



Research Article



Hydrochemical assessment of the Beeshazar and associated lakes in Central Nepal

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Abstract

Water quality deterioration has threatened aquatic life around the world including Nepal, which has been a serious issue for environmental sustainability and economic development. This study evaluated and interpreted hydrochemical parameters of the Beeshazar and associated lakes in Central Himalaya, Nepal. The study revealed that the water in the lake was slightly alkaline as the average pH was 7.52. The correlation and principal component analysis (PCA) identified both geogenic and anthropogenic processes as the controlling factors of hydrochemistry whereas the cluster analysis (CA) showed relatively more pollution in the associated Laxmi Lake. Also, the water quality index (WQI) classified the water as “good” for drinking purposes (i.e., WQI = 33.90), while the pollution index (PI) values were characterized as sub-cleanness and slightly polluted. In general, both the WQI and PI signify that water in the lake complex is currently safe for drinking purposes. It is further confirmed from the comparative analysis of chemical variables with other lakes in the region, WHO and national water quality guidelines for aqua culture that the most of the analyzed water parameters exhibited relatively low concentrations and were within the prescribed guidelines. However, the elevated concentrations of NO_3^- and PO_4^{3-} may pose serious problems for retaining water quality in the future. The results could be considered for future planning and management of the Ramsar Lakes of the lowland areas in the Himalaya and also as a valuable reference for the freshwater researchers at the national and international levels.

Keywords Hydrochemical parameters · Multivariate techniques · Pollution index · Water quality index · Ramsar site

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1 Introduction

Freshwater ecosystems hold hydrological and ecological importance because of their potential role in providing multiple services to the inhabitants and the environment

[1, 2]. These ecosystems are considered as an indispensable component of the earth surface as they support and regulate climatic patterns, drinking and irrigation water quality, fishing, hydropower generation, ecotourism, soil formation, groundwater recharge, flood protection and

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other services for sustaining the human and environmental health [3]. Globally, the lake ecosystem may exist naturally or manmade and pollution in the lake water has become a rising environmental concern. There are various point and non-point sources of the pollutants including excessive nutrient contents, organic chemicals, toxic and trace metals and pesticide residues that are responsible for the deterioration of water quality in the lake ecosystems [4, 5]. Domestic, agriculture, urban and industrial activities are considered to be the major sources of pollutants to the lake ecosystems [6]. In addition, lake characteristics such as homogeneity, heterogeneity, physiographic locations and land-use practices in the surrounding environments may also impact the spatial and temporal variations of water quality. For instance, shallow lakes are characterized by a high degree of heterogeneity in both spatial and temporal levels and are considered to be more sensitive towards the pollution sources, particularly caused by anthropogenic activities. Moreover, lakes are comparatively less dynamic and are readily susceptible to exogenic contaminants [7, 8].

Hydrochemistry of lake water has been widely used to characterize the water quality and source tracking of the chemical variables from natural processes such as rock-weathering, evapo-crystallization, precipitation and contribution from the anthropogenic activities [9]. Various studies have been performed to assess the water quality and hydrochemistry of the lakes in Nepal and linked to local geology, climate and other environmental factors. Some of the works conducted in different lakes including Nagdaha [6]; Nainital, Sattal, Bhimtal and Naukuchiyatal [10]; Renuka lake [11]; Sella and Tsokyo Tso [12]; Begnas and Rupa [13]; Suraj, Sissu, Chandra and Deepak lakes [14]; Mansar [15]; Betkot lake [16] and Lake Qinghai catchments [17] exhibited the impacts of anthropogenic activities and global climate change on the hydrogeochemical dynamics. The Beeshazar and associated lakes are one of the major sources of water for drinking and irrigation purposes in the low land area of Central Nepal. As there is a Khageri Irrigation Canal passing through the vicinity of the lake cluster, the water quality of the lakes has great significance to the water quality of the Canal. The most of the aforementioned studies have focused general hydrochemistry but systematic chemical characterization of water quality concentrating on drinking and irrigational aspects using multivariate statistical analysis is limited. The novelty of this study is new insights on water quality of the Beeshazar and the associated lakes by using various chemical indices, principal component analysis (PCA) and cluster analysis (CA).

Wetlands being integrated systems are affected by changes in the key physical as well as chemical parameters of the hydrosphere at the catchment scale. Like many

other regions in the world, the water quality in the lakes of Nepal is also found in the most vulnerable conditions. The wetlands located in the low land in Nepal are quite sensitive to global climate change and anthropogenic impacts including domestic, urban and industrial effluents and agricultural runoff [18–21]. The major threats in those lakes are sedimentation, invasion, eutrophication, encroachment and loss of water quality due to natural and anthropogenic inputs and the present study sites (the Beeshazar and associated lakes) are not the exceptions to the above-mentioned issues. Therefore, the primary aim of this study is to evaluate the hydrochemistry and water quality status of the Ramsar listed Beeshazar and associated lakes in Central Himalaya, Nepal (Reference No. 1313) using multivariate statistical analysis. This study would have a great significance to formulate and implement water quality improvement programs for the sustainability of the lake complex. Additionally, the study could help to generate new knowledge and database on drinking and irrigational water quality in the Ramsar based lakes which need wide dissemination to the academic and policy perspectives.

2 Materials and methods

2.1 Study area and site description

The Beeshazar and associated lakes (27.37° N and 84.26° E) are situated in the Ratnanagar Municipality, Chitwan district of Central Nepal (Fig. 1). The lake complex is 15 km away from the Narayanghat Bazaar and covers an area of about 32 km² including mosaics of diverse habitats; open water bodies, marshes, swamps, grasslands and forests. The complex includes Beeshazar, Kumal, Laxmi, Kingfisher and Tikauli lakes. The complex has an open water area of about 1 km² and represents one of the largest freshwater lake complex in the low land (Tarai) region of Nepal. Considering the ecological, economic and aesthetic importance of the lake complex, it has been included in the Ramsar list in 2003 [22].

The climate of the area is subtropical and characterized by two distinct climatic seasons namely summer and winter. The summer season extends from March to June, during which the maximum average day temperature is 35.1 °C which falls to a minimum of 19.8 °C at night. This area receives about 2000–2500 mm rainfall in a year and about 80% of the total annual rainfall occurs during the monsoon months between June and September [22].

