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Seasonal Variation of Water Chemistry of Panchpokhari: a Case Study of an Alpine Lake Series in the Central Himalayas

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Abstract

Panchpokhari (five lakes) is a well-known alpine lake series which includes five lakes situated at an elevation of 4160 masl. in the Sindhupalchowk district of Central Nepal. The lake series has vital socio-cultural, religious and environmental significance and provides habitats for highly sensitive aquatic biodiversity. The present research was carried out with the aim of assessing detailed water characteristics and its implications for the lake environment of Panchpokhari. Water samples were collected during the pre-monsoon and post-monsoon seasons from the inlet, outlet, littoral zone, middle (central), deepest basin of the main lake (lake 1), human influence site as well; and only from the inlet and outlet of other associated lakes. The paper mainly focused on physico-chemical parameters such as temperature, pH, electrical conductivity, TDS, cations (Ca^{++}, Mg^{++}, Na^{+} & K^{+}), anions (Cl-, SO_4^{--} & HCO_3^{-}), nutrients (TN & TP) and total silica. Panchpokhari lake series is characterized by low concentration of nutrients indicating an oligotrophic state. However, the low values of pH could be an indication of natural or anthropogenic influences. The major cations and anions were in the order of $Mg^{++} > Na^{+} > K^{+} > Ca^{++}$ & $SO_4^{--} > HCO_3^{-} > Cl^{-}$ and $Mg^{++} > K^{+} > Na^{+} > Ca^{++}$ & $SO_4^{--} > Cl^{-} > HCO_3^{-}$ during pre-monsoon and post-monsoon respectively in all five lakes. Most of the analyzed parameters showed significantly higher concentrations during pre-monsoon, probably due to dilution effect of monsoon rain.

Keywords: High Altitude; Alpine Lake; Himalayan Region; Water Chemistry; Major Ions; Nutrients

1.Introduction

In Nepal, water bodies' cover 5.06% of total land area [1] and 3.2% is occupied by lakes, ponds and reservoirs out of an estimated coverage of 720,000 ha of water bodies [2]. A total of 5358 lakes have been reported in varied ecological conditions from subtropical low land Terai to alpine high altitude of Himalayan range, of which 42 percentage are situated in high land, i.e., above 3000 m asl [3]. Among these, the Panchpokhari of Sindhupalchowk district of Nepal is a permanent alpine fresh water lake series and is a unique natural wetland in high Himalaya Palearcticbio-geographical region; it has major cultural, religious and socio-economic value. As these lakes are considered as holy, every year during the month of August Hindus and Buddhist pilgrims gathered there to perform the rituals on the occasion of famous cultural festivals, i.e., Janai Purnima (full moon festival). According to local people's perception human activities, whether religious, touristic or research oriented have been increasing day by day. Consequently, the increased number of lake visitors in recent years may have a negative impact on the water bod-

ies because of haphazard waste disposal and their improper management. The area is rich with biodiversity [4], although the healthy growth of the vegetation is annually controlled which remains almost for six months due to heavy snow fall.

The Himalaya regions harbor many lakes and wetlands of different characters due to varied landscapes making them a unique ecosystem in the nature. Nowadays, these water bodies are becoming very important in the global context as they are highly potential research areas to investigate climate change impacts with respect to their pristine habitat [5], remote location [6] with less human intervention, unproductive [7] are the excellent indicators as well as hotspots and ideal for the studies of environmental changes [5,8-10]. High mountain lakes in extreme habitats can also witness small localized impacts on environmental changes [11,12]. As a research point of view, present study area is also potential for assessing the local as well as long range transported air borne pollutants impact studies. Very little work has been recorded from this area like on biodiversity i.e. floral and faunal by [4] and mentioned its need to be conserved for the long lasting of our natural assets as suggested. The aquatic organisms, e.g., diatoms study [13] has also been conducted in this lake series as similar from the other lakes of southern aspect of the Nepalese Himalayas [14-17]. However, no such type of studies on water chemistry of the Panchpokhari lake series published yet. Therefore; the present study was carried out with the aim of assessing major water characteristics and the physico-chemical status of the lake environment.

