Assessment of hydrochemical characteristics of the Taudaha lake, Kathmandu, Nepal

Ganga Paudel*, Bindu Dahal, Ramesh Raj Pant*, Kiran Bishwakarma***, Sanjeeb Sharma*, Suman Man Shrestha*, Motee Lal Sharma** and Mahesh Prasad Awasthi***

*Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal.

**Central Department of Chemistry, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal.

***Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China.

Abstract: Taudaha Lake is an important lake in central Nepal because of its cultural, aesthetic, ecological and economic values. The assessments of water quality and hydrochemical characteristics were carried out by collecting samples from 20 different sites of the lake in August 2021. Analysis of temperature, pH, electrical conductivity, total dissolved solids, turbidity, dissolved oxygen, total hardness, major cations ($Ca^{2+,}$ Mg^{2+}, Na^+, K^+, Fe^{3+} and NH_4^+) and major anions (HCO_3^-, Cl^-, NO_3^-, SO_4^{2-} and PO_4^{3-}) were carried out to assess the overall hydrochemistry of the lake. The obtained data were interpreted by using multivariate statistical techniques to explore pollution sources and characteristics of sampling points and compared with WHO and irrigation guidelines. Slightly alkaline water with less distinct spatial variation was found. The pattern of major ions is in order of $Ca^{2+}> Mg^{2+}> Na^+> K^+> Fe^{3+}> NH_4^+$ and $HCO_3^-> Cl^-> SO_4^{2-}> NO_3^-> PO_4^{3-}$. All parameters lie within the limit of WHO guidelines. Principal component analysis (PCA) provides four major components with 73.06% cumulative variance and hierarchical cluster analysis classifies five clusters. Results of PCA, CA, Piper, Gibbs, and mixing plots suggested that the hydrochemistry of the lake is primarily controlled by underlying carbonate-dominate lithology. Similarly, Wilcox diagram suggests that lake water is not severely affected by anthropic pollution and is suitable for irrigational purposes. It is recommended for further study on seasonal, and depth-wise water quality variations along with socio-ecological and ecotourism perspectives in the future.

Keywords: Hydrochemistry; Geogenic weathering; Anthropic impacts; Taudaha lake.

Introduction

Wetlands are considered as a most important freshwater resource, providing specific ecological functions and economic values [1,2]. They serve as a part of the ecosystem for aquatic life and also are used for domestic and irrigation purposes [3,4]. Being both culturally and aesthetically important for people throughout the world, they stipulate socio-economic benefits through tourism and recreational purposes. However, the momentous rise in the human population and environmental changes including global climate change have now created outrageous pressures to the wetland ecosystems [5,6]. Meanwhile, the quality of lake water has been affected by the natural process as well as anthropogenic discharges such as weathering, soil erosion, topography, climate change, precipitation, industrial

Author for correspondence: Ramesh Raj Pant, Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Email: rpant@cdes.edu.np

Received: 28 Mar 2022; First Review: 02 May 2022; Second Review: 17 May 2022; Accepted: 18 May 2022.

Doi: https://doi.org/10.3126/sw.v15i15.45651

activities, agricultural land use, sewage discharge, and the human exploitation of water resources [7]. The anthropogenic inputs constitute a constant polluting source whereas surface runoff is a seasonal manifestation mainly affected by climatic conditions [8].

Hydrologically closed lakes respond rapidly to environmental changes, and typically carry extensive geochemical records [9]. Lake water gets contaminated more quickly than the rivers and groundwater due to its open exposure and easy admission of agricultural pollutants and surface runoffs [10,11]. There is a lack of quick natural purification and resilience like rivers water bodies so, it is essential to maintain lake water quality for maintaining the ecological and human health. The factors lead to chemical pollution, eutrophication, introduction of alien plants and animal species on wetlands causing aquatic diversity and water quality to degrade. Thus, the water quality of the wetland has become a great issue in recent years.

Altogether 5,358 lakes have been recorded of which 419 lakes are found in the mid- hills between 500 m to 2,999 m altitude in Nepal [12]. Many of these lakes are under pressure of sedimentation, encroachment and agricultural expansion, water pollution, overuse of wetland resources, eutrophication and poverty that decreases the total coverage area of wetlands. Previous studies revealed as runoffs from the urban settlement around the lake and nutrients from the surrounding areas contribute to eutrophication in urban based lakes such as Phewa [13,14]. However, some other lakes such as Rajarani of eastern Nepal is found to relatively less affected by anthropogenic pollution because of its unexplored and pristine nature [15]. The lakes in low land such as Beeshazari complex are becoming eutrophic due to the richness of nitrogen and phosphorus stretched from agricultural land and waste from the Khageri canal [16]. Additionally, the water chemistry of major freshwater bodies in Nepal such as Rara, Phewa. were studied by various scholars and found that the majority of lakes are dominated by Ca-HCO_3 [17,18]. Monitoring and assessment of lake water provide the basic information on the condition of water bodies that helps in restoration, conservation and management of water resources [13] and provides future potentials of recreation, fisheries and provision of safe drinking water. Evaluation and monitoring are of high priority for the determination of current conditions and long-term trends for effective management. Assessment of hydrochemistry illustrates the health of the aquatic environments including the current status and potential sources of the chemical pollutants. However, there is a gap in the hydrochemical characteristics and water quality of the lakes in Nepal. Subsequently, chemical characterization of water in water basins is extremely important to figure out the weathering and geochemical reactions, anthropogenic and climate change implications on the water resources [5]. Taudaha Lake is one of the important wetland in central Nepal holding historical and religious importance inside Kathmandu valley. It has multiple benefits for ecological and human perspective including economic, ecological and aesthetic services [19]. The proximity of the lake to a highly urbanized Kathmandu metropolitan city and its ecological and economic significance makes it an ideal location for such a study [20]. From the literature review, it was found that two-fifth area of this lake was covered by invasive species of *Myriophyllum aquaticum*, *Eichhornia crassipses*, *Nymphoides indica* and *Trapa bispinosa*. But now these all are removed by different conservation and management practices. Thus, the conservation of the Taudaha Lake is crucial and it has become necessary to evaluate water quality to observe the pollution sources of the lake for the safeguarding of place. The major objective of the present study is to assess the qualitative conditions of water along with characterization of hydrochemistry for exploring the pollution sources of the Taudaha Lake using multivariate statistical analysis. It is anticipated that this study could provide insights for controlling water pollution, eutrophication and the actions helping to restore its innate state.

Materials and method

Study area

Taudaha Lake is situated in Kirtipur Municipality-6, Kathmandu district, Nepal. Geographically it lies at 27º 38'

55.5"N and 85º 16' 54.8" E with altitude of 1291 m on the way to Dakshinkali shrine about 6 km away from city center of Kathmandu (Figure 1). It is small lake of an area of 4 ha with maximum depth of 6 m mainly fed by rainfall and surface flows[20]. It has eight corners with uneven in shape, two inlets which are major sources of water in the lake especially during the monsoon season and only one outlet.

Figure 1: Location of study area of the Taudaha Lake, Kathmandu, Nepal

This lake was named as Newari word 'Ta' means snake and 'daha' means great lake which holds the ancient history of Kathmandu Valley. This lake not only holds its importance in cultural perspectives but also an important site for diversity of flora and fauna especially for the fishes and migratory birds [20]. It has been fed by pipelines water during the month of winter when water level downs. During irrigation and wet season, the lake receives a discharge from the surrounding cropland [21]. The climate in the Taudaha Lake is subtropical climate, with annual rainfall ranging from 1000 mm to 1200 mm and average annual maximum temperature varies between 16°C to 24°C [22].

Sampling and analytical techniques

The field work and sampling was carried out during August 2021 in monsoon season. A total of 20 water samples were collected from 20 sampling sites in littoral zone and middle segments of the lake (Figure 1). The selection of sampling locations was based upon diverse land use patterns, anthropogenic activities, inlet, outlet and accessibility. Samples were collected in well labelled and washed 1L plastic water bottle and preserved by following standard procedures before being delivered to the laboratory [23].

