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Research Article

HYDROCHEMISTRY OF KUPINDE LAKE AT THE LESSER HIMALAYA IN KARNALI PROVINCE, NEPAL

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ABSTRACT

Hydrochemical assessment of the freshwater lakes provides important insights into the sources of dissolved ions, geochemical processes, and anthropogenic activities taking place in the environment. This study focuses on the assessment of hydrochemistry and water quality of Kupinde Lake, Karnali Province, Nepal. Surface water samples were collected from 24 different locations of the lake in October 2021 and analyzed for 18 different physico-chemical parameters. The pH, temperature, electrical conductivity and total dissolved solids were measured on-site, and concentration of major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+, HCO_3^-, Cl^-, SO_4^{2-}, PO_4^{3-}, NO_3^-), including hardness and free CO_2 were measured in the laboratory. The results revealed that lake water was alkaline with abundance of the major ions in the following order: $Ca^{2+} > Mg^{2+} > Na^+ > K^+ > NH_4^+$ and $HCO_3^- > Cl^- > SO_4^{2-} > PO_4^{3-} > NO_3^-$ for the cations and anions, respectively. The lake water was dominated by Ca-HCO_3, indicating calcium carbonate dominated lithology in the area. Gibb's plot and Piper diagram illustrated rock weathering as the most dominant process in controlling the hydrochemistry of the lake basin. The suitability of water for drinking and irrigation was determined using geochemical indices and WHO standards. The results indicated that the Kupinde Lake water could be used for drinking and irrigation purposes in terms of measured hydrochemical variables.

Keywords: Hydrochemical facies, hydrochemistry, multivariate analysis, irrigation parameters, water quality

INTRODUCTION

Wetlands are natural or man-made landscapes like swamps, marsh, fen, lakes, and streams (Keddy, 2010). These areas are located between the terrestrial and aquatic systems and serve as a habitat for birds, amphibians, fish, and reptiles (Bhandari, 2009). Wetlands are unique ecosystems, and they provide a variety of ecosystem services including climate regulation, carbon storage, water reservoirs, runoff containment and flood risk reduction (Cimon-Morin & Poulin, 2018). Wetlands also support a high amount of biodiversity compared to their space by providing a habitat for a diverse range of flora and fauna (Kingsford *et al.,* 2016). Despite their importance, wetlands are disappearing at alarming rates around the world, with up to 71 percent of global wetland area converted to other land-cover types since 1900 (McCarthy *et al.,* 2018).

Wetlands in the Himalayas are suffering from global climate change and rampant development, which are threatening their ecological health (Pant *et al.,* 2021). Specially, the hydrochemistry and water quality of these pristine wetlands has been altered due to human encroachment and contamination of various pollutants including excessive use of various chemical fertilizers and pesticides (Hey *et al.,* 2012). In order to be suitable for a particular use, water must meet a variety of biological, chemical, and physical characteristics (Pfister *et al.*, 2011; Gorde & Jadhav, 2013). In lesser Himalayan lakes such as Begnas and Phewa lakes in Nepal, major ions, such as Ca^{2+}, Mg^{2+}, and HCO_3^-, were found in higher concentrations (Khadka & Ramanathan, 2013; Khadka & Ramanathan, 2021). These major ions are also dominant in high altitude Himalayan Rara lake (Kaphle *et al.,* 2021). There is also evidence that it contains a high concentration of Ca^{2+}, Mg^{2+}, and HCO_3^- in the Rewalsar Lake in the Lesser Himalaya, India (Gaury *et al.*, 2018). The concentration of major ions in lake water determines its suitability for drinking and irrigation (Gaury *et al.,* 2018, Pant *et al.,* 2021) as well as providing valuable insight into the sources of dissolved ions, weathering, and hydrogeochemical processes (Singh *et al.,* 2016). The chemistry of lakes is influenced by many factors, including rocks and soils in the catchment area, atmospheric gases, aerosols, basin morphology, climate, fauna, and flora in the area, and human activities (Hey *et al.*, 2012; Gaury *et al.*, 2018). The pollution of Himalayan lakes is due to rock weathering and human activities in the catchment (Das & Kaur, 2001; Gaury *et al.,* 2018; Kaphle *et al.,* 2021). Thus, wetland ecosystems are facing the most serious problem worldwide, and impact on water quality is recognized as one of the key environmental issues (Amankwaa *et al.,* 2020).

Nepal occupies 745,00 hectares (5% of the total area) of freshwater ecosystem, which include rivers, lakes, ponds, wetlands, reservoirs, and irrigated rice fields, that support diverse flora and fauna (Sharma, 2008). Hydrochemistry of freshwater lakes, especially in western Nepal, has received limited scientific investigation. Kupinde Lake is located in the Salyan District of western Nepal and is one of the most popular tourist destinations in the region. The lake's most significant features are its ecological, religious, and social values, as well as its recreational importance (Sunar *et al.*, 2022). There is ongoing construction and improvement of roads around the lake area, as well as the development of a large tourist complex. In the area, domestic tourists have increased over the past few years due to the improvement of the access roads. As a result, the lake could experience increased anthropogenic impacts, threatening its ecosystem services and unique biodiversity. However, there is no scientific study conducted on the physicochemical characteristics and water quality of the lake. Therefore, in order to understand the hydrochemistry and water quality of the lake, this investigation was carried out. The main objective of the study was to reveal the hydrochemistry and status of water quality for drinking and irrigation in Kupinde Lake, Salyan District, Nepal.

MATERIALS AND METHODS

Study Area

The Kupinde Lake is located in the Salyan District of Karnali Province, Nepal (Fig. 1). It lies 28°24'56.64"N and 82° 3'26.10"E and at an elevation about 1153 m above sea level and 15 km^2 away from the district headquarters. Salyan District is a hilly area covering an area of 1462 km^2 with a population of 238,515 (CBS, 2021). The district is bounded by Rolpa on the east, Surkhet and Bardiya on the west, Rukum and Jajarkot on the north and Dang and Banke on the south. The district has a sub-tropical to temperate climate with maximum temperature of 31°C and minimum of 3°C and annual average rainfall is of 1100 mm (Rawal & Joshi, 2022). Kupinde Lake is situated in the south-eastern region of Salyan District and is one of the most popular tourist destinations and natural water resources in the district. It occupies 0.24 km^2 which is surrounded by forest and agriculture land (Sunar *et al.*, 2022).

