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Major Ion Chemistry of Surface Sediments of Brackish Endorheic Lake Tso Moriri - A High Altitude Ramsar Site in Western Himalaya

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ABSTRACT

Tso Moriri lake is a brackish high altitude (4520 m.a.s.l) oligotrophic endorheic lake situated on the left bank of Indus river in Changthang region of Ladakh. The lake is breeding ground of black necked crane and bar-headed geese and has been designated as Ramsar site in 2002. The present study is one of the preliminary investigations on the chemistry of major ions of surface sediments of Tso Moriri lake. The sediments were collected from various sites (depth range 2.5 - 44 meters) with the help of Ekman dredge during 2004-2006. The findings of the study revealed that the lake sediments are alkaline (pH range, 7.80 - 8. 90) with high conductivity values (930-22700µS). The sediments contained relatively low levels of organic carbon (2.8% - 6.7%) and organic matter (0.48- 11.50%).Although nitrogen content (HN_3-N and NO_3-N) of the sediments was found to be poor, yet concentration of HN_3-N was comparatively higher than NO_3-N at all the sites. However, phosphorus concentration (exchangeable phosphorus and total phosphorus) of the sediments is high as compared to nitrogen. The sediments are enriched with exchangeable cations with concentrations varying in the sequence of Mg>Ca>Na>K at all the sites. Most of the chemical parameters (pH, HN_3-N, NO_3-N and exchangeable cations) showed significantly ($P>0.05$) higher concentration in winter season as compared to summer season. Aquatic vegetation also played a prominent role on the sediment chemistry having significantly ($P>0.05$) higher values of OC, OM, NO_3-N, and ex-P and TP at vegetative sites in relation to non-vegetative sites. The principal component analysis (PCA) of the sediments categorized the sediments in three principal factors explaining the cumulative variability of about 82%. Strong positive loading of all the chemical parameters in factor 1st (67.49%) except pH depicts that the sediment chemistry of Tso Moriri lake was mainly regulated by inflow components, macrophytic vegetation, evapo-concentration processes and sulfate reduction in the lake basin.

Keywords: *Himalaya, Indus, Closed lake, Exchangeable Cations, Jammu and Kashmir.*

INTRODUCTION

Sediments are one of the fundamental components of aquatic ecosystems and play an important role in lake metabolism and internal loading (Yanga *et al.,* 2019). They also act as a store house for both external and internal material (Wetzel, 2001; Shah *et al*., 2019) and hence are regarded as the artifact of lake history and chemical transformations of transported material (Avramidis *et al.,* 2013). Physico-chemical environment of the sediment-water interface is very crucial (Lee *et al.,* 2019) which further indicates whether the storehouse (sediments) will act as a sink or source for nutrients (Randal *et al.,* 2019). Sediments affect the water quality of lake ecosystems as a consequence of mass transfer processes of nutrients between sediments and overlying water columns due to their dynamic and active character (Yu *et al.,* 2017). The mass transfer of nutrients at sediment water interface is regulated by physical (wind, temperature, hydrostatic pressure and oxygen concentration) (Söndergaard *et al*., 1992; De- Vilente *et al.,* 2006; Kowalczewska-Madura *et al.,* 2018), chemical (gradient of nutrients concentration in the sediment-water interface, pH, redox potential) (Carling *et al*., 2013) and biological characteristics like presence of macrophytes, microbial community and bioturbation; (Rejmankova and Houdkova, 2006; Huser *et al*., 2016; He *et al*., 2017). Therefore, information of nutrient status of sediments and their interactions with overlying water column are very vital for understanding the whole nutrient dynamics and internal loading in lakes (Boström *et al*., 1988; Kowalczewska-Madura *et al.,*2018).

The biogeochemical conditions of sediments are usually anoxic, reductive which provides favorable conditions for releasing of nutrients, especially phosphorous and enhances internal phosphorous loading in the lake and wetlands (Wetzel, 2001) However, macrophytes have ability to modify the sediment water interface by transporting oxygen to sediments creating oxic geochemical environment, thus retards the internal loading (Wetzel, 2001).

Ladakh is a cold high altitude desert located in western Himalayan region having number of glacial high altitude lakes. The area has usually remained free from human activity probably due to very low human population density. Furthermore, due to difficult terrain and inaccessibility, the area has been mostly unexplored except the tourist activity during the short summer period of the year. Consequently, very few works have been carried out on Ladakh lakes especially on sediment chemistry (Hutchison *et al*., 1943; Sekar, 2000; Ahmad *et al.*, 2013: Prasad *et al.,* 2016). However, these studies clearly lack relationship of ion chemistry within the surface sediments. Hence, we investigate the major ion chemistry in the surface sediments of the Tso Moriri lake and how they are influenced by biological and geochemical processes in the lake ecosystem.

