

GEOCHEMICAL SIGNATURES OF WATER BODIES AND SOURCES IN THE QINGHAI LAKE AREA, CHINA

LIU, Y.^{1,2,3*} – WANG, J.^{2,3} – REN, Z.⁴ – WANG, H.^{2,3}

¹*East China Normal University, Shanghai 200241, China*

²*State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin
China Institute of Water Resources and Hydropower Research, Beijing 100038, China*

³*Department of Water Resources, China Institute of Water Resources and Hydropower
Research, Beijing 100038, China*

⁴*Flathead Lake Biological Station, University of Montana, Polson, MT 59860, USA*

**Corresponding author
e-mail: liuyang@iwhr.com*

(Received 8th Mar 2019; accepted 21st May 2019)

Abstract. The chemical composition of dissolved constituents in aquatic ecosystems is of fundamental importance in regulating chemical and biological dynamics and processes. There are many factors that can determine and affect chemical composition of lakes and rivers. This paper presents fundamental geochemical information for the waters in Qinghai Lake area in China and assesses geochemical patterns, relationships between the elements, and potential mechanisms for these patterns. The concentrations of 30 elements from 16 water samples were measured. The results showed that Ca (8.1-88.9 mg/L), K (5.1-372.7 mg/L), Mg (6.3-1127.0 mg/L), Na (10.0-6459.0 mg/L), and S (4.8-2002.0 mg/L) were the dominant elements in all water samples but exhibited considerable variation among systems. The tributaries had high Ca, relatively low Na+K, and low salinity, indicating rock weathering as the dominant factor determining their geochemistry. The satellite lakes (except the two largest ones) showed low Ca, moderate Na+K and Mg, and low salinity, indicating the combined effects of many factors. Correlation analyses suggested that B, K, Li, Mg, and Na concentrations are determined by evaporation and crystallization and dissolution of sulfate minerals while Al and Fe concentrations are affected mostly by rock weathering.

Keywords: *geology, chemical composition, trace elements, salinity, basin*

Abbreviations: the Buha River: BHR; the Shaliu River: SLR; the Haergai River: HER; the Quanji River: QJR; the Heima River: HMR; the Daotang River: DTR; cluster analysis: CA; coefficient of variation: CV; total dissolved solids: TDS; Qinghai Lake: QL; Moon Lake: ML; Sun Lake: SL; Lanhua Lake: LHL; Ganzihe Lake: GZL; Erhai Lake: EHL; Haiyanwan Lake: HYL; Gahai Lake: GHL

Introduction

Major and trace elements are natural components in aquatic ecosystems worldwide and play important roles in chemical and biological processes (Gaillardet et al., 2003; Bounouira et al., 2013; Qin et al., 2015; Sunny et al., 2018). Some trace elements are commonly required by biota due to their key role in biosynthetic processes and metabolism as cofactors for enzymes (Havig et al., 2015; Daniel et al., 2018). These elements include aluminum (Al), boron (B), chlorine (Cl), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn) (Çelik and Oehlenschläger, 2007; Tuzen, 2009; Mahmood et al., 2018). However, due to their toxicity, non-degradability, persistence, and bioaccumulation, trace element pollution of

the environment has become one of the most serious global issues in recent years (Tam and Wong, 2000; Cui et al., 2011; Hsieh et al., 2013; Li et al., 2015). Indeed, even bioessential elements will yield toxic effects at high concentrations (Goldhaber, 2003; Anan, 2019).

Major and trace elements are added to an aquatic ecosystem through different pathways, including geological erosion, atmospheric deposition, or anthropogenic sources (Vystavna et al., 2012; Al Abdullah et al., 2014; Shakeri et al., 2014; Xu, 2018). Under natural conditions, the chemical composition of aquatic ecosystems is determined by the weathering of terrigenous minerals, evaporation and crystallization, and precipitation (Négrel et al., 1993; Liang and Wenshun, 2019). Elements originated from rock weathering are transported to downstream water bodies through streams and rivers, carrying the characteristic features of their source's lithology. Upon reaching standing water, evaporation and crystallization are important mechanisms that produce Na-rich and highly saline lakes and ponds, due to sodium's high solubility (Gibbs, 1970). In addition, concentrations of various elements in aquatic systems can be strongly altered by anthropogenic activities, including mining, wastewater discharge, atmospheric deposition, and fertilizer runoff (Yang and Rose, 2005; Yu et al., 2014; Hayzoun et al., 2015; Lynam et al., 2015; Otachi et al., 2015; Baharuddin and Samsudin, 2018). Even remote lakes are not exempt from contamination by the long-range transported trace elements (Battarbee et al., 2009; Elser et al., 2009; Kyllonen et al., 2009). Thus, geochemical signatures of rivers and lakes are determined by and in turn provide important information about the geology of the area, types of rock weathering, anthropogenic activities, biological processes, and atmospheric deposition in drainage basins (Foster and Charlesworth, 1996; Xu et al., 2010; Singh et al., 2015; Walther and Nims, 2015; Wang et al., 2018).