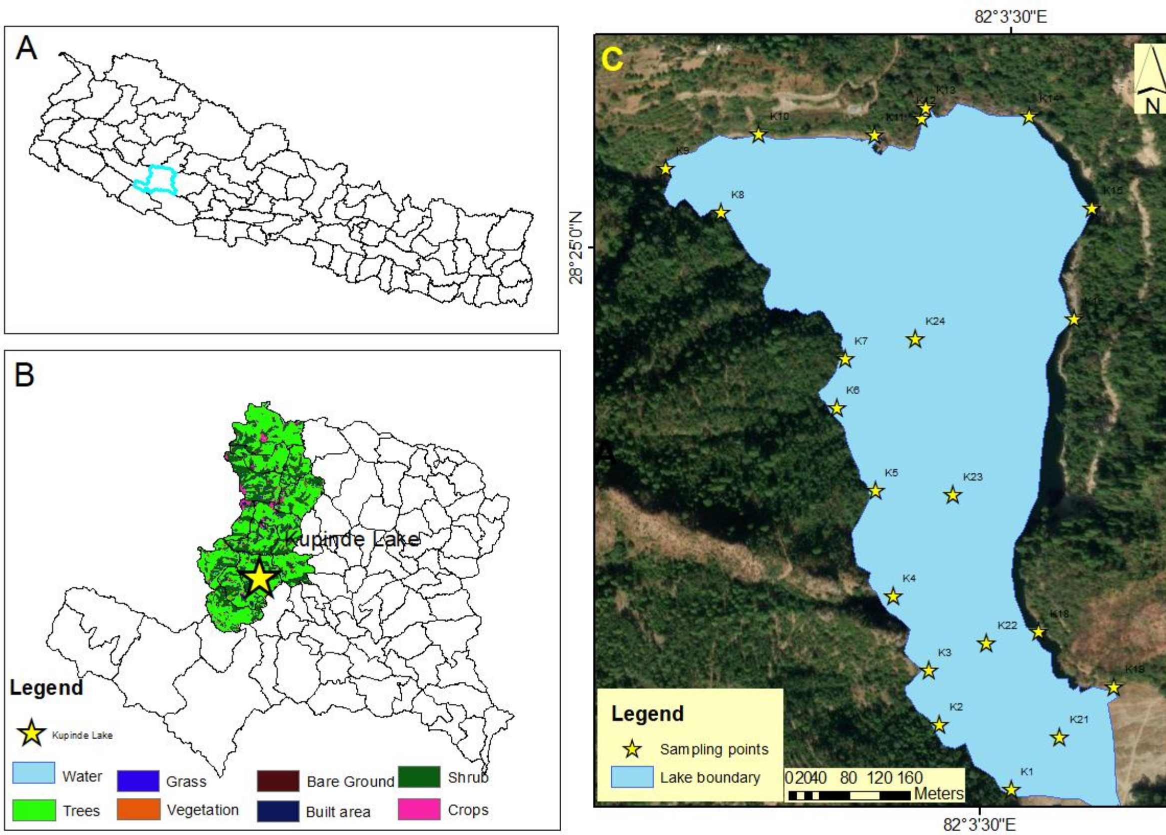

Figure 1. Map of the study area showing sampling sites. (A) Map of Nepal showing Salyan district, (B) map of Salyan district showing Kupinde Lake (C), and map of Kupinde Lake showing sampling points.

Sampling and Laboratory Analysis

A total of 24 sampling points were selected from the lake for the spatial analysis of water quality in October 2021. The water samples were collected systematically from the periphery and middle of the lake using a boat. The location of the water sample was recorded with a Garmin e-trex10 GPS (Garmin, Chicago, IL). Water samples were collected in high density polyethylene (HDPE) bottles and were carefully transported and stored under freezing conditions before further analysis. Out of 24 samples, 20 were taken from the periphery and four were from the inner area of the lake (Fig. 1). The physical parameters like pH, temperature, total dissolved solids (TDS) and electric conductivity (EC) were measured on-site. The other chemical parameters were analyzed in the laboratory as per the standard methods prescribed by APHA (APHA, 2005). Alkalinity (HCO_3^-) was analyzed by acid-base titration. Total hardness (TH) and calcium hardness were analyzed titrimetrically using EDTA titration. Magnesium hardness was calculated as the differences between total hardness and calcium hardness. Chloride (Cl^-) was determined by $AgNO_3$ titration. Sodium (Na^+) and potassium (K^+) were determined using flame photometric method. In addition, chemical parameters like ammonium (NH_4^+), nitrate (NO_3^-), and phosphate (PO_4^{3-}) were analyzed by phenate, brucine and stannous chloride method, respectively using UV-visible spectrophotometer in the laboratory at the Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University (CDES-TU), Kathmandu, Nepal.

Data Analysis

For analyzing the data, the overall hydrochemistry, source identification, and grouping the similar sampling points, the multivariate statistical analysis was done. The descriptive statistics (maximum, minimum, mean, and standard deviation), correlation matrices and Shapiro-Wilk test were also performed for testing the elaborating the dataset using IBM SPSS v.25 software. Correlation matrix (corrplot) was generated in R environment using RStudio software (R-Core Team, 2022). In the multivariate analysis, the principal component analysis (PCA) and cluster analysis were performed. For the PCA, the sample adequacy was examined by Kaiser-Meyer-Olkin (KMO) and the Bartlett Sphericity, and the outcomes were found to be satisfactory. In addition, the Piper plot, Gibb's plot and the Mixing diagram were used for the understanding of hydrochemical characteristics and source identification of the chemical variables. Furthermore, the irrigation suitability of the lake water was determined by using the following equations.

1. Sodium absorption ratio (SAR) = $\frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$ (Richards, 1954)
2. Sodium percentage (Na %) = $\frac{(Na^+ + K^+)*100}{(Ca^{2+}+Mg^{2+}+Na^+ + K^+)}$ (Richards, 1954)
3. Kelly's ratio (KR) = $\frac{Na^+}{(Ca^{2+}+Mg^{2+})}$ (Kelly, 1940)
4. Permeability index (PI) = $\frac{(Na^+ + \sqrt{HCO_3^-})*100}{Ca^{2+}+Mg^{2+}+Na^+}$ (Doneen, 1964)
5. Magnesium Hazard (MH)= $\frac{Mg^{2+}*100}{(Ca^{2+}+Mg^{2+})}$ (Paliwal, 1976)
6. CROSS = $\frac{Na^+ + 0.56K^+}{\sqrt{\{Ca^{2+}+0.6Mg^{2+}\}/2}}$ (Rengasamy & Marchuk, 2011)

RESULTS AND DISCUSSION

Hydrochemistry of Kupinde Lake

The mean temperature of Kupinde Lake was 22.58 ^{O}C and varies over a range of spatial and temporal scales (Table 1). The pH of Kupinde Lake water was 8.16, ranging from 7.9 to 9.2, indicating the lake is slightly alkaline. A variety of factors affect the pH of freshwater, including regional geology, hydrology, climate, anthropogenic factors, rainfall, and soil type (Feng *et al.,* 2017; Zhu *et al.,* 2022). The pH of lake water was found to be alkaline for all the sampling sites and shown to be within the permissible limit of the World Health Organization (WHO, 2011). The pH values in this study are consistent with the previous studies Chandra Tal Western Himalayan, India, Rara lake in Mugu and Beeshazar and associated lakes in Chitwan Nepal (Singh *et al.,* 2016; Gurung *et al.,* 2018; Pant *et al.,* 2021). The mean EC was found to be 136 µS/cm with range from 129 to 143 µS/cm and TDS was 68 mg/L with range from 64 to 72 mg/L. The EC of Rara Lake (193 µS/cm) are comparatively higher (Kaphle *et al.,* 2021), whereas Ramaroshan (67 µS/cm) and Rajarani (54 µS/cm) are comparatively lower (Adhikari *et al.,* 2020; Dangol *et al.,* 2022). The EC is the parameter which indicates the mobility of the ions and is directly related to the total dissolved solids (TDS). Minerals, salts, metals, ions, and organic matter dissolved in water constitute TDS. EC and TDS were substantially associated among hydrochemical parameters. As a result, the highest and lowest EC and TDS values were found in the sample locations K18 and K20. The highest concentration of EC and TDS are most likely owing to road construction, whereas the lowest concentrations are most likely due to the Kailubarah Temple at the sampling points. Obtaining relatively low levels of TDS in this area could be possible due to the religious belief that people should not dispose of their garbage near temples. Both EC and TDS were found to be below WHO acceptable limits (WHO, 2011). Hence, the water of the lake is suitable for drinking as well as for sustaining aquatic ecosystems. In this study, Ca^{2+} is the dominant cation, with a mean concentration of 27.97 mg/L, and ranges from 22.4 to 36 mg/L. The mean concentration of Mg^{2+} is 11.23 mg/L with a range from 4.39 to 20.5 mg/L. Factors influencing the concentration of Ca^{2+} and Mg^{2+} in surface water include geological contents, soil type, plant cover, weather conditions, land relief, and type and intensity of water supply (Potasznik & Szymczyk, 2015).