2. Materials and Methods

2.1 Study area

The study area Panchpokhari lies in the central Himalayan region of Nepal between the latitudes of 28º2.41'-28º2.54' E and longitudes of 85º42.96'-85º43.25' N at an elevation of 4160 masl (Fig. 1). It is about 100 km North-East of Kathmandu, the capital city, and located in the Bhotang VDC of Sindhupalchowk district of central Nepal. The area belongs to the Langtang National Park; one of the most intensively studied regions in the Himalayas [18,19]. There is heavy rainfall between the month of May and September. The mean annual temperature is 20C recorded from the nearest meteorological station, i.e., in Kyanjin Gompa [19] and the lake is generally frozen until the end of April. Heavy snow fall typically occurs here for nearly six months and melting of winter snow generally starts from the month of May in the summer, draining as cold water into the Panchpokhari Lakes.

2.2 Location Map

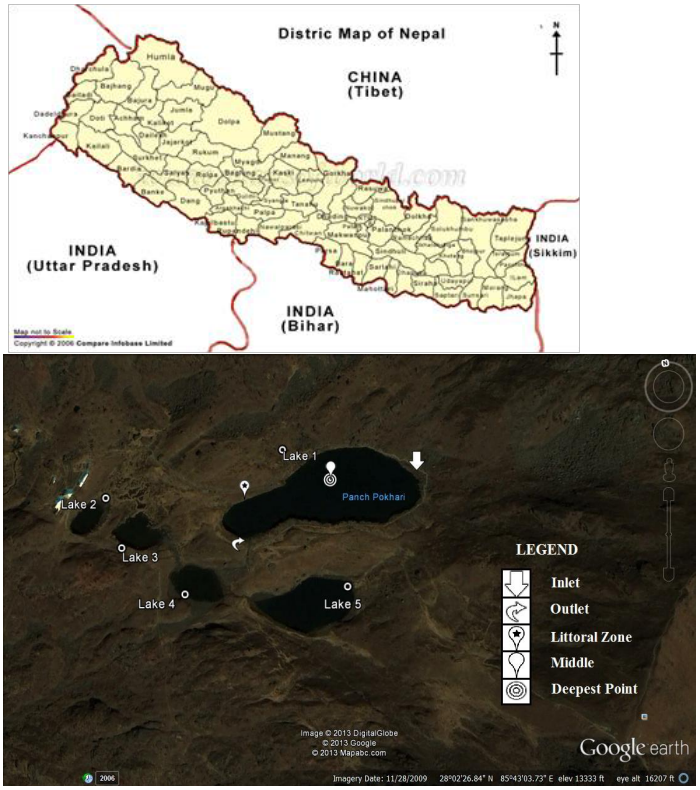


Figure1. Google image of Panchpokhari showing five different sampling points.

(Source: Google Earth, accessed on June 19, 2013; Modified from Google Maps)

2.3 Sampling sites

In Panchpokhari lake series, one of the lakes is considerably larger than others located in the valley and coded as Lake-1. The other four lakes were coded serially from the left (counter-clockwise) as lakes-2, -3, -4 and -5. Lake-2 is located near the rest house whereas Lake-3 and Lake-4 are located almost at the central part of the valley. All of the lakes -2 through -5 are very small and shallow. Therefore, Lake-1 was studied thoroughly and water samples were collected from five different locations, i.e., the inlet, outlet, littoral zone, middle (centre) and deepest point of the lake as the representative of entire water quality. From other three, namely, Lake-3, Lake-4 and Lake-5, inlet and outlet locations were considered. Samples were collected from the inlet, outlets, littoral zone and human influence area from Lake-2 because of easy accessibility. The latter was most suited to study the direct impacts of human activities. An inflatable boat was used for sample collection. The details of sampling location of Lake-1 with latitude and longitude are given in (Table 1).

Table 1. Geo-coordinates of sampling location of Lake-1.

S. No.	Longitude (East)	Latitude (North)	Sampling sites
1	850 43. 141′	280 02. 521′	Inlet
2	850 42. 958′	280 02. 481′	Outlet
3	850 42. 971′	280 02. 520′	Littoral zone
4	850 43. 056′	280 02. 523′	Middle (central)
5	850 43. 057′	280 02. 526′	Deepest

2.4 Sample collection and preservation

Samples were collected in a pre-washed, clean plastic container (500ml) for the analysis of chemical parameters like nitrate, nitrite, ammonia, organic nitrogen, and TP. Concentrated H_2SO_4 was added immediately as preservative. The same volume of water samples were also collected in unpreserved condition for other chemical parameters analysis such as sodium, potassium, chloride, sulphate and total silica. All water samples were transported in an ice-box to the Laboratory of the Aquatic Ecology Centre at Kathmandu University, Dhulikhel, and Kavre for the further processes.

