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# Geochemical and multivariate assessment of water quality in the Rajarani Lake, Dhankuta, Nepal

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## ABSTRACT

The Himalayan freshwater lakes embody the treasure of the country, crystal-clear nature of which offers water for drinking, irrigation and other domestic purposes and provide shelter to numerous species, preserve aquatic biodiversity and habitat of the area. The freshwater lake is one of the major sources of livelihood amenities in Nepal and replenishes groundwater, positively influence the quality of downstream watercourses. In the present study, 20 water samples were collected from different points of Rajarani Lake, and analyzed for water temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), oxygen-reduction potential (ORP), turbidity, dissolved oxygen (DO), total hardness (TH), major cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$ and $NH_4^+$) and major anions ($HCO_3^-$, $Cl^-$, $NO_3^-$, and $PO_4^{3-}$). The acquired data were interpreted using multivariate statistical technique with principal component analysis (PCA) and cluster analysis (CA) to evaluate controlling factors and characteristics of sampling locations in the lake.PCA results demonstrated major three factors contributing to water quality in lake with a 73.89% of cumulative variance. Similarly, CA results characterized sampling locations into four clusters indicating differentiation in the chemical concentrations. Results of the assessment through PCA, CA and comparison with other Himalayan lakes showed that Rajarani Lake is not severely affected by the pollution because it is still unexplored and thus pristine in nature. This study suggests that water quality of lake environment needs to be further investigated, focusing on depth-wise and temporal levels for its sustainability.

**Keywords:** Hydrochemical characterizations; Water quality; Rajarani Lake; Principle component analysis; Cluster analysis

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## INTRODUCTION

High altitude freshwater ecosystems have an important ecological function but are under increasing impacts from anthropogenic activities and climate change. In the recent decade, due to rapid industrialization and haphazard urbanization, water quality throughout the globe have largely degraded creating more vulnerable situation in developing countries (Pant et al., 2018; Pal et al., 2019). Water quality deterioration has a serious impact on ecosystems and the environment, which is much more significant than one might imagine. Freshwater occupies ~ 2.50% of the total water on earth, out of which <1% is accessible to humans for domestic, irrigation and industrial usages. Given the small amount of freshwater and its increasing depletion has resulted in a shortage of usable water resources, which is an emerging problem in the 21$^{st}$ century that needs to be given more attention (Sun et al., 2010).

Lakes are an integral part of the hydrological cycle, important water resources for irrigation, household water supply, transportation, fishing, biodiversity conservation and environmental balance (Wiegand et al., 2013). Due to its open exposure and easily accessible to agricultural pollutants and surface runoff, lake water gets contaminated more quickly than groundwater (Bu et al., 2010). The quality of water in these lakes depends not only on natural processes such as precipitation inputs, erosion and weathering of crustal material and inter-relationship between biota but also on anthropogenic influences such as urban sprawl, industrial and agricultural activities (Sun et al., 2010; Lopez-Moreno et al., 2011; Diamantini et al.,2018) Lakes are inland bodies of water that lack natural purification and resilience like lotic water bodies, and quality of lake water is essential in maintaining a healthy lake ecosystem (Bhateria and Jain, 2016). There are numerous enclosed water bodies all over Nepal, including lakes, ponds, dams, and other small wetlands (Jha, 2008; Gurung et al., 2019). A recent report of the National

Lakes Conservation Development Committee has identified a total of 5,358 lakes in Nepal (including 2,323 glacial lakes) spreading at different elevations and locations (Jha, 2008; Taylor et al., 2014).

As a result of rapid development of human society, socio-economic growth, technological advancement and climate change, lake itself is having severe problems like shrinkage, pollution, contamination of potentially toxic trace elements, salinization and eutrophication (Rupakheti et al., 2017; Pant et al., 2019c). Similarly, long-range transport of pollutants to the Himalaya could load nutrients on lake ecosystem and enhance eutrophication (Pant and Adhikari, 2015; Bhattarai et al., 2019b; Ram et al., 2020). This sediment loads strongly influences multi-usage components of lake water (Filik et al., 2008; Zhong et al., 2018). Moreover, high level of aerosol optical depth and clear indication of biomass burning on Himalayan atmospheric environment is reported by tracers (Bhattarai et al., 2019a; Bhattarai et al., 2019b; Wan et al., 2019), and these aerosols constitute a wide range of carbonaceous substances, such as black carbon (Neupane et al., 2019) and mercury (Sun et al., 2020). These pollutants, once deposited to aquatic ecosystems, could adversely affect water quality resulting bioaccumulation and biomagnifications (Pant , 2013; Pant et al., 2018). However, it is inferred that water quality in most countries has become a critical issue as there is a limited volume of freshwater. Therefore, considering the multiple uses of lake water and concern for environmental and public health, systematic study of spatial and temporal changes through water quality monitoring is very important for the management of water and in controlling degradation of water quality (Papatheodorou et al., 1999; Papatheodorou et al., 2006).

Water quality monitoring programs have generated an enormous database and these large data sets are often difficult to analyze for meaningful interpretation. Thus, they require a data reduction method to simplify their structure and extract useful and interpretable information (Simeonova and Simeonov, 2006). Multivariate treatment of environmental data is widely used to characterize and evaluate surface water quality. Analysis such as cluster, correlation, descriptive and principle component seeks to explain governing processes by reducing and classifying data and are applied primarily to hydrochemistry and water quality assessment (Voudouris et al., 2000; Lambrakis et al., 2004). These techniques simplify large data sets by grouping them into components or clusters based on their relationships between specified variables. Correlation coefficient measures the relationship between dependent and independent variables. If correlation coefficient is +1 or −1, it shows perfect linear relationship between the variables, while most of the values of hydrochemical variables lie in between +1 and −1 (Shrestha, 2018).

