Research Article

First results on physico-chemical status and bathymetry of lakes in Ramaroshan Wetland, Far-West Nepal

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Abstract
This study investigates the bathymetry of three major lakes and the water quality of nine lakes at Ramaroshan Lake Complex Area (RLCA), Far-Western Nepal. Lakes were surveyed based on line transects using Echosounder (depth measuring gauge) and GPS to collect the data for bathymetry. Water samples were collected from 43 sites of nine lakes, considering the land use patterns, anthropogenic activities, inlets, and outlets. Twenty physico-chemical parameters were analyzed to know the water characteristics and pollution level. The bathymetry map showed that Jingale is the deepest lake (44 m), followed by Batula (15 m) and Mathillo Dhaune (9.5 m). There was no significant spatial variability in the concentration of physicochemical parameters among the sampling sites. The mean concentrations of cations and anions were in the order of $Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}$, and $HCO_3^{-}> Cl^{-}> SO_4^{2-}> PO_4^{2-}> NO_3^{-}$, respectively. Principal component analysis (PCA) and cluster analysis (CA) techniques were applied to assess the influence of pollution levels and their controlling mechanism. PCA showed 79.89 % of the cumulative variance with > 1.26 Eigenvalue. Similarly, CA showed that Jingale Lake (in cluster 2) sites were less polluted than other sampling sites. Piper diagram concluded that there was a dominance of mixed water type belonging to Ca-Mg-Cl compared to Ca-HCO$_3$. Furthermore, the Water Quality Index (WQI) value of the lakes in the study area was 27 indicating good water quality (slightly polluted).

Keywords: Bathymetry, far-western region, Nepal, Ramaroshan Lake Complex Area, water quality

Introduction

Wetlands are the most productive environment providing many ecosystem services; biodiversity conservation, recreation and tourism, carbon sequestration, etc. Besides, wetlands are the source of sustainable livelihoods, support human wellbeing through eco-tourism activities and wetland productivity such as fisheries and paddy production. Groundwater recharge, sediment and nutrient retentions and export, and flood control are the other ecosystem services provided by wetlands (Cheng et al., 2014; Hushulong, 2012; Lamsal et al., 2015; Zedler & Kercher, 2005). Wetlands are helpful in achieving Sustainable Development Goals (SDGs) related to water, climate, ecosystems, and human wellbeing. However, wetland ecosystems are the most threatened natural resources; they have continuously been degrading by both natural as well as anthropogenic activities such as unsustainable grazing and fishing (Gibbs, 2000). Moreover, wetlands are facing several other threats such as pollution, eutrophication, invasion, sedimentation, and over-exploitation of natural resources, human encroachment, and climate change (Sharma et al., 2005).

Morphometry represents the lake form characteristics and their basin, which depends upon the topography and geological events occurring in that area (Awulachew, 2006). Morphology is the key indicators to determine and identify the environmental status of wetlands (Moses et al., 2011). The morphometry characteristics and water quality can influence the physico-chemistry, distribution of aquatic life, littoral zone development and ecosystem productivity, hydrodynamics, food web structure, and biogeochemical cycle of lakes. Shallow and small lakes have comparatively lower nutrient recycling and regeneration rates and more sensitive to environmental stressors compare to a large lake (Hakanson, 2005; Moses et al., 2011; Noges, 2009; Stefanidis & Papastergiadou, 2012). Also, the water storage dynamics influence the hydrological cycle, regional environment, and climate (Qiao et al., 2019). The annual variations in the weather and global climate change have an unprecedental effect on the physical characters and biological properties of the lake (George et al., 2007; Schindler et al., 1996).

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In Nepal, approximately 5,385 lakes have been recorded, of which 419 lakes are located in the mid-hills between 500 m to 2,999 m (Bhuju et al., 2013). Ramaroshan Lake Complex Area (RLCA) is an aesthetically, culturally and ecologically important area that is facing several threats mainly caused by anthropogenic activities such as unsustainable grazing, fishing, foraging, and fodder collection. (DOF, 2017) has recorded only seven lakes in this area, categorizing four lakes as 'good' and the remaining three as 'degrading' lakes. However, this area is popularly known as *Barha Banda Athhara Khanda* (means 12 lakes and 18 patches of grasslands). Due to the high eco-tourism potential of the area, the Government of Nepal (GoN) started to develop infrastructures without conducting scientific research and environmental impact assessment. In addition, this area has been declared as a potential Ramsar Site by the local government, which covers an area of 3051.29 ha, including 2954.26 ha forest, 55.05 grasslands (patan), 30 ha lakes and 11.98 ha river (DOF, 2017). The GoN has already included Ramaroshan Area as one of the top 100 tourist destinations of Nepal for the promotion of tourism year in 2019 (Upadhayaya, 2019). However, the scientific study related to inventory, morphometry of lake, understanding of the status of the water quality and overall wetland ecology is still lacking in the RLCA.

The purpose of this study is to provide fundamental information regarding the morphometric and water quality parameters of the selected lakes in RLCA, which can support the government in developing a scientific management plan for the sustainable and wise use of natural resources in the near future.