Water temperature (WT), total dissolved solid (TDS), electrical conductivity (EC) and pH were measured on-site. pH and temperature were measured by pH meter (Milwaukee pH55, UK), EC and TDS by EC meter (Milwaukee EC59, Europe). The collected water samples were taken to the Central Department of Environmental Sciences Tribhuvan University, Kirtipur, Kathmandu for chemical analysis. Until the laboratory analysis, all the samples were kept in the refrigerator at 4°C. Turbidity was measured by turbidity meter (Hach Lange 2100AN IS). The major cations Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} were analyzed by flame photometer (Wagtech- MNo: -1382, UK). Parameters like dissolved oxygen demand (DO) and biological oxygen demand (BOD) were determined by Winkler's Iodometric titration Method and chemical oxygen demand (COD) by Open Air Reflux method (Optics technology and CE, Mno.: 110034, India). Other chemicals like Chloride (Cl^{-}), total hardness (TH), alkalinity (HCO_3^-) and free CO_2 by argentometric titration, complexometric (EDTA) titration, acid-base titration and phenolphthalein titration, respectively provided by standard guidelines. Ammonia (NH_4^+), nitrate (NO_3^-), iron (Fe^{3+}), sulphate (SO_4^{2-}) and phosphate (PO_4^{3-}) were measured by spectrophotometer (SSI- UV2101, UK).

For quality assurance and quality control, special care was taken during sampling and laboratory analysis. To avoid contamination,

distilled deionized water was used for the analysis. The sterilized sampling bottles were rinsed with the lake water twice before taking the original samples. Samples were checked sometime twice for concurrent reading.

Statistical Analysis

All statistical analysis were conducted using excel 2019, IBM SPSS Statistic 26, Grapher and Origin Pro 9.0. Descriptive statistical analysis was performed to evaluate the spatial variations of dataset. Spearman's Rank correlation coefficient analysis was used to correlate the calculated variables. Hierarchical clustering analysis (HCA) was performed to group similar sampling sites and evaluate water quality of lake.

Principal component analysis (PCA) was performed to reduce the dimensionality of dataset and explore the major sources of water pollution [24].

The Piper diagram was used to assess geochemical characterization of water quality [25]. Gibbs and mixing plots were used for the controlling mechanism of natural water quality [26,27]. Besides it, the suitability of lake water for irrigation was evaluated by estimating Na^+% and sodium adsorption ratio (SAR), and plotting Wilcox diagram. Sodium alkaline hazard and salinity hazard of the water of irrigation and calculated as:

$$Na^+\% = [(Na^+ + K^+) / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)] * 100$$

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+}) / 2}$$

Where concentrations are expressed in meqL-1.

Drinking and irrigation water quality index was compared with WHO standard and irrigation guideline [28, 29].

Results and discussion

General hydrochemistry

The descriptive statistical results obtained from both laboratory analysis and in-situ measurements of twenty-one physicochemical parameters of Taudaha Lake water and it's comparison with WHO guidelines are presented in Table 1. The water temperature of lake was recorded in the range of 14 to 31.2ºC with mean temperature of 28.44ºC± 3.68. Such fluctuation on water temperature may be due to rise in atmospheric temperature during the sampling period from morning to afternoon. The measured water temperature value is similar to the water temperature of Beeshazari associated lakes and indicates that water is suitable for chemical and biological activities of organisms [16]. pH plays important role for characterizing inorganic chemicals and impacting biotic life present in water where pH of 6.5 to 8.5 is suitable for the survival of aquatic plants. pH values usually changed by the presence of organic and inorganic solutes together with reaction of carbon dioxide and the higher pH leads to precipitation of the ionic species to the soil and sediments in the lentic environments [30]. Here in our study, slightly alkaline pH was found with mean value of 8.28 ± 0.1 which is similar to the past study of same lake in monsoon season and suitable for aquatic life [21]. Since, free CO_2 and pH have inverse relationship indicating the low carbon dioxide in lake. Here slightly alkaline pH may be due to runoff from cement factory, located near at inlet of lake. High pH in water is characterized by carbonate-dominated underlying lithology[3]. The mean pH value of current study is consistent with some other lakes of Nepal such as Ghodaghodi lake i.e. 7.97 ± 0.516 [10,31] and high land Rara Lake i.e. 8.42 ± 0.3 [17].

The electrical conductivity (EC) in water bodies is due to ionization of dissolved solids which have come from anthropogenic activities of nearby settlement area, tourism activities and high pollution load of agro-farms [32]. EC in the present study ranges between 206 µS/cm to 288 µS/cm with mean value of 271 µS/cm ± 23.44; higher than Ghodagodhi Lake [31] and Rara Lake [17] indicates that water was moderately ionized with dissolved solids. This could be due to the increased anthropogenic activities. Likewise, TDS was found to be in the range of 109 to 146 mg/L and contributed by runoff from agricultural land including fertilizers and pesticides and runoff of dissolved salts from nearby road and settlements.

Table 1: Descriptive statistics of hydrochemical variables of Taudaha Lake and it's comparison with WHO guideline.

Variable	Taudaha Lake				WHO guideline (2011)
	Min	Max	Mean	S D	
Temperature	14.00	31.20	28.44	3.68	20
pH	8.10	8.50	8.28	0.10	6.5-8.5
EC	206.00	288	271	23.44	800-1000
TDS	109.00	146	138	9.38	500
Ca^{2+}	21.11	28.33	25.02	1.75	100
Mg^{2+}	7.43	13.71	11.01	1.77	50
K^{+}	2.61	7.09	4.94	1.15	10
Na^{+}	6.32	11.82	9.07	1.59	200
NH_4^{+}	0.16	0.31	0.23	0.05	0.5
Cl^{-}	13.25	19.88	15.91	1.93	250
Fe^{3+}	0.08	0.98	0.39	0.27	-
NO_3^{-}	0.62	0.69	0.65	0.02	50
SO_4^{2-}	4.79	8.68	6.13	1.01	250
HCO_3^{-}	101.03	156.80	113.81	12.02	-
PO_4^{3-}	0.13	0.29	0.25	0.04	0.8
TH	112.00	142.00	128.67	8.86	80-120
F-CO_2	2.20	9.02	5.05	2.29	6
Turbidity	2.88	10.85	6.50	2.62	-
DO	3.65	6.09	5.27	0.70	4-6
BOD	12.10	19.40	14.98	1.75	-
COD	31.43	60.00	44.92	9.22	-

All parameters are in mg/L except temperature (°C), EC (µS/cm), turbidity (NTU) and pH

Descriptive statistic results revealed the pattern of cations and anions in the order of Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}> Fe^{3+}> NH_4^{+} and HCO_3^{-}>Cl^{-}> SO_4^{2-}> NO_3^{-}>PO_4^{3-}, respectively presented in Table 1 and Figure 2. This result reveals that lake is dominated by carbonate and bicarbonate lithology and contribute to slightly alkaline water. Similar order of cations and anions reported in the majority of Himalayan regions[6] indicates that Taudaha Lake might be alluvial deposits in the past. High value of Ca^{2+}, Mg^{2+} and HCO_3^{-} may be due to maximum seepage and runoff from surrounding soils during monsoon season which is higher than Beeshazar associated lakes [16] and Rajarani Lake [15].

Anthropogenic discharges such as municipal effluent discharges, agricultural runoff and urban runoff are major contributor of rising concentration of NH_4^{+}, Cl^{-}, NO_3^{-} and PO_4^{3-} ion on the lake water [33,34]. Ammonium ion is pH and temperature dependent, its concentration increases when water pH decreases from 8.7[32]. Thus, conversion of ionized ammonium into unionized ammonia takes place with rise in pH and temperature of water [34]. Wide use of large amount of sodium chloride by human society for several purposes is major reason of rising Cl^{-} concentration in freshwater and its effects on aquatic environment [35]. Cl^{-} concentration in many lakes of Europe has been increased by salts, waste water, farming, soil weathering, precipitation and solid waste incineration [36].

Nitrate may originate from fertilizers and runoff from agriculture areas. Also, rise in atmospheric nitrogen by reason of industrial revolution that contributes nitrate pollution on lake water[37]. The mean concentration of PO_4^{3-} ions was found to be 0.25 ± 0.04 mg/L reveals that agricultural impact of nearby farmland is significant. Whereas sediment load is major factor of phosphate pollution in lake water of Erie Central Basin of North America [38]. Underlying sediments release the phosphorus into water which may have impact on water quality [39]. In our study, lower concentration of NH_4^{+}, Cl^{-} and NO_3^{-} ion has been found than maximum permissible limit of WHO guideline, suggests less anthropogenic influence on the lake water.

