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Spatial distribution of drinking, irrigation water quality, and health risk indices of high-altitude lakes

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ABSTRACT

High-altitude lakes (HAL) play a key role in several ecological services of the environment by managing the water supply and flood control. The slow rate of inflowing contaminant circulation results in a buildup of higher levels of contamination level and makes these lakes more vulnerable. The present study focused on determining HAL's water quality parameters (WQP) in Swat District, northern Pakistan. Water samples (n=32) were collected and analyzed for basic parameters, anions, and potentially harmful elements (PHE). Results of examined parameters were noted under WHO threshold values, except for a few samples of iron (Fe) and arsenic (As). The concentrations of WQP in HAL were used to calculate drinking and irrigation water quality indices (WQI). Results revealed that the water of HAL was excellent and suitable for drinking and irrigation purposes. Gibbs plot and Piper model were used to identify water as a mixed type and source characterization of rock dominance. Water quality data were used for average daily dose (ADD) and hazard quotient (HQ) to find HAL water's potential health risks. The highest ADD value of 188 µg/kg-day was observed for nitrate (NO_3), and the lowest of 0.31 µg/kg-day was noted for arsenic (As). However, maximum HQ values of 0.18 were

reported for As and were observed to be less than the threshold of 1. Therefore, based on water quality, the HAL was recommended for use in drinking, domestic, and irrigation purposes.

Keywords: Average daily dose; hazard quotient; cancer risk; drinking water quality index; irrigation water quality index; spatial distribution

1. Introduction

Potentially harmful elements (PHE) in the aquatic environment are highly persistent, toxic, and bioaccumulative (Kebede and Geleta, 2023). Among PHE, iron (Fe), zinc (Zn) (Ciosek et al., 2023), and manganese (Mn) (Pei et al., 2023) are essential for the healthy growth and development of the human body. However, excessive levels of these elements in water and food are toxic for human beings (Din et al., 2023; Sevin et al., 2023). Other PHE such as arsenic (As), lead (Pb), and cadmium (Cd) are incredibly toxic and enlisted as carcinogens by the World Health Organization (WHO) (Muhammad and Ullah, 2022). Exposure to As for a long time in contaminated water may increase the chances of lung and skin cancer (Gul et al., 2019; Nuvolone et al., 2023). Pb and Cd detectable levels in drinking water possess life-threatening effects and cause problems with kidney disorders, hypertension, vomiting issues, and heart and intellectual problems in children (Muhammad et al., 2011; 2022).

Potentially harmful elements and other water quality parameters (WQP) contamination were sourced from the natural/ lithogenic phenomena, particularly denudation of mineralized zones or ore deposits, involving bedrock erosion and geothermal processes (Du et al., 2024; He et al., 2021; Li et al., 2023; Muhammad, 2023), and anthropic developmental activities like agrochemicals practices, domestic, mining, and industrial waste discharge and disposal (Amin et al., 2021; Wu et al., 2018). In urban and populated areas, the primary source of PHE contamination is anthropic factors. However, in remote and rural areas, the lithogenic agrogenic processes are the main culprits of water contamination (Haq and Muhammad, 2023; Zhu et al., 2023).

Globally, 1.6 billion and 2.8 billion people will lack safe drinking water and sanitation facilities in 2030 (Baye, 2021; Lan et al., 2022; Raimi et al., 2019). In developing countries, the supply of enough quantity of quality water for the fast-growing population is a major challenge (Haq et al., 2023; Muhammad, 2023). Drinking water is one of the leading causes of mortality in infants. In developing countries, women play a major role in household management including water supply (Ray, 2007). In rural areas, young girls and women walk several kilometers to fetch water for drinking and other domestic uses (Khan et al., 2016).

Lakes play the most crucial role in controlling and managing several ecological services of the environment, such as water supply for drinking and irrigation (Yin et al., 2023a; Yin et al., 2023b), fish production, and flood control. Lakes have a prolonged rate of contaminant circulation, which results in a buildup of increase in contamination levels, making these more vulnerable than any other aquatic system. Lakes water is exposed to different PHE contamination due to atmospheric deposition of suspended particles (Wijaya et al., 2016).

Globally, water quality monitoring has been studied, and the introduction and development of new techniques and indices for identifying water palatability for drinking and irrigation were focused on and reported (Muhammad, 2023; Samtio et al., 2023). A few of these indices and techniques include drinking water quality index (WQI), irrigation WQI (Unigwe and Egbueri, 2023), cancer and non-cancer risk indices (Sheng et al., 2023; Tafesse et al., 2023), geospatial (Bahrami and Zarei, 2023), statistical and machine learning technique for source apportionment (Xu et al., 2022; Yang et al., 2021; Zhou et al., 2023a; Zhou et al., 2023b). These indexical approaches and techniques involve large data sets that are difficult to explain to relevant non-technical stakeholders in everyday ways. Indexical approaches and techniques enable the technical team to communicate the water quality status effectively to the non-technical stakeholders (general public and policymakers) (Ali and Muhammad, 2022; Ali et al., 2019).

Drinking and irrigation WQI has recently been focused on in various studies worldwide (Ghebremedhin and Gupta, 2023; Liu and You, 2023; Turan and Aldemir, 2023). Lake water has been a significant source of drinking and irrigation in developed and developing countries. However, water quality monitoring, risk assessment, and evaluation for drinking and irrigation purposes on lake water have yet to be focused on northern Pakistan's rural areas. However, rural areas in northern Pakistan are more prone to agrogenic and lithogenic sources of pollution. Therefore, this study has been focused on drinking and irrigation water quality assessment of HAL water. Drinking and irrigation WQI of HAL water has been used for the geospatial maps. The WQ) was evaluated for the potential health risk assessment. The water quality of HAL water was characterized by a Piper diagram and Gibbs plots identification of water quality types and source characterization.