Ca^{2+} and Mg^{2+} levels were found to be within the range of WHO recommendations for drinking purposes. This could be due to the less weathering of the underlying rocks and relatively less anthropogenic interferences. Furthermore, Ca^{2+} and Mg^{2+} are the major ions responsible for the total hardness. Hardness of the water ranged from 86 to 174 mg/L with the mean value at 115.92 mg/L. Total hardness can be classified as follows: 1) soft (0-30 mg/L), 2) moderately soft (30-60 mg/L), 3) moderately hard (60-120 mg/L), 4) hard (120-180 mg/L), and 5) very hard (>180 mg/L) (WHO, 2011). Most of the samples from Kupinde Lake were categorized as moderately hard. The main causes of moderate hardness of water could be due to less intense weathering of major ions in the region (Pant, 2011; Mahato *et al.,* 2018). Total calcium hardness ranged from 56 to 90 mg/L with mean 69.92 mg/L. Magnesium hardness varied from 18 to 84 mg/L with mean 46 mg/L. Na^{+} concentrations ranged from 6.5 to 8.5 mg/L with a mean value of 7.38 mg/L. K^{+} varies between 2.4 and 4.9 mg/L with a mean value of 3.47 mg/L. NH_4^{+} was in the range of 0.09 to 0.44 mg/L with a mean value of 0.11 mg/L. The dominancy order of the major cations was $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > NH_4^{+}$. These findings in Kupinde Lake were consistent with Rara Lake (Kaphle *et al.,* 2021).

The bicarbonate (HCO_3^-) was the most dominant among anions with the concentration ranging from 40 to 300 mg/L with a mean of 157.71 mg/L. It is formed primarily from the weathering and decomposition of organic matter in the catchment (Jha *et al.,* 2009). Additionally, HCO_3^- is a major constituent of carbonate rocks containing calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) (Mallick, 2017). The Cl^- concentration ranged from 4.26 to 8.52 mg/L, with a mean of 6.04 mg/L indicating that atmospheric inputs and anthropogenic sources have a minor influence on Cl^- input to the lake (Pant *et al.,* 2021). Furthermore, SO_4^{2-} varied from 0.13 to 2.28 mg/L with a mean 0.64 mg/L. Moreover, PO_4^{3-} varies from 0.11 to 0.29 mg/L with mean value 0.19 mg/L. Limited amounts of NO_3^- are present in the present study varying from 0.05 to 0.06 mg/L with mean value 0.06 mg/L. Among the dissolved ions, Cl^-, NO_3^-, and SO_4^{2-} mainly come from anthropogenic sources, such as fertilizers applied to fields, industrial effluents, and atmospheric emissions (Sun *et al.,* 2010). However, the area surrounding the lake shows less anthropogenic disturbance, indicating that it is less polluted. The dominancy order of the major anions was $HCO_3^- > Cl^- > SO_4^{2-} > PO_4^{3-} > NO_3^-$. Previous investigations in the Rajarani Lake (Adhikari *et al.,* 2020), Jhilmila Lake (Pal *et al.,* 2021), Ramaroshan Lake (Dangol *et al.,* 2022), and Ghodaghodi Lake (Pant *et al.,* 2021) indicated similar superiority of major anions except NO_3^- and PO_4^{3-}.

Table 1. Descriptive statistics of the physiochemical parameters of the Kupinde Lake

Parameter	Min	Max	Mean	SD	WHO (2011)
Temp	21.8	25	22.58	0.69	-
pH	7.9	9.2	8.16	0.29	6.5 - 8.5
EC	129	143	136	3.04	800-1000
TDS	64	72	68	1.67	500
F-CO_2	4.4	11	7.43	2.13	-
Cl^-	4.26	8.52	6.04	1.34	250
HCO_3^-	40	300	157.71	69.09	80-120
TH	86	174	115.92	27.67	-
Calcium hardness	56	90	69.92	10.82	-
Magnesium hardness	18	84	46	20.21	-
Ca^{2+}	22.4	36	27.97	4.33	100
Mg^{2+}	4.39	20.5	11.23	4.93	50
PO_4^{3-}	0.11	0.29	0.19	0.05	0.8
NO_3^-	0.05	0.06	0.06	0	50
NH_4^+	0.09	0.44	0.11	0.07	0.5
SO_4^{2-}	0.13	2.28	0.64	0.5	250
K^+	2.4	4.9	3.47	0.65	100
Na^+	6.5	8.5	7.38	0.6	200

Concentration in mg/L except pH, Temp. (°C) and EC in μS/cm

Hydrogeochemical Facies

Piper plot (Piper, 1944) was used for the characterization and source identification of major ions. The milli-equivalent percentage of major ions was plotted in the trilinear diagram as shown in (Fig. 2). A water type is classified and named based on previous studies (Pant *et al.,* 2021). Most of the samples were placed in the lower left corner of cation triangle indicating a high concentration of Ca^{2+} and in the lower left corner of anion triangle showing high concentration of HCO_3^-. The alkali earth metals Ca^{2+} and Mg^{2+} dominated the alkali metals (Na^+ and K^+) and weak acids (HCO_3^-) dominated the strong acids (Cl^- and SO_4^{2-}). On the Piper diagram, both cations and anions fall into the Ca-HCO_3 type in the central diamond field. Carbonate dominated lithology was identified as the dominant mechanism that regulates the hydrogeochemistry of the Kupinde Lake. The finding of this study was similar to Phewa Lake in the lesser Himalaya (Khadka & Ramanathan, 2021), Ghodaghodi Lake (Pant *et al.,* 2020) and Rara Lake (Kaphle *et al.,* 2021).

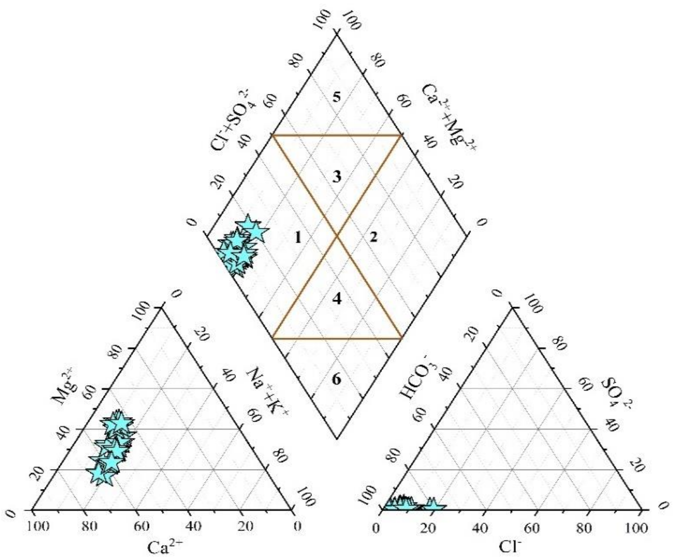

Figure 2. Characterization of hydrochemical facies of the Kupinde Lake based on the Piper diagram

Controlling Mechanism of the Hydrochemistry

Gibb's diagram can be used to determine the major chemistry-controlling mechanisms of the water bodies (Gibbs, 1970). The effects of hydrochemistry on the surface water environment include precipitation, rock weathering, and evaporation (Pant *et al.,* 2018). The lower concentration of TDS and higher ratios of Na^+/ (Na^+ + Ca^{2+}) and Cl^-/ (Cl^- + HCO_3^-) suggest precipitation influences which lies in the lower right corner. Generally, rock weathering occurs when the TDS concentration is moderate and the ratios of Na^+/ (Na^+ + Ca^{2+}) and Cl^-/ (Cl^- + HCO_3^-) are lower on the left. Likewise, the upper right corner of the diagram represents dominance of evaporation which influences the concentrations of TDS with high of Na^+/ (Na^+ + Ca^{2+}) and Cl^-/ (Cl^- + HCO_3^-) ratios (Pant *et al.,* 2018). The concentration of TDS and ratios of Na^+/ (Na^+ + Ca^{2+}) and Cl^- / (Cl^- + HCO_3^-) are plotted in the diagram (Fig. 3). The majority of the samples exhibited moderate TDS and low ratios of Na^+/ (Na^++ Ca^{2+}) and Cl^- / Cl^- + HCO_3^-) showing a dominant influence of rock weathering in the lake water. All the sampling sites are mainly affected by carbonate type rock weathering. This is evidenced by the increased concentration of major cations Ca^{2+}, Na^+ and anions HCO_3^- and Cl^- in the lake catchment. This finding is similar to those of previous studies, which have shown that rock weathering significantly impacts Himalayan lakes (Pant *et al.,* 2020; Kaphle *et al.,* 2021; Kaushik *et al.,* 2021).

