Tracing the Imprints of Climate Change on the Water Quality of Eastern Himalayan High altitude lake (Pangang Teng Tso Lake)

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Abstract: High altitude lake research is a main indicator of global climate change. Pangang Teng Tso Lake is situated at 13000ft in the Eastern lesser Himalaya region. A comprehensive study of Pangang Teng Tso Lake was carried out with the major objective to understand the hydro-geochemical processes and water quality of lake. Water sampling of the lake were done in the pre-monsoon and post monsoon season. Our result showed that Ca-Mg-SO_4 was water type in pre-monsoon season whereas in the post-monsoon season, Na^+-K^+-SO_4^{2-} water type. In the pre-monsoon season, significant relationships were observed between $Ca2^+$-EC, Mg^{2+}-EC, Ca^{2+}-Mg^{2+} and NO_3^-–K^+. During the post-monsoon season, significant and positive relationships were observed between EC-NO_3^-, Mg^{2+}-Cl^-, PO_4^{3-}-SO_4^{2-}, PO_4^{3-}-SiO_2 and SO_4^{2-}-SiO_2. Hydro-geochemical processes like weathering, dissolution and precipitation seem to be playing vital role in governing the lake water chemistry. Our finding shows that lake gain acidic character during post monsoon season. Carbonate weathering and atmospheric precipitation were strong factors controlling the lake water chemistry. The overall hydro-geochemical evaluation of the lake water suggested that the lake is no influenced by anthropogenic input. Previous study of others lakes of the eastern Himalayan region by other authors have reported that little seasonal variation in the water chemistry and it is due to anthropogenic inputs in the vicinity of lakes.

Key words: *High Altitude Lake, geochemical processes, weathering, dissolution, precipitation, anthropogenic inputs*

"1.Introduction"

Lakes have great ecological and environmental values as they form an important component of the hydrological cycle. Despite containing less than 0.02% of the water in the hydrosphere, lakes' geological significance is much greater than what this value suggests[1] .

High altitude lakes are normally oligotrophic; they are located on non-sedimentary basins and remain ice-covered during a large part of the year. The hydrochemistry of High altitude lakes is predominantly influenced by the lithology, mineralogy of their catchment area, weathering process operation in vicinity of lakes and the weathering resistance [2],[3]. The lake water geochemistry infers the linkage between evaporation, chemical weathering, precipitation and the water chemistry of the lakes describes catchment characteristics and the seasonal changes in the behaviour of the major ions [4].

Study of High Altitude Lake hydro-geochemistry is of importance as the change in Lake Chemistry. The High Mountain lakes are significantly influenced by climatic changes and anthropogenic activities over many centuries [5]. Although far from local sources of pollution, the ecology of these lakes is strongly influenced by the atmospheric deposition of pollutants (acidity and toxic air pollutants) and by climate change. Because of their sensitivity to anthropogenic influences, they are also excellent sensors of change and can be used to infer the speed, direction and biological impact of changing air quality and climate [6].

Himalayan High altitude lakes have gained less attention so far in terms of conservation and water management, but they are becoming increasingly important under climate change scenario. Preliminary study of P. T. Tso Lake was carried out in order to understand the hydro-geochemical processes controlling the lake water quality. There is complete lack of scientific information on Eastern Himalayan high altitude lake till now. A novel study of P. T. Tso Lake was done with two main objectives (a) to understand the hydro-geochemical processes governing the lake water chemistry; (b) to understand the change in lake water chemistry with altitude of the eastern Himalayan lakes ; comparison was made between P. T. Tso Lake and six other high altitude lakes of the western Himalaya.

“2.Study Area Description and Climatic Condition:”

2.1 Geological Setting of the Study Area:

Pangang Teng Tso Lake, of Arunachal Pradesh (India), is popularly known as P. T. Tso Lake and is located at a distance of 18 kilometres from Tawang Township (Fig. 1). Pangang Teng Tso Lake is situated at 13000ft in the Eastern lesser Himalaya region. The latitude and longitude of the lake varied from 27°38’14.7’’ to 91°51’24.2’’ and 27°38’22.5’’ to 91°51’25.5’’.The district is bounded by Lower Tibet in the north, Bhutan in the south and West Kameng district in the East. During the winter months, the lake remains entirely frozen. The soils of the district are generally loamy or sandy loam mixed with coarser soil particles. Soil in the major part of the district is red sandy soils and skeletal soils. In the forested regions, the soil generally contains high humus and nitrogen due to extensive coverage of forests. Soils in the mountains regions are relatively lacking in organic materials. This category of soil is reddish in colour and acidic in nature. The soil found along the foothill areas is alluvial, loamy or sandy loam mixed with gravel and pebble brought down by rain waters from high altitudes.

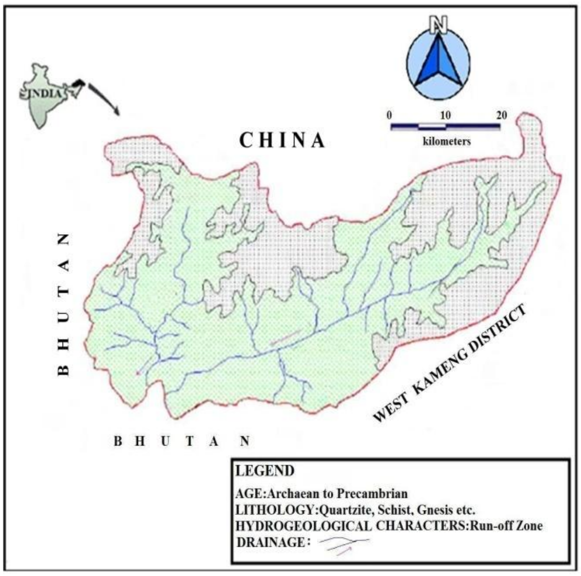

Figure 1.a: Hydro-geomorphology of Tawang district, Arunachal Pradesh.

