HYDROCHEMICAL ASSESSMENT OF JHILMILA LAKE, KANCHANPUR, NEPAL

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Abstract: Freshwater contamination remains a challenging issue for the sustainable management of wetland ecosystems. This study aims to evaluate the water quality of Jhilmila Lake, Kanchanpur, Nepal by adopting standard test procedures, geochemical indices, and multivariate statistical analysis. The surface water samples were collected during the post-monsoon season in 2018 to assess the hydrochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS) and dissolved oxygen (DO), ammonium (NH_4^+), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), phosphate (PO_4^{3-}), bicarbonate (HCO_3^-) and total hardness (TH). The EC ranged from 162-190 µS/cm while TDS was 87-101 mg/L. The concentration of DO in the lake was in the range of 4.77-6.21 mg/L, indicated mild organic pollution. Moreover, the results revealed the moderate alkaline nature of water with the pattern of average ionic dominance of $Ca^{2+}>Na^+>Mg^{2+}>K^+>NH_4^+$ for cations, and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$ for anions. The principal component analysis demonstrated four major components indicating the association of EC, TDS, Ca^{2+}, Mg^{2+}, and HCO_3^-; Na^+, PO_4^{3-} and SO_4^{2-}; NO_3^- and K^+; and Cl^- for PC1, PC2, PC3, and PC4, respectively exhibiting both the geogenic and anthropic origin. Overall, the Jhilmila Lake was less polluted, and all the measured water quality parameters were found within permissible limits in terms of drinking purposes. The findings of this study could help for the sustainable management of the lake by providing better insights into the water quality and hydrochemistry of the lake.

Keywords: Hydrochemical parameters; Water quality assessment; Water contamination; Jhilmila lake.

INTRODUCTION

Wetlands are the most productive ecosystems in the world and are important for the sustainability of human and other ecological systems. Lake ecosystems are an indispensable part of human existence including the flora and fauna. Additionally, they have immense importance in terms of ecological, economic, and aesthetic values[1–3]. Importantly, the ecological services of the lake ecosystem have deep-rooted relationships with the civilizations of society. Surface water quality has been deteriorated due to the increase in population, industrialization, and anthropic activities[4]. An increase in water pollution not only deteriorates the water quality but also threatens human health, ecological balance and, economic and social

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prosperity[5, 6]. The contaminations in the lake water are mainly due to natural geogenic and anthropic activities including domestic, industrial, and municipal effluents and agricultural runoff**.** The lake ecosystems are under intense degradation for the last couple of decades and thus depicts the degradation of the civilization within the lake basins. In the meantime, the lake ecosystems are less dynamic and readily contaminated by the inorganic and organic loadings and thus, are a matter of concern to public health, therefore getting scientific attention.

The prior researches revealed that the lake ecosystems located in the Terai and mid- Hill regions of Nepal have been experiencing high anthropic pressure[7–9]. Rapid urbanization due to mass migration from hilly and mountain regions, unplanned developmental activities, and intensive farming are some of the major causes for the deterioration of freshwater quality in the low land Terai region of Nepal[6,10]. The freshwater lakes in the eastern and central parts of the Terai region of the country are well documented, however, the lakes of western Terai are very less explored except Betkot and Ghodaghodi lakes[11, 12]**.** Therefore, there is a gap in hydrochemical studies of surface waters of the medium and small-scale lakes from the Sudurpaschim Province, Nepal.

Jhilmila Lake, located in the Sudurpaschim Province, Nepal, is one of the most important tourist destinations. The major aspects of the lake are the religious and social values in addition to ecological importance. Despite providing various ecological services, economic and aesthetic values, the lake basin is vulnerable to various natural and anthropic activities due to its location in the geologically fragile Churiya range. Thus, the conservation of freshwater lakes has immense importance for the sustainability of human livelihoods and the natural environment. As per our best knowledge, there is no scientific publication from the lake to date. Hence, there is an urgent need to assess the hydrochemistry for the sustainability of aquatic health. Thus, the objective of this study was to determine the hydrochemical properties of the surface water of the lake using principal component analysis. The findings of the study could be used as recommendations to manage surface water pollution and to preserve ecological sustainability in Jhilmila Lake, Kanchanpur, Nepal.