The main recharge sources of water in the Beeshazar and associated lakes are the Khageri irrigation canal, rainwater and three major rivers that are the Narayani, Rapti and Reu with several small lakes, marshy lands and pools [22]. The soil and geological features of the area are

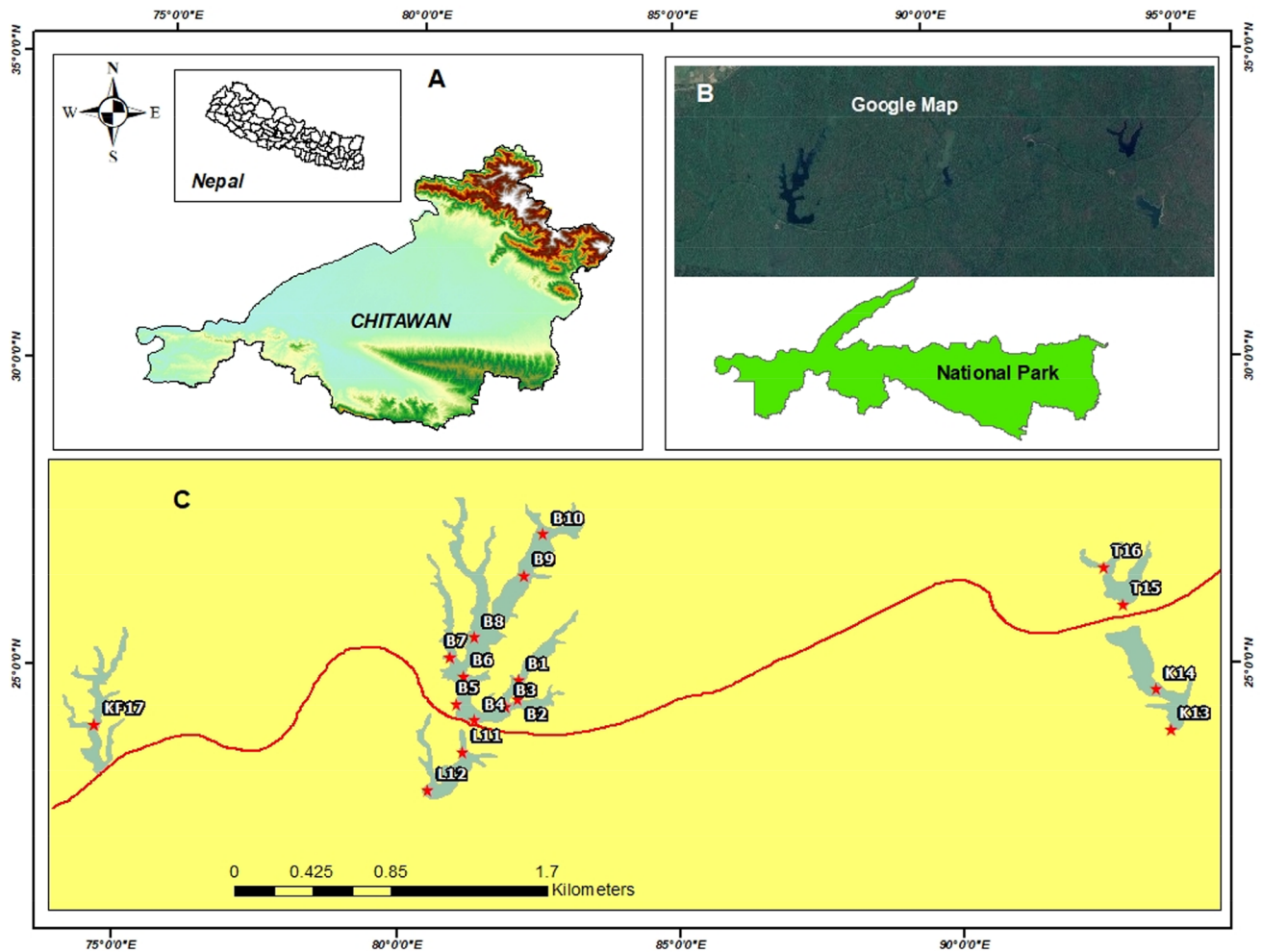


Fig. 1 Map of study area (Beeshazar and associated lakes, Chitwan, Nepal). A: Map of Nepal with Chitwan district, B: Chitwan National Park, C: Sampling sites in the study area

dominated by the alluvial deposits with sandy loam mixed with coarser soil particles and sediments containing boulder, gravel, silt and clay brought down during monsoon from high altitudes of the region. Due to extensive coverage of vegetation and dense forests, the soil of the lake area contains a high amount of humus. The surrounding area of the lake complex is characterized by subtropical forests dominated by Sal (*Shorea robusta*) and moist deciduous vegetation including grassland and riverine forests [22, 23].

2.2 Sampling and analysis

Sampling sites were selected in such a way to bear the maximum representation of the inlet, outlet and changing pattern of land use of the lake complex. Altogether 17 surface water samples were collected from the Beeshazar (n = 10); Laxmi, Kumal and Tikauli (n = 2, from each); and

Kingfisher (n = 1) lakes on March 2016 (Fig. 1). The samples from different sites were collected in clean 1L plastic bottles after rinsing with the same water from the collection site. The parameters like water temperature (WT), pH, electrical conductivity (EC), total dissolved solids (TDS) and dissolved oxygen (DO) were measured *in-situ* by using a multi-parameter device (HI-98,129, HANNA, Romania) and DO meter immediately after the collection of the samples, whereas total hardness (TH), ammonia (NH_4^+), nitrate (NO_3^-), phosphate (PO_4^{3-}), chloride (Cl^-) and alkalinity were analyzed in the laboratory of the Central Department of Environmental Science, Tribhuvan University, Nepal [24, 25].

The water samples were filtered using 0.45 mm Milipore membrane filters with a hand-operated vacuum pump. The raw samples were sealed in the sampling bottles and were preserved at 4 °C to avoid any major alteration for various hydrochemical analyses. The parameters

of the collected water samples were analyzed as per the standard methods prescribed by APHA (2005) [24]. Chemical parameters NO_3^- , PO_4^{3-} and NH_4^+ were measured through phenol di-sulphonic acid method, stannous chloride method and phenate method using the spectrophotometer (model S2200) under 410 nm, 690 nm and 635 nm, respectively. In addition, Cl^- was measured by argentometric titration method, while the TH and alkalinity were analyzed by the titration method [14]. High-grade chemical reagents were used for the analysis. Two field blanks were prepared with deionized water. Controls were performed on appropriate blank solutions. These blank samples were used in a spectrophotometer for the calibration. The results of blank samples displayed very negligible contamination during sampling and transportation of the samples. For quality control, special care was taken during sample collection and laboratory analyses following standard procedures [1, 23]. The analytical precision was maintained using the known standard and it was within $\pm 15\%$.

2.3 Statistical analysis

The descriptive statistics, correlation, principal component analysis (PCA) and cluster analysis (CA) were performed using statistical package for social sciences (SPSS) software (Version 21.0). A correlation matrix was applied to describe the degree of relationship between hydrochemical parameters. Spearman’s correlation matrix was used to display the relationship between the variables. Multivariate analysis was performed by using CA and PCA techniques. Hierarchical agglomerative CA was performed on the normalized dataset using Ward’s method with Euclidean distances to identify similar sites in the different study lakes. PCA of the normalized dataset was performed to classify the major sources and the controlling factors of the hydrochemical variables in the lake complex [1].

2.4 Water quality analysis

Water quality index (WQI) is one of the most effective ways of transforming a large number of hydrochemical datasets into a single numerical value to summarize the overall water quality [4]. The WQI was calculated as:

$$\text{WQI} = \sum (\text{Ci} / \text{Si} \times \text{Wi}) \times 100 \tag{1}$$

where, $\text{Wi} = \text{wi} / \sum \text{wi}$, wi is the weight of each parameter and $\sum \text{wi}$ is the sum of the weightings of all parameters. Here, Ci is the concentration of the chemical variable in each water sample and Si is the WHO guidelines for drinking water [26].