MATERIAL AND METHODS

Study Area

Tso Moriri is one of the largest inland high altitude lakes located in the Changthang Plateau of Ladakh region (78°14′ to 78°25′ and 32°40′ to 30°2′N, 4520 m.a.s.l) with an N-S extension of 27 Km and E-W extension of 5-7 Km (Dubey and Shukla, 2008).The lake has surface area of 148.8 sq Km with maximum depth of 105m at the center (Mishra *et al*., 2015). The Tso Moriri is an endorheic lake fed by a number of streams originating from glaciers. The main tributaries to the lake are Gyoma in the Northern part, Korzuk in the Northwestern side and Phersey in the southern part (Fig 1 a & b). The lake is situated about 250 km from Leh town and used for grazing animals and has feeble tourist activity during the summer.

The climate of the Tso Moriri lake is arid, and cold (Philip and Mazari, 2000) and remains under ice cover from January to March. The temperature are below freezing from December to March and increases as the summer season approaches. The mean annual precipitation in the region is about 100mm (Wünnemann *et al*., 2010).

Tso Moriri lake was designated as Ramsar site in 2002. Tso Moriri is one the main breeding ground outside China for one of the most endangered species – Black Necked Crane (Chandan *et al.*, 2014). Besides it also is a habitat for other birds (Bar Headed Geese) and animals (Snow Leopard). The entire littoral zone of the Tso Moriri has luxuriant growth of submerged monospecific strands of *Potamogeton pectinatus*, however, the density of macrophytes strands is high at confluence zone of the streams. The basin is preferred pasturing area for Changpa- the local shepherd of Tibetan origin and provides rich pastures for domestic livestock. These high altitude pastures of Changthang are homes of Pashmina goat hence main centres for production and supply of Pashmina wool especially to Indian plains and Kashmir valley (WWF, 2007). Moreover, a part of north western periphery of lake is used for agricultural activity during brief summer by the people of Korzok village.

The geological map of Tso Moriri area is shown in Fig1b. The northern part of the lake is surrounded by metamorphosed puga gneiss complex which is dominated by schists (Berthelsen, 1953). The Haimanta group (meta-sedimentary lower proterozoic to Cambrian age) is dominated by carbonate lithology and is exposed in the southern fringe of the catchment (Steck *et al*., 1998). The southwest area of the lake is characterized by Rupshu granite, whereas eastern part of the lake is dominated by limestone, dolomite, shales and sandstone belonging to Lamayuru Formation (Mesozoic age) (Steck *et al.,* 1998). Since Tso Moriri is feeded by several local streams hence numerous Quaternary fan deposits from marine Tethys sediments had been reported by several workers (e.g. Steck *et al.,* 1998, Steck 2003, Mishra *et al.,* 2015).

During the current study five sites were selected from the lake depending upon presence/absence of macrophytes strands, accessibility and depth (Fig. 1a). The general characteristics of the sites are described below.

Site TM1: It is located at the confluence of Gyoma stream with the lake (33°, 00.584′ N and 78°, 15.777' E). It is relatively shallow (2.5 m depth) due to deposition of silt brought by the Gyoma stream from its catchment and has luxuriant growth of submerged macrophytes like *Potamogeton pectinatus.*

Site TM2: The site is located in the littoral zone of the lake in the vicinity of the confluence point of Korzok stream on the northwestern area of the lake at 32°, 57.827'N and 78°, 15.554'E. The site is 4.7m deep, containing dark and silty textured sediments and has high density of *Potamogeton pectinatus.*

Site TM3: The site is located on the western bank at 32° 58.207' N and 78°, 16.977’E. It is 44m deep with sparse vegetation, having dark and clayey textured sediments.

Site TM4: The site is located towards the eastern bank of the lake at 32°, 55.435' N and 78°, 21.570' E. TM5.It is marked by sudden steep slope and have average depth of 36m. The sediments are dark in colour and clay textured.

Site TM5: This site is located in the northeastern part of the lake at 32°, 00.101' N and 78°, 17.636' E. The site is shallow in nature with only 6 m deep and devoid of macrophythic vegetation. The sediments were yellowish and sandy in texture.

