Research Article

Distribution and risk appraisal of dissolved trace elements in Begnas Lake and Rupa Lake, Gandaki Province, Nepal

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Abstract

Contamination of the trace elements (TEs) in the freshwater ecosystems is becoming a worldwide problem. This study was carried out to investigate the TEs contamination, and their associated health risk in Begnas Lake and Rupa Lake, Gandaki Province, Nepal. A total of 30 water samples were collected from both lakes during the pre-monsoon season in 2016. The samples were analyzed for the TEs including copper (Cu), lead (Pb), zinc (Zn), nickel (Ni), cobalt (Co), chromium (Cr), cadmium (Cd), manganese (Mn), cesium (Cs), and arsenic (As) using inductively coupled plasma mass spectrometry. The results exhibited that the mean concentrations of all the TEs were higher in Rupa Lake as compared to Begnas Lake except Pb. Principal component analysis and cluster analysis revealed that both the geogenic and anthropic sources were the major contributors of TEs in the lake water. Anthropic activities were considered to contribute the TEs like Zn and Mn in lake water mainly via agricultural runoff, while evaluating the risk of TEs on human health all the elements showed $HQ < 1$ and $CR < 10^{-4}$ indicating currently very low health risk concerns. In good agreement with above, the water quality index (WQI) of the Begnas Lake and Rupa Lake was 2.67 and 5.66, respectively, specifying the lake water was safe for drinking and public health concern. This appraisal would help the policymakers and concerned stakeholders for the sustainable management of Ramsar listed freshwater lakes in the Himalayas.

Keywords Trace elements · Water quality · Health risk assessment · Hazard quotient · Gandaki Province · Nepal

1 Introduction

Contamination of freshwater with toxic trace elements (TEs) due to natural processes such as atmospheric accumulation, geological weathering as well as anthropic activities such as domestic and urban sewerages, industrial effluents, and agro-runoff is of great concern worldwide [1]. The freshwater lakes are susceptible to chemical contaminations as they are stagnant in nature [2]–[5]. The TEs such as arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), cesium (Cs), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) are the major contaminants having significant toxicity to the human health if their concentrations exceed the desirable limits [6, 7]. The As, Cd, Cr, Pb, and Zn have both carcinogenic and non-carcinogenic risks to public health. For instance, Pb interrupts the gonad secretions [8] and Zn can damage the digestive, nervous, and blood circulation system in the human [9]. Similarly, excessive concentration of Cu affects the digestive system, liver, and brain [10]. Thus, the appraisal of TEs and their

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associated potential risks in lake water quality is imperative from a human and ecological health perspective [11, 12].

Prior studies have highlighted that the consumption of contaminated water with elevated concentrations of TEs may cause multiple health issues including cancer [13]–[16]. The freshwater lakes in the Himalaya are quite sensitive toward the TEs contamination and, thus, intensive scientific investigations have been carried out in the headwater region of the Tibetan Plateau [17]–[20]. However, in the central Himalayan region, the characterization and health risk appraisal of the TEs contamination on the freshwater bodies are limited [21]. Long-range transport of TEs has been highlighted as one of the major sources of contamination in the glacier-fed water resources in the Himalayas [4]. Additionally, the more recent studies have underlined that the melt-water region in the Himalaya, lowland, and urban areas are found to be relatively more susceptible to TEs contamination due to global climate change and anthropic activities including rampant settlements, industrializations, and modern agriculture[9, 22, 23].

The freshwater lakes are the main sources of drinking and irrigational water supply in Nepal; however, their quality appraisal is in the primitive stage [24, 25]. The Begnas Lake and Rupa Lake are located in the central Himalayas, having high anthropic disturbances in the vicinity, especially due to agro-runoff, fisheries, municipal wastes, boating, and religious activities, etc. Majorities of the studies have focused on the water quality, limnological, phytoplankton, macrophytes, and zooplankton investigations in these lakes [2, 26]. However, to our best knowledge, there is no scientific literature on health risk assessment of TEs in the lake water. The objective of this study is to assess the status of TEs, and their potential human health risk with hazard quotients and carcinogenic risk in the Ramsar listed Begnas Lake and Rupa Lake of the Gandaki Province, Nepal.

2 Material and methods

2.1 Study area

The Begnas Lake and Rupa Lake are situated in the Gandaki Province, Nepal. These lakes play a vital role in the livelihood stability of the people and ecological sustainability. The Begnas Lake lies at an altitude of 650 m.a.s.l. about 13 km east of core-urban Pokhara city. The catchment of the lake occupies an area of about 20 km^2 in between the Greater Himalaya and the Mahabharat range (28.13 N to 28.21 N and 84.08 E to 84.17 E). The lake covers the surface area of 3.28 km^2 and the depth ranges from 6.6 m to 10 m.

The northern side of the lake is far from urban settlements with dominant agro-practices.

Similarly, the catchment area of the Rupa Lake is located in the eastern part of the Pokhara Metropolitan City (28.14 N to 28.20 N and 84.10 E to 84.17 E, elevation 600 m.a.s.l.). The surface area of the lake is 1.35 km^2 with an average depth of 3 m.

Both the lakes are located in the subtropical climatic region. The annual temperatures range from 12 °C to 29 °C and the rainfall occurs more than 80% during the monsoon season from June to September [27]. The geology of the Began and Rupa basins is characterized by an intermontane fluvial basin. The basins consist of loamy to sandy gravel, silt, and clay deposits of quaternary age brought from the Annapurna mountain range [28, 29]. Precambrian to Palaeozoic talc-rich red phyllite, schist, limestone, quartzite, gneiss, and carbonaceous conglomerate with inter-bedded schist are the major geological formations in the region. Due to the presence of the soluble calcareous material in the clastic sediments of the lake basins, the karst structures like subsurface flow channels, cavities; sinkholes, pinnacles, solution chimneys, etc., are widely developed at the surface and underground in both the lake basins [30]. The lakes are surrounded by forest having *Shorea robusta, Engelhardtia spicata, Syzygium* spp.*, Lagerstromia* spp.*, and *Phyllanthus emblica* as the major tree species [26]. Both the lakes are designated as the Ramsar site (No. 2257) in 2016 along with other lake clusters of Pokhara valley.

2.2 Sampling and analytical methods

In this study, water samples were collected from 30 different sites from both the lakes (15 from each lake) during pre-monsoon season in 2016. The sampling sites were selected on the basis of hydroclimatic conditions, topographic variations, and land-use features. Samples were collected in acid-washed 20-mL ultra-clean high-density polyethylene (HDPE) bottles and stored in a refrigerator at 4 °C until further analysis. To avoid the adsorption of TEs on the wall of the bottles, the samples were acidified (pH < 2) by using concentrated ultrapure nitric acid. A total of 10 TEs, namely Cu, Pb, Zn, Ni, Co, Cr, Cd, Mn, Cs, and As, were analyzed using inductively coupled plasma-mass spectrometry (ICP-MS, X-7 Thermo Elemental) at Institute of Tibetan Plateau Research, Chinese Academy of Sciences (ITP‒CAS), Beijing, China, and data processing methods were explained elsewhere [22]. The accuracy of the analytical protocol was ascertained based on repeated measurement of the externally certified reference solution, showing the analytical precision < 5% [31].