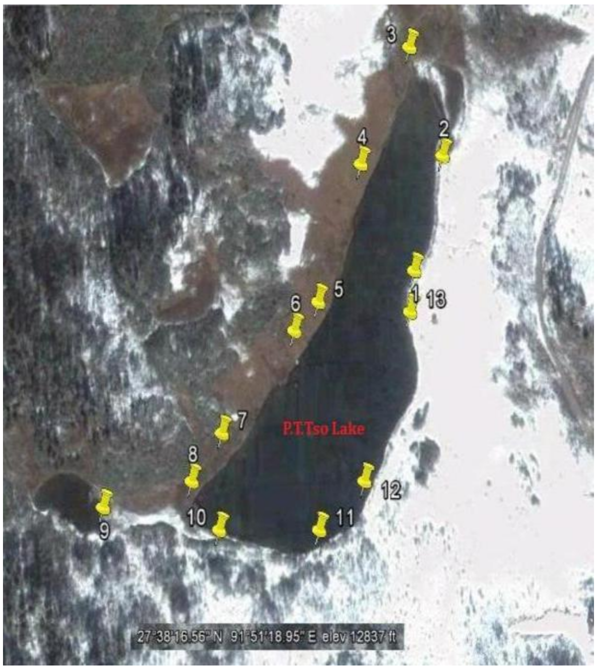

Figure 1.b: Map showing P.T.Tso Lake with sampling locations.

2.2 Climatic Condition:

The climatic condition of Arunachal Pradesh is governed by the Himalayan system. The climate of Tawang district is largely influenced by the nature of its terrain. The summer is moderate and extreme cold in winter. However, the mountain peaks are covered with perpetual snow. In winter, temperature falls below freezing point. Annual rainfall of Tawang district varies from 1500 to 2000 mm. Most of the rainfall is received during the monsoon period, from June to September. Heavy rainfall is received during summer season and occasional rainfall/snowfall during winter season. January and February are the driest months of the year. The summer rainfall occurs under the spell of South-West monsoon.

“3.Material and methods:”

Water samples were collected in different polypropylene bottles. The numbers of water samples were 17 and 13 in the pre- and post-monsoon seasons, respectively. The sampling sites were selected in such a way so as to bear maximum representativeness for the lake. On-site measurements included electrical conductivity (EC) and pH using portable Orion Thermo water analyzing kit (Model Beverly, MA, 01915). Alkalinity was also measured in the field using a titration method. Three duplicate samples were collected and filtered using 0.45μm Millipore membrane filters at each location. For analyses of major cations, one Liter of each sample was acidified by adding about 8 ml of ultra-pure nitric acid to bring pH less than 2. For NO_3^- analysis, HBO_3 acid was used as preservative [7]. The samples were stored at 4ºC until analysis. The analysis was done by standard techniques using Atomic Absorption Spectrophotometer (for Na^+, K^+, Ca^{2+} and Mg^{2+}) and Spectrophotometer (for Cl^-, NO_3^- and SO_4^{2-}) [8]. The precision of the chemical analyses was carefully defined by checking ion charge balance, which was generally found within ±10%.

Using SPSS, Pearson's correlation matrix was obtained to display linear relationship between the different physico-chemical parameters in different seasons. A correlation analysis is a bivariate method, applied to describe the degree of relation between two hydro-chemical parameters. The result of the correlation analysis is considered in the subsequent interpretation.

Factor analysis was performed using Statistical Package for Social Sciences (SPSS) software (Version 16.0). The data have been standardized and presented using standard statistical procedures[9] With the help of linear combinations, an originally large number of variables are reduced to a few factors. These factors can be interpreted in terms of new variables. Factor analysis aims to explain observed relation between numerous variables in term of simpler relations

"4.Result:"

The analytical precision for the measurement of ions was determined by calculating the Normalized Inorganic Charge Balance [10] which is defined as (T_{Z+} - T_{Z-}/ T_{Z+} + T_{Z-}) and represents the fractional difference between the total cations and total anions [11]. As exemplified by[10], the measured major ions (Na^+, Ca^{2+} , Mg^{2+} , K^+, Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-) are generally enough to give a charge balance. All the lake water samples show a charge imbalance mainly in favor of negative charge excess. A maximum charge balance of -35.82% was recorded for the pre-monsoon samples and -29.28% for the post-monsoon samples. Charge imbalance has in favor of anions maybe to the result of high organic content of the water and/or fluctuating bicarbonate content in the area. Another reason may be less precision of the titration method that was used for bicarbonate estimation in this study.

The average chemical composition of the P. T. Tso Lake is given in the Table 1. The results reveal that all the major cations in the lake except Na decreased in post-monsoon season whereas all the major anions except NO_3^- increased in post-monsoon season, though the variation is not too high.