Similarly, the pollution index (PI) is a technique to assess the potential pollution load that contributes to the rating the water quality accurately and timely. The PI was calculated as [27]:

$$\text{PI} = 1/n \sum_{i=1}^n \text{Ci}/\text{Si} \tag{2}$$

$\text{PI} = 1/n \sum_{i=1}^n \text{Ci}/\text{Si}$ where PI is a comprehensive pollution index, Ci is the measured concentration of the pollutant (mg/L), Si is the limits allowed by the WHO standard and n is the number of selected pollutants.

3 Results and discussion

3.1 General hydrochemical patterns

The statistical summary of the measured hydrochemical parameters in the Beeshazar and associated lakes of Chitwan, Nepal is presented in Table 1. The results are compared with WHO guidelines and also with the national water quality guidelines for aqua culture (NWQGAC), Nepal [26, 28]. An increase in the WT may decrease the portability of water due to the high interaction of various chemicals and their reactivity [21, 29]. The WT in the lake complex studied ranged from 24.90 °C to 30.70 °C with an average value of 27.58 ± 2.1 °C. It indicates that water is suitable for the chemical and biological functioning of aquatic organisms [6].

Generally, DO value should be about 6 mg/L for drinking purposes and > 4 mg/L for sustaining the healthy aquatic ecosystems including the metabolic activities of microorganisms [30]. In this study, the concentration of

Table 1 Statistical summary of hydrochemical parameters of the Beeshazar and associated lakes, Chitwan, Nepal

| Par | Range | Mean \pm SD | NWQGAC | WHO (2011) limits |
|--------------------|-----------|-------------------|---------|-------------------|
| WT | 24.9–30.7 | 27.58 \pm 2.1 | – | – |
| pH | 7–7.89 | 7.52 \pm 0.3 | 6.5–8.5 | 6.5–8.5 |
| EC | 52–123 | 85 \pm 21.6 | 1500 | 750 |
| TDS | 30–63 | 49 \pm 10.8 | 1000 | 600 |
| TH | 28–160 | 59.52 \pm 36.4 | 500 | 500 |
| Alk | 20–70 | 34.41 \pm 12.97 | – | 300 |
| Cl^- | 6.39–25.6 | 12.78 \pm 5.24 | 250 | 250 |
| DO | 4.26–6.69 | 5.49 \pm 0.74 | – | – |
| NO_3^- | 0.23–6.67 | 2.19 \pm 1.81 | 50 | 50 |
| PO_4^{3-} | 0.03–0.91 | 0.42 \pm 0.26 | – | 1.0 |
| NH_4^+ | 0.04–0.09 | 0.07 \pm 0.01 | – | 1.5 |

All the variables are expressed in mg/L, except pH, WT (°C) and EC ($\mu\text{S}/\text{cm}$)

DO varied from 4.26 to 6.69 mg/L which is within the permissible range for the survival and growth of the aquatic organisms. The present study recorded the average pH value of 7.52 ± 0.26 , indicating the mildly alkaline water in the lake complex (Table 1). Regardless of the different locations, the pH values remain almost neutral to mild alkaline which satisfies the permissible limits of the NWQGAC and WHO guidelines [26, 28, 31].

Likewise, EC and TDS concentrations in our study were relatively low ($85 \pm 21.6 \mu\text{S}/\text{cm}$ and $49 \pm 10.8 \text{ mg}/\text{L}$), respectively. These values were within the guidelines provided by NWQGAC and WHO, which may be attributed due to low salinity and mineral contents. The low ionic strength and TDS mainly contribute to the salinity of water and thus the EC is a good indicator for salinity for getting the general insights of the lake complex [26, 28, 32]. Hence, the water of the lake complex is suitable for drinking purposes and also for the aquatic biota for their survival, growth and development.

Based on hardness, water can be categorized into soft water ($< 60 \text{ mg}/\text{L}$), medium water ($60\text{--}119 \text{ mg}/\text{L}$), hard water ($120\text{--}180 \text{ mg}/\text{L}$) and very hard water ($> 180 \text{ mg}/\text{L}$). The minimum concentration of TH was found in the Beeshazar Lake ($41 \text{ mg}/\text{L}$) whereas the maximum concentration was found in the Laxmi Lake ($160 \text{ mg}/\text{L}$) (Table 2). The TH in the study sites is within the prescribed guideline of NWQGAC and WHO and all the lakes have soft waters (except Laxmi Lake) [26, 28]. Although the major cations are not separately analyzed in this study, the TH indicates that the inputs of Ca^{2+} and Mg^{2+} are relatively high in the lake complex [14]. Similarly, the values of alkalinity were ranged from 20 to 70 mg/L and suitable for domestic purposes and also characterizes the carbonate-dominated lithology in the lake complex (Table 2).

The concentration of the Cl^- was ranged from 6.39 to 25.6 mg/L (Table 2), which is lower than the WHO maximum permissible limit [26]. It indicates that the contribution of atmospheric inputs and anthropogenic sources (e.g., inorganic fertilizers and sewers) have a relatively minor contribution to Cl^- contents in the lake complex. The concentrations of NO_3^- and NH_4^+ were observed between the range of 0.23 to 6.67 mg/L (mean: 2.19 ± 1.81) and 0.04 to 0.09 mg/L (mean: $0.07 \pm 0.01 \text{ mg}/\text{L}$), respectively (Table 2). Both of the NO_3^- and NH_4^+ were within the permissible range of recommended values and overall low anthropogenic interferences in the lake complex. However, the maximum concentration of NO_3^- was found to be 6.67 mg/L (Table 2), signifying the spatial discrimination in terms of anthropogenic contaminations in the lake complex. The high concentration of NO_3^- in some of the sampling points could be attributed due to agriculture runoffs, as there is intensive farming in the vicinity of the lake complex [33].

The mean concentration of PO_4^{3-} was found to be $0.42 \pm 0.26 \text{ mg}/\text{L}$. Relatively high concentrations of PO_4^{3-} were found in some of the sampling points, indicating the site-specific anthropogenic signature in the lake complex. Although underlying lake sediments and alluvial soil deposits are the main sources of phosphorus, the elevated concentrations of the PO_4^{3-} in the lake complex were supposed to be contributed from the farmlands in surrounding areas [21].