High total hardness in water is the main reason of calcium and magnesium salts dominated underlying rock lithology and high rock water interactions [40,41]. Total hardness of Taudaha Lake water was found to be 112 mg/L to 142 mg/L with mean value of 128.24±8.86 mg/L, suggests higher concentration of calcium and magnesium compounds. Low mean concentration of free CO_2 i.e. 5.05 mg/L in lake water of Taudaha may be due to slightly alkaline water and higher concentration of bicarbonates and carbonates. Resuspension of bottom sediments and quantity of wind received are major causes of turbidity in lake. Thus, it is mainly affected by suspended solid particles either deposited from surrounding of lake or with in the lake [42]. Moderate turbidity was measured in Taudaha Lake as compared with WHO guideline with mean value of 6.5±2.62 NTU which is suitable for aquaculture and similar result was found in lake Ramaroshan [43].

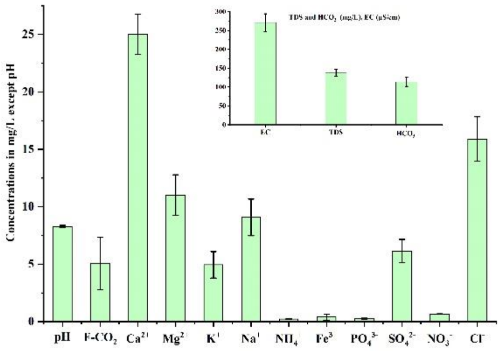

Figure 2: Mean concentration and spatial variation of physicochemical parameters in Taudaha lake, Nepal

Turbulence in lentic water is low that limit the diffusion of oxygen, so photosynthesis by aquatic plants is major source of DO in lentic water bodies [44]. Moderate DO was measured in present study suggests lake water of Taudaha is suitable for survival of aquatic organisms. Similar results has been reported at other lakes such as in the Ghodagodhi (6.63±1.15 mg/L) and the Rara (6.73±0.06 mg/L). Moderate DO in lake water is because of lower amount of light, fish activities, low photosynthetic activity in lake environment and, not too low is due to less organic pollutants and very low diversity of macrophytes [43].

BOD is the concentration of dissolved oxygen consumed by microbial decomposition of organic pollutants, either accumulated in lake from the surrounding area of lake or within lake itself as leaves and woody debris, dead plants and animals [45]. The mean concentration of BOD and COD were found to be 14.98 ±1.75 and 44.93±9.22 mg/L. Thus, lake water is suitable for survival of fishes on comparison with guidelines for water quality management for fish culture in Tripura [46]. This low BOD concentration might be due to low microbial activities, low organic pollutants from nearby area and less numbers of macrophytes. All measured hydrochemical variables are within the limits of WHO Guidelines for drinking water in the Taudaha Lake (Table 1).

The less distinct spatial variations among the concentration of hydrochemical variables in Taudaha Lake was observed and presented in Figures 2 and Figure 3. Minimum SD of pH revealed that all sites have similar pH within desirable and suitable range. Comparatively low TDS and EC on site T7 was reported with less human interference. While low TDS on sites T1 (outlet) may be due to nearby forest covered area and bottom settlement of mobile ions in outlet. High value of HCO_3^- was reported in the outlet than other sites suggesting higher accumulation of bicarbonates in this region from other regions, while low in middle of the lake (T18 to T20).

Low total hardness in T7 and outlet is similar to the reason of low EC and TDS in these sites. Likewise, higher concentration of Ca^{2+} and Mg^{2+} were found in sites T9 and T10 area around newly settled built up and cemented parked area. Slightly high concentration of Cl^- and SO_4^{2-} have assessed in sites 9, 20, 16, 18 and 15 may be due to impact from nearby hotels, road sites and agricultural lands. Comparatively sampling sites 8, 12, 9, 10, 4, 6 and 5 were more polluted with higher concentration of COD, Ca^{2+}, Mg^{2+}, free CO_2 and Cl^- may be due to anthropic impact from agricultural and human settlements. High COD in inlet of the lake may be due to chemical discharge and runoff from nearby farm land of the lake.

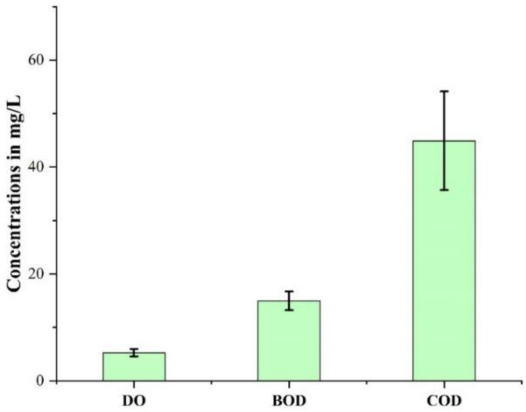

Figure 3: Mean concentration and spatial variation of DO, BOD and COD in the Taudaha Lake, Nepal

Characterization of hydro-chemical facies

Hydrochemical properties of Taudaha Lake were identified through the piper trilinear diagram (Figure 4). The diagram was prepared by using concentration of major cations and anions. The anionic plot reveals that lake water is dominated by HCO_3^- over strong acid (SO_4^{2-} and Cl^-) and cationic plot reveals alkaline earth metal (Ca^{2+} and Mg^{2+}) over alkali metals (Na^+ and K^+). Diamond shaped Piper plot shows that Ca-HCO_3 is dominant ion in the lake water, suggesting hydrochemistry of lake is mainly controlled by carbonate and bicarbonate dominant underlying lithology of lake. Similar findings have been recorded at Ghodaghodi Lake[26], Gokyo Lake, water bodies of Langtang Valley and Paanch Pokhari[22].

Source apportionment and controlling factors

The mechanism controlling water chemistry of the Taudaha Lake was determined by Gibbs plot (Figures 5). The Gibbs diagram representing the simple plot of TDS versus the ratio of Na^+/ (Na^+ + Ca^{2+}) and Cl^-/ (Cl^- + HCO_3^-) to determine three controlling factors of hydrochemistry such as precipitation, evaporation and rock weathering [26,47]. The Gibbs plot plotted for Taudaha Lake revealed that most of the water samples were characterized by medium TDS value and low ratios of Na^+/ (Na^+ + Ca^{2+}) and Cl^-/ (Cl^- + HCO_3^-) and is situated on the left side of the central zone indicating rock weathering is major controlling mechanism in water chemistry. Similar type of results were observed in other lakes such as Rara, and Ghodaghodi. That's why, the result of Gibbs plot for this study are in good agreement with those results obtained for lesser Himalayan lakes [32], suggesting that lithology of lakes and rivers of this region is dominated by carbonate and bicarbonate dominant salts and minerals.

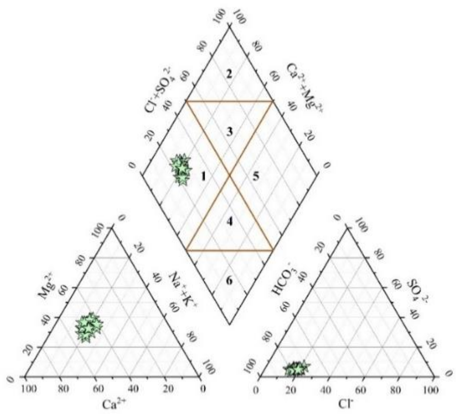

Figure 4: Piper Trilinear Diagram classify the hydrochemical properties of Taudaha Lake, Nepal

The variations in hydrochemistry of lake water is illustrated by mixing diagrams of Na^+ normalized molar ratios of Ca^{2+} versus HCO_3^- and Ca^{2+} versus Mg^{2+} (Figure 6).

In the present study, most of the water samples are located towards the end member of carbonate showing the dominancy of carbonate weathering (Figure 6b), while some of samples are located in the middle of the carbonate and silicate weathering (Figure 6a). In summary, all of these ionic relations indicate that the hydrochemistry of Taudaha Lake water is mainly regulated by carbonate weathering followed by minor contributions from silicate weathering. This finding is similar to the study carried out in Gandaki River Basin (GRB) of Central Himalayan Nepal [32], suggesting the Taudaha Lake may be dominated by alluvial deposits of GRB dominated by carbonate weathering.