Qinghai Lake, located on the northeastern margin of the Qinghai-Tibet Plateau, is an endorheic brackish lake and the largest natural lake in China. It is also a globally important wetland for biological diversity conservation (Ramsar, 2015; Sarker et al., 2019). However, due to global climate change and human activities, the lake level declined by 4.33 m from 1955 to 2005 and grassland degradation in its catchment has expanded to 37% of the whole watershed area in 2010 (Li et al., 2007, 2009; Chen et al., 2011; Luo et al., 2013). Because of its fragility, sensitivity to global climate change and anthropogenic impacts, and its importance in maintaining ecological security of northeast Qinghai-Tibet Plateau, the Qinghai Lake watershed has recently become an intensive place for research (An et al., 2006; Hao, 2008; Barakat et al., 2018). Furthermore, this area has special hydrological and limnological characteristics. Adjacent to the main lake, there are a number of "satellite lakes"; these are separated from the main lake by barrier dunes and do not receive river or stream inflows (except Erhai Lake, which receives stream inflow). In contrast, the main lake has more than 40 tributaries. Reflecting these differences, Qinghai Lake and the satellite lakes are significantly different from each other in biological, chemical, and hydrologic conditions (Liu et al., 2009; Ao et al., 2014; Meng et al., 2014; Rawat and Singh, 2018). Previous studies of Qinghai Lake have focused on the reconstruction of the region's paleoenvironment and paleoclimate, geology, hydrology, ecological management, hydrobiology, fishery resources, climate change, soil, and sediment geochemistry and have especially emphasized the main lake (Shi et al., 2004; Henderson and Holmes, 2009; Cao and An, 2010; Jin et al., 2010; Liu and Lai, 2013). However, integrated and comparative studies on multi-element geochemistry in the main lake, its satellite lakes,

and tributaries are lacking. Hence, both from a fundamental and an environmental point of view, it is crucial to assess the geochemical signatures of the aquatic ecosystems in Qinghai Lake area. The main objectives of this study were: (1) to document the basic geochemistry of Qinghai Lake, its adjacent lakes, and its inflowing rivers; (2) to identify the geochemical patterns of elements in those systems; (3) to evaluate possible determinant mechanisms causing these differences. The results provide an integrative view of the geochemical characteristics, distribution patterns, and processes of Qinghai Lake area.

Materials and methods

Study area

Qinghai Lake (QL, 36°32' - 37°15' N, 99°36' - 100°47' E) is a remote endorheic saline lake located at 3194 m above sea level on the Qinghai-Tibet Plateau and lies at a junction of three major climatic systems, the Westerlies, the East Asian, and Indian summer monsoons (An et al., 2012; Chen et al., 2015). It is the largest lake in China with a surface area of 4260 km², a catchment area of 29,660 km², and an average depth of 21 m. Mean annual precipitation in the basin is 389.1 mm and average annual evaporation is 895.4 mm. Annual mean temperature is -0.3°C with a linear warming rate of 0.28°C /10a. More than 40 rivers and streams flow into Qinghai Lake but most of them are seasonal. There are five main tributaries: the Buha River (BHR), the Shaliu River (SLR), the Haergai River (HER), the Quanji River (QJR), and the Heima River (HMR). Together, these contribute 83% of the total runoff. On the eastern margin of Qinghai Lake there are number of satellite lakes, separated from the main lake by barrier dunes or sand bars (Li et al., 1996). None of the satellite lakes have stream inflows with the exception of Erhai Lake which receives input from the Daotang River (DTR).

Sampling

Field surveys were conducted in late July 2015. A total of 16 water samples was collected, including 10 lake samples and 6 river samples (*Fig. 1*). Of the 10 lake samples, 3 were collected from Qinghai Lake (QL-1, QL-2, and QL-3) and the others were collected from 7 satellite lakes (Moon Lake (ML), Sun Lake (SL), Lanhua Lake (LHL), Ganzihe Lake (GZL), Erhai Lake (EHL), Haiyanwan Lake (HYL), and Gahai Lake (GHL)). Because there was no boat available to reach the center of the lakes, lake water samples were taken from sites about 20-30 m away from the edge of the lakes at depths >50 cm. River water samples were collected in the deepest part of the channel at depths of ~10 cm. All water was filtered through 0.2-µm GF/F filters, stored in 100-ml acid-cleaned polyethylene bottles, fixed with 0.1 ml of concentrated nitric acid, shipped to the laboratory under refrigeration, and frozen until analysis.

Analyses

Element concentrations in the water samples were measured using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). There were 30 elements measured in total: Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Si, Sr, Tl, V, and Zn.

Cluster analysis (CA) and Analysis of Variance (ANOVA) were performed to assess general patterns of element concentrations. A Gibbs plot was used to assess the dominant determining mechanisms. Correlation analyses were conducted to identify between-element associations. All the analyses and graphs were done using SPSS 20.0 and ORIGIN 9.2.

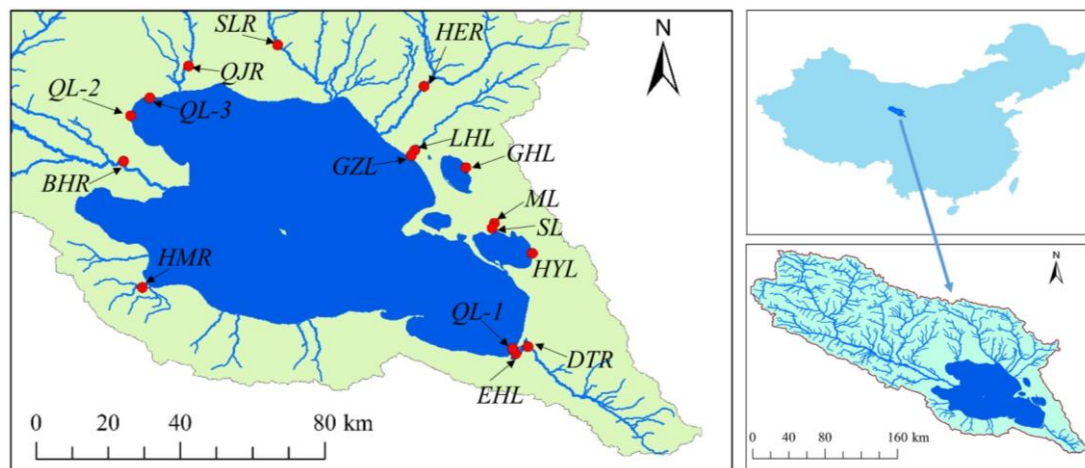


Figure 1. Study area and sample sites. HMR, DTR, HER, SLR, QJR, and BHR are river sample sites. EHL, HYL, SL, ML, GHL, GZL, LHL, QL-1, QL-2, and QL-3 are lake sample sites