2.3 Statistical analysis

Multivariate statistical techniques were used for the evaluation and interpretation of the TEs dataset. Spearman's rank correlation was used to assess the potential associations between the TEs as data were not normally distributed [32]. Hierarchical agglomerative cluster analysis (CA) was performed to assess the variability of the TEs on the dataset and to group the similar sampling sites [33, 34]. Also, principal component analysis (PCA) was applied to identify the potential pollutants' sources in the lake water [35].

2.4 Water quality index (WQI)

The WQI has been widely used in recent years for the water quality assessment [23, 36, 37]. In this study, to assess the WQI of lake water using TEs, the weight of each TEs (Wi) was assigned according to the relative significance of the elements [1]. Nine elements (except Cs) were chosen to analyze the WQI. Among them, Pb, Cd, and Cr; and Ni and Zn were given the highest and the lowest ranking, respectively, based on their potential health effect [23]. The WQI was calculated using Eqs. (1) and (2):

$$WQI = \sum_{i=1}^{n} Wi \times \left(\frac{Ci}{Si} \right) \times 100 \tag{1}$$

where the relevant weightage (W$_i$) of each parameter is calculated as:

$$Wi = wi / \sum_{i=1}^{n} wi \tag{2}$$

wi: the weight of each parameter, ∑wi: the sum of the weightings of all parameters, Ci: concentration of each TE in each water sample, and Si: World Health Organization Guidelines for Drinking Water [38] for each TE.

The WQI is classified into five different categories: excellent (WQI < 50), good (WQI = 50–100), permissible (WQI = 100–200), poor (WQI = 200–300), and very poor (WQI > 300) [23, 39, 40].

2.5 Metal index (MI)

The metal index (MI) was calculated for TEs using maximum allowable concentration (MAC) of elements in drinking water guidelines, which accounts for TEs with possible effects on human health [9, 41]. The MI was calculated using Eq. (3):

$$MI = \sum \left(\frac{C}{MAC} \right) \tag{3}$$

C: average concentration of TEs.

The MI > 1 is considered as polluted and, thus, cannot be used for drinking purposes [9].

2.6 Health risk assessment (HRA)

The methodology for the assessment of public health risk due to contamination of TEs in drinking water has been described in previous studies [41]–[43]. The major pathways of TEs exposure to human health are ingestion, inhalation, and dermal absorption. The exposure dose for ingestion and dermal absorption were calculated using Eqs. (4) and (5):

$$ADDi = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{4}$$

$$ADDd = \frac{C \times SA \times Kp \times ET \times EF \times ED \times CF}{BW \times AT} \tag{5}$$

where ADD_i is the exposure dose through the ingestion of water, ADD_d is the dermal absorption (mg/kg/day), C indicates the average concentration of TEs in water (mg/L), IR is the ingestion rate (2.5 L/day), EF is the exposure frequency (350 days/year assuming that the local people spend the remaining 15 days outside from the study site), ED represents the exposure duration (68 years, 23,800 days), BW is the average body weight (65 kg), AT is the averaging time (in days), SA is the exposed skin area (17,000 cm^2), Kp is the skin permeability coefficient in water (cm/h), ET is the exposure time spent in bathing and shower (0.6 h/day), and CF is the unit conversion factor (1 L/1,000 cm^3). In this study, the skin permeability coefficients in lake water were assumed to be 0.001, 0.0006, 0.002, and 0.0002 for As, Mn, Cu, and Cd; Zn and Cr; Co and Pb; and Ni, respectively (Tripathee et al., 2016; Wu et al., 2009). The characterization of non-carcinogenic risks such as hazard quotients (HQ) and hazard index (HI) was carried out using US EPA guideline (2004). The HI from both the dermal absorption and ingestion was calculated using Eqs. (6) and (7):

$$HQingestion = \frac{ADD}{RfD} \tag{6}$$

$$HQdermal = \frac{ADD}{RfD} \tag{7}$$

where TEs toxicity reference dose (RfD) is 0.0003 mg/kg-day.

The health risk is considered when the HQ values are > 1 [44]. To evaluate the total potential non-carcinogenic risks posed by more than one pathway, HI is applied for assessing the general tendency for the non-carcinogenic effects and is calculated using Eq. (8):

$$HI = HQ_{ingestion} + HQ_{dermal} \qquad (8)$$

2.7 Cancer risk (CR)

CR is the probability that people will develop cancer during their lifetime because of the exposure to toxic chemicals under specific scenarios [45]. The CR of As, Cd, Pb, and Cr was calculated as according to Equations (9), (10) and (11):

$$CR_{ingestion} = ADDi/CSF \qquad (9)$$

$$CR_{dermal} = ADDd/CSF \qquad (10)$$

And the cancer index (CI) was calculated as:

$$CI = CR_{ingestion} + CR_{dermal} \qquad (11)$$

Here, CSF is the carcinogenic factor (1.5 mg/kg/day obtained from US EPA Guideline (2004)).

3 Results and discussion

3.1 General characteristics of TEs

The statistical summary of TEs (As, Cd, Co, Cr, Cs, Cu, Mn, Ni, Pb, and Zn) of Begnas Lake and Rupa Lake is presented in Table 1. and Fig. 1. In Rupa Lake, the concentration of Zn, Mn, and Cu exhibited a maximum variation with a high standard deviation. Nevertheless, the average concentration of the TEs was in the dominance order of Zn > Mn > Cu > As > Cr > Pb > Ni > Cs > Co > Cd. Based on the mean values, the TEs in the lake water can be divided into three groups [22]: (a) Zn (concentration > 10 µg/L); (b) Mn, As, and Cu (concentrations 1–10 µg/L); and (c) Ni, Cr, Cd, Cs, Cs, Co, and Pb (concentration < 1 µg/L). The relatively high concentration of Zn might be due to the geogenic process and anthropic activities including agro-runoff.

Similarly, the average concentration of TEs in the Begnas Lake was in the dominancy order of Zn > Mn > Cu > As > Pb > Cr > Ni > Co > Cs > Cd. In the lake, the TEs variation was less noticeable (except Zn) (Fig. 2). The increased concentration of Zn may be due to the intense farming activities in the vicinity of this lake also. Based on mean values, TEs can be categorized into two groups: (a) Zn, Mn, and Cu (concentrations 1–10 µg/L); (b) Cd, Co, Cr, Ni, Pb, As, and Cs (concentrations < 1 µg/L).