Rapid growth in the numbers of tourists and other anthropogenic activities in Rajarani lake area may cause water quality deterioration. Water pollution in the lake became a common visible criterion and it has been exacerbated in last few decades, primarily because of population growth and changing climatic conditions. Since a study of lake environment in mid-land regions of Nepal is minimal and those a few were reported from the central areas (Pant et al., 2019a; Pant, 2019b; Pal et al., 2019).Therefore, there is a need to determine the aspects of pollutions as well as their levels for academic research, policy and other perspectives. Thus, the objective of this paper is to analyze the hydrochemistry and assess the water quality of Rajarani Lake, Nepal by using multivariate statistical tool and geochemical indices.

## MATERIAL AND METHODS

### Study area

Rajarani Lake is situated in Dhankuta district of Province 1, Central Himalaya of eastern Nepal and is approached from a distance of 37 km away from Dharan Sub-metropolitan City (Fig. 1). This region is made up of grey and white quartzite garnet-biotite-muscovite-quartz schist and gneiss. The nature of soil present is non-plastic and is formed by in-situ weathering of parent rock. Deep gullies are prominent features caused by intensive erosion and denudation of soil. Because of its natural beauty, Rajarani lake is a popular destination for tourists and trekkers and recently explored touristic location. It is situated at $26^0$88' 93" N and $87^0$43'48" E with the altitude of 1600 m a.s.l. Lake covers an area of ~ 0.20 $km^2$ and depth up to 9 m, and N-S elongated and surrounded by forest of *Myrica esculenta, Castanopsis sp., Rhododendron arboreum, Pinus roxburghii* and *Alnus nepalensis* (Shrestha and Rai, 2017).

### Sampling and analysis

Water samples were collected during winter (January, 2020) in clean plastic bottles with full precaution. Samples were carefully transported and stored under freezing conditions before further analysis. A total of 20 purposive samples were collected from the surface of Rajarani Lake (ten from the periphery and ten from the middle portion of the lake). Lake is groundwater-fed and water leaches out from the surrounding forest. Water that arrives from forested land was considered