Table 1: Statistical summary of the hydro-geochemical parameters of the lake water in the pre- and post-monsoon seasons (all units are in mg/L except for pH and EC, which is in µS/cm)

PARAMETER	PRE MONSOON		POST MONSOON	
	RANGE	AVG±SD	RANGE	AVG±SD
pH	6-7.6	7.08±0.08	4.41-6.29	5.86±0.49
EC	6-40	15.6±17.5	1.5-4.9	3.53±0.9
Na^+	0-0.6	0.4±0.15	3.6-4.6	4.3±0.3
K^+	0.1-9	0.7±2.15	0.3-0.4	0.32±0.04
Ca^{2+}	0.5-6.2	2.2±1.9	1.3-2.0	1.5±0.2
Mg^{2+}	0.28-1.6	0.6±0.5	0.4-0.7	0.5±0.09
HCO_3^-	6-10	8.2±0.9	20-24	21.8±1.5
Cl^-	0.6-0.8	0.7±0.1	0.3-0.8	0.5±0.2
SO_4^{2-}	3.1-6.5	4.1±0.95	4.1-8.7	4.7±1.2
NO_3^-	0.95-1.4	1.06±0.1	0.28-1.25	0.5±0.3
PO_4^{3-}	0.07-0.13	0.09±0.03	0.09-0.4	0.14±0.12
SiO_2	1.15-2.68	1.77±0.45	1.36-2.82	1.85±0.37
Tz^+	0.11-0.47	0.21±0.13	0.31-0.35	0.32±0.016
Tz^-	0.24-0.27	0.25±0.01	0.44-0.56	0.48±0.04
$(Ca^{2+}+Mg^{2+})/Tz^+$	0.14-0.97	0.76±0.28	0.33-0.44	0.37±0.04
$(Na^++K^+)/Tz^+$	0.3-5.2	1.55±1.64	0.57-0.65	0.63±0.03
Mg^{2+}/Ca^{2+}	0.27-0.52	0.44±0.09	0.49-0.57	0.55±0.03
Ca^{2+}/Mg^{2+}	1.9-3.7	2.48±0.63	1.8-2	1.89±0.097
$SiO_2/(Na^++K^+)$	7.70-613.3	133.3±212.9	6.82-13.56	9.76±2.12
$(Ca^{2+}+Mg^{2+})/(Na^++K^+)$	0.17-36.3	10.55±12.67	0.48-0.79	0.59±0.10
$HCO_3^-/(Ca^{2+}+Mg^{2+})$	0.29-3.2	1.3±0.9	2.12-3.61	3.05±0.56

"5.Discussion"

Water characteristics are relatively uniform in shallow lakes which are mixed by winds [12]. Other factors responsible for the abundance and variation in major cations (Na^+, Ca^{2+} , Mg^{2+} and K^+) and anions (Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-, PO_4^{3-}) in surface water are weathering, atmospheric precipitation and possible atmospheric activities[4].

5.1 Hydro-geochemistry of the lake water

The pH of lake water ranged from slightly alkaline in the range of 6–7.6 with the average of 7.08±0.08 in the pre-monsoon season to slightly acidic in the range of 4.41–6.29 with an average of 5.86±0.49 in the post-monsoon season. Seasonal variations in the pH control the weathering pattern and availability of dissolved solids in lake water[4].Electrical conductivity (EC) is a measure of the ionic strength and is dependent on the concentration, volume and rate of movement of ionic species[10]. The conductivity of the lake was very less with an average of 15.6±17.53 µS/cm in the pre-monsoon season and an average of 3.53±3.53 µS/cm in the post-monsoon season, i.e. the is lake very dilute. Such low EC indicates that the lake had very little dissolved ions, i.e. the lake is very pure. The order of the concentration of major cations was $Ca^{2+}>Mg^{2+}>Na^+=K^+$ in the pre-monsoon season and $Na^+>Ca^{2+}>Mg^{2+}>K^+$ in the post-monsoon season. All the major cations except Na^+ decreased in the post-monsoon season. This is probably due to silicate weathering as a result of the addition of water in the monsoon season, which releases Na into the water. The order of the concentration of major anions in the lake water was HCO_3^->SO_4^{2-}>Cl^- >NO_3^->PO_4^{3-} during both the pre- and the post-monsoon seasons. The results reveal that the concentration of all the anions except NO_3^- and Cl^- increased in the post-monsoon season.

The range of NO_3^- in P. T. Tso Lake was 0.015–0.02 meq/L in the pre- and 0.001–0.02 meq/L in the post-monsoon season. The values indicate that P. T. Tso Lake is a clean lake because the concentration of NO_3^- was within the World Health Organization limit[13] (WHO, 1984). The small decrease in the concentration of NO_3^- in post-monsoon seasons maybe the result of mineralization of the N-containing compounds by micro-organisms. Occurrence of PO_4^{3-} in P. T. Tso Lake varied from 0.002–0.004 meq/L in the pre-monsoon season to 0.003–0013 meq/L in the post-monsoon season. The possibility of anthropogenic influence on the lake in the form of fertilizer runoff from farmlands or sewage effluents of solid waste deposition is nil in this locality, so these cannot be considered as the cause of increase in the PO_4^{3-}concentration. Therefore, the explanation for this rise in PO_4^{3-} concentration is given by the atmospheric contribution in the form of wet deposition in the monsoon season. The relatively low concentration of NO_3^- and PO_4^{3-} maybe the consequence of their uptake by micro-organisms[4] .