The concentrations of all the elements were more or less the same in both the lakes except As, Mn, and Zn (Fig. 2). Precisely, the mean concentrations of As, Mn, and Zn were 1.54, 1.90, and 3.70 times higher, respectively, in the Rupa Lake than the Begnas Lake. The As and Mn are the sensitive redox elements, and both are highly soluble in aqueous brines in the divalent form due to the formation of stable chloride complexes. Such contaminants are released from the anthropic activities including a poultry farm, additives, pesticide, and major source of Zn in the lake water could be the agricultural practices in the lake vicinity [8]. Thus, discharge of agricultural effluents and domestic sewage to the lakes might have increased the concentrations of As, Mn, and Zn.

In the Begnas Lake, the TEs concentrations range between 0.01 and 3.53 µg/L, whereas the concentrations in Rupa Lake range between 0.01 and 13.06 µg/L. In the case of Rupa Lake, As and Ni concentrations were higher than that of the global mean value. The concentrations of the elements in both the lakes are compared with World Health Organization guidelines (WHO), US EPA, and the global mean value (Table 2). The average concentrations of all the TEs in both the lakes were within the guidelines values for drinking purposes. This indicates that the TEs are mostly derived from the geogenic weathering process. Cu concentrations of both the lakes were similar to Gosainkunda Lake [4], while the concentrations of the other TEs were comparable with the other lakes and rivers from the Himalayan region (Table 2). The mean concentration of TEs within the standards and comparable to the global level indicating that their concentrations may not be harmful

Table 1 General statistics of TEs in Begnas Lake and Rupa Lake, Pokhara Valley, Nepal (concentration of the TEs is expressed in µg/L)

Lakes		As	Cd	Co	Cr	Cs	Cu	Mn	Ni	Pb	Zn
Begnas Lake	Min	0.79	BD	0.02	0.26	0.01	0.41	1.30	0.14	0.18	2.05
	Max	0.95	0.01	0.06	0.92	0.04	4.95	7.52	0.50	2.38	6.65
	Mean	0.87	0.01	0.03	0.45	0.02	1.70	2.98	0.27	0.61	3.53
	SD	0.05	0.00	0.01	0.20	0.01	1.54	1.71	0.13	0.72	1.50
Rupa Lake	Min	1.14	BD	0.04	0.44	0.01	0.53	2.08	0.21	0.19	2.94
	Max	1.56	0.03	0.15	0.95	0.35	5.44	15.50	0.69	1.04	47.55
	Mean	1.34	0.01	0.06	0.58	0.09	1.81	5.67	0.37	0.48	13.06
	SD	0.14	0.01	0.03	0.13	0.11	1.55	4.36	0.17	0.22	14.83

BD Below detection limit

to the human beings and aquatic environment at present. However, attention should be given to the increasing anthropic activities such as use of excessive pesticides, growing urbanization which might exceed the contaminants in future, causing risks of the harmful effects to the aquatic environment as well as human health.

3.2 Hierarchical clustering analysis (HCA)

The contaminated sites were identified with the help of a dendrogram (Figs. 3 and 4). In the Begnas Lake, CA showed three major clusters, namely Clusters 1, 2, and 3 comprising 73.33%, 6.67%, and 20% sampling points, respectively. Clusters 1 and 2 have more or less comparable concentrations of TEs to each other except Mn. The elevated concentration of Mn in Cluster 2 could

be due to the anthropic sources. The dataset showed that Cluster 3 was relatively more contaminated especially by Cr, Cu, Pb, and Zn. All these TEs ascribed their anthropic sources which could be due to agricultural runoff and domestic wastes.

Similarly, two distinct clusters were observed in Rupa Lake (Fig. 4) with 13.33% and 86.66% sampling points in Cluster 1 and 2, respectively. Results suggested that a notable spatial variation between the clusters in terms of Cu, Zn, and Mn. Based on the mean concentrations, Cu and Zn were 4.30 and 6.13 times higher, whereas Mn was 2.38 times lower in Cluster 1 as compared to Cluster 2. Thus, from both the clusters, it is deduced that the major sources of TEs in both the lakes were geogenic with minor anthropic signature. The sources of the elevated concentrations of Cr, Cu, Mn, Pb, and Zn are the agro-runoff and urban settlement areas around the lakes.
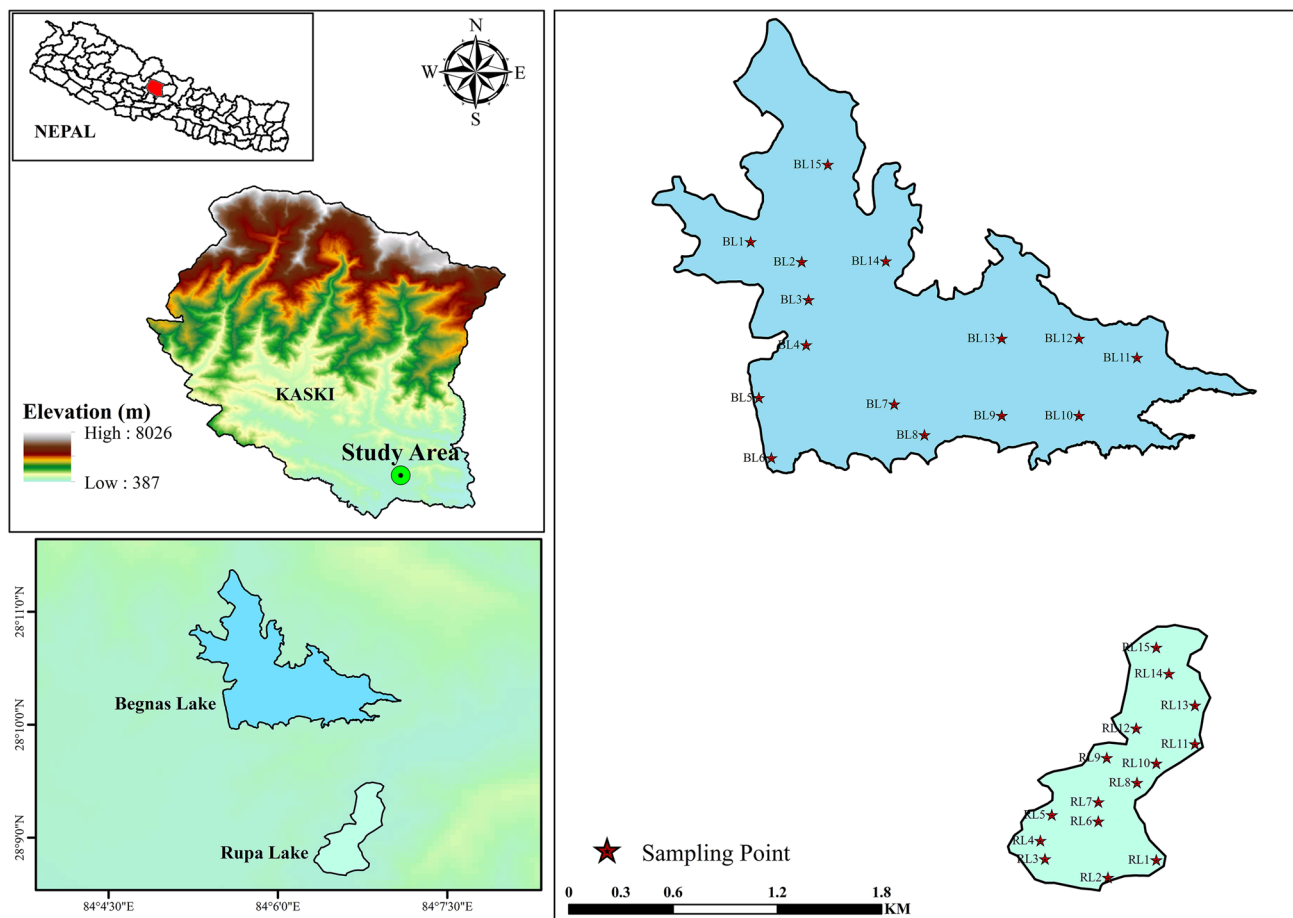