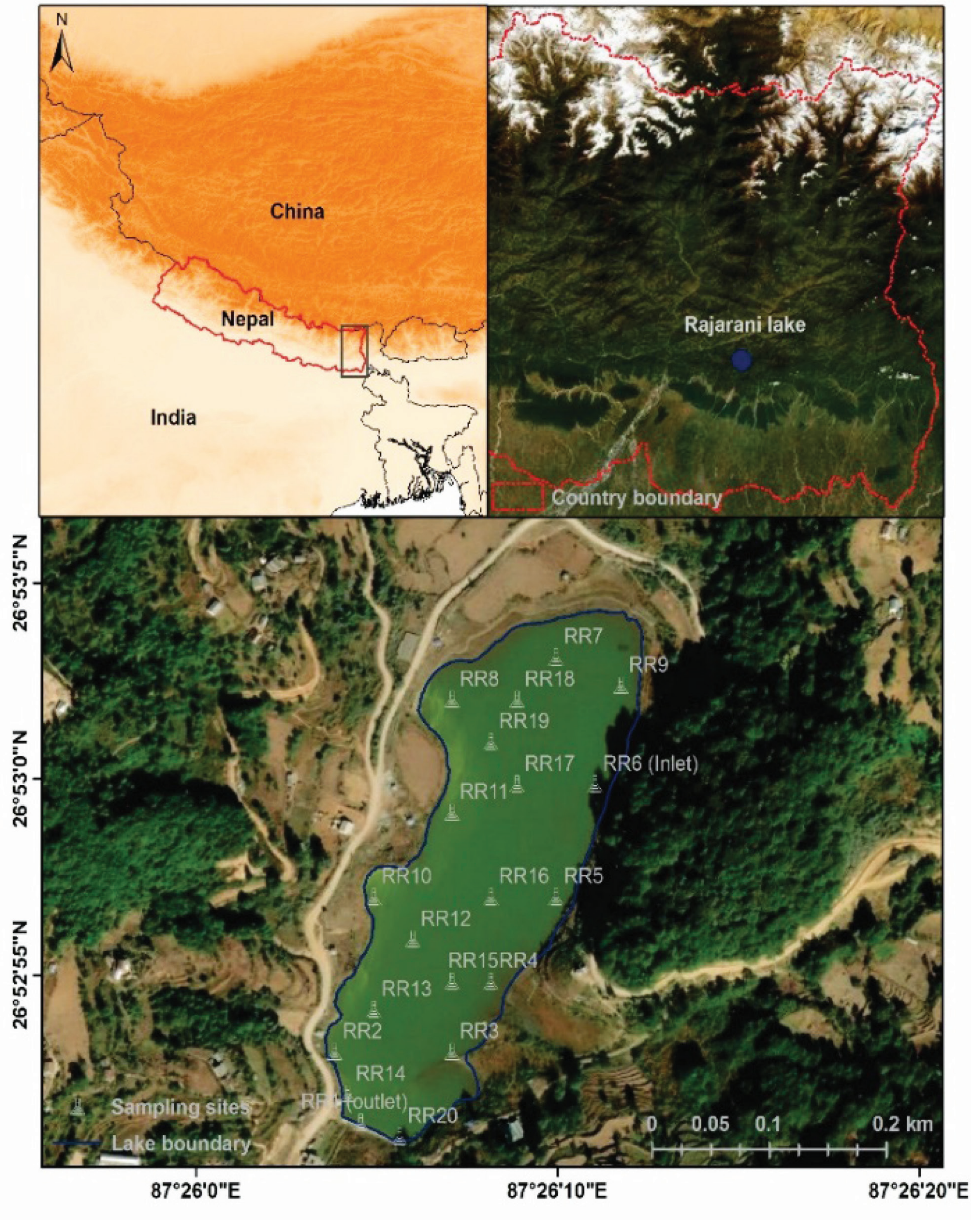


**Fig. 1: Map of study area of the Rajarani Lake, Dhankuta, Province 1, Nepal.**

inlet of the lake in this study. Sites were selected, which represent a maximum area of lake with inlet, middle and the outlet. Parameters like water temperature (WT), pH, electrical conductivity (EC), total dissolved solid (TDS), oxidation-reduction potential (ORP), and turbidity were analyzed at the sampling site following the standard protocol and method of American Public Health Association (APHA) and American Society for Testing and Material (ASTM) using calibrated standard Instrument i.e. multi-parameter probe and dissolved oxygen (DO) was also measured onsite using DO meter.

The chemical parameters like total hardness (TH), calcium hardness (CaH), magnesium hardness (MgH), alkalinity ($HCO_3^-$) and chloride content ($Cl^-$) were analyzed using titrimetric method. Other chemical parameters like ammonium ($NH_4^+$), nitrate ($NO_3^-$), iron ($Fe^{2+}$) and phosphate ($PO_4^{3-}$) were analyzed by using UV-visible spectrophotometer. Potassium ($K^+$), Calcium ($Ca^{2+}$), Magnesium ($Mg^{2+}$) and Sodium ($Na^+$) were analyzed using Flame Photometer in laboratory of Central Department of Environmental Science, under the Institute of Science and Technology, Tribhuvan University (CDES-TU), Kathmandu, Nepal.

### Statistical analysis

All statistical analyses were conducted using SPSS 26 and OriginPro 9.0. Following are some of the statistical techniques for the analysis and interpretation of the dataset.

### Cluster analysis (CA)

CA is widely applied to access the variability and classify objects or clusters to reveal their intrinsic characteristics based on their nearness or similarity. In this study, hierarchical agglomerative CA was performed on the normalized data set using Ward's method, where the missing data were replaced with the mean of the case. Ward's method is the most commonly used manner among several clustering algorithms (Hajigholizadeh and Melesse, 2017) and it is an extremely powerful method to group the cases for hierarchical agglomerative clustering (Willett, 1987; Panda, 2006). It is also the most common approach that forms higher clusters step by step using Euclidean distances as a measure of similarity. The clustering result is usually illustrated by a dendrogram which provides a visual summary of the clustering processes, exhibiting high internal (within a cluster) homogeneity and high external (between clusters) heterogeneity (Hajigholizadeh and Melesse, 2017). In this study, the Euclidean distance between-groups linkage method was used as a measure of similarity.

### Principle component analysis (PCA)

PCA is applied to extract significant principal components (PCs). By explaining the correlation among several random uncorrelated environmental variables in terms of a small number of underlying factors or PCs, PCA can reduce the dimensionality of the dataset without extreme loss of information (Vega et al., 1998). Each PC is significantly correlated to specific variables representing a different dimension of the water quality (Zhao et al., 2011). Additionally, PC provides information on the most meaningful parameters, which describe a whole dataset affording data reduction with minimum loss of its original value (Helena et al., 2000).

### Correlation matrix (CM)

CM is adopted to identify the potential new associations among measured variables. The Spearman rank-order correlation coefficient (Spearman's correlation) is a nonparametric measure of strength and direction of association that exists between two variables (Hauke and Kossowski, 2011). In this study, Spearman's correlation was used to assess the potential association among different hydrochemical variables.

## RESULTS AND DISCUSSION

### General hydrochemistry

The overall results obtained from twenty samples, both in-field measurement and laboratory analysis are presented in Table 1. The table contains minimum, maximum, average and standard deviations of all twenty different variables. The temperature of surface water is affected by multiple variables such as diurnal sunshine, weather, terrain, slope and aspects, and source region temperature of inlets and groundwater. In addition, temperature plays a vital role in controlling the physiochemical and biological parameters of water, and also considered as one of the most crucial parameters in freshwater environment. In this study, the average temperature was $10.07 \pm 0.58$ recorded in lake (Table 1), which is relatively low as compared to many other freshwater lakes in Nepal. pH is a measure of the acidity or alkalinity of water, expressed in terms of its concentration of hydrogen ions. In present study, its value ranged from 8.42 to 10.37 in the sampling sites with an average of $8.71 \pm 0.46$.pH is most important in determining corrosive nature of water. Generally, pH value of 6.50 to 8.50 is suitable for the growth and development of aquatic organisms, in this study the mean pH values lies with the prescribed limit.

Similarly, the amount of dissolved solid determines the electrical conductivity (EC) of water (Meride and Ayenew, 2016). EC is a useful tool to evaluate the purity of water. The mean EC recorded in lake (54 µS/cm) is within the WHO guideline, indicating that lake water was not much ionized and has lower level of ionic concentrations due to minor dissolved solids (WHO, 2004). The low TDS values indicate small concentrations of minerals in water. Maximum limit for TDS is 1000 mg/L, which is prescribed for drinking purposes (WHO, 2004). In this study, TDS values ranged from 50 to 70 mg/L, with an average value of 32 mg/L, which is below the maximum permissible limit.