SO_4^{2-} concentration of P. T. Tso Lake varied from 0.06–0.13 meq/L in the pre-monsoon season to 0.08–0.18 meq/L in the post-monsoon season. This can be explained by the increased dissolution of secondary minerals in the lake surface sediments derived from the black shales [10]. SO_4^{2-} in P. T. Tso Lake is derived from atmospheric deposition and oxidation of S compounds in the lake bottom sediments at the boundary layer between aerobic and anaerobic environment. Such processes are common at the surface of reduced sediment that gets covered by oxygenated water.

Concentration of Cl^- varied from 0.016–0.023 meq/L in the pre-monsoon season to 0.0080.023 meq/L in the post-monsoon season. The major cation that characterized the lake water was Ca^{2+} in the pre-monsoon season and Na in the post-monsoon season. Ca^{2+}+Mg^{2+} together accounted for about 79.4% and 37.3% of all the major cations in pre- and post-monsoon season, respectively. The ratio of (Ca^{2+}+Mg^{2+})/(Na^++K^{2+}) varied from 10.55 in pre-monsoon season to 0.59 in post-monsoon season. The HCO_3^-/(Ca^{2+}+Mg^{2+}) ratio for both pre- and post-monsoon season was greater than 2, indicating the contribution of carbonate weathering in the lake water.

The Ca^{2+}/SO_4^{2-} ratio (Fig. 2a) was greater than 1 for pre-monsoon season indicating that H_2SO_4 does not replace H_2CO_3 as a source of protons for rock weathering[14]. The (Ca^{2+}+Mg^{2+})/Tz^+ ratio was 0.76 for the pre-monsoon season and 0.37 for the post-monsoon season. The ratio indicated the abundance of Ca^{2+} and Mg^{2+} in the pre-monsoon season, which could be the result of carbonate weathering.

Ca^{2+}+Mg^{2+} vs Tz^+ plot (Fig. 2b) suggested that Ca^{2+} and Mg^{2+} were the major cations in the pre-monsoon season, which further supports the carbonate weathering in the pre-monsoon season. Whereas Ca^{2+} and Mg^{2+} do not seem to form a great share in the entire major cations during the post-monsoon season, which could be the result of silicate weathering.

High percentage of Na^++K^+ in all the major cations during the post-monsoon season, as suggested by the Na^++^+K vs Tz+ graph (Fig. 2c), further supports silicate weathering during post-monsoon season. Mg^{2+}/Ca^{2+} ratio was less than 0.5 for the pre-monsoon samples, which suggests low saturation index and carbonate precipitation[4].

In all seasons P. T. Tso was enriched with HCO_3^- accounting for around 50%–60% of all the anions in the lake. The concentration of HCO_3^- ranged from 1.31–1.64 meq/L in the pre-monsoon season to 1.64–1.97 in the post-monsoon season. The occurrence of carbonate minerals in the sediment of the lake maybe a cause of this high percentage of carbonate in both the seasons. Consequently, P. T. Tso contained relatively high concentrations of Ca^{2+} and HCO_3^- in the pre-monsoon season and Na and HCO_3^- in the post-monsoon season, although there were seasonal changes in the other chemical constituents as well.

Silica ranged from 1.15–2.68 mg/L in the pre-monsoon seasons to 1.36–2.82 mg/L in the post-monsoon season. Comparatively high concentration of silica in the post-monsoon season may be attributed to the weathering of silicate minerals [12], [15]. This observation is supported by the high SiO_2/(Na^++K^+) ratio [14].

The general reaction for weathering of silicate minerals with H_2CO_3 can be written as

(Na^+, K^+, Ca^{2+}, Mg^{2+}) silicate + H_2CO_3 ↔ H_4SiO_4 + HCO_3^- + Na^+ + K^+ + Mg^{2+} + Ca^{2+} + solid particles-Eq (1)

The quantities of cations and anions released to solution are determined by proton source, composition of parent rock and secondary minerals produced during chemical weathering [10]. The chemical compositions of low salinity waters are controlled by the amount of dissolved salts furnished by atmospheric precipitation and chemical weathering[16]. In monsoon, the major cations and anions are the result of atmospheric precipitation, but in winter and summer they are the consequence of atmospheric precipitation and chemical weathering processes [17]. Chemical weathering plays a major role in controlling the composition of natural waters [18],[19],[20],[21]. Since natural water is the common weathering agent, it follows that the accumulation of cations and silica in water is an index of the extent of weathering.

In general, it is expected that the evaporation process would cause an increase in concentration of all species in water. If the evaporation process is dominant, assuming that no mineral species are precipitated, the Na^+/Cl^- ratio would be unchanged [22]. Hence the plot of Na^+/Cl^- vs EC (Fig. 2d) would give a horizontal line, which would then be an effective indicator of concentration by evaporation and evapo-transpiration. If halite dissolution is responsible for sodium, the Na^+/Cl^- ratio should approximately be equal to 1, whereas a ratio greater than 1 is typically interpreted as Na released from silicate weathering reaction [23]. In the present study, the molar ratio of Na^+/Cl^- generally ranged from 0–0.023 in pre-monsoon season and from 0.11–0.48 in the post-monsoon season. All the ratios of Na/Cl for both pre- and post-monsoon season indicate that ion exchange was the major process prevalent in the lake.

