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Hydrochemical characterization of lentic and lotic environments of Ramaroshan area, Sudurpaschim Province, Nepal

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Abstract

Ramaroshan of Sudurpaschim Province is rich in biodiversity, and ecologically distinct but scientifically unexplored rural and remote area of Nepal. There is a holy perennial Kailash River as a lotic and aesthetically well-known Ramarosan Lake Cluster (Batula Lake) as a lentic environment located in the region. This study has analyzed and then characterized the water quality status of both the lentic and lotic environments. The physicochemical parameters such as temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and major ions were analyzed for the hydrochemical characterization. The results revealed that the dominancy orders of cations and anions of the study area were found to be $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+} > NH_4^{+}$ *and* $HCO_3^{-} > Cl^{-} > SO_4^{2-} > PO_4^{3-} > NO_3^{-}$*, respectively. The concentrations of most of the parameters were relatively higher in the Kailash River than the Batula Lake except for the* SO_4^{2-}, PO_4^{3-} *and* NH_4^{+}*. The water facies displayed the* $Ca\text{-}HCO_3$ *type indicating the calcium carbonate type of lithology in the area. Additionally, the carbonate weathering is also higher than the silicates and evaporates. Similarly, the source controlling mechanisms indicated that the hydrochemistry of the Ramaroshan area is determined by both geogenic weathering and precipitation. Water quality assessment for irrigation parameters confirmed its suitability for irrigational purposes. The finding of this study could be the baseline dataset for assessing the future status and management of water resources of the Ramaroshan area.*

Keywords: Hydrochemistry, weathering, irrigation parameters, Ramaroshan area

Introduction

Water resources are the backbone for economic development and ecological integrity (Wu et al., 2018). From the ecological perspective, the ecosystem services from freshwater such as drinking water, regulating climate patterns, hydropower generation, ecotourism, soil formation, and groundwater recharge have been a foundation for human civilization. However, there is always a great challenge in securing water to satisfy the requirements of humans and ecosystems with rampant development, global climate change, and rapid urbanization (Amangabara & Ejenma, 2012). Both the natural processes and the anthropic activities alter the chemical compositions of the freshwater resources. Even the high mountain water resources, which are supposed to be pristine, are found to be vulnerable and threatened by anthropic activities like long-range transport of pollutants (Battarbee et al., 2002, Grabherr et al., 2006; Rupakheti et al., 2017, Gurung et al., 2018), climate change (Adrian et al., 2009), tourism, religious activities, and pollution (Chandan et al. 2008; Neupane et al., 2010).

The hydrochemical characterization is widely applied to evaluate the water bodies' physical, chemical, and biological status (Steingruber & Colombo, 2006). The chemical composition provides baseline information about weathering as ecological changes (Barnett et al., 2005; Zhu et al., 2012; Hagedorn & Whittier, 2015). So, the study on the hydrochemical characteristics of water bodies like rivers and lakes has been paid much more attention (Tripathee et al., 2014; Xiao et al., 2015; Nazri et al., 2016; Yang et al., 2017).

In Nepal, hydrochemical studies have been performed at different spatial and temporal levels such as Rara, Begnas, Rupa, Nagdaha, and Betkot lakes, and Gandaki River Basin, and so on (Khadka & Ramanathan, 2013; Pant, 2013; Gurung et al., 2018; Pant et al., 2018; Pant et al., 2019a; 2019b). However, the rural and remote areas of Nepal for instance high-land areas of Sudurpaschim Province are yet to be explored. Ramaroshan area of the province is one of them. The area is renowned for its 12 lakes and 18 *Patans* (lust grassland) in the junction of 3 districts viz. Accham, Bajura and Kalikot. It lies 42 km away from Mangalsen the district headquarters of Achham district. The climate of the area is sub-tropical, mild temperate, and cool-temperate. Geologically, the study area belongs to the Kalikot and Salyanigad formations. Kalikot formation has Budhi Ganga gneiss group and Ghattegad carbonates group (limestone, calcareous schist, and quartz biotite schists), whereas Salyanigad formation consists of gneisses augen, aplite granite, gneisses, and biotite gneisses (Dahal, 2017). The main objective of this study is to reveal the hydrochemistry of the lentic and lotic water bodies of the Ramaroshan Area.

Methodology

The study area

The Kailash River and Lake Cluster of Ramaroshan area (Batula Lake) was the study area (Fig. 1) for hydrochemical characterization. Batula Lake (Geographic Location: 29°13′ N & 81°28′ E) is one of the lakes of the Ramaroshan Lake Complex Area (RLCA) located at an altitude of 2406 m asl, with a basin area of 249.6 ha and core area of 3.2 ha. The lake has an average depth of 5 m with a maximum depth of 15 m (Chalaune et al., 2020). The Kailash River is one of the main rivers that flow down the hills of the Ramaroshan Area. The water discharge from Batula Lake is confluence into the Kailash River. The catchment area of Kailash River is home to 112 flowering plants and 12 species of cryptogames , eight species of wetland-dependent birds including migratory species (Poudel & Adhikari, 2020).