3.2 Spatial patterns of hydrochemical parameters

The descriptive statistics of hydrochemical parameters at the study lake complex are shown in Table 2 and Fig. 2. The mean pH values of all the studied lakes were found to be neutral to the slightly alkaline with a negligible

Table 2 Spatial variation in hydrochemical parameters of the Beeshazar and associated lakes, Chitwan, Nepal

| Par | Beeshazar | | Laxmi | | Kumal | | Tikauli | | Kingfisher |
|--------------------|-----------|-----------------|-----------|-----------------|-----------|------------------|-------------|------------------|------------|
| | Range | Mean \pm SD | Range | Mean \pm SD | Range | Mean \pm SD | Range | Mean \pm SD | |
| WT | 24.9–29.5 | 26.15 ± 13 | 29.6–30.7 | 30.1 ± 0.78 | 29.4–29.5 | 29.45 ± 0.07 | 29.8–29.9 | 29.85 ± 0.07 | 29.90 |
| pH | 7–7.89 | 7.55 ± 0.32 | 7.2–7.68 | 7.44 ± 0.34 | 7.5–7.6 | 7.55 ± 0.07 | 7.3–7.76 | 7.53 ± 0.33 | 7.76 |
| EC | 52–101 | 84 ± 18.68 | 121–123 | 122 ± 0.35 | 68–71 | 69 ± 1.77 | 77–86 | 82 ± 6.65 | 86.00 |
| TDS | 30–63 | 50 ± 11.4 | 60–62 | 61 ± 0.18 | 40.9–42 | 42 ± 0.92 | 46–52 | 49 ± 4 | 52.00 |
| TH | 41–53 | 47.2 ± 5.8 | 150–160 | 155 ± 7.07 | 46–50 | 48 ± 2.83 | 52–54 | 53 ± 1.41 | 52.00 |
| Alkalinity | 25–70 | 39.5 ± 13.8 | 20–30 | 25 ± 7.1 | 20–30 | 25 ± 7.07 | 20–30 | 25 ± 7.07 | 20.00 |
| Cl^- | 6.39–14.2 | 9.02 ± 2.2 | 17–25.6 | 21.3 ± 3 | 8.52–1136 | 9.94 ± 2.01 | 11.36–12.78 | 12.07 ± 1 | 12.78 |
| DO | 4.26–6.69 | 5.26 ± 0.74 | 4.86–5.88 | 5.37 ± 0.72 | 6.08–6.28 | 6.18 ± 0.14 | 4.86–6.28 | 5.57 ± 1 | 6.28 |
| NO_3^- | 0.23–4.09 | 1.75 ± 1.14 | 5.85–6.67 | 6.67 ± 0.58 | 1.04–2.68 | 1.86 ± 1.16 | 1.02–1.89 | 1.46 ± 0.62 | 1.02 |
| PO_4^{3-} | 0.03–0.81 | 0.34 ± 0.24 | 0.74–0.81 | 0.78 ± 0.05 | 0.38–0.54 | 0.46 ± 0.11 | 0.23–0.91 | 0.57 ± 0.48 | 0.23 |
| NH_4^+ | 0.07–0.08 | 0.07 ± 0 | 0.07 | 0.07 ± 0 | 0.06–0.09 | 0.08 ± 0.02 | 0.04–0.08 | 0.06 ± 0.03 | 0.04 |

n = 10, 2, 2, 2 and 1 from the Beeshazar, Laxmi, Kumal, Tikauli and Kingfisher lakes, respectively

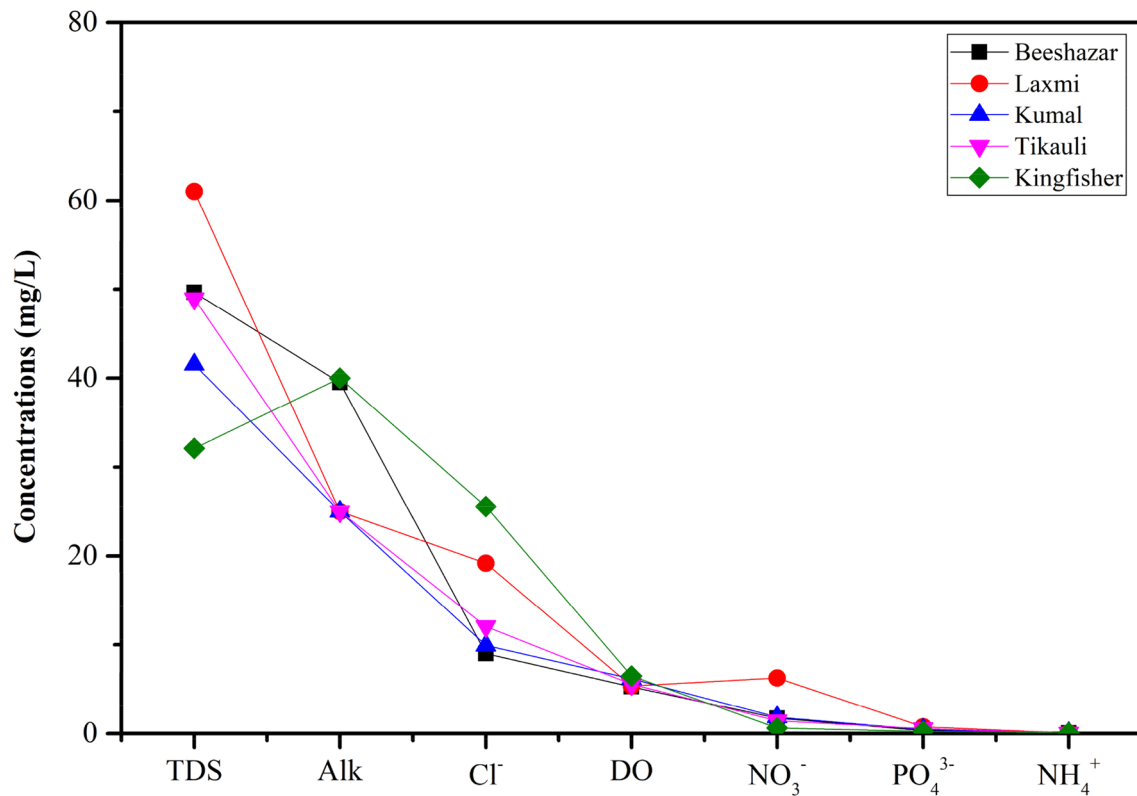


Fig. 2 Spatial patterns of hydro-chemical parameters in the Beeshazar and associated lakes, Chitwan, Nepal

variation. Similarly, the average temperature of the lakes was obtained within the desirable limits. However, EC and TDS displayed a substantial spatial variability in the different lakes. For instance, the mean concentration of EC and TDS was found to be elevated in the Laxmi Lake compared to the other lakes which might be due to the low outflow rate of water and interferences of agricultural runoff and activities of wild animals [34]. These results are also supported by the high concentrations of nitrate in Laxmi Lake (Fig. 2). Similarly, the mean value of TH in Laxmi Lake was found relatively higher than the other lakes, indicating the higher carbonate weathering with more anthropogenic interference in the lake. The higher concentration of TH in the Laxmi Lake is also consistent with the results of EC and TDS. Results showed that the mean value of DO was found in the order of Kingfisher > Kumal > Tikauli > Laxmi > Beeshazar. The higher value of DO in the water designates the better water quality, thus, the aforementioned order of the lakes also characterizes the spatial water quality variations in the lake complex [35].