Oxidation-reduction (redox) reactions can affect drinking water treatment and distribution in a significant way. Measurements of oxidation-reduction potential (ORP) in water reflect the tendency of major constituents in water to accept or lose electrons (Copeland and Lytle, 2014). The higher value of ORP i.e., 172 millivolt (mV) reflects presence of higher amount of oxygen in water, which indicated that bacteria easily decompose dead tissue and contaminate water.

**Table 1: Descriptive statistics of hydrochemical variables of the Rajarani Lake, Dhankuta, Nepal.**

| Parameters | Min | Max | Mean | SD |
|---|---|---|---|---|
| Temp | 9.20 | 11.00 | 10.07 | 0.58 |
| pH | 8.42 | 10.37 | 8.71 | 0.46 |
| EC | 50.00 | 70.00 | 54.05 | 6.86 |
| TDS | 28.00 | 50.00 | 32.15 | 6.57 |
| ORP | 105.00 | 253.00 | 171.57 | 36.79 |
| DO | 5.10 | 6.42 | 5.83 | 0.32 |
| Tub. | 0.98 | 11.60 | 8.97 | 2.21 |
| $Ca^{2+}$ | 3.20 | 8.00 | 5.56 | 1.17 |
| $Mg^{2+}$ | 0.49 | 3.90 | 1.96 | 1.24 |
| $K^{+}$ | 2.58 | 2.76 | 2.67 | 0.07 |
| $Na^{+}$ | 7.00 | 9.70 | 8.09 | 0.53 |
| $Cl^{-}$ | 7.1 | 14.91 | 11.64 | 1.91 |
| $NH_4^{+}$ | 0.31 | 0.40 | 0.37 | 0.02 |
| $NO_3^{-}$ | 0.06 | 0.07 | 0.06 | 0.01 |
| $PO_4^{3-}$ | 0.21 | 0.32 | 0.25 | 0.03 |
| $Fe^{2+}$ | 0.49 | 0.87 | 0.62 | 0.10 |
| TH | 14.00 | 36.00 | 22.05 | 7.20 |
| CaH | 10.00 | 20.00 | 14.00 | 2.75 |
| MgH | 2.00 | 16.00 | 8.05 | 5.07 |
| $HCO_3^{-}$ | 25.00 | 40.00 | 32.75 | 4.44 |

Dissolved oxygen (DO), is another essential component for water quality, ecological status, productivity and in overall health of a lake and reflects physical and biological processes of aquatic life. The average DO concentration of Rajarani Lake was noted to be 5.83 mg/L ranging from 5.10 to 6.42 mg/L. Lower level of oxygen in the lake might be due to lower amount of light, and low photosynthetic activity in lake environment. DO concentrations are constantly affected by diffusion and aeration, photosynthesis, respiration and decomposition processes (Kumar et al., 2017). Turbidity of water is related to the expression of optical property and reflects the intensity of light scattered by particles present in water. Turbidity reported in our study ranged from 0.98 NTU to 11.60 NTU, with an averaged value of 8.97 ± 2.21 NTU (Kumar and Ravindranath, 1998).

Alkalinity predominantly derived from the weathering of carbonate and silicates minerals. Carbonate alkalinity occurs only in the absence of carbon dioxide and when pH is > 8.30 mg/L (Dutta and Molhotra, 1986). The average alkalinity of Rajarani Lake is 33 ± 4.44 mg/L ranging from 25 to 40 mg/L. Carbonate and bicarbonate ions are major drivers of total alkalinity. Total hardness includes bicarbonates, chlorides and sulphates of calcium and magnesium, etc. This study shows that total hardness ranged from 14-36 mg/L, with an average value of 22.05 mg/L. The highest amount of calcium content in water recorded as 8 mg/L while the lowest 3.20 mg/L, with the mean 5.56± 1.17mg/L. Calcium is one of the most abundant ions in freshwater and plays a pivotal role in shell construction, bone-building etc. Magnesium act similar phenomenon as calcium, in an ion exchange reaction and influences the absorption of sodium equally (Potasznik and Szymczyk, 2015). $Ca^{2+}$ and $Mg^{2+}$ are essential ions of surface waters mostly influenced by catchment geology (Sharifinia et al., 2013). The highest amount of magnesium is 3.90 mg/L and minimum is 0.49 mg/L. The amount of magnesium is essential for chlorophyll bearing plant for photosynthesis and acts as a limiting factor for growth of phytoplankton (Dagaonkar and Saksena, 1992).

According to Solanki and Pandit (2006), the concentration of chlorides can be related to purity or impurity of water and mainly derived from halite dissolution from underlying geology, and the process of cyclic salt deposition. The chloride concentration in water ranged from 7.10 mg/L to 14.91 mg/L, with mean of 11.64 ±1.91 mg/L. High amount of $Cl^{-}$ ions are mainly from anthropogenic sources, which might have originated from domestic effluents and roads (Paudyal et al., 2016). High chloride concentrations indicate the presence of organic matter, presumably of animal origin (Pant, 2013; Tripathee et al., 2014).

The proper quantity of sodium in human body prevents many fatal diseases like kidney damages, hypertension, headache, etc. In most of the countries, the amount of water supply bears less than 20 mg/L, while in some countries, the sodium quantity in water exceeded 250 mg/L (WHO, 1984). Mean sodium concentration in the lake is 8.09 mg/L, with the highest and lowest value as 9.70 mg/L and 7 mg/L, respectively. The highest amount of sodium is by addition of wastewater containing soap solution while the lowest amount is because of bioaccumulation by living organisms. Potassium deficiency may lead to depression, muscle weakness, heart rhythm disorder, etc. The mean concentration of potassium in this study was found to be 2.67± 0.7 mg/L, which is with the WHO permissible limit for drinking water.