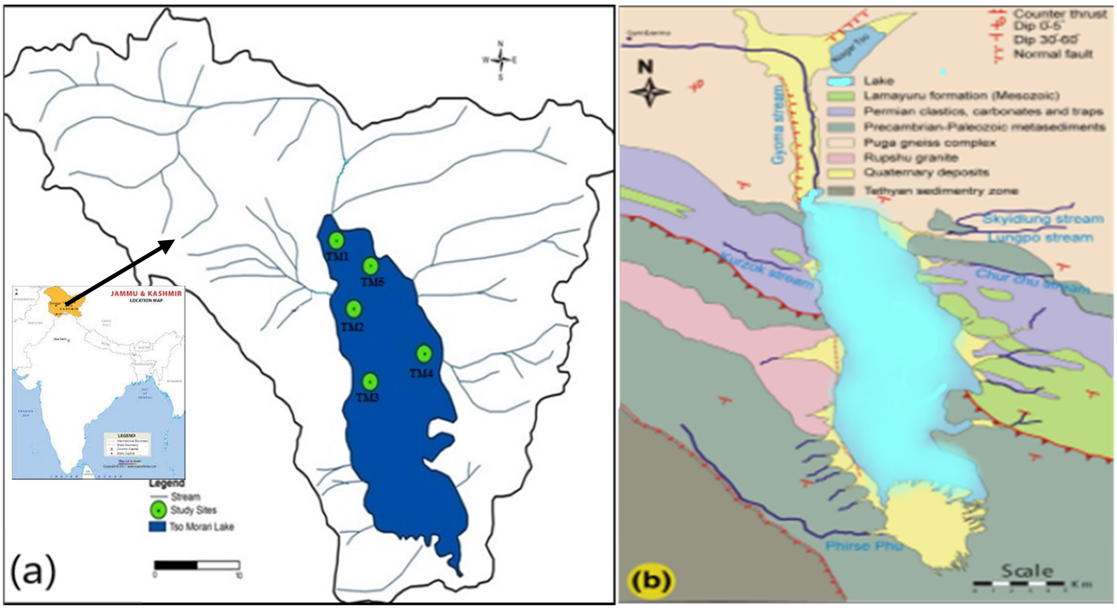

Fig. 1 (a) Map of Tso Moriri lake showing location of study sites;(b) Geological Map of Tso Moriri lake (Source: Mishra *et al*., 2015)

METHODOLOGY

Sediment samples were collected with the help of Ekman dredge from the lake between 2004 to 2006 years. The samples were collected for 9 months depending on the accessibility. The samples were stored in air tight polythene bags and subsequently transported to laboratory for analysis. The analysis was performed on both wet and dry samples to avoid losses and changes in the samples. Parameters like pH, electrical conductivity (EC), nitrate nitrogen (NO_3-N), and ammonical nitrogen (NH_4^+-N), were analyzed on wet samples while as the rest of parameters were analyzed on air dry samples. pH and conductivity was recorded by digital pH meter (Systronics-MKVI) and digital conductivity meter (Systronics-DB-104) respectively. Organic carbon was determined by Walkley and Black method (Page *et al*., 1982), NH_4^+-N was estimated by indophenols blue method (Page *et al*., 1982). NO_3-N was determined by Phenol disulfonic acid method (Jackson, 1973). Available phosphorus was determined by Olsen's method and total phosphorus was measured spectro-photometrically (Model- Systronics 106) with molybdenum blue method following tri-acid digestion (nitric acid: sulfuric acid: perchloric acid in the ratio of 9:4:1) (Page *et al*., 1982). Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+ were extracted in 1N ammonium acetate solution by centrifugation and decantation method in a 1:10 soil extract ratio. Ca^{2+}, Mg^{2+}, ions were determined by versenate method, whereas Na^+ and K^+ were estimated by digital flame photometer.

Statistical Analysis

Statistical analysis was performed on SPSS 16 software. One way ANOVA followed by post hoc test (Tukeys HSD) was used to compare the variation between sites. T-test was used to compare the seasonal variation and effect of vegetation on sediment chemistry. Correlation analysis was also performed to check the variation between the different chemical parameters. PCA was applied to reflect the overall variability in the data set (12 x 5 x 9 = 540 observations).

RESULTS AND DISCUSSION

Sediment chemistry

The descriptive statistic of various chemical parameters of sediments in Tso Moriri lake is shown in Table 1. Change in ion chemistry between different sites in Tso Moriri lake is presented in Fig. 2 and Fig. 3. The mean sediment pH values are alkaline at all the sites and ranged between 7.80 to 8.90 (Table 1). The alkaline pH in the sediments of Tso Moriri infers evapo-concentration processes in the lake basin which might have enriched the sediments with carbonates of calcium and magnesium by facilitating their precipitation (Wang *et al.*, 2007; Rodriguez *et al.,* 2008; Zang, *et al.,* 2019). This situation is also confirmed by Mishra *et al.* (2015), who reported the dominance of carbonate minerals of allogenic and authigenic origin in the sediments of Tso Moriri. Conductivity is influenced by a variety of factors like surrounding lithology (Lintern *et al*., 2018; Bhateria and Jain, 2016) weathering rate (Jiang *et al.,* 2020), mineralization processes and evapo-concentration processes (Wang *et al.*, 2007). The conductivity of the lake sediments varied from 930 to 2700 µS. The mean conductivity values showed significant difference ($F_{4,\ 35}$ = 26.543; p = 0.000) between the study sites. TM4 and TM5 sites had significantly lower values, than TM1 and TM2 (Fig.2b). The variation in conductivity among sites is apparently due to high concentration of exchangeable cations such as Ca, Mg, Na and K, which are precipitated as calcite, aragonite and halite from inland brackish water and saline lakes (Rodriguez *et al.*, 2008; Zang *et al.,* 2019). In addition it is also substantiated by significant positive correlation of Ca (r=0.751; p<0.01), Mg (r=0.718; p<0.01) and Na (r=0.650; p<0.01) with conductivity (Table.4). The organic carbon and organic matter of the sediments varied from 0.28% to 6.70% and 0.48% to 11.50% respectively. The mean values of organic carbon and organic matter of sites TM5 and TM4 were significantly lower ($F_{4,35}$=17.49; p =0.000) than TM1 and TM2 (Fig. 2 d and e). The organic carbon of lake sediments is governed by a variety of factors like biomass production by photosynthesis, organic loading from catchment, temperature, dissolved oxygen and microbial decomposition (Bianchini, 2006; Schmidt *et al.,* 2002, Rejmankova and Houdkova, 2006). Moreover, the organic matter is almost decomposed in aerobic sediments and thus unlikely to accumulate in lakes like Tso Moriri which contain fairly high levels of dissolved oxygen at sediment water interface (Goldshalk and Wetzel, 1976; Goldshalk and Barko 1985; Barko and Smart, 1986 Peret and Bianchini, 2004) The harsh climatic conditions, (Rawat and Adhikari, 2005) very brief growing season, and low productivity of lake could be another reason of low organic carbon and organic matter in the sediments (Wetzel, 2001; Last and Ginn, 2009). The exchangeable NH_3-N of the sediments ranged from 30 µg/g to 134 µg/g whereas, exchangeable NO_3-N varied from 25 µg/g to 203 µg/g (Table 1).