Materials and Methods
Study area
Ramaroshan Lake Complex Area (RLCA) is a mid-hill wetland in a remote area of Far-western Nepal extending from 1401 to 3792 m asl (Fig. 1). The mean annual temperature varies from 30°C to 1°C, and precipitation ranges between 1486-1739 mm (DOF, 2017). The geological formations of RLCA are Sallyani Gad and Kalikot formation, similarly the rock types in this area consist of Granite, Gneisses, Limestone and Schist (Dahal & Dahal, 2017). RLCA provides the habitat for 112 flowering plants and 12 species of cryptograms, eight species of wetland-dependent birds, including migratory species (Poudel & Adhikari, 2020). Similarly, the study area harbors 15 species of mammals, 13 species of butterflies (Karki et al., 2002), RLCA provides potential water resources for the benefit of diverse ecosystem services, support local livelihoods, drinking, irrigation, and energy production. It is the headwater of the Kailash River, which provides ecosystem services in large scales and supports downstream people.

Sampling and Analysis
The lake bathymetry (depth, volume and area) was obtained by line transects (N shape) method using an Echosounder (depth measuring gauge; Plastimo echotest-II) accompanied by GPS points (Garmin Venture SC) at each sampling point. Bathymetry measurements were taken from three major lakes, viz., Jingale, Batula and Mathillo Dhaune. The number of sampling points varied for different lakes depending on the size of the lakes; for example, 149 sampling points were taken from Jingale, 42 from Batula, and 26 from Mathilo Dhaune, respectively. Finally, bathymetry maps of these three lakes were produced with the help of ArcGIS 10.4 and Surfer Pro by Golden software 11.

Altogether 43 water samples were collected from the nine lakes in January 2020. Sampling sites were established to represent the overall variability, such as inlets, outlets, land covers, human disturbances, the middle and the deepest parts (Fig. 1). The water samples were collected in a 1 L high-density polyethylene (HDPE) bottle after rinsing three times by the lake water following standard procedures as described in Eaton et al. (2005) and Sharma et al. (2012). The *in-situ* measurement of physico-chemical parameters such as temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) was done by multi-parameter instrument HANA, dissolved oxygen (DO) by DO meter, alkalinity and free CO_2 by titration method, and transparency by using a Secchi disc. For the laboratory analysis, water samples were filtered using 0.45 mm Millipore filters with the hand-operated vacuum pump, and samples were acidified with 2/3 drops of conc. Nitric acid and sulphuric acid in the field for maintaining pH 2 for the measurement of cations and anions, respectively. All water samples were maintained at 4°C before they reach the laboratory.

The water quality index (WQI) of lakes was calculated by the following equation (Bora & Goswami, 2017; Brown et al., 1972).

$$WQI = \sum_{i=1}^{n} QiWi \Big/ \sum_{i=1}^{n} Wi \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, Qi is used for rating value of ith parameters and calculated as $Qi = \left[\frac{Vi - Vo}{Si - Vo}\right]$; vi is the observed value of ith parameters, Si is the standard permissible value of ith parameters, and V_0 is the ideal value (zero for all parameters except pH: 7.0 and DO: 14.6 mg/L) prescribed by BIS (2012); wi unit weight assigned by i^{th} parameters and was calculated as $Wi = \frac{K}{Si}$ and $K = 1 / \sum_{i}^{n} \frac{1}{Si}$ where, K is the constant of proportionality, which is determined from the condition K= 1.
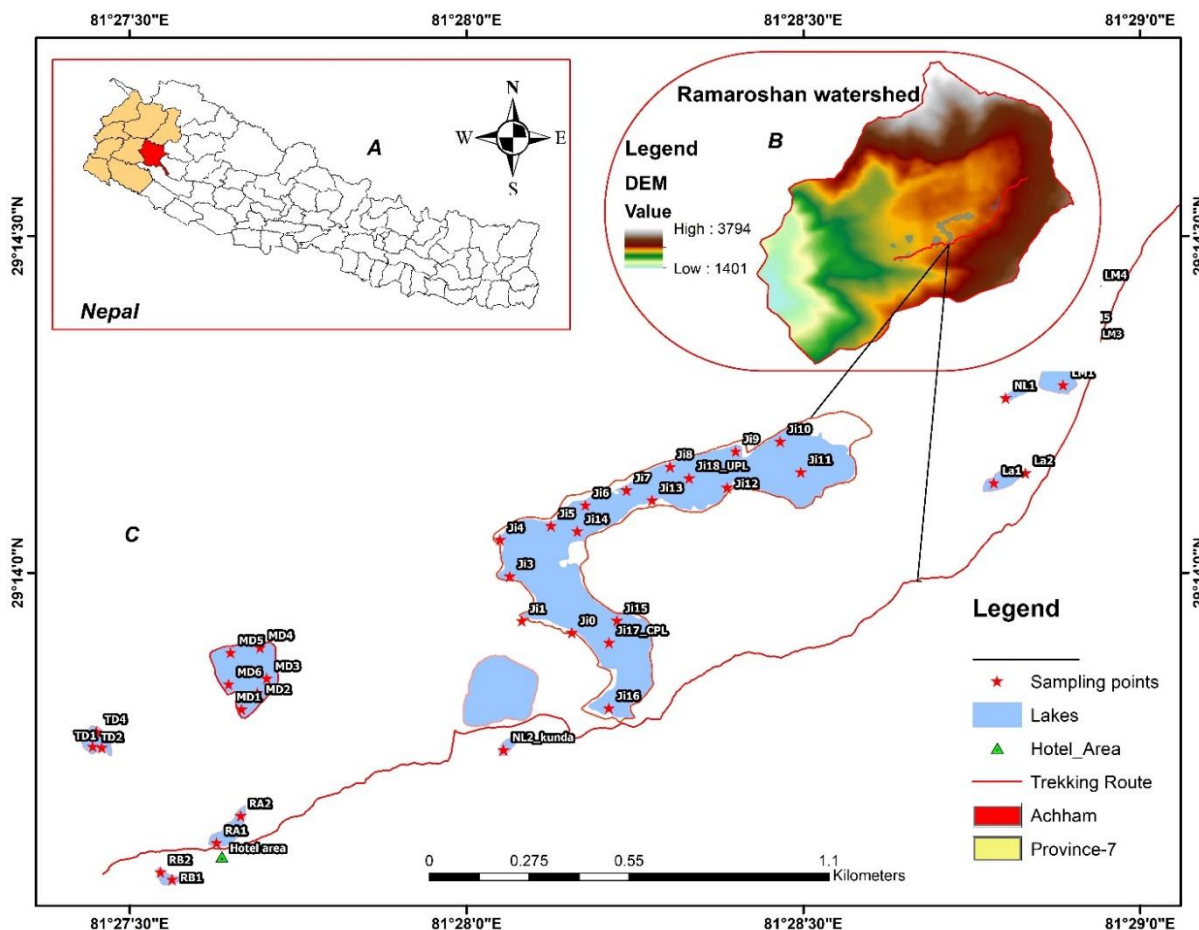
Figure 1 Figure showing the location of the study area in the map of Nepal (a); watershed map of the study area (b); and sampling locations in different lakes in the study area (c).