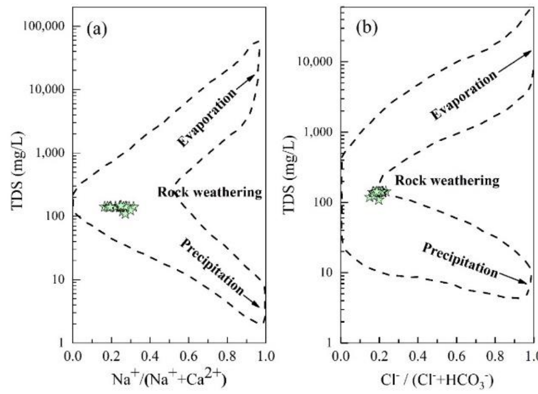

Figure 5: Gibbs diagram and variation of mean ratio of (a) Na^+/ (Na^+ + Ca^{2+}) and (b) Cl^-/ (Cl^- + HCO_3^-) as a function of TDS

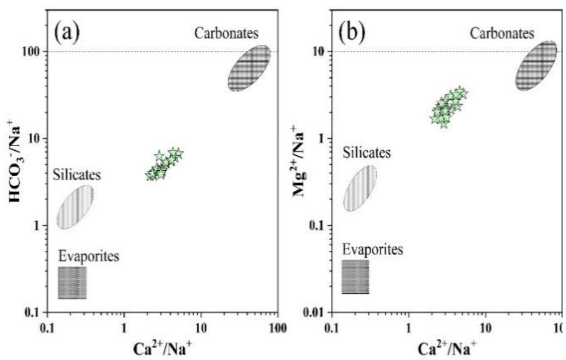

Figure 6: Mixing diagram of Na^+ normalized molar ratios of a) Ca^{2+} versus HCO_3^- and b) Ca^{2+} versus Mg^{2+}

Principal Component Analysis (PCA)

PCA transforms original variables into smaller independent set of variables called principal components (PCs) [48]. Among twenty one parameters, principal component analysis (PCA) was carried out for TDS, Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+, Cl^-, NO_3^-, SO_4^{2}, HCO_3^-, Fe^{3+} and PO_4^{3-}. Obtained results were interpreted on the basis of eigenvalues (>1) and rotated component matrix in Table 2.

Table 2. Rotated component matrix of hydrochemical composition in Taudaha Lake, Nepal

Variables	PC1	PC2	PC3	PC4
TDS	0.46	-0.03	**0.64**	0.00
Ca^{2+}	0.01	-0.04	**0.89**	0.24
Mg^{2+}	0.42	-0.17	0.11	**-0.56**
K^+	0.10	-0.21	0.12	**0.73**
Na^+	0.45	0.07	**-0.76**	-0.11
NH_4^+	**0.88**	-0.07	0.00	0.12
Cl^-	0.26	**0.79**	0.15	-0.34
NO_3^-	0.08	-0.03	0.28	**0.83**
SO_4^{2-}	-0.01	**0.95**	-0.06	0.00
HCO_3^-	-0.48	**0.55**	-0.32	0.19
Fe^{3+}	**-0.83**	-0.12	0.09	0.05
PO_4^{3-}	-0.44	**0.49**	-0.32	-0.03
Eigen value	3.14	2.54	1.74	1.35
% of Variance	26.15	21.16	14.46	11.28
Cumulative %	26.15	47.32	61.78	73.06

Kaiser- Meyer- Olkin (KMO) and Bartlett's Sphericity tests were applied to evaluate validity of PCA before analysis [49]. PCA revealed that measured hydrochemical variables were categorized into major 4 components viz. PC1, PC2, PC3 and PC4. Component matrix and loading plot (Figure 7) were used to identify the correlation between the variables in terms of their source of generation and effects on water chemistry. PC1 had strong positive and negative loading on NH_4^+ and Fe^{3+} with 26.15% of the total variance. Loading plot represents both have different source of origin suggesting that ammonia has anthropogenic origin and, interaction of aqueous ammonia on many iron complex compound is the origin of iron oxides on water [50]. Likewise, decomposition of organic matters and nitrogenous compounds by bacteria are major sources of NH_4^+ in lake[51].

PC2 explained that 21.16 % of the total variance had strong positive loading on Cl^- and SO_4^{2-} and moderate positive on HCO_3^- and PO_4^{3-}. Normally Cl^- and SO_4^{2-} have anthropogenic origin and HCO_3^- and PO_4^{3-} have geogenic origin. In case of our study, all these variables lie in same component of loading plot indicates that weathering of rock is major source of anions and strong impact on water chemistry of the lake. Similar finding obtained in lake Jhilmila [52]. Similarly, PC3 explained 14.46 % of variance had strong positive loading on Ca^{2+}, moderate positive on TDS and strong negative on Na^+. Thus, these factors are from same sources in the Taudaha Lake. From loading plot, it is clear that Na^+ and TDS might be contributed from mixed geogenic and anthropogenic sources whereas calcium from weathering of calcium bearing rocks. Comparatively, PC4 accounted for very low percentage of variance had strong positive loading on NO_3^-, moderate positive on K^+ and moderate negative loading on Mg^{2+} ion. These association reveals that the minor anthropogenic effects in the lake water might be due to nearby agricultural land and construction activities. Similar results obtained in Lake Phewa [53].

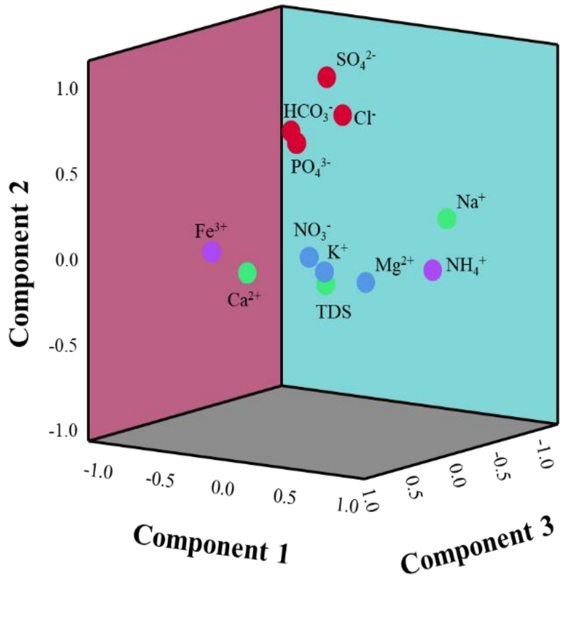

Figure 7: Component plot in rotated space

Correlation matrix

Correlation matrix is a widely used statistical tool to show degree of correlation among hydro-chemical variables [54]. The correlation among hydrochemical variables of the Taudaha Lake are shown in Table 3. A strong positive correlation indicates that they are originated from similar sources. Various parameters show moderate positive and negative correlation at 99% or 95% of significance level. This analysis reveals that there was strong positive correlation between TDS and EC ($p<0.05$). Concentration of EC in lake water increases with increase in concentration of TDS, so it is a good indicator of EC concentration. Total hardness being sum of calcium hardness and magnesium hardness shows moderate positive correlation with Ca^{2+} and Mg^{2+}. Sulphate is positively correlated with phosphate and bicarbonate. Moderate positive correlation had been observed between other parameters such as CO_2-DO, WT -DO, WT-CO_2, pH- CO_2, CO_2-COD ($p<0.05$) while moderate negative correlation between variables pH-COD, Ca^{2+}-Na^{+} and Cl^{-}-turbidity ($p<0.05$).

Likewise, some variables show moderately positive correlation between them, are EC-Ca^{2+}, TDS-NH_4^{+}, NH_4^{+}-BOD and CO_2-DO, while moderately negatively correlated are HCO_3^{-}-DO, and PO_4^{3-}-total hardness ($p<0.01$). The positive correlation between temperatures as previously recorded as low temperature favours high DO concentration in surface waters [55]. Reduction of DO takes place with rise in turbidity of lake water [56]. Water temperature causes increased in pH level and rapids the conversion of free CO_2 to organic carbon by photosynthesis. Similarly, free CO_2 in water becomes high when pH down and rise microbial activity by decomposition [56].