The mean values of NH_3-N were significantly higher ($F_{4,35}$ =13.97; p =0.000) at site TM1 and TM2 (105±35.1µg/g) than other sites (Fig. 2e). Likewise the significantly highest ($F_{4,35}$ =4.12; p =0.008) mean value of NO_3-N was recorded for TM1 and TM2 and lowest was recorded at site TM5 (Fig. 2f). The low values of NH_3-N and NO_3-N in Tso Moriri is due to low organic loading from the catchment and patchy distribution of macrophytes in the lake. However, the concentration of NH_3-N and NO_3-N was high at confluence points of the lake, which receive high organic load from nearby pasture lands and are subsequently mineralized into ammonia and nitrate by microbial community associated with macrophytes. Mishra *et al.* (2014) has also reported high concentration of nitrate from feeding streams of Tso Moriri. Kufel and Kufel (2002) observed high nitrification rates in marophytic community as they transport oxygen to the microbial community and thus makes them ideal sites for nitrification (Gacia, *et al.,* 2009; Vila- Costa *et al.,* 2016). The exchangeable phosphorus in the sediments ranged from 50µg/g to 480µg/g and total fluctuated from 420µg/g to 1630µg/g respectively. The mean values of exchangeable phosphorus were significantly lower ($F_{4,35}$=31.74; p= 0.000) at TM4 and TM5 than TM1 and TM2 (Fig. 2g). The mean total phosphorus is also significantly lower ($F_{4,35}$=20.29; p=0.000) at TM4 and TM5 than TM1, TM2 and TM3 (Fig. 2h).

Table 1. Range of different chemical parameters of sediments in Tso Moriri lake

Variable	Minimum	Maximum	Mean	Std. Deviation
pH	7.80	8.90	8.42	0.30
Conductivity (µS/cm)	930	2700	1815	419
Organic Carbon (%)	0.28	6.70	2.51	1.38
Organic Matter (%)	0.48	11.50	4.27	2.37
Ex. Ammonia (µg/g)	30	134	75	24
Ex. Nitrate (µg/g)	25	203	93	50
Ex. Phosphorus (µg/g)	50	480	232	133
Total Phosphorus (µg/g)	420	1630	892	314
Ex. Calcium (cmoles (+)/kg)	7.2	27.6	17.4	4.9
Ex. Magnesium (cmoles (+)/kg)	10.0	39.0	25.4	8.1
Ex. Sodium (cmoles (+)/kg)	1.2	4.3	2.4	0.8
Ex. Potassium (cmoles (+)/kg)	0.46	1.84	0.93	0.31

The high biomass production of macrophytes and allogenic organic matter at confluence areas of the lake releases large organic phosphorus under rapid bacterial decomposition (Wetzel, 2001; Palomo *et al*., 2004) which afterward gets tied up with inorganic particles (Krom and Berner, 1981: Wang *et al.,* 2007). This is also depicted by significant positive correlation of phosphorous with organic carbon (r=0.807; p<0.01) and organic matter (r=0.805; p<0.01). The internal phosphorus loading in endorheic lakes is also accelerated by sulfate reduction (Smolders *et al.*, 2006) thus reduces the phosphorus content of the sediments by releasing large quantities of phosphorus into overlying water column (Smolders *et al.*, 2006: Wilfert *et al.*, 2020). It is the main reason why inland lakes are limited by nitrogen rather than by phosphorus (Khan, 2003). The cations progression is in the order of Mg>Ca>Na>K and ranged from 10.0 cmoles