The Na^+ vs Cl^- plot (Fig. 2e) indicates that all the pre- and post-monsoon samples lie below the 1:1 ratio that supports the above inference that silicate weathering is not dominant. Lower 1:1 ratio indicates higher chloride concentration probably because of rise in water level, in pre-monsoon season by snow melt and in the post-monsoon season by precipitation. Water level rise causes more salt dissolution from the soil.

The ratio of $Ca^{2+}/Mg^{2+}=1$ indicates dissolution of dolomite, whereas $Ca^{2+}/Mg^{2+}>1$ is indicative of higher calcite contribution [24]. Higher Ca^{2+}/Mg^{2+} ratio (>2) indicates the dissolution of silicate minerals. The Ca^{2+}/Mg^{2+} ratio for both pre-monsoon samples (except one, which is 3.7) and post-monsoon samples lie between 1 and 2, which indicates greater calcite dissolution contribution into the lake water chemistry (Table1).

The plot of $Ca^{2+}+Mg^{2+}$ vs $SO_4^{2-}+HCO_3^-$ will be close to the 1:1 equiline if the dissolution of calcite, dolomite and gypsum are the dominant reactions in a system. Ion exchange tends to shift the points to right because of an excess of $SO_4^{2-} + HCO_3^-$ [25],[26]. If reverse ion exchange is the process, it shifts the points to the left. The plot of $Ca^{2+} + Mg^{2+}$ vs $SO_4^{2-} + HCO_3^-$ (Fig. 2f) for both pre- and post-monsoon season tends towards the right, which indicates ion exchange to be the dominant process except an exception in the pre-monsoon season.

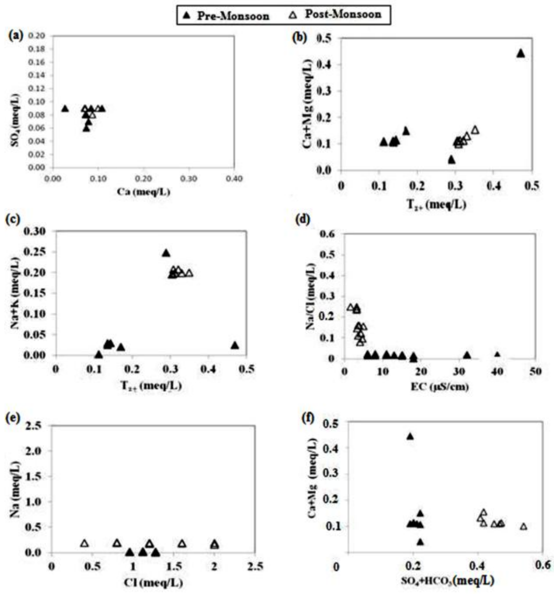

Figure 2: Different Scatter plots expressing hydro-geochemical processes (a) SO_4^- vs Ca^{2+}; (b)Ca +Mg vs Tz^+ ; (c) Na+K vs Tz^+ ;(d) Na/Cl vs EC; (e) Na vs Cl and (f) Ca+Mg vs SO_4^{2-} + HCO_3^-in P.T.Tso Lake.

"6. Graphical representation of the hydro-geochemical data:"

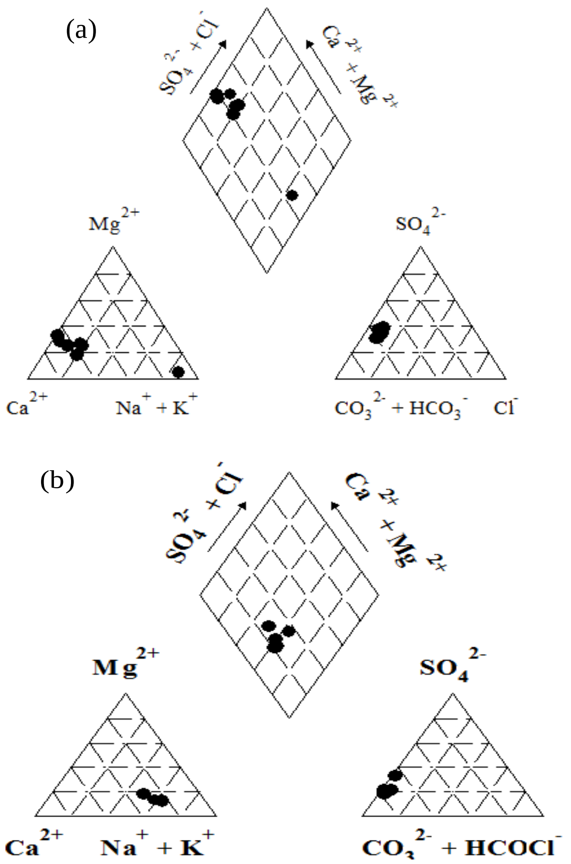

Figure 3: Piper plot showing the types of water of P.T.Tso Lake in (a) pre- and (b) post-monsoon season.

An overall characterization of hydro-geochemical data is presented through Piper (1944) [27] tri-linear diagram Figure 3a for pre- and Figure 3b for post-monsoon season. During the pre-monsoon season, Ca-Mg-SO_4 was the major water type and during the post-monsoon season, Na-$HCO_3^-$was the major water type we found in the water sample of Pangang Teng Tso Lake. This type of water sample generally found due to the Silicate weathering. This substantiates the previous interpretation of silicate weathering in the post-monsoon season.

The equilibrium state of the lake water with respect to the possible reactants and product minerals was evaluated by graphical approach. The graphical approach describes the mineral stability fields of minerals in equilibrium with water, in terms of activity ratios of ions in water [28], [29],[30]. The stability fields of crystalline minerals adequately serve as reference points to predict which mineral will react with the water and the direction and the extent of the reaction [31].