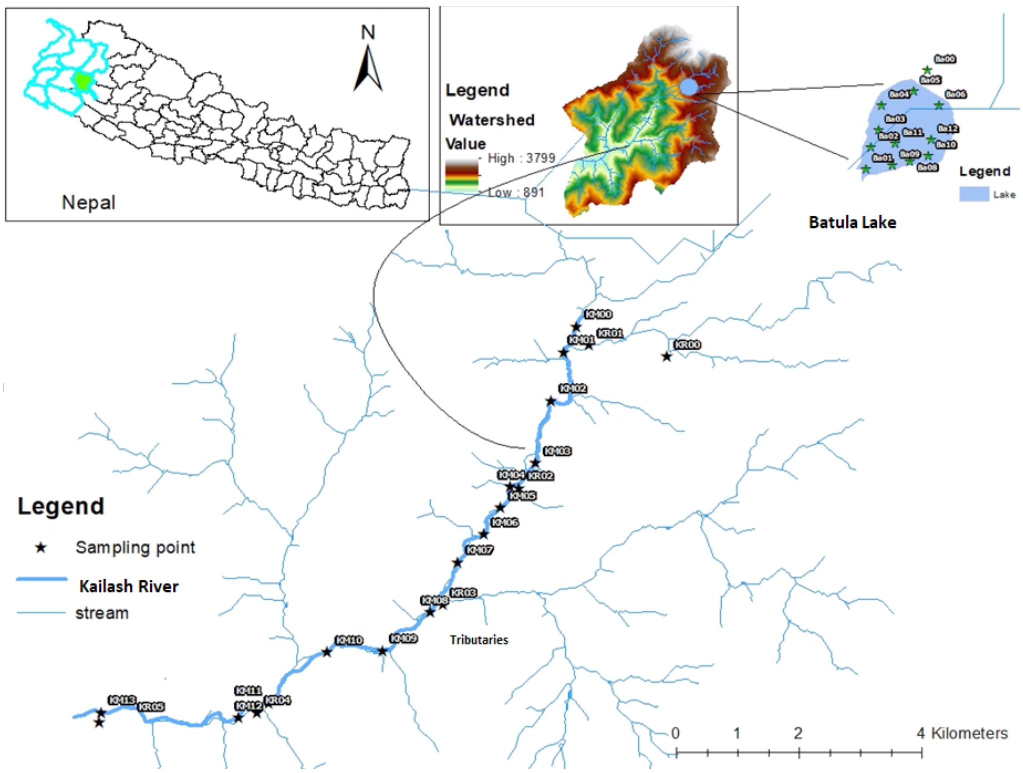

Figure 1: Study map showing the sampling points of Batula Lake and Kailash River, Ramaroshan area, Sudurpashchim Province, Nepal

Sampling

Surface water samples were collected in the month of January 2020. The sampling was conducted on the basis of land use/land cover change, and other environmental characteristics. Altogether 35 samples of water were collected of which 13 were collected from Batula Lake and 14 from the main Kailash River, and 8 from its tributaries. The samples were collected from the depth of 15 cm in 1L and 250 mL HDPE bottles. The samples for cations were preserved by adding conc. HNO_3 for maintaining pH < 2. The pH, transparency, temperature, EC, and TDS were determined in-situ using HANNA multipurpose meter. Similarly, the concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined in-situ by the complex-metric titration method. Sodium (Na^+) and potassium (K^+) were analyzed through the flame photometer in the lab. The concentration of bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and chloride (Cl^-) were analyzed in-situ through titration whereas, sulfate (SO_4^{2-}), nitrate (NO_3^-), phosphate (PO_4^{3-}), and ammonia (NH_4^+) by the spectrophotometer in the laboratory. Calibration of equipment with standards and use of blank for reagent quality were adopted for quality control. For the overall analysis, APHA (2005) was referred for analysis in Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University, Nepal.

Data analysis

Descriptive statistics, as well as graphical analysis, were performed to evaluate and interpret the obtained dataset in this study. Piper plot (Piper, 1944), Gibbs diagram (Gibbs, 1970), and mixing diagrams were used for understanding hydrochemical characteristics. Principal component analysis (PCA) and hierarchical cluster analysis (CA) were used in order to identify the source of major ions and correlate between them. Descriptive statistics were done using SPSS version 26.0 and MS Excel 2016. Water suitability for irrigation was determined by using the following parameters:

Sodium absorption ratio (SAR) = $\frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$ (Richards, 1954)

Sodium percentage (Na %) = $\frac{(Na^+ + K^+)*100}{(Ca^{2+}+Mg^{2+}+Na^+ + K^+)}$ (Richards, 1954)

Kelly's ratio (KR) = $\frac{Na^+}{(Ca^{2+}+Mg^{2+})}$ (Kelly, 1940)

Permeability index (PI) = $\frac{(Na^+ + \sqrt{HCO_3^-})*100}{Ca^{2+}+Mg^{2+}+Na^+}$ (Doneen, 1964)

Magnesium Hazard (MH)= $\frac{Mg^{2+}*100}{(Ca^{2+}+Mg^{2+})}$ (Rengasamy & Marchuk, 2011)

Wilcox diagram (Wilcox, 1958)

Results and discussion

General hydrochemistry

Table 1 summarized the results obtained from the analysis of the water samples. The table contains average, standard deviation (SD), maximum (max.), and minimum (min.) concentrations of the 14 water parameters. Based on the mean pH value in Kailash River, the water is slightly alkaline as the maximum value recorded was 8.26. This might be due to the high concentration of the bicarbonate-dominated under-lying lithology (Begum et al., 2009).