2. Material and methods

2.1. Study area

Geographically, the Swat Valley is located between latitudes of 34°35' to 35°50' N and longitudes of 72°05' to 72°30' E. The "Switzerland of the East" study area is famous for its natural diversity and beauty. The area hosts 2.31 million people, occupying an area of 5337 km^2 (Rafiq et al., 2021). The valley is bisected by River Swat, the area's primary surface water source. Variations in temperature during summer existed between 40ºC high and 16ºC low. During winter, temperatures range between 11ºC and 2ºC (Ali et al., 2020). The study area has several kinds of vegetables, fruits, and grains because of its fertile soil. District Swat is the largest producer of emerald deposits in the country. Due to its rich history and green alpine meadows, HAL, snow-covered mountains, and dense forests, the area is a center for attraction of both local and international tourists (Ahmad et al., 2014). It shares a neighborhood with Ghizer (Gilgit-Baltistan) and Chitral in the north, Malakand and Bunir in the south, and Indus Kohistan and Shangla in the east (Begum et al., 2015; Muhammad and Usman, 2022).

2.2. Geology

Kohistan Island arc (KIA) is a main geological feature in the area and consists of volcanic, volcano-sedimentary, and plutonic rocks (Shah and Shervais, 1999). Plutonic rocks in the study area consist of granitoids of the Kohistan batholith (Sullivan et al., 1993). Close Teru volcanic rocks, granitoid and magmatism rocks of the KIA are present (Petterson and Treloar, 2004; Sullivan et al., 1993). The extension of Paleocene faunas in limestone from Baraul Banda to the Utror volcanic area is exposed (Khan, 1979). The lithological features, including siltstones, basaltic andesite, tholeiitic, ignimbrites, sandstones, and rhyolite, have covered the area (Kazmi and Jan, 1997).

2.3. Sampling procedure

Water samples of HAL (n=5-7 for each lake) were collected in September 2021 (Fig. 1). Sampling was made in two different sizes of high-density polyethylene bottles. Each sample was collected 3 ft away from the bank facing toward the lake. Nitric acid (HNO_3) was added to one bottle after sample collection for PHE analyses. Through Multi-Parameter Analyzers (MPA, CONSORT 6030, Belgium), basic water parameters such as pH, electrical conductivity (EC), turbidity, and total dissolved solids (TDS) were measured within the lake. The exact locations of water samples were marked and recorded through the Global Positioning System (GPS, Garmin etrex 10).

2.4. Experimental procedures

The experimental procedures and assessment of anions, e.g., fluoride (F), nitrate (NO_3), iodide (I), and chloride (Cl), were determined with the help of a MPA and titration methods of APHA (2005) were used for determination of carbonates (CO_3) and bicarbonates (HCO_3) in non-acidified samples. In acidified HAL water samples, several PHE, including Na, K, Ca, Mg, Fe, and Mn, were determined through Flame Atomic Absorption Spectrophotometer (AAanalyst 700, PerkinElmer, USA). For As analysis, the Mercury Hydride Generation system of AAS was used.

2.5. Data precession and accuracy

The PHE contamination was determined through AAS with a standard set of r>0.999 to confirm the precision and accuracy of the results. The standard working solutions were prepared daily from the certified standard solutions (1000 mg/L) of the corresponding element with de-ionized water, Fluka Kamica (Buchs, Switzerland). Each sample was analyzed in triplicate, and after every 10 samples, the analyses were spiked with a blank and standard (i.e., 5 µg/L) of the concerned element. The reproducibility of PTE was noted at 92±5% and 88±8% confidence levels. All chemicals used for PTE analyses were of analytical grade.

2.6. Grading of lake water

The WQI is very helpful in converting complex water quality data into simple water quality values and provides significant information for water quality management (Dao et al., 2020). The following WQI equation by Adimalla and Qian (2019) is used for the suitability of HAL water for drinking purposes:

$$\mathrm{W}i = {}^{\mathrm{w}i}\!/\textstyle\sum_{\mathrm{n}}^{\mathrm{i}} \mathrm{w}i \qquad (1)$$

$$\mathrm{Q}i = (\mathrm{Ci} - \mathrm{Cip}/\mathrm{Si} - \mathrm{Cip}) \times 100 \qquad (2)$$

$$\mathrm{Sl}i = \mathrm{W}i \times \mathrm{Q}i \qquad (3)$$

$$WQI = \sum_{i}^{n} Sli \quad (4)$$

where Wi (relative weight), wi (value of the determined parameter), *n* (total number of a parameter), C*i*(concentration), S*i* (standard value for each parameter), Cip (ideal value of each parameter, i.e., C*ip* = 7 for pH, C*ip* = 0, for the rest of parameters).

The below-given equations of sodium adsorption ratio (SAR) and Na% were used to evaluate HAL water of irrigation activities Liu and Han (2020).

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad (5)$$

$$Na\% = (Na/Na + Mg + Ca + K)*100 \quad (6)$$

Residual sodium carbonate (RSC) for HAL water was calculated in equation 7.

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad (7)$$

The RSC values of HAL are classified <1.25, 1.25-2.5, and >2.5 as good, medium, and bad, respectively (Richards, 1954; Singaraja, 2017).

2.7. Health risk assessment

This study evaluated toxic WQP of Fe, F, NO_3, Mn, and As for risk assessment to children and adults through consumption of HAL. For this purpose, average daily intake (ADD, mg/kg-day) and hazard quotient (HQ) indices were adapted from USEPA (1999) and Zhang et al. (2020):

$$ADD = C \times DI/BW \quad (8)$$

$$HQ = ADD/RfD \quad (9)$$

where the concentration (C, mg/L), daily intake of water (DI, average 2 L/day), body weight (BW, average of 70 kg for adults and average of 30.6 kg for children), and RfD: is the reference dose for each PHE (Isiuku and Enyoh, 2020; Yousefi et al., 2019). RfD values for the Fe, F, NO_3, Mn and, As were 0.7, 0.06, 1.6, 0.14, and 0.0003 mg/kg-day (US EPA, 2005).

2.8. Statistical analyses

Statistical values, including mean and standard deviation of WQP in HAL water, were determined with MS Office (Excel, 2016 v) and Sigma plot ver. 12.5 was used for the graphical representation of WQP data. Piper diagram and Gibbs plots were used to identify water type and source characterization.

