments by affecting redox potential and stimulating mineralization of organic matter. The re-suspension of sediments by strong wave action may have increased the total phosphorus content in saline area in Tso Khar. In Manasbal lake, the large macrophytic cover facilitate co-precipitation of phosphorus with calcium and significantly enhance the phosphorous sorption ability of sediments by affecting the contents of organic matter, CEC, Ca, Fe, Al, exchangeable Ca, and oxygen supply, thus maintains relatively low total phosphorus concentration in the lake. The Tso Morari and Tso Khar lake has high concentration of sulfate content than feeding streams and springs which suggest sulfate enrichment in these lakes.

The preferential precipitation of calcium carbonate with increase in salinity leads to increase in pH of Tso Morari and Tso Khar. The pH of sediments in Manasbal Lake was slightly alkaline. The low concentration of organic carbon and organic matter in the Ladakh lakes could be attributed to sparse cover and low productivity of macrophytes and other primary producers and short growing season. In the hypersaline zone of Tso Khar the growth of macrophytes gets restrict by partial inhibition of photosynthesis. In contrast to Tso Morari and Tso Khar, significantly high concentration of organic carbon and organic matter in the Manasbal lake could be attributed to high primary productivity of macrophytes which cover 90% of the lake and high organic loading from the catchment. The relatively high concentration of exchangeable Manasbal NH_4-N and NO_3-N of Manasbal lake is related to organic loading and high inputs of autochthonous organic matter from the macrophytic vegetation.

The exchangeable cations in Tso Morari were dominated by magnesium followed by calcium, sodium and potassium. There was high sodium and potassium content as compared to Ca and Mg in saline area of Tso Khar, which seems to be attributable to chemical precipitation of halite and crossnite during the evolution process of the brine. The exchangeable cations at all the sites in Manasbal lake were dominated by calcium followed by magnesium and sodium and least was recorded for potassium.

During the investigation 38 macrophytic species, belonging to 29 genera and 23 families were recorded from the three lakes. *Potamogeton pectinatus* was the only species occurring in all the three lakes. The Tso Morari recorded monospecific strands of *P. pectinatus* in its littoral zone only. The Tso Khar recorded mixed stands of *P. pectinatus* and *Ranunculus aquatalis* only in its freshwater zone and the saline area didn’t support any macrophytic vegetation. The low macrophyte diversity in both these waters is attributable to high altitude and salinity which limit speciation and restrict macrophytic growth. The macrophytic community of Manasbal Lake was represented by all the four life form-classes- emergents (40%), rooted floating leaf type (22%), submerged (27%) and free floating (11%). However, the submerged macrophytes cover significant area of the lake, while as emergent floating and rooted floating types together constituted less than 20% of the lake area. *C. demersum* had absolute dominance over other species in the lake, which is related to its high vegetative propagation, cosmopolitan nature, lack of true roots, and high surface area: volume ratio, all these characteristics making it a strong competitor for nutrients. Most of macrophytic species found in Manasbal are cosmopolitan and show no preference for sediments of a particular fertility due to their similar morphological and nutritional requirements. In Manasbal species like *Chara* spp, *M. spicatum*, *H. verticillata* preferred high transparency, low concentrations of phosphorus, conductivity and organic carbon, whereas *C. demersum* and *P. pectinatus* were associated with high values of total phosphorous, organic matter and conductivity. However, nutrient preferences to community level are more apparent than individual species which is reflected by high species diversity and richness at least polluted sites.

On the whole it may be concluded that the geochemistry of the lake sediments, which was in itself influenced by the chemistry of the inflowing water and the evapo-concentration process in the lakes, governs the occurrence and abundance of the various macrophytes taxa in the three lakes. Overall the results of present study indicate that the structure and composition of macrophytes in the three lakes is regulated mainly by altitude and salinity, however, changes in depth, transparency, light, texture and nutrient availability especially organic matter, N and P, in sediments as well as overlying water column also has a major influence on their distribution.

Chapter 8

SUMMARY

8. SUMMARY

- High altitude lakes are unique in North-western Himalaya, where the association between tectonic, geomorphologic features, altitude and arid climate allows the formation of different water bodies with varying depth and salinity. However, these lakes have received very little attention due to remote location and very high altitude. During the present study geochemistry of Tso Morari, Tso Kar and Manasbal lakes and its effects on vegetation dynamics were studied during 2004 to 2006. Tso Morari and Tso Khar are situated in Ladakh region having desert type of climate where evaporation exceeds precipitation and therefore favours development of saline lakes. Manasbal lake is a fresh water lake located in Kashmir Valley which experience temperate climatic conditions where precipitation exceeds evaporation.
- Tso Morari is brackish and deep land locked lake, fed by several springs and glacial streams originating from high mountain glaciers. The major tributaries to the lake include the Gyoma in the Northern end, Korzuk in the North western side and Phersey stream from southwest side of the Lake. As a closed-basin lake, the only loss of the water is through evaporation.
- Tso Khar is a hyper saline and shallow land locked lake situated at an altitude of about 4500 masl in Rapsu valley of Zanaskar range. The basin receives water from nearby glaciers mainly in spring and early summer via the periodically active Pulong Kha Phu river from the east and the perennial Nuruchan Lungpa river from the south. Both rivers enter the freshwater lake Startsabuk Tso, while the hyper-saline Tso Kar is only fed by water exchange through a small conduit 6 to 8 meters in width and 2.5 km long between both lakes. There are number of freshwater and hot springs within and around the periphery of the lake basin.

- Manasbal is the deepest, fresh water Valley lake of Kashmir situated at an altitude of 1590 masl covering an area of 2.8 Km^2. The Manasbal lake does not have any prominent inlet and receives water through springs found in and around the lake. A small stream which is dry for most part of the year brings water to Manasbal during spring and summer season. The lake is connected to River Jhelum through an outlet called Nunnyar.

Water chemistry

- On the basis of habitat structure, 7 site in Tso Morari, 5 in Tso Khar and 5 in Manasbal were selected to study the water chemistry. Tso Morari being very deep can be easily classified as cold monomictic water body, while Tso Khar being shallow could not be assigned to any category on the basis of thermal stratification. Mansbal lake remains stratified for a period of 8 to 9 months from March to November and mix up only during the winter months of December to February and hence is categorized as warm monomictic lake.
- The physico-chemical analysis of the water samples revealed significant difference between the lakes. The Water chemistry in lake ecosystems is controlled mainly by three important factors viz. precipitation, evaporation and rock dominance in the catchment. The three water bodies showed significant differences in the transparency. Tso Morari being the deepest had highest values of transparency followed by Manasbal and Tso Khar.
- The pH of the three lakes was alkaline due to presence high quantities of carbonates of calcium and magnesium. The alkaline pH of Tso Khar and Tso Morari was due enrichment of incoming waters as a result of evapo-concentration effect and alkalinity generated by sulfate reduction. Whereas in Manasbal lake the calcareous catchment and photosynthetic activity of submerged macrophytes regulated the alkaline pH of water.

- The highest conductivity was found in Tso Khar followed by Tso Morari and least in Manasbal. The conductivity of Ladakh lakes was influenced by dry climatic conditions, closed drainage, and geothermal springs. The conductivity of Manasbal lake was influenced by continuous flushing and high precipitation rate of valley.
- The dissolved oxygen of the lakes showed significant fluctuations. The dissolved oxygen of the three lakes decreased in the order of Manasbal> Tso Morari> Tso Khar. The high TDS, salinity and low atmospheric pressure of Ladakh lakes maintain low dissolved oxygen in the water.
- The carbon dioxide was absent from the Tso Morari and Tso Khar except in streams and springs sites, while the carbon dioxide was always present in the Manasbal lake except during extensive photosynthetic rate in summer. The alkalinity of Tso Morari and Tso Khar was very high as compared to Manasbal lake and was contributed by both carbonates and bicarbonates. In Manasbal Lake, the alkalinity was dominated by bicarbonate ion. The hardness of the three lakes also showed significant differences. The highest hardness was recorded in Tso Khar followed by Tso Morari and Manasbal. The hardness of the Ladakh lakes was contributed by Ca and Mg carbonates, sulfate and chloride ions, while the hardness of Manasbal lake was solely due to Ca and Mg carbonates.
- The cation composition of the three lakes showed significant difference which reflects their catchment characteristics and evapo-crystallization processes. The cation progression of Tso Morari was Mg> Ca >Na >K which suggest lake water is depleted in Ca and enriched with Mg. The cation progression of saline area of Tso Khar was Na> K> Mg>Ca which showed that lake is enriched with Na and K and depleted in Mg and Ca. The cation progression of Manasbal lake was Ca > Mg>Na >K. The Tso Khar lake had highest Cl concentration than Tso Morari and Manasbal lake.

- The nitrate content of the three lakes did not show significant variation, except at saline sites of Tso Khar which had significantly high concentration of nitrate. The ammonia content of Tso Khar was highest followed by Manasbal and Tso Morari. The total phosphorus was highest in Tso Morari followed by Tso Khar and Manasbal. Due to presence of sulfate which accelerates the internal phosphorous loading resulting in high concentration of phosphorous.
- The Tso Morari and Tso Khar lake has high concentration of sulfate content than feeding streams and springs which suggest sulfate enrichment in these lakes. The sulfate content of Manasbal lake was lowest of the three lakes. The silicate content of the three lakes was almost similar having values below 20 mg/l. TDS values of the three lakes were significantly different. The saline area of Tso Khar lake had TDS value above 1000mg/l followed by Tso Morari and least was recorded in Manasbal lake.