Fig. 1 Sampling points in the Begnas Lake and Rupa Lake, Gandaki Province, Nepal

3.3 Principal component analysis and correlation matrices

Principal component analysis (PCA) reduces the dimensionality of the dataset and one of the most powerful multivariate statistical tools to interpret the sources of TEs [32]. The PCA output of the TEs (As, Pb, Co, Mn, Cs, Ni, Cr, Cu, Zn, and Cd) is presented in Fig. 5 and Table 3. Before the analysis, the Kaiser–Meyer–Olkin (KMO) and Bartlett's sphericity tests were performed to examine the validity of PCA. The components are classified as strong, moderate, and weak corresponding to absolute loading values of > 0.75, 0.75–0.50, and < 0.50, respectively. These strong and moderate associations among the TEs were considered to have a major influence on the lake water quality [46].

In the Begnas Lake, two principal components (PCs) with eigenvalue > 1, explained about 76.32% of the total variances. Here, PC1 accounting for 65.36% of the total variance had strong positive loadings on Co, Cr, Cu, Ni, Pb, and Zn. The co-location of these TEs is likely to indicate the common sources and appeared to be more connected with anthropic activities. PC2 explains 10.96% of the total variance, had strong positive loadings on Mn, strong negative loading on As, moderate positive loadings on Cs, and weak positive loadings on Cd. The co-location of these TEs indicated the geological and lithological sources.

The Spearman's rank correlation matrix of Begnas Lake is illustrated in Table 4. A strong correlation between Ni-Cr; Ni-Cu; Zn-Cr; Zn-Cu and Zn-Ni pairs ($p < 0.01$) indicated that they are originated from both geogenic and anthropic sources. Moreover, the moderate correlation between Cr-Co; Cu-Co; Cu-Cr; Mn-Co; Ni-Co; Pb-Cr; Pb-Cu; Pb-Ni and Pb–Zn pairs ($p < 0.05$) indicated that they are mainly originated from geogenic sources.
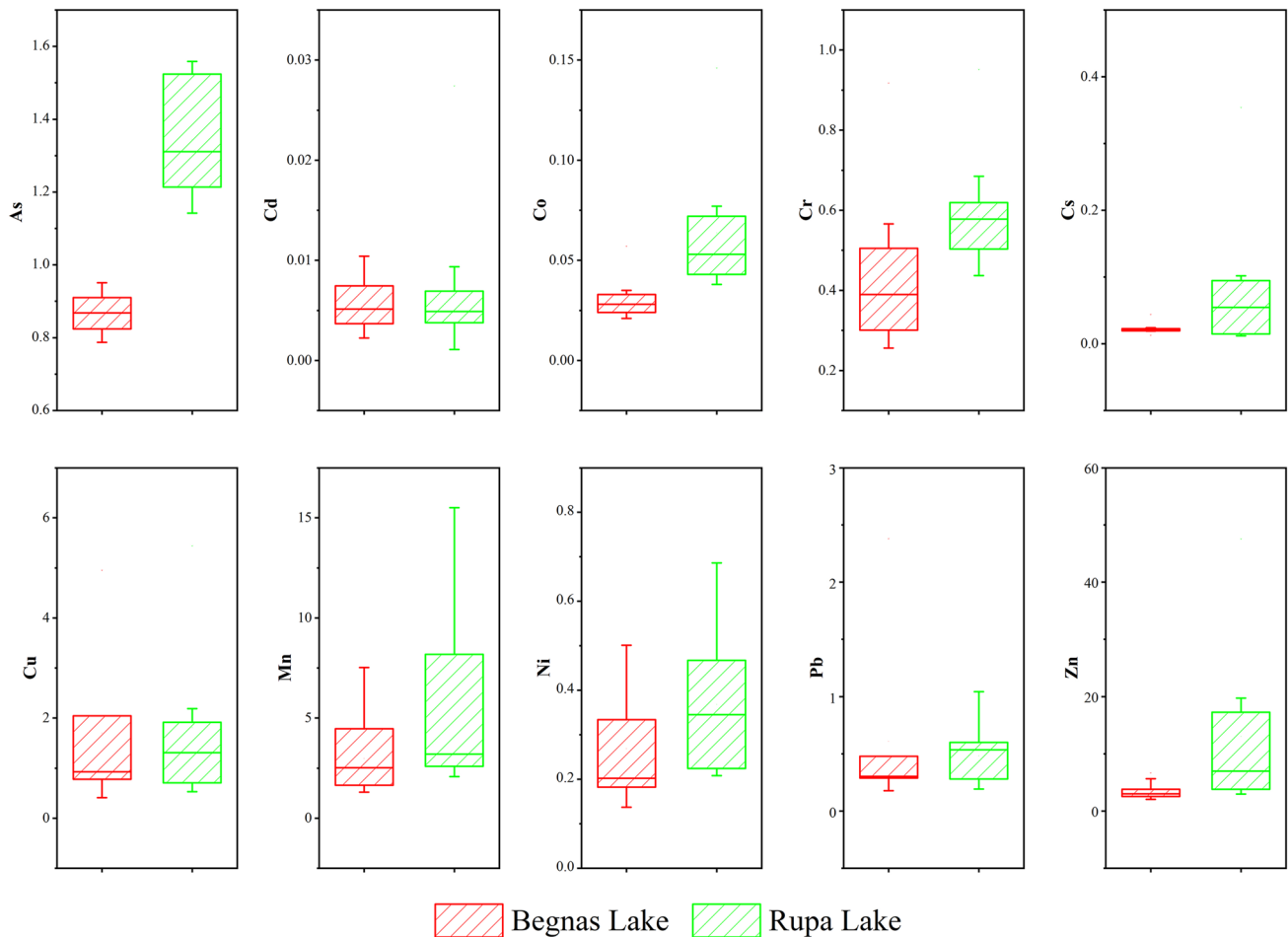

