Water chemistry and source analysis of major ions of Bangong Lake in Tibetan Plateau

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Abstract: Bangong Lake, was an inland lake on the Tibetan Plateau, which was an international lake across China and India. The water chemistry characteristics were analyzed by testing the chemical composition of the lake water in Bangong Lake. The Gibbs diagram was used to explore the main controlling factors of lake water, and the main ion source of lake water was described in combination with the proportion of dissolved ions. The results showed that the center was brackish water and the east was fresh water of the Bangong Lake with a weak alkaline water. From the surface to the bottom, the temperature, dissolved oxygen and redox potential were decreasing, while the conductivity was increasing. The main cation of lake water was Na+, the main anion was Cl-, and the main chemical type was SO4-Cl-Na. The soluble ions in the central water were mainly controlled by evaporation and concentration, while the soluble ions in the eastern water were mainly controlled by rock weathering. The cations in the water were mainly derived from the silicate rock weathering and the dissolution of evaporite, and the anions was mainly derived from the dissolution of evaporite.

1. Introduction
The lake area of the Tibet Plateau accounted for nearly half of the total area of China's lakes[1]. Studies had concluded that the area of high-energy lakes in Tibet Plateau had expanded in the past 40 years, mainly due to factors such as rising temperature, increasing rainfall, melting glaciers, and thawing of frozen soil[2]. When these external rainwater and meltwater merged into the lake, the ion concentration in the lake water of the receiving lake
was reduced, the lake gradually began to fade, and the water chemistry characteristics also change[3]. Related studies had shown that the chemical ion composition of Nam Co, Yamzhog Yumo Co, and Pung Co were mainly controlled by evaporation and concentration[4, 5]. The chemical ion composition of lake water was mainly controlled by rock weathering in Kongmu Co and Daggyaima Co[5, 6].

Bangong Lake belongs to the inland lake of the Tibetan Plateau, spanning China and India. It was the largest lake (604 km²) in the Tibetan Plateau. Approximately two-thirds (413 km²) in the western of the lake was in Chinese territory, and the rest was distributed in Kashmir of India(Fig. 1). The average altitude of the lake was 4241 m[7]. Rivers entering the Bangong Lake were mainly distributed in the eastern lakes in China, including the Dormaqu in the north, Angmai in the east and the Magazangbo in the south. From east to west, the lake of Bangong Lake was consisted by fresh water, brackish water and salt water. Water chemical type of in Bangong Lake was Na-HCO₃ by the average value of cations and anions. However, it was found that the cations and anions in Bangong Lake were distributed outside the Gibbs model, and the main control factor of its ion source cannot be identified[8]. Therefore, it was necessary to study the water chemistry characteristics of the Bangong Lake.

An investigation on the water environment of Bangong Lake in China (both internal and eastern) was carried out in August 2018 for revealing the water chemical characteristics, main controlling factors and the sources of main ions, so as to provide basic data support for grasping the water chemistry characteristics of Bangong Lake.

2. Sample collection and analysis

According to the characteristics of the lake, 6 sampling points were arranged(Figure 1). Surface water samples were collected for shallow area in the depth of 1-2 m(1 and 2), Surface and middle-level water samples were collected for waters in depth of 2-15 m(5 and 6), surface, middle-level and bottom water samples were collected for shallow area in depth of 15-22 m(3 and 4). The temperature(T), pH, conductivity(EC), dissolved oxygen(DO), total dissolved solids (TDS) and Redox potential(ORP) were monitored by a portable water quality multiparameter analyzer(EXO2, YSI). The concentrations of main cations including Ca²⁺, K⁺, Na⁺ and Mg²⁺ were determined by inductively coupled plasma mass spectrometer(ICP-MS, Perkinelmer NexION 300X). Determination of main anion Cl⁻, NO₃⁻ and SO₄²⁻ by ion chromatograph(Dionex ics-900). The dual indicator neutralization method was adopted to determine CO₃²⁻ and HCO₃⁻[6].

Figure 1. The water sampling sites in the Banggong lake
3. Results and Discussion

3.1 Physical and chemical properties of lake water

The physical and chemical properties of the lake water monitored were presented in Table 1. The water temperature range was 15.7~17.3°C, the average value was 16.5°C. The DO concentration range was 6.3~7.5 mg/L, the average concentration was 6.9 mg/L. The pH range was 8.5~9.0, the average value was 8.8, which was a weakly alkaline water. The TDS concentration range was 0.32~3.70 g/L, and the average value was 1.66 g/L. The sampling point of 1 was moderate salt water (3.0~10 g/L), the sampling point of 2 and 3 were basically brackish water (1.0~3.0 g/L), the sampling point of 4-6 were fresh water (<1.0 g/L) [6]. The ORP was 93.9~237.7 mv, with an average of 171.4 mv. The EC ranged was 0.33~4.71 mS/cm, and the mean value was 2.60 mS/cm, indicating that the ionic strength of the lake was relatively high as a whole [9]. The pH and salinity were significantly positively correlated with the EC (R>0.7). From west to east, the conductivity and salinity in the surface water showed a significant decrease trend (Figure 2). The T, pH value and ORP remained relatively stable. ORP potential fluctuated without obvious rule.

Table 1. Physical and chemical properties of water in Bangong Lake

| Term | T (°