Sediment Chemistry

- Surface sediments were collected on seasonal basis from the selected sites used for water sampling and analyzed for various physicochemical parameters. During the present study, all the three lakes showed significant variation in sediment characteristics owing to their different geological location and lake features.
- The pH of surface sediments in the lakes remained alkaline throughout study period. The Ladakh lakes had high pH (>8), particularly the saline area of Tso Khar (> 10). The Manasbal Lake had low pH (<8) values than Ladakh lakes. The highest conductivity was found in Tso Khar sediments followed by Tso Morari and least was recorded in Manasbal lake.
- The organic carbon and organic matter of sediments in Tso Morari and Tso Khar was low due to low diversity and low productivity of these two lakes as compared to Manasbal lake. The nitrate and ammonia concentration of Tso

Morari sediments was high at vegetated sites than non vegetated sites, however in Tso Khar lake saline sites had high concentration of nitrate and ammonia. The Manasbal lake had low concentration of nitrate and ammonia as compared to other two lakes. The total phosphorus of the three lakes showed significant differences being highest in Manasbal lake followed by Tso Morari and Tso Khar.

- The cations of the three lakes also showed varied patters and differences. The high cation concentrations were observed at saline area of Tso Khar, followed by Tso Morari and least was recorded in Manasbal lake. However, the cation progression was similar Ca>Mg>Na>K in the sediments of Tso Morari, Manasbal and fresh water sites of Tso Khar. The cation progression at saline area of Tso Khar was Na>K>Ca>Mg.

Vegetation

- The macrophytic vegetation survey carried out at different study sites in the three lakes during the investigation period resulted in identification of 38 macrophytic species, belonging to 29 genera and 23 families.
- As the three lakes were located in different altitudinal and climatic zones, only one species *Potamogeton pectinatus* was found to be present in all the three lakes. The macrophytic species richness during the present study decreased with increase in altitude and salinity.
- The macrophytic vegetation of Tso Morari was represented by monospecific strands of *Potamogeton pectinatus*. The macrophytic density was very high at confluence sites with silty sediments and low at sandy sites. The macrophytic vegetation was restricted to littoral zone only.
- The macrophytic vegetation of Tso Khar was represented by *Potamogeton pectinatus* and *Ranunculus aquatalis.* The saline area of the lake does not

support any macrophytic vegetation. The community was dominated by the *Potamogeton pectinatus.*

- The macrophytic vegetation at Manasbal lake was represented by 37 species belonging to 22 families and 28 genera.
- The macrophytic community of Manasbal Lake was represented by all the four life form-classes belonging to emergents (40%), rooted floating leaf type (22%), submerged (27%) and free floating (11%). However, the submerged macrophytes cover significant area of the lake, while as emergent floating and rooted floating types together constituted less than 20% of the lake area.
- The Sorenson's similarity index based on species composition indicate that site M1 had high degree of similarity with site M4 (71%), M3 (67%) and M2 (66%), which may be due to their littoral nature and similarity in their sediment and water characteristics as was observed during the present study.
- The study of IVI values revealed that *Ceratophyllum demersum* was the dominated species at M1, M2 M3 and co-dominant at M4 indicating its absolute dominance over other species in the Mansbal Lake.
- The Shannon's Diversity Index showed high diversity of macrophytes at site M4 (2.14±0.55) and lowest at site M2 (1.53± 0.59).

Impact of geochemistry on vegetation dynamics

- The geochemical environment of the lakes had impact on vegetation dynamics. The present study showed that three lakes had significant differences in their geochemistry, which is influenced by climatic conditions, catchment characteristics and drainage pattern of the lakes. A variety of environmental factors interact, in affecting the productivity, distribution and species composition of macrophytic communities. Foremost among these are light, water temperature, sediment composition and inorganic carbon availability. Light, depth and temperature are important in determining morphology and distribution (with altitude, season and depth), thereby influencing productivity and species composition as well.

- The macrophytic vegetation of Tso Morari was restricted to littoral zones and it appears that macrophytic distribution was regulated by the depth, rather than chemistry of water. The mean values of depth, transparency and sulphate showed significant difference between the vegetative and non-vegetative sites and hence may be responsible for structuring the vegetation in Tso Morari lake.
- The sediment characteristics also had a significant impact on vegetation. The mean values of sediment organic carbon, organic matter, NH_3-N, exchangeable phosphorus, total phosphorus and exchangeable K, were significantly ($p < 0.05$) higher at vegetative sites when compared to non-vegetative sites**.**
- The geochemical chemistry of Tso Khar revealed two significant regions in the lake, one being saline and other as fresh water. The fresh water sites were dominated by *potamogeton pectinatus and Runanculus aquatalis* and the saline area of the lake was devoid of vegetation.
- The results indicate that the macrophytic community of Tso Khar is limited by high salt content, and low concentration of dissolved oxygen and low organic matter in the sediments. Further high sulfide content which is well known phototoxic compound may have also limited the growth of macrophytes.
- In Manasbal lake macrophytic species showed broad tolerances to different water and sediment variables. The macrophytic distribution was mainly limited by depth, while nutrient concentrations had no effect on vegetation but they may have altered the composition of different macrophytes as was depicted by distribution of macrophytes at different sites.
- Some species like *Chara* spp, *Myriophyllum spicatum*, *hydrilla verticillata* appeared to be associated with high transparency and low concentrations of phosphorus, conductivity and organic carbon. *Ceratophyllum demersum* and *P.*

pectinatus were associated to high values of total phosphorous, organic matter and conductivity, while other species seem to be able to grow throughout the range of concentrations encountered.

- Many species are cosmopolitan and show no preference for sediments of a particular fertility due to their similar morphological and nutritional requirements, therefore makes it very difficult to separate the individual species on the basis geochemical parameters of the water and sediments. However nutrient preferences to community level are apparent than individual species which is reflected by high species diversity and richness at least polluted sites. Further, low light availability together with anoxic and muddy sediments are the key factors hampering growth of macrophytes.
- The differences in geochemistry of the studied lakes are apparently due to differences in climatic condition, rock dominance in catchment, land use, drainage, geothermal springs and evapo-crystallization processes.
- The geochemical evolution of Ladakh lakes is primarily controlled by inflow composition, selective removal processes of dissolved species, and evapo-crystallization processes in the lake basin. The cation progression of Tso Morari was Mg> Ca >Na >K which suggests the lake water to be depleted in Ca and enriched with Mg due to selective precipitation of Ca at high pH. The cation progression of saline area of Tso Khar was Na> K> Mg>Ca which showed that the lake is enriched with Na and K as they behave as perfectly conserved species. The cation progression of Manasbal lake was Ca > Mg>Na >K,which reflect dominance of Ca over other cations which is relate with the Ca rich lime rocks in the catchment and low pollution load.
- The principal source of nitrate and ammonia in Tso Morari lake is the leaching from the catchment which is popular grazing ground for the domestic and nomadic livestock. The high concentration of nitrate and ammonia in saline zone of Tso Khar lake may be linked to ground water discharge from springs within and around periphery of the lake, while the low nitrate and ammonia content in

Manasbal is due to rapid uptake and assimilation by macrophytes and their associated flora.

- The high phosphorus content in Tso Morari and Tso Khar was related to internal phosphorus loading enhanced by sulfate reduction in sediments by affecting redox potential and stimulating mineralization of organic matter. The relatively low total phosphorus concentration in Manasbal lake are maintained by the large macrophytic which facilitate co-precipitation of phosphorus with calcium and significantly enhance the phosphorous sorption ability of sediments by affecting the contents of organic matter, CEC, Ca, Fe, Al, exchangeable Ca.
- The low concentration of organic carbon and organic matter in the Ladakh lakes could be attributed to sparse cover and low productivity of macrophytes and other primary producers and short growing season. In contrast to Tso Morari and Tso Khar, significantly high concentration of organic carbon and organic matter in the Manasbal lake could be attributed to high primary productivity of macrophytes which cover 90% of the lake and high organic loading from the catchment.
- The relatively high concentration of exchangeable Manasbal NH_4-N and NO_3-N of Manasbal lake is related to organic loading and high inputs of autochthonous organic matter from the macrophytic vegetation whereas, low NH_4-N and NO_3-N in Tso Morari and Tso Khar are related to low productivity and short growing season.
- The exchangeable cations in Tso Morari and Tso Khar were influenced by selective precipitation of salts like, calcite, dolomite, halite and crossnite during the evolution process of the brine, while the exchangeable cations in Manasbal lake were influenced by catchment lithology.
- During the investigation 38 macrophytic species, belonging to 29 genera and 23 families were recorded from the three lakes. *Potamogeton pectinatus* was

the only species occurring in all the three lakes. The Tso Morari recorded monospecific strands of *P. pectinatus* in its littoral zone only. The Tso Khar recorded mixed stands of *P. pectinatus* and *Ranunculus aquatalis* in fresh water zone only in its freshwater zone and the saline area didn't support any macrophytic vegetation. The low macrophyte diversity in both these waters is attributable to high altitude and salinity which limit speciation and restrict macrophytic growth.

- The macrophytic vegetation at Manasbal lake was represented by 37 species belonging to 22 families and 28 genera. The macrophytic community of Manasbal Lake was represented by all the four life form-classes-emergents (40%), rooted floating leaf type (22%), submerged (27%) and free floating (11%). However, the submerged macrophytes cover significant area of the lake, while as emergent floating and rooted floating types together constituted less than 20% of the lake area.
- Most of macrophytic species found in Manasbal are cosmopolitan and show no preference for sediments of a particular fertility due to their similar morphological and nutritional requirements. However species like *Chara* spp, *M. spicatum*, *H. verticillata* preferred high transparency, low concentrations of phosphorus, conductivity and organic carbon, whereas *C. demersum* and *P. pectinatus* were associated with high values of total phosphorous, organic matter and conductivity. However nutrient preferences to community level are apparent than individual species which is reflected by high species diversity and richness at least polluted sites species.
- The geochemistry of the lake sediments, which was in itself influenced by the chemistry of the inflowing water and the evapo-concentration process in the lakes, governs the occurrence and abundance of the various macrophytes taxa in the three lakes.