Table 1: Summary of the hydrochemical parameters of Batula Lake and Kailash River, Ramaroshan area, Sudurpashchim Province, Nepal

Parameters	Batula Lake				Kailash River				WHO limits
	Average	SD	Min	Max	Average	SD	Min	Max	
Tem.	8.26	3.51	3.30	15.30	11.17	0.95	8.70	12.40	-
pH	7.43	0.17	7.13	7.69	7.74	0.36	6.62	8.26	6-8.5
EC	67.85	31.76	20.00	106.00	126.00	73.26	45.00	322.00	-
TDS	34.85	16.6	10.00	54.00	65.00	38.56	24.00	168.00	1000
Ca^{2+}	10.28	4.67	2.40	16.00	20.22	14.97	8.00	66.40	100
Mg^{2+}	3.27	1.46	0.98	5.86	5.10	2.10	1.46	10.25	50
Na^+	5.50	0.25	5.10	6.10	5.76	0.18	5.40	6.10	200
K^+	2.30	0.64	1.09	3.30	2.80	0.94	0.08	4.60	100
NH_4^+	0.12	0.09	0.07	0.43	0.09	0.02	0.07	0.14	0.5
HCO_3^-	39.23	14.92	15.00	60.00	54.45	33.79	20.00	140.00	600
Cl^-	12.12	3.42	7.10	18.46	14.03	3.60	7.10	22.72	250
NO_3^-	0.05	0.01	0.04	0.07	0.05	0.01	0.04	0.08	50
SO_4^{2-}	1.96	3.29	0.29	12.67	1.62	0.52	0.99	3.62	250
PO_4^{3-}	0.22	0.12	0.13	0.56	0.16	0.03	0.02	0.22	1

The mean value of EC and TDS was found to be 126.00±73.26 µS/cm and 65.00±38.56 mg/L, respectively in the Kailash River, whereas the mean value recorded in Batula Lake was 67.85±30.4 µS/cm and 34.85±16.6 mg/L. These values were under the guideline provided by WHO limits. The higher concentration of TDS and EC in Kailash River than Batula Lake might be due to the high concentration of the ionic species and weathering of the chemicals with the movement of river water (Singh & Hasnain, 1999; Das & Kaur 2001). Previous studies have shown that the majority of Himalayan freshwater bodies have relatively very low TDS values (< 100 mg/ L) (Pant et al., 2018). In the present study, the lake and river being at high altitude have shown a similar trend except for some samples from the tributary of Kailash River. Similarly, the TDS and EC were found to be 94.75± 3.29 mg/L and 189.93± 5.3 µS/cm, respectively in Rara Lake

(Gurung et al., 2018) which is greater than the present study concentration of Batula Lake. The mean concentrations of major ions were greater in the Kailash River than the Batula Lake except for SO_4^{2-}, PO_4^{3-} and NH_4^+ which is greater in Batula Lake. The reason behind having greater value for PO_4^{3-} and NH_4^+ may be organic matter, dead logs, and macrophytes in Batula Lake. In this study, HCO_3^- was only the anion that primarily contributed to the total alkalinity. The mean concentration of HCO_3^- recorded was 39.23 ± 14.92 mg/L and 53.24 ± 32.63 mg/L in Batula and Kailash River, respectively. A high concentration of HCO_3^- in the Kailash might be contributed to weathering reactions (Chakrapani et al., 2009). The maximum concentration of chloride was recorded from the water sample near the settlement area of the Kailash River. The greywater from the settlement area is directly mixed in the Kailash River which might be the reason for higher chlorides. The mean concentration of Cl^- was 12.12±3.43 mg/L in Batula Lake which is found to be lower than previous studies of lakes like Begnas, Rupa, Khaste Lake (Pant et al., 2019a) but higher than Jhilmila (Pal et al., 2021) and Betkot Lake (Pant et al., 2019b) from the western region of Nepal.

The mean concentrations of cations were in the order of $Ca^{2+} > Na^+ > Mg^{2+} > K^+ > NH_4^+$ in both Kailash River and Batula Lake. A similar order was observed in the Tamor River (Ghimire et al., 2021), Bagmati River, and Jhilmila Lake but slightly different than Gandaki River (Pant et al., 2018). Meanwhile, the mean concentration of anions were in the order of $HCO_3^- > Cl^- > SO_4^{2-} > PO_4^{3-} > NO_3^-$ in the study area. The mean concentrations of major ions were under the guidelines of WHO that the water is also suitable for drinking purposes as people depend on these resources for drinking.

Hydrochemical facies

For the characterization and source identification of the major ions, Piper Plot (Piper, 1944) was used. The milliequivalent percentage (meq%) of the major ions is plotted in a trilinear diagram (Figure 2) illustrating the water characteristics of the Batula Lake and Kailash River. On the cation plot, most of the samples from both the study area had Ca^{2+} as the dominant cation. Similarly, the anion plot showed that HCO_3^- and Cl^- were dominant anions in samples of both the Batula Lake and Kailash River. The Piper plot showed the dominance of alkaline earth metal over alkali metal such as $Ca^{2+} + Mg^{2+} > Na^+ + K^+$ and anions such as $HCO_3^- > SO_4^{2-} + Cl^-$. The diamond plot can be classified into the six water facies i.e. 1) Ca-HCO_3, 2) Na-Cl, 3) Mixed Ca-Na-HCO_3, 4) Mixed Ca-Mg-Cl, 5) Ca-Cl, 6) Na-HCO_3 (Khadka & Ramanatha, 2012). As per the classification, the water type was found to be Ca- HCO_3 type and Ca-Mg-Cl type in both ecosystems. About 95% of samples in Kailash River and 84% of samples from Batula Lake had the Ca-HCO_3 type whereas 5% and 16% of samples in Kailash River and Batula Lake were found to have Ca-Mg-Cl type of water, respectively. The dominance of Ca-HCO_3 water type and alkaline earth metal signifies the carbonate-dominated underlying lithology.