The data were analyzed by multivariate statistical analysis technique such as Spearman's correlation, principal component analysis (PCA) and cluster analysis (CA) with the help of Statistical Package for Social Sciences (SPSS) version 21.0. Piper plot was prepared with the help of RockWorks17 and water quality index was prepared with the help of R version 4.0.3.

Results and Discussion
Bathymetry of major lakes
The largest and deepest lake in RLCA is the Jingale Lake, with a maximum depth of 44 m (Table 1), followed by Batula Lake (max depth, 15 m) and Mathillo Dhaune (max. depth 9.5 m). Secchi disk value showed the maximum transparency of 8 m, 4.3 m and 3 m at Jingale, Batula and Mathilo Dhaune Lakes, respectively. One of the lakes, supposedly the third-largest based on the surface area, could not be sampled for bathymetry due to snow/ice cover at the time of sampling.

The Jingale Lake is an L-shaped narrow lake with an area of 20.92 ha situated at an altitude of 2410 m asl (Table 1; Fig. 2). There are small inlets to the lake in the northern part that

originates from the outlet of Lamadaha Lake and Lisedaha Lake . It has only one outlet in the southwest part. This lake is surrounded by boulders, rocks, eroding debris, local footpath, and dense forest coverage on the west-north part, whereas other parts are surrounded by rocks and dense forest.

The Batula Lake is the second largest lake of the RLCA, with an area of 4.68 ha (Table1). It is more or less oval in shape (Fig. 3). There is an inlet in the north part of the lake originating from the outlet of Jingale Lake. It is situated at an elevation of 2405 masl. This lake has a local footpath zone all around except in the inlet area. Batula Lake has a similar land cover as the Jingale Lake.

The Mathilo Dhaune Lake is nearly circular in shape and is the fourth-largest lake of the RLCA with an area of 2.37 ha with a maximum depth of 9.5 m (Fig. 4). It lies at an elevation of 2320 masl. The inlet of the lake originates from the outlet of Batula Lake, but there is no surface outflow. The littoral zone of the lake has no vegetation and is covered by boulders and rocks up to15 m from the lake-edge. Beyond the rocky littoral zone, the lake is surrounded by dense forest.
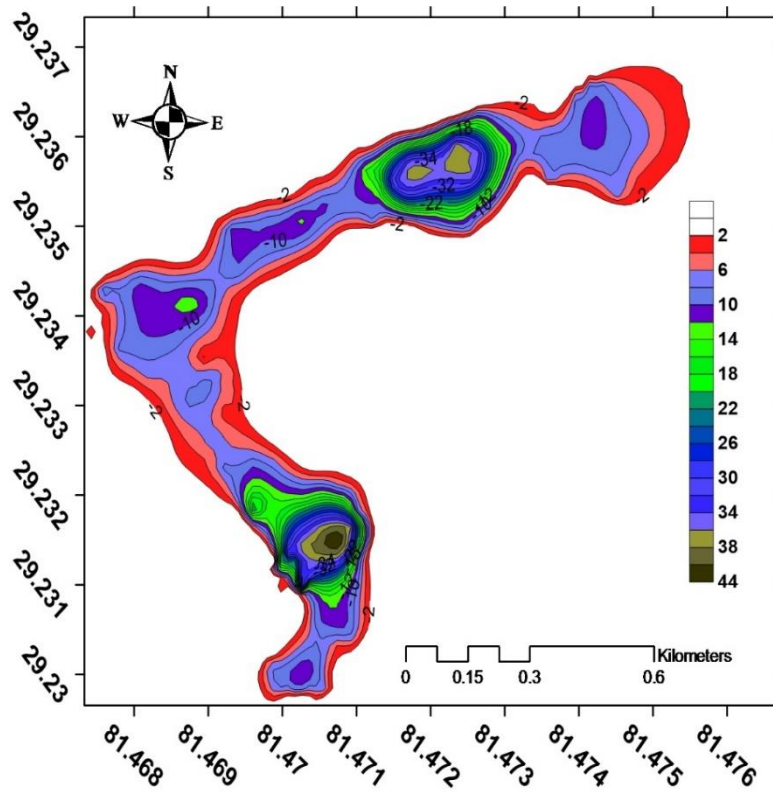
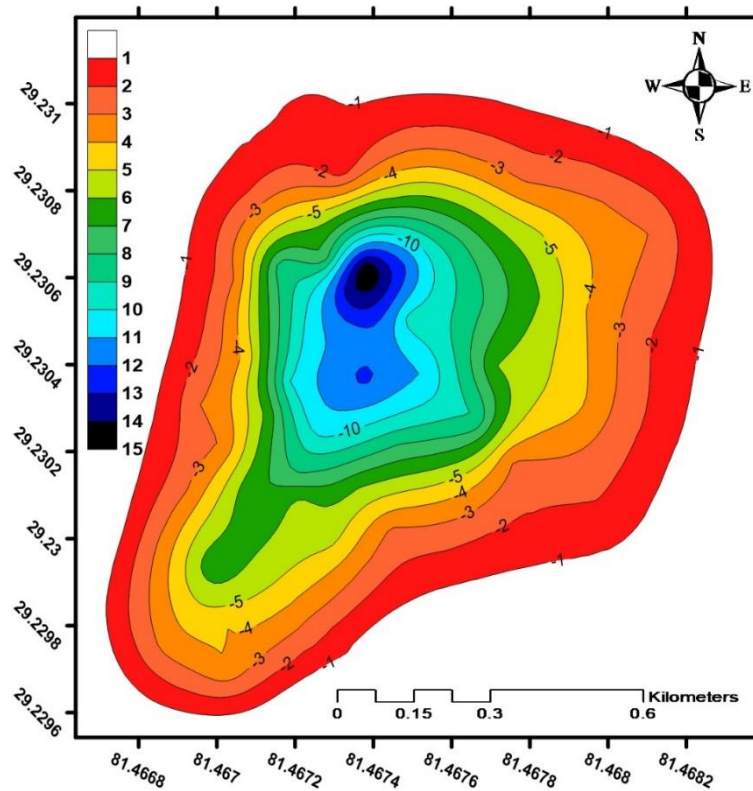**Figure 2** Bathymetry map of the Jingale Lake, one of the lakes in Ramaroshan Lake Complex