Chapter 9

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9. REFERENCES

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APPENDIX

Table I. Pearson's correlations coefficients calculated for physico-chemical parameters of water in Tso Morari lake

	Air temperature	Water temperature	Depth	Transparency	pH	Cond	DO	CO_2	Alkalinity	TH	Ca	Mg	Na	K	Cl	NO_3	NH_4	TP	SO_4	SiO_2
Water temp.	.844(**)																			
Depth	0.154	-0.017																		
Transparency	.251(*)	0.066	.943(**)																	
pH	0.081	0.048	0.186	0.191																
Cond	0.158	0.102	.520(**)	.541(**)	.391(**)															
DO	-.290(*)	-.256(*)	-.345(**)	-.333(**)	-0.21	-.328(**)														
CO_2	-0.171	-0.134	-.270(*)	-.290(*)	-.660(**)	-.481(**)	.364(**)													
Alkalinity	0.051	0.043	.363(**)	.343(**)	.441(**)	.667(**)	-0.101	-.487(**)												
Hardness	.268(*)	0.184	.520(**)	.487(**)	.312(**)	.694(**)	-.301(*)	-.405(**)	.636(**)											
Ca	0.084	0.083	-0.024	-0.039	-0.228	-0.167	-0.134	0.021	-.301(*)	0.075										
Mg	.243(*)	0.15	.480(**)	.478(**)	.327(**)	.639(**)	-.272(*)	-.421(**)	.601(**)	.872(**)	-0.019									
Na	0.164	0.047	.535(**)	.539(**)	.484(**)	.810(**)	-.270(*)	-.492(**)	.753(**)	.667(**)	-.287(*)	.643(**)								
K	0.131	0.039	.381(**)	.428(**)	0.179	.408(**)	-0.001	-0.194	.405(**)	.277(*)	-0.208	0.201	.597(**)							
Cl	0.02	-0.013	.290(*)	.289(*)	.364(**)	.266(*)	-.286(*)	-.359(**)	.268(*)	.309(**)	0.077	.310(**)	.419(**)	.249(*)						
NO_3	-0.16	-0.172	0.139	0.08	0.126	0.082	0.06	-0.036	0.081	-0.075	-.254(*)	-0.041	0.083	-0.066	-0.045					
NH_4	0.181	.234(*)	-0.117	-0.138	-0.222	-0.155	0.104	0.07	-0.149	0.029	.336(**)	0.008	-.248(*)	-0.12	0.194	-0.221				
TP	-0.027	0.049	.282(*)	0.228	.291(*)	.475(**)	-0.061	-.355(**)	.463(**)	.404(**)	-0.044	.257(*)	.436(**)	0.157	.401(**)	0.086	0.008			
SO_4	-0.053	-0.119	.620(**)	.624(**)	.289(*)	.664(**)	-.240(*)	-.414(**)	.567(**)	.507(**)	-0.071	.518(**)	.735(**)	.463(**)	.469(**)	0.063	-0.184	.428(**)		
SiO_2	0.163	0.188	0.216	0.135	-0.067	.310(**)	0.066	-0.047	.357(**)	.276(*)	-0.201	.241(*)	.327(**)	.302(**)	-0.074	-0.021	0.215	0.066	0.051	
TDS	-0.123	-0.208	.555(**)	.490(**)	.424(**)	.560(**)	-.278(*)	-.459(**)	.627(**)	.486(**)	-0.061	.465(**)	.605(**)	.270(*)	.479(**)	0.162	-.315(**)	.421(**)	.634(**)	0.107

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). **N=72**

Table II. Pearson's correlations coefficients calculated for physico-chemical parameters of water in Tso Khar lake

	Air temp.	Water temp.	Depth	TransP.	pH	Cond	DO	CO_2	Talk	TH	Ca	Mg	Na	K	Cl	NO_3	NH_4	TP	SO_4	SiO_2
Water temp.	.858(**)																			
Depth	.373(*)	.551(**)																		
Transparency	.390(**)	.431(**)	.588(**)																	
pH	0.121	.379(*)	.381(**)	0.078																
Cond	0.006	0.044	-0.04	-0.254	0.218															
DO	-0.231	-0.21	0.075	0.268	-0.168	-.601(**)														
CO_2	-0.137	-0.276	-.324(*)	-0.106	-.635(**)	-.376(*)	0.324													
Alkalinity	0.072	-0.001	-0.108	-0.29	0.199	.742(**)	-.773(**)	-.426(**)												
Hardness	0.056	0.084	0.002	-0.265	.297(*)	.833(**)	-.710(**)	-.388(**)	.860(**)											
Ca	0.175	0.151	-0.094	-0.068	0.209	.649(**)	-.558(**)	-.312(*)	.625(**)	.676(**)										
Mg	0.043	0.061	-0.202	-.295(*)	0.205	.850(**)	-.611(**)	-.337(*)	.769(**)	.858(**)	.596(**)									
Na	0.01	0.037	0.008	-.312(*)	0.254	.920(**)	-.596(**)	-.351(*)	.719(**)	.804(**)	.592(**)	.758(**)								
K	0.053	0.048	0.229	-0.121	0.121	.688(**)	-.610(**)	-0.275	.578(**)	.592(**)	.368(*)	.360(*)	.721(**)							
Cl	0.059	0.124	-0.017	0.005	0.268	.826(**)	-.549(**)	-.315(*)	.673(**)	.831(**)	.658(**)	.807(**)	.760(**)	.475(**)						
NO_3	0.189	0.153	-.358(*)	-.390(**)	0.141	.673(**)	-.642(**)	-0.272	.606(**)	.589(**)	.605(**)	.783(**)	.644(**)	0.239	.492(**)					
NH_4	-0.232	-0.096	-0.115	-0.074	.366(*)	0.274	-0.14	-0.271	0.19	0.2	.351(*)	0.247	0.205	0.137	0.201	0.266				
TP	0.101	-0.113	-0.073	0.002	-0.153	0.169	-.447(**)	-0.153	.455(**)	0.203	0.083	0.042	0.215	.498(**)	0.043	0.099	-0.037			
SO_4	-0.175	-0.174	0.079	-0.175	0.179	.652(**)	-.586(**)	-.391(**)	.592(**)	.631(**)	0.289	.424(**)	.607(**)	.731(**)	.530(**)	0.137	0.079	.484(**)		
SiO_2	0.222	0.159	0.192	-0.029	0.217	-0.171	-0.077	-0.105	-0.011	-0.059	-0.227	-0.117	-0.15	-0.033	-.294(*)	-0.147	0.086	0.197	-0.031	
TDS	0.013	0.082	0.064	-0.287	0.271	.712(**)	-.440(**)	-.400(**)	.601(**)	.678(**)	.502(**)	.515(**)	.704(**)	.761(**)	.528(**)	.439(**)	.319(*)	0.239	.616(**)	0.042

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). N=45

Table III. Pearson's correlations coefficients calculated for physico-chemical parameters of water in Manasbal lake.

	Air temperature	Water temperature	Depth	Transparency	pH	Cond	DO	CO_2	Alkalinity	TH	Ca	Mg	Na	K	Cl	NO_3	NH_4	TP	SO_4	SiO_2
Water temp.	.842(**)																			
Depth	.184(*)	-0.082																		
Transparency	0.07	.241(**)	.491(**)																	
pH	.394(**)	.710(**)	-.395(**)	.241(**)																
Cond	-0.078	-.398(**)	.269(**)	-.387(**)	-.505(**)															
DO	-.354(**)	0.026	-.522(**)	.315(**)	.515(**)	-.501(**)														
CO_2	-0.038	-.390(**)	.469(**)	-.276(**)	-.745(**)	.500(**)	-.671(**)													
Alkalinity	-0.103	-.503(**)	.494(**)	-.321(**)	-.748(**)	.621(**)	-.680(**)	.720(**)												
Hardness	-0.134	-.536(**)	.591(**)	-.226(**)	-.782(**)	.634(**)	-.668(**)	.850(**)	.806(**)											
Ca	-.391(**)	-.574(**)	.366(**)	-.216(**)	-.660(**)	.462(**)	-.401(**)	.704(**)	.596(**)	.803(**)										
Mg	-.308(**)	-.500(**)	.438(**)	-0.141	-.616(**)	.439(**)	-.425(**)	.700(**)	.587(**)	.771(**)	.891(**)									
Na	-.253(**)	-.505(**)	.386(**)	-.285(**)	-.587(**)	.556(**)	-.537(**)	.618(**)	.614(**)	.736(**)	.693(**)	.708(**)								
K	-.403(**)	-.509(**)	0.103	-.365(**)	-.567(**)	.433(**)	-.363(**)	.511(**)	.485(**)	.524(**)	.584(**)	.532(**)	.672(**)							
Cl	-0.062	-.205(*)	0.095	-.448(**)	-.348(**)	.336(**)	-.483(**)	.458(**)	.415(**)	.432(**)	.451(**)	.408(**)	.433(**)	.472(**)						
NO_3	-0.163	-.275(**)	-0.11	-.503(**)	-.342(**)	.483(**)	-.285(**)	.357(**)	.360(**)	.396(**)	.422(**)	.360(**)	.447(**)	.505(**)	.443(**)					
NH_4	0.069	-.376(**)	.588(**)	-.373(**)	-.686(**)	.665(**)	-.835(**)	.777(**)	.835(**)	.870(**)	.622(**)	.620(**)	.721(**)	.515(**)	.517(**)	.386(**)				
TP	-.175(*)	-.517(**)	.282(**)	-.412(**)	-.698(**)	.600(**)	-.596(**)	.676(**)	.654(**)	.765(**)	.573(**)	.555(**)	.708(**)	.703(**)	.518(**)	.513(**)	.754(**)			
SO_4	-0.042	-.281(**)	.346(**)	-.260(**)	-.499(**)	.364(**)	-.512(**)	.636(**)	.541(**)	.644(**)	.657(**)	.661(**)	.524(**)	.430(**)	.546(**)	.289(**)	.628(**)	.520(**)		
SiO_2	-0.044	-.418(**)	.650(**)	-.198(*)	-.696(**)	.568(**)	-.749(**)	.739(**)	.800(**)	.803(**)	.628(**)	.627(**)	.650(**)	.471(**)	.476(**)	.239(**)	.885(**)	.620(**)	.641(**)	
TDS	.259(**)	0.037	.330(**)	-.209(*)	-.176(*)	.401(**)	-.499(**)	.329(**)	.405(**)	.366(**)	.167(*)	0.158	.284(**)	.224(**)	.250(**)	.248(**)	.521(**)	.290(**)	.334(**)	.484(**)