The Kupinde Lake water chemistry is influenced by the chemical weathering of rock. Generally, carbonates, silicates, and evaporates are the dominant sources of rock weathering and Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, and Cl^- influenced chemical rock weathering in hydrochemical composition (Pant *et al.,* 2018). The Na-normalized hydrochemistry of Kupinde Lake revealed that most of the samples were found between the carbonate and silicate end-members, indicating the lake has both types of rock weathering (Fig. 4). The weathering process for carbonate rock is more rapid than that for silicate rocks (Fan *et al.,* 2014). Carbonates and silicates are formed based on the amount of TDS and CO_2 in water (Fan *et al.,* 2014). Based on the results of this study, the dominant tendency of TDS has affected the formation of carbonates. In contrast, the lowest trend of CO_2 has affected the formation of silicates.

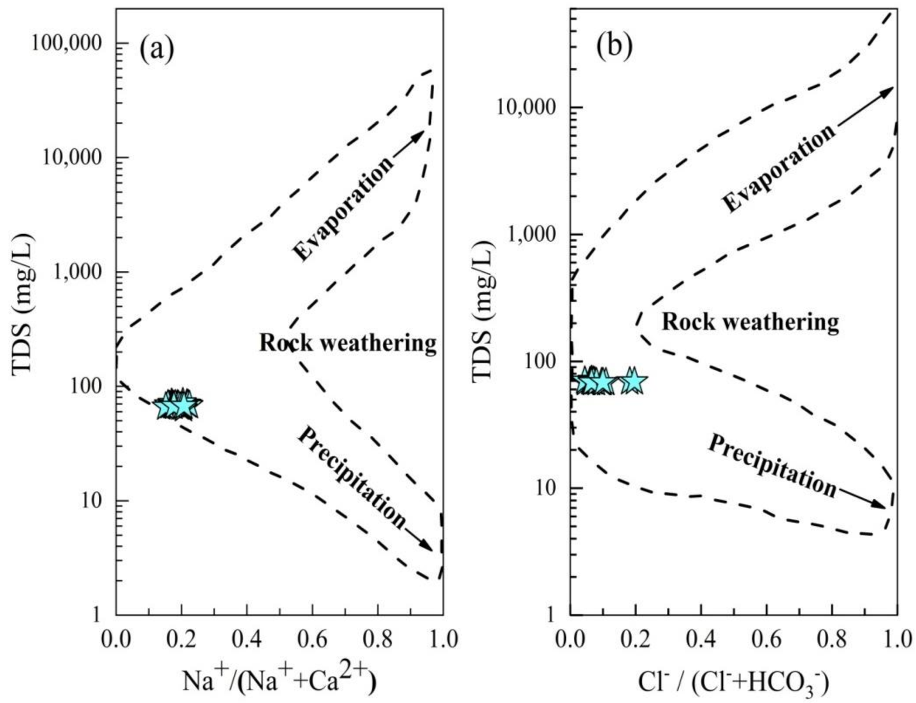

Figure 3. Gibbs diagram showing the major ions source of Kupinde Lake

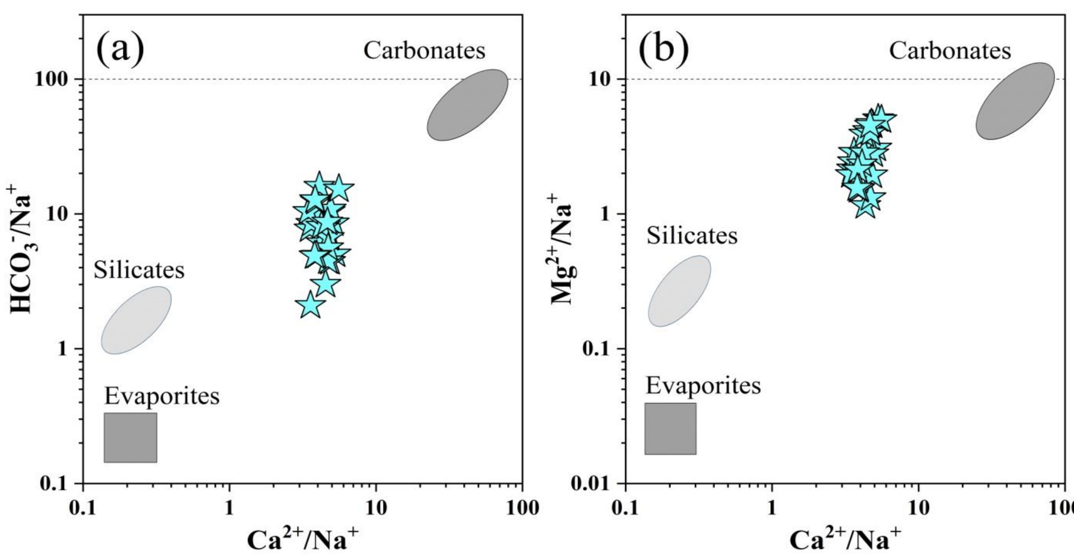

Figure 4. Mixing diagram (a) Ca^{2+}/Na^+ versus HCO_3^-/ Na^+ and (b) Ca^{2+}/ Na^+ versus Mg^{2+}/Na^+) in the Kupinde Lake

Associations among Physicochemical Parameters

The pH showed a strong positive correlation with NH_4^+ (Fig. 5). A majority of the $NH4^+$ in rivers and lakes originates from atmospheric deposits, fertilized and manured agricultural land, and urban wastewater. These sources contribute significantly to the rise in pH (Schuurkes & Mosello, 1988). The physical parameters EC and TDS show a strong positive correlation with one another. Typically, the higher the concentration of chemical ions in water or the dissolved salts, the higher the conductivity. As a result, conductivity is correlated with the amount of total dissolved solids and the amount of chloride ions in the solution. Similar, strong positive correlation between EC and TDS was observed in Rudra Sagar Lake (Pal *et al.,* 2015). The association between TH-Magnesium hardness and TH- Mg has a significant positive correlation with each other (Fig. 5). It is evident that these chemicals have a common origin, which may be derived from carbonate weathering (Singh *et al.,* 2016). Hydrogen ion concentration (pH) is negatively correlated with free CO_2 and Na^+. Water's pH is negatively correlated with CO_2, due to CO_2 reduction during photosynthesis (Zhang *et al.,* 2018). In the same way, K^+ tends to be negatively correlated with temperatures.

The hierarchical agglomerative clustering approach using the major ions (HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-} and NH_4^+) clustered 24 samples into five main clusters with low distance criterion from 0 to 5 (Fig. 6). Cluster-1 was formed by six samples (4, 5, 6, 17, 18, and 20) from lesser disturbance areas towards the side of large rocky mountain. Samples 17 and 18 were located close to dense forest, and sampling site 20 lies near the Kailubarah Temple. The cluster-2 (sites 19 and 21) was formed of the samples from disturbed area near the road and lobby. Cluster-3 and 4 were formed of samples taken from the periphery of the lake and are connected by a road and small path. The cluster-3 was composed of seven samples (1, 2, 3, 7, 13, 14, and 23) and cluster-4 was composed of two samples (sites 9 and 10). Cluster-5 was formed by the samples of inlet and center point of sampling sites (8, 11, 12, 15, 16, 22, and 24).