Similarly, the mean Cl⁻ values of different lakes were reported in the order of Laxmi > Kingfisher > Tikauli > Kumal > Beeshazar. The relatively high Cl⁻ content in the Laxmi Lake indicates the higher ionic strength, which may be resulting from the leaching of soil

salts due to intensive agricultural practices in the vicinity of the lake complex. Besides, the order of mean concentrations of NO₃⁻ and NH₄⁺ in the studied lakes were found to be Laxmi > Kumal > Beeshazar > Tikauli > Kingfisher; and Kumal > Beeshazar > Laxmi > Tikauli > Kingfisher, respectively. The high concentration of NO₃⁻ in the Laxmi Lake was again characterized by intensive agriculture activities in the surrounding areas [33]. The findings showed that the mean concentration of PO₄³⁻ was found in the order of Laxmi > Tikauli > Kumal > Beeshazar > Kingfisher Lakes. From all these analyses, it was found that the Laxmi Lake has a relatively high pollution load as compared to the other lakes (Fig. 2).

3.3 Cluster analysis (CA)

A dendrogram with hierarchical clustering based on EC, TDS, TH, alkalinity, Cl⁻, NO₃⁻, PO₄³⁻ and NH₄⁺ revealed that the sampling sites into 3 distinctive clusters exhibiting their pollution magnitudes as clean, slightly polluted and polluted (Fig. 3). Cluster 1 corresponding to sites 1, 4, 5, 6, 9 and 10 represents less pollution than the other sites. All of these sampling points were from the main Beeshazar Lake. Cluster 2 includes the sites 2, 3, 7, 8, 13,

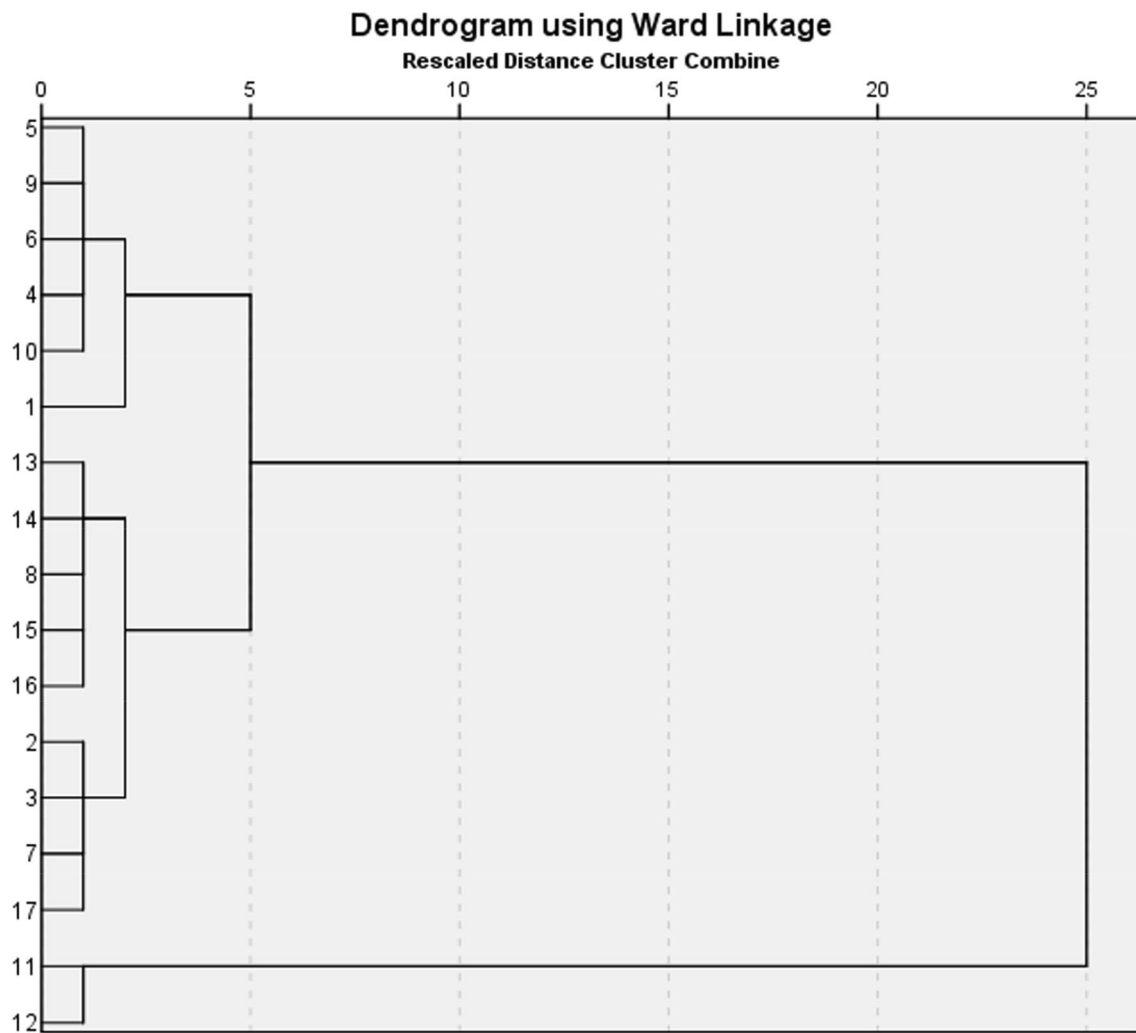


Fig. 3 Dendrogram based on hierarchical cluster of sampling sites of the Beeshazar and associated lakes, Chitwan, Nepal. (Sites: 1 to 10 represent B1 to B10, 11 and 12 represent L11 and L12, 13 and

14 represents K13 and K14, 15 and 16 represents T15 and T16, and 17 represents KF17)

14, 15, 16 and 17 and are slightly polluted than Cluster 1, might be due to agricultural runoff and high wildlife recreational activities [36]. These sampling points were located from the Beeshazar, Kumal, Tikauli and Kingfisher lakes. Similarly, the Cluster 3 contains just two sites (11 and 12) from the Laxmi Lake which was characterized by presence of algal blooms and human disturbance, especially agricultural runoff. Additionally, anthropic activities are found in this area from the perspective of recreation and research activities. The CA results showed that the Clusters 1 and 2 have better water quality than the Cluster 3, which are consistent with the results given by the spatial variations as shown in Fig. 2.

3.4 Principal component analysis (PCA)

The PCA was executed for EC, TDS, TH, alkalinity, Cl^- , NO_3^- , PO_4^{3-} and NH_4^+ and the results were interpreted on the basis of factor loadings (eigenvalues > 1). Studied hydrochemical variables were categorized into 4 principal components (PC1, PC2, PC3 and PC4) in the loading plot (Fig. 4). The PCA results can be classified as strong, moderate and weak, if the factor loadings are > 0.75, 0.75–0.50 and 0.50–0.30, respectively [1, 36]. The test results suggested that the PCA can be significant in the present study [Kaiser–Meyer–Olkin (KMO) = 0.62]. The result of the analysis of water quality parameters based on PCA is shown in Table 3. The PC1 clarifies the strong positive loadings on EC and TDS, with 34.43% of the total variance and moderate positive loadings on

Fig. 4 Loading plots for the principal component of the monitoring data of the hydro-chemical variables of the Beeshazar and associated lakes, Chitwan Nepal