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). N=144

Table IV. Pearson's correlations coefficients calculated for chemical parameters of sediments in Tso Morari lake

	pH	Cond	OC	OM	NO_3	NH_4	ExP	TP	ExCa	ExMg	ExNa
Cond	-.437(**)										
OC	-.385(**)	.621(**)									
OM	-.386(**)	.624(**)	.996(**)								
NO_3	-.341(*)	.328(*)	.469(**)	.451(**)							
NH_4	-.397(**)	.591(**)	.764(**)	.758(**)	.627(**)						
ExP	-.466(**)	.595(**)	.767(**)	.750(**)	0.275	.729(**)					
TP	-.502(**)	.496(**)	.807(**)	.805(**)	.327(*)	.764(**)	.821(**)				
ExCa	-.568(**)	.751(**)	.786(**)	.781(**)	.608(**)	.764(**)	.667(**)	.669(**)			
ExMg	-.526(**)	.718(**)	.796(**)	.786(**)	.561(**)	.736(**)	.685(**)	.624(**)	.937(**)		
ExNa	-.438(**)	.649(**)	.696(**)	.698(**)	.475(**)	.796(**)	.710(**)	.669(**)	.775(**)	.712(**)	
ExK	-.450(**)	.548(**)	.672(**)	.677(**)	.535(**)	.777(**)	.568(**)	.644(**)	.713(**)	.671(**)	.813(**)

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

N=45

Table V. Pearson's correlations coefficients calculated for chemical parameters of sediments in Tso Khar lake

	pH	Cond	OC	OM	NO_3	NH_4	ExP	TP	ExCa	ExMg	ExNa
Cond	.936(**)										
OC	-.949(**)	-.924(**)									
OM	-.950(**)	-.924(**)	1.000(**)								
NO_3	.888(**)	.955(**)	-.887(**)	-.886(**)							
NH_4	-0.139	0.047	0.166	0.167	0.204						
ExP	-.931(**)	-.933(**)	.915(**)	.915(**)	-.893(**)	0.079					
TP	-.957(**)	-.901(**)	.955(**)	.956(**)	-.861(**)	0.22	.941(**)				
ExCa	.773(**)	.893(**)	-.769(**)	-.769(**)	.914(**)	0.259	-.834(**)	-.755(**)			
ExMg	.502(**)	.638(**)	-.604(**)	-.605(**)	.628(**)	0.13	-.550(**)	-.535(**)	.698(**)		
ExNa	.934(**)	.965(**)	-.917(**)	-.917(**)	.937(**)	0.059	-.919(**)	-.902(**)	.892(**)	.610(**)	
ExK	.933(**)	.959(**)	-.915(**)	-.915(**)	.952(**)	0.023	-.926(**)	-.901(**)	.900(**)	.582(**)	.969(**)

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). N=36

Table VI. Pearson's correlations coefficients calculated for chemical parameters of sediments in Manasbal lake.

	pH	Cond	OC	OM	NO_3	NH_4	ExP	TP	ExCa	ExMg	ExNa
Cond	-.477(**)										
OC	-.328(*)	.857(**)									
OM	-.323(*)	.863(**)	.997(**)								
NO_3	.511(**)	0.099	.337(*)	.327(*)							
NH_4	-.530(**)	.879(**)	.779(**)	.779(**)	0.182						
ExP	-.442(**)	.810(**)	.736(**)	.734(**)	0.218	.854(**)					
TP	-.572(**)	.861(**)	.752(**)	.754(**)	0.038	.803(**)	.878(**)				
ExCa	-0.098	.537(**)	.381(*)	.386(*)	0.045	.536(**)	.337(*)	0.285			
ExMg	-0.018	.537(**)	.381(*)	.391(*)	0.154	.508(**)	.352(*)	0.304	.914(**)		
ExNa	-.559(**)	.808(**)	.616(**)	.615(**)	-0.122	.767(**)	.677(**)	.701(**)	.703(**)	.611(**)	
ExK	-.414(**)	.867(**)	.827(**)	.821(**)	0.091	.803(**)	.688(**)	.699(**)	.685(**)	.615(**)	.829(**)

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). N=40

Table VII. ANOVA between sites for physico-chemical parameters of water in Tso Morari lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Airtemperature	Between Groups	346.151	7	49.450	.586	.765
	Within Groups	4559.753	54	84.440		
	Total	4905.904	61			
Watertemperature	Between Groups	75.953	7	10.850	.443	.871
	Within Groups	1322.724	54	24.495		
	Total	1398.677	61			
Depth	Between Groups	21283.873	7	3040.553	4321.933	.000
	Within Groups	37.990	54	.704		
	Total	21321.863	61			
Transparency	Between Groups	2676.936	7	382.419	63.709	.000
	Within Groups	324.143	54	6.003		
	Total	3001.079	61			
pH	Between Groups	2.834	7	.405	2.590	.022
	Within Groups	8.439	54	.156		
	Total	11.273	61			
Cond	Between Groups	21312911	7	3044701.525	27.346	.000
	Within Groups	6012453	54	111341.718		
	Total	27325363	61			
DO	Between Groups	15.747	7	2.250	1.462	.200
	Within Groups	83.066	54	1.538		
	Total	98.814	61			
CO2	Between Groups	472.658	7	67.523	3.462	.004
	Within Groups	1053.278	54	19.505		
	Total	1525.935	61			
Talk	Between Groups	1036359	7	148051.267	16.627	.000
	Within Groups	480827.0	54	8904.204		
	Total	1517186	61			
TH	Between Groups	8789288	7	1255612.639	8.577	.000
	Within Groups	7905517	54	146398.467		
	Total	16694806	61			
Ca	Between Groups	109119.2	7	15588.457	1.319	.259
	Within Groups	638102.5	54	11816.714		
	Total	747221.7	61			
Mg	Between Groups	555910.0	7	79415.721	8.244	.000
	Within Groups	520213.9	54	9633.591		
	Total	1076124	61			
Na	Between Groups	38205.527	7	5457.932	19.752	.000
	Within Groups	14921.183	54	276.318		
	Total	53126.710	61			
K	Between Groups	5292.106	7	756.015	4.841	.000
	Within Groups	8433.587	54	156.178		
	Total	13725.694	61			
Cl	Between Groups	2644.426	7	377.775	2.172	.051
	Within Groups	9391.913	54	173.924		
	Total	12036.339	61			
NO3	Between Groups	386773.1	7	55253.299	1.517	.181
	Within Groups	1966948	54	36424.956		
	Total	2353721	61			
NH4	Between Groups	1650.437	7	235.777	.415	.889
	Within Groups	30654.611	54	567.678		
	Total	32305.048	61			
TP	Between Groups	2064496	7	294928.053	4.592	.000
	Within Groups	3468054	54	64223.222		
	Total	5532550	61			
SO4	Between Groups	983027.4	7	140432.485	13.333	.000
	Within Groups	568746.0	54	10532.333		
	Total	1551773	61			
SiO2	Between Groups	221.004	7	31.572	.799	.592
	Within Groups	2134.238	54	39.523		
	Total	2355.242	61			
TDS	Between Groups	2407774	7	343967.669	10.870	.000
	Within Groups	1708777	54	31644.022		
	Total	4116551	61			

Table VIII. ANOVA between sites for physico-chemical parameters of water in Tso Khar lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Airtemperature	Between Groups	133.599	4	33.400	.342	.848
	Within Groups	3029.151	31	97.715		
	Total	3162.750	35			
Watertemperature	Between Groups	71.783	4	17.946	.304	.873
	Within Groups	1827.905	31	58.965		
	Total	1899.688	35			
Depth	Between Groups	12.074	4	3.019	5.542	.002
	Within Groups	16.885	31	.545		
	Total	28.959	35			
Transparency	Between Groups	1.014	4	.253	1.600	.199
	Within Groups	4.909	31	.158		
	Total	5.923	35			
pH	Between Groups	.697	4	.174	1.064	.391
	Within Groups	5.078	31	.164		
	Total	5.775	35			
Cond	Between Groups	3.32E+09	4	829380191.5	51.667	.000
	Within Groups	4.98E+08	31	16052565.67		
	Total	3.82E+09	35			
CO2	Between Groups	387.381	4	96.845	3.689	.014
	Within Groups	813.841	31	26.253		
	Total	1201.222	35			
Talk	Between Groups	26739952	4	6684988.119	16.218	.000
	Within Groups	12778235	31	412201.132		
	Total	39518188	35			
TH	Between Groups	47058323	4	11764580.68	29.325	.000
	Within Groups	12436511	31	401177.783		
	Total	59494834	35			
Ca	Between Groups	171019.7	4	42754.917	8.896	.000
	Within Groups	148987.3	31	4806.043		
	Total	320007.0	35			
Mg	Between Groups	4163888	4	1040972.076	31.007	.000
	Within Groups	1040741	31	33572.301		
	Total	5204630	35			
Na	Between Groups	3.27E+09	4	816455849.6	42.874	.000
	Within Groups	5.90E+08	31	19043177.14		
	Total	3.86E+09	35			
K	Between Groups	95314613	4	23828653.22	18.614	.000
	Within Groups	39684379	31	1280141.269		
	Total	1.35E+08	35			
Cl	Between Groups	1.81E+08	4	45347932.91	13.426	.000
	Within Groups	1.05E+08	31	3377720.294		
	Total	2.86E+08	35			
NO3	Between Groups	22972519	4	5743129.767	62.238	.000
	Within Groups	2860586	31	92276.965		
	Total	25833105	35			
NH4	Between Groups	37388.619	4	9347.155	.590	.672
	Within Groups	490847.3	31	15833.783		
	Total	528235.9	35			
TP	Between Groups	211396.5	4	52849.122	.927	.461
	Within Groups	1767463	31	57014.940		
	Total	1978860	35			
SO4	Between Groups	781588.2	4	195397.043	12.852	.000
	Within Groups	471314.6	31	15203.696		
	Total	1252903	35			
SiO2	Between Groups	49.516	4	12.379	.349	.842
	Within Groups	1098.484	31	35.435		
	Total	1148.000	35			
TDS	Between Groups	6843558	4	1710889.584	13.042	.000
	Within Groups	4066810	31	131187.433		
	Total	10910369	35			