Figure 3 Bathymetry map of the Batula Lake, one of the lakes in the Ramaroshan Lake Complex.
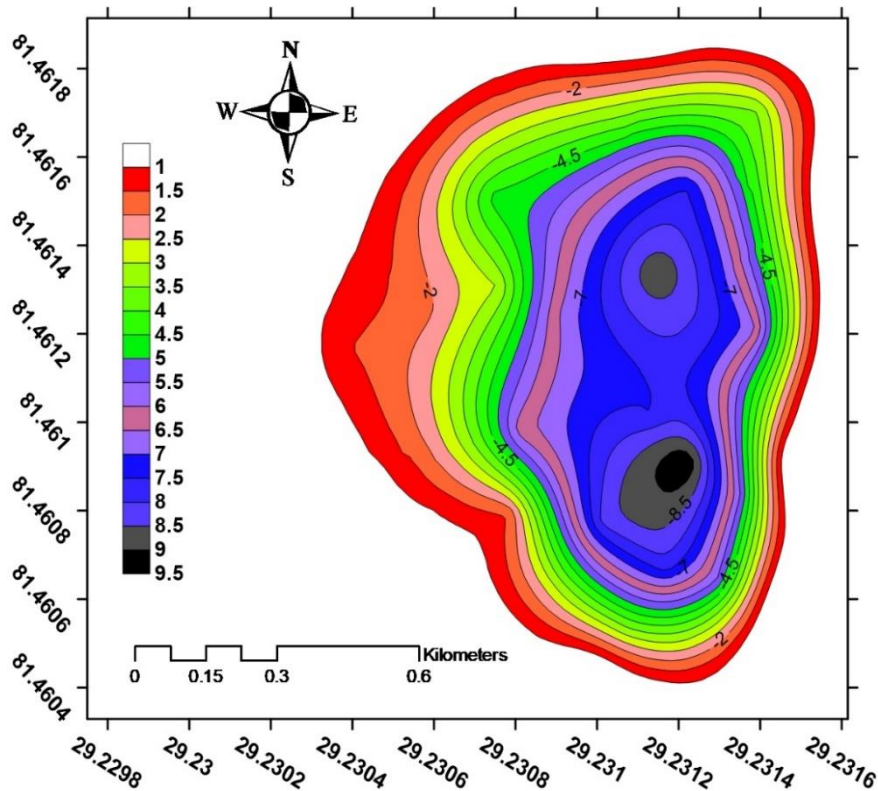
Figure 4 Bathymetry map of the Mathillo Dhaunne Lake, one of the lakes in the Ramaroshan Lake Complex.

Table 1 Morphometric measurement of three lakes in RLCA, Achham District, Nepal in January 2020

Lake	Area (ha)	Coordinates	Elevation (m asl)	Mean Depth	SD	Max. Depth (m)	Volume (m³)	Status
Jingale	20.92	29°14'03.73"N; 81°28'7.29"E	2410	12.8	10.6	44.0	2692769.0	Perennial
Batula	4.68	29°13'49.45"N; 81°28'3.06"E	2405	8.0	3.6	15.0	375399.1	Perennial
Mathillo Dhaunne	2.37	29°13'51.48"N; 81°27'40.33"E	2320	5.9	2.3	9.5	140515.9	Perennial

Water chemistry

The summary of the 20 different water parameters is given in Table 2. The pH values ranged between 6.4 and 8.0, which lies within the guidelines recommended by NDWQI (GoN, 2005) and is also suitable for aquatic organisms. The water temperature of the lakes in RLCA is moderate that varies from 3.8 °C to 15 °C, identical to the regional temperature of the mid-hill areas during the winter season (Bhateria & Jain, 2016).