(+)/kg) to 39.0 cmoles (+)/kg), 7.0 cmoles (+)/kg) to 27.6 cmoles (+)/kg) 1.2 to 4.3 cmoles (+)/kg) and 0.46 cmoles (+)/kg) to 1.84 cmoles (+)/kg) respectively (Table 1). The mean values of all the exchangeable cations were significantly lower at TM5 as compared to rest of sites (Fig. 3). This is due to low OM at this site which decreases the binding capacity of cations. The geochemical evolution in evaporative lakes without river

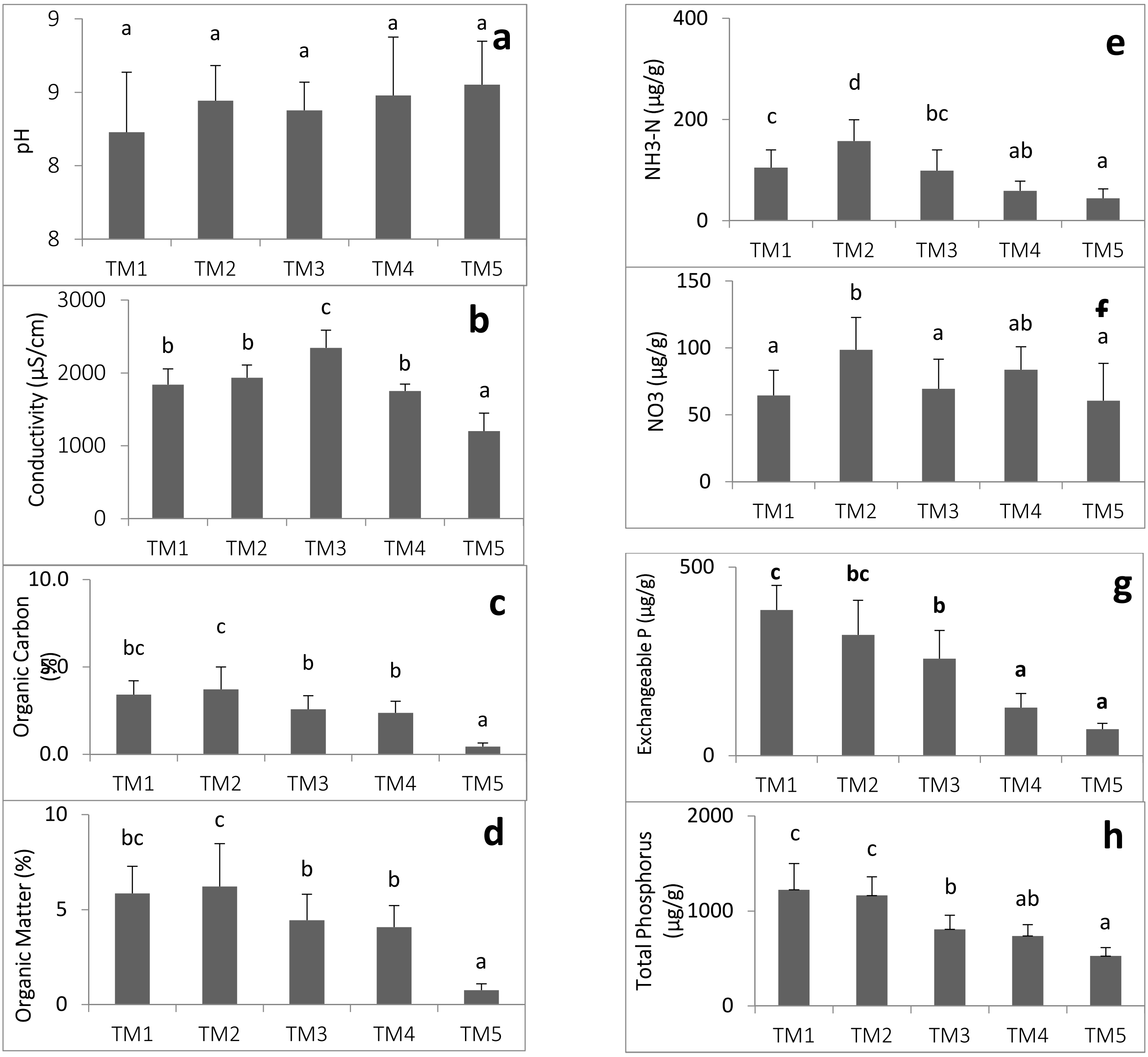

Fig. 2. Changes in (a) pH, (b) conductivity, (c) OC, (d)OM, (e) ammonia, (f) NO_3-N, (g) Exe P and (h) total phosphorous (at different study sites mean ± SD) in Tso Moriri lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different between the sites (Tukey HSD)

outlets is primarily controlled by inflow composition, selective removal processes of dissolved species, and concentration processes in the lake basin (Zang *et al.,* 2008). In closed lake ecosystems evaporation- precipitation processes play a key role in hydrochemistry (Gibbs, 1970) and facilitate crystallization and precipitation of minerals from water column and thus may increase the concentration of cations in sediments (Sekar, 2000; Ryves *et al.,* 2006; Zang *et al.*, 2019). Kilham and Cloke (1990) and Mishra *et al.* (2014) also reported precipitation of dolomite, halite, aragonite and calcite in the endorheic lakes of Tanzania and Ladakh respectively.