Table IX. ANOVA between sites for physico-chemical parameters of water in Manasbal lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Airtemperature	Between Groups	2853.909	5	570.782	10.507	.000
	Within Groups	7496.651	138	54.324		
	Total	10350.560	143			
Watertemperature	Between Groups	1282.735	5	256.547	5.200	.000
	Within Groups	6807.905	138	49.333		
	Total	8090.640	143			
Depth	Between Groups	3665.411	5	733.082	3365.121	.000
	Within Groups	30.063	138	.218		
	Total	3695.474	143			
Transparency	Between Groups	421.199	5	84.240	601.298	.000
	Within Groups	19.333	138	.140		
	Total	440.532	143			
pH	Between Groups	51.365	5	10.273	23.444	.000
	Within Groups	59.593	136	.438		
	Total	110.957	141			
Cond	Between Groups	401071.9	5	80214.379	26.491	.000
	Within Groups	417855.0	138	3027.935		
	Total	818926.9	143			
DO	Between Groups	1794.759	5	358.952	75.326	.000
	Within Groups	657.615	138	4.765		
	Total	2452.373	143			
CO2	Between Groups	5514.056	5	1102.811	45.549	.000
	Within Groups	3341.167	138	24.211		
	Total	8855.222	143			
Talk	Between Groups	604666.1	5	120933.217	71.176	.000
	Within Groups	234470.9	138	1699.065		
	Total	839137.0	143			
TH	Between Groups	386421.1	5	77284.211	85.871	.000
	Within Groups	124200.5	138	900.004		
	Total	510621.6	143			
Ca	Between Groups	10849.729	5	2169.946	17.823	.000
	Within Groups	16801.708	138	121.752		
	Total	27651.438	143			
Mg	Between Groups	854.583	5	170.917	19.669	.000
	Within Groups	1199.167	138	8.690		
	Total	2053.750	143			
Na	Between Groups	1148.285	5	229.657	37.623	.000
	Within Groups	842.375	138	6.104		
	Total	1990.660	143			
K	Between Groups	91.258	5	18.252	13.783	.000
	Within Groups	182.740	138	1.324		
	Total	273.998	143			
Cl	Between Groups	2822.583	5	564.517	18.552	.000
	Within Groups	4199.167	138	30.429		
	Total	7021.750	143			
NO3	Between Groups	282104.6	5	56420.911	16.834	.000
	Within Groups	462512.7	138	3351.541		
	Total	744617.2	143			
NH4	Between Groups	5267524	5	1053504.867	730.060	.000
	Within Groups	199139.4	138	1443.039		
	Total	5466664	143			
TP	Between Groups	1001107	5	200221.328	36.587	.000
	Within Groups	755195.3	138	5472.430		
	Total	1756302	143			
SO4	Between Groups	206.368	5	41.274	17.654	.000
	Within Groups	322.625	138	2.338		
	Total	528.993	143			
SiO2	Between Groups	2513.479	5	502.696	128.477	.000
	Within Groups	539.958	138	3.913		
	Total	3053.438	143			
TDS	Between Groups	77212.951	5	15442.590	14.490	.000
	Within Groups	147069.2	138	1065.719		
	Total	224282.2	143			

Table X. ANOVA between sites for physico-chemical parameters of sediments in Tso Morari lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.488	4	.122	1.213	.323
	Within Groups	3.524	35	.101		
	Total	4.013	39			
Cond	Between Groups	5017070	4	1254267.579	26.543	.000
	Within Groups	1653927	35	47255.062		
	Total	6670998	39			
OC	Between Groups	50.223	4	12.556	17.498	.000
	Within Groups	25.114	35	.718		
	Total	75.338	39			
OM	Between Groups	142.143	4	35.536	15.911	.000
	Within Groups	78.172	35	2.233		
	Total	220.315	39			
NO3	Between Groups	8184.527	4	2046.132	4.128	.008
	Within Groups	17347.873	35	495.654		
	Total	25532.400	39			
NH4	Between Groups	63333.553	4	15833.388	13.971	.000
	Within Groups	39666.222	35	1133.321		
	Total	102999.8	39			
ExP	Between Groups	542599.3	4	135649.824	31.747	.000
	Within Groups	149551.5	35	4272.899		
	Total	692150.8	39			
TP	Between Groups	2783009	4	695752.307	20.299	.000
	Within Groups	1199611	35	34274.593		
	Total	3982620	39			
ExCa	Between Groups	412.761	4	103.190	6.560	.000
	Within Groups	550.533	35	15.730		
	Total	963.294	39			
ExMg	Between Groups	1197.729	4	299.432	7.372	.000
	Within Groups	1421.689	35	40.620		
	Total	2619.418	39			
ExNa	Between Groups	12.277	4	3.069	6.895	.000
	Within Groups	15.579	35	.445		
	Total	27.856	39			
ExK	Between Groups	1.535	4	.384	5.877	.001
	Within Groups	2.285	35	.065		
	Total	3.820	39			

Table XI. ANOVA between sites for physico-chemical parameters of sediments in Tso Khar lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	22.737	3	7.579	91.439	.000
	Within Groups	2.155	26	.083		
	Total	24.892	29			
Cond	Between Groups	1.38E+10	3	4602625051	275.191	.000
	Within Groups	4.35E+08	26	16725224.36		
	Total	1.42E+10	29			
OC	Between Groups	67.951	3	22.650	83.814	.000
	Within Groups	7.026	26	.270		
	Total	74.978	29			
OM	Between Groups	199.851	3	66.617	84.101	.000
	Within Groups	20.595	26	.792		
	Total	220.446	29			
NO3	Between Groups	377263.8	3	125754.594	106.241	.000
	Within Groups	30775.583	26	1183.676		
	Total	408039.4	29			
NH4	Between Groups	161.533	3	53.844	.034	.991
	Within Groups	40720.333	26	1566.167		
	Total	40881.867	29			
ExP	Between Groups	600557.6	3	200185.864	86.569	.000
	Within Groups	60123.208	26	2312.431		
	Total	660680.8	29			
TP	Between Groups	1711733	3	570577.553	50.160	.000
	Within Groups	295756.7	26	11375.258		
	Total	2007489	29			
ExCa	Between Groups	1842.990	3	614.330	25.836	.000
	Within Groups	618.228	26	23.778		
	Total	2461.219	29			
ExMg	Between Groups	493.961	3	164.654	9.507	.000
	Within Groups	450.309	26	17.320		
	Total	944.270	29			
ExNa	Between Groups	4569925	3	1523308.384	131.260	.000
	Within Groups	301736.9	26	11605.265		
	Total	4871662	29			
ExK	Between Groups	309174.0	3	103058.005	146.710	.000
	Within Groups	18264.012	26	702.462		
	Total	327438.0	29			

Table XII. ANOVA between sites for physico-chemical parameters of sediments in Manasbal lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	3.280	4	.820	33.513	.000
	Within Groups	.856	35	.024		
	Total	4.136	39			
Cond	Between Groups	606022.8	4	151505.688	13.822	.000
	Within Groups	383638.6	35	10961.104		
	Total	989661.4	39			
OC	Between Groups	59.656	4	14.914	13.771	.000
	Within Groups	37.904	35	1.083		
	Total	97.560	39			
OM	Between Groups	178.067	4	44.517	13.491	.000
	Within Groups	115.491	35	3.300		
	Total	293.558	39			
NO3	Between Groups	28773.650	4	7193.413	4.361	.006
	Within Groups	57735.125	35	1649.575		
	Total	86508.775	39			
NH4	Between Groups	134767.6	4	33691.900	12.728	.000
	Within Groups	92649.375	35	2647.125		
	Total	227417.0	39			
ExP	Between Groups	107791.4	4	26947.838	8.966	.000
	Within Groups	105196.6	35	3005.618		
	Total	212988.0	39			
TP	Between Groups	2127423	4	531855.713	19.988	.000
	Within Groups	931292.1	35	26608.346		
	Total	3058715	39			
ExCa	Between Groups	459.416	4	114.854	1.826	.146
	Within Groups	2201.375	35	62.896		
	Total	2660.791	39			
ExMg	Between Groups	19.804	4	4.951	.797	.536
	Within Groups	217.540	35	6.215		
	Total	237.344	39			
ExNa	Between Groups	1.212	4	.303	12.258	.000
	Within Groups	.865	35	.025		
	Total	2.077	39			
ExK	Between Groups	.129	4	.032	8.531	.000
	Within Groups	.132	35	.004		
	Total	.262	39			