## Multivariate Statistical Analysis

*Hierarchical cluster analysis*

Cluster analysis (CA) is a system connected to gathering the information into groups or classes. Hierarchical agglomerate cluster gives instinctive closeness among the dataset and is regularly outlined by a dendrogram (McKenna, 2003). In this study hierarchical agglomerative CA was performed on the normalized dataset by Ward's method, using Squared Euclidean distance as a measure of similarity. It yielded a dendrogram (Fig. 2), grouping all 20 sampling sites of the lake into four statistically significant clusters with low distance criteria between 0 and 5. The classification varied with significant level because each cluster is recognized by different hydrological, geological and climatic conditions (Pant et al., 2018). CA grouped similar observations into four different clusters based on the observed values.

Cluster 1 formed by 4 sampling sites (i.e., site: 4, 5, 6 and 7) out of 20 which shows the influence of matter received from relatively disturbance sites i.e. periphery of lake. Sites 2 and 3 have fewer disturbances

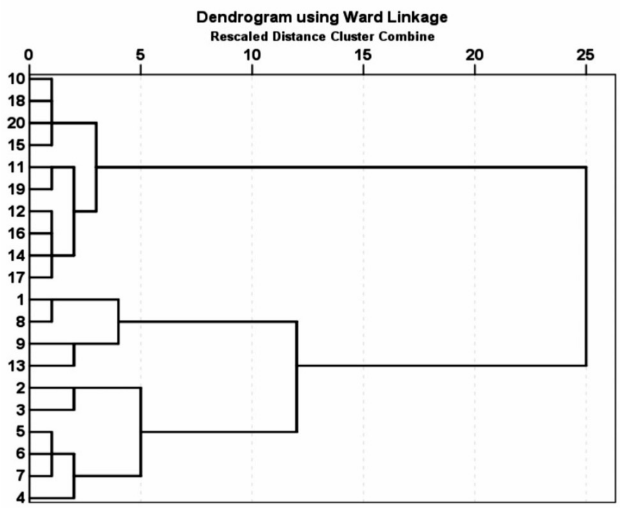


**Fig. 2: Dendrogram of the hydrochemical variables in the Rajarani Lake based hierarchical cluster of sampling sites, Nepal.**

and are the area near inlet and formed Cluster 2. The reason for being less disturbed might be because human intervention at this site is not possible as it lies in hillside region. Sites 1, 8, 9 and 13 are placed in Cluster 3, which lies just near to the road, any runoff that comes out from the roadside would reach these sites. The rest of the sampling sites (i.e., site: 10, 18, 20, 15, 17, 11, 19, 14, 16 and 12) formed Cluster 4, which mostly lie in the middle portion of the lake, where there is less anthropogenic disturbance.

*Principal component analysis (PCA)*

PCA provides information on the most meaningful parameters which describe a complete dataset allowing data reduction with minimum loss of original information (Helena et al., 2000; Singh et al., 2005). PCA transforms original variables into a smaller set of independent variables (Vega et al., 1998), called principal components (PCs). PCA was performed on 13 variables that are possibly correlated, including EC, TDS, major ions ($Ca^{2+}$, $Mg^{2+}$, $Fe^{2+}$, $NH^{4+}$, $Cl^-$, $NO_3^-$, and $PO_4^{3-}$), total hardness, calcium hardness, magnesium hardness and alkalinity (HCO3-) (Fig.3). PCA results of the selected variables are presented in Table 2, and it indicates leading PCs with loading values for each parameter. Loading values are classified > 0.75, 0.75-0.50, and 0.50-0.30 as strong, moderate, and weak, respectively (Pant et al., 2018).

PC1 accounts for 40.69% of total variance with strong positive loading value of ions of calcium, and magnesium, total hardness, calcium hardness and magnesium hardness. The first component was loaded with crustal elements. However, due to fossil fuel combustion and solid waste dumping, some minor contributions could also be of anthropogenic origin (Paudyal et al. 2016).

**Table 2: Varimax rotated component matrix of hydrochemical variables of the Rajarani Lake, Dhankuta Nepal.**

| Parameter | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| EC | 0.24 | 0.87 | -0.20 |
| TDS | 0.24 | 0.87 | -0.20 |
| $Ca^{2+}$ | 0.93 | -0.01 | 0.19 |
| $Mg^{2+}$ | 0.84 | 0.22 | -0.20 |
| $Cl^-$ | -0.06 | 0.00 | 0.80 |
| $NH_4^+$ | -0.79 | -0.12 | 0.21 |
| $NO_3^-$ | -0.27 | 0.64 | 0.01 |
| $PO_4^{3-}$ | 0.39 | 0.71 | .14 |
| $Fe^{2+}$ | -0.46 | 0.34 | 0.46 |
| TH | 0.95 | 0.13 | -0.08 |
| CaH | 0.93 | -0.04 | 0.14 |
| MgH | 0.84 | 0.22 | -0.20 |
| $HCO_3^-$ | 0.04 | -0.33 | 0.56 |
| % of Variance | 40.69 | 21.79 | 11.41 |
| Cumulative % | 40.69 | 62.48 | 73.89 |

PC2, accounting 21.79% of total variance, has strong and moderate positive loading on EC, TDS, $NO_3^-$ and $PO_4^{3-}$. These variables are highly correlated with each other as well, since, EC and TDS have a direct relationship with each other. Several factors may have contributed to this situation, such as climatic conditions, especially during dry seasons, where increased evapotranspiration rate may have contributed to the increased salinity of water. PC3 with total variance of 11.41% has strong, moderate and weak positive loadings of $Cl^-$, $HCO_3^-$, and $Fe^{2+}$, respectively. The source of these elements could be of anthropogenic origin because of solid waste dumping.