MATERIALS AND METHODS

Study area

This study was carried out in the Jhilmila Lake situated in Bhimdatta Municipality, Kanchanpur, Nepal. The Lake (80.1877 E and 29.0675 N) (Fig.1) is located at an altitude of approximately 668 m above sea level. Its basin area covers 40.20 ha and core lake area of 4.30 ha with a maximum depth of 9 m. The lake is about 9 km away from the human settlement at Bramhadev and 21 km far from the headquarter of Kanchanpur district i.e., Mahendranagar. It is a natural freshwater lake inter-connected with marshes and meadows surrounded by tropical deciduous forest. The surrounding area of the lake is dominated by Sal forest (*Shorea robusta*) with an association of pine and rhododendron trees. Different kinds of birds such as *Casmerodius albus* migrate from Siberia. The fishes and reptiles in the lake are represented by *Clarias batrachus, Labeo rohita, Bufo melanostictus, Calotes versilor,* and the mammals are*, Felis bengalensis, Lutra lutra, Macaca mulatta,* etc. It has historical and cultural importance as thousands of Hindu pilgrims from Nepal, India, and other countries visit the lake for taking a holy bath after visiting Purnagiri temple in Uttarakhand, India, and Siddhanath Temple, Nepal. People have faith that curses and bad spirits get washed away after bathing in it. The average annual precipitation in the area is 1630-1705 mm and is concentrated during the monsoon period (~80% of the total rainfall).The average annual temperature ranged from 6-38°C.

Sample collection and analysis

The sampling sites in the lake were selected randomly by collecting a total of 10 water samples during the post-monsoon season, 2018 (Fig. 1**)**. Moreover, topography, land use and land cover change, and level of potentially contaminated sites were the basis for the selection of the sites. To avoid contamination, non-powder vinyl clean gloves and masks were used during sample collection and laboratory work, and the distilled deionized water was used for the analysis. The sterilized sampling bottles were rinsed with the lake water thrice before taking the original samples. All water samples were taken from a depth of ~15 cm from the water surface. After the collection, the samples were acidified immediately by adding 2 ml concentrated HNO_3 as described by APHA (2005). The sampling bottles were labeled and were packed inside the double polyethylene zip-lock bags and delivered to the laboratory. Until the laboratory analysis, all the samples were kept in the refrigerator at 4°C [13].

Meanwhile, the chemical parameters such as electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), dissolved oxygen (DO), major cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+), and the major anions (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, HCO_3^-) were analyzed using the standard methods [12]. The pH, EC, and TDS were measured in the field using a multi-parameter instrument (HANNA), and dissolved oxygen (DO) was determined by a modified Winkler method instrument onsite. The concentrations of Na^+ and K^+ ions were determined by using Flame Photometer. Similarly, the determination of NO_3^-, SO_4^{2-}, PO_4^{3-}, and NH_4^+ were carried out by using Spectrophotometer. The titrimetric method of analysis was used for Cl^-, Ca^{2+}, Mg^{2+}, and HCO_3^- ions. Likewise, SO_4^{2-} was measured by the Gravimetric method using Barium chloride crystals as a precipitating agent. TH, Ca^{2+}, and Mg^{2+} were measured by complexometric (EDTA) titration**.** The amount of Cl^- was determined by argentometric titration method using potassium dichromate as an indicator and expressed in mg/L. These analyses were carried out in the laboratory at the Central Department of Environmental Sciences, Tribhuvan University, Kirtipur, Nepal. For quality control, special care was taken during sampling and laboratory analyses. Principal component analysis (PCA) was used to identify the potential associations among the hydrochemical parameters and controlling mechanism.