Table XIII. Descriptive statistics of water samples between vegetative and non vegetative sites in Tso Morari Lake

Descriptives

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Airtemperature	1	24	9.0542	8.41510	1.71772	5.5008	12.6076	-7.00	22.00
	2	20	11.9500	8.51917	1.90495	7.9629	15.9371	-3.00	26.00
	Total	44	10.3705	8.48960	1.27986	7.7894	12.9515	-7.00	26.00
Watertemperature	1	24	8.8333	5.27848	1.07746	6.6044	11.0622	1.00	17.00
	2	20	8.2000	4.27169	.95518	6.2008	10.1992	2.00	19.00
	Total	44	8.5455	4.80288	.72406	7.0852	10.0057	1.00	19.00
Depth	1	24	4.2375	1.65235	.33729	3.5398	4.9352	2.00	6.90
	2	20	41.7200	3.89664	.87131	39.8963	43.5437	34.50	46.00
	Total	44	21.2750	19.09455	2.87861	15.4697	27.0803	2.00	46.00
Transparency	1	24	3.4000	1.20362	.24569	2.8918	3.9082	2.00	5.50
	2	20	15.7700	4.06540	.90905	13.8673	17.6727	11.20	23.00
	Total	44	9.0227	6.84822	1.03241	6.9407	11.1048	2.00	23.00
pH	1	24	8.8133	.35510	.07248	8.6634	8.9633	8.05	9.29
	2	20	8.7615	.22481	.05027	8.6563	8.8667	8.00	9.04
	Total	44	8.7898	.30076	.04534	8.6983	8.8812	8.00	9.29
Cond	1	24	1446.1667	380.10315	77.58823	1285.6632	1606.6702	488.00	1937.00
	2	20	1533.8000	421.36840	94.22084	1336.5935	1731.0065	1035.00	2390.00
	Total	44	1486.0000	397.08988	59.86355	1365.2736	1606.7264	488.00	2390.00
DO	1	24	7.9167	1.15558	.23588	7.4287	8.4046	6.00	11.00
	2	20	7.2850	1.03785	.23207	6.7993	7.7707	4.40	8.70
	Total	44	7.6295	1.13641	.17132	7.2840	7.9750	4.40	11.00
CO2	1	24	.1250	.61237	.12500	-.1336	.3836	.00	3.00
	2	20	.4000	1.78885	.40000	-.4372	1.2372	.00	8.00
	Total	44	.2500	1.27817	.19269	-.1386	.6386	.00	8.00
Talk	1	24	371.7917	101.69134	20.75766	328.8512	414.7322	168.00	520.00
	2	20	349.8000	114.96022	25.70589	295.9970	403.6030	180.00	496.00
	Total	44	361.7955	107.20803	16.16222	329.2012	394.3897	168.00	520.00
TH	1	24	866.1667	418.12206	85.34881	689.6092	1042.7241	184.00	1800.00
	2	20	1049.0000	459.74341	102.80175	833.8335	1264.1665	460.00	2100.00
	Total	44	949.2727	442.02454	66.63771	814.8850	1083.6605	184.00	2100.00
Ca	1	24	28.4583	17.66101	3.60504	21.0007	35.9159	5.00	86.00
	2	20	74.6500	192.85426	43.12352	-15.6086	164.9086	5.00	892.00
	Total	44	49.4545	130.92807	19.73815	9.6488	89.2603	5.00	892.00
Mg	1	24	200.7917	111.87764	22.83693	153.5499	248.0335	66.00	560.00
	2	20	238.2500	117.99950	26.38549	183.0245	293.4755	22.00	485.00
	Total	44	217.8182	114.90568	17.32268	182.8837	252.7527	22.00	560.00
Na	1	24	64.5000	21.39077	4.36637	55.4675	73.5325	2.00	97.00
	2	20	72.1000	12.08261	2.70175	66.4452	77.7548	40.00	89.00
	Total	44	67.9545	17.99736	2.71320	62.4828	73.4262	2.00	97.00
K	1	24	18.0417	10.12736	2.06724	13.7653	22.3181	1.00	37.00
	2	20	23.8000	19.64045	4.39174	14.6080	32.9920	2.00	77.00
	Total	44	20.6591	15.28785	2.30473	16.0112	25.3070	1.00	77.00
Cl	1	24	27.3750	15.39851	3.14321	20.8728	33.8772	2.00	54.00
	2	20	29.8500	10.71779	2.39657	24.8339	34.8661	10.00	46.00
	Total	44	28.5000	13.38430	2.01776	24.4308	32.5692	2.00	54.00
NO3	1	24	291.5000	185.36146	37.83675	213.2287	369.7713	115.00	887.00
	2	20	343.1500	178.54272	39.92337	259.5894	426.7106	102.00	664.00
	Total	44	314.9773	182.04452	27.44424	259.6307	370.3239	102.00	887.00
NH4	1	24	45.0833	22.66949	4.62739	35.5108	54.6558	6.00	87.00
	2	20	42.0500	23.13911	5.17406	31.2206	52.8794	11.00	86.00
	Total	44	43.7045	22.66703	3.41718	36.8131	50.5960	6.00	87.00
TP	1	24	494.0417	275.11713	56.15805	377.8699	610.2134	100.00	1080.00
	2	20	499.3500	332.35401	74.31662	343.8035	654.8965	128.00	1638.00
	Total	44	496.4545	298.83062	45.05041	405.6017	587.3074	100.00	1638.00
SO4	1	24	235.2500	132.86549	27.12106	179.1458	291.3542	23.00	480.00
	2	20	343.5000	110.48482	24.70516	291.7915	395.2085	101.00	520.00
	Total	44	284.4545	133.45053	20.11842	243.8819	325.0272	23.00	520.00
SiO2	1	24	8.0417	5.22934	1.06743	5.8335	10.2498	1.00	17.00
	2	20	9.1500	8.24797	1.84430	5.2898	13.0102	.00	28.00
	Total	44	8.5455	6.70805	1.01128	6.5060	10.5849	.00	28.00
TDS	1	24	461.1667	180.92892	36.93196	384.7671	537.5663	100.00	840.00
	2	20	588.1000	258.83502	57.87727	466.9615	709.2385	100.00	980.00
	Total	44	518.8636	226.27392	34.11208	450.0701	587.6572	100.00	980.00

Table XIV. ANOVA between vegetative and non vegetative sites for physico-chemical parameters of water in Tso Morari lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Airtemperature	Between Groups	91.482	1	91.482	1.277	.265
	Within Groups	3007.670	42	71.611		
	Total	3099.152	43			
Watertemperature	Between Groups	4.376	1	4.376	.186	.668
	Within Groups	987.533	42	23.513		
	Total	991.909	43			
Depth	Between Groups	15326.594	1	15326.594	1832.447	.000
	Within Groups	351.288	42	8.364		
	Total	15677.882	43			
Transparency	Between Groups	1669.275	1	1669.275	201.846	.000
	Within Groups	347.342	42	8.270		
	Total	2016.617	43			
pH	Between Groups	.029	1	.029	.319	.575
	Within Groups	3.860	42	.092		
	Total	3.890	43			
Cond	Between Groups	83777.467	1	83777.467	.525	.473
	Within Groups	6696479	42	159439.965		
	Total	6780256	43			
DO	Between Groups	4.353	1	4.353	3.572	.066
	Within Groups	51.179	42	1.219		
	Total	55.532	43			
CO2	Between Groups	.825	1	.825	.499	.484
	Within Groups	69.425	42	1.653		
	Total	70.250	43			
Talk	Between Groups	5276.001	1	5276.001	.453	.505
	Within Groups	488947.2	42	11641.599		
	Total	494223.2	43			
TH	Between Groups	364669.4	1	364669.394	1.906	.175
	Within Groups	8036915	42	191355.127		
	Total	8401585	43			
Ca	Between Groups	23276.401	1	23276.401	1.370	.248
	Within Groups	713836.5	42	16996.107		
	Total	737112.9	43			
Mg	Between Groups	15306.837	1	15306.837	1.164	.287
	Within Groups	552435.7	42	13153.231		
	Total	567742.5	43			
Na	Between Groups	630.109	1	630.109	1.990	.166
	Within Groups	13297.800	42	316.614		
	Total	13927.909	43			
K	Between Groups	361.728	1	361.728	1.568	.217
	Within Groups	9688.158	42	230.670		
	Total	10049.886	43			
Cl	Between Groups	66.825	1	66.825	.368	.548
	Within Groups	7636.175	42	181.814		
	Total	7703.000	43			
NO3	Between Groups	29102.427	1	29102.427	.876	.355
	Within Groups	1395927	42	33236.346		
	Total	1425029	43			
NH4	Between Groups	100.376	1	100.376	.192	.664
	Within Groups	21992.783	42	523.638		
	Total	22093.159	43			
TP	Between Groups	307.401	1	307.401	.003	.954
	Within Groups	3839582	42	91418.607		
	Total	3839889	43			
SO4	Between Groups	127833.4	1	127833.409	8.416	.006
	Within Groups	637955.5	42	15189.417		
	Total	765788.9	43			
SiO2	Between Groups	13.401	1	13.401	.293	.591
	Within Groups	1921.508	42	45.750		
	Total	1934.909	43			
TDS	Between Groups	175768.0	1	175768.048	3.644	.063
	Within Groups	2025827	42	48233.979		
	Total	2201595	43			

Table XV. Descriptive statistics of water samples between vegetative and non vegetative sites in Tso Khar Lake