Results and discussion

Basic geochemical patterns

The concentrations of studied elements in the water samples are shown (Table 1). Concentrations of Cr and Sb were below the limits of detection for all sites. Arsenic was detected only in the main lake and the two satellite lakes. P was detected only in five satellite lakes and one tributary (Heima River) with low concentrations (3.8-22.2 $\mu\text{g/L}$), indicating that the waters in Qinghai Lake area are oligotrophic, especially the main lake. Ca (8.1-88.9 mg/L), K (5.1-372.7 mg/L), Mg (6.3-1127.0 mg/L), Na (10.0-6459.0 mg/L), and S (4.8-2002.0 mg/L) were the dominant elements in all water samples (>1 mg/L, Table 1), with a high CV of 88.21%, 209.78%, 132.49%, 158.26%, and 163.37%, respectively. The coefficient of variation (CV) also showed that 22 elements had a CV higher than 50%, which means that most of the element distributions have very high variation.

Cluster Analysis (CA) of the chemical data grouped the samples into four statistically significant clusters: main lake cluster (including HYL and GHL), satellite lake cluster, tributary cluster (excepting DTR), and DTR (Fig. 2). DTR was separated from the tributary cluster because of higher concentrations for most elements, which might be caused by intensive anthropogenic activities and low runoff. Based on the ANOVA analysis, the main lake cluster had significantly higher Ag, B, Co, Li, Mg, Na, S, and Ti concentrations ($P < 0.05$) than the satellite lake cluster but significantly lower V concentration ($P < 0.05$). Compared to the tributary cluster, the main lake cluster had significantly higher concentrations of B, Co, Li, Mg, Na, S, and Ti ($P < 0.05$) but significantly lower Al, Ca, Cu, and V concentrations ($P < 0.05$). Relative to the tributary cluster, the satellite lake cluster had significantly higher Mg ($P < 0.05$) but significantly

lower Ag, Al, Ca, and Cu concentrations ($P < 0.05$). HYL and GHL are the two largest satellite lakes and are separated from the main lake by sand bars, which likely allowed some degree of hydrological connectivity. Thus, it is not surprising that GHL and HYL were grouped in the main lake cluster. Nevertheless, GHL had higher concentrations of B, K, Li, Mg, Na, and S than HYL and these concentrations in HYL were higher than in the main lake. Other satellite lakes are surrounded by grassland and are considerably smaller. Their chemical composition is likely to be more easily affected by the terrestrial environment as well as precipitation and in-lake biological processes.

Table 1. Basic water geochemistry of Qinghai Lake, satellite lakes, and tributaries

	Main Lake			Satellite Lakes							Tributaries					
	QL-1	QL-2	QL-3	ML	SL	LHL	GZL	EHL	HYL	GHL	DTR	HMR	BHR	QJR	HGR	SLR
Na (mg/L)	2786.0	3089.0	3333.0	101.6	95.3	24.4	24.8	153.7	4109.0	6459.0	119.1	23.7	23.5	12.2	10.0	34.9
S (mg/L)	696.7	754.7	912.9	4.8	31.3	12.7	5.1	52.4	1036.0	2002.0	53.2	13.5	21.6	6.6	18.0	24.8
Mg (mg/L)	612.7	666.4	714.7	141.6	91.8	39.7	39.7	84.5	892.7	1127.0	65.7	14.5	17.9	6.3	21.5	25.8
K (mg/L)	16.8	28.2	32.4	30.6	39.2	8.3	7.1	15.7	95.8	372.7	10.7	9.8	6.9	6.2	5.1	6.7
Ca (mg/L)	10.7	11.6	11.5	8.1	9.2	29.8	14.1	9.4	10.1	18.1	46.3	88.9	72.4	61.0	83.9	78.0
B (mg/L)	7.6	8.3	8.8	1.3	1.6	0.5	0.5	0.9	10.6	16.1	0.8	0.3	0.4	0.2	0.3	0.3
Tl (mg/L)	11.8	13.6	15.6	2.2	3.0	0.6	0.6	1.4	0.0	0.0	0.9	0.3	0.3	0.1	0.4	0.4
Si (mg/L)	0.1	0.1	--	0.3	1.7	0.7	4.0	0.5	0.1	--	4.3	2.7	2.1	1.3	2.9	2.0
Sr (µg/L)	34.5	41.5	35.9	1178.0	1215.0	246.1	99.4	35.5	38.0	82.0	832.8	311.3	432.0	195.3	252.2	294.2
Li (µg/L)	413.2	468.2	513.1	75.3	94.5	3.0	8.0	43.6	665.7	1516.0	24.9	--	6.3	--	1.0	4.6
Al (µg/L)	45.3	39.4	41.2	53.7	45.5	77.1	66.5	46.0	33.3	50.0	104.0	136.6	138.8	113.1	134.0	140.2
Ba (µg/L)	12.1	12.5	13.1	190.7	212.0	58.6	33.7	4.5	13.8	10.2	40.0	70.7	73.1	54.0	98.2	83.4
Bi (µg/L)	19.1	20.4	15.7	16.0	13.2	13.4	11.5	16.0	16.3	14.8	37.1	11.4	17.6	8.2	38.2	20.0
Se (µg/L)	8.0	28.5	31.8	12.2	32.3	9.0	8.9	11.2	36.9	27.1	8.6	14.8	12.8	15.1	16.2	14.5
Fe (µg/L)	9.6	4.6	4.2	16.9	3.0	12.1	34.2	13.7	3.2	4.8	26.6	8.8	9.2	6.1	14.9	11.7
V (µg/L)	--	0.6	0.9	12.7	14.7	11.6	12.6	13.5	--	--	13.5	13.3	12.3	11.8	12.2	11.6
Ag (µg/L)	9.8	10.0	10.2	4.6	4.0	4.3	5.0	7.2	10.0	11.7	7.8	7.4	8.6	8.3	12.9	12.3
P (µg/L)	--	--	--	6.1	13.1	14.5	3.8	5.1	--	--	--	22.2	--	--	--	--
As (µg/L)	7.9	1.0	--	--	--	--	--	3.8	--	10.2	0.0	--	--	--	--	--
Zn (µg/L)	1.8	3.9	2.0	3.7	0.9	3.5	4.7	2.8	0.9	3.2	4.2	12.9	20.6	2.5	1.7	3.8
Cu (µg/L)	3.7	3.9	3.2	3.2	2.9	2.6	3.5	3.8	3.5	2.3	4.7	6.9	5.4	5.7	4.1	4.5
Pb (µg/L)	2.7	1.7	2.3	1.6	--	4.0	3.8	4.4	--	--	5.6	5.9	3.9	1.5	5.7	2.1
Mn (µg/L)	1.0	2.4	0.7	3.8	0.5	4.5	2.7	1.7	0.0	1.8	17.7	4.4	2.7	0.8	3.9	1.4
Mo (µg/L)	3.9	3.9	3.1	2.3	1.4	2.7	1.1	3.6	4.0	0.2	6.9	1.6	1.6	1.8	6.5	2.3
Co (µg/L)	3.5	3.6	4.2	2.3	2.7	2.0	2.1	2.1	3.4	3.7	2.7	2.6	2.2	3.1	2.7	3.2
Ni (µg/L)	1.1	1.4	1.3	1.5	2.5	1.9	4.4	1.5	1.6	1.0	5.6	3.4	3.2	1.8	3.1	2.7
Cd (µg/L)	0.4	0.6	0.5	0.3	0.2	0.2	0.3	0.3	0.4	0.6	0.3	0.5	0.5	0.8	0.8	0.8
Be (µg/L)	0.0	0.0	--	0.1	0.1	0.1	0.1	0.0	0.0	--	0.1	0.0	0.0	0.0	0.0	0.0
Cr (µg/L)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sb (µg/L)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Note: -- is below the minimum detection limit of the instrument