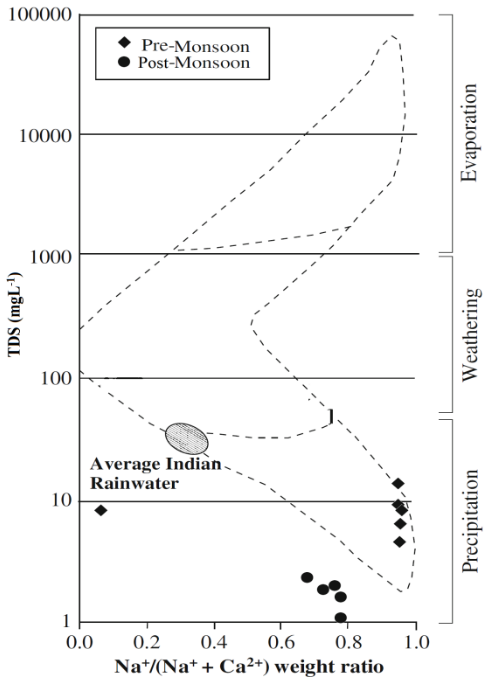

Figure 4: Gibbs Plot showing the mechanisms controlling the water quality of P.T.Tso Lake in pre- and post-monsoon season.

Precipitation is the major source of release of major cations and anions in the water of the P. T. Tso Lake i.e. it controls the water chemistry of the lake in the pre-monsoon season (Fig. 4). The lake showed rock-water interaction and very less extent of evaporation. Rain seemed to be the main governing factor for water chemistry of the lake. On the other hand, in the post monsoon season also, precipitation was the main governing factor. Thus, it can be said that enrichment occurred because of precipitation.

"7. Statistical analyses:"

7.1Correlation matrix:

The correlation matrices are given in Table 2 shows the correlation among different hydrogeochemical parameters of lake water samples. Table 3 reveals water parameter related to pre- and post-monsoon season. In the pre-monsoon season, significant relationships were observed between Ca^{2+}-EC, Mg^{2+}-EC, Ca^{2+}-Mg^{2+} and NO_3^--K^+.In the pre-monsoon season, strong correlation were found between Ca^{2+}-EC and Mg^{2+}-EC, it suggested the high EC due to the contribution of Ca^{2+} and Mg^{2+} cations. It also supported the carbonate weathering theory during the pre-monsoon season. Significant correlation (<0.5) were also observed between Mg^{2+}-pH, Na^+-Cl^-, NO_3^--SO_4^{2-}, SO_4^{2-}-HCO_3^- and HCO_3^--SiO_2 in the pre-monsoon season.

Table2: Correlation matrix of the hydro-geochemical parameters of P.T.Tso Lake in the pre-monsoon season

Parameter	pH	EC	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	HCO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
EC	0.736										
Cl^-	-0.452	-0.607									
NO_3^-	-0.226	-0.368	-0.302								
PO_4^{3-}	0.231	0.162	0.135	-0.243							
SO_4^{2-}	-0.712	-0.72	0.443	0.651	-0.042						
HCO_3^-	-0.921**	-0.463	0.354	0.082	-0.308	0.561					
Na^+	-0.207	-0.199	0.584	-0.048	-0.3	0.345	0.367				
K^+	-0.064	-0.202	-0.471	0.897**	-0.263	0.332	-0.167	-0.061			
Ca^{2+}	0.442	0.853*	-0.295	-0.395	-0.084	-0.454	-0.112	0.175	-0.383		
Mg^{2+}	0.571	0.917**	-0.359	-0.423	-0.015	-0.558	-0.250	0.108	-0.354	0.987**	
SiO_2	-0.675	-0.365	-0.155	0.261	-0.676	0.213	0.726	0.053	0.226	-0.233	-0.315

** Co-relation is significant at 0.01
* Co-relation is significant at 0.05

During the post-monsoon season(table 3), significant and positive relationships were observed between EC-NO_3^-, Mg^{2+}-Cl^-, PO_4^{3-}-SO_4^{2-}, PO_4^{3-}-SiO_2 and SO_4^{2-}-SiO_2. Strong negative correlations were found between pH-PO_4^{3-}, pH-SO_4^{2-}, EC-PO_4^{3-}, Ca^{2+}-Cl^-, Ca^{2+}-Mg^{2+} and Mg^{2+}-SiO_2.

7.2 Factor analysis:

Factor analysis, also known as principal component analysis (PCA), is an efficient way of displaying complex relationships among many variables and their roles [32], [33], [34]. Factor analysis of major ions along with physical parameters of P. T. Tso Lake indicates four trends for pre-monsoon season and three trends for post-monsoon season.