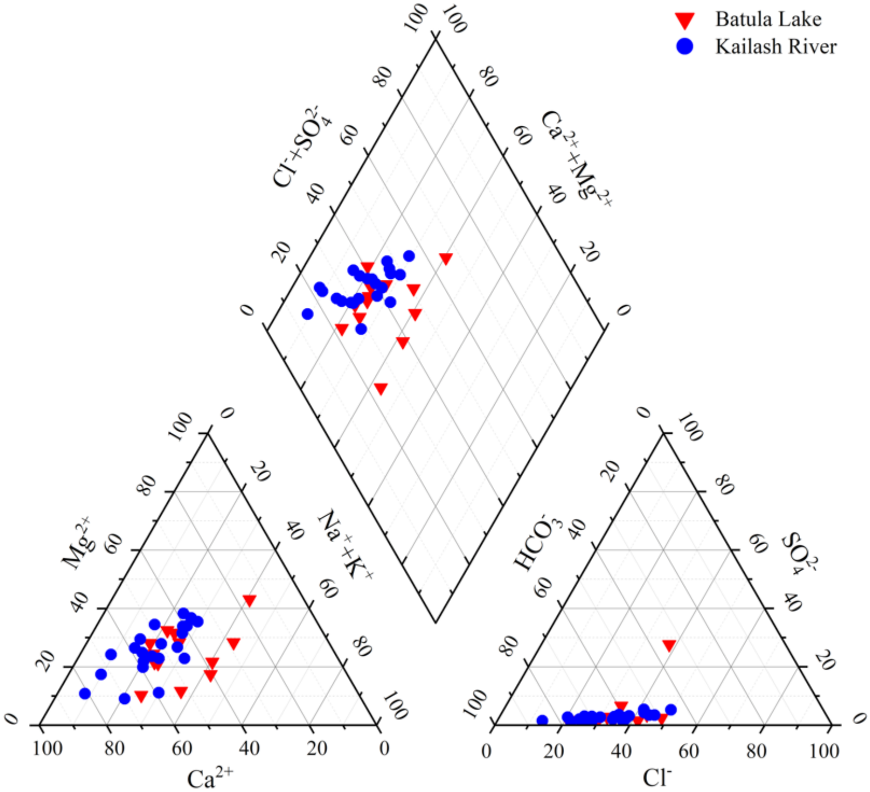

Figure 2: Piper diagram showing the hydrochemical facies of Batula Lake and Kailash River, Ramaroshan area, Sudurpaschim Province, Nepal

Controlling mechanisms

Gibbs Plot (Gibbs, 1970) shows the three mechanisms which control the water chemistry of the surface water: they are rock dominance, evaporation/crystallization, and precipitation. It is plotted between the TDS and Na^+ / $Na^+ + Ca^{2+}$ and Cl^- / $Cl^- + HCO_3^-$. Figure 3 showed that hydrochemistry of the Kailash River and Batula Lake was found to be precipitation dominant followed by rock weathering. The water samples from Batula Lake had a TDS value lower than $Na^+/Na^+ + Ca^{2+}$ and $Cl^-/Cl^- + HCO_3^-$ resulting in precipitation dominance. It indicates that atmospheric precipitation or runoff is the main factor controlling the composition of chemical components in the region. In the

Gibbs diagram, 36.36% samples of Kailash River lied in rock weathering dominance and the rest in precipitation dominance. The hydrochemistry of study lakes and rivers in Nepal like West Seti River Basin in Sudurpaschim Province (English et al., 2000), Begnas Lake (Khadka & Ramanatha, 2012), Dudhkoshi River Basin (Paudyal et al., 2016), Rara Lake (Gurung et al., 2018), downstream of Gandaki River Basin (Pant et al., 2018) recorded rock weathering dominance which is a contrast to the present study.

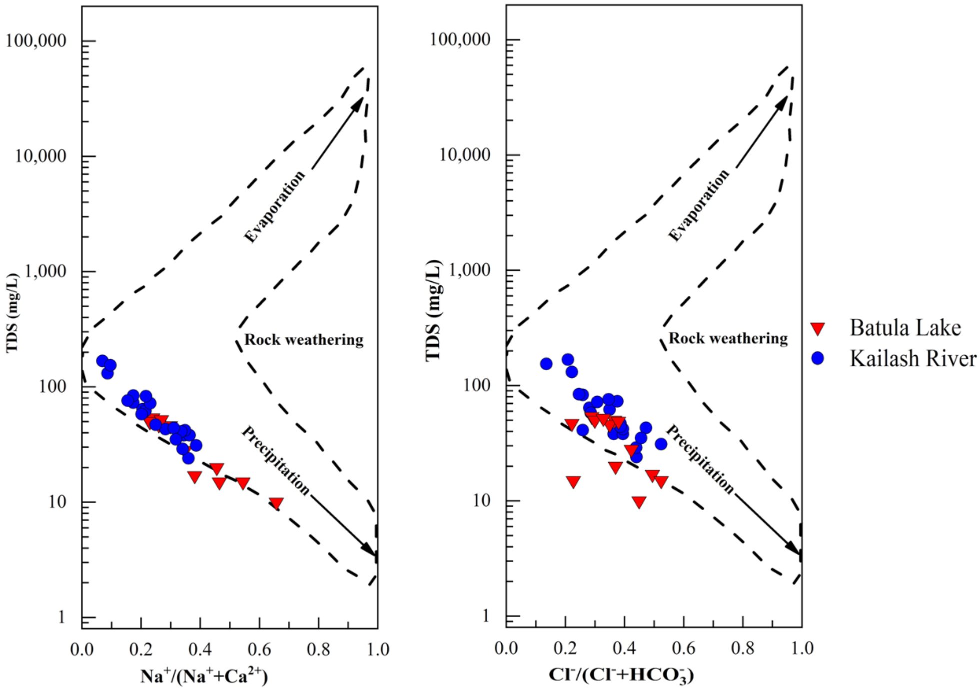

Figure 3: Gibbs plot showing major processes controlling surface water chemistry of the Batula Lake and Kailash River, Ramaroshan Area, Sudurpaschim Province, Nepal

(Concentration of Na^+, Ca^{2+}, Cl^- and HCO_3^- are in meq/L and TDS in mg/L)

Chemical weathering

The major ions in the water bodies are contributed from the carbonate weathering, silicate weathering, and dissolution of evaporites.