2.5 Sample analysis

Physical parameters like pH, temperature, electrical conductivity and total dissolved solids were measured by using a multi-parameter probe (Orion Star Series Multimeter Test Kit,) in situ. Bicarbonate alkalinity was analyzed immediately after the collection of sample by titrimetric method (conc. H_2SO_4). Chloride and total hardness were also analyzed by titrimetric method. Other chemical parameters such as nitrate, nitrite, ammonia, organic nitrogen, TN, orthophosphates, total phosphate, sulphate and silica were analyzed by UV-visible spectrophotometric method by Thermo Spectronic (GENESYS 10 UV) model and total silica and sulphate as well. Major cations such as Ca^{++}, Mg^{++}, Na^{++} and K^{++} were analyzed by M Series Atomic Absorption Spectrometers (AAS) of Thermo Electron Corporation (GE 650255), Cambridge, UK model with direct air acetylene flame. All the sample collection techniques, analytical methods and quality control mechanisms were performed according to the standard methods for the examination of water and wastewater [20]. In the laboratory, at least 4 different concentrations of standards were prepared as fresh standards from stock solutions during the analysis of each parameter; double distilled water was used as a blank for calibration and quality control mechanism. The analyzed physico-chemical parameters, units and their brief test methods are mentioned in (Table 2).

2.6 Data analysis

Descriptive statistics was performed using Microsoft Office EXCEL 2010 worksheet. Pearson correlation between variables was estimated using SPSS.16 statistic software (SPSS Company). Comparison of different parameters in two seasons was performed using Mann-Whitney Rank Sum Test (SigmaPlot 12.3, SPSS Company) owing to the non-normal distribution of most of the data. The data from the five lakes were pooled together for the comparison in each season. The comparisons were considered statistically significant at $p < 0.05$ unless otherwise indicated.

Table 2. The analyzed physico-chemical parameters, unit and their brief test methods.

S. No.	Parameters	Units	Test method/Instrument used
	Physico-chemical parameters:		
1	Water Temperature	0C	Thermometer
2	pH	-	Orion Star Series Multimeter Test Kit
3	Electrical Conductivity	µS/cm	Orion Star Series Multimeter Test Kit
4	Total Dissolved Solids (TDS)	mgL-1	Orion Star Series Multimeter Test Kit
	Major cations and anions:		
5	Bicarbonate Alkalinity (HCO3-)	mgL-1	Titrimetric (H2SO4)
6	Chloride (Cl-)	mgL-1	Argentrometric
7	Total Hardness as CaCO3	mgL-1	EDTA Titration
8	Calcium (Ca++)	mgL-1	Direct Air Acetylene Flame/AAS
9	Magnesium (Mg++)	mgL-1	Direct Air Acetylene Flame/AAS
10	Sodium (Na+)	mgL-1	Direct Air Acetylene Flame/AAS
11	Potassium (K+)	mgL-1	Direct Air Acetylene Flame/AAS
12	Sulphate (SO4--)	mgL-1	Spectrophotometric (Turbidimetric)
13	Orthophosphates (PO4---)	mgL-1	Ammonium molybdate ascorbic acid reduction.
14	Total Phosphate (TP)	mgL-1	Potassium persulphate digestion followed by Ammonium molybdate ascorbic acid reduction.
15	Ammonia (NH3)	mgL-1	Spectrophotometric (Nesslerization)
16	Nitrite (NO2)	mgL-1	Spectrophotometric (NED - dihydrochloride)
17	Nitrate (NO3)	mgL-1	UV Spectrophotometric (Screening))
18	Organic Nitrogen	mgL-1	Kjeldahl digestion
19	Total Nitrogen (TN)	mgL-1	N-NO3 + N-NO2 + Organic nitrogen
20	Total Silica (SiO2)	mgL-1	Spectrophotometric (Molibdosilicate)

3. Results and Discussion

3.1 Physical parameters

The seasonal mean (STDEV), values of analyzed physico-chemical parameters of the Panchpokhari Lake water samples are presented in (Tables 3 and 4).