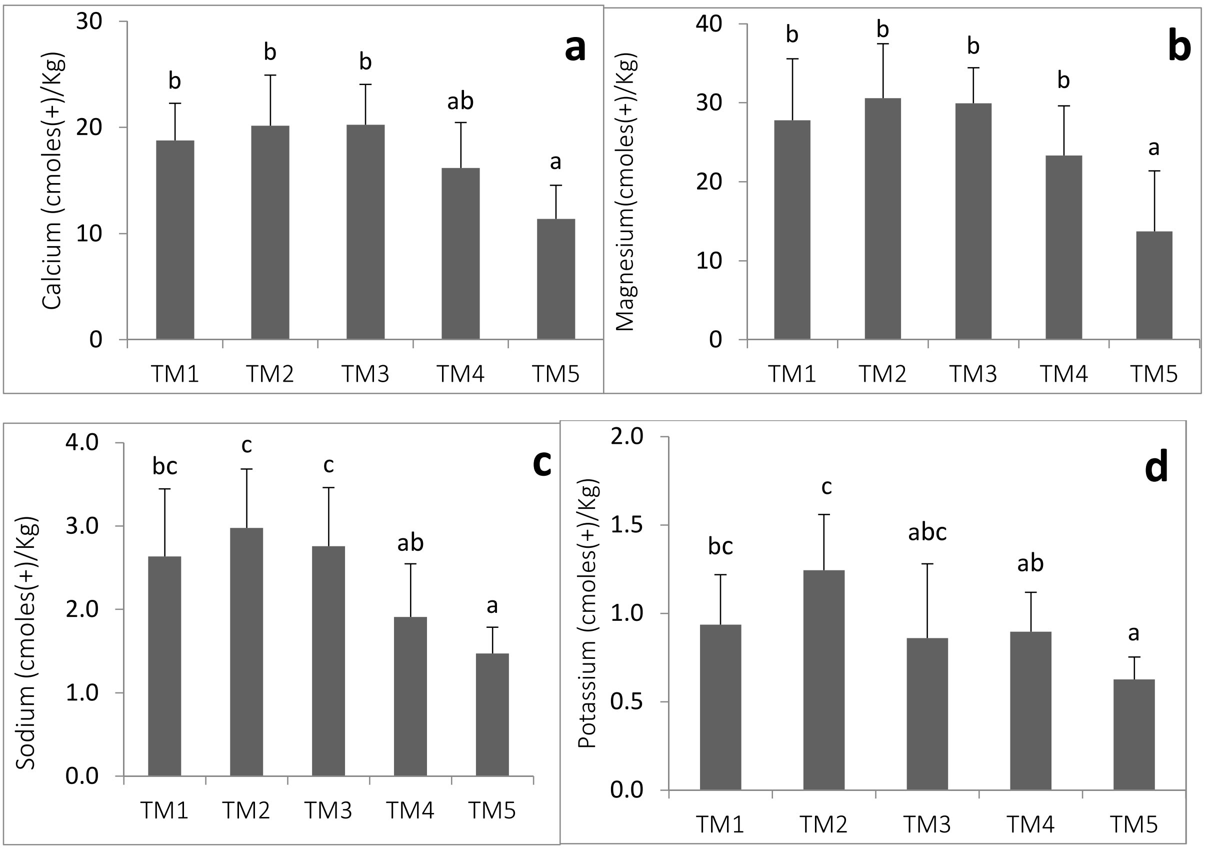

Fig. 3. Changes in exchangeable (a) Ca, (b) Mg, (c) Na and (d) K at different study sites (mean ± SD) in Tso Moriri lake. Different letters on the bars indicate that the means are significantly ($p < 0.001$) different among the sites (Tukey HSD)

Seasonal variations

The seasonal variation in the major ions in the sediments of the Tso Moriri lake is shown in Table 2. The seasonal variation of the data was performed by t-test comparing the sediment chemistry between summer (n=4) and winter (n=5) seasons irrespective of the sites. The summer season included June, July, August and October, November, December were included as winter season. The results revealed that the pH was significantly higher (8.64±0.04) in summer season, which clearly suggests high rates of carbonate deposition due to high photosynthetic rates by the phytoplankton and macrophytes (Wetzel, 2001). The organic carbon, organic matter and exchangeable phosphorus is higher in winter season, but difference was insignificant (Table, 3; P= 0.08). However, the conductivity (1931µS), exchangeable NH_4-N (85.47 µg/g), NO_3-N (110.36 µg/g), TP (976.3 µg/g) and exchangeable cations (Ca 19.62 cmoles (+)/kg; Mg 28.40 cmoles (+)/kg; Na 2.62 cmoles (+)/kg; K 1.05 cmoles (+)/kg) were significantly higher (P<0.05) in winter season at all the sites. The high values are due to low uptake by the vegetation during winter and release of organic matter by the senesce of the vegetation and plankton.