Table 2: Ionic ratios of hydrochemical variables of both Batula Lake and Kailash River, Ramaroshan area, Sudurpashchim Province, Nepal

Parameters	Batula Lake				Kailash River			
	Average	Std	Max	Min	Average	std	Max	Min
Ca^{2+}/Na^{+}	2.14	0.96	3.36	0.52	4.06	3.06	13.40	1.59
Mg^{2+}/Na^{+}	1.12	0.51	2.02	0.36	1.68	0.70	3.40	0.48
HCO_3^-/ Na^+	2.69	1.04	4.11	1.07	3.58	2.26	9.26	1.30
HCO_3^-/ Ca^{2+}	1.47	0.83	4.10	0.80	0.93	0.14	1.20	0.64
$HCO_3^-/ (Na^++K^+)$	2.16	0.81	3.35	0.81	2.75	1.66	7.18	0.99
$(Ca^{2+}+Mg^{2+})/(Na^++K^+)$	2.61	0.98	4.32	1.30	4.40	2.49	11.23	2.16
Ca^{2+}/SO_4^{2+}	41.24	42.09	124.91	1.06	29.30	16.08	76.83	10.50
Na^+/Cl^-	0.76	0.21	1.15	0.43	0.67	0.18	1.21	0.41
$HCO_3^-/ (HCO_3^-+SO_4^{2+})$	0.93	0.11	0.99	0.55	0.95	0.02	0.98	0.90
$(Ca^{2+}+Mg^{2+})/Tz^+$	0.71	0.09	0.81	0.57	0.79	0.07	0.92	0.68
$(Na^++K^+)/Tz^+$	0.29	0.09	0.43	0.19	0.21	0.07	0.32	0.08

(All the concentrations are in meq/L)

Mostly, Ca^{2+} and Mg^{2+} originate from the weathering of carbonates, silicates, and evaporite; Na^+ and K^+ from evaporites and weathering of silicates whereas SO_4^{2-} and Cl^- from evaporites. The mean ratio of Na^+/Cl^- was <1 for both Batula Lake and Kailash River which indicates the single source of sodium and chloride ions (Li et al., 2009). The result was in contrast with the study of Bagmati River (Pant et al., 2021) but similar to the study in Gandaki Basin River (Pant et al., 2018). The pollution in the Bagmati River might be the region for the multiple sources as Bagmati River flows through heavily populated city but the Kailash River flows through the rural area of Nepal.

Carbonate weathering is influenced by the protons. For the estimation of these sources and their origin whether from carbonation or oxidation, the C-ratio of $HCO_3^-/ HCO_3^- + SO_4^{2-}$ is studied (Brown et al., 1996). As per Pant et al., (2018), the C-ratio is < 0.50 indicates the coupled chemical reactions of both carbonate dissolution and sulfide oxidation, whereas C-ratio close to 1 indicates the carbonation reactions and dissociation of CO_2 deriving protons from atmospheric inputs. The mean value C-ratio of Batula Lake and Kailash River was > 0.5 i.e. 0.9 and 0.95, respectively. This determines the carbonate reaction and CO_2 deriving protons from the atmosphere. Again, the high ratio of Ca^{2+}/SO_4^{2-} i.e. >20 (Singh et al., 2014) for both lake and river confirmed carbonate as a major source of protons for rock weathering.

The high mean ratio of Ca^{2+}+Mg^{2+}/Tz^{+} is > 0.7 and the low ratio Na^{+}+K^{+}/Tz^{+} is < 0.3 in both the lake and and the river. These suggested that carbonate weathering is higher than that of silicates and evaporates (Khadka & Ramanathan, 2012) in the study area. The Na-normalized molar ratio plot of Ca^{2+}/Na^{+} versus HCO_3^{-}/Na^{+} showed spatial variability in hydrochemistry with end members of carbonate, silicate, and evaporites. In the present study, almost all the samples from Batula Lake and Kailash River were towards the carbonate end member indicating the dominance of carbonate weathering. Meanwhile, a few samples from Batula Lake were located near silicate end members, which indicates silicate weathering (Figure 4a and b).

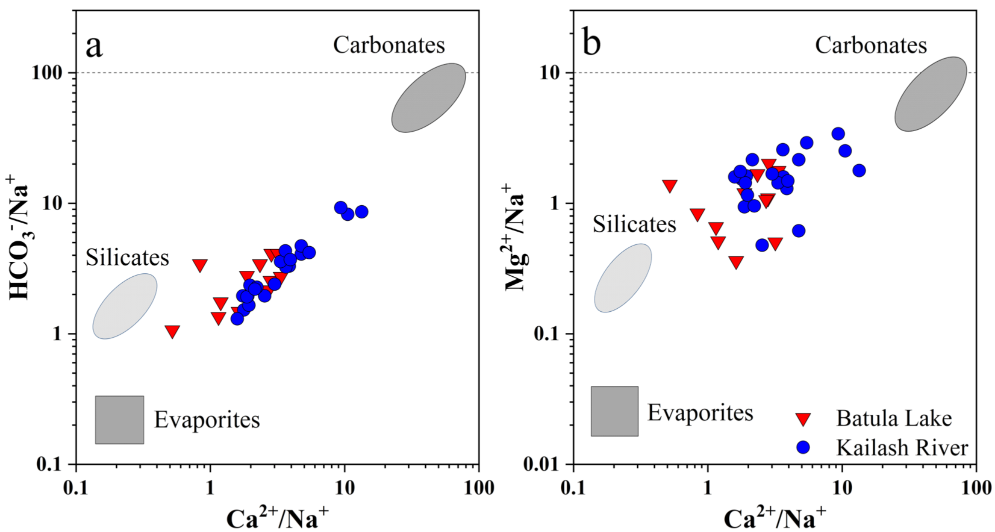

Figure 4: Mixing diagram of Na-normalized molar ratios of (a) Ca^{2+} versus HCO_3^{-} and (b) Ca^{2+} versus Mg^{2+}, Ramaroshan area, Sudurpashchim Province, Nepal