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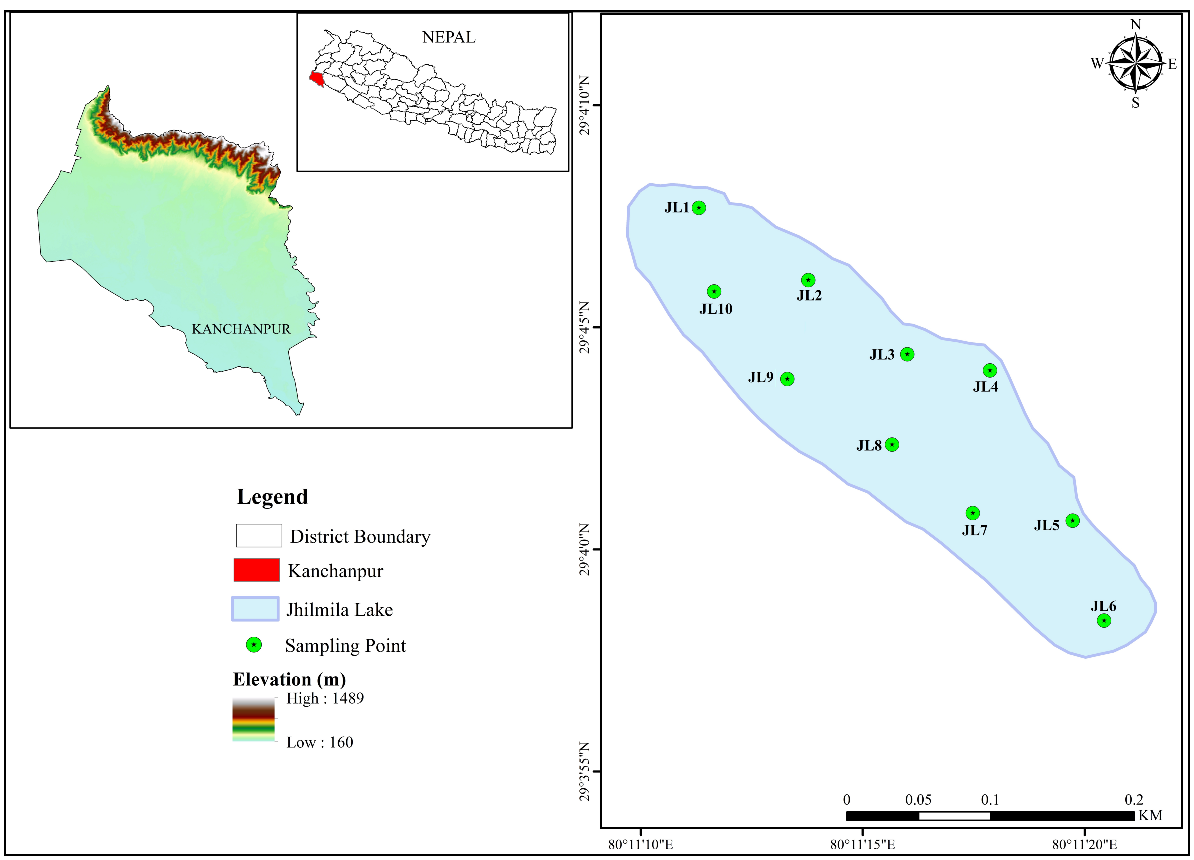

Figure 1: Map of the study area (a) Jhilmila Lake (b) locations of sampling sites, Kanchanpur, Nepal

RESULTS AND DISCUSSION

General hydrochemistry

The descriptive statistics of hydrochemical compositions of the Jhilmila Lake is presented in Table 1. pH determines the speciation of chemicals and the biotic life both in lentic and lotic water systems. The variation of pH of water depends on the input of organic and inorganic loads together with the reaction of carbon dioxide. High pH favors the precipitation of ions and also affects the carbon dioxide, carbonate, and bicarbonate equilibrium in the aquatic system. The average pH of the water in the lake was slightly alkaline (i.e., 7.35) indicating the lake has carbonate-dominated underlying lithology, and also exhibited that the lake water was suitable for drinking purposes from the perspective of pH values [15].

EC indicates the extent of inorganic pollution, total dissolved solids, and ionized species in the water. Generally, high EC is due to the increased anthropic activities, less dilution, and high pollution load [16]. The EC value of the lake water varied from 81 -139 µS/cm which were found to lie within the WHO drinking water guidelines (<1000 mg/L). The TDS concentrations were the indicators of chemical weathering or anthropic contaminations. The excess TDS imparts the color, totality alkalinity, and conducting nature of water and affects the irrigation quality and ecological health of the lake. The TDS contents in the present study were found (45-76 mg/L) within the WHO guidelines (< 500 mg/L). In addition, the slight high value of TDS in the lake is also caused by the inputs of wastewater, and organic loads caused by anthropic activities like bathing, movement of tourists including pilgrim activities in the lake area.