Table 3: Correlation matrix of the hydro-geochemical parameters of P.T.Tso Lake in the post monsoon season

er	pH	EC	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	HCO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
	0.738										
	0.318	0.365									
	0.730	0.954**	0.408								
	-0.916**	-0.805*	-0.456	-0.785*							
	-0.881**	-0.753	-0.456	-0.743	0.991**						
	-0.349	-0.144	-0.392	-0.282	0.128	0.126					
	0.268	0.082	-0.377	-0.079	-0.290	-0.346	0.183				
	0.350	-0.104	0.070	-0.234	-0.193	-0.135	0.117	0.095			
	0.334	0.444	-0.840*	0.609	-0.387	-0.378	-0.626	-0.581	-0.254		
	0.509	0.535	0.742	0.718	-0.570	-0.554	-0.470	-0.539	-0.151	-0.931**	
	0.181	0.167	-0.527	-0.279	-0.287	0.183	0.462	0.680	0.478	-0.809	-0.893*

** Co-relation is significant at 0.01

* Co-relation is significant at 0.05

The number of significant factors within the data is established by considering only those with an Eigen value greater than 1.0. The degree of association between each variable and each factor is given by its loading on that factor. Table 4 (for pre-monsoon season) and Table 5 (for post-monsoon season) indicate the loading of each variable on each factor and the communality of each variable accounted for in the analysis

Table 4: Multivariate factor analysis of surface water of P.T.Tso Lake for the pre monsoon season

	Component				
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Communalities**
pH	.615	-.681	.128	-.277	0.935
EC	.896	-.241	-.097	-.287	0.952
Cl^-	-.479	-.082	-.481	.702	0.961
NO_3^-	-.299	.126	.914	.052	0.943
PO_4^{3-}	-.220	-.722	-.321	-.107	0.685
SO_4^{2-}	-.597	.197	.354	.568	0.844
HCO_3^-	-.289	.802	-.198	.357	0.892
Na^+	.143	.162	.003	.915	0.884
K^+	-.155	.021	.966	-.109	0.969
Ca^{2+}	.938	.017	-.201	.131	0.937
Mg^{2+}	.959	-.093	-.186	.046	0.966
SiO_2	-.180	.949	.139	-.142	0.972
Initial Eigen Value	5.045	2.551	2.077	1.267	
%Variance	42.045	21.255	17.308	10.556	
Cumulative% Variance	42.045	63.3	80.609	91.164	

In the pre-monsoon season, factor 1 accounted for 42.04% of variance in the data and it shows a strong geochemical association between EC, pH, Ca and Mg. Carbonate weathering was responsible for the strong relationship between these parameters. This also indicates Ca^{2+} and Mg^{2+} being the dominant cations in the P. T. Tso Lake. Factor 2 represents association between Cl^- and Na^+, which indicates halite dissolution. Factor 3 is accounted for by NO_3^- and K^+. Factor 4 did not represent any relationship between any two variables. This indicates the multiple sources controlling the lake water quality.

Table 5: Multivariate factor analysis of surface water of P.T.Tso Lake for the post monsoon season

	Component			
	Factor 1	**Factor 2**	**Factor 3**	**Communalities**
pH	.902	.130	.301	0.921
EC	.867	.145	-.234	0.827
Cl^-	.312	.794	.171	0.757
NO_3^-	.839	.324	-.335	0.921
PO_4^{3-}	-.973	-.122	-.164	0.989
SO_4^{2-}	-.963	-.102	-.135	0.957
HCO_3^-	-.126	-.603	.011	0.379
Na^+	.378	-.776	.123	0.760
K^+	.056	-.083	.963	0.937
Ca^{2+}	.312	.926	-.186	0.990
Mg^{2+}	.489	.834	-.122	0.951
SiO_2	-.771	-.515	.036	0.861
Initial Eigen value	6.512	2.540	1.197	
%Variance	54.263	21.168	9.974	
Cumulative% Variance	54.263	75.431	5.405	

In the post-monsoon season, factor 1 accounted for 54.26% of the variance and shows a strong relationship between Cl^-, Ca^{2+} and Mg^{2+}. Factor 2 represents association between EC, Cl^- and NO_3^-. Factor 2 shows the dominant nature of NO_3^-, which accounts for anthropogenic sources and mineralization and precipitation of N-containing organic compounds. Factor 3 represents association between pH, SO_4^{2-} and K^+. Factor 4 did not represent any association between any two variables.

We can say that processes like weathering, dissolution, precipitation, etc. seem to be the major reasons for the observed chemical characteristics of the lake. There seems to be very little or no anthropogenic influence on the lake.

"8.Effective CO_2 pressure:"

The 'effective CO_2 pressure' or 'internal CO_2 pressure' (Log pCO_2) for both the seasons is estimated in the P. T. Tso Lake. For estimation, pH values and HCO_3^- concentration were used (Table 6). It is indicating a global trend that natural water bodies are commonly out of equilibrium with the atmosphere [35]. This is because of the fact that long standing water bodies have a significant fraction of high-CO_2 groundwater and the re-equilibration occurs with the atmosphere by releasing the excess $CO_{2.}$ But the rate is relatively slow [36],[37],[4]. The pCO_2 was increased in the post-monsoon season. Therefore, it can be said that there was addition of bicarbonate with the rain which further supports weathering. So there will be more enrichment in the future.