Table 3. Mean and STDEV values of Panchpokhari lake series in pre-monsoon season.

Analyzed Parameters	Units	Lake 1 Mean (STDEV)	Lake 2 Mean (STDEV)	Lake 3 Mean (STDEV)	Lake 4 Mean (STDEV)	Lake 5 Mean (STDEV)
Temp	^{0}C	6.34 (±0.51)	6.55 (±0.44)	7.15 (±0.92)	6.60 (±0.28)	6.60 (±0.57)
pH	-	5.38 (±0.32)	5.64 (±0.48)	6.06(±0.20)	3.97 (±0.70)	4.63 (±0.12)
EC	µS/cm	9.02 (±2.41)	9.78 (±1.08)	9.28 (±0.06)	9.40 (±2.86)	9.98 (±3.81)
TDS	mg/L	10.00 (±2.55)	11.75 (±1.71)	11.00 (±1.41)	75.5 (±95.46)	11.50 (±3.54)
HCO3	mg/L	8.88 (±1.96)	6.92 (±1.73)	8.24 (±0.43)	5.49 (±0.86)	7.93 (±2.59)
Ca^{++}	mg/L	11.38 (±1.89)	11.02 (±3.53)	15.23 (±7.37)	19.64 (±5.11)	10.83 (±2.84)
Mg^{++}	mg/L	4.28 (±1.93)	4.56 (±2.02)	6.20 (±2.92)	8.87 (±4.98)	4.50 (±0.18)
Na^{+}	mg/L	0.21 (±0.04)	0.22 (±0.09)	0.21 (±0.03)	0.17 (±0.02)	0.17 (±0.09)
K^{+}	mg/L	0.55 (±0.66)	0.50 (±0.21)	0.47 (±0.03)	0.64 (±0.15)	0.55 (±0.23)
TP	mg/L	0.27 (±0.10)	0.29 (±0.08)	0.31 (±0.01)	0.18 (±0.00)	0.24 (±0.00)
TN	mg/L	9.03 (±3.44)	11.13 (±4.75)	10.72 (±7.21)	13.68 (±0.13)	16.55 (±6.44)
SO_4^{--}	mg/L	4.90 (±2.23)	6.08 (±2.51)	6.53 (±0.47)	3.92 (±1.42)	6.10 (±2.84)
Cl^{-}	mg/L	16.2 (±2.80)	18.5 (±10.08)	29.75 (±22.98)	13.00 (±2.83)	22.50 (±10.61)
SiO_2	mg/L	0.42 (±0.19)	0.41 (±0.29)	0.39 (±0.25)	0.48 (±0.20)	0.45 (±0.16)

Table 4. Mean and STDEV values of Panchpokhari lake series in Post-monsoon season.

Analyzed Parameters	Units	Lake 1 Mean (STDEV)	Lake 2 Mean (STDEV)	Lake 3 Mean (STDEV)	Lake 4 Mean (STDEV)	Lake 5 Mean (STDEV)
Temp	(^{0}C)	10.14 (±0.167)	10.3 (±0.191)	11.35 (±0.354)	11.00 (±0.99)	11.60 (±0.141)
pH	(-)	5.76 (±0.128)	5.86 (±0.071)	5.81 (±0.170)	5.90 (±0.085)	5.73 (±0.184)
EC	(µS/cm)	7.37 (±1.432)	5.40 (±0.772)	12.24 (±0.339)	6.96 (±1.414)	6.96 (±1.407)
TDS	(mg/L)	11.0 (±1.871)	8.00 (±1.414)	19.0 (±0.000)	10.50 (±2.121)	10.50 (±2.121)
HCO3	(mg/L)	8.26 (±0.364)	36.90 (±33.961)	9.60 (±3.394)	6.84 (±1.188)	7.44 (±0.339)
Ca^{++}	(mg/L)	0.72 (±0.436)	0.65 (±0.111)	1.66 (±0.064)	0.95 (±0.057)	0.89 (±0.148)
Mg^{++}	(mg/L)	0.12 (±0.084)	0.08 (±0.050)	0.34 (±0.177)	0.11 (±0.007)	0.12 (±0.014)
Na^{+}	(mg/L)	0.18 (±0.058)	0.57 (±0.094)	0.58 (±0.014)	0.15 (±0.163)	0.09(±0.078)
K^{+}	(mg/L)	0.17 (±0.122)	0.07 (±0.042)	0.41 (±0.099)	0.20 (±0.021)	0.25 (±0.099)
TP	(mg/L)	0.09 (±0.018)	0.18 (±0.153)	0.11 (±0.014)	0.09 (±0.014)	0.07 (±0.014)
TN	(mg/L)	2.29 (±0.448)	2.53 (±0.661)	1.78 (±0.212)	2.32 (±0.000)	2.32 (±0.014)
SO_4^{--}	(mg/L)	3.34 (±1.968)	6.68 (±3.827)	4.18 (±1.181)	3.90 (±3.939)	5.01 (±2.362)
Cl^{-}	(mg/L)	4.60 (±1.342)	3.25 (±0.957)	1.50 (±0.707)	5.00 (±1.414)	3.00 (±1.414)
SiO_2	(mg/L)	0.09 (±0.024)	0.07 (±0.011)	0.35 (±0.261)	0.08 (±0.066)	0.04 (±0.009)