Fig. 2 Comparison of trace elements (TEs) concentration between Begnas Lake and Rupa Lake, GandakiProvince, Nepal (concentration of the TEs are expressed in µg/L)

Table 2 Comparison of trace elements (TEs) in Begnas Lake and Rupa Lake, Gandaki Province, Nepal, comparison with other study, drinking water guidelines and other continental average value (concentration of the TEs is expressed in µg/L)

Lakes	As	Cd	Co	Cr	Cs	Cu	Mn	Ni	Pb	Zn
Begnas lake	0.87	0.01	0.03	0.45	0.02	1.7	2.98	0.27	0.61	3.53
Rupa lake	1.34	0.01	0.06	0.58	0.09	1.81	5.67	0.37	0.48	13.06
Phewa lake[1]	–	0.003	1.44	0.71	–	0.3	393.88	0.28	0.16	4.55
Gosainkunda lake[1]	–	0.002	0.11	0.21	–	1.76	4.03	0.76	0.65	13.79
Gandaki river[2]	–	0.01	0.15	4.98	–	1.06	3.77	0.67	0.11	4.47
Indravati river[3]	–	–	0.02	0.43	–	3.38	11.3	2.42	0.93	11.28
Dudhkoshi river[3]	–	–	0.01	0.8	–	2.21	25.28	–	2.19	19.2
Bagmati river[4]	–	–	0.38	0.58	–	11.29	158.71	2.18		37.05
Nepalese standard[5]	50	3	–	50	–	–	200	–	10	3000
WHO limits[6]	10	–	50	–	–	2000	400	70	15	3000
Global Mean[7]	0.62	0.08	0.14	0.07	0.01	–	34	0.8	0.08	0.6
Asia mean[7]	0.15–2.0	0.0089–0.0038	0.01	–	–	0.76–0.91	0.55–2.2	0.30–1.42	–	0.039–0.36
Africa mean[7]	0.11–0.17	17–30	0.058–0.43	0.4–0.533	0.0026–0.016	0.63–1.397	0.44–29.72	0.35–5.04	–	0.89–3.12
Europe mean[7]	0.21–2.21	0.02–0.42	0.084–0.26	<0.85–11.46	0.01	0.456–3.53	3.76–48	0.92–5.06	–	4.98–27
North America mean[7]	0.12–0.91	0.014–0.18	0.02	0.241–2.1	0.0006–0.0070	0.841–1.930	0.41–14.86	0.47–10.39	–	0.12–3.79
South America mean[7]	–	0.17	0.017–0.766	0.72	0.006–0.013	0.227–1.997	0.46–113.52	0.21–0.92	–	0.27–3.1

1: [9]; 2: [9]; 3, 4: [21]; 5: [47]; 6: [39]; 7:[12]

In the Rupa Lake, four PCs with eigenvalues > 1 explained about 85.71% of the total variance. PC1 accounts for 34.31% of the total variance, which had strong positive loadings on Co, Cr, Mn, and Pb and moderate positive loadings on As. PC2, which explained 28.98% of the total variance, had strong positive loadings on Cu, Ni, and Zn. Similarly, PC3 explained 12.31% of the total variance, and also had strong loadings on Cs. And, PC4 explained about 10.11% of the total variance with strong loading on Cd. The co-locations of the PC1, PC2, and PC3 indicated that they are primarily associated with natural weathering and transportation of the materials. The PC4 specified their common sources and is likely to be influenced by agricultural activities that could be deduced to the mixed sources including lithogenic and anthropic.

The correlation coefficient of Rupa Lake is illustrated in Table 4. A strong correlation indicates similar sources such as weathering and transport processes [12], agriculture runoff, untreated municipal, and industrial wastes [4]. In the study, Zn was strongly correlated with

Ni ($p < 0.01$) indicating that Zn and Ni were also contributed from anthropic sources. Similarly, Mn-Co; Pb-As; Pb-Cu; Zn-Cs; and Zn-Cu pairs were moderately correlated with each other ($p < 0.05$) showing their more than one sources.

PCA results attributed the major geogenic contributions with minor anthropic signatures in both the lakes, and the results are in good agreement with correlation analysis in both the lakes.