Multivariate analysis

Cluster analysis

Hierarchical cluster analysis is the process to make clusters within a data set having similarities and build a hierarchy of clusters that are represented by the dendrogram (Figure 5). Hierarchical clustering with the Ward Method of Linkage was used to minimize the variance within the group. In hydrochemical studies, cluster analysis is used to group the similar sites having similar geochemical characteristics indicating the similar ongoing process affected by similar processes and sources (Saleh & Shehata, 1999; Pant et al., 2018). In this study, the parameters like pH, EC, TDS, HCO_3^{-}, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, PO_4^{3-} and NH_4^{+} were used to cluster water sampling sites from the study area.

Statistically, 3 clusters were obtained with a low distance criterion between 0 and 5 both from Batula Lake and Kailash River, respectively. Cluster 1 consists of 54.28% samples of both the lake and river. Cluster 2 consists of 37.14% of the total samples and Cluster 3 consists of only 8.57% samples. Interestingly, Cluster 3 contains only the samples from the river. These sites are characterized by the settlement area or small cluster settlements showing towards the anthropic activities. This determines that Cluster 3 has slightly polluted water sampling sites. These sampling sites are clustered together due to the high value of the EC, TDS, and major ions. These sites are the tributaries of that might be due to the use of this river as vehicles pathway. This cluster shows that the similarity in ongoing geological processes, similar climatic and anthropic factors.

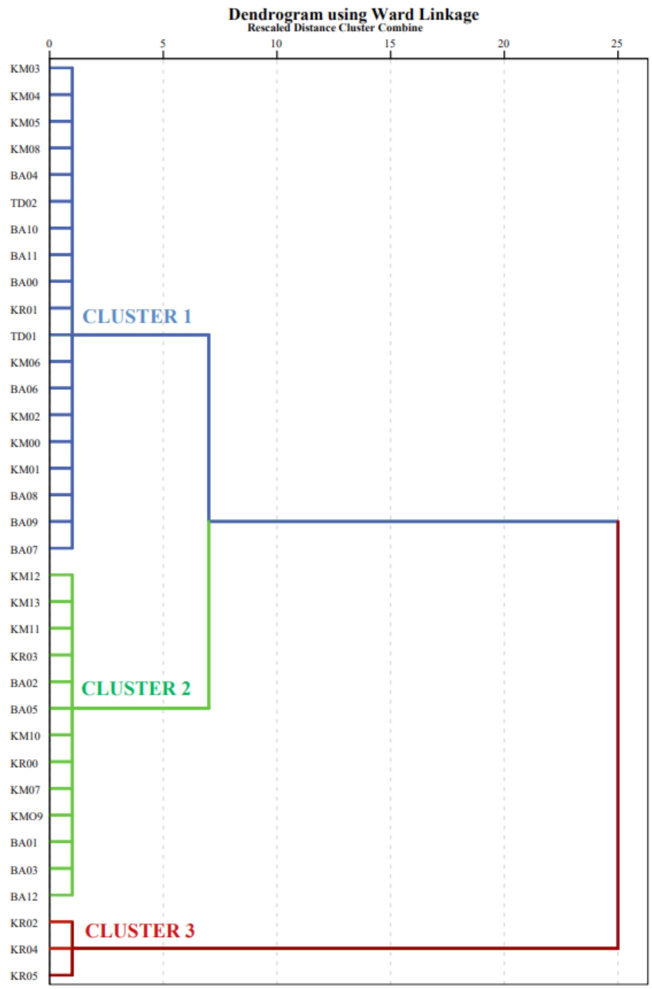

Figure 5: Cluster analysis of Batula Lake and Kailash River, Ramaroshan Area, Sudurpashchim Province, Nepal

Principal component analysis

Principal component analysis (PCA) is commonly used for reducing the dimensionality of the data set with minimum loss of the original information. Principal components (PC) are extracted through the process of orthogonal transform of correlated variables to the set of linearly uncorrelated variables. The eigenvalues of the PCs are the degree of their associated variables whereas the correlation between PCs and original data is loadings (Verol et al., 1998).

For the identification of parameters influence in water, PCA was executed with the 11 parameters TDS, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-} and NH_4^+ of samples from the study area. In this study, the value of the Kaiser-Mayer-Olkin test was greater than 0.6 which shows the samples are adequate for the PCA test. The principal component (PCs) with the Eigenvalues greater than 1 was further analyzed (Figure 6) with the factor loading (Table 2). As per the PCA, 4 major principal components were observed for both Batula Lake and Kailash River. According to Liu et al., (2003), the factor loadings can be classified into the absolute loading values of > 0.75, 0.75-0.50, and 0.50-0.30 as strong, moderate, and weak, respectively. In the present study, PC1 explained 39.055% total variance with the strong loading of TDS, HCO_3^- and Ca^{2+} in both the river and lake, and moderate loading of Mg^{2+}, and Cl^-. The strong loading plots of PC1 indicated that carbonate rock weathering impacted the hydrochemistry in the lake as well as the river. PC2 explained 18.32% of the total variance, having the strong loading on NO_3^- and moderate loading of K^+ and PO_4^{3-}. It indicated anthropic activities like forest and agricultural runoff and untreated sewage discharge or fecal contamination in lakes and rivers. Since, NO_3^-, $K^{+,}$ and PO_4^{3-} lies in the same PC which indicates the similar source of these ions. Similarly, PC3 explained 13.02% of total variance having the strong loading of Na^+ and moderate negative loading on NH_4^+, this indicates that the source of Na^+ and NH_4^+ is different in the region. Again, PC4 explained 9.05% of total variance having the strong loading on SO_4^{2-} indicating the minimum anthropic signature in the area with the natural origin of SO_4^{2-}.