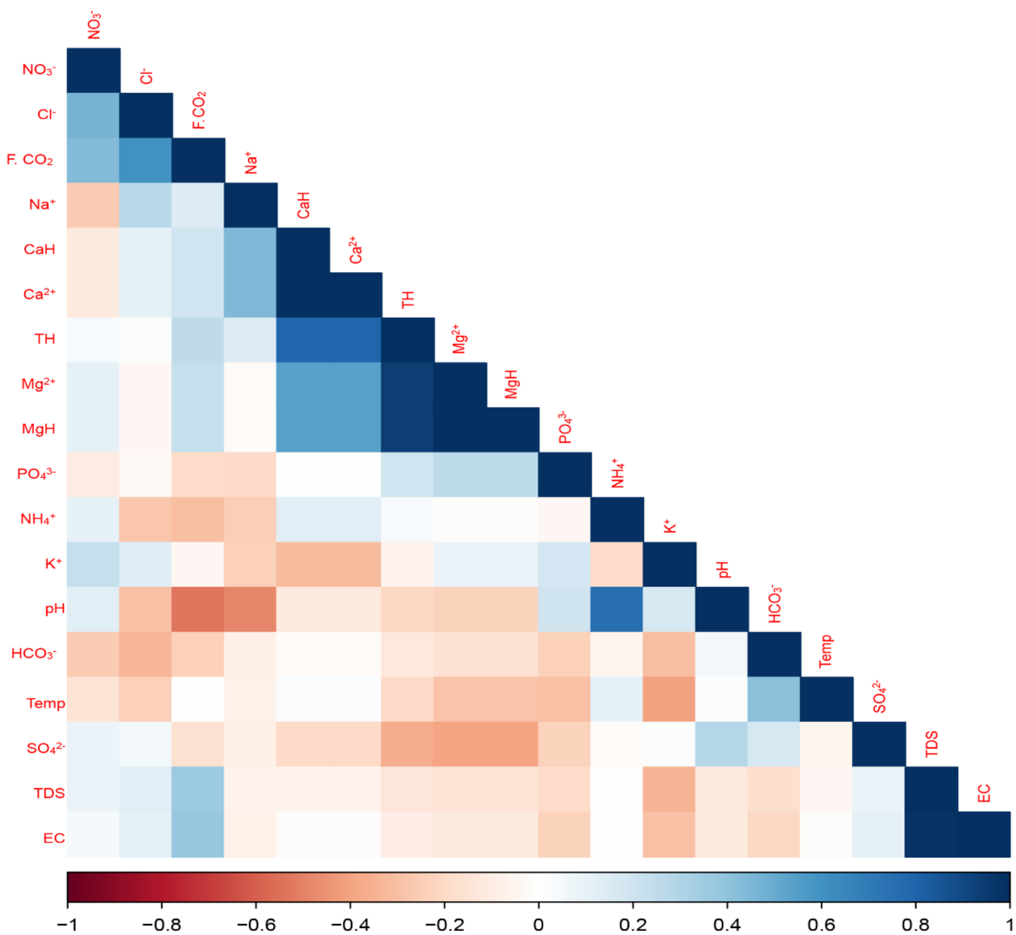

Figure 5. Corrplot showing the correlation among physicochemical parameters of the Kupinde Lake. Corrplots with blue and red colors indicate positive and negative correlations. The full blue represents r = 1 and the full red represents r = -1, all values were significant at p< 0.05

PCA is one of the powerful tools for hydrochemical studies which attempts to explain the variance of a large dataset of inter-correlated variables with a smaller set of independent variables and thus reduces the dimensionality of the large datasets. In this study the PCA was applied to TDS and the major cations and anions. A total of five principal components have been extracted (Table 2). The five components explained 76.05 % of the total variance. To assess PCA, an eigenvalue greater than one has been considered. In the definition of factor loadings, a factor loading is graded as strong, moderate, or weak when it is greater than 0.75, between 0.75 and 0.50, and between 0.50

and 0.30 (Pant *et al.,* 2020). The first principal component (PC1) explains 24.78 % of the variance in the data, and Calcium hardness, Magnesium hardness, Mg^{2+}, and Ca^{2+} are strongly positively loaded, which might be due to common sources of ions (Singh *et al.,* 2016). Silicates and carbonates containing calcium and magnesium are the main sources of these parameters (An *et al.,* 2020). PC2 shows strong positive loadings with Cl^- and NO_3^- whereas HCO_3^- displays moderately negative loadings, which explains about 14.43 % of total variance in the results. The influences of rainfall and anthropogenic inputs on lakes could be responsible for this association (Mu *et al.,* 2014; Singh *et al.,* 2016). In addition, natural waters contain a high level of HCO_3^- due to CO_2 dissolution, weathering of carbonate minerals, and carbonate-rich geological formations (Jha *et al.,* 2009; Fan *et al.,* 2014; Mallick, 2017). In PC3, PO_4^{3-} had a moderately positive loading and SO_4^{2-} had a moderately negative loading, which accounts for 13.08 % of the variance in the result indicating less polluted lake water. Similarly, it was observed that NH_4^+ is moderately loaded in PC4 and Na^+ is strongly negative loaded, which accounts for 12.09 % of the variance. The NH_4^+ and Na^+ could be originated from diverse sources. The majority of ammonium pollution originates from anthropogenic sources including industrial emissions, sewage, and fertilizer leachate (Du *et al.,* 2017) whereas Na^+ is released from the dissolution of evaporates and the weathering of silicate rocks (An *et al.,* 2020). The TDS is strongly negative loaded and the K^+ is moderately positive loaded, explaining 11.66 % of the total variance in PC5.

Water Quality Status

All sampling points were found excellent in the EC's categorization, and the Kupinde Lake water was deemed suitable for irrigation (Table 3). Irrigation water can be classified into five types in terms of Na^+ (Acharya *et al.,* 2020). Similarly, the average value of Na% is 15.53, categories as excellent with compare standard value. The sodium adsorption ratio (SAR) was 0.30, which is divided into three categories depending on SAR content, with lowest SAR content indicating ideal for irrigation. The Wilcox diagram (Fig. 8) exhibited plotted water samples of Kupinde Lake into C1S1 section, indicating excellent category for irrigation. In addition, KR values were within the safe category for irrigation, the lake water is suitable for irrigation. Irrigation water was divided into three categories based on the PI values. The average PI value indicated that the water was of good quality. In this investigation, the CROSS values of the lake water are excellent category. Kupinde Lake water was suitable for drinking as it was within the range of given guidelines for pH, EC, TDS, and all the cations and anions (WHO, 2011). However, we acknowledge that this study has not analyzed the microbial parameters of water.