3.4 Water quality index (WQI)

WQI of Begnas Lake and Rupa Lake is presented in Table 5. According to WHO, the Cd, Cr, Pb, and Mn are given the maximum weightage due to their high toxicity to public health. The health impact of such metals is peripheral neuropathy, carcinogenicity (skin, lung, and bladder cancer), tubular neurodevelopment, cardiovascular diseases, adverse pregnancy, hypertension, and infertility [38]. The WQI of the lakes was found to be 2.67 and 5.66, respectively, as in Table 5. Based on the WQI values (WQI < 50),
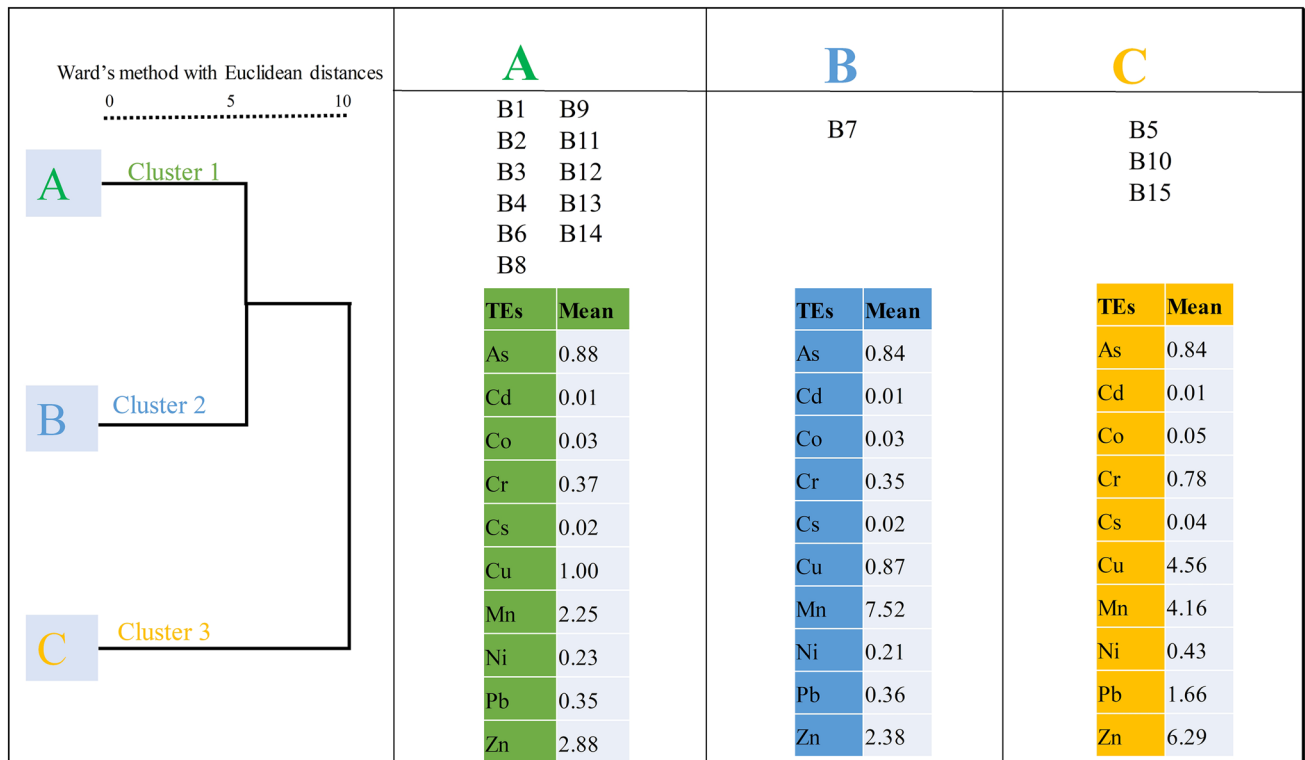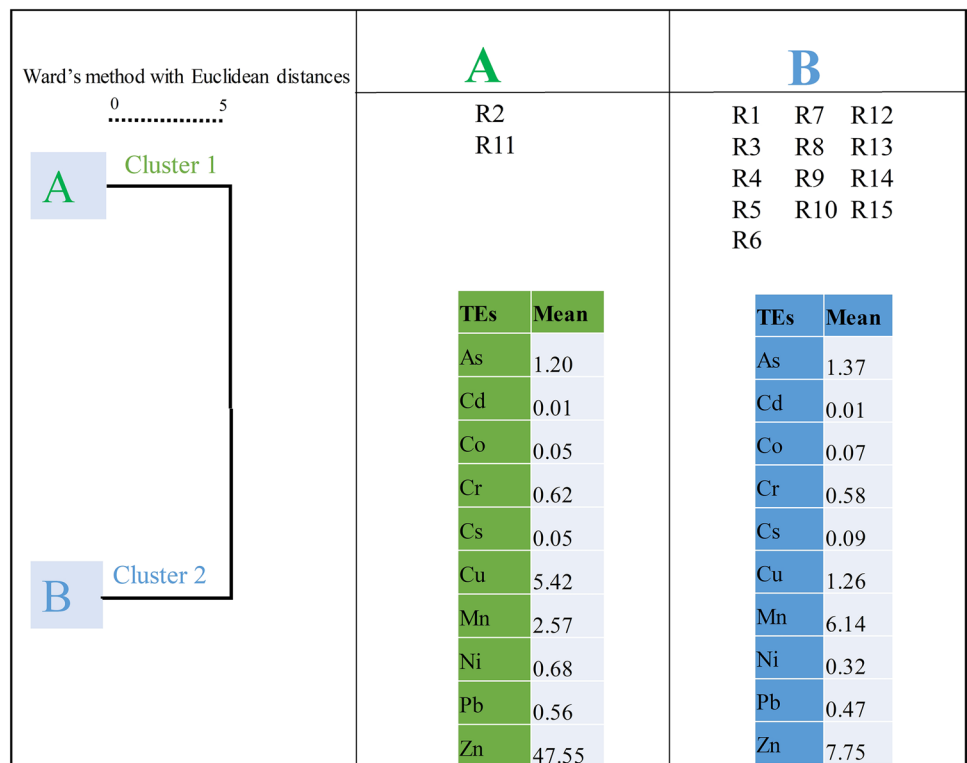
Ward's method with Euclidean distances

A

B1   B9
B2   B11
B3   B12
B4   B13
B6   B14
B8

TEs	Mean
As	0.88
Cd	0.01
Co	0.03
Cr	0.37
Cs	0.02
Cu	1.00
Mn	2.25
Ni	0.23
Pb	0.35
Zn	2.88

B

B7

TEs	Mean
As	0.84
Cd	0.01
Co	0.03
Cr	0.35
Cs	0.02
Cu	0.87
Mn	7.52
Ni	0.21
Pb	0.36
Zn	2.38

C

B5
B10
B15

TEs	Mean
As	0.84
Cd	0.01
Co	0.05
Cr	0.78
Cs	0.04
Cu	4.56
Mn	4.16
Ni	0.43
Pb	1.66
Zn	6.29

A — Cluster 1
B — Cluster 2
C — Cluster 3

Fig. 3 Clustering of water samples in dendrogram from the Begnas Lake, Gandaki Province, Nepal (concentration of the TEs are expressed in µg/L)

Fig. 4 Clustering of water samples in dendrogram from the Rupa Lake, Gandaki Province, Nepal (concentration of the TEs are expressed in µg/L)

Ward's method with Euclidean distances

A — Cluster 1
B — Cluster 2

A

R2
R11

TEs	Mean
As	1.20
Cd	0.01
Co	0.05
Cr	0.62
Cs	0.05
Cu	5.42
Mn	2.57
Ni	0.68
Pb	0.56
Zn	47.55

B

R1   R7   R12
R3   R8   R13
R4   R9   R14
R5   R10 R15
R6

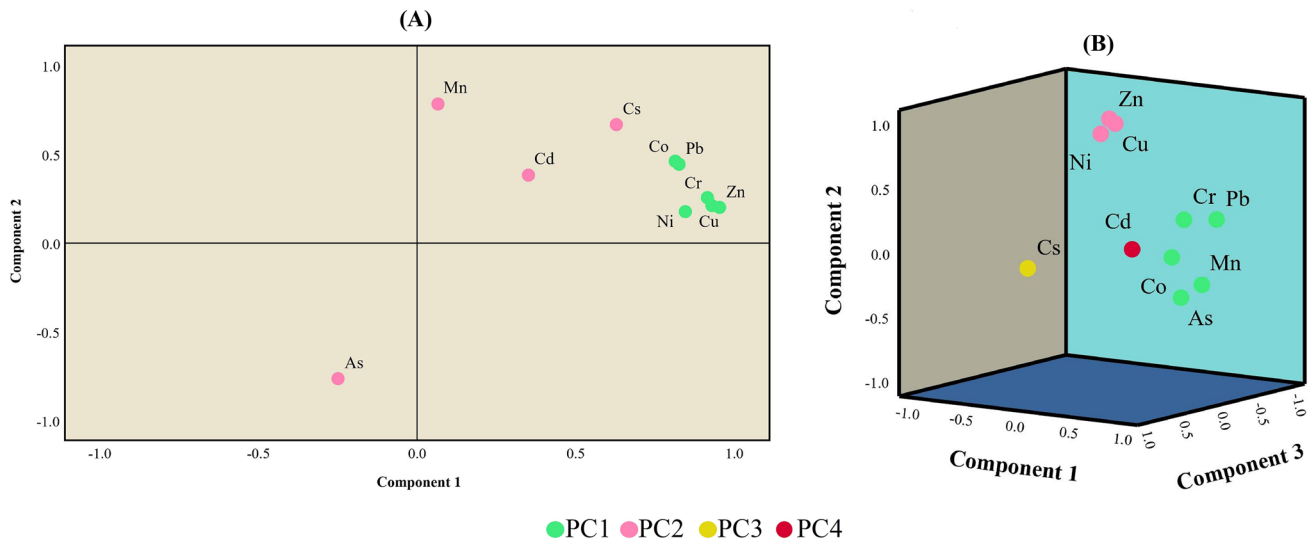| TEs	Mean
As	1.37
Cd	0.01
Co	0.07
Cr	0.58
Cs	0.09
Cu	1.26
Mn	6.14
Ni	0.32
Pb	0.47
Zn	7.75