DO determine the degree of organic pollution and the level of oxygen dissolved naturally in water. Its amount decreases with increasing the load of organic pollution. The concentration of DO in the lake varied from 4.77-6.21 mg/L, indicating mild organic pollution. Generally, DO > \4 mg/L is suitable for drinking purposes and it was considered as 6 mg/L for the healthy aquatic life and metabolic activities of microorganisms[17]. The DO value of this study revealed that the lake supports aquatic life. The direct diffusion from air and photosynthesis activity of autotrophs maintain the DO in water bodies[18]. The TH of water determines the water quality and depends on the dissolved minerals present. The TH in water is due to the sum of concentrations of alkaline earth metal ions such as Ca^{2+} and Mg^{2+}. In this study, the average TH of water was found to be in the range of 58.49 -126.57 mg/L. The maximum value of TH was more than the WHO drinking water limit (<75 mg/L) indicating the moderate geogenic weathering and anthropic signature.

The dominancy order of major cations and anions was Ca^{2+}>Na^{+}>Mg^{2+} >K^{+}>NH_4^{+}; and HCO_3^{-}>Cl^{-}> SO_4^{2-}>NO_3^{-} >PO_4^{3-}, respectively. Among the major cations, Ca^{2+} and NH_4^{+} display the highest and lowest concentrations, contributing ~40% and 1.47% in the total cationic budget, respectively in the lake. The major ions including K^{+}, NH_4^{+}, and Na^{+} were also contributed from the agricultural activities in the vicinity of the lake[19]. The possible sources of Na^{+} and K^{+} are domestic wastes and fertilizers. The dominant anion in the lake was HCO_3^{-} which accounts for 88 % followed by Cl^{-} and SO_4^{2-} with 10.69% and 0.50% (Table 1). The PO_4^{3-} was reported as the least abundant anion with an average contribution of 0.20%. The variation in the hydrochemical parameters in the lake is mainly influenced by geogenic weathering and anthropic inputs.

Eutrophication is the major problem found in lakes due to PO_4^{3-}, NO_3^{-}, and NH_4^{+}, etc. Their excessive concentration may lead to the growth of plants and algae and threaten the sustainability of the lake environment. The results revealed that NH_4^{+} contents in Jhilmila Lake were found to vary from 0.19-0.54 mg/L. Most of the sampling sites showed total NH_4^{+} contents lie in permissible WHO guidelines. However, the NH_4^{+} contents were found comparatively more in some sampling points in the lake could be due to sewage contaminations and natural degradation of organic matters.

The Cl^{-} concentration in water is the indicator of anthropic disturbance and excessive chloride with sodium make the water salty and increases the level of TDS in water[20]. The Cl^- concentration of the Jhilmila Lake water was found to be 8.20-11.65 mg/L, which were within the WHO drinking water guidelines (<250 mg/L). The slightly higher concentration of Cl^- in some sampling point could be due to anthropic activities like bathing, movement of tourists, pilgrim activities around the lake. The study showed that the concentration of PO_4^{3-} was in the range of 0.16-0.35 mg/L, the maximum concentration was exceeding the WHO guidelines (<0.02 mg/L) for drinking water indicating relatively moderate eutrophication in the lake. The sources of PO_4^{3-} in the lake water could be from the anthropic activities. The results revealed that the concentration of NO_3^- in the Jhilmila Lake was in the range of 0.07-0.56 mg/L, i.e., within the WHO guidelines for drinking water (<75 mg/L).