Cluster Analysis (CA)

Hierarchical clustering analysis was applied to group similar sampling sites and similar water samples [57] affected by similar sources through the dendrogram [58]. The Ward's linkage methods were used for clustering 20 sampling locations of Taudaha Lake. The dendrogram shows four distinct clusters with low distance criterion between 0 and 5 (Figure 8). Cluster 1 formed by ten sampling sites viz. 2, 3, 11, 14, 15, 16, 17, 18, 19 and 20. Among them sites 18, 19 and 20 lie in the middle of the lake. Sites 2, 3, 11, 14, 15, 16, 17 and 18 lie in the periphery of lake having slightly higher concentration of Cl^{-} and SO_4^{2-} due to mixed effect of diverse land use pattern of nearby area of forest land, hotels, road site and agricultural lands. Cluster 2 comprises of the 7 sampling sites (8, 12, 9, 10, 4, 6 and 5) around the agricultural and human settlements area. Cluster 3 includes site 7 and 13 with comparatively low pH and high COD due to chemical discharge and runoff from nearby farm land in inlet of the lake. Only one sampling site T5 (outlet) lies in cluster 5 with distinctive physicochemical properties.

On the basis of TDS data set result, the mean TDS (mg/L) is in the order of cluster 1>2>4>3 (i.e. 142> 140> 119>116). Here, cluster 1 has highest TDS range followed by cluster 2 indicates these sites are comparatively more polluted might be due to anthropogenic (cultivated land, settlements) and geogenic influences. Clusters 3 and 4 have relatively low TDS as compared to clusters 1 and 2 indicating low level of pollution. The classification result of CA may not provide the accurate perspective on water quality and does not exactly coincide with the distribution of the different sites in the Taudaha Lake which is similar to clustering carried out in the Betkot Lake [59]. However, all these groups are characterized by different trend patterns of hydro -chemical variation of the lake water controlled by both geogenic and anthropogenic influences.

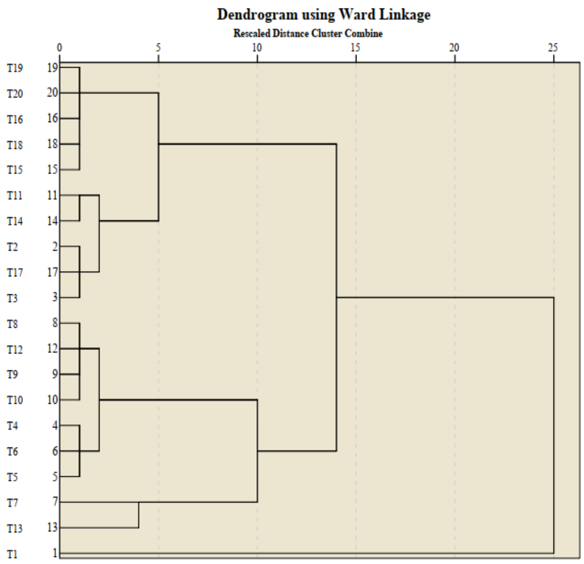

Figure 8: Hierarchical clusters of sampling Sites of Taudaha Lake, Nepal

Water quality for irrigation purposes

Lake water provides water supply for the purpose of drinking, irrigation and industrial uses. The irrigation suitability of the water depends upon the type and concentration of dissolved salts where Na^+ and EC play vital role [3]. Excess sodium contents in lake water produces undesirable effect because of reaction of sodium with soil and reduction of soil permeability. Thus, there has no support to plant growth causing calcium deficiency and deflocculating. That's why, Na^+% and Sodium adsorption ratio (SAR) are the major parameters used to determine irrigation quality of surface water [1].

The calculated values of Na^+ and SAR of the Taudaha Lake water is presented in Table 4 and compared with standard. The Na^+ of the lake ranges from 22.12 % to 34.31 %, suggesting water is good for irrigational purposes. Likewise, SAR value of the lake is 3.03, categorized as excellent, greater than 10. From irrigational perspective, Taudaha Lake water is suitable for irrigation and similar results were obtained in Ghodagodi lake.

Table 4. Irrigation water quality of Taudaha lake, Nepal

Parameters	Mean	Max	Min	SD	Categories
Na^+	28.00	34.31	22.12	3.12	Good
SAR	3.03	4.05	2.02	0.57	Excellent

Irrigation water quality of Taudaha Lake was classified by Wilcox classification [60], based on the Na^+% concerning the electrical conductivity (Figure 9). This diagram shows that majority of water samples fall in between C1-S1 and C2-S1 zone of medium salinity and low sodium hazard. This result indicates water is suitable for irrigation with little danger of salinity hazard and most suitable for slightly salt tolerant crops.

Comparative analysis

Comparative analysis of hydrochemical characteristics of the Taudaha Lake was done with several other lakes as shown in Table 5. Lakes such as Mai Pokhari, Khaste and Ramaroshan have shown lower pH indicating their acidic nature, in contrast to which lake like Begnas have shown higher pH value exceeding the WHO guideline values. This high pH can show detrimental effects on carbonate and bicarbonate equilibrium.

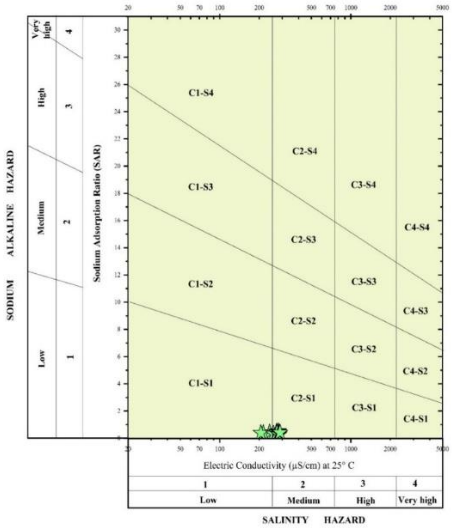

Figure 9: Wilcox diagram illustrating the irrigational water quality based on SAR and EC of Taudaha Lake, Nepal

Most of the EC values of the lakes were well under 500 µS/cm showing low ionic strength. Accordingly, TDS also follows the same trend, as the Taudaha Lake shows the TDS value of 138 mg/L which in lower when compared with the Betkot Lake. This relatively high TDS values can have undesirable impact on both human and ecological health. The TDS values of Rajarani and Ramaroshan was found to be extremely low being 32 and 40.02 mg/L, respectively as compared to present study of Taudaha Lake.

The average anionic concentration (mg/L) of the current research following the dominant pattern is $HCO_3^- > Cl^- > NO_3^-$, following the array of other lakes. Freshwater ecosystems typically have alkalinity levels ranging from 20 to 200 mg/L. Lower alkalinity values indicate insufficient buffering capacity of water, implying that these waters are least capable of tolerating pH shifts. The NO_3^- content of the Taudaha Lake was found to be 0.65 mg/L which is higher than most of the lakes in Table 5. Whereas the NO_3^- concentration of the Begnas lake was relatively higher than other lakes (5.3 mg/L) followed by Rupa Lake (2.8 mg/L). Nitrate concentrations are greatly enhanced in agricultural catchments, underlain by thick, porous soils.

Table 3: Spearman's Rank Correlation Coefficient (r) among different physicochemical parameters of water sample (p< 0.01 &* p< 0.05)**

	Temp	pH	EC	TDS	Ca^{2+}	Mg^{2+}	K^+	Na^+	NH_4^+	Cl^-	Fe^{3+}	NO_3^-	SO_4^{2-}	HCO_3^-	PO_4^{3-}	TH	F-CO_2	Turbidity	DO	BOD	COD
Temp	1.00																				
pH	0.10	1.00																			
EC	0.38	0.35	1.00																		
TDS	0.44	0.31	**0.81****	1.00																	
Ca^{2+}	0.31	0.41	**0.51***	0.28	1.00																
Mg^{2+}	-0.27	-0.07	-0.13	0.05	-0.00	1.00															
K^+	0.37	-0.31	0.08	0.08	0.16	-0.18	1.00														
Na^+	-0.02	-0.01	-0.09	0.03	**-0.66****	0.20	-0.09	1.00													
NH_4^+	0.43	0.31	0.40	**0.53***	-0.04	0.15	0.08	0.41	1.00												
Cl^-	-0.23	0.21	-0.11	0.08	-0.10	0.25	-0.14	0.17	0.02	1.00											
Fe^{3+}	0.05	-0.03	-0.04	-0.31	0.19	-0.27	-0.06	-0.26	**-0.45***	-0.36	1.00										
NO_3^-	**0.60****	-0.06	0.22	0.34	0.35	-0.22	**0.57****	-0.23	0.16	-0.12	-0.00	1.00									
SO_4^{2-}	-0.20	-0.12	-0.41	-0.20	-0.27	-0.12	-0.05	0.02	-0.13	**0.64****	-0.36	0.05	1.00								
HCO_3^-	-0.25	-0.37	**-0.54***	**-0.55***	-0.24	-0.03	0.18	0.18	-0.32	0.39	0.04	-0.16	**0.61****	1.00							
PO_4^{3-}	-0.18	**-0.57****	-0.55*	**-0.56****	-0.39	-0.27	0.06	-0.15	**-0.47***	-0.05	0.09	0.10	**0.56****	0.39	1.00						
TH	0.00	0.24	0.22	0.23	**0.67****	**0.71****	0.05	-0.24	0.11	0.14	-0.11	0.12	-0.24	-0.13	**-0.50***	1.00					
F-CO_2	**0.61****	**0.55***	0.15	0.364	0.10	-0.40	0.01	0.04	**0.48***	-0.15	0.01	0.37	-0.10	-0.35	-0.33	-0.19	1.00				
Turbidity	0.22	0.09	0.39	0.226	0.33	-0.12	0.05	-0.08	0.17	**-0.58****	**0.44***	0.38	**-0.57****	**-0.45***	-0.29	0.16	0.26	1.00			
DO	**0.58****	0.40	0.38	0.43	**0.55***	-0.15	0.26	-0.38	0.29	-0.01	-0.04	**0.49***	-0.34	-0.50*	-0.46*	0.25	**0.55***	0.23	1.000		
BOD	0.26	0.23	0.38	0.22	-0.05	-0.38	0.30	0.34	0.45*	-0.36	-0.33	0.14	-0.27	-0.27	-0.21	-0.25	0.29	0.16	0.11	1.00	
COD	-0.39	-0.56**	-0.25	-0.36	-0.16	0.36	0.11	-0.05	-0.41	-0.22	-0.10	-0.31	-0.25	0.08	0.20	0.13	**-0.73****	-0.26	-0.30	0.00	1.00