Fig. 5 Factor loading plots of principal component analysis (PCA) of trace elements (TEs), **a** Begnas Lake and **b** Rupa Lake, Gandaki Province, Nepal

Table 3 Factor loadings table of principal component analysis (PCA) of Begnas and Rupa Lake, Gandaki Province, Nepal

Variables	Begnas Lake		Rupa Lake			
	PC 1	PC 2	PC 1	PC 2	PC 3	PC 4
As	−0.25	−0.76	0.62	−0.36	−0.17	−0.41
Cd	0.35	0.38	0.13	−0.03	−0.21	0.86
Co	0.81	0.46	0.79	0.03	0.19	0.30
Cr	0.92	0.26	0.79	0.30	0.03	0.01
Cs	0.63	0.67	−0.04	−0.04	0.93	−0.18
Cu	0.93	0.21	−0.01	0.93	−0.20	−0.13
Mn	0.07	0.78	0.91	−0.21	−0.04	0.22
Ni	0.85	0.18	0.15	0.93	0.23	0.12
Pb	0.83	0.44	0.87	0.26	−0.28	−0.18
Zn	0.95	0.20	0.02	0.99	−0.07	0.02
Eigenvalues	6.54	1.10	3.43	2.90	1.23	1.01
Variance (%)	65.36	10.96	34.31	28.98	12.31	10.11
Cumulative (%)	65.36	76.32	34.31	63.29	75.60	85.71

the water quality of both the lakes was excellent and acceptable for drinking purposes. The results are also in good agreement with previous studies of the same area [4, 9].

3.5 Metal index (MI)

If the MI of the lake water is > 1, it is unacceptable for drinking purposes [9]. The MI value of the water in Begnas Lake and Rupa Lake was 0.45 and 1.39, respectively (Table 5 and Fig. 6). The findings showed that the Begnas Lake was

relatively safe for drinking and household applications, whereas the Rupa Lake did not comply with the MI guidelines precisely for Zn (MI = 1.30). It indicates that the elevated concentration of Zn in in the Rupa Lake could have adverse impacts on its portability. Prior literature from the Phewa Lake suggested that the MI index for Zn, Mn, and As was estimated to be 3.36 [9], suggesting that the TEs have elevated concentrations in the freshwater lakes of Pokhara Valley, Nepal.

Table 4 Correlation matrix of TTEs in Begnas Lake and Rupa Lake

Variables	As	Cd	Co	Cr	Cs	Cu	Mn	Ni	Pb	Zn
Begnas Lake										
As	1.00									
Cd	−0.19	1.00								
Co	−0.28	0.42	1.00							
Cr	−0.11	−0.02	0.58[*]	1.00						
Cs	−0.29	0.39	0.22	0.16	1.00					
Cu	−0.13	0.29	0.54[*]	0.67[**]	0.46	1.00				
Mn	−0.44	0.15	0.60[*]	0.46	0.17	0.09	1.00			
Ni	−0.25	0.38	0.59[*]	0.76[**]	0.21	0.84[**]	0.31	1.00		
Pb	−0.44	0.07	0.41	0.66[**]	0.07	0.67[**]	0.28	0.74[**]	1.00	
Zn	−0.21	0.28	0.44	0.70[**]	0.46	0.90[**]	0.07	0.85[**]	0.64[**]	1.00
Rupa Lake										
As	1.00									
Cd	0.37	1.00								
Co	0.30	0.50	1.00							
Cr	−0.18	−0.09	0.36	1.00						
Cs	0.33	0.20	0.30	0.11	1.00					
Cu	0.21	0.19	0.08	0.11	0.11	1.00				
Mn	0.43	0.35	0.54[*]	0.33	0.12	−0.03	1.00			
Ni	−0.37	0.19	0.20	0.26	0.42	0.33	−0.31	1.00		
Pb	0.65[**]	0.50	0.33	0.24	0.21	0.72[**]	0.43	0.07	1.00	
Zn	−0.08	0.18	0.22	0.41	0.52[*]	0.61[*]	−0.20	0.82[**]	0.38	1.00

3.6 Health risk assessment (HRA)

The HRA is the tool for assessing the potential public health risk posed by TEs. The hazard index (HI) and hazard quotient (HQ) for As, Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn were

Table 5 Water quality index (WQI) and metal index (MI) of the Begnas Lake and Rupa Lake, Gandaki Province, Nepal

TEs	WQI		MI	
	Begnas Lake	Rupa Lake	Begnas Lake	Rupa Lake
Cd	0.057	0.06	0.003	0.003
Cr	0.155	0.2	0.009	0.012
Cu	0.059	0.06	0.009	0.009
Pb	1.052	0.71	0.061	0.041
Mn	0.103	0.05	0.007	0.014
As	0.005	0.01	0	0
Zn	1.217	4.5	0.353	1.306
Co	0.003	0	0.001	0.001
Ni	0.013	0.07	0.004	0.005
Total	2.66	5.66	0.45	1.392

analyzed (Table 6). The results of Begnas Lake revealed that As, Cd, Cr, Mn, Co, Pb, and Cu were relatively high contributors of HI, where As and Pb could be the chronic exposures to inhabitants in terms of ingestion (Table 6). Moreover, As, Cd, Cr, and Mn were relatively high contributors to the inhabitants via the dermal path. In the case of Rupa Lake, As, Cd, Co, Cr, Cu, Mn, Pb, and Zn (except Ni) were relatively high contributors in terms of HI, where As, Co, Cr, Cu, Mn, Pb, and Zn could be the chronic exposures to inhabitants in terms of ingestion (Table 6). Also, As, Cd, Cr, and Mn were found relatively high contributors to the inhabitants via the dermal path in the Rupa Lake. In both the lakes, the HI and HQ values were < 1 signifying that there are minimal adverse impacts to the public from the consumptions of lake waters.