Table 3: Summary of principal component analysis showing a component matrix of Ramaroshan area, Sudurpashchim Province, Nepal

Factor loading	Component matrix of Ramaroshan Area			
	Components			
	1	2	3	4
TDS	**0.95**	0.17	0.10	-0.09
HCO_3^-	**0.94**	0.19	-0.03	0.02
Cl^-	**0.60**	0.07	0.26	0.35
NO_3^-	0.35	**0.78**	0.12	-0.04
SO_4^{2-}	0.02	-0.12	-0.02	**0.81**
PO_4^{2-}	-0.16	**0.61**	-0.38	0.48
Ca^{2+}	**0.95**	0.17	0.02	0.05
Mg^{2+}	**0.63**	0.14	0.25	-0.12
Na^+	0.06	0.04	**0.82**	-0.14
K^+	0.32	**0.63**	0.19	-0.19
NH_4^+	-0.17	-0.14	**-0.60**	-0.43
Eigen values	4.68	2.19	1.56	1.08
% of variance	39.05	18.32	13.02	9.05
Cumulative %	39.05	57.37	70.40	79.46

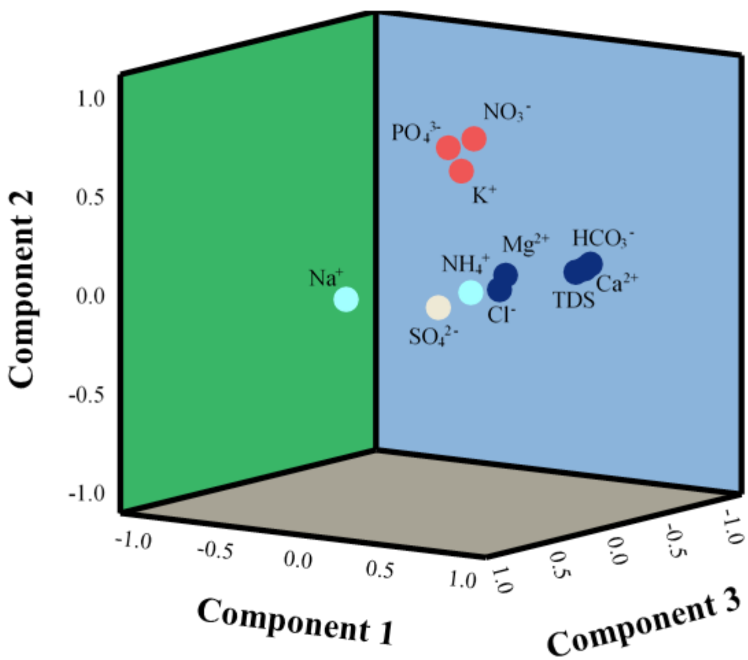

Figure 6: Principal component Batula Lake and Kailash River, Ramaroshan Area, Sudurpaschim Province, Nepal

Water quality for the irrigation purposes

The river and lake water of the Ramaroshan area is widely used for drinking and irrigation purposes. Hence, the monitoring of water quality for irrigation is important to maintain soil health as well as crop production. In the long-term irrigated lands with poor water quality, salinization is a major problem especially in heavy and clayey soils (Singh et al., 2008). The water has high concentration dissolve ions alters the soil characteristics (Ravikumar et al., 2011) where Na^+ plays a vital role (Elango, 2005). The water suitability for irrigation based on Na^+ can be assessed by SAR, Na%, Wilcox Diagram, Kelly's Ratio, and permeability index (PI) whereas Mg^{2+} concentration is used to measure magnesium hazard.

SAR is used to calculate the sodium hazard, showing the degree of cation- exchange reaction in the soil and irrigation water. Generally, high sodium replaces the Ca^{2+} and Mg^{2+} of soil, increasing the soil's impermeability. In the present study, the mean values of SAR were 0.4±0.1 and 0.33±0.1 for Batula Lake and Kailash River, respectively. Since, SAR value was found to be < 10 which shows the water quality is excellent based on classification (Singh et al., 2008). The previous study in Bagmati River, Gandaki River, Indrawati River, and Dudh Koshi River (Sharma et al., 2020), and Karmansha River (Acharya et al., 2020) showed that the water was suitable for irrigation based on SAR. According to Wilcox (1948), a Na % value having less than 60% is suitable for irrigation purposes. The mean values of Na% obtained were 30±8.7 and 21.4± 6.6 of Batula Lake and Kailash River, respectively. Since all the sampling points had Na% < 60% in the present study; thus, the water was suitable for irrigation in the Ramaroshan area.

Wilcox Diagram (1958) is used for assessing the suitability of irrigation water using the value of SAR and EC. In the Wilcox Diagram (Figure 7) C1, C2, C3, C4 types indicate salinity hazards, and S1, S2, S3, S4 types indicate sodium alkaline hazards. The majority of water samples from Batula Lake and Kailash River in the present study belonged to C1S1 i.e. low salinity with low sodium hazard whereas only two samples of Kailash River belonged to C2S1 i.e. medium salinity and low sodium hazard as shown in Figure 7. Thus, water was found to be suitable for the irrigation in Ramaroshan area.