Factor loading plot of PCs (Fig. 3) also has a good agreement with the above-mentioned explanations that $Ca^{2+}$, $Mg^{2+}$, TH, CaH and MgH have some positive linkage. In contrast, EC and TDS are closely associated with each other. Similarly, $NO_3^-$ and $PO_4^{3-}$ also has a positive relation with TDS and EC. Likewise, alkalinity ($HCO_3^-$) and $Cl^-$ are linked with each other and $NH_4^+$ and $Fe^{2+}$ showed good association. This analysis shows that majority of elements might be derived from the crustal origin; however, there has been evidences of some anthropogenic emissions too.

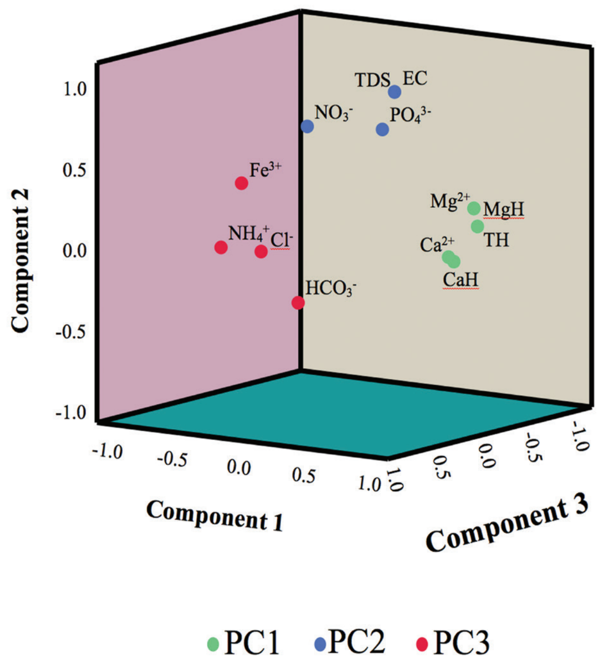


**Fig. 3: Principal component analysis of the hydrochemical variables of the Rajarani Lake, Nepal.**

### Correlation matrices of hydrochemical variables

The Spearman correlation coefficient of parameters was calculated and is shown in Table 3. Strong positive and negative correlations among various physicochemical parameters were obtained during analysis. It increases the ability to obtain an overview of dataset, thus enabling us to identify variables which have a greater significance to this study. Temperature has a significant positive correlation with pH, EC, TDS, $Mg^{2+}$, $PO_4^{3-}$, and TH at 99% confidence interval indicating presence of dissolved salt, separates into ions electrically charged atoms and other organic and inorganic components in the lake. However, temperature was negatively correlated with $NH_4^+$ ($r = -0.59$, $p < 0.01$) which implies decrease in ammonium with increase in temperature in lake. pH in the lake is mainly driven by $Mg^{2+}$ and TH related compounds as they are positively correlated at a 99% confidence interval. EC showed high correlation with TDS. TH being sum of calcium hardness and magnesium hardness thus shows high correlation with them as well as shows a positive correlation with their ionic forms.

### Comparative analysis

Hydrochemical characteristics of Rajarani lake and other selected lakes for the comparative assessment are shown in Table 4. EC values in previous studies of the Himalayan region was tabulated and compared with this study. In present study, mean value of EC is 54µS/cm, which is one of the lowest compared to other lakes in Table 4. EC reflected lower ionic strengths in water of Rajarani lake, and thus low values of TDS. The amount of mineral and salt impurities dissolved in water can affect the amount of salt build-up in agricultural land, corrosion of pipes, and toxicity of drinking water and hence affect EC. Most of the EC values of lakes were < 500 µS/cm, while only a few lakes exceeded. Highest EC values of lake recorded were, Tsokyo Tso Lake with value 820 µS/cm followed by Nainital with a value 706 µS/cm. Similarly, following the pattern of EC, TDS value of the present study is found to be lowest i.e.32.15 mg/L, compared to other lakes of Himalayas region. Table 4 clearly shows highest TDS value in Tsokyo Tso of 525 mg/L, followed by Nainital of 452 mg/L. Higher value of TDS is generally harmful to both human and ecological health. The mean pH value of present lake recorded is 8.71, which is comparable to other Himalayas lakes (Table 4). However, two lakes were reported having pH values < 7, namely Sella and Tsokyo Tso, indicating acidic environmental conditions in the lakes. High pH indicates that carbon dioxide, carbonate and bicarbonate equilibrium is affected. Similarly, three lakes are reported to have pH values > 9, namely in the Suraj, Sattal and Naukuchiya lakes, indicating highly alkaline environment and exceed WHO guideline value.

The average anionic concentration (mg/L) of the present study following the pattern of dominance is $HCO_3^- > Cl^- > NO_3^-$, which is comparable to many other lakes of Himalayan. Alkalinity values of 20-200 mg/L are common in freshwater ecosystem. The lower alkalinity value indicates inadequate buffering capacity of water that means these water are least capable of resisting changes in pH and therefore are most