Water temperature is a critical factor of great importance for aquatic ecosystems as it affects the organisms and physico-chemical characteristic of water [21]. Surface water temperature was lower in pre-monsoon and higher in post-monsoon (T=120; t1=t2=15; P<0.001; Fig. 2) reflecting seasonal changes corresponding to the fluctuation of air temperature [22,23]. Panchpokhari was covered with snow during the pre-monsoon season leading to the low mean water temperature. pH plays an important role in balancing the aquatic ecosystem and its fluctuation depend upon various factors such as pollution, photosynthesis, suspended particles and influence of freshwater, etc. It is also very important in determination of water quality since it affects other chemical reactions such as solubility and metal toxicity [24]. Average pH value of the lake water varied from 3.47 to 6.20 in pre-monsoon and 5.53 to 5.98 in post-monsoon season. Lower variability of the post-monsoon water could be explained as the dilution effect of monsoon rain. In addition, pre-monsoon was more acidic compared to post monsoon (T=172; t1=t2=15; P=0.014; Fig. 2). Average pH values of these lakes (Table 3) were more acidic as compared to the Gokyo lake series from the same Himalayan range [25]. Acidic pH negatively affects the aquatic ecosystem [26]. Soil pH was also highly acidic with a mean pH value of 3.49 in the study area [27]. Leaching of minerals from acidic granitic rocks and sandstone during the precipitation might be one the reasons for such a low pH of the lake waters. Fluctuations of pH in remote alpine lakes are caused due to climate changes and anthropogenic impacts [28].

Electrical Conductivity (EC) is the measurement of ability to conduct electric current which gives the ions activity in the solution. It is a good and rapid method to measure TDS as well and is directly related to Total solids [29]. TDS is a measure of the total ions in solution, higher the value of dissolved solids, greater the amount of ions in the water [30]. The average value of EC was recorded between 9.02 – 9.98 µS/cm and 5.40 – 12.24µs/cm in the pre-monsoon and post-monsoon seasons, respectively. Higher values of EC were recorded in the post-monsoon (T=294; t1=t2=15; P=0.011; Fig. 2) because EC is also affected by temperature; warmer the water higher the conductivity [31]. Similarly, average values of TDS were recorded between 10 – 75.5 mg/L and 8 -19mg/L in the pre- and post-monsoon seasons, respectively. EC and TDS values seem to be in a similar range in the lake series. One of the lowest values of EC was observed by Lacoul and Freedman [32] in the Langtang area of High Himalayas as compared to other high altitude lakes in Nepal; and a similar trend was also recorded in Gosainkunda Lake [33]. However, TDS was quite high in Lake 4 during the pre-monsoon and in both lakes -3 and -4 during the post-monsoon as compared to the other lakes. Lake-4 is located at approximately the middle part of the basin and seems to be the outlet of other lakes, hence might have received more deposition of ions. High concentration of TDS during post-monsoon might have been due to the addition of solids from the catchment. The GoN [34] has recommended an upper limit of 2000 mg/L for TDS as being desirable for freshwater organisms; and the present study has much lower values(Table 4).