The relative amounts of the dominant elements (Na, K, Ca, and Mg) in the water samples can be seen more clearly in the ternary diagram (Fig. 3). The main lake cluster is grouped in the high Na+K sector but with low Mg and Ca. In contrast, the satellite lake cluster was grouped in the middle of the diagram with low Ca but relatively high Mg and Na+K. The tributary waters were very different from the lake waters, situated in a sector with high Ca but relatively low Mg and Na+K. Overall, Ca was the most abundant element in tributaries.

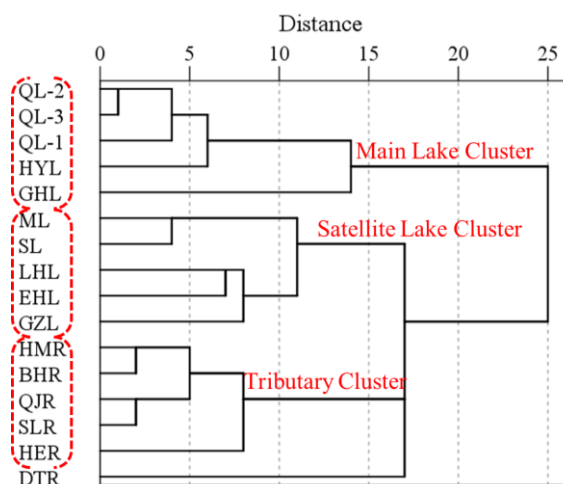


Figure 2. Cluster dendrogram of the sample sites based on the studied elements

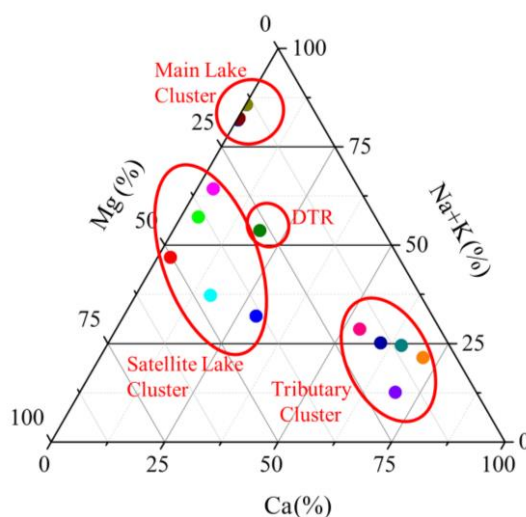


Figure 3. Ternary diagram of dominant elements in the water samples

Determinants of water geochemistry

There are three main factors that determine surface water geochemistry: evaporation and crystallization, rock weathering, and precipitation. The relative importance of these factors can be assessed via the relationship between total dissolved solids (TDS) and the weight ratio of Na/(Na+Ca). In this model, water with high TDS and high Na (high Na/(Na+Ca)) has chemistry dominated by evaporation and crystallization, while waters

with moderate TDS and high Ca (low Na/(Na+Ca)) are dominated by rock weathering and those with low TDS and high Na are dominated by precipitation. The water samples from Qinghai Lake's tributaries are located in the middle part of the plot (Fig. 4), indicating that rock weathering is the dominant factor determining their chemical composition (Ca-rich and moderate salinity) of the tributaries.