3. Results and discussion

3.1. Water quality parameters

The values of WQP in the HAL were summarized (Table 1). The maximum average acidity, e.g., pH value of 7.2±0.1, was noted for Kandol Lake, while the minimum of 6.8±0.1 for Spin Khawar Lake. Basic parameters, e.g., EC and TDS, showed the uppermost average values of 135±4.4 µS/cm and 90.1±2.1 mg/L in Izmis Lake, while the lowermost of 83.6±5.6 µS/cm and 55.7±3.7 mg/L in Spin Kawar Lake, respectively (Table 1). These WQP of HAL were noted to be within the WHO (2017) thresholds. The pH and EC values in the present study were noted lower than that of a study conducted by Varol et al. (2012) on reservoirs lakes in Turkey. Higher values in the reservoirs lakes of Turkey were attributed to higher concentrations of anions, cations, and other salts in its water.

Among anions, the higher average concentration of 3.02±0.1, 26.2±0.8, and 34.9±2.1 mg/L were noted in Izmis Lake for the NO_3, SO_4, and HCO_3, while lower 2.1±0.1, 18±0.5, and 22±3.4 mg/L were observed in Spine Khawar Lake, respectively. The highest average concentration of 3.04±0.14 and 0.11±0.03 mg/L were noted in Cl and F in Shahi Bagh Lake, while the lowest 1.61±0.18 and 0.04±0.02 mg/L in Kandol Lake, respectively. The I showed a maximum concentration of 0.26±0.01 in Kandol Lake, while the minimum of 0.11±0.01 in Izmis Lake (Table 1). The concentration of anions in the HAL water was under WHO (2017) thresholds. However, F and NO_3 were noted to be higher than Naltar Lakes water Muhammad

(2023). The variation in concentration of various anions in HAL water was attributed to local bedrock geology and agrogenic activities. Cl, F, I, SO_4 and HCO_3 concentrations were lower in the study area than in Naltar Lakes.

The cations such as Ca, Mg, Na, and K showed uppermost average concentrations of 9.26±0.34, 1.06±0.1, 2.81±0.2, and 3.3±0.3 mg/L in Izmis, while lowermost of 2.99±0.5, 0.12±0.1, 1.09±0.1, and 0.90±0.1 mg/L in Spine Khawar Lake, respectively (Table 1). These cations concentrations of HAL were observed within WHO (2017) thresholds and lower than Naltar Lakes water by Muhammad (2023). The PHE showed higher average concentrations of 322±94.1, 49.0±15.9, and 8.56±0.4 μg/L for Fe, Mn, and As in Izmis Lake, while lower of 41.8±15.9 and 22.7±6.7 μg/L in Kharkhary Lake, and 4.97±0.4 μg/L in Kandol Lake (Table 1). The concentrations of PHE of HAL were observed within WHO (2017) thresholds except for Fe in Izmis Lake only. The concentration of Fe was noted as higher, while Mn was lower than Naltar Lakes water by Muhammad (2023). This variation in Fe and Mn concentration could be attributed to bedrock geology in the area. The studied PHE concentration in water was noted lower than reservoir water in Turkiye (Varol, 2013, 2020). Higher concentrations of PHE in reservoir water were attributed to upstream agrogenic activities.

3.2. Grading of lake water

3.2.1. Drinking water quality index

The values of drinking WQI have been presented in Figure 2, and spatial distribution in Figure 3. The uppermost average drinking WQI value of 7.40±0.88 was noted for Izmis Lake, and the lowermost of 3.34±0.60 for Shahi Bagh Lake (Fig. 2). The spatial distribution showed that Izmis lake was noted with higher number of sampling point having higher WQI values (Fig. 3). Based on drinking WQI values, HAL water were classified as excellent for drinking purposes in all the studied lakes (Ali and Muhammad, 2023; Yidana and Yidana, 2010). The drinking WQI values of the present study were noted by Muhammad (2023) as lesser than those of Naltar Lakes water. This variation in drinking WQI resulted from a variation in the WQP attributed to the local lithological processes.

3.2.2. Irrigation water quality indices

The average of various irrigation WQI values for HAL water were summarized (Fig. 2), and each sample spatial distribution (Fig. 4). Among HAL water, the Izmis Lake showed the highest average SAR value of 0.21±0.01 meq/L. At the same time, Spin Khawar Lake was noted with a lowest average value of 0.11±0.01 meq/L. The spatial distribution showed that Izmis Lake was noted with a higher number of sampling points having the highest SAR values (Fig. 4). Overall, the SAR value of HAL showed that water is in excellent category (0-10) for irrigation of agriculture crops (Haq and Muhammad, 2023; Richards, 1954). Similarly, the maximum average RSC value was 1.06±0.07 meq/L, while Spin Khawar Lake was noted with a lowest average value of 0.51±0.06 meq/L (Fig. 2). Water of the HAL in this study was noted as good and suitable for irrigation (Richards, 1954; Singaraja, 2017). The uppermost average Na% value of 35.6±8.48 meq/L was observed in the water of Kandol Lake, and the lowest value of 22.6±0.74 meq/L in Shahi Bagh Lake. Based on Na% (20-40%), the water of HAL was classified in the good category for irrigation purposes (Haq and Muhammad, 2023; Singaraja, 2017; Wilcox, 1955). These values of irrigation WQI were noted to be lower than those of a previous study conducted on steamwater Turkiye (Çankaya et al., 2023).

3.3. Hydrogeochemistry

The concentrations of WQP in any natural water depend on the geochemical environment, including the availability and solubility of minerals, natural/lithogenic processes, and conditions. It has been noted that water chemistry in rock dominance is Ca/Mg-Cl/SO_4. With the passage of time and flow, the Cl is replaced with HCO_3 and of Ca by the Na ions (Marandi and Shand, 2018). Gibbs plot models have been used to identify the key factor regulating the water chemistry, and results were presented (Fig. 5). Results showed that water of the HAL is mainly determined by the rock dominance (88%), followed by precipitation dominance (12%), and evaporation showed no impact. This study further used hydrogeochemical facies of water in the HAL for the Piper-Hill diagram (Piper 1944), and the results are presented in Figure 6. Results revealed that most sampling points in HAL were grouped as mixed type group Ca/Mg-SO_4/Cl, followed by the calcium-magnesium bicarbonate (Ca/Mg-HCO_3). Due to bedrock geology, this Ca/Mg-SO_4/Cl dominancy in the HAL occurred in the water of the HAL.