Table 2. The seasonal variation in chemical parameters of sediments in Tso Moriri lake

Parameters	**Summer (n=20)**	Std. Error Mean	**Winter (n=25)**	Std. Error Mean	**P value (Sig.)**
pH	8.64	0.04	8.24	0.05	0.00
Conductivity (µS/cm)	1669.00	91.84	1931.30	79.14	0.04
Organic Carbon (%)	2.10	0.25	2.83	0.30	0.08
Organic Matter (%)	3.58	0.43	4.82	0.51	0.08
Ex. Ammonia (µg/g)	62.65	5.99	85.47	3.35	0.00
Ex. Nitrate (µg/g)	70.95	9.50	110.36	9.93	0.01
Ex. Phosphorus (µg/g)	192.95	24.70	263.60	28.47	0.08
Total Phosphorus (µg/g)	785.75	55.95	976.36	67.61	0.04
Ex. Calcium (cmoles (+)/kg)	14.53	0.84	19.62	0.91	0.00
Ex. Magnesium (cmoles (+)/kg)	21.63	1.42	28.40	1.62	0.00
Ex. Sodium (cmoles (+)/kg)	2.02	0.16	2.62	0.17	0.01
Ex. Potassium (cmoles (+)/kg)	0.80	0.05	1.05	0.06	0.01

Effect of vegetation on lake sediments

To verify the effect of submerged vegetation on sediment chemistry, the sites were categorized into vegetative and non-vegetative areas and compared with t-test to determine the effect of vegetation on sediment chemistry. It was found that vegetation did not have any significant effect on pH, conductivity and exchangeable cations of the sediments. However, organic carbon, organic matter, exchangeable nitrate, exchangeable phosphorus and total phosphorus were significantly higher at vegetative sites (Table. 3). The high values of organic carbon and organic matter may be due to high primary productivity of macrophytes and entrapment of suspended organic matter carried by the incoming streams. The high concentration of NO_3-N in littoral area reflects high nitrification rate under oxic conditions (MaCarthy *et al.*, 2007). Furthermore, the high concentration of phosphorus at the vegetative sites could be attributed to high organic matter which acts as source of organic phosphorus (Brenner *et al.,* 2006). The microbial degradation of organic matter releases organic phosphorus which is retained in sediments by-clays, Al, Fe, Ca compounds (Olila and Reddy, 1995; Reddy and D'Angelo, 1997). 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 Moriri lake (Table 4). Moreover, the submerged macrophytes alter physico- chemical environment of water which increases the co- precipitation of phosphorus with carbonates and thus increase the phosphorus content of the sediments. Further high concentration of phosphorous at the vegetative sites is possibly also due to the sedimentation of suspended load carried by the local streams from the catchment.

Table 3. The variability of different chemical parameters of sediments under vegetative and non-vegetative sites in Tso Moriri lake

Parameters	**Vegetative (n=27)**		**Non-Vegetative (n=18)**		**t-test**
	Mean	Std. Error Mean	**Mean**	Std. Error Mean	**P Vaule (Sig.)**
pH	8.34	0.08	8.43	0.06	0.37
Conductivity (µS/cm)	1887.80	46.45	2048.30	83.06	0.10
Organic Carbon (%)	3.57	0.25	2.47	0.15	0.00
Organic Matter (%)	6.04	0.43	4.25	0.27	0.00
Ex. Ammonia (µg/g)	81.50	6.45	76.54	4.47	0.53
Ex. Nitrate (µg/g)	131.11	10.91	79.00	8.28	0.00
Ex. Phosphorus (µg/g)	353.22	19.82	192.28	20.06	0.00
Total Phosphorus (µg/g)	1193.70	55.07	772.15	29.21	0.00
Ex. Calcium (cmoles (+)/kg)	19.47	0.97	18.22	0.97	0.37
Ex. Magnesium (cmoles (+)/kg)	29.19	1.71	26.65	1.37	0.26
Ex. Sodium (cmoles (+)/kg)	2.81	0.18	2.34	0.17	0.06
Ex. Potassium (cmoles (+)/kg)	1.11	0.07	0.92	0.05	0.05

Principal component analysis (PCA)

To understand the underlying geochemical, and other hydrochemical processes in the lake basin, principal component analysis (PCA) was carried out on the entire dataset and yielded three principal components(PCs) having Eigen values more than one with cumulative variability of about 82% (Table 5 and Fig. 4). All parameters showing significant (>0.700) loadings within the three factors. The first PC reveals 67.5% of the total variance, having a strong and positive component loading mainly from, Cond., OC, OM, NH_3–N, Ex-P, TP, Ex-Ca, Ex-Mg, Ex-Na and Ex-K. The second PC reflects 8% of the total variance, with only exchangeable nitrate showing strong positive loadings. The third PC account for about 6.5% variance depicting negative component loadings only with pH. The 1st PC indicates the main role of conductivity, OC, OM, exchangeable cation, Ex-NH_3, Ex-P, TP which infers the role of geochemical processes, like selective evapo-crystallization and precipitation, sulfate reduction and biogenic induced precipitation within the lake basin. However, the influential character of nitrate in the 2nd PC is due to leaching of nitrate from the pasture land which finally transports into the lake by several local streams. The 3rd PC, has only pH as dominant character which reveals both allogenic and authigenic carbonate sources, however, the allogenic sources are the key components in determining the pH (Mishra *et al.,* 2014).