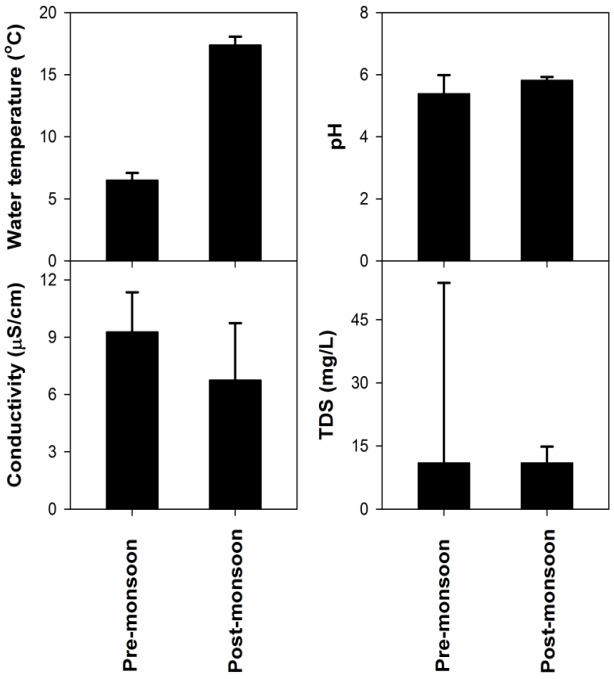


Figure 2. Physical parameters (Temp, pH, EC & TDS) in Panchpokhari Lake series.

Major cations and anions

Parameters such as calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), potassium (K^{+}), chlorides (Cl^{-}), bicarbonate alkalinity (HCO_3^{-}) and sulphate (SO_4^{--}) were the major cations and anions that have been studied. Generally, calcium is found in all natural water and its major source is rock leaching. The high concentration of Ca^{++} in Panchpokhari (Fig. 3) was thought to be mainly due to weathering of calcium bearing rocks and minerals such as calcites, genesis, limestone etc. According to Wetzel [35], calcareous rocks from surrounding catchment are one of the sources of calcium and similar trend was also recorded in other high altitude lakes of Nepal such as Gosainkunda and Gokyo [36,37]. The Ca^{++} and Cl^{-} were the major dominant cation and anion respectively in pre-monsoon; whereas Ca^{++} and HCO_3- were dominant in the post-monsoon. Although Ca^{++} was dominant in both of the seasons, its concentration was significantly higher during pre monsoon (T=345; t1=t2=15; P<0.001). The maximum quantity of chloride content was recorded in summer (T=345; t1=t2=15; P<0.001, Fig. 4), which may be due to high temperature and high rate of decomposition of organic matter. The chronic standard of chloride for aquatic life is 230 mg/l [38]; whereas UN [39] recommended that more than 350mg/l is harmful for aquatic animals. The concentrations of chloride were safe for the aquatic biota in

the present study (Table 4). Mg^{++} also showed significantly higher concentration during pre monsoon (T=345; t1=t2=15; P<0.001, Fig. 4).

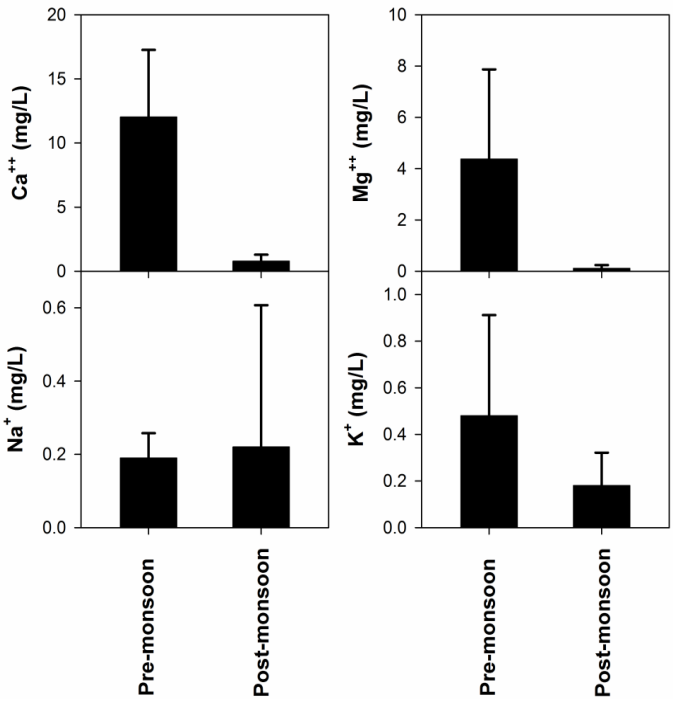


Figure 3. Seasonal comparison of major cations (Ca^{++}, Mg^{++}, Na^{+} & K^{+}) concentration in Panchpokhari lake series. (Pooled data)