3.4. Health risk assessment

The average ADD values via HAL water consumption for adults and children were summarized (Fig. 7ab). Results noted the uppermost average ADD values via Izmis Lake's water intake for the children due to NO_3, while the lowermost of Kandol Lake's water for the adults were attributed to As. Maximum ADD values of NO_3 were attributed to its higher contamination in the water. Among the various age groups, the uppermost ADD values of children were attributed to their low body weight. The water of Izmis Lake was observed to have higher ADD values among the lakes. The higher ADD of Izmis Lake was attributed to higher water contamination levels than others. The ADD values for the present study were noted as higher than those of Naltar Lakes by Muhammad (2023).

Results of the average HQ values via HAL water consumption for adults and children were summarized (Fig. 7cd). Results noted the maximum average HQ values via Izmis Lake's water intake for the children attributed to As, while the lowermost via Kandol Lake's water for the adults due to Fe. Maximum HQ values of As through water consumption were attributed to its higher toxicity and low reference dose values. Among various age groups, the highest HQ values of children were attributed to their vulnerability and low body weight. Among the lakes, the water of Izmis Lake was observed to have higher HQ values than others. The highest

HQ of Izmis Lake was attributed to a higher water contamination level than others for most of WQP. The HQ values in this study were lower than those reported for pond water (Tokatlı and Varol, 2021; Tokatlı et al., 2023; Varol, 2019). Higher HQ values of pond water were attributed to extensive agriculture activities upstream.

3.5. High-altitude lakes importance

High-altitude lakes of the study are a source of irrigation and drinking water for the downstream areas. These lakes recharge the groundwater sources and maintain the ecological flow as well. These lakes are also sources of fish and recreation for the tourists during summer season. However, the tourists not only contaminate the water and surrounding area of HAL with food and trash but result in over-exploitation of the local resources. The second threat to the HAL is climate change which has disturb the pattern of the rainfall in the area. Drought periods or high-intensity rainfall also resulted in the filling or siltation of these HAL. To curb the problems of contamination and over exploitation policy needs to be develop for the management of HAL. The HAL needs to be classified on the basis of their sensitivity and not disturbed during the fish breeding season. Further public awareness campaigns to guide the tourists for the sustainable use of HAL resources.

This study was limited to single-season sampling and water only. Further studies are recommended for the temporal and seasonal evaluation of water quality in the area. This study also recommends the determination of PHE in sediment and evaluation of pollution factors and ecological risk assessment.

4. Conclusions

This study concluded that water quality basic parameters, anions, and cations were found below the WHO drinking water thresholds for all studied HAL. However, the concentration of PHE, including Fe (15% samples) and As (3% samples), has surpassed these limits in HAL. The calculated drinking and irrigation WQI values were below the respective threshold limits, suggesting higher suitability for the said purposes. Gibbs plots classified water as rock dominant, followed by precipitation weathering. The Piper model revealed that water was dominated by the Ca/Mg-SO_4/Cl type. This study observed the maximum ADD and HQ values through intake of NO_3 and As for Izmis lake water consumption of children. Higher ADD and HQ values of NO_3 and As were attributed to their higher concentration and toxicity. This study noted that HQ values for the PHE studied were less than 1. This study noted the suitability of HAL water for drinking and irrigation purposes and further recommends future studies on the seasonal variation of PHE in the HAL water and sediments.

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Data Availability *The data that support the findings of this study are available from the corresponding author upon reasonable request.*

Code Availability *Not applicable*

Declarations

Authors Contributions ***Dr. Said Muhammad*** *Design this study, Conceptualization, Methodology, Writing- Original draft preparation,* ***Mr. Aasim Zeb:*** *Data curation, sampling collection,* ***Mr. Rizwan Ullah, Ms. Sehrish Amin, Dr. Cem Tokatli****, Writing- Reviewing and Editing,* **Dr. Ashfaq Ahmad,** *Funding, Writing- Reviewing and Editing*

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Table 1. Water quality parameters in the water of high-altitude lakes, Swat District, northern Pakistan

Parameters	Statistics	Spin Khawar Lake	Kandol Lake	Izmis Lake	Shahi Bagh Lake	Kharkhary Lake	WHO[b]
pH	Mean	6.8	7.2	6.9	7.1	7	6.5-8.5
	Stdev	0.1	0.1	0.1	0.04	0.1	
TDS (mg/L)	Mean	55.7	60.9	90.1	72.2	62.9	1000
	Stdev	3.7	4.6	2.9	3.61	6	
EC (µS/cm)	Mean	83.6	91.4	135	108	94.3	1400
	Stdev	5.6	6.9	4.4	5.41	9	
NO_3 (mg/L)	Mean	2.1	2.2	3.02	3	2.7	50
	Stdev	0.1	0.1	0.1	0.07	0.1	
Cl (mg/L)	Mean	2.62	1.61	2.63	3.04	2.74	250
	Stdev	0.15	0.18	0.1	0.14	0.1	
F (mg/L)	Mean	0.1	0.04	0.05	0.11	0.09	1.5
	Stdev	0.05	0.02	0	0.03	0.05	
SO_4 (mg/L)	Mean	18	18.5	26.2	19.5	19.6	500
	Stdev	0.5	0.5	0.8	0.16	0.5	
HCO_3 (mg/L)	Mean	22	24.9	34.9	26.6	24.2	250
	Stdev	3.4	4.3	2.1	3.44	5.5	
I (µg/L)	Mean	0.19	0.26	0.11	0.13	0.19	
	Stdev	0.01	0.01	0.01	0.01	0.01	
Ca (mg/L)	Mean	2.99	4.74	7.96	9.26	4.78	200
	Stdev	0.5	0.8	1.2	0.34	0.3	
Mg (mg/L)	Mean	0.12	0.37	1.06	0.26	0.19	50
	Stdev	0.1	0.1	0.1	0.01	0	
Na (mg/L)	Mean	1.09	1.69	2.81	2.28	1.75	200
	Stdev	0.1	0.1	0.2	0.05	0.1	
K (mg/L)	Mean	0.90	1.58	3.3	1.61	0.93	12
	Stdev	0.1	0.1	0.3	0.02	0.1	
Fe (µg/L)	Mean	125	58	322	82.1	41.8	300
	Stdev	80.4	19.7	94.1	38.9	15.9	
Mn (µg/L)	Mean	34.5	23.1	49	24.6	22.7	400
	Stdev	9.2	8	15.9	6.38	6.7	
As (µg/L)	Mean	5.95	4.97	8.56	8.54	6.69	10
	Stdev	0.5	0.4	0.4	0.26	0.3	