Electrical conductivity (EC) in the present study ranged between 25 μS/cm and 193 μS/cm, which is within the guideline value provided by GoN (2005). Generally, EC shows a significant correlation with many water parameters such as pH, temperature, total hardness, calcium, total solids, total dissolved solids, iron concentration, and chemical oxygen demand (Bhateria & Jain, 2016). The salinity in water bodies is contributed by the number of cations and anions such as Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, PO_4^{3-} and HCO_3^-. Therefore, EC is also a good indicator of salinity changes in the lakes. The lentic water

bodies receive dissolved solids from various sources such as runoff, urban runoff and soil erosion (Kent & Belitz, 2004). In the present study, the total dissolved solids (TDS) ranged from 12 mg/L to 100 mg/L. If TDS exceeds 500 mg/L, it indicates hard water bodies not suitable for aquatic life. In addition, such water bodies pose a serious threat to kidney and heart disease patients (Al-hadithi, 2012). EC and TDS were in the order of Lamadaya > Jingale > Mathilo Dhaunne > Tallo Dhaune > Lisedali > New lakes (1, 2) > Rame Daha A > Rame Daha B, respectively.

DO is one of the key factors in determining the health of water bodies. In the present study, DO values ranged from 7. 4 mg/L to 9.72 mg/L, which is suitable for aquatic organisms. The mean value of DO in the present study is comparable to Rara Lake, which is higher than post-monsoon and lower than pre-monsoon season (Gurung et al., 2018); it might be due to the season of sampling (winter season in the present study) and availability of more macrophytes in lakes of RLCA. There

is variability in concentrations of DO among the lakes in RLCA with higher in Mathillo Dhaune followed by Tallo Dhaune, Jingale, and Rame Daha. Such variability among the studied lakes could be due to the difference in sampling hours. The mean concentration of NO_3^-, PO_4^{3-}, NH_4, and SO_4^{2-} were observed within the range of recommendation by (WHO, 2011; NDWQS, 2005).

The turbidity in the present study varied from 0.1 NTU to 14 NTU, which is suitable for aquaculture (Shahzad et al., 2018). Turbidity gives an idea of the suspended particles in the water bodies that can affect physical, chemical, and biological conditions mainly by controlling light penetration and water temperature (Srivastava et al., 2011). The concentration of CO_2 in the present study ranged from 2.2 to 6.6 mg/L, which is suitable for the aquatic organism as well as within the range prescribed by WHO (2011).

Major ions
The overall summary of major ions in this study is presented in Table 3 which shows a decreasing order as $Ca^{2+} > Mg^{2+} > Na^+ > K^+$ for cations and $HCO_3^- > Cl^- > SO_4^{2-} > PO_4^{2-} > NO_3^-$ for anions, respectively. The comparison of the mean

concentration of major ions in the present study with previous studies from Rara Lake (2990 masl), Gokyo Lake (5000 masl) and Gosaikunda Lake (4700 masl), Paanch Pokhari, and Langtang Valley lakes are given in Table 3. The comparison of the relative ionic proportion of selected freshwater bodies with the present study revealed that the parameter, such as Na^+, was the most dominant cations in the study area. The dominance of Na^+ in water bodies might be due to the silicate weathering from surrounding rocks and the ion exchange process in water bodies (Kumar et al., 2019; Mallick, 2017). Therefore, this warrants further study in this direction.

The decreasing or increasing concentrations of different parameters in order such as $SO_4^{2-} < Ca^{2+}$ and $Na^+ > Mg^{2+} > K^+ > HCO_3^- > Cl^-$ are probably due to differences in their geological settings and anthropogenic activities. The overall comparison of the previous study (Table 3) has shown that the Gokyo, Paanch Pookhari and Gosaikunda Lakes have a similar type of parameters except for Cl^- in Gosaikunda Lake, but the Rara Lake, Langtang valley and Ramaroshan Lake cluster also has a similar type of parameter except for Na^+ in Ramaroshan lake cluster.

Table 2 Summary of the physico-chemical parameters of lake waters in the Ramaroshan Lakes Area.

Parameters	Max	Min	SD	Mean	NDWQS	WHO (2011)
pH	8.01	6.4	0.20	6.9	6.5-8.5	6.5-8.5
EC	193	25	36.71	77.41	1500	1500
TDS	100	12	19.02	40.02	1000	1000
Temp	15	3.8	2.84	8.52	20	20
DO	9.72	7.4	0.69	8.36	--	6
K^+	3.6	0.08	0.77	1.34	--	10
Na^+	6.1	5.1	0.23	5.6	--	200
Turbidity	14	0.1	2.07	0.85	--	--
NO_3^-	0.07	0.04	0.008	0.04	50	10
PO_4^{2-}	0.24	0.1	0.027	0.158	--	1
NH_4	0.29	0.064	0.065	0.12	--	0.5
SO_4^{2-}	3.36	0.05	0.62	1.04	250	250
Cl^-	21.3	2.83	3.91	11.83	250	250
Total Hardness	110	16	19.03	44.11	500	500
Mg-Hardness	36	4	6.38	14	--	250
Ca-Hardness	86	8	16.91	29.69	--	250
Ca^{2+}	34.4	3.2	3.2	6.76	200	75
Mg^{2+}	8.784	0.97	1.55	3.41	--	30
	145	10	23.98	43.58	--	120
Free CO_2	6.6	2.2	1.61	3.32	--	6