Ionic composition of freshwaters indicates the salinity of water and is a measure of inorganic ion concentration either in mg/L or m. eq/L unit. It can be governed by various factors like catchment runoff, atmospheric precipitation, evaporation etc. and are dominated by four major positive cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and negative anions (HCO_3^- ,$CO3^{--}$, SO_4^- and Cl^-). However, nitrate ($NO3^{--}$) and phosphate (PO_4^{--}) also plays the role in the ionic composition, but they are of biological importance and minor component of ions, hence its amount is negligible i.e., <1. (waterontheweb).

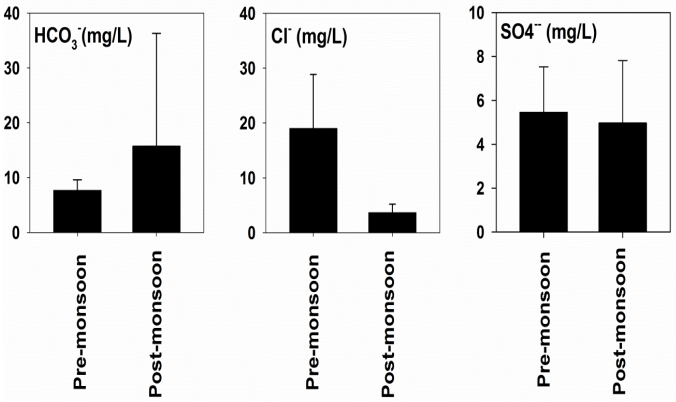


Figure 4. Seasonal comparison of major anion (HCO_3-, Cl- & SO_4^{--}) in Panchpokhari lake series (pooled data).

Ions composition	Pre monsoon (%)	Post monsoon (%)	In typical fresh water (%)
Cations			
Calcium (Ca^{++})	59	59	63
Magnesium (Mg^{++})	7	9	17
Sodium (Na^{+})	9	19	15
Potasium (K^{+})	25	13	4
Others			1
Anions			
Bicarbonates (HCO_3^-)	23	63	73
Sulphate ($SO4^{--}$)	60	16	16
Chlorides (Cl^-)	17	21	10
Others			1

Table 5. Ionic composition in the present study compared to the typical fresh water (waterontheweb).

In the lake series, the cation and anion composition followed the order: $Mg^{++} > Na^{+} > K^{+} > Ca^{++}$ and $SO_4^{--} > HCO_3^- > Cl^-$, respectively, in the pre-monsoon season. Whereas, cation and anion compositions were in the order: $Mg^{++} > K^{+} > Na^{+} > Ca^{++}$ and $Cl^- > SO_4^{--} > HCO_3^-$ respectively, in the post-monsoon season in all the lakes (Table 5).

A typical freshwater lake has an ionic balance (waterontheweb); which is also visible in the present study for example four major cations [calcium (63%), magnesium (17%) sodium (15%), potassium (4%)] and three major anions [bicarbonate (73%), sulphate (16%), chloride (10%)] form the main bulk, whereas other ions are <1% (waterontheweb) as shown in (Table 5). Ions balance is in the ordered of $K^{+} > Na^{+} > Mg^{++} > Ca^{++}$ and $Cl^- > SO_4^{--} > HCO_3^-$ respectively. Thus, a similar trend as reported elsewhere was observed in the Panchpokhari lake series however, there appears to be some seasonal variability in the ions concentration that might be due to the monsoon rainfall.