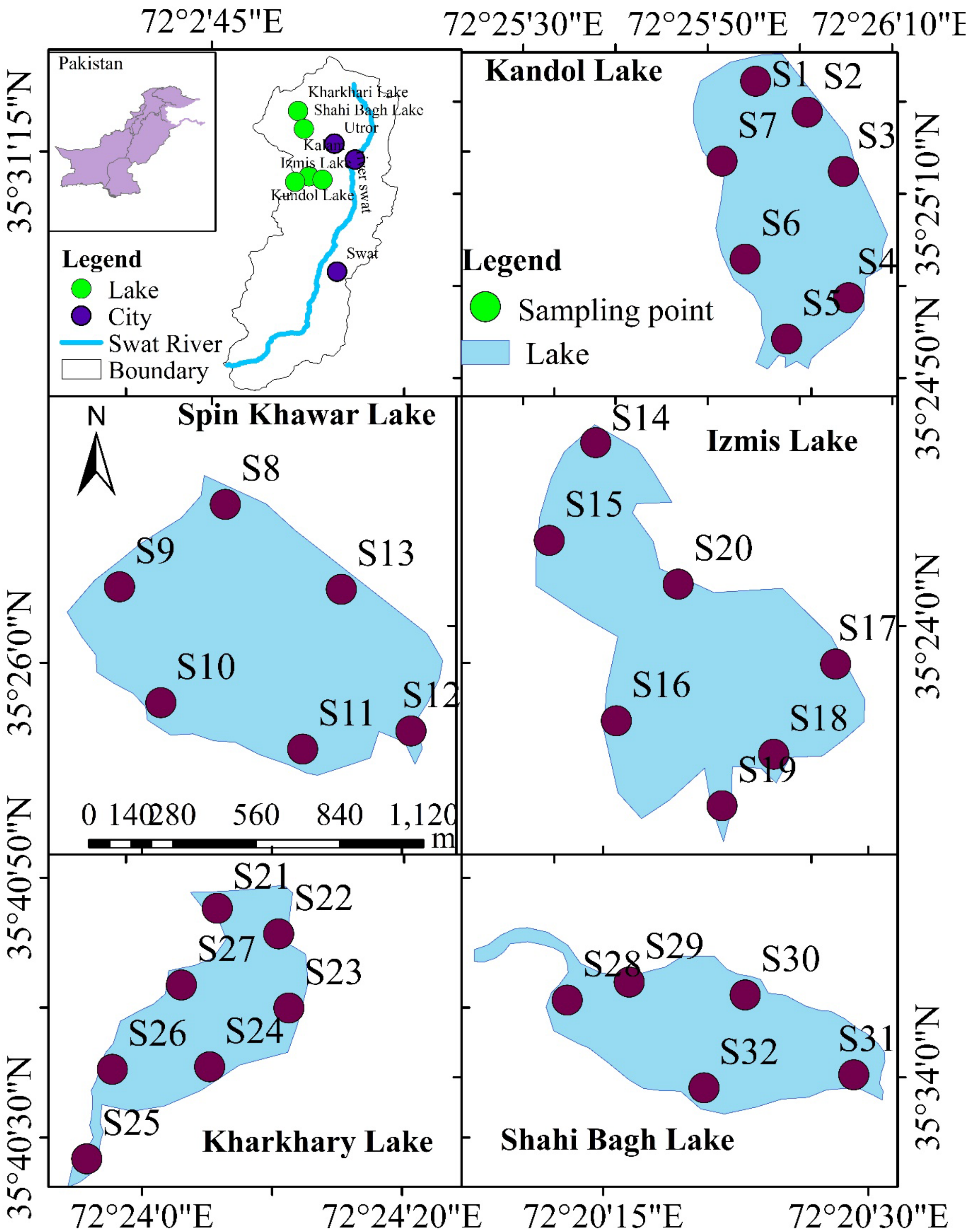

Fig.1. Location map of water sampling spots in high-altitude lakes, Swat District, northern Pakistan.

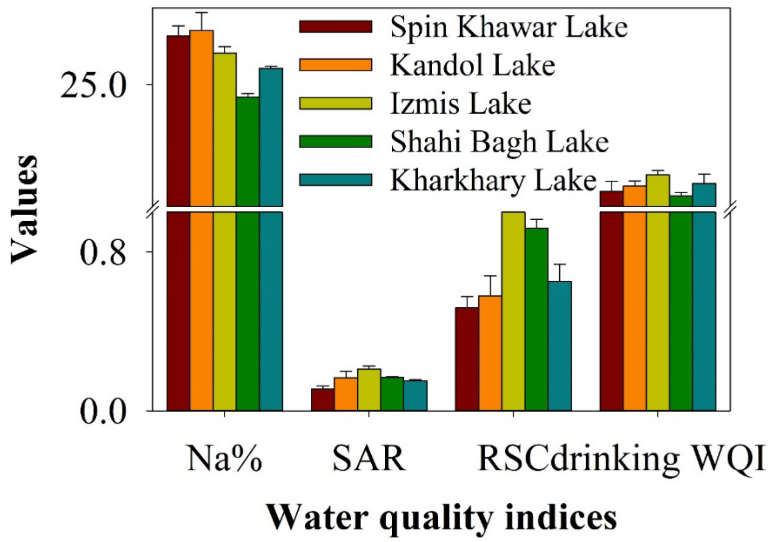

Fig. 2. Sodium percent (Na%), Sodium adsorption ratio (SAR), residual sodium bicarbonates (RSC), water quality index (WQI), and other irrigation indices for the water of high-altitude lakes, Swat District, northern Pakistan