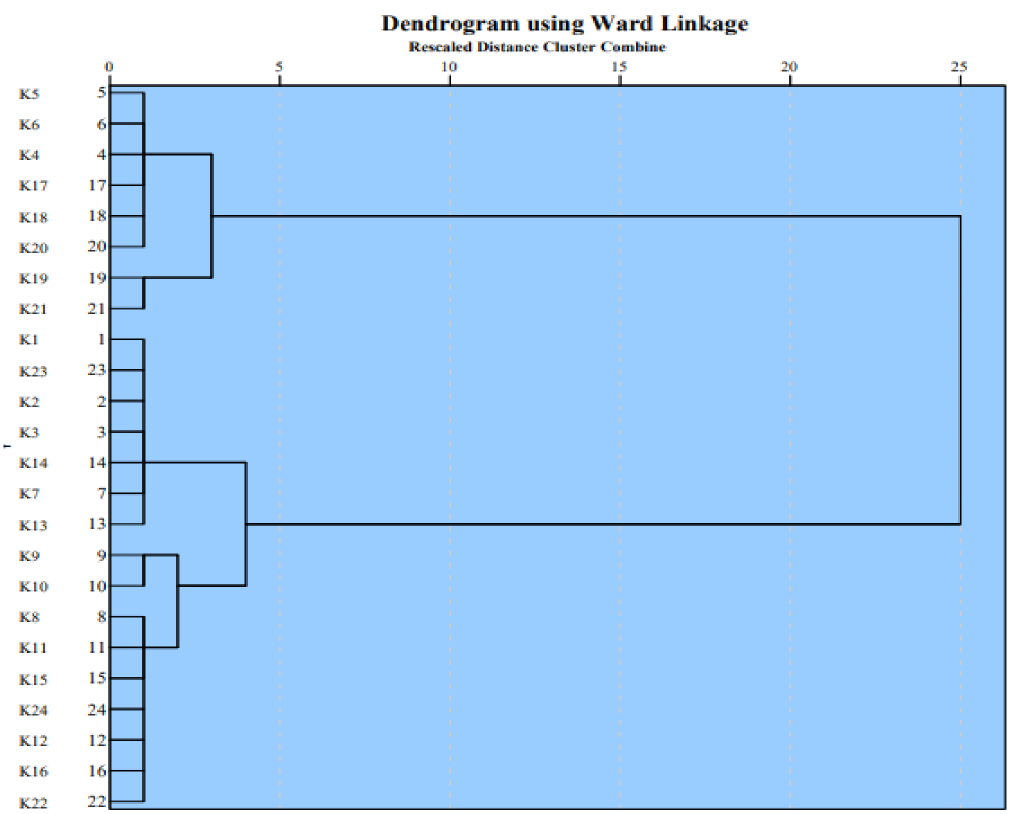

Figure 6. Dendrogram of the hydrochemical variables in the Kupinde Lake based hierarchical cluster of sampling sites

Table 2. Varimax rotated component matrix of Kupinde Lake

Parameter	Component				
	1	2	3	4	5
TDS	-0.15	0.23	0.03	0.08	**-0.79**
Cl^-	0.05	**0.76**	-0.09	-0.45	-0.06
HCO_3^-	0.01	**-0.60**	-0.55	0.09	0.21
Calcium hardness	**0.93**	-0.05	-0.03	-0.19	-0.15
Magnesium hardness	**0.77**	0.12	0.41	0.20	0.27
Ca^{2+}	**0.93**	-0.05	-0.03	-0.19	-0.15
Mg^{2+}	**0.77**	0.12	0.41	0.20	0.27
PO_4^{3-}	-0.01	-0.06	**0.73**	0.04	0.20
NO_3^-	0.03	**0.82**	-0.19	0.33	0.09
NH_4^+	0.16	-0.08	-0.10	**0.68**	-0.31
SO_4^{2-}	-0.28	0.10	**-0.64**	0.03	0.06
K^+	-0.26	0.39	0.23	0.01	**0.68**
Na^+	0.33	-0.07	-0.12	**-0.80**	-0.19
% of Variance	**24.78**	**14.43**	**13.08**	**12.09**	**11.66**
Cumulative %	**24.78**	**39.21**	**52.30**	**64.39**	**76.05**

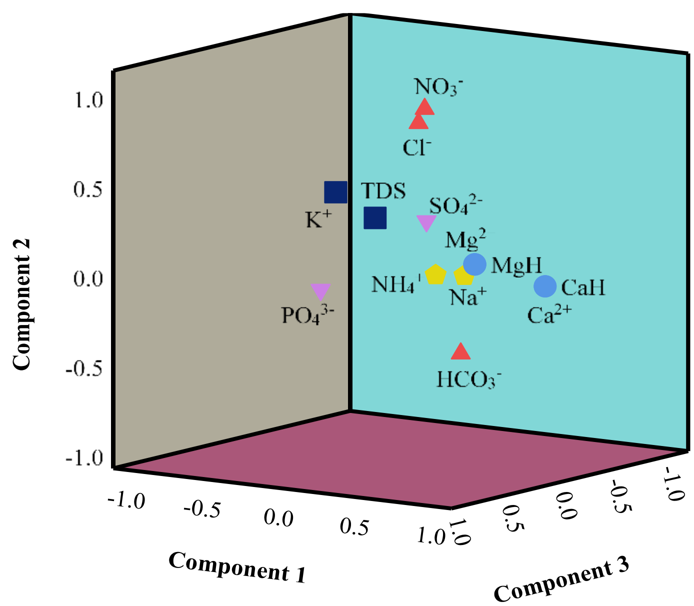

Figure 7. Factor loading plot of the principal component analysis

Table 3. Classification of water samples for irrigation based on various parameters

Parameter	Average value	Category
EC	136.54	Excellent
Na%	15.53	Excellent
SAR	0.30	Excellent
MH	38.38	Suitable
KR	0.14	Safe
PI	74.74	Class I
CROSS	0.38	Excellent

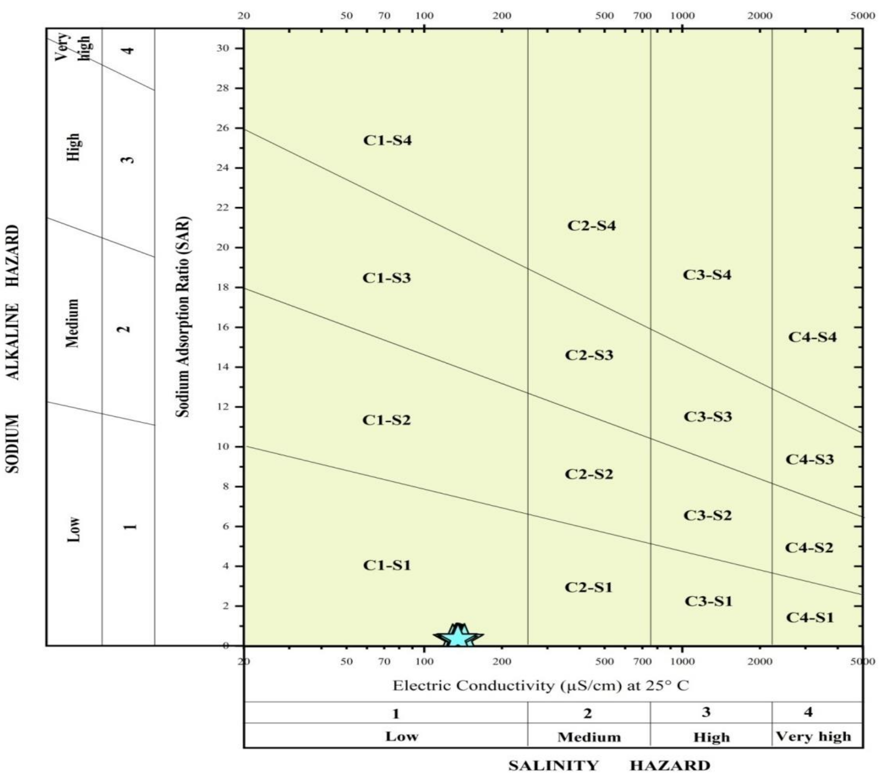

Figure 1. Wilcox diagram showing the suitability of water for irrigation purposes

CONCLUSIONS

The hydrochemical analysis of the Kupinde Lake revealed slightly alkaline and moderately hard water with its EC and TDS lying within WHO guidelines. The major cations are abundant in the order $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} > NH_4^{+}$, while anions are abundant in the order $HCO_3^{-} > Cl^{-} > SO_4^{2-} > PO_4^{3-} > NO_3^{-}$. Based on the results of this study, all physicochemical parameters were within the WHO permissible limits. The dominant hydrochemistry of the Kupinde Lake water was carbonate weathering. The hydrochemistry of Kupinde Lake water is primarily influenced by carbonate rock weathering. Based on the irrigation parameters of Kupinde Lake water, all samples fell within the excellent category, thus the lake water is an excellent irrigation resource. This study provides a set of reference values for assessing the potential impacts of ongoing development around the lake in the future.