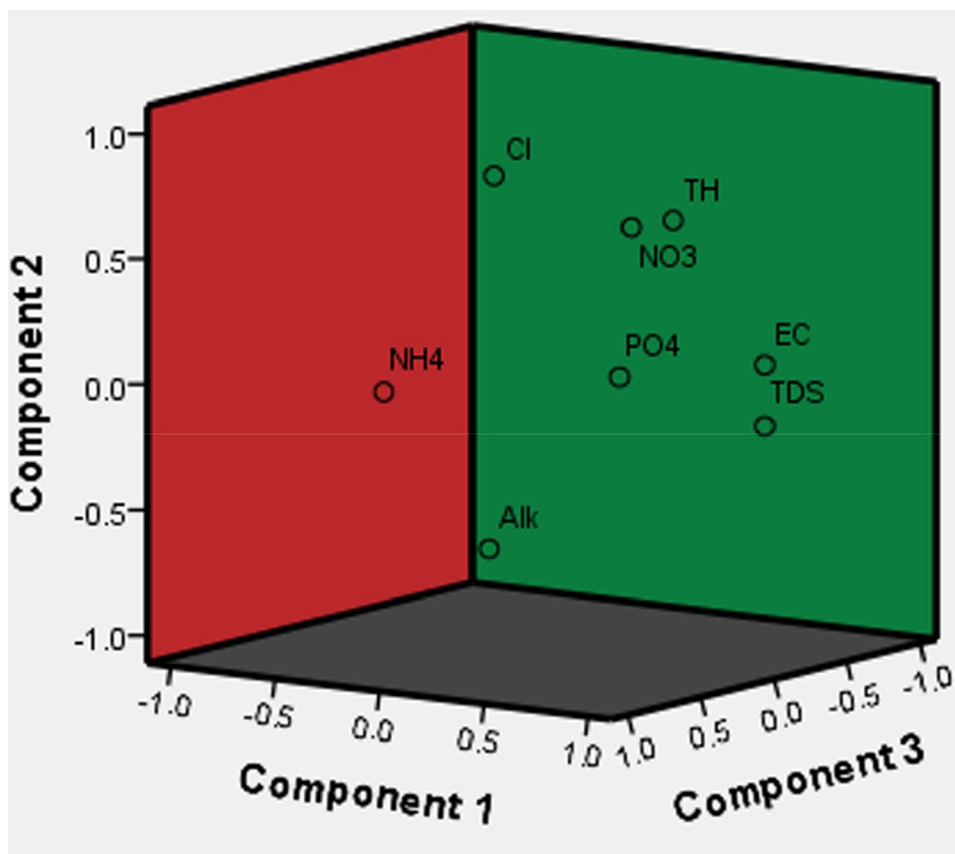


Table 3 Component matrix of hydrochemical dataset of the Beeshazar and associated lakes, Chitwan, Nepal

| Factors | Rotated component matrix | | | |
|-------------------------------|--------------------------|---------------|--------------|--------------|
| | PC 1 | PC 2 | PC 3 | PC 4 |
| pH | -0.20 | 0.16 | -0.86 | -0.19 |
| EC | 0.94 | 0.07 | -0.07 | -0.18 |
| TDS | 0.90 | -0.16 | 0.00 | -0.25 |
| TH | 0.69 | 0.63 | -0.03 | 0.07 |
| Alkalinity | 0.03 | - 0.68 | 0.22 | 0.37 |
| Cl ⁻ | -0.04 | 0.78 | 0.29 | 0.17 |
| DO | -0.27 | 0.20 | 0.80 | -0.22 |
| NO ₃ ⁻ | 0.58 | 0.50 | -0.17 | 0.22 |
| PO ₄ ³⁻ | 0.70 | 0.08 | 0.12 | 0.41 |
| NH ₄ ⁺ | -0.12 | 0.02 | -0.02 | 0.89 |
| Eigenvalues | 3.44 | 1.74 | 1.60 | 1.31 |
| Variance (%) | 34.43 | 17.39 | 15.96 | 13.08 |
| Cumulative % | 34.43 | 51.82 | 67.78 | 80.86 |

TH, PO₄³⁻ and NO₃⁻. Generally, a higher value of the EC shows high values of TDS due to more concentrations of dissolved ions. In these results, moderate ionic strength was reflected by EC in all the lakes and the analyzed ions

have either moderate or weak positive or negative association with EC and TDS. This is due to the reason that some of the major ions that could have a major influence on EC and TDS are not analyzed.

PC2 explains 17.39% of the total variance and strong positive loading on Cl⁻ and moderate positive loading on TH, NO₃⁻ and moderate negative loading on alkalinity (Alk). It indicates that Cl⁻, NO₃⁻ and TH are contributing to the same sources, whereas the alkalinity source could be different. From the results, it is clear that Cl⁻, NO₃⁻ and TH could be contributed from mixed geogenic and anthropogenic sources, whereas the prime source of alkalinity could be the weathering of carbonate dominated underlying lithology in the lake complex. The PC3 explains 15.96% of the total variance and strong positive loading on DO, signifying that the major sources of DO in the lake complex are distinct from the other chemical variables. Lastly, the PC4 elucidates 13.08% of total variance with strong loading on NH₄⁺, suggesting that the different origins of ammonium compounds from other sources. Since the lake complex is surrounded by dense forest with a huge accumulation of leaf litter, the decomposition of the nitrogenous compounds and organic matters by heterotrophic bacteria could be the primary source of NH₄⁺ in the lakes.

3.5 Correlation analysis

The correlation coefficient between the measured hydrochemical parameters is presented in Table 4. The correlation of various hydrochemical variables can be classified into different categories such as moderate positive correlation ($r = 0.5$ to 0.79), strong positive correlation ($r > 0.80$), moderate negative correlation ($r = -0.5$ to -0.79) and strong negative correlation ($r > -0.80$) [1, 14]. In the present study, WT shows a moderate positive correlation with Cl^- ($p < 0.05$) and pH showed a moderate negative correlation with DO. Similarly, EC showed a strong positive correlation with TDS ($p < 0.01$), indicating that a probability of a common source of inorganic chemicals and confirming the potential role of TDS on the mobility of the ions in the lake complex. As the concentrations of TDS is directly associated with the EC values, the strong positive correlation between them also confirms the reliable data quality in the study. These correlations are consistent with the CA and PCA results.

3.6 Comparative analysis

The comparative assessment of the hydrochemical parameters of waters from the selected lakes is shown in Table 5. In the present study, the highest mean value of EC i.e. $122 \mu\text{S}/\text{cm}$ from the Laxmi Lake and the lowest value ($69 \mu\text{S}/\text{cm}$) from the Kumal Lake, both of which are one of the lowest values as compared to the lakes listed in Table 5. Most of the Himalayan lakes have EC values $< 500 \mu\text{S}/\text{cm}$, however, some of the lakes have values ranges from 500 – $1000 \mu\text{S}/\text{cm}$ (Table 5). Similar to the EC patterns, the TDS concentrations of the present study also revealed one of the least concentrations as compared to the other lakes in the region.