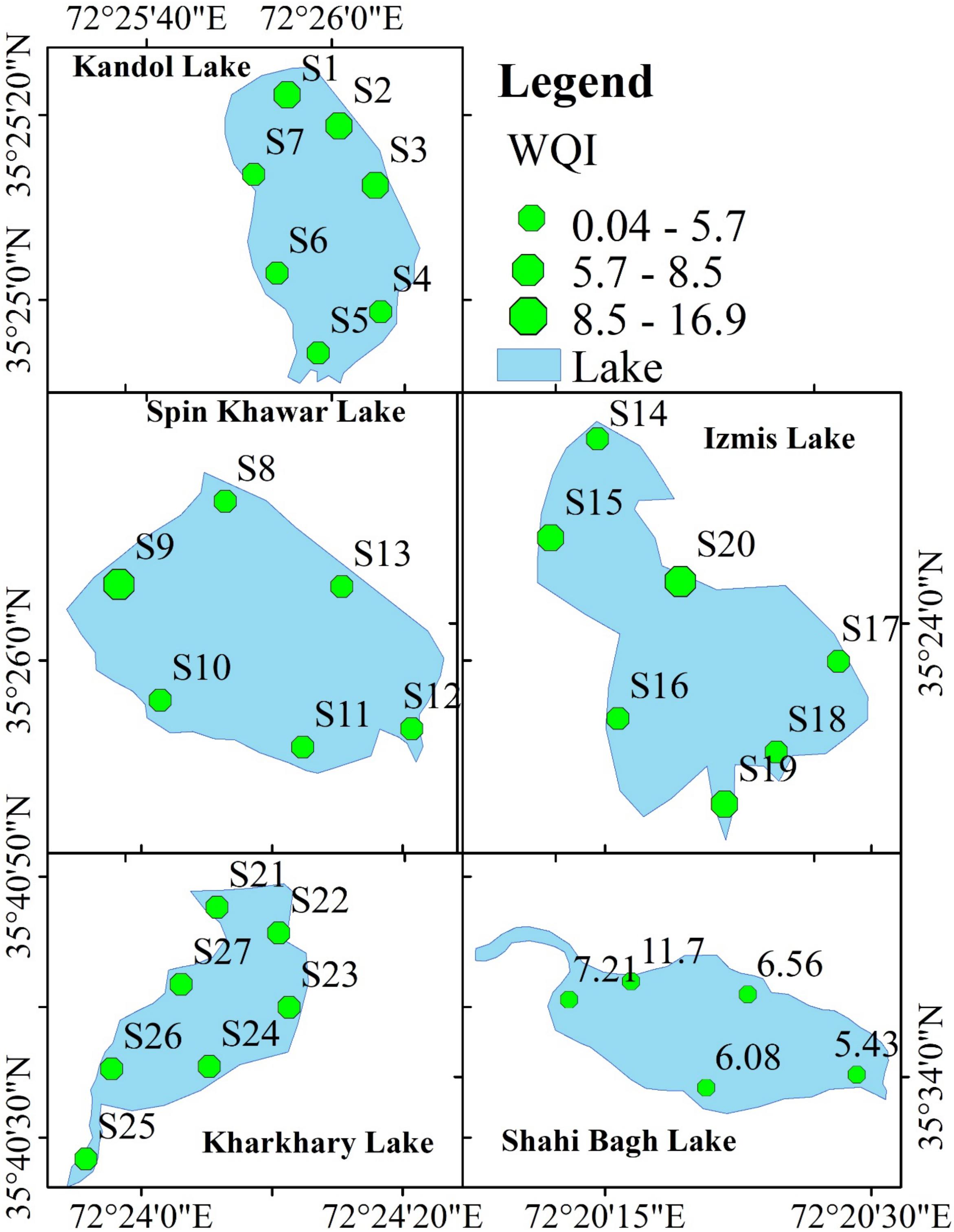

Fig. 3. Spatial distribution of water quality index of high-altitude lakes, Swat District, northern Pakistan