Table 1. The hydrochemical compositions of the Jhilmila Lake, Kanchanpur, Nepal

Site	pH	EC	TDS	DO	Ca^{2+}	Mg^{2+}	K^+	Na^+	NO_3^-	PO_4^{3-}	NH_4^+	SO_4^{2-}	Cl^-	HCO_3^-	TH
1	7.84	100	54	5.95	7.08	2.67	2.20	6.40	0.15	0.35	0.36	0.80	9.02	24.86	76.50
2	7.50	81	45	5.97	5.64	2.17	2.68	5.22	0.07	0.17	0.25	0.40	8.20	19.96	58.78
3	7.20	138	76	6.04	11.66	4.32	2.00	5.90	0.56	0.19	0.19	0.33	10.39	40.61	126.55
4	7.45	104	56	5.88	8.06	2.83	2.36	6.04	0.41	0.16	0.23	0.35	8.38	27.45	92.26
5	7.20	90	49	5.94	5.63	2.16	2.70	6.20	0.40	0.20	0.54	0.70	10.80	19.92	58.76
6	6.60	83	46	6.21	5.31	1.93	1.99	5.61	0.16	0.17	0.23	0.39	11.65	18.35	58.49
7	7.30	95	54	5.45	7.21	2.72	2.77	5.53	0.28	0.18	0.36	0.51	9.19	25.31	76.67
8	7.43	87	48	4.77	5.64	2.17	2.78	5.42	0.27	0.17	0.25	0.40	10.82	19.96	58.78
9	7.36	139	76	5.91	11.69	4.33	2.77	5.63	0.29	0.17	0.19	0.33	10.41	40.69	126.57
10	7.58	104	57	5.98	8.06	2.83	2.96	6.14	0.51	0.16	0.23	0.35	8.38	27.45	92.26
Max	**7.84**	**139**	**76**	**6.21**	**11.69**	**4.33**	**2.96**	**6.40**	**0.56**	**0.35**	**0.54**	**0.80**	**11.65**	**40.69**	**126.57**
Min	**6.60**	**81**	**45**	**4.77**	**5.31**	**1.93**	**1.99**	**5.22**	**0.07**	**0.16**	**0.19**	**0.33**	**8.20**	**18.35**	**58.49**
Mean	**7.35**	**102**	**56**	**5.81**	**7.60**	**2.81**	**2.52**	**5.81**	**0.31**	**0.19**	**0.28**	**0.46**	**9.72**	**26.46**	**82.56**
SD	**0.32**	**21**	**11**	**0.41**	**2.38**	**0.86**	**0.35**	**0.38**	**0.16**	**0.06**	**0.11**	**0.17**	**1.23**	**8.17**	**26.68**
WHO	**6.5-8.5**	**750**	**600**	**5**	**100**	**50**	**100**	**200**	**50**	**1**	**1.5**	**250**	**250**	**300**	**500**

All units are in mg/L (except EC: µS/cm, Temperature °C, and pH)

Principal Component Analysis (PCA)

The major sources and controlling mechanism of hydrochemical variables in the Jhilmila Lake were assessed by applying the PCA (Fig. 2 and Table 2). The PCA was carried out based on EC, TDS, and major ions. The validity of the data set was examined by Kaiser-Meyer–Olkin (KMO) and Bartlett's sphericity tests. The component loadings were classified as strong and moderate corresponding to absolute loading values > 0.75, 0.50 - 0.75, respectively[21, 22]. In this study, four principal components with eigenvalues >1 explained 91.06% of the total variance. The loading plot indicated that the PC1 accounted for 48.53% of the total variance, had strong loadings on EC, TDS, Ca^{2+}, Mg^{2+}, and HCO_3^-, whereas moderate loading on NO_3^-. The loading plots of PC1 indicated that carbonate rock weathering in the lake has a strong impact on the overall hydrochemistry of the lake water. Likewise, PC2 explained 22.08% of the total variance and had strong loadings on Na^+, PO_4^{3-} and SO_4^{2-}, and moderate loading on NH_4^+.