Table 4. Pearson's correlations coefficients calculated for chemical parameters of Sediments in Tso Moriri lake (N=45)

Parameters	**pH**	**Cond**	**OC**	**OM**	**NO_3**	**NH_3**	**ExP**	**TP**	**ExCa**	**ExMg**	**ExNa**
Cond	-.437(**)										
OC	-.385(**)	.621(**)									
OM	-.386(**)	.624(**)	.996(**)								
NO_3	-.341(*)	.328(*)	.469(**)	.451(**)							
NH_3	-.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).

Table 5. Principal component loadings of the parameters for the entire data sets

Variables	**PCA1**	**PCA2**	**PCA3**
pH	-0.580	-0.152	**-0.720**
Cond	**0.752**	-0.010	0.242
OC	**0.903**	-0.223	-0.185
OM	**0.898**	-0.230	-0.180
NO_3	0.598	**0.676**	-0.226
NH_3	**0.892**	0.074	-0.225

Ex P	**0.826**	-0.393	0.061
TP	**0.835**	-0.353	-0.018
Ex-Ca	**0.920**	0.167	0.108
Ex-Mg	**0.895**	0.113	0.090
Ex-Na	**0.861**	0.048	-0.060
Ex-K	**0.810**	0.224	-0.122
Eigenvalue	**8**	**1**	**1**
Variability (%)	**67.490**	**8.000**	**6.560**
Cumulative %	**67.490**	**75.490**	**82.050**

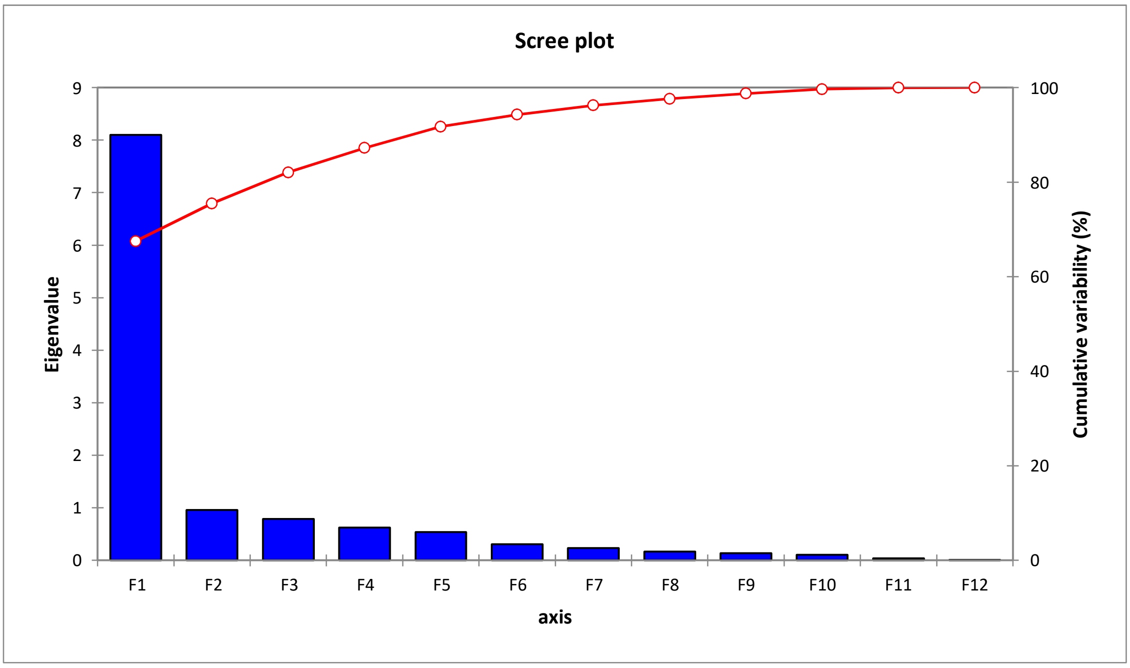

Fig. 4. Scree plot of the factors along with Eigen values and percentage variability

CONCLUSIONS

The major ion chemistry of surface sediments of Tso Moriri lake shows significant spatial as well as temporal variation. The pH, HN_3-N, NO_3-N and exchangeable cations were high during winter months as compared to summer season. Vegetation also had significant effect on the sediment chemistry. The cation composition of sediments reflects evapo-crystallization and precipitation processes under alkaline conditions. The sediments retained low phosphorous concentration due to sulfate induced internal phosphorous loading to overlying water column. From different statistical analysis it was observed that inflow composition, and macrophytic vegetation, in the lake basin also regulate the sediment ion chemistry.

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