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AUTHOR CONTRIBUTIONS

CBS: performed field work, laboratory analysis, data analysis and prepared manuscript; LK: conceptualized the study, revised, and finalized the manuscript, supervised the study; RRP: analyzed data, revised the manuscript; BT: performed field sampling, laboratory analysis and revised the manuscript; BC: performed field work, revised the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest between the authors in this publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

REFERENCES

Acharya, A., Sharma, M.L., Bishwakarma, K., Dahal, P., Chaudhari, S.K., Adhikari, B., Neupane, S., Pokhrel, B.N., & Pant, R.R. (2020). Chemical characteristics of the Karmanasha River water and its appropriateness for irrigational usage. *Journal of Nepal Chemical Society, 41*, 94–102.

Adhikari, B., Pant, R.R., Baral, U., Shrestha, S., Neupane, S., Khanal, B., Acharya, A., & Bhattarai, H.R. (2020). Geochemical and multivariate assessment of water quality in the Rajarani Lake, Dhankuta, Nepal. *Journal of Nepal Geological Society, 60,* 37–49. https://doi.org/10.3126/jngs.v60i0.31264.

Amankwaa, G., Yin, X., Zhang, L., Huang, W., Cao, Y., & Ni, X. (2020). Hydrochemistry and multivariate statistical analysis of the quality of water from Lake Bosomtwe for agricultural and human consumption. *Journal of Water Supply: Research and Technology-Aqua*, *69*, 704–719. https://doi.org/10.2166/aqua.2020.061.

An, S., Jiang, C., Zhang, W., Chen, X., & Zheng, L. (2020). Influencing factors of the hydrochemical characteristics of surface water and shallow groundwater in the subsidence area of the Huainan Coalfield. *Arabian Journal of Geosciences, 13*, 191. https://doi.org/10.1007/s12517-020-5140-3.

APHA. (2005). Standard methods for the examination of water and wastewater. 21st Edition, American Public Health Association, Washington, DC.

Bhandari, B. (2009). Wise use of wetlands in Nepal. *Banko Janakari, 19*, 10–17. https://doi.org/10.3126/banko.v19i3.2206.

CBS. (2021). Government of Nepal Central Bureau of Statistics. Kathmandu, Nepal.

Cimon-Morin, J., & Poulin, M. (2018). Setting conservation priorities in cities: approaches, targets and planning units adapted to wetland biodiversity and ecosystem services. *Landscape Ecology, 33,* 1975–1995. https://doi.org/10.1007/s10980-018-0707-z.

Dangol, A., Pant, R.R., Chalaune, T.B., Sharma, J., Thapa, B., Thapa, L.B., & Bishwakarma, K. (2022). Hydrochemical characterization of lentic and lotic environments of Ramaroshan Area, Sudurpaschim Province, Nepal. *Geographical Journal of Nepal, 15*, 83–102. https://doi.org/10.3126/gjn.v15i01.42888.

Das, B., & Kaur, P. (2001). Major ion chemistry of Renuka Lake and weathering processes, Sirmaur District, Himachal Pradesh, India. *Environmental Geology*, *40*, 908–917. https://doi.org/10.1007/s002540100268.

Doneen, L.D. (1964). *Notes on water quality in agriculture*. Department of Water Science and Engineering, University of California, Davis.

Du, Y., Ma, T., Deng, Y., Shen, S., & Lu, Z. (2017). Sources and fate of high levels of ammonium in surface water and shallow groundwater of the Jianghan Plain, Central China. *Environtal Science: Processes and Impacts, 19,* 161–172. https://doi.org/10.1039/c6em00531d.

Fan, B.-L., Zhao, Z.-Q., Tao, F.-X., Liu, B.-J., Tao, Z.-H., Gao, S., & Xhang, L.-H. (2014). Characteristics of carbonate, evaporite and silicate weathering in Huanghe River basin: A comparison among the upstream, midstream and downstream. *Journal of Asian Earth Sciences, 96,* 17–26. https://doi.org/10.1016/j.jseaes.2014.09.005.

Feng, Z., Su, B., Xiao, D.-D., & Ye, L.-Y. (2017). Study on pH value and its variation characteristics of the main rivers into Dianchi Lake under the anthropogenic and natural processes, Yunnan, China. *Journal of Information and Optimization Sciences, 38,* 1197–1210. https://doi.org/10.1080/02522667.2017.1367501.

Gaury, P.K., Meena, N.K., & Mahajan, A.K. (2018). Hydrochemistry and water quality of Rewalsar Lake of Lesser Himalaya, Himachal Pradesh, India. *Environmental Monitoring and Assessment*, *190*, 1-22.

Gibbs, R.J. (1970). Mechanisms controlling world water chemistry. *Science, 170,* 1088–1090. https://doi.org/10.1126/science.170.3962.1088.

Gorde, S.P., & Jadhav, M.V. (2013). Assessment of water quality parameters: A review. *International Journal of Engineering Research and Applications*, *3*, 2029–2035.

Gurung, S., Gurung, A., Sharma, C.M., Jüttner, I., Tripathee, L., Bajracharya, R.M., Raut, N., Pradhananga, P., Sitaula, B.K., Zhang, Y., Kang, S., & Guo, J. (2018). Hydrochemistry of Lake Rara: A high mountain lake in western Nepal. *Lakes & Reservoirs: Science, Policy and Management for Sustainable Use, 23,* 87–97. https://doi.org/10.1111/lre.12218.

Hey, D.L., Kostel, J.A., Crumpton, W.G., Mitsch, W. J., & Scott, B. (2012). The roles and benefits of wetlands in managing reactive nitrogen. *Journal of Soil and Water Conservation, 67*, 47A–53A. https://doi.org/10.2489/jswc.67.2.47A

Jha, P.K., Tiwari, J., Singh, U.K., Kumar, M., & Subramanian, V. (2009). Chemical weathering and associated CO_2 consumption in the Godavari River basin, India. *Chemical Geology, 264,* 364–374. https://doi.org/10.1016/j.chemgeo.2009.03.025.

Kaphle, B., Wang, J.-b., Kai, J.-l., Lyu, X.-m., Paudayal, K.N., & Adhikari, S. (2021). Hydrochemistry of Rara Lake: A Ramsar lake from the southern slope of the central Himalayas, Nepal. *Journal of Mountain Science, 18,* 141–158. https://doi.org/10.1007/s11629-019-5910-0.

Kaushik, H., Ramanathan, A., Soheb, M., Shamurailatpam, M.S., Biswal, K., Mandal, A., & Singh, C. (2021). Climate change-induced high-altitude lake: Hydrochemistry and area changes of a moraine-dammed lake in Leh-Ladakh. *Acta Geophysica, 69,* 2377–2391. https://doi.org/10.1007/s11600-021-00670-x.

Keddy, P.A. (2010). Wetland Ecology: Principles and Conservation (2nd ed.). New York: Cambridge University Press. p. 497

Khadka, U.R., & Ramanathan, A.L. (2013). Major ion composition and seasonal variation in the Lesser Himalayan lake: case of Begnas Lake of the Pokhara Valley, Nepal. *Arabian Journal of Geosciences*, *6*, 4191-4206. https://doi.org/10.1007/s12517-012-0677-4.

Khadka, U.R., & Ramanathan, A.L. (2021). Hydrogeochemical analysis of Phewa Lake: A lesser Himalayan lake in the Pokhara Valley, Nepal. *Environment and Natural Resources Journal, 19,* 68–83. https://doi.org/10.32526/ennrj/19/2020083.