Similarly, the average concentration of pH of the present study is comparable with most of the Himalayan lakes where it ranges from 7 to 9. pH is directly associated with the bicarbonate, carbonate and hydroxide ions in the water. The values of alkalinity in the present study are comparable with many of the freshwater lakes in the regions, as it ranged from 20 to $200 \text{ mg}/\text{L}$. The level of alkalinity $< 10 \text{ mg}/\text{L}$ indicates poorly buffered lakes meaning that these water bodies are the least capable of resisting changes in pH and therefore, are the most susceptible to problems that occur as a result of acidic pollutants. Moreover, the mean Cl^- the content of the present study is also comparable to many of the lakes in the region (Table 5).

NO_3^- concentrations of the present study showed relatively low mean values and comparable with the many other Himalayan lakes. However, the concentrations of NO_3^- in the Laxmi Lake reported the second-highest after Pandoh Lake, demonstrating the anthropogenic imprints where there might be some contributions from the Khageri Irrigational Canal and agricultural runoff from the surrounding areas. Relatively higher NO_3^- and NH_4^+ concentrations in some of the sampling points of the present study may be due to the favorable ecological conditions in the lake complex (e.g., high mean temperature and huge accumulations of organic matters) for rapid mineralization processes of nitrogen-containing compounds and the activities of heterotrophic microorganisms, which is rare in many of the Himalayan lakes. Finally, most of the results of the present study were comparable with the previous studies conducted in the Himalayan freshwater lakes and also within the prescribed range of WHO and NWQGAC guideline values [Tables 1 and 5; [26, 28].

Table 4 Correlation matrix of hydrochemical parameters of the Beeshazar and associated lakes, Chitwan, Nepal

| | Tem | pH | EC | TDS | TH | Alk | Cl^- | DO | NO_3^- | PO_4^{3-} | NH_4^+ |
|--------------------|--------------|---------------|---------------|-------|-------|-------|---------------|-------|-----------------|--------------------|-----------------|
| Tem | 1.00 | | | | | | | | | | |
| pH | -0.48 | 1.00 | | | | | | | | | |
| EC | 0.27 | 0.07 | 1.00 | | | | | | | | |
| TDS | 0.30 | -0.02 | 0.96** | 1.00 | | | | | | | |
| TH | 0.44 | 0.17 | -0.30 | -0.28 | 1.00 | | | | | | |
| Alk | -0.32 | -0.25 | 0.10 | 0.17 | 0.43 | 1.00 | | | | | |
| Cl | 0.56* | -0.34 | 0.40 | 0.30 | 0.10 | -0.41 | 1.00 | | | | |
| DO | 0.45 | -0.59* | -0.24 | -0.13 | -0.20 | -0.10 | 0.37 | 1.00 | | | |
| NO_3^- | 0.25 | 0.29 | -0.39 | -0.45 | 0.31 | -0.28 | 0.29 | -0.33 | 1.00 | | |
| PO_4^{3-} | 0.27 | -0.11 | -0.05 | 0.02 | 0.37 | 0.04 | -0.08 | -0.07 | 0.20 | 1.00 | |
| NH_4^+ | -0.01 | -0.10 | -0.19 | -0.21 | -0.19 | 0.14 | 0.15 | 0.05 | 0.08 | 0.30 | 1.00 |

The bold values indicate significant correlation

*Correlation is significant at the 0.05 level (2-tailed) and **Correlation is significant at the 0.01 level (2-tailed)

Table 5 Comparison of hydrochemical variables of the Beeshazar and Associated Lakes with selected lakes of Nepal and India

| Lakes | pH | EC | TDS | NO ₃ ⁻ | Cl ⁻ | HCO ₃ ⁻ | References | Sampling period |
|------------|------|-----|-----|------------------------------|-----------------|-------------------------------|---------------|--|
| Beeshazar | 7.55 | 84 | 50 | 1.75 | 9.02 | 34.4 | Present study | March, 2016 |
| Laxmi | 7.44 | 122 | 61 | 6.26 | 19.1 | 25.3 | | |
| Kumal | 7.55 | 69 | 42 | 1.86 | 9.94 | 25.3 | | |
| Tikauli | 7.53 | 82 | 52 | 1.46 | 12.07 | 25.5 | | |
| Kingfisher | 7.76 | 86 | 52 | 1.02 | 12.78 | 20.3 | | |
| Nagdaha | 7.8 | 195 | 106 | 1.64 | 27.07 | 71.59 | [6] | December, 2010 and March, 2011 |
| Nainital | 8.7 | 706 | 447 | | 15.3 | 351 | [10] | Spring season, 2005 |
| Sattal | 9.7 | 119 | 76 | – | 7.3 | 54.4 | | |
| Bhimtal | 8.9 | 181 | 109 | – | 6.4 | 91.1 | | |
| Naukuchiya | 9.4 | 148 | 81 | – | 6.6 | 73.9 | | |
| Renuka | 8.4 | 590 | 378 | – | 11.9 | 146 | [11] | March–April 2001 |
| Sella | 6.55 | 8.5 | – | 0.7 | 0.5 | 8.5 | [12] | May, 2011 and November, 2011 |
| Tsokyo Tso | 6.5 | 13 | – | 0.8 | 0.6 | 9.5 | | |
| Rupa | 7.87 | 52 | 37 | 2.46 | 16.52 | – | [13] | June, 2016 |
| Begnas | 9.04 | 36 | 25 | 1.77 | 20.04 | – | | |
| Suraj | 9.1 | 140 | – | 0.13 | 5 | 130 | [14] | August, 2009–October, 2011 |
| Sissu | 8.5 | 200 | – | 4.13 | 56 | 286 | | |
| Deepak | 8.8 | 130 | – | 0.15 | 4.3 | 120 | | |
| Chandra | 8.6 | 180 | – | 0.5 | 3.55 | 150 | | |
| Mansar | 7.99 | 194 | 124 | 0.76 | 6 | 125 | [15] | October–November, 1998 |
| Betkot | 7.7 | 337 | 168 | 0.06 | 12.2 | 24.92 | [16] | November, 2018 |
| Begnas | 7.7 | 82 | 60 | 6.1 | 4.34 | 17.8 | [37] | November, 2008; April, 2009 and August, 2009 |
| Pandoh | 7.35 | 72 | 53 | 10 | 1.53 | 43 | [38] | August, 2004; January, 2005 and May, 2005 |
| Phewa | 6 | 43 | – | 0.4 | 1.68 | – | [39] | June, 2015 |
| Jagdishpur | 6.91 | 379 | – | – | 9.65 | 220 | [40] | Winter, spring, summer and autumn, 2007 |
| Rara | 8.32 | 189 | 95 | 1.63 | 5.79 | 76.16 | [41] | October, 2015 and April, 2006 |

All the variables are expressed in mg/L, except pH and EC ($\mu\text{S}/\text{cm}$)