**Table 3: Correlation matrices of hydrochemical variables of the Rajarani Lake, Dhankuta, Nepal.**

| Para. | Temp. | pH | EC | TDS | ORP | DO | Tub | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $Na^+$ | $Cl^-$ | $NH_4^+$ | $NO_3^-$ | $PO_4^{3-}$ | $Fe^{2+}$ | TH | CaH | MgH | $HCO_3^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1.00 | | | | | | | | | | | | | | | | | | | |
| pH | 0.75** | 1.00 | | | | | | | | | | | | | | | | | | |
| EC | 0.79** | 0.44 | 1.00 | | | | | | | | | | | | | | | | | |
| TDS | 0.79** | 0.44 | 0.99** | 1.00 | | | | | | | | | | | | | | | | |
| ORP | 0.34 | 0.42 | -0.03 | -0.03 | 1.00 | | | | | | | | | | | | | | | |
| DO | -0.48* | -0.55* | -0.12 | -0.12 | -0.33 | 1.00 | | | | | | | | | | | | | | |
| Tub | -0.19 | -0.37 | -0.25 | -0.25 | -0.20 | 0.09 | 1.00 | | | | | | | | | | | | | |
| $Ca^{2+}$ | 0.48* | 0.55* | 0.24 | 0.24 | 0.23 | -0.24 | -0.06 | 1.00 | | | | | | | | | | | | |
| $Mg^{2+}$ | 0.69** | 0.66** | 0.46* | 0.46* | 0.07 | -0.46* | -0.13 | 0.68** | 1.00 | | | | | | | | | | | |
| $K^+$ | -0.27 | -0.55* | -0.06 | -0.06 | -0.21 | 0.22 | 0.21 | -0.37 | -0.49* | 1.00 | | | | | | | | | | |
| $Na^+$ | 0.21 | 0.12 | 0.08 | 0.08 | 0.22 | -0.03 | -0.39 | 0.28 | 0.26 | -0.18 | 1.00 | | | | | | | | | |
| $Cl^-$ | -0.33 | -0.08 | -0.23 | -0.23 | 0.19 | -0.16 | -0.10 | -0.05 | -0.28 | 0.05 | 0.10 | 1.00 | | | | | | | | |
| $NH_4^+$ | -0.59** | -0.51* | -0.45* | -0.45* | -0.34 | 0.29 | 0.07 | -0.63** | -0.52* | 0.03 | -0.20 | 0.19 | 1.00 | | | | | | | |
| $NO_3^-$ | 0.12 | -0.08 | 0.34 | 0.34 | -0.44* | -0.16 | 0.31 | -0.17 | -0.08 | 0.07 | -0.43 | -0.03 | -0.04 | 1.00 | | | | | | |
| $PO_4^{3-}$ | 0.71** | 0.54* | 0.55* | 0.55* | 0.34 | -0.31 | -0.10 | 0.54* | 0.38 | -0.29 | 0.28 | -0.07 | -0.41 | 0.21 | 1.00 | | | | | |
| $Fe^{2+}$ | -0.20 | -0.30 | 0.09 | 0.09 | -0.26 | 0.34 | 0.22 | -0.38 | -0.34 | -0.05 | -0.33 | 0.13 | 0.52* | 0.33 | 0.07 | 1.00 | | | | |
| TH | 0.61** | 0.64** | 0.36 | 0.36 | 0.13 | -0.41 | -0.08 | 0.89** | 0.93** | -0.47* | 0.30 | -0.15 | -0.59** | -0.11 | 0.49* | -0.36 | 1.00 | | | |
| CaH | 0.48* | 0.54* | 0.23 | 0.23 | 0.24 | -0.23 | -0.05 | 0.99** | 0.67** | -0.37 | 0.27 | -0.06 | -0.62** | -0.18 | 0.54* | -0.37 | 0.88** | 1.00 | | |
| MgH | 0.69** | 0.66** | 0.46* | 0.46* | 0.07 | -0.46* | -0.13 | 0.68** | 0.99** | -0.49* | 0.26 | -0.28 | -0.52* | -0.08 | 0.38 | -0.34 | 0.93** | 0.67** | 1.00 | |
| $HCO_3^-$ | -0.18 | 0.02 | -0.29 | -0.29 | 0.29 | 0.12 | 0.32 | 0.07 | -0.17 | 0.13 | -0.37 | 0.26 | 0.03 | -0.11 | -0.17 | -0.01 | -0.10 | 0.08 | -0.17 | 1.00 |

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2tailed).

**Table 4: Comparison of hydrochemical variables of the Rajarani Lake with the selected lakes of Nepal, India and the guideline values.**