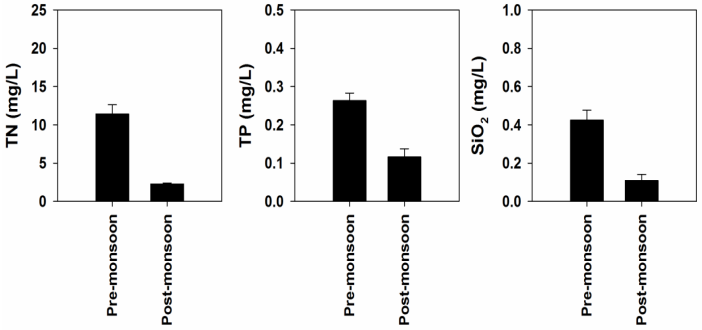
3.2 Nutrients

Nitrogen and phosphorus has been considered as major nutrients and are the limiting factors for all kind of freshwater bodies. Its abundance in aquatic system causes the eutrophication which has very serious consequences for the lake water. Phosphorus is the first limiting nutrient for plants in freshwater [40] which is available in the form of phosphate (PO_4-P) in natural water and generally found in low to moderate concentration. The average concentration of TP ranged from 0.18 – 0.31 mg/L and 0.07 – 0.18 mg/L in pre-monsoon and post-monsoon respectively in the lake series. Nevertheless, phosphorus showed significantly higher concentration during pre monsoon (T= 330; t1=t2=15; P<0.001).

Nitrogen is the most abundant element in the atmosphere and is an essential constituent of all living organisms. It oc-

curs in various forms like ammonia, nitrite, nitrate [inorganic and kjeldahl nitrogen (organic)]. The average concentration of TN ranged from 9.03 – 16.55mg/L and 1.78 – 2.53mg/L in pre-monsoon and post-monsoon respectively in all the lakes of Panchpokhari. TN was significantly higher during pre monsoon (T=345; t1=t2=15; P<0.001). The recorded values of TP seem to be lower than TN and suggested that the Lakes are still oligotrophic; and a similar trend was also reported in the other high altitude lakes of Nepal [32,33,36]. According to Saxena [41], phosphate concentration <10, 10-20, >20 are oligotrophic, mesotrophic and eutrophic, respectively.

Figure 5. Major nutrient (TN and TP) concentration in Panchpokhari Lake series.



Silica is a group of minerals composed of one atom of silicon and two atoms of oxygen (SiO2). It is also known as Quartz and second mostly abundant element in the earth's crust as found in dissolved and particulate form in the natural water. In the present study, it was measured as in total form of silica. Silicon is an important nutrient in surface waters because it is very essential nutrient for diatoms [42]. The average concentration of silica ranged from 0.39 - 0.48 mg/L and 0.04 - 0.035mg/L in the pre-monsoon and post-monsoon respectively, where pre monsoon had significantly higher concentration (T=336; t1=t2=15; P<0.001). Silicon concentrations vary in surface waters because water bodies receiving atmospheric inputs have lower concentration compared to the ones having surrounding catchment as their source [43]. It is derived from the weathering of silicates and aluminosilicates in the bed rock and soil of surrounded area as well [44,45]. The average values of most of the analyzed physico-chemical parameters lie within Nepal Drinking Water Quality Standard [46] as well as for Nepal Water Quality Guidelines for the Protection of Aquatic Ecosystem [47].

Conclusion

The average values of most of the parameters fell within the range for Nepal Water Quality Guidelines for the protection of aquatic ecosystem as well as within the NDWQS, with an exception of pH. The low pH values could be due to the influence of long range transport of atmospheric pollutants or some mineral sources leaching from the surrounding catchment of the lake. Nonetheless, anthropogenic impacts may also be a contributing factor. As the lakes are located in a remote area far from human settlement, the impact seems to be only seasonal and during the festival time. Dominance of Ca^{++}, Cl^{-} and HCO_3^{-} suggested that the lake has been impacted by both natural and anthropogenic inputs and predominance with carbonate weathering. Thus, on the basis of result obtained; the water chemistry of Panchpokhari lake series was noted to be in the oligotrophic state. Nonetheless, the past history of the lake is largely unknown; hence detailed study of lake series is still scanty, especially with regard to water chemistry. However, if the existing situation continues, the lakes could be significantly altered due to human activities, and the anthropogenic inputs will be dominant rather than natural and atmospheric processes. The concentrations of most of the analyzed parameters were lower during post-monsoon as compared to the pre-monsoon showing a seasonal differences that might be due to dilution effect of monsoon rain. Further research is needed to augment and verify the findings of this study, especially detailed of long range pollution impact study. The application of sensitive biological indicators, such as diatoms, could help elucidate the main cause of impacts to the Panchpokhari lake series which is ongoing.

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