Table 4: Table showing hydrochemical variables in different sites of the Taudaha Lake (raw data)

ID	Temp	pH	EC	TDS	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	NH_4^{+}	Cl^{-}	Fe^{3+}	NO_3^{-}	SO_4^{2-}	HCO_3^{-}	PO_4^{3-}	TH	F-CO_2	Turbidity	DO	BOD	COD
T1	26.50	8.3	240	119	23.89	7.43	3.52	9.45	0.17	16.09	0.89	0.65	7.60	157	0.276	112	5.50	8.23	4.05	13.70	31.43
T2	26.70	8.5	215	139	25.56	13.71	4.00	9.68	0.16	17.99	0.48	0.63	6.14	112	0.263	140	5.28	4.79	5.27	12.10	41.71
T3	27.90	8.3	282	143	23.33	12.57	2.61	10.18	0.31	19.88	0.17	0.62	8.68	112	0.270	128	3.74	4.25	4.46	13.20	34.29
T4	28.30	8.2	281	140	22.22	10.29	5.43	11.55	0.22	13.25	0.56	0.63	4.79	114	0.265	116	4.18	7.89	4.86	15.90	54.86
T5	27.80	8.3	281	141	22.78	12.00	4.74	10.64	0.25	15.15	0.21	0.64	5.33	106	0.268	124	3.52	4.49	3.65	19.40	58.86
T6	28.20	8.3	281	140	25.56	13.14	3.26	10.32	0.22	18.93	0.08	0.63	6.41	117	0.267	138	2.20	3.13	4.86	15.60	59.43
T7	28.10	8.1	206	109	21.11	12.00	4.17	8.95	0.17	15.15	0.34	0.64	5.33	106	0.279	118	2.86	4.68	5.68	12.40	60.00
T8	14.00	8.3	283	141	28.33	10.86	6.96	6.32	0.21	17.99	0.21	0.66	6.14	112	0.261	140	2.42	5.96	5.95	15.40	51.43
T9	28.40	8.2	283	141	26.67	12.00	4.39	6.59	0.16	14.20	0.98	0.66	5.06	106	0.270	138	2.42	10.85	5.27	12.40	52.57
T10	29.30	8.2	279	140	25.00	9.14	5.26	8.00	0.17	13.25	0.11	0.66	6.79	110	0.290	122	4.40	5.27	4.86	15.80	50.86
T11	30.10	8.3	281	138	26.11	8.57	5.96	6.86	0.16	16.09	0.96	0.65	6.60	125	0.279	124	3.30	2.88	5.27	15.20	42.29
T12	29.40	8.2	257	141	25.00	13.14	6.30	8.09	0.25	17.04	0.18	0.68	6.87	114	0.276	136	4.40	3.72	5.68	13.20	48.00
T13	29.80	8.1	272	123	24.44	12.57	7.09	11.82	0.26	15.15	0.31	0.68	6.33	125	0.278	132	2.86	9.97	4.46	15.50	47.43
T14	31.20	8.2	280	142	23.89	9.14	5.43	10.18	0.22	18.93	0.22	0.67	7.41	121	0.270	118	7.70	3.55	5.78	15.20	38.86
T15	29.80	8.4	273	138	25.56	8.57	4.48	9.32	0.26	15.15	0.24	0.66	6.33	108	0.271	122	9.02	5.79	5.95	17.20	38.86
T16	30.10	8.3	284	142	26.11	10.29	4.43	7.27	0.22	14.20	0.60	0.69	6.06	106	0.274	130	5.72	9.57	5.68	15.30	39.43
T17	30.70	8.3	280	140	27.22	12.57	5.17	7.45	0.28	14.20	0.31	0.65	5.06	112	0.125	142	6.38	6.69	5.75	15.00	44.00
T18	30.71	8.33	284.33	143.49	25.83	10.74	5.24	9.37	0.28	15.25	0.31	0.67	5.49	106.00	0.21	130.83	7.87	8.73	5.90	15.65	36.45
T19	30.86	8.35	286.29	144.75	25.89	10.75	5.21	9.58	0.29	15.19	0.29	0.67	5.26	103.51	0.19	131.13	8.40	9.41	5.99	15.73	34.74
T2	31.01	8.36	288.26	146.02	25.94	10.76	5.18	9.79	0.30	15.14	0.27	0.67	5.04	101.03	0.18	131.43	8.93	10.09	6.09	15.81	33.03

Table 5: Comparison of hydrochemical variables of the Rajarani Lake with other lakes.

Lake	Temp	pH	EC	TDS	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	NH_4^{+}	Cl^{-}	Fe^{3+}	NO_3^{-}	SO_4^{2-}	HCO_3^{-}	PO_4^{3-}	TH	F-CO2	Tur	DO	BOD	COD
Taudaha	28.44	8.28	271	138	25.02	11.01	4.94	9.07	0.23	15.91	0.39	0.65	6.13	113.81	0.25	128.67	5.05	6.5	5.27	14.98	44.92
Taudaha[21]	-	8.5	231	124	-	-	-	6.4	-	18.6	-	-	-	111.7	0.6	106.3	21.6	-	5.8	-	-
Rara[17]	12.71	8.53	131.28	-	9.17	-	-	-	-	15.3	-	-	-	-	-	-	-	-	-	-	-
Beshazar[16]	26.15	7.55	84	50	-	2.81	2.52	5.81	0.28	9.72	-	0.31	0.46	26.46	0.19	82.56	-	-	5.81	-	-
Rajarani[15]	10.07	8.71	54	32	5.56	1.96	8.09	2.67	0.37	11.64	0.62	0.06	-	32.75	0.25	22.05	-	8.97	5.83	-	-
Jagadispur[1]	23.99	7.58	288.11	156.39	-	-	-	-	-	-	-	0.23	-	147.56	-	-	-	-	6.09	-	19.97
Begnas[30]	26.73	9.04	-	-	-	-	-	-	0.1	20.4	-	1.77	-	-	0.1	13.75	13.32	-	6.46	26.28	-
Rupa[30]	25.45	8.2	52.33	36.7	-	-	-	-	0.17	16.52	-	2.8	-	-	0.15	16.53	14.83	-	5.09	53.83	-
Ramaroshan[51]	8.52	6.9	77.41	40.02	6.76	3.41	1.34	5.6	0.12	11.83	-	0.04	1.04	-	0.15	44.11	3.32	0.85	8.36	-	-
Betkot[59]	18.3	7.77	337	168	1.48	0.98	2.9	0.33	0.23	2.42	-	0.71	-	2.52	0	188	7.32	10.62	2.98	7.02	21.06

The Fe^{3+} concentration of the Taudaha (0.39 mg/L) was well under the permissible limits of the WHO guidelines and was found to be lower than in Rajarani Lake (0.62 mg/L). In the case of cationic concentration, the current research on Taudaha lake followed the pattern of Ca^{2+} > Mg^{2+}> Na^{+}> K^{+}> NH_4^{+}. This pattern shows higher influence of the bedrock and water interaction keeping in the mind as the thought of similar pattern followed by most of the compared lakes in Table 5. This is most likely owing to preferential weathering of the less resistant bedrock, as seen by the increased calcite concentrations [58].