Kingsford, R.T., Basset, A., & Jackson, L. (2016). Wetlands: conservation's poor cousins. *Aquatic Conservation: Marine and Freshwater Ecosystems, 26,* 892–916. https://doi.org/10.1002/aqc.2709.

Mahato, S., Mahato, A., Karna, P.K., & Balmiki, N. (2018). Investigating aquifer contamination and groundwater quality in eastern Terai region of Nepal. *BMC Research Notes, 11,* 321. https://doi.org/10.1186/s13104-018-3445-z.

Mallick, J. (2017). Hydrogeochemical characteristics and assessment of water quality in the Al-Saad Lake, Abha Saudi Arabia. *Applied Water Science, 7,* 2869–2882. https://doi.org/10.1007/s13201-017-0553-1.

McCarthy, M.J., Radabaugh, K.R., Moyer, R.P., & Muller-Karger, F.E. (2018). Enabling efficient, large-scale high-spatial resolution wetland mapping using satellites. *Remote sensing of Environment, 208,* 189–201. https://doi.org/10.1016/j.rse.2018.02.021.

Mu, X., Brower, J., Siegel, D. I., Fiorentino Ii, A. J., An, S., Cai, Y., Xu, D., & Jiang, H. (2014). Using integrated multivariate statistics to assess the hydrochemistry of surface water quality, Lake Taihu basin, China. *Journal of Limnology, 74,* 906. https://doi.org/10.4081/jlimnol.2014.906.

Pal, K.B., Bishwakarma, K., Chalaune, T.B., Upadhaya, D., Joshi, T.R., Thapa, L.B., Sharma, M.L., Joshi, S., & Pant, R.R. (2021). Hydrochemical assessment of Jhilmila Lake, Kanchanpur, Nepal. *Scientific World, 14,* 124–131. https://doi.org/10.3126/sw.v14i14.35023.

Pal, M., Samal, N.R., Roy, P.K., & Roy, M.B. (2015). Electrical conductivity of lake water as environmental monitoring–A case study of Rudrasagar Lake. *Journal of Environmental Science, Toxicology and Food Technology, 9,* 66–71. https://doi.org/10.9790/2402-09316671.

Pant, B.R. (2011). Ground water quality in the Kathmandu valley of Nepal. *Environmental Monitoring Assessment, 178,* 477–485. https://doi.org/10.1007/s10661-010-1706-y.

Pant, R.R., Chalaune, T.B., Dangol, A., Dhital, Y.P., Sharma, M.L., Pal, K.B., Shah, S.T.H., Shrestha, A.K., & Thapa, L.B. (2021). Hydrochemical assessment of the Beeshazar and associated lakes in Central Nepal. *SN Applied Sciences, 3,* 38. https://doi.org/10.1007/s42452-020-03983-6.

Pant, R.R., Pal, K.B., Bishwakarma, K., Thapa, L.B., Dangol, A., Dawadi, B., Poudel, P., Nhattarai, B., Joshi, T.K., & Bhatt, Y.R. (2020). Application of multivariate approaches to the hydro-chemical assessment of the Ghodaghodi Lake, Sudurpaschim Province, Nepal. *Nepal Journal of Science and Technology, 19,* 46-54.

Pant, R.R., Pathak, G., Pal, K.B., Bishwakarma, K., Thapa, L.B., Dhital, Y.P., Bhatta, Y.R., Joshi, G.R., & Rijal, K. (2021). Water quality and health risk assessment of trace elements contamination in Ghodaghodi Lake, Sudurpaschim Province, Nepal. *Nepal Journal of Environmental Science, 9,* 29–40. https://doi.org/10.3126/njes.v9i1.36603.

Pant, R.R., Qaiser, F.U.R., Wang, G., Adhikari, S., Bishwakarma, K., Baral, U., Rimal, B., Bhatta, Y.R., & Rijal, K. (2021). Hydrochemical appraisal and solute acquisitions in Seti River Basin, Central Himalaya, Nepal. *Environmental Monitoring and Assessment, 193,* 1–21. https://doi.org/10.1007/s10661-021-09437-9.

Pant, R.R., Zhang, F., Rehman, F.U., Koirala, M., Rijal, K. & Maskey, R. (2020). Spatiotemporal characterization of dissolved trace elements in the Gandaki River, Central Himalaya Nepal. *Journal of Hazardous Materials, 389*, 121913. https://doi.org/10.1016/j.jhazmat.2019.121913.

Pant, R.R., Zhang, F., Rehman, F.U., Wang, G., Ye, M., Zeng, C., & Tang, H. (2018). Spatiotemporal variations of hydrogeochemistry and its controlling factors in the Gandaki River Basin, Central Himalaya Nepal. *Science of the Total Environment, 622,* 770–782. https://doi.org/10.1016/j.scitotenv.2017.12.063.

Pfister, S., Bayer, P., Koehler, A., & Hellweg, S. (2011). Projected water consumption in future global agriculture: Scenarios and related impacts. *Science of the Total Environment*, *409*(20), 4206–4216. https://doi.org/10.1016/j.scitotenv.2011.07.019.

Piper, A.M. (1944). A graphic procedure in the geochemical interpretation of water-analyses. *Eos, Transactions American Geophysical Union, 25,* 914–928.

Potasznik, A., & Szymczyk, S. (2015). Magnesium and calcium concentrations in the surface water and bottom deposits of a river-lake system. *Journal of Elementology, 20,* 677–692. https://doi.org/10.5601/jelem.2015.20.1.788.

Rawal, T., & Joshi, S. (2022). Assessing Landslide susceptibility of Bangad Kupinde municipality, Salyan, Karnali Province, Nepal. *Research Square (Preprint)*, PPR485550. https://doi.org/10.21203/rs.3.rs-1471402/v1.

R-Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Richards, L.A. (1954). *Diagnosis and improvement of saline and alkali soils*. United States Department of Agriculture.

Schuurkes, J.R., & Mosello, R. (1988). The role of external ammonium inputs in freshwater acidification. *Swiss Journal of Hydrology, 50,* 71–86. https://doi.org/10.1007/BF02538372.

Sharma, C.M. (2008). Freshwater fishes, fisheries, and habitat prospects of Nepal. *Aquatic Ecosystem Health & Management, 11,* 289–297. https://doi.org/10.1080/14634980802317329.

Singh, V.B., Ramanathan, A.L., & Mandal, A. (2016). Hydrogeochemistry of high-altitude lake: a case study of the Chandra Tal, Western Himalaya, India. *Arabian Journal of Geosciences, 9,* 308. https://doi.org/10.1007/s12517-016-2358-1.

Sun, H., Han, J., Li, D., Zhang, S., & Lu, X. (2010). Chemical weathering inferred from riverine water chemistry in the lower Xijiang basin, South China. *Science of the Total Environment, 408,* 4749–4760.

Sunar, C.B., Pandey, N., Chand, B., Upadhyaya, L.P., Thapa, B., Pant, R.R., & Khanal, L. (2023). Effect of water physicochemistry on amphibian abundance in Sub-tropical Kupinde Lake of the Nepal Himalaya. *International Journal of Bonorowo Wetlands, 12*(2), 89–95. https://doi.org/10.13057/bonorowo/w120205.

WHO. (2011). Guidelines for drinking-water quality. *WHO Chronicle, 38,* 104–108.

Zhang, Q.H., Sun, P.A., He, S.Y., Wen, H. , Liu, M.L., & Yu, S. (2018). Fate and origin of major ions in river water in the Lhasa River basin, Tibet. *Huanjing Kexue, 39,* 1065–1075. https://doi.org/10.13227/j.hjkx.201706239.

Zhu, D., Cheng, X., Li, W., Niu, F., & Wen, J. (2022). Temporal and spatial variation characteristics of water quality in the middle and lower reaches of the Lijiang River, China and their responses to environmental factors. *International Journal of Environmental Research and Public Health, 19,* 8089. https://doi.org/10.3390/ijerph19138089.