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Airtemperature	1	14	9.7143	10.28388	2.74848	3.7765	15.6520	-7.00	25.00
	2	15	10.0000	8.96023	2.31352	5.0380	14.9620	-5.00	25.00
	Total	29	9.8621	9.44807	1.75446	6.2682	13.4559	-7.00	25.00
Watertemperature	1	14	11.3214	7.64503	2.04322	6.9073	15.7355	.00	23.00
	2	15	11.5333	8.17546	2.11089	7.0059	16.0608	.00	23.00
	Total	29	11.4310	7.78245	1.44516	8.4707	14.3913	.00	23.00
Depth	1	14	1.0714	1.07305	.28678	.4519	1.6910	.00	2.80
	2	15	1.2667	.82347	.21262	.8106	1.7227	.00	2.60
	Total	29	1.1724	.93995	.17454	.8149	1.5299	.00	2.80
Transparency	1	14	.2786	.56046	.14979	-.0450	.6022	.00	2.20
	2	15	.5200	.30519	.07880	.3510	.6890	.00	.80
	Total	29	.4034	.45551	.08459	.2302	.5767	.00	2.20
pH	1	14	8.6229	.26134	.06985	8.4720	8.7738	8.25	9.03
	2	15	8.5167	.48692	.12572	8.2470	8.7863	7.55	9.28
	Total	29	8.5679	.39137	.07268	8.4191	8.7168	7.55	9.28
Cond	1	14	20775.57	6654.16807	1778.401	16933.5692	24617.5737	11066.00	31000.00
	2	15	1833.2000	1122.58504	289.85021	1211.5331	2454.8669	833.00	5140.00
	Total	29	10977.79	10676.34289	1982.547	6916.7295	15038.8568	833.00	31000.00
CO2	1	14	.1429	.53452	.14286	-.1658	.4515	.00	2.00
	2	15	2.1333	5.42305	1.40023	-.8699	5.1365	.00	20.00
	Total	29	1.1724	3.98272	.73957	-.3425	2.6874	.00	20.00
Talk	1	14	2107.1429	928.12921	248.05296	1571.2570	2643.0287	144.00	3740.00
	2	15	639.8667	582.47132	150.39345	317.3048	962.4285	68.00	1740.00
	Total	29	1348.2069	1061.30463	197.07932	944.5082	1751.9056	68.00	3740.00
TH	1	14	2824.0714	937.04351	250.43541	2283.0386	3365.1042	1490.00	4672.00
	2	15	555.1333	293.00143	75.65264	392.8745	717.3921	90.00	1160.00
	Total	29	1650.4828	1334.91245	247.88702	1142.7092	2158.2563	90.00	4672.00
Ca	1	14	195.1429	104.58479	27.95146	134.7574	255.5283	60.00	410.00
	2	15	77.7333	52.68161	13.60233	48.5592	106.9074	12.00	196.00
	Total	29	134.4138	100.15542	18.59839	96.3167	172.5109	12.00	410.00
Mg	1	14	684.9286	381.09084	101.85081	464.8933	904.9639	198.00	1452.00
	2	15	79.1333	46.39715	11.97969	53.4394	104.8272	33.00	177.00
	Total	29	371.5862	404.24661	75.06671	217.8190	525.3534	33.00	1452.00
Na	1	14	19549.29	6790.21706	1814.762	15628.7311	23469.8403	12210.00	39986.00
	2	15	47.3333	23.06100	5.95432	34.5626	60.1041	22.00	99.00
	Total	29	9462.0690	10943.82565	2032.217	5299.2603	13624.8776	22.00	39986.00
K	1	14	3030.7143	2098.84032	560.93867	1818.8800	4242.5486	1140.00	7250.00
	2	15	20.9333	22.07606	5.70001	8.7080	33.1586	3.00	88.00
	Total	29	1473.9310	2094.82009	388.99833	677.1041	2270.7580	3.00	7250.00
Cl	1	14	4613.7857	2857.35852	763.66119	2963.9960	6263.5754	1240.00	9990.00
	2	15	31.3333	21.55613	5.56577	19.3959	43.2707	10.00	82.00
	Total	29	2243.5517	3036.71437	563.90370	1088.4474	3398.6561	10.00	9990.00
NO3	1	14	1372.0714	1090.15260	291.35554	742.6361	2001.5068	191.00	2988.00
	2	15	319.9333	193.47590	49.95526	212.7900	427.0767	49.00	746.00
	Total	29	827.8621	925.62437	171.88413	475.7734	1179.9508	49.00	2988.00
NH4	1	14	160.7143	69.27807	18.51534	120.7143	200.7143	78.00	345.00
	2	15	94.8000	75.31382	19.44594	53.0926	136.5074	6.00	265.00
	Total	29	126.6207	78.66403	14.60754	96.6985	156.5429	6.00	345.00
TP	1	14	439.3571	314.82415	84.14029	257.5831	621.1312	64.00	1228.00
	2	15	360.8667	185.73248	47.95592	258.0115	463.7219	117.00	807.00
	Total	29	398.7586	254.67411	47.29180	301.8858	495.6315	64.00	1228.00
SO4	1	14	349.5714	212.23634	56.72255	227.0298	472.1130	181.00	787.00
	2	15	135.7333	65.04445	16.79441	99.7129	171.7538	37.00	257.00
	Total	29	238.9655	186.69407	34.66822	167.9509	309.9801	37.00	787.00
SiO2	1	14	10.0000	5.44906	1.45632	6.8538	13.1462	2.00	21.00
	2	15	12.2000	6.80546	1.75716	8.4313	15.9687	4.00	28.00
	Total	29	11.1379	6.18018	1.14763	8.7871	13.4887	2.00	28.00
TDS	1	14	1251.5714	474.51477	126.81941	977.5948	1525.5481	905.00	2284.00
	2	15	433.9333	340.36797	87.88263	245.4438	622.4228	100.00	960.00
	Total	29	828.6552	579.10444	107.53699	608.3756	1048.9347	100.00	2284.00

Table XVI. ANOVA between vegetative and non vegetative sites for physico-chemical parameters of water in Tso Khar lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Airtemperature	Between Groups	.591	1	.591	.006	.937
	Within Groups	2498.857	27	92.550		
	Total	2499.448	28			
Watertemperature	Between Groups	.325	1	.325	.005	.943
	Within Groups	1695.537	27	62.798		
	Total	1695.862	28			
Depth	Between Groups	.276	1	.276	.305	.586
	Within Groups	24.462	27	.906		
	Total	24.738	28			
Transparency	Between Groups	.422	1	.422	2.115	.157
	Within Groups	5.388	27	.200		
	Total	5.810	28			
pH	Between Groups	.082	1	.082	.524	.475
	Within Groups	4.207	27	.156		
	Total	4.289	28			
Cond	Between Groups	2.60E+09	1	2598304187	118.253	.000
	Within Groups	5.93E+08	27	21972449.85		
	Total	3.19E+09	28			
CO2	Between Groups	28.690	1	28.690	1.865	.183
	Within Groups	415.448	27	15.387		
	Total	444.138	28			
Talk	Between Groups	15589961	1	15589961.31	26.393	.000
	Within Groups	15948329	27	590678.868		
	Total	31538291	28			
TH	Between Groups	37279201	1	37279200.58	79.779	.000
	Within Groups	12616555	27	467279.802		
	Total	49895755	28			
Ca	Between Groups	99822.387	1	99822.387	14.887	.001
	Within Groups	181048.6	27	6705.505		
	Total	280871.0	28			
Mg	Between Groups	2657498	1	2657498.373	37.407	.000
	Within Groups	1918131	27	71041.876		
	Total	4575629	28			
Na	Between Groups	2.75E+09	1	2754085890	124.058	.000
	Within Groups	5.99E+08	27	22199965.41		
	Total	3.35E+09	28			
K	Between Groups	65598072	1	65598072.07	30.924	.000
	Within Groups	57273522	27	2121241.548		
	Total	1.23E+08	28			
Cl	Between Groups	1.52E+08	1	152060781.5	38.680	.000
	Within Groups	1.06E+08	27	3931295.396		
	Total	2.58E+08	28			
NO3	Between Groups	8016168	1	8016167.586	13.550	.001
	Within Groups	15973686	27	591617.995		
	Total	23989853	28			
NH4	Between Groups	31461.570	1	31461.570	5.990	.021
	Within Groups	141803.3	27	5251.972		
	Total	173264.8	28			
TP	Between Groups	44612.363	1	44612.363	.680	.417
	Within Groups	1771437	27	65608.776		
	Total	1816049	28			
SO4	Between Groups	331124.6	1	331124.604	13.865	.001
	Within Groups	644806.4	27	23881.717		
	Total	975931.0	28			
SiO2	Between Groups	35.048	1	35.048	.915	.347
	Within Groups	1034.400	27	38.311		
	Total	1069.448	28			
TDS	Between Groups	4841094	1	4841094.190	28.733	.000
	Within Groups	4549040	27	168482.976		
	Total	9390135	28			

Table XVII. Descriptive statistics of sediment samples between vegetative and non vegetative sites in Tso Morari Lake