In case of the DO, the concentration of Taudaha lake was found to be 5.27 mg/L which is lower than that of both Ramaroshan lake (8.36 mg/L) and Rara Lake (7.5 mg/L), showing comparatively high biological activity in Taudaha Lake. In contrast, Lake of Mai Pokhari and Betkot were found poor in DO concentration with the concentration of 2.13 and 2.98 mg/L. Low DO concentration can be the result of higher bacterial actions and higher temperature [55]. Comparatively, water chemistry of Taudaha Lake is controlled by weathering of carbonated and bicarbonate rocks, along with minimum impacts of anthropogenic activities.

Conclusions

The present study of hydrochemistry and water quality of Taudaha Lake explained that water is suitable for sustaining aquatic lives, domestic and irrigational purposes. Slightly alkaline pH with moderate DO value indicates that the lake water has been less polluted by organic pollutants from anthropogenic sources. The order of cationic and anionic dominancy is Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}> Fe^{3+}> NH_4^{+} and HCO_3^{-}>Cl^{-}>SO_4^{2-}>NO_3^{-}>PO_4^{3-}, respectively. This result was supported by Piper diagram, Gibbs plot and Mixing diagram and concluded that hydrochemistry of lake water was mainly affected by weathering of rocks dominated by Ca^{2+} and HCO_3^{-}. Four clusters among all sampling sites with moderately positive and negative correlation between physicochemical parameters indicates that there is mixed effects of weathering of rocks and diverse land use patterns around the lake area. PCA analysis suggests both geogenic and anthropogenic influences on the water quality. Moreover water chemistry was controlled by geogenic influences than anthropogenic activities and suitable for agricultural purpose with excellent SAR and Na%. This study suggests further need of investigation on water quality in terms of socio-ecological and ecotourism perspectives. Precisely, the study recommended for the seasonal and depth wise water quality assessment of the lake.

Acknowledgements

We are thankful to Enhancing Green Economy in 3 countries in Asia (EGEA) program for financial support and the Central Department of Environmental Science (CDES, TU) for providing laboratory facilities for this research. Our deep gratitude goes to Mr. Ramesh Basnet and Ms. Pooja Bhusal for assistance in Lab work and Ms. Sushmita Kafle and Mr. Gaurav Kumar Raut for helping in sampling and data collection in field work. We also thank the Taudaha Conservation Committee and Kirtipur Municipality for necessary support to carry out this study.

References

1. Sapkota, M., Pant, R. R., Pathak, L., Khanal, B., Shrestha, S., Poudel, B., Poudel, S., Thapa, L. B., Pal, K. B., Bishwakarma, K. and Durdiev, K. 2021. Assessment of water quality using multivariate statistical approaches in Jagadishpur reservoir, Lumbini province, Nepal. *Sustainable Water Resources Management*. **7(5)**: 1-12.
2. Chaudahary, R. K. and Devkota, A. 2018. Evaluation of limnological status of Jagadishpur reservoir, Kapilvastu district, Nepal. *International Journal of Applied Sciences and Biotechnology*. **6**: 255–260.
3. Acharya, A., Sharma, M. L., Bishwakarma, K., Dahal, P., Chaudhari, S. K., Adhikari, B., Neupane, S., Pokhrel, B. N. and 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.
4. Singh, S., Ghosh, N. C., Gurjar, S., Krishan, G., Kumar, S. and Berwal, P. 2018. Index-based assessment of suitability of water quality for irrigation purpose under Indian conditions. *Environmental Monitoring and Assessment*. **190(1)**: 1-14.
5. Singh, V. B., Ramanathan, A. L. and Mandal, A. 2016. Hydrogeochemistry of high-altitude lake: a case study of the Chandra Tal, Western Himalaya, India. *Arabian Journal of Geosciences.* **9**: 1–9.
6. Tripathee, L., Kang, S., Huang, J., Sillanpaa, M., Sharma, C. M., Luthi, Z. L., Guo, J. and Paudyal, R. 2014. Ionic composition of wet

precipitation over the southern slope of central Himalayas, Nepal. *Environmental Science and Pollution Research*. **21(4)**: 2677–2687.

7. Yang, L., Song, X., Zhang, Y., Yuan, R., Ma, Y., Han, D. and Bu, H. 2012. A hydrochemical framework and water quality assessment of river water in the upper reaches of the Huai river basin, China. *Environmental Earth Sciences*. **67(7)**: 2141–2153.
8. Singh, K. P., Malik, A., Mohan, D. and Sinha, S. 2004. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti river (India) - A case study. *Water Research*. **38(18)**: 3980–3992.
9. Zhang, F., Qaiser, F. U. R., Zeng, C., Pant, R. Zhang, F., R., Wang, G., Zhang, H. and Chen, D. 2019. Meltwater hydrochemistry at four glacial catchments in the headwater of Indus River. *Environmental Science and Pollution Research.* **26(23)**: 23645–2366.
10. Bhatta, R., Tuladhar, S., Regmi, D., Joshi, R., Dahal, B.M., Gurung, S., Raut, N., Kafle, K. R., Kayastha, R., Prasad, A. and Tripathee, L. 2019. Water quality of Ghodaghodi Lake : a Ramsar site in western Nepal. 1–6.
11. Herath, I. K., Wu, S. J., Ma, M. H., Jianli, W. and Chandrajith, R. 2019. Tracing controlling factors of riverine chemistry in a headwater tributary of the Yangtze River, China, inferred from geochemical and stable isotopic signatures. *Environmental Science and Pollution Research.* **26(23)**: 23899-23922.
12. Bhuju, D., Sharma, S., Jha, P. and Gaire, N. 2013. Scientific Discourse of Lakes in Nepal. *Nepal Journal of Science and Technology.* **13**: 147–158.
13. Khadka, U. R. and Ramanathan, A. 2020. Hydrogeochemical Analysis of Phewa Lake: A Lesser Himalayan Lake in the Pokhara Valley, Nepal. *Arabian Journal of Geosciences*. **6(11)**: 4191–4206.
14. Acharya, S. 2020. Land use and land cover changes in the catchments impact the ecosystem in Phewa, Begnas, and Rupa lakes, Nepal. *Journal of Nepal Geological Society.* **60**: 195–205.
15. Adhikari, B., Pant, R. R., Baral, U., Shrestha, S., Neupane, S., Khanal, B., Acharya, A. and Bhattarai, H. 2020. Geochemical and multivariate assessment of water quality in the Rajarani Lake, Dhankuta, Nepal. *Journal of Nepal Geological Society.* **60**: 37–49.
16. Pant, R. R., Chalaune, T. B., Dangol, A., Dhital, Y. P., Sharma, M. L., Pal, K. B., Shah, T. H., Shrestha, A. K. and Thapa, L. B. 2021. Hydrochemical assessment of the Beeshazar and associated lakes in Central Nepal. *SN Applied Science.* **3(1)**: 38.
17. 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. and Guo, J. 2018. Hydrochemistry of Lake Rara: A high mountain lake in western Nepal. *Lakes & Reservoirs: Research & Management*. **23(2)**: 87–97.
18. Rupakheti, D., Tripathee, L., Kang, S., Sharma, C. M., Paudyal, R. and Sillanpaa, M. 2017. Assessment of water quality and health risks for toxic trace elements in urban Phewa and remote Gosainkunda lakes, Nepal. *Human and ecological risk assessment: an international journal*. **23(5)**: 959-973.
19. Bhatt, L. R., Lacoul, P., Lekhak, H. D. and Jha, P. K. 1999. Physico-chemical characteristics and phytoplanktons of Taudaha lake, Kathmandu. *Pollution Research.* **18**: 353–358.
20. Shrestha, S. and Adhikari, P. L. 2016. Investigating temporal variation of water quality and benthic macroinvertebrates in Taudaha lake, Kathmandu, Nepal. *Journal of Water Resource and Protection.* **08**: 1283–1296.
21. Pradhananga, A. R., Shakya, R. K. and Shakya, P. R. 2012. Assessment of physico-chemical parameters of surface water quality of Taudaha lake of Kathmandu and their comparison with other global published values. *Bibechana*. **9**: 141–150.
22. DHM. 2015. Study of Climate and Climatic Variation over Nepal. *Nepal Hydrological and Meteorological Research Center and Consultancy P. Ltd.*
23. APHA. 2005. Standard Methods for the Examination of Water and Wastewater. *American Public Health Association, Washington DC*. **1220**.
24. Vega, M., Pardo, R., Barrado, E. and Debán, L. 1998. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Research.* **32(12)**: 3581–3592.
25. Piper, A. M. 1944. A graphic producer in the geochemical interpretation of water analysis. *American Geophysical Union.* **25(6)**: 914–928.
26. Gibbs, R. J. 1970. Mechanisms controlling world water chemistry. *Science.* **170**: 1088–1090.
27. Gaillardet, J., Dupré, B., Louvat, P. and Allègre, C. J. 1999. Global silicate weathering and CO consumption rates deduced from the chemistry of large rivers. *Chemical Geology.* **159(1-4)**: 3–30.
28. WHO. 2011. Guidelines for drinking-water quality. 4th edition, Geneva. *World Health Organization*.
29. Richards, L. A. 1954. Diagnosis and improvement of saline and alkali soils. *United State Department of Agriculture*. **78(2)**: 154.
30. Pant, R. R., Pal, K. B., Adhikari, N. L., Adhikari, S. and Mishra, A. D. 2019. Water quality assessment of Begnas and Rupa lakes, lesser himalaya Pokhara, Nepal. *Journal of Institute of Engineering.* **15(2)**: 113–122.
31. Pant, R. R., Pal, K. B., Bishwakarma, K., Thapa, L. B., Dangol, A., Dawadi, B., Poudel, P., Bhattarai, B., Joshi, T. R. and Bhatt, Y. R. 2020. Application of multivariate approaches to the hydro-chemical assessment of the Ghodaghodi lake , sudurpaschim province , Nepal. *Nepal Journal of Science Technology.* **19(2)**: 46–54.
32. Pant, R. R., Zhang, F., Rehman, F. U., Wang, G., Ye, M., Zeng, C. and Tang, H. *et al.* 2018. Spatiotemporal variations of hydrogeochemistry and its controlling factors in the Gandaki River Basin, Central Himalaya Nepal. *Science of Total Environment.* **622–623**: 770–782.
33. Kaphle, B., Wang, J., Kai, J., Lü, X., Paudayal, K. and 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.
34. Lin, K., Zhu, Y., Zhang, Y. and Lin, H. 2019. Determination of ammonia nitrogen in natural waters: recent advances and