Note: {Units of all the variables are mg/L, except pH, WT (°C), and EC (μS/cm)}

Table 3 Comparison among different major ions concentration of Ramaroshan lake and previous studies from mid-hill and high-altitude lakes in Nepal

Lakes	Na^+	Mg^{2+}	K^+	Ca^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	References
Ramaroshan lakes	5.6 ± 0.23	3.41 ± 1.55	1.34 ± 0.77	6.76 ± 3.2	11.83 ± 3.91	1.04 ± 0.62	43.58 ± 23.98	Present study
Lake Rara	0.35 ± 0.19	5.89 ± 3.65	0.80 ± 0.51	9.17 ± 2.67	0.10 ± 0.05	0.14 ± 0.09	54.02 ± 23.5	(Gurung et al., 2018)
Gokyo Lakes	0.9 ± 0.22	0.4 ± 0.03	0.6 ± 0.06	5.13 ± 0.91	0.2 ± 0.05	4.3 ± 1.15	17 ± 2.24	(Lacoul & Freedman, 2006)
Paanch Pokhari	0.31 ± 0.24	0.2 ± 0.11	0.22 ± 012	1 ± 0.4	3.5 ± 1.39	4.2 ± 1.3	13.9 ± 13	(Raut et al., 2017)
Gosainkunda Lake	0.5 ± 5.44	1.30 ± 0.7	0.3 ± 0.07	3.5 ± 2.05	20.50 ± 14	3.94 ± 2.4	17.5 ± 3.3	(Raut et al., 2013)
Langtang Valley	1.9 ± 1.3	1.64 ± 1.3	2.08 ± 1.5	10.77 ± 5.53	8.24 ± 2.3	5 ± 5.31	36.63 ± 15.2	(Tuladhar et al., 2015)

Correlation analysis has been widely used to understand the interrelation between the physicochemical parameters. The result shows that EC and TDS have a strong significant correlation with each other as well as total hardness (TH), Ca-hardness (Ca-H) and Ca^{2+} ($p < 0.01$). This shows that Ca-H and Ca^{2+} have the similar source and contribute for the EC, TDS and TH. The result also identified the significant correlation of total alkalinity with EC, TDS, TH, Ca-H, and Ca^{2+} at ($p < 0.01$). This indicates a similar source of TH, total alkalinity, EC and TDS along with Mg^{2+} and Ca^{2+} ions.

PCA results are plotted in Fig. 5, loading values, and component matrix was used to understand and identify the controlling factors of water chemistry in RLCA.
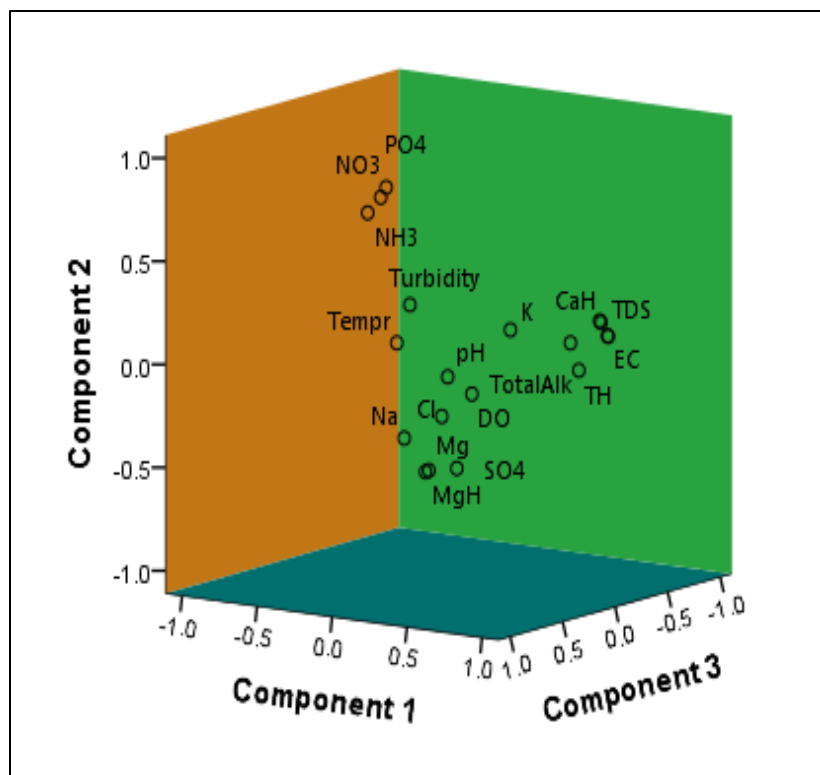

Figure 5 Plot showing principal component analysis (PCA) of physico-chemical parameters in the Ramaroshan Lake Complex

Loading factors are classified into three different categories such as strong > 0.75, moderate > 0.75-0.50 and weak > 0.50-0.30, respectively (Lui et al., 2003) with eigenvalues ≥1.0 consider as significant (Sharma & Tiwari, 2018). PC1 explained 30.52 % of the variance having strong loading factors such as EC, TDS, TH, Ca-H, and Ca^{2+}; and with moderate loading of total alkalinity (HCO_3^-). These factors are mainly contributed by natural sources from the carbonate weathering and lithology of the study area. Similarly, PC2 explained 15.79 % of the total variance with a strong loading factor of PO_4^{2-} and NO_3^-, probable sources being the debris and organic matters. Other PCs have no strong loading factors showing less governance over the water chemistry.