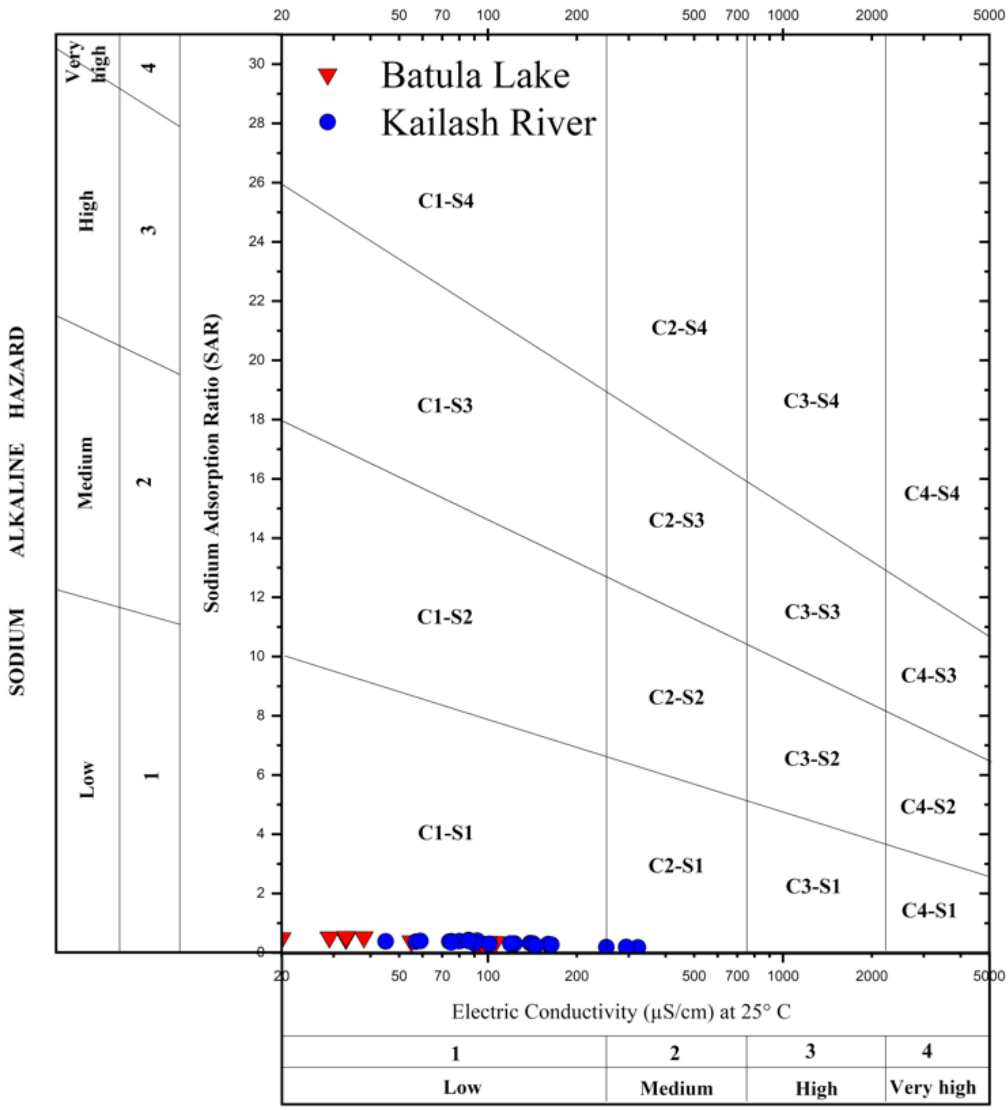

Figure 7: Wilcox showing the irrigation suitability of Batula Lake and Kailash River, Ramaroshan Area, Sudurpaschim Province, Nepal

Kelly's Ratio is the measurement of Na^{+} against Ca^{2+} and Mg^{2+} (Kelly, 1940). Kelly's Ratio of more than one indicates water is unsuitable for irrigation. Kelly's ratio was lower than 1 in the present study indicated water suitable for irrigation. The mean values of Kelly's ratio were 0.36±0.2 and 0.22±0.1 for Batula Lake and Kailash River, respectively. The permeability of the soil is affected by the irrigation water quality and the soil type. The concentration of Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- contents in water mainly influence soil profile (Singh et al., 2015). On the basis of PI, water quality can be classified into Class I (> 75%), Class II (25%-75%), and Class III (<25%) indicating excellent, good, and unsuitable for irrigation (Doneen, 1964). PI value for the waters samples varied from 74.89 to 178.83 and 42.58 to 99.63 of Batula Lake and Kailash River, respectively. So, the water samples lie in Class I and II category of (Doneen, 1964) which indicated water has excellent to good permeability and is suitable for irrigation.

Besides Na^+, the monitoring of the Mg^{2+} ion in the water is required. Though Mg^{2+} and Ca^{2+} are in the equilibrium state in water, the high concentration of Mg^{2+} in irrigation increases the alkalinity and affects the crop yield. The water having MH > 50 is unsuitable for irrigation (Szabolcs & Darab, 1964). The mean values of MH were 35.8±14.2 and 33.05±11.6 for Batula Lake and Kailash River, respectively. The majority of the samples didn't exceed the limits, so the water is suitable for irrigation.

Conclusion

The hydrochemistry of both the Batula and Kailash River of Ramaroshan Lake Complex, Sudurpashchim Province, Nepal were more or less similar in terms of their chemical concentrations. Among the major ions, calcium and bicarbonate were the most dominant cation and anion, which is consistent with Ca-HCO_3 dominate water type, indicating calcium carbonate type of lithology. The hydrochemistry of water was found to be controlled by rock weathering as well as precipitation. The analysis of irrigation parameters shows water in the Ramaroshan area is suitable for irrigation. This study builds the baseline dataset for assessing future anthropic influence on the water resource of the Ramaroshan area and subsequent development for future lake management strategies. However, the results of the present study are only based on a single season, so it is suggested for the monitoring of the water chemistry for different seasons for the in-depth insights. Additionally, along with the study of hydrochemistry at spatiotemporal level, the biological aspect is also recommended for the further study.

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