applications. *Trends in Environmental Analytical Chemistry*. **24**: 00073.

35. Klee, R. J. and Graedel, T. E. 2004. Elemental cycles: a status report on human or natural dominance. *Annu. Rev. Environ. Resour*. **29**: 69-107.
36. Müller, B. and Gächter, R. 2012. Increasing chloride concentrations in Lake Constance: characterization of sources and estimation of loads. *Aquatic sciences*. **74**: 101-112.
37. Bhatt, M. P., McDowell, W. H., Gardner, K. H. and Hartmann, J. 2014. Chemistry of the heavily urbanized Bagmati River system in Kathmandu Valley, Nepal: export of organic matter, nutrients, major ions, silica, and metals. *Environmental Earth Science.* **71**: 911–922.
38. Petticrew, E. L. and Arocena, J. M. 2001. Evaluation of iron-phosphate as a source of internal lake phosphorus loadings. *Science of the total Environment*. **266**: 87-93.
39. Wu, Z., Wang, X., Chen, Y., Cai, Y. and Deng, J. 2018. Assessing river water quality using water quality index in Lake Taihu Basin, China. *Science of the Total Environment.* **612**: 914–922.
40. Singh, A. K., Mahato, M. K., Neogi, B., Tewary, B. K. and Sinha, A. 2012. Environmental geochemistry and quality assessment of mine water of Jharia coalfield, India. *Environmental Earth Science.* **65(1)**: 49–65.
41. Thomas, J., Joseph, S. and Thrivikramji, K. P. 2015. Hydrochemical variations of a tropical mountain river system in a rain shadow region of the southern Western Ghats, Kerala, India. *Applied Geochemistry* **63**: 456–471.
42. Yunus, A. P., Masago, Y. and Hijioka, Y. 2020. COVID-19 and surface water quality: Improved lake water quality during the lockdown. *Science of the Total Environment.* **731**: 139012.
43. 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.
44. Boyd, C. E. 1979. Water quality in warmwater fish ponds. Craftmaster Printers. *INC, Opelika Alabama*. **412**.
45. Bhateria, R. and Jain, D. 2016. Water quality assessment of lake water: a review. *Sustainable Water Resources Management.* **2(2)**: 161–173.
46. Santhosh, B., and Singh, N. P. 2007. Guidelines for water quality management for fish culture in Tripura. *ICAR Research Complex for NEH Region, Tripura Center, Publication*. **29(10)**.
47. Bishwakarma, K., Wang, G. X., Zhang, F., Adhikari, S., Karki, K. and Ghimire, A. 2022. Hydrochemical characterization and irrigation Evaluation of iron-phosphate as a source of internal lake phosphorus loadings. *Science of the total Environment*. **266**: 87-93.
48. Filzmoser, P., Hron, K. and Reimann, C. 2009. Principal component analysis for compositional data with outliers. *Environmetrics.* **20**: 621–632.
49. Pant, R. R., Zhang, F., Rehman, F. U., Wang, G., Ye, M., Zeng, C. and Tang, H. 2020. Spatiotemporal characterization of dissolved trace elements in the Gandaki river, central himalaya Nepal. *Journal of Hazardeous Materials.* **389**: 121913.
50. Cheng, Q., Nengzi, L., Bao, L., Wang, Y., Yang, J. and Zhang, J. 2017. Interactions between ammonia, iron and manganese removal using pilot-scale biofilters. *Journal of Water Supply: Research and Technology - AQUA.* **66(3)**: 157–165.
51. Chalaune, T. B., Dangol, A., Sharma, J. and Sharma, C. M. 2020. First results on physico-chemical status and bathymetry of lakes in Ramaroshan wetland, far-west Nepal. *Nepal Journal of Environmental Science.* **8**: 17–27.
52. Pal, K. B., Bishwakarma, K., Chalaune, T. B., Upadhaya, D., Joshi, T. R., Thapa, L. B., Sharma, M. L., Joshi, S. and Pant, R. R. 2021. Hydrochemical assessment of Jhilmila lake, Kanchanpur, Nepal. *Scientific World.* **14(14)**: 124–131.
53. Paudyal, K., Baral, H. and Keenan, R. J. 2018. Assessing social values of ecosystem services in the Phewa lake watershed, Nepal. *Forest Policy and Economics.* **90**: 67–81.
54. Anshumali and Ramanathan, A. L. 2007. Seasonal variation in the major ion chemistry of Pandoh lake, Mandi district, Himachal pradesh, India. *Applied Geochemistry*. **22(8)**: 1736–1747.
55. Bose, S. K. and Gorai, A. C. 1993. Seasonal fluctuation of plankton in relation to physico-chemical parameters of a freshwater tank of Dhanbad, India. *Journal of Freshwater Biology*. **5(2)**: 133–140.
56. Araoye, P. A. 2009. The seasonal variation of pH and dissolved oxygen (DO) concentration in Asa lake Ilorin, Nigeria. *International Journal of Physical Sciences.* **4(5)**: 271–274.
57. Galazoulas, E. C. and Petalas, C. P. 2014. Application of multivariate statistical procedures on major ions and trace elements in a multilayered coastal aquifer: the case of the south Rhodope coastal aquifer. *Environmental Earth Science.* **72(10)**: 4191–4205.
58. McKenna, J. E. 2003. An enhanced cluster analysis program with bootstrap significance testing for ecological community analysis. *Environmental Modelling and Software*. **18(3)**: 205-220.
59. Pant, R. R., Dhakal, M., Baral, U., Dangol, A., Dhakal, T. M., Thapa, L. B. and Pal, K. B. 2019. Water quality assessment of the Betkot lake, Sudurpaschim province, Nepal. *North American Academic Research.*
60. Wilcox, L. 1955. Classification and use of irrigation waters. *US Department of Agriculture.*