3.7 Comprehensive pollution index (PI)

The PI approach was applied to evaluate the impact of anthropogenic activities and spatial variations in the hydrochemical characteristics on the water quality of the Beeshazar and associated lakes. Based on PI, the water quality level can be categorized into five groups namely cleanness (PI: ≤ 0.20), sub-cleanness (PI: 0.12 to 0.40), slight pollution (PI: 0.41 to 1.0), moderate pollution (PI: 1.01 to 2.0) and severe pollution (PI: ≥ 2.01) [27]. Results of the PI are presented in Fig. 5 and showed that the overall sites were found sub-cleanness and slightly polluted, as discussed in the previous study [27]. The PI values of sampling sites in B1, B2, B3, B4, B5, B6, B7, B8, B9, B10, L11, L12, K13, K14, T15, T16 and KF17 were found to be 0.43, 0.39, 0.40, 0.38, 0.43, 0.36, 0.34, 0.36, 0.36, 0.39, 0.52, 0.51, 0.45, 0.40, 0.45, 0.39 and 0.38, respectively, indicating the lowest pollution in Beeshazar and the highest pollution in the Laxmi Lake. A total of 11 out of 17 sampling sites (B2–B4 and B6–B10) from Beeshazar; and K14, T16 and KF17 from Kumal, Tikauli and Kingfisher, respectively, lied in the

sub-cleanness category and the rest of 6 sites (i.e., B1 and B5 from Beeshazar; L11 and L12 from Laxmi; K13 and T15 from Kumal and Tikauli, respectively) have slightly polluted water on the basis of PI analysis. The result can also be justified by the range of the water quality parameters in sampling points of different lakes and the CA results.

3.8 Water quality index (WQI)

WQI aims to give a single value to the water quality of a source along with reducing a large number of hydrochemical variables into a simple expression for the easy interpretation of the dataset. The weighted arithmetic water quality index method is widely used to classify the water quality according to the degree of purity and used to determine the suitability of water for drinking purposes. The WQI can be classified into five categories as excellent (0–25); good (26–50); poor (51–75); very poor (76–100); and unsuitable for drinking (> 100) [4]. In this study, the WQI score for drinking water was computed using the guidelines of WHO and the WQI of the Beeshazar and

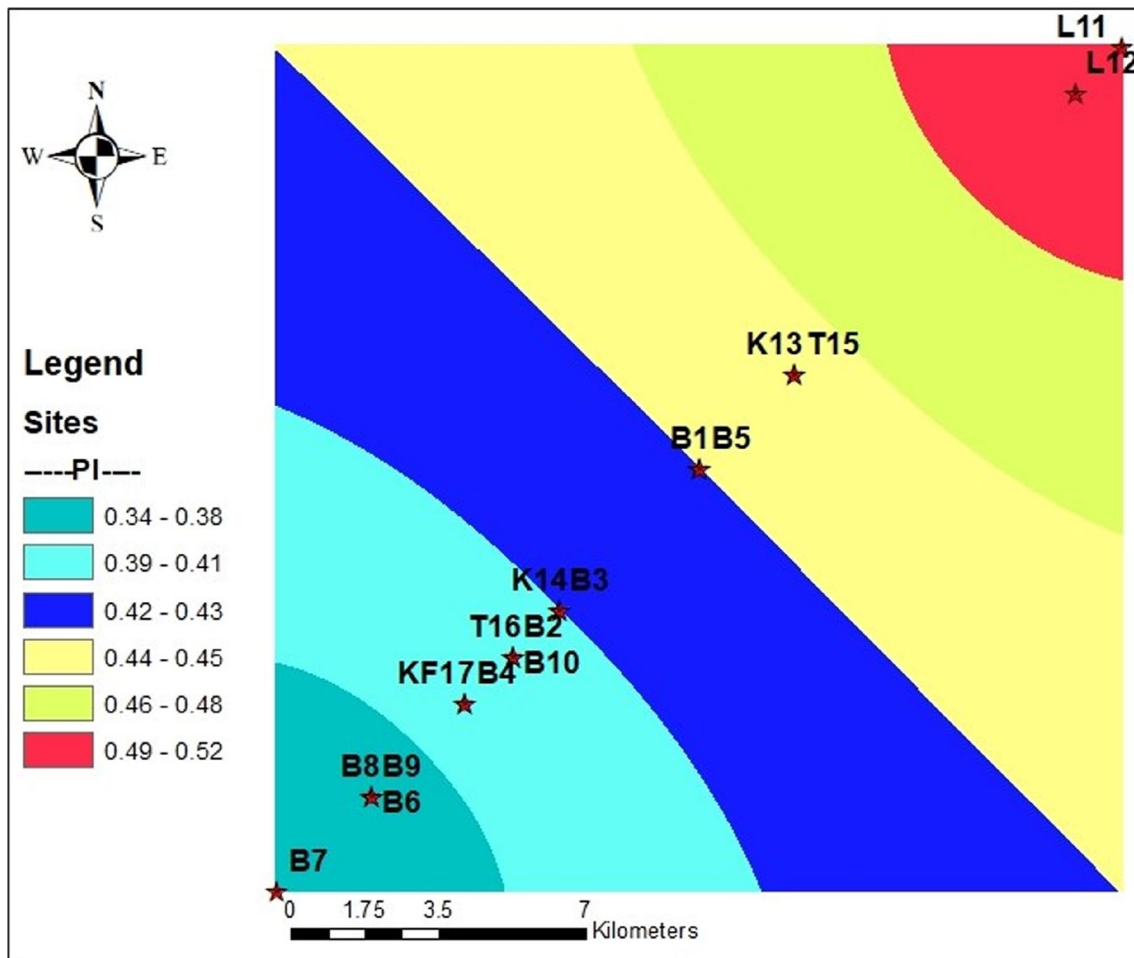


Fig. 5 Spatial distribution of water quality according to comprehensive pollution index (PI) in Beeshazar and associated lakes, Chitwan, Nepal

associated lakes was found to be 33.90, which lies in the category of good water. Thus, from the WQI, it can be assured that the water quality of the Beeshazar and associated lakes were at a safe level for drinking purposes.

4 Conclusion

All the water bodies in the Beeshazar and lake complex are dominated by alkaline water with a mean pH value of 7.52. The hydrochemistry of the area was impacted by both geogenic and anthropogenic sources and distinct spatial variations were obvious in the lake complex. Moreover, the spatial disparity among the lakes was elucidated from the elevated concentrations of EC, TDS, TH, NO_3^- and PO_4^{3-} in the Laxmi Lake. Interestingly, the groundwater inflow nearby the Khageri Irrigation Canal and farmland areas in the vicinity are also suspected as

the major contributors to the elevated concentrations of the chemicals in the lake complex.

Comprehensive pollution index marked 11 sampling sites of the study area as sub-cleanness and the rest as slightly polluted, but the overall water quality index of studied lakes was found to be 33.90, which concludes that the water in the lake complex is currently safe for the drinking purposes. In good agreement with the above, all the analyzed water parameters lie within the prescribed guidelines provided by the WHO and NWQGAC. However, the lake complex is surrounded by intensive farmlands and the anthropogenic signature in terms of elevated concentrations of NO_3^- and PO_4^{3-} may pose serious problems for retaining water quality in the future.

This study can contribute to the effective use of available water resources with maintaining its natural quality and the results of the study could be considered for the further planning and management of the Ramsar listed lakes in the region. Comprehensive further investigations

are recommended in the lake complex focusing on hydro-geochemical characterizations at spatiotemporal levels.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest.

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