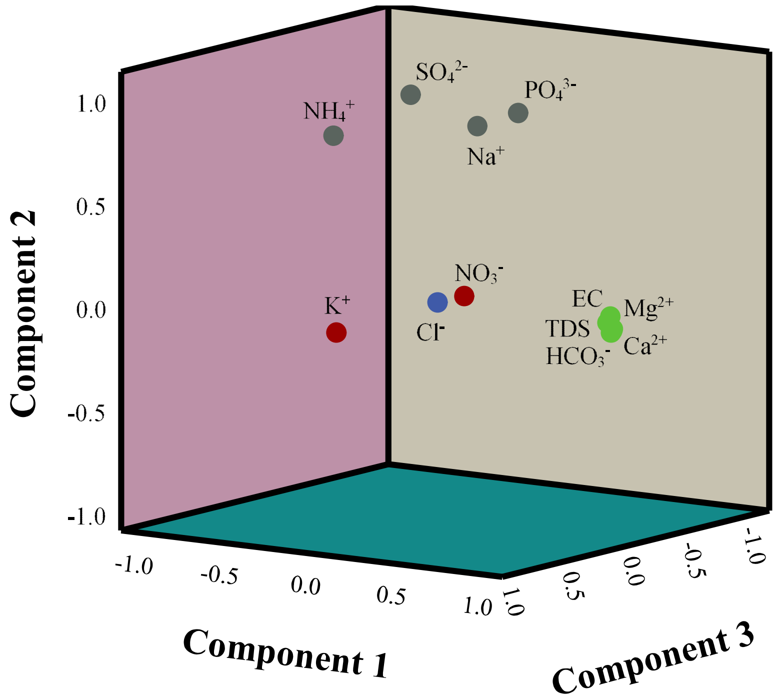

Figure 2: Principal component analysis of hydrochemical compositions in the Jhilmila Lake, Kanchanpur, Nepal

Table 2. Principal components loadings of hydrochemical compositions in the Jhilmila Lake, Kanchanpur, Nepal.

	PC1	PC2	PC3	PC4
EC	**0.989**	-0.019	0.036	0.063
TDS	**0.984**	-0.047	0.052	0.067
Ca^{++}	**0.990**	-0.097	0.030	-0.027
Mg^{++}	**0.981**	-0.084	0.004	-0.009
K^+	-0.192	-0.130	**0.631**	-0.542
Na+	0.272	**0.843**	0.120	-0.004
NO_3^-	0.587	0.132	**0.677**	0.137
PO_4^{---}	0.022	**0.781**	-0.578	-0.093
NH_4^+	-0.459	**0.747**	0.276	0.081
SO_4^{--}	-0.338	**0.888**	-0.197	-0.017
Cl^-	-0.032	-0.056	0.017	**0.941**
HCO_3^-	**0.988**	-0.091	0.019	-0.019
Eigen Value	5.824	2.650	1.384	1.070
Variance (%)	48.537	22.080	11.52	8.915
Cumulative (%)	48.537	70.617	82.147	91.062

The association of Na^+ with SO_4^{2-} and PO_4^{3-} exhibited that the hydrochemistry is linked with mixed salts solutions and related properties of aqueous solutions. Additionally, PC3 explained 11.52% of the total variance and had moderate loadings on K^+ and NO_3^-. The association of chemical variables in the PC3 revealed that the minor anthropic signature in the lake water might be attributed to the pilgrims and touristic activities. Finally, PC4 elucidated the 8.92% and strong loadings on Cl^- indicating the anthropic impact in the lake water.

CONCLUSION

In this study, the hydrochemical composition and weathering mechanisms of surface water at Jhilmila Lake, Kanchanpur, Nepal has been analyzed and characterized based on chemical compositions using principal component analysis (PCA). The water in the lake was found to be slightly alkaline with an average pH of 7.35. The dominancy order of major cations and anions were Ca^{2+}> Na^+> Mg^{2+}> K^+> NH_4^+; and HCO_3^-> Cl^-> SO_4^{2-}> NO_3^-> PO_4^{3-}, respectively. The study has revealed that lake water had low salt contents due to low concentrations of EC, TDS, and major ions. Major ions including Na^+ and Cl^- had higher concentrations in the proximity of the anthropically disturbed areas but their concentrations were within the WHO standards. The PCA demonstrated four major components indicating the association of EC, TDS, Ca^{2+}, Mg^{2+}, and HCO_3^-; Na^+, PO_4^{3-}, and SO_4^{2-}; NO_3^- and

K^+; and Cl^- for PC1, PC2, PC3, and PC4, respectively exhibiting both the geogenic and anthropic origin of the chemical variables in the lake.

Meanwhile, natural governing factor including weathering of soil materials appeared to play a significant role. In addition, the water quality of Jhilmila Lake was governed by anthropic sources to some extent such as bathing, movement of tourists, pilgrim activities in the vicinity of the lake area. Overall, the lake was relatively less polluted, hence, the water was in pristine conditions and suitable for domestic uses. However, protection practices need to be adopted for its sustainability under the context of rapid urbanization and increasing anthropic activities in the proximity of the lake. This study will be a significant asset for the professionals and concerned stakeholders for the sustainable management of the lake and it is recommended that further in-depth study should be conducted based on the depth-wise and seasonality basis.

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