From the wards linkage based dendrogram diagram (McKenna, 2003) (Fig. 6), 43 samples are grouped into distinct 3 clusters. Cluster 1 is composed of 62.79% of total samples (include 11 sites from Jingale, all sites from Tallo Dhaune, Mathilo Dhaune and Rame DahaA, and one site each from Lisedali, New Lake1, and Rame DahaB) having higher concentrations of EC, TDS, TH, Ca and total alkalinity compared to the sites in Cluster 2 and lower than Cluster 3. Similarly, Cluster 2 is composed of 32.56% (include seven sites from Jingale, four sites from Lamadaya, and one site each from New Lake 2, Lisedali, and Rame Daha B), and Cluster 3 is composed of 4.66% (include single sites from Jingale and Lamadaya). On the basis of the concentration of parameters in samples, the pollution status of clusters can be ordered as Cluster 2 < Cluster 1 < Cluster 3, which indicates that Cluster 2 is least polluted than other clusters. The cluster 1 and 3 are slightly polluted than cluster 2, might be due to high human disturbance, high wildlife recreational activities, eutrophication, presence of algal blooms and anthropic activities like recreation (Pant et al., 2019).

Water quality index (WQI)
The water quality index (WQI) can be categorized into five different classes (Brown et al., 1972). Out of 9 lakes, three

lakes had the lower WQI value (25) with excellent water quality, whereas the remaining six lakes had good (slightly polluted) water quality with WQI ranging from 26-32 (Fig. 7). This explanation is also supported by the mean concentration of SO_4^{2-}, NO_3, TH, and free CO_2, which were higher in the lakes with higher WQI values. In overall rating, the WQI value of lakes in RLCA was indicating good water quality with a slightly polluted status.
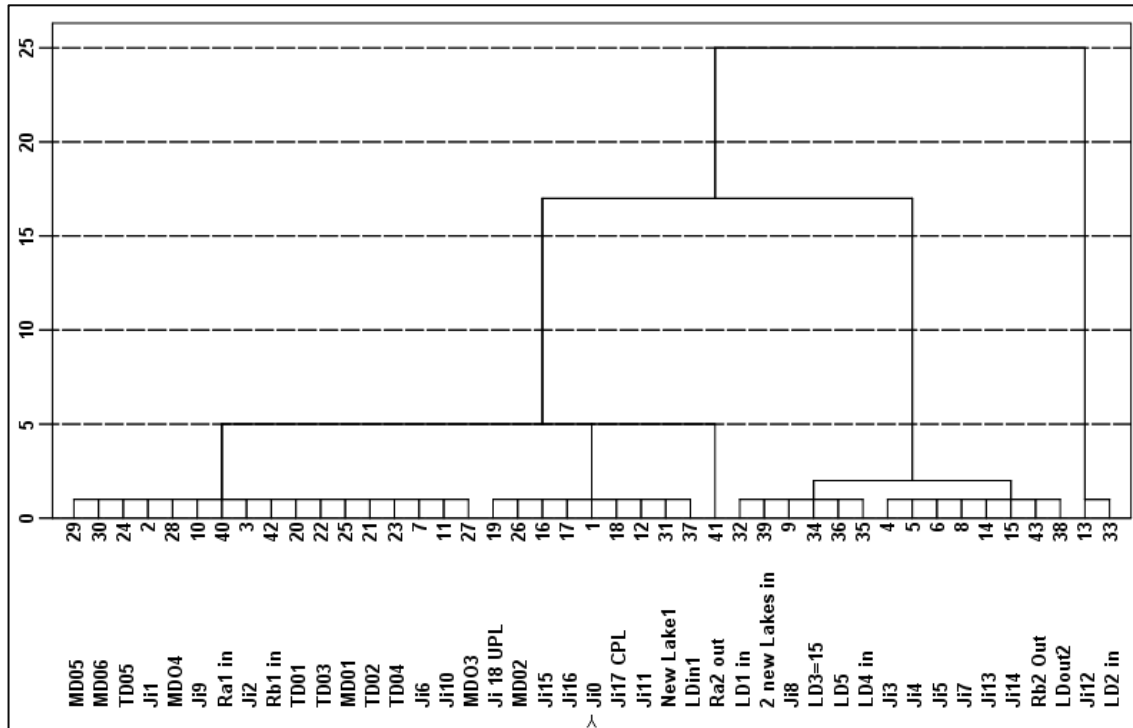