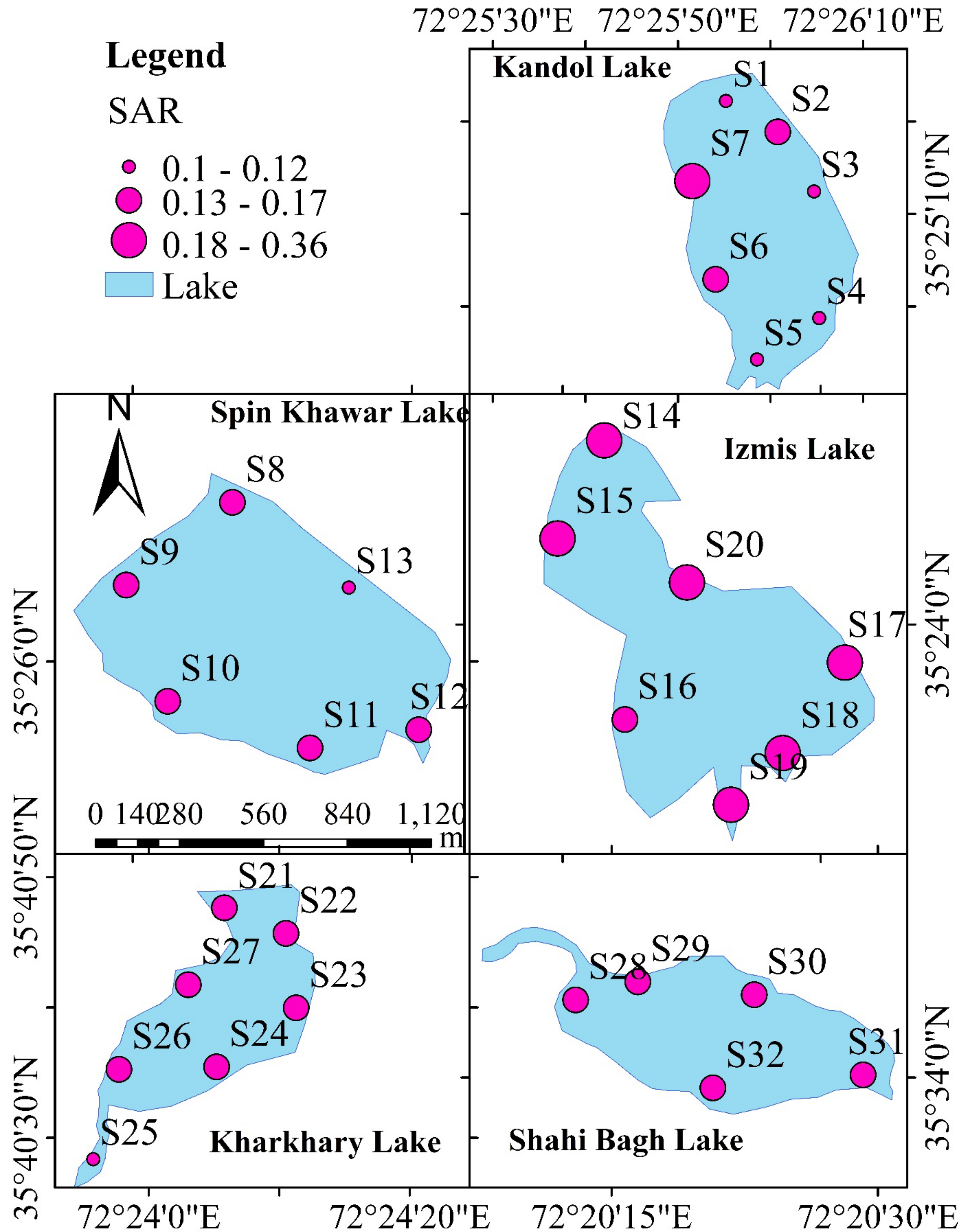

Fig. 4. Spatial distribution of sodium adsorption ratio (meq/L) of high-altitude lakes, Swat District, northern Pakistan

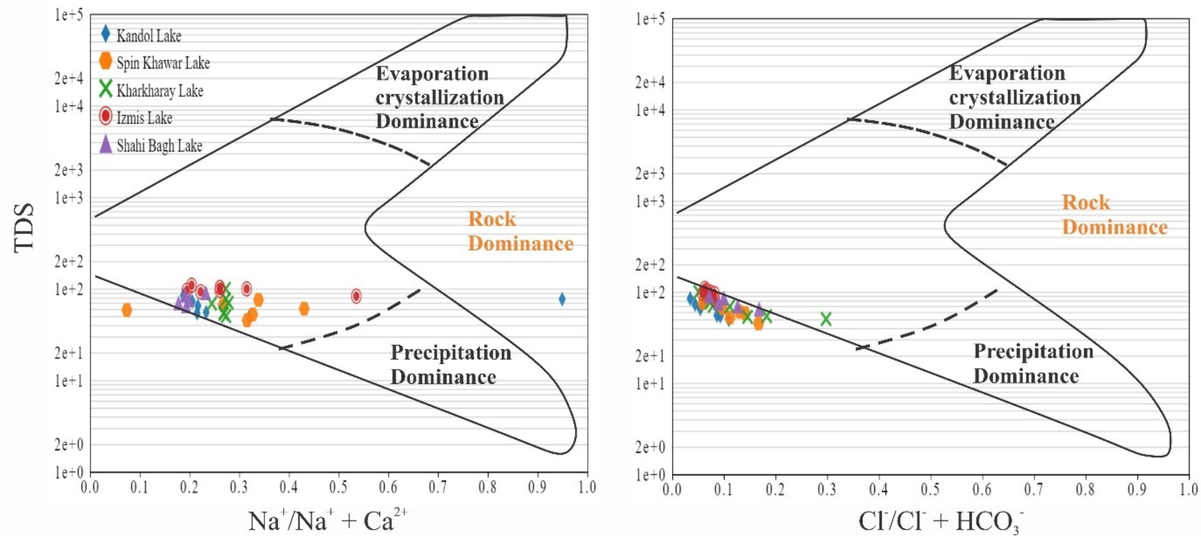

Fig. 5. Gibbs plot diagram for the water of high-altitude lakes, Swat District, northern Pakistan