| Lake | EC | TDS | pH | $HCO_3^-$ | $^-Cl$ | $NO_3^-$ | $Ca^{2+}$ | $Mg^{2+}$ | $^+Na$ | $^+K$ | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rajarani | 54 | 32 | 8.71 | 32.75 | 11.64 | 0.06 | 5.56 | 1.96 | 8.09 | 2.67 | Present study |
| Begnas | 91 | 58 | - | 25.3 | 2.6 | 5.3 | 7 | 2 | 3.9 | 1.4 | Khadka & Ramanathan, 2013 |
| Suraj | 140 | 90 | 9.1 | 130 | 5 | 0.1 | 32.1 | 10.5 | 2.6 | 0.3 | Singh et al., 2014 |
| Sissu | 200 | 128 | 8.5 | 286 | 56 | 4.1 | 53 | 30 | 10.5 | 2.7 | Singh et al., 2014 |
| Deepak | 130 | 83 | 8.8 | 120 | 4.3 | 0.1 | 30.5 | 8.8 | 2.8 | 0.3 | Singh et al., 2014 |
| Renuka | 590 | 378 | 8.4 | 146 | 11.9 | - | 57.7 | 38.3 | 8.3 | 2 | Das & Kaur, 2001 |
| Pandoh | 81 | 52 | 7.1 | 49.2 | 2.4 | 10.3 | 18 | 3.3 | 3.8 | 2.1 | Anshumali & Ramanathan, 2007 |
| Nainital | 706 | 452 | 8.7 | 351 | 15.3 | - | 32.7 | 59.3 | 13.1 | 3.7 | Das, 2005 |
| Sattal | 119 | 76 | 9.7 | 54.4 | 7.3 | - | 11.1 | 5.4 | 2.7 | 0.7 | Das, 2005 |
| Bhimtal | 181 | 116 | 8.9 | 91.1 | 6.4 | - | 19.8 | 6.7 | 4.4 | 2.1 | Das, 2005 |
| Naukuchiya | 148 | 95 | 9.4 | 73.9 | 6.6 | - | 14.6 | 5.5 | 4.3 | 0.2 | Das, 2005 |
| Sella | 520 | 333 | 6.1 | 11.3 | 0.5 | 0.7 | 0.9 | 0.3 | 2.2 | 0.3 | Deka et al. 2015 |
| Tsokyo Tso | 820 | 525 | 6.5 | 9.5 | 0.6 | 0.8 | 1.3 | 0.3 | 0.9 | 0.5 | Deka et al., 2015 |
| Chandra | 212 | 136 | 8.1 | 118 | 0.5 | 0.5 | 22.4 | 13.2 | 0.9 | 1.4 | Singh et al., 2016 |
| Mansar | 416 | 267 | 8.4 | 96.83 | - | 0.63 | 21.6 | 6.45 | 11.02 | 2.68 | Kumar et al., 2006 |
| Surinsar | 545 | 349 | 8.4 | 127 | - | 0.5 | 38 | 13 | 10 | 0.4 | Singh et al., 2016 |
| *NWQGAC | 1500 | 1000 | 6.5-8.5 | - | 50 | - | - | - | - | - | Nepal Gazette, 2006 |
| *WHO | 1500 | 1000 | 6.5-8.50 | 600 | 250 | 50 | 100 | 50 | 200 | 100 | WHO, 2011 |

*Guideline values

and 19.10 mg/L, respectively). Unlike other parameters, $NO_3^-$ concentration in present study is found to be lowest among all other lakes in the table (i.e. 0.06 mg/L). $NO_3^-$ was recorded high in Pandoh lake, Laxmi lake and Sissu lake (i.e., 10.30 mg/L, 6.26 mg/L and 4.10 mg/L, respectively) and thus not comparable with this study.

$Na^+$ concentration in present study is found to be highest among other cation concentrations in lake, which shows the contrasting results while comparing with other Himalayan lakes. $Na^+$ concentration in present lake is 8.09 mg/L, which can be compared with the few Himalayan lakes, while others have lower concentrations. The highest amount of sodium occurs by weathering of silicate dominated minerals in addition to wastewater containing soap solution and the lowest amount can be because of bioaccumulation by living organisms. Some other lakes in the Himalaya such as Nainital (13.10 mg/L) have recorded the highest $Na^+$ concentration.

This present study contains a lower concentration of $Ca^{2+}$ (5.56 mg/L), which is one of the lowest among other lakes compared. Lowest concentration of $Ca^{2+}$ was found to be of Sella 0.90 mg/L and Tsokyo Tso which is 1.30 mg/L. Similarly, a lower concentration of $Mg^{2+}$ (1.96 mg/L) of present study is comparable to a few lakes in Table 4. The highest $Mg^{2+}$ concentration was recorded of Renuka lake 38.30 mg/L and the lowest of Tsokyo Tso and Sella (0.30 mg/L). The concentration of $K^+$ in present lake is 2.67 mg/L. Highest $K^+$ concentration was recorded in Nainital of 3.70 mg/L and lowest of Naukuchiya lake of 0.20 mg/L. Thus, the status of ionic strength of Rajarani lake is relatively lower than other lakes. Finally, all results of present study were found within the range of WHO and NWQGAC guideline values and comparable with other Himalayan freshwater lakes.

## CONCLUSIONS

With the multivariate statistical methods, surface water quality is experimentally analyzed in Rajarani Lake located on the southern slope of Central Himalaya, Nepal. Twenty sampling sites were set on the lake and twenty parameters were measured in each sampling site to evaluate surface water quality. Major ions follow the order of $Na^+ > Ca^{2+} > K^+ > Mg^{2+} > Fe^{2+}$ for cations, and $HCO_3^-$>$Cl^-$ >$PO_4^{3-}$ >$NO_3^-$ for anions. PCA reduced multivariate data to three components that could show the potential relationship among different hydrochemical variables. From cluster analysis, it was found that spatial classifications are exactly consistent with the geographical locations of sampling sites, and water quality is better in the middle portion and the area near outlet. The correlation matrix showed an indication of carbonate dominated lithology in lake basin. The comparative assessment showed that the lake was found in ecologically acceptable conditions and the major measured chemical parameters were below the guidelines of WHO for drinking water and also mostly meet the guidelines of NWQGAC.

This study provides detailed information on the water quality of Rajarani Lake. The result of the research concludes that the lake is not severely affected by the pollution because it is still unexplored and pristine. However, it is necessary to adopt control measures to minimize the addition of inputs from various sectors, especially anthropogenic interference considering its tourism potential. Thus, water quality of lake environments needs to be further investigated, focusing on depth-wise and temporal levels.

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## AUTHOR’S CONTRIBUTIONS

R.R. Pant conceived and designed the study and drafted the manuscript. B. Adhikari did sampling and data collection, along with first draft preparation. S. Neupane, A. Acharya and B. Khanal carried out laboratory analysis. S. Shrestha did statistical analysis and study area map preparation. H. Bhattrai revised and review the figures and tables. U. Baral participated in the revision and coordination processes during the manuscript preparation. All authors reviewed and approved the final manuscript.

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