Descriptives

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
pH	1	25	8.3964	.33940	.06788	8.2563	8.5365	7.80	8.90
	2	15	8.4247	.29768	.07686	8.2598	8.5895	7.85	8.88
	Total	40	8.4070	.32076	.05072	8.3044	8.5096	7.80	8.90
Cond	1	25	1695.6000	383.37406	76.67481	1537.3510	1853.8490	930.00	2200.00
	2	15	2068.0000	362.86952	93.69251	1867.0496	2268.9504	1630.00	2700.00
	Total	40	1835.2500	413.58339	65.39328	1702.9796	1967.5204	930.00	2700.00
OC	1	25	2.6972	1.68166	.33633	2.0030	3.3914	.28	6.70
	2	15	2.4800	.70832	.18289	2.0877	2.8723	1.20	3.60
	Total	40	2.6158	1.38987	.21976	2.1712	3.0603	.28	6.70
OM	1	25	4.5620	2.87173	.57435	3.3766	5.7474	.48	11.50
	2	15	4.2667	1.24135	.32052	3.5792	4.9541	2.00	6.20
	Total	40	4.4513	2.37678	.37580	3.6911	5.2114	.48	11.50
NO3	1	25	75.6400	28.55970	5.71194	63.8511	87.4289	30.00	134.00
	2	15	76.0667	20.62407	5.32511	64.6454	87.4879	38.00	102.00
	Total	40	75.8000	25.58666	4.04561	67.6170	83.9830	30.00	134.00
NH4	1	25	106.7200	56.54093	11.30819	83.3811	130.0589	25.00	203.00
	2	15	80.3333	37.55694	9.69716	59.5350	101.1317	32.00	168.00
	Total	40	96.8250	51.39085	8.12561	80.3894	113.2606	25.00	203.00
ExP	1	25	273.9200	148.02982	29.60596	212.8163	335.0237	50.00	480.00
	2	15	196.6000	88.71930	22.90722	147.4689	245.7311	80.00	386.00
	Total	40	244.9250	133.21958	21.06386	202.3193	287.5307	50.00	480.00
TP	1	25	1006.8800	366.22230	73.24446	855.7109	1158.0491	420.00	1630.00
	2	15	774.4667	135.58596	35.00814	699.3817	849.5517	532.00	990.00
	Total	40	919.7250	319.55979	50.52684	817.5248	1021.9252	420.00	1630.00
ExCa	1	25	17.2080	5.30856	1.06171	15.0167	19.3993	7.20	27.60
	2	15	18.3533	4.42926	1.14363	15.9005	20.8062	10.60	26.00
	Total	40	17.6375	4.96989	.78581	16.0481	19.2269	7.20	27.60
ExMg	1	25	25.2920	9.25342	1.85068	21.4724	29.1116	10.00	39.00
	2	15	26.8667	6.21722	1.60528	23.4237	30.3096	15.20	35.00
	Total	40	25.8825	8.19540	1.29581	23.2615	28.5035	10.00	39.00
ExNa	1	25	2.4360	.89437	.17887	2.0668	2.8052	1.20	4.30
	2	15	2.3667	.78437	.20252	1.9323	2.8010	1.30	3.70
	Total	40	2.4100	.84514	.13363	2.1397	2.6803	1.20	4.30
ExK	1	25	.9720	.34943	.06989	.8278	1.1162	.50	1.80
	2	15	.9200	.24842	.06414	.7824	1.0576	.50	1.30
	Total	40	.9525	.31296	.04948	.8524	1.0526	.50	1.80

Table XVIII. ANOVA between vegetative and non vegetative sites for physico-chemical parameters of sediments in Tso Morari lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.007	1	.007	.071	.791
	Within Groups	4.005	38	.105		
	Total	4.013	39			
Cond	Between Groups	1300142	1	1300141.500	9.199	.004
	Within Groups	5370856	38	141338.316		
	Total	6670998	39			
OC	Between Groups	.442	1	.442	.224	.638
	Within Groups	74.895	38	1.971		
	Total	75.338	39			
OM	Between Groups	.818	1	.818	.142	.709
	Within Groups	219.497	38	5.776		
	Total	220.315	39			
NO3	Between Groups	1.707	1	1.707	.003	.960
	Within Groups	25530.693	38	671.860		
	Total	25532.400	39			
NH4	Between Groups	6527.402	1	6527.402	2.571	.117
	Within Groups	96472.373	38	2538.747		
	Total	102999.8	39			
ExP	Between Groups	56047.335	1	56047.335	3.348	.075
	Within Groups	636103.4	38	16739.564		
	Total	692150.8	39			
TP	Between Groups	506399.6	1	506399.602	5.536	.024
	Within Groups	3476220	38	91479.484		
	Total	3982620	39			
ExCa	Between Groups	12.298	1	12.298	.491	.488
	Within Groups	950.996	38	25.026		
	Total	963.294	39			
ExMg	Between Groups	23.246	1	23.246	.340	.563
	Within Groups	2596.172	38	68.320		
	Total	2619.418	39			
ExNa	Between Groups	.045	1	.045	.062	.805
	Within Groups	27.811	38	.732		
	Total	27.856	39			
ExK	Between Groups	.025	1	.025	.254	.617
	Within Groups	3.794	38	.100		
	Total	3.820	39			

Table XIX. Descriptive statistics of sediment samples between vegetative and non vegetative sites in Tso Khar Lake

Descriptives

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
pH	1	14	8.2800	.35570	.09507	8.0746	8.4854	7.80	8.90
	2	16	10.0194	.20927	.05232	9.9079	10.1309	9.70	10.40
	Total	30	9.2077	.92646	.16915	8.8617	9.5536	7.80	10.40
Cond	1	14	1444.2857	256.11639	68.44998	1296.4085	1592.1629	890.00	1760.00
	2	16	44203.75	6271.81832	1567.955	40861.7339	47545.7661	35700.00	58600.00
	Total	30	24249.33	22161.42267	4046.104	15974.1221	32524.5446	890.00	58600.00
OC	1	14	3.2107	.82414	.22026	2.7349	3.6866	2.10	5.20
	2	16	.2369	.08761	.02190	.1902	.2836	.13	.40
	Total	30	1.6247	1.60793	.29357	1.0243	2.2251	.13	5.20
OM	1	14	5.5036	1.41277	.37758	4.6879	6.3193	3.60	8.90
	2	16	.4044	.15310	.03827	.3228	.4860	.22	.70
	Total	30	2.7840	2.75709	.50337	1.7545	3.8135	.22	8.90
NO3	1	14	82.3571	33.17229	8.86567	63.2040	101.5103	32.00	140.00
	2	16	307.1250	33.18006	8.29502	289.4446	324.8054	260.00	380.00
	Total	30	202.2333	118.61839	21.65666	157.9405	246.5262	32.00	380.00
NH4	1	14	115.1429	44.15681	11.80140	89.6475	140.6382	48.00	206.00
	2	16	116.8750	32.15768	8.03942	99.7394	134.0106	72.00	176.00
	Total	30	116.0667	37.54623	6.85497	102.0467	130.0867	48.00	206.00
ExP	1	14	335.6429	69.68899	18.62517	295.4056	375.8801	232.00	420.00
	2	16	54.6875	23.32015	5.83004	42.2611	67.1139	25.00	103.00
	Total	30	185.8000	150.93739	27.55727	129.4391	242.1609	25.00	420.00
TP	1	14	844.0714	130.69428	34.92952	768.6108	919.5321	630.00	1038.00
	2	16	365.3750	70.44986	17.61247	327.8349	402.9151	236.00	480.00
	Total	30	588.7667	263.10411	48.03602	490.5220	687.0114	236.00	1038.00
ExCa	1	14	14.8143	4.45004	1.18932	12.2449	17.3837	9.30	24.60
	2	16	30.4875	4.96385	1.24096	27.8424	33.1326	19.60	38.20
	Total	30	23.1733	9.21247	1.68196	19.7333	26.6133	9.30	38.20
ExMg	1	14	14.0714	4.88694	1.30609	11.2498	16.8931	7.80	23.00
	2	16	20.8812	4.37831	1.09458	18.5482	23.2143	11.20	30.20
	Total	30	17.7033	5.70623	1.04181	15.5726	19.8341	7.80	30.20
ExNa	1	14	2.7371	.56426	.15081	2.4113	3.0629	1.92	3.50
	2	16	784.1250	144.39708	36.09927	707.1812	861.0688	513.00	947.00
	Total	30	419.4773	409.86381	74.83055	266.4317	572.5230	1.92	947.00
ExK	1	14	1.0557	.19864	.05309	.9410	1.1704	.62	1.34
	2	16	203.3750	38.12589	9.53147	183.0591	223.6909	138.00	302.00
	Total	30	108.9593	106.25896	19.40014	69.2816	148.6371	.62	302.00

Table XX. ANOVA between vegetative and non vegetative sites for physico-chemical parameters of sediments in Tso Khar lake

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	22.590	1	22.590	274.804	.000
	Within Groups	2.302	28	.082		
	Total	24.892	29			
Cond	Between Groups	1.37E+10	1	1.365E+10	646.910	.000
	Within Groups	5.91E+08	28	21103154.21		
	Total	1.42E+10	29			
OC	Between Groups	66.033	1	66.033	206.703	.000
	Within Groups	8.945	28	.319		
	Total	74.978	29			
OM	Between Groups	194.147	1	194.147	206.706	.000
	Within Groups	26.299	28	.939		
	Total	220.446	29			
NO3	Between Groups	377220.4	1	377220.402	342.717	.000
	Within Groups	30818.964	28	1100.677		
	Total	408039.4	29			
NH4	Between Groups	22.402	1	22.402	.015	.902
	Within Groups	40859.464	28	1459.267		
	Total	40881.867	29			
ExP	Between Groups	589388.1	1	589388.148	231.481	.000
	Within Groups	71292.652	28	2546.166		
	Total	660680.8	29			
TP	Between Groups	1710989	1	1710988.688	161.577	.000
	Within Groups	296500.7	28	10589.310		
	Total	2007489	29			
ExCa	Between Groups	1834.184	1	1834.184	81.905	.000
	Within Groups	627.035	28	22.394		
	Total	2461.219	29			
ExMg	Between Groups	346.257	1	346.257	16.212	.000
	Within Groups	598.013	28	21.358		
	Total	944.270	29			
ExNa	Between Groups	4558900	1	4558900.142	408.135	.000
	Within Groups	312761.9	28	11170.067		
	Total	4871662	29			
ExK	Between Groups	305633.8	1	305633.764	392.480	.000
	Within Groups	21804.263	28	778.724		
	Total	327438.0	29			