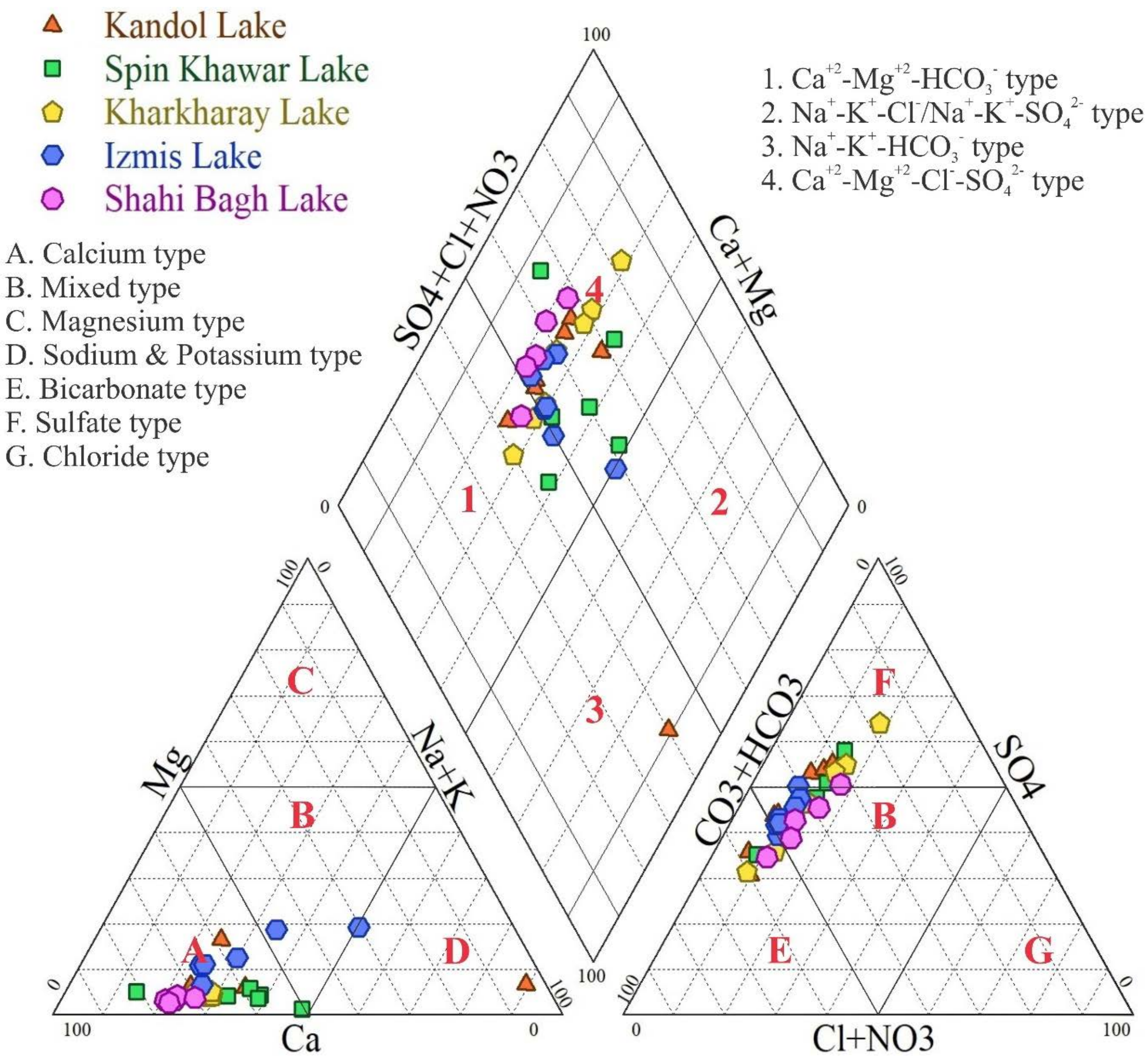

Fig. 6. Piper plot model for the water of high-altitude lakes, Swat District, northern Pakistan

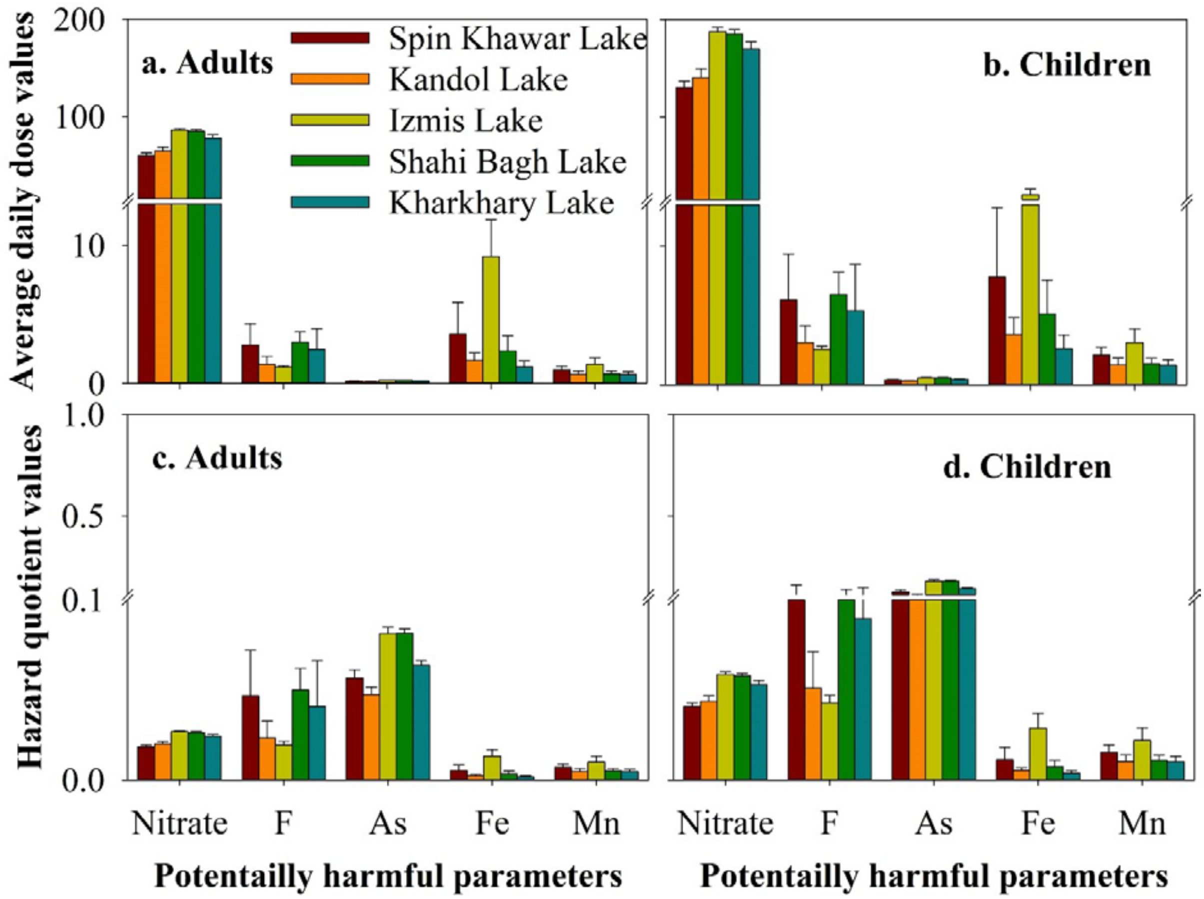

Fig. 7. Health risk assessment via consumption of toxic water parameters in the water of high-altitude lakes, Swat District, northern Pakistan, **a.** average daily dose (µg/kg-day) of adults, **b.** children, **c.** hazard quotient of adults, **d.** children