***Table 6* :**log m HCO_3^- and log pCO_2 for the P.T.Tso Lake

Sites	**Pre-monsoon season**		**Post-monsoon season**	
	log $mHCO_3$	**log pCO_2**	**Log $mHCO_3$**	**log pCO_2**
1	-0.889	1.603	-0.491	2.881
2	-0.889	2.703	-0.4498	2.852
3	-0.889	1.703	-0.431	3.152
4	-0.889	1.503	-0.491	3,071
5	-0.889	1.103	-0.491	3.131
6	-0.889	1.503	-0.412	3.73
7	-0.889	1.603	-0.4498	4.732

"10.Chemical composition of water in Himalayan lakes:"

The average chemical composition of the water in the Himalayan lakes is given in Table 8. Almost all the ions were substantially higher in lakes in the Himalayan range, probably because of the prevalence of more reactive type bedrock [38]. All lakes are alkaline except P. T. Tso Lake, which has an average pH of 6.47. Ca^{2+} and Mg^{2+} are the dominant cations in most of the Himalayan lakes. The values of major cations and anions for most of the lakes are generally greater than that for Pandoh Lake and P. T. Tso Lake. The molar Mg^{2+}/Ca^{2+} ratio in Nainital, Bhimtal, Sattal and Naukuchiatal [39],[10] ranges from <0.5 to >4.5, which indicates high saturation index and carbonate precipitation compared to Pandoh Lake and P. T. Tso Lake. The variabilities with respect to geological settings, climate, water chemistry and biological activities in these lakes limit generalizations about mechanism of carbonate sedimentation [39].

Compared with other Lakes, Nainital and Begans [40] has higher HCO_3^- values. The major sources of anions except HCO_3^- are attributed to rainfall, sewage effluents, and fertilizers and are partly regulated by biological activities in those lakes, whereas for P. T. Tso Lake and Pandoh Lake the anthropogenic source contributions seem to be less (Table 8). Previous studies also indicate that Himalayan mountains do not have halite/evaporate deposits but a strong NaCl source is speculated in the Bhimtal-Naukuchiatal basin because these lakes underwent two phases of evaporation in an arid climate in the past [40].

Table 8: *Average chemical composition of water in several Himalayan lake systems (all units are in meq/L except for EC which is in µS/cm)*

Lake	**Nainital**	**Bhimtal**	**Sattal**	**Naukuchiatal**	**Renuka**	**Pandoh**	**Begnas**	**P.T. Tso**
Location	HP*	Uttrakhand	Uttrakhand	Uttrakhand	HP	HP	Nepal	A.P*
pH	8.37	7.94	7.43	7.45	8.38	7.13	7.28	6.47
Cond.	313	101	59.7	70	550	80.8	92.90	9.57
Ca^{2+}	24.63	9.52	28.74	25.77	2.89	0.90	6.98	0.1
Mg^{2+}	194.58	40.85	21.59	21.32	3.19	0.28	2.11	0.05
Na^+	23.86	0.20	4.75	7.72	0.36	0.17	3.84	0.11
K^+	0.26	0.12	0.07	0.09	0.05	0.05	1.80	0.02
SO_4^{2-}	21.33	1.30	0.91	0.71	0.13	0.06	7.69	0.09
NO_3^-	1.15	0.70	0.50	0.22	NA	0.17	5.31	0.01
Cl^-	7.91	4.23	3.11	0.28	0.34	0.07	2.97	1.07
HCO_3^-	29.6	7.90	12.6	10.2	2.40	0.81	24.75	1.58
Mg^{2+}/Ca^{2+}	>4.5	<0.5	<0.5	<0.5	0.67	0.22	0.13	0.50
Reference	Chakrapani (2005)				Das & Kaur (2001)	Anshumali & Ramanathan (2007)	Khadka & Ramanathan (2012)	Present Study

- A.P, Arunachal Pradesh
- H.P, Himachal Pradesh

The SO_4^{2-} concentration varies from <65 mg/L in Naukuchiatal to 1024 mg/L in Nainital Lake; these values are greater than that in P. T. Tso Lake. This could be the result of inputs from open drains, efficient oxidation of sulphides in the bottom of the lake and dissolution of gypsum [10], [39]. Therefore, it can be said that all the western Himalayan lakes, except Pandoh Lake, mentioned here are very much influenced by anthropogenic activities. The chemistry of the western Himalayan lakes is different because the environmental conditions are also different.

"11.Conclusion:"

P. T. Tso is a clean lake that is influenced by only natural processes like weathering and atmospheric deposition. The lake hardly showed any influence from anthropogenic sources. The pH of the lake is varied from slightly alkaline in the pre-monsoon season to slightly acidic in the post-monsoon season. The seasonal variation in pH maybe responsible for the variations in the chemistry of the other components in the lake water. The results reveal that all the major cations in the lake except Na decreased in post-monsoon season whereas all the major anions except NO_3^- increased in post-monsoon season, though the variation was not too high. The rise in PO_4^{3-} concentration maybe the result of atmospheric contribution in the form of wet deposition in the monsoon season. The relatively low concentration of both the anions (NO_3^- and PO_4^{3-}) maybe because of their uptake by micro organisms. Among the lakes of the eastern Himalaya, not much variation in the water chemistry was observed.

While comparing P. T. Tso Lake with the lakes of western Himalaya it was found that the other lakes were slightly alkaline whereas P. T. Tso Lake was slightly acidic. The variability with respect to geological settings, climate, water chemistry and biological activities in these lakes limit generalizations about mechanism of carbonate sedimentation. Sulphate concentration in Naukchiatal and Nainital are comparatively much greater than that of the P. T. Tso Lake. This was probably because of inputs from the open drains, efficient oxidation of sulphides in the bottom of the lake and dissolution of gypsum. The dominance of the atmospherically derived sources was also noticed as the quality of dry/wet depositions majorly depends on the nature of aerosols, which seems to vary in both Eastern and Western Himalaya regions because of the significant difference in the population density, life style and biomass burning for cooking around the lakes.

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