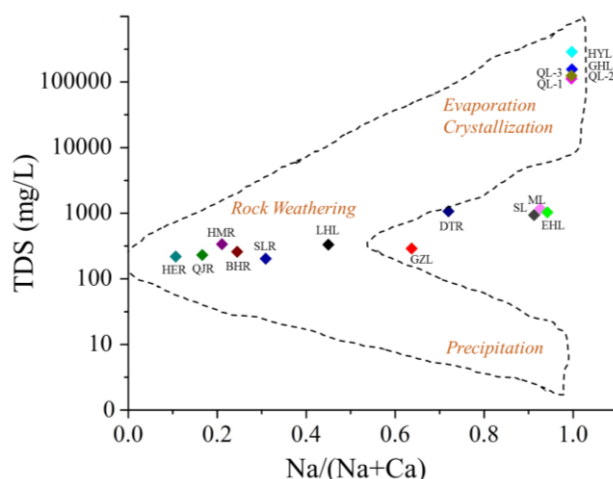


Figure 4. The relationship between TDS and the weight ratio Na/(Na+Ca) in the water samples (the dash line is cited from Gibbs 1970)

In contrast, the water samples from the main lake, HYL, and GHIL are Na-rich and high in salinity (Fig. 4), indicating the evaporation and crystallization are the dominant determining factors for those lakes. Other water samples, which are mostly from the satellite lakes, are located in a zone intermediate between the precipitation end and the evaporation and crystallization end (Fig. 4), indicating that combination of factors determines the water geochemistry of the satellite lakes, including evaporation and crystallization, rock weathering, precipitation, hydrology, and biological processes (Shiller, 1997; Zwolsman and Van Eck, 1999).

The relationships between elements

The relationships between elements may provide further insights into their sources or the processes affecting the overall geochemical composition (Mwanamoki et al., 2015). If the elements show high correlation, they likely originated from the same source or are affected by similar mechanisms. Table 2 shows correlation relationships for the elements that had higher average concentrations (>0.01 mg/L) in the water samples. B, K, Li, Mg, S, and Se all had significantly positive relationships with Na, indicating that they are strongly affected by evaporation and crystallization processes. B, K, Li, Mg, S, and Se also had significantly positive relationships with each other, consistent with joint regulation via interactions with Na solubility during evaporation and crystallization. In contrast, Al and Si had significant relationships with Ca, indicating that they were largely determined by rock weathering. Al and Fe also showed significantly positive relationships with Si, indicating a source associated with silicate weathering. Moreover, there was a significant relationship ($r=0.88$, $P<0.01$) between Ba and Sr. Ba and Sr have

similar geochemical behavior, and their concentrations are largely determined by geological composition of the drainage basin and weathering processes (An et al., 2006; Watmough, 2014; Fu et al., 2018). In the water samples, the main lake cluster had very high S concentrations (697.7-2002.0 mg/L), followed by tributaries (6.6-53.2 mg/L) and satellite lakes (4.8-52.4 mg/L). S also had significantly positive relationships with B, K, Li, Mg, and Na, suggesting that sulfate mineral dissolution is another possible source of these elements in Qinghai Lake regional waters.

Table 2. Correlations among selected elements in the waters of Qinghai Lake area

	Al	B	Ba	Bi	Ca	Fe	K	Li	Mg	Na	S	Se	Si	Sr	Tl
Al	1.00														
B	-0.62	1.00													
Ba	0.18	-0.47	1.00												
Bi	0.29	-0.11	-0.01	1.00											
Ca	0.98	-0.51	0.12	0.29	1.00										
Fe	0.20	-0.49	0.00	0.31	0.05	1.00									
K	-0.33	0.78	-0.22	-0.14	-0.27	-0.31	1.00								
Li	-0.52	0.97	-0.41	-0.12	-0.43	-0.44	0.91	1.00							
Mg	-0.65	0.99	-0.48	-0.10	-0.54	-0.49	0.72	0.94	1.00						
Na	-0.58	1.00	-0.51	-0.10	-0.47	-0.48	0.79	0.97	0.99	1.00					
S	-0.53	0.99	-0.49	-0.10	-0.43	-0.46	0.85	0.99	0.97	0.99	1.00				
Se	-0.47	0.64	0.00	-0.16	-0.34	-0.68	0.43	0.58	0.65	0.62	0.60	1.00			
Si	0.63	-0.63	0.18	0.41	0.55	0.72	-0.37	-0.56	-0.65	-0.61	-0.58	-0.46	1.00		
Sr	0.09	-0.41	0.88	0.14	-0.01	0.15	-0.16	-0.35	-0.42	-0.45	-0.43	-0.07	0.27	1.00	
Tl	-0.50	0.42	-0.27	0.00	-0.44	-0.31	-0.12	0.23	0.46	0.39	0.33	0.31	-0.46	-0.25	1.00

Note: Numbers in bold indicate elements that present a significant ($P < 0.05$) coefficient of correlation

Conclusion

This paper reports patterns in the aqueous geochemistry in the main lake, satellite lakes, and tributaries in Qinghai Lake area, including basic water geochemistry information. Our analyses provide an integrated and comparative view of the multi-element geochemistry among different waters in this particular area. The element distributions in the waters varied considerably. In general, the main lake had higher concentrations of most elements than the satellite lakes and the tributaries. However, the two largest satellite lakes showed the highest concentrations of B, K, Li, Mg, Na, and S. The satellite lakes seem to have different degrees of communication with the main lake and with external influences. The geochemical differences among the lakes may necessitate different physiological adjustments among aquatic biota in coping with the geochemical environment. Meanwhile, the low P concentrations that we document indicate the aquatic ecosystems in Qinghai Lake are oligotrophic or ultra-oligotrophic and thus likely sensitive to changes in external nutrient loading, such as inputs from non-point (fertilizer runoff) or point (sewage outfalls) sources. Therefore, further studies with more extensive biological and chemical scope and taken from whole watershed are recommended to better understand the lake basin's spatial geochemistry patterns and consequently to assess the effects of geochemical variations on biological and ecological processes in the aquatic ecosystems in Qinghai Lake area.