3.7 Cancer risk (CR)

The TEs such as As, Cd, Cr, and Pb are considered as the carcinogenic elements [43]. The CR depends on age with exposure condition and duration of exposure to the carcinogenic elements [23]. These factors should be
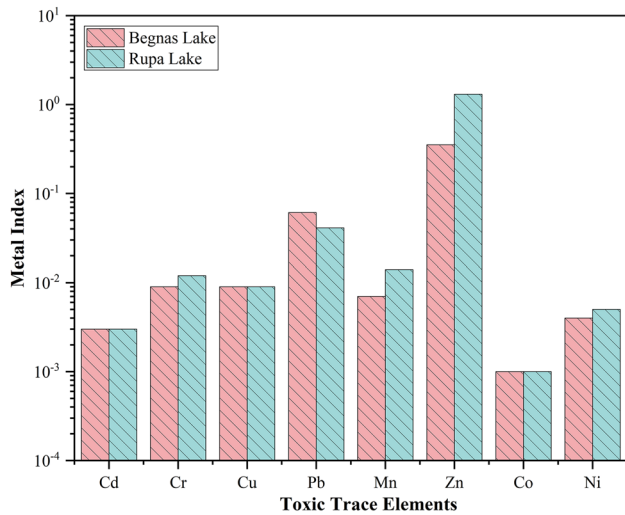
Fig. 6 Metal index of trace elements (TEs) for the Begnas Lake and Rupa Lake, Gandaki Province, Nepal

considered while assessing the CR. The CR assessment of the TEs has been presented in Table 7. The acceptable range of CR by the US EPA is 10^{-6} to 10^{-4}. Thus, the result showed the CR $< 1 \times 10^{-4}$ in both Rupa Lake and Begnas Lake, indicating the level of TEs within the tolerance limit. In addition, these results demonstrated that the CR was comparable in both the study lakes. However,

Table 6 Health risk assessment (HRA) of Begnas Lake and Rupa Lake, Gandaki Province, Nepal

TEs	Cw	HQ ing	HQ derm	HI
Begnas lake				
As	0.87	1.19×10^{-1}	2.98×10^{-3}	1.22×10^{-1}
Cd	0.01	8.18×10^{-4}	8.44×10^{-3}	9.26×10^{-3}
Co	0.03	4.09×10^{-3}	8.44×10^{-5}	4.18×10^{-3}
Cr	0.45	6.14×10^{-3}	1.27×10^{-2}	1.88×10^{-2}
Cu	1.7	1.74×10^{-3}	5.98×10^{-5}	1.80×10^{-3}
Mn	2.98	6.10×10^{-3}	1.57×10^{-3}	7.67×10^{-3}
Ni	0.27	5.52×10^{-4}	4.22×10^{-6}	5.57×10^{-4}
Pb	0.61	1.78×10^{-2}	6.13×10^{-5}	1.79×10^{-2}
Zn	3.53	4.81×10^{-4}	1.49×10^{-5}	4.96×10^{-4}
Rupa lake				
As	1.34	1.83×10^{-1}	4.60×10^{-3}	1.87×10^{-1}
Cd	0.01	8.18×10^{-4}	8.44×10^{-3}	9.26×10^{-3}
Co	0.06	8.18×10^{-3}	1.69×10^{-4}	8.35×10^{-3}
Cr	0.58	7.91×10^{-3}	1.63×10^{-2}	2.42×10^{-2}
Cu	1.81	1.85×10^{-3}	6.36×10^{-5}	1.91×10^{-3}
Mn	5.67	1.16×10^{-2}	2.99×10^{-3}	1.46×10^{-2}
Ni	0.37	7.57×10^{-4}	5.78×10^{-6}	7.63×10^{-4}
Pb	0.48	1.40×10^{-2}	4.82×10^{-5}	1.41×10^{-2}
Zn	13.06	1.78×10^{-3}	5.51×10^{-5}	1.84×10^{-3}

it was lower than the previous study conducted in the same region indicating the better water quality in this study (9) Table 7.

Table 7 Cancer risk assessment of the trace elements (TEs) of Begnas Lake and Rupa Lake, Gandaki Province, Nepal

TEs	Cw	Cr_{ing}	Cr_{der}	CI	CR level	CR category
Begnas lake						
As	0.87	2.37×10^{-5}	2.45×10^{-7}	2.40×10^{-5}	$< 1.00 \times 10^{-3}$	Very Low
Cd	0.01	2.73×10^{-7}	2.81×10^{-9}	2.76×10^{-7}	$< 1.00 \times 10^{-3}$	Very Low
Cr	0.45	1.23×10^{-5}	1.27×10^{-7}	1.24×10^{-5}	$< 1.00 \times 10^{-3}$	Very Low
Pb	0.61	1.66×10^{-5}	1.72×10^{-8}	1.67×10^{-5}	$< 1.00 \times 10^{-3}$	Very Low
Zn	3.53	9.63×10^{-5}	5.96×10^{-7}	9.69×10^{-5}	$< 1.00 \times 10^{-3}$	Very Low
Rupa lake						
As	1.34	3.65×10^{-5}	3.77×10^{-7}	3.69×10^{-5}	$< 1.00 \times 10^{-3}$	Very Low
Cd	0.01	2.73×10^{-7}	2.81×10^{-9}	2.76×10^{-7}	$< 1.00 \times 10^{-3}$	Very Low
Cr	0.58	1.58×10^{-5}	1.63×10^{-7}	1.60×10^{-5}	$< 1.00 \times 10^{-3}$	Very Low
Pb	0.48	1.31×10^{-5}	1.35×10^{-8}	1.31×10^{-5}	$< 1.00 \times 10^{-3}$	Very Low
Zn	13.06	3.56×10^{-4}	2.20×10^{-6}	3.58×10^{-4}	$< 1.00 \times 10^{-3}$	Very Low

4 Conclusion

This study was undertaken to evaluate the sources, distributions, and potential health risks of trace elements (TEs) in Begnas Lake and Rupa Lake, Gandaki Province, Nepal. In the Rupa Lake, the average concentration of the TEs was in the dominance order of Zn > Mn > Cu > As > Cr > Pb > Ni > Cs > Co > Cd, whereas in the Begnas Lake, the order of concentrations was Zn > Mn > Cu > As > Pb > Cr > Ni > Co > Cs > Cd. The two and four principal components were observed in the Begnas Lake and Rupa Lake, respectively, signifying the geogenic contributions with minor anthropic signatures of TEs in both the lakes. The PCA results conclude that the elevated concentrations of Cr, Cu, Mn, Pb, and Zn were contributed from both geogenic and anthropic sources.

Based on the water quality index, both the lakes were safe and acceptable for drinking purposes. However, the metal index in Rupa Lake in terms of Zn may pose adverse impacts to the consumers. The hazard index and hazard quotient signify that there were minimum adverse impacts to the public from the consumptions of lake waters. Also, the cancer risk of the TEs indicates that both the Begnas Lake and Rupa Lake have low risk (CI < 1×10^{-4}). Overall, the water quality of both the lakes was found to be good, but more prevention and control measures should be taken to keep water resources safer for the protection of human health and the aquatic ecosystem. Finally, this study should be a baseline for the distribution and risk appraisal of TEs in the lakes; however, seasonality impacts with depth-wise investigations are recommended for the further studies.

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Declarations

Conflict of interest The author(s) declare that they have no conflict of interest.

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