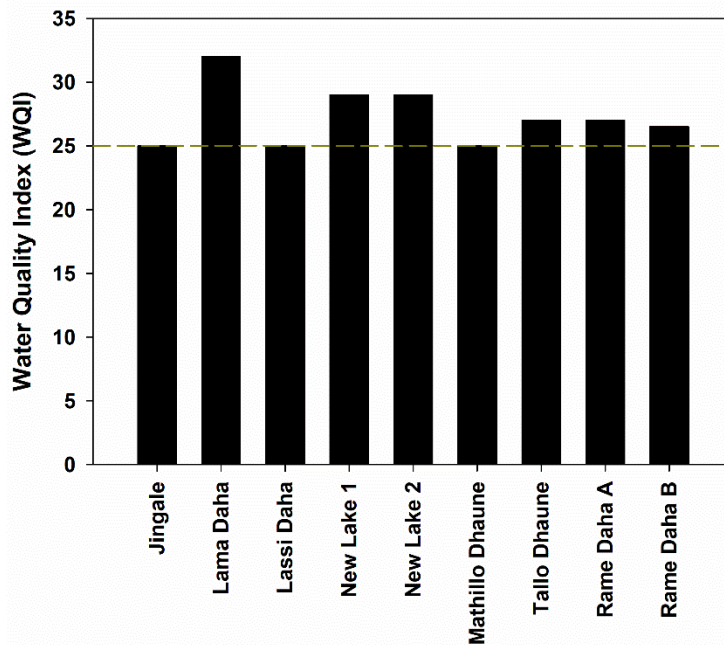**Figure 6** Hierarchical cluster analysis based on wards linkage method

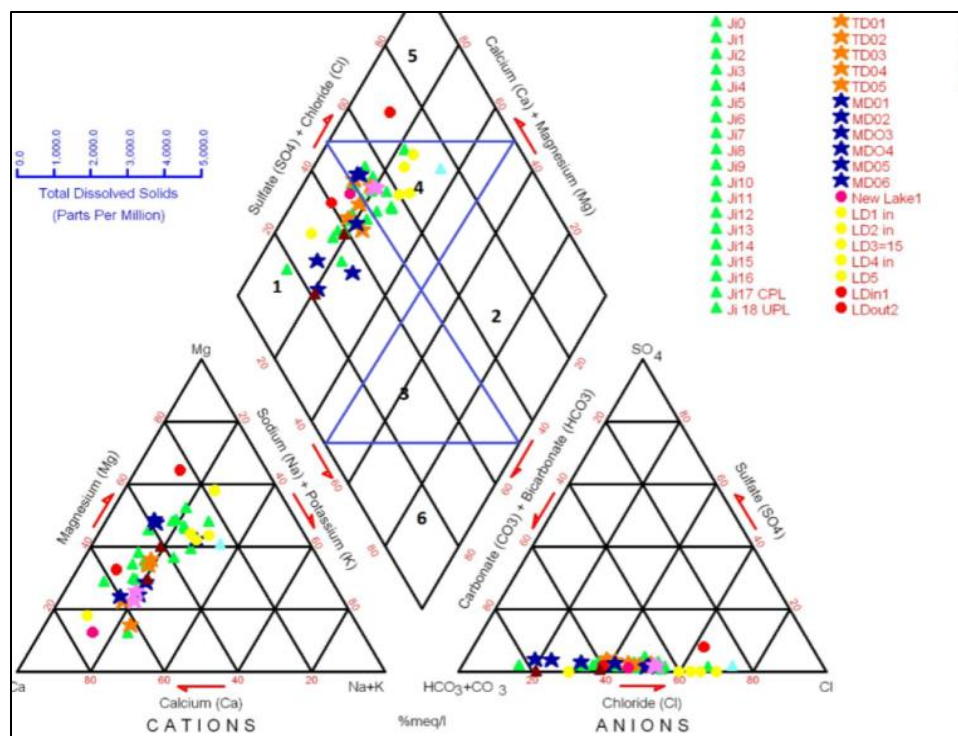**Figure 7** Plot showing the WQI values of Ramaroshan Lake Complex.

Figure 8 Piper Trilinear diagram classify the hydrochemical properties of the water of the lake

The hydrochemical properties of the RLCA are presented in the trilinear diagram (Fig. 8), which is an effective procedure to segregate the concentration of major cations Ca^{2+}, Mg^{2+}, Na^+, K^+ and anions HCO_3^-, SO_4^{2-}, Cl^- for understanding sources of these dissolved constituents in water (Piper, 1944; Ravikumar et al., 2015).

The water type can be classified into six classes in the piper diagram (Fig. 8): 1) Ca-HCO₃, 2) Na-Cl, 3) Mixed Ca-Na-HCO₃, 4) Mixed Ca-Mg-Cl, 5) Ca-Cl, and 6) Na-HCO₃. In the present study, about 58% of samples belong to Ca-Mg-Cl mixed type whereas 41 % to Ca-HCO₃ type. Also, from the plot, it revealed that alkaline earth metals (Ca + Mg) are dominant over alkali metals (Na + K) with the dominant of HCO₃ and Cl acids. The results suggest the carbonate weathering in the studied area. Similar findings have also been reported in nearly located high mountain Rara Lake (Gurung et al., 2018).

Conclusion

The study of morphometric characteristics and physico-chemical parameters was accomplished for the first time in the RLCA, mid-hill, far-west Nepal. The physico-chemical parameters of the lake waters were within the guidelines of WHO and NDWQS. Ca^{2+} and HCO_3^- were the dominant cation and anion, respectively, indicating higher carbonate weathering of surrounding rocks as the dominant sources of major ions. The piper diagram has shown dominance of earth alkaline metal such as $Ca^{2+} + Mg^{2+} > Na^+ + K^+$ and acidic

anions metal such as $SO_4^{2-}+Cl^- > Na^+ + K^+$, respectively. The PCA analysis showed that EC, TDS, TH, Ca^{2+}, and HCO_3^- were strong loading factors, which demonstrates the high contribution of lithology in the study area. The WQI indicated that the water qualities of RLCA were in good condition (i.e., only slightly polluted).

Acknowledgements

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