Acknowledgements. We are grateful to the anonymous reviewers for the comments. This study was supported by National key research and development program (No. 2018YFC0408103), the Open Fund of State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research (No. 2016TS01), Hunan Province Science and Technology Major Project (No. 2018SK1010), the Ministerial Science Program of the Ministry of Water Resources (Grant nos. 126301001000160014-2), and Tianjin Province Science and Technology Plan Project (No. 17YFCZZC00210).

REFERENCES

- [1] Al Abdullah, J., Michèl, H., Funel, G. B., Féraud, G. (2014): Distribution and baseline values of trace elements in the sediment of Var River catchment, southeast France. – *Environmental Monitoring and Assessment* 186: 8175-8189.
- [2] An, Z. S., Ai, L., Song, Y. G., Colman, S. M. (2006): Lake Qinghai scientific drilling project. – *Scientific Drilling* 2: 20-22.
- [3] An, Z. S., Colman, S. M., Zhou, W., Li, X., Brown, E. T., Jull, A. J., Cai, Y., Huang, Y., Lu, X., Chang, H., Song, Y., Sun, Y., Xu, H., Liu, W., Jin, Z., Liu, X., Cheng, P., Liu, Y., Ai, L., Li, X., Liu, X., Yan, L., Shi, Z., Wang, X., Wu, F., Qiang, X., Dong, J., Lu, F., Xu, X. (2012): Interplay between the westerlies and Asian monsoon recorded in Lake Qinghai sediments since 32 ka. – *Scientific Reports* 2: 619.
- [4] Anan, H. S. (2019): Contribution To The Paleontology, Stratigraphy And Paleobiogeography Of Some Diagnostic Pakistanian Paleogene Foraminifer In The Middle East. – *Earth Sciences Pakistan* 3(1): 23-28.
- [5] Ao, H., Wu, C., Xiong, X., Jing, L., Huang, X., Zhang, K., Liu, J. (2014): Water and sediment quality in Qinghai Lake, China: a revisit after half a century. – *Environmental Monitoring and Assessment* 186: 2121-2133.
- [6] Baharuddin, D., Samsudin, M. D. M. (2018): Effect Of Ph And Moisture Content On Current Den sity Of Impressed Current Cathodic Protection: Response Surface Methodology Study. – *Environment & Ecosystem Science* 2(2): 15-19.
- [7] Barakat, A., Khellouk, R., Jazouli, A. E., Touhami, F., Nadem, S. (2018): Monitoring of forest cover dynamics in eastern area of Béni-Mellal Province using ASTER and Sentinel-2A multispectral data. – *Geology, Ecology, and Landscapes* 2(3): 203-215.
- [8] Battarbee, R. W., Kernan, M., Rose, N. (2009): Threatened and stressed mountain lakes of Europe assessment and progress. – *Aquatic Ecosystem Health and Management* 12: 118-128.
- [9] Bounouira, H., Choukri, A., Cherkaoui, E. I., Moursli, R., Chakiri, S., Said, F., Bounakhla, M., Embarch, K. (2013): Geochemical behaviour of major and trace elements in dissolved and particulate phases of the Bouregreg River (Morocco). – *Journal of Radioanalytical and Nuclear Chemistry* 295: 1067-1083.
- [10] Cao, J. J., An, Z. S. (2010): Introduction and progress of the project for technology integration and experimental demonstration of ecological and environmental rehabilitation in Qinghai Lake basin. – *Journal of Earth Environment* 1: 158-161.
- [11] Çelik, U., Oehlenschläger, J. (2007): High contents of cadmium, lead, zinc and copper in popular fishery products sold in Turkish supermarkets. – *Food Control* 18: 258-261.
- [12] Chen, L., Chen, K. L., Liu, B. K., Hou, G. L., Cao, S. K., Han, Y. L., Yang, L., Wu, Y. P. (2011): Characteristics of climate variation in Qinghai Lake basin during the recent 50 years. – *Journal of Arid Meteorology* 29: 483-487.
- [13] Chen, L., Jin, Z., Wan, D., Zhang, F. (2015): Spatial uniformity in the mineralogical and geochemical compositions of surface sediments in Lake Qinghai and their controlling factors. – *Limnology* 16: 113-125.

- [14] Cui, B., Zhang, Q., Zhang, K., Liu, X., Zhang, H. (2011): Analyzing trophic transfer of heavy metals for food webs in the newly-formed wetlands of the Yellow River Delta, China. – *Environmental Pollution* 159: 1297-1306.
- [15] Daniel, G. I., Henry, O. U., Ayodeji, B. B., Silas, M. Y. (2018): Land Suitability Analysis For The Production Of Cocoyam In Benue State, Nigeria. – *Earth Sciences Malaysia* 2(2): 25-30.
- [16] Elser, J. J., Andersen, T., Baron, J. S., Bergstrom, A. K., Jansson, M., Kyle, M., Nydick, K. R., Steger, L., Hessen, D. O. (2009): Shifts in lake N:P stoichiometry and nutrient limitation driven by atmospheric nitrogen deposition. – *Science* 326: 835-837.
- [17] Foster, I., Charlesworth, S. M. (1996): Heavy metals in the hydrological cycle: trends and explanation. – *Hydrological Processes* 10: 227-261.
- [18] Fu, H., Li, Z., Liu, Z., Wang, Z. (2018): Research on Big Data Digging of Hot Topics about Recycled Water Use on MicroBlog Based on Particle Swarm Optimization. – *Sustainability* 10: 2488.
- [19] Gaillardet, J., Viers, J., Dupré, B. (2003): Trace elements in river waters. – In: Heinrich, D. H., Karl, K. T. (eds.) *Treatise on geochemistry*. Oxford: Pergamon; p. 225-272.
- [20] Gibbs, R. J. (1970): Mechanisms controlling world water chemistry. – *Science* 170: 1088-1090.
- [21] Goldhaber, S. B. (2003): Trace element risk assessment: essentiality vs. Toxicity. – *Regulatory Toxicology and Pharmacology* 38: 232-242.
- [22] Hao, X. (2008): A green fervor sweeps the Qinghai-Tibetan Plateau. – *Science* 321: 633-635.
- [23] Havig, J. R., McCormick M. L., Hamilton, T. L., Kump, L. R. (2015): The behavior of biologically important trace elements across the oxic/euxinic transition of meromictic Fayetteville green lake, new york, usa. – *Geochimica et Cosmochimica Acta* 165: 389-406.
- [24] Hayzoun, H., Garnier, C., Durrieu, G., Lenoble, V., Le Poupon, C., Angeletti, B., Ouammou, A., Mounier, S. (2015): Organic carbon, and major and trace element dynamic and fate in a large river subjected to poorly-regulated urban and industrial pressures (Sebou River, Morocco). – *Science of the Total Environment* 502: 296-308.
- [25] Henderson, A. C. G., Holmes, J. A. (2009): Palaeolimnological evidence for environmental change over the past millennium from Lake Qinghai sediments: a review and future research prospective. – *Quaternary International* 194: 134-147.
- [26] Hsieh, I. T., Mok, H. K., Ko, F. C., Acik, S. (2013): Environmental assessment of trace element bioaccumulation in Sipunculan from seagrass and wetland sediments. – *Environmental Monitoring and Assessment* 185: 2269-2279.
- [27] Jin, Z., You, C., Wang, Y., Shi, Y. (2010): Hydrological and solute budgets of Lake Qinghai, the largest lake on the Tibetan Plateau. – *Quaternary International* 218: 151-156.
- [28] Jin, Z., You, C., Yu, T., Wang, B. (2010): Sources and flux of trace elements in river water collected from the Lake Qinghai catchment, NE Tibetan Plateau. – *Applied Geochemistry* 25: 1536-1546.
- [29] Kyllonen, K., Karlsson, V., Ruoho-Airola, T. (2009): Trace element deposition and trends during a ten year period in Finland. – *Science of the Total Environment* 407: 2260-2269.
- [30] Li, J., Philp, R. P., Pu, F., Allen, J. (1996): Long-chain Alkenones in Qinghai Lake sediments. – *Geochimica et Cosmochimica Acta* 60: 235-241.
- [31] Li, X. Y., Xu, H. Y., Sun, Y. L., Zhang, D. S., Yang, Z. P. (2007): Lake-level change and water balance analysis at Lake Qinghai, west China during recent decades. – *Water Resources Management* 21: 1505-1516.
- [32] Li, X. Y., Ma, Y. J., Xu, H. Y., Wang, J. H., Zhang, D. S. (2009): Impact of land use and land cover change on environmental degradation in Lake Qinghai watershed, northeast Qinghai-Tibet Plateau. – *Land Degradation & Development* 20: 69-83.

- [33] Li, T., Li, X., Zhong, H., Yang, C., Sun, G., Luo, W. (2015): Distribution of trace metals and the benthic foraminiferal assemblage as a characterization of the environment in the north Minjiang River estuary (Fujian, China). – *Marine Pollution Bulletin* 90: 227-241.
- [34] Liang, Z., Wenshun, W. (2019): Parametric Architectural Design Based On Optimization Algorithm. – *Engineering Heritage Journal* 3(1): 13-17.
- [35] Liu, W., Li, X., Zhang, L., An, Z., Xu, L. (2009): Evaluation of oxygen isotopes in carbonate as an indicator of lake evolution in arid areas: the modern Qinghai Lake, Qinghai–Tibet Plateau. – *Chemical Geology* 268: 126-136.
- [36] Liu, X., Lai, Z. (2013): Optical dating of sand wedges and ice-wedge casts from Qinghai Lake area on the northeastern Qinghai-Tibetan plateau and its palaeoenvironmental implications. – *Boreas* 42: 333-341.
- [37] Luo, C. F., Xu, C. J., You, H. Y., Jin, S. H. (2013): Analysis on grassland degradation in Qinghai Lake basin during 2000-2010. – *Acta Ecologica Sinica* 33: 4450-4459.
- [38] Lynam, M. M., Dvonch, J. T., Hall, N. L., Morishita, M., Barres, J. A. (2015): Trace elements and major ions in atmospheric wet and dry deposition across central Illinois, USA. – *Air Quality, Atmosphere & Health* 8: 135-147.
- [39] Mahmood, S., Kazmi, S. T., Ali, S. S. (2018): Comparison Of Drinking Water Bottles Of Different Countries Along With Zamzam Water, Pakistan. – *Earth Sciences Pakistan* 2(1): 05-14.
- [40] Meng, X. L., He, Y. B., Song, Z. Y., Ao, H. Y., Zhang, H., Jiang, X. M. (2014): Structure and spatial distribution patterns of macrozoobenthos in Qinghai Lake area. – *Acta Hydrobiologica Sinica* 38: 819-827.
- [41] Mwanamoki, P. M., Devarajan, N., Niane, B., Ngelinkoto, P., Thevenon, F., Nlandu, J. W., Mpiana, P. T., Prabakar, K., Mubedi, J. I., Kabele, C. G., Wildi, W., Poté, J. (2015): Trace metal distributions in the sediments from river-reservoir systems: case of the Congo River and lake ma Vallée, Kinshasa (democratic republic of Congo). – *Environmental Science and Pollution Research* 22: 586-597.
- [42] Négrel, P., Allègre, C. J., Dupré, B., Lewin, E. (1993): Erosion sources determined by inversion of major and trace element ratios and strontium isotopic ratios in river water: the Congo basin case. – *Earth and Planetary Science Letters* 120: 59-76.
- [43] Otachi, E. O., Plessl, C., Körner, W., Avenant-Oldewage, A., Jirsa, F. (2015): Trace elements in water, sediments and the elongate Tigerfish *Hydrocynus Forskahlii* (cuvier 1819) from lake Turkana, Kenya including a comprehensive health risk analysis. – *Bulletin of Environmental Contamination and Toxicology* 95: 286-291.
- [44] Qin, D., Jiang, H., Bai, S., Tang, S., Mou, Z. (2015): Determination of 28 trace elements in three farmed cyprinid fish species from northeast china. – *Food Control* 50: 1-8.
- [45] Ramsar, C. O. P. (2015): The list of wetlands of international importance.
- [46] Rawat, K. S., Singh, S. K. (2018): Water Quality Indices and GIS-based evaluation of a decadal groundwater quality. – *Geology, Ecology, and Landscapes* 2(4): 240-255.
- [47] Sarker, M. K. U., Majumder, A. K., Haque, M. Z., Hossain, M. S., Nayeem, A. A. (2019): Assessment Of Inland Water Quality Parameters Of Dhaka City, Bangladesh. – *Environment & Ecosystem Science* 3(1): 13-16.
- [48] Shakeri, A., Afrasiabian, A., Rezaei, M., Karimi, M. (2014): Assessment of trace elements contamination in surface sediments of the Bakhtegan Lake, Iran. – *Iranian Journal of Science and Technology* 38: 75-85.
- [49] Shi, J. Q., Qi, H. F., Yang, J. X. (2004): The natural conditions and the present fishery resources situation of Qinghai Lake. – *Freshwater Fisheries* 34: 3-5.
- [50] Shiller, A. M. (1997): Dissolved trace elements in the Mississippi river: seasonal, interannual, and decadal variability. – *Geochimica et Cosmochimica Acta* 61: 4321-4330.
- [51] Singh, V. B., Ramanathan, A., Sharma, P., Pottakkal, J. G. (2015): Dissolved ion chemistry and suspended sediment characteristics of meltwater draining from Chhota Shigri glacier, western Himalaya, India. – *Arabian Journal of Geosciences* 8: 281-293.

- [52] Sunny, A. A., Omowumi, A., Chris, O. A. (2018): Improved Magnetic Data Analyses And Enhancement Techniques For Lithological And Structural Mapping Around Akure, Southwestern Nigeria. – *Earth Sciences Malaysia* 2(1): 16-21.
- [53] Tam, N. F., Wong, Y. S. (2000): Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. – *Environmental Pollution* 110: 195-205.
- [54] Tuzen, M. (2009): Toxic and essential trace elemental contents in fish species from the black sea, turkey. – *Food and Chemical Toxicology* 47: 1785-1790.
- [55] Vystavna, Y., Huneau, F., Sch Fer, J., Motelica-Heino, M., Blanc, G., Larrose, A., Vergeles, Y., Diadin, D., Le Coustumer, P. (2012): Distribution of trace elements in waters and sediments of the Seversky Donets transboundary watershed (Kharkiv region, Eastern Ukraine). – *Applied Geochemistry* 27: 2077-2087.
- [56] Walther, B. D., Nims, M. K. (2015): Spatiotemporal variation of trace elements and stable isotopes in subtropical estuaries: I. Freshwater endmembers and mixing curves. – *Estuaries and Coasts* 38: 754-768.
- [57] Wang, P., Cao, J., Han, Y., Jin, Z., Wu, F., Zhang, F. (2015): Elemental distribution in the topsoil of the Lake Qinghai catchment, NE Tibetan Plateau, and the implications for weathering in semi-arid areas. – *Journal of Geochemical Exploration* 152: 1-9.
- [58] Wang, K., Zhou, S. Z., Zhou, Y. T., Ren, J., Li, W. L., Lan, Y. (2018): Synthesis of Porous Carbon by Activation Method and its Electrochemical Performance. – *International Journal of Electrochemical Science* 13(11): 10766-10773.
- [59] Watmough, S. A. (2014): Calcium, strontium and barium biogeochemistry in a forested catchment and insight into elemental discrimination. – *Biogeochemistry* 118: 357-369.
- [60] Xu, H., Hou, Z., An, Z., Liu, X., Dong, J. (2010): Major ion chemistry of waters in Lake Qinghai catchments, NE Qinghai-Tibet Plateau, china. – *Quaternary International* 212: 35-43.
- [61] Xu, D. (2018): Research On Brand Construction And Development Of Agricultural Products In Guizhou. – *Engineering Heritage Journal* 2(2): 19-24.
- [62] Yang, H., Rose, N. (2005): Trace element pollution records in some UK lake sediments, their history, influence factors and regional differences. – *Environment International* 31: 63-75.
- [63] Yu, Y., Song, J., Duan, L., Li, X., Yuan, H., Li, N. (2014): Sedimentary trace-element records of natural and human-induced environmental changes in the East China Sea. – *Journal of Paleolimnology* 52: 277-292.
- [64] Zwolsman, J. J. G., Van Eck, G. T. M. (1999): Geochemistry of major elements and trace metals in suspended matter of the Scheldt estuary, southwest Netherlands. – *Marine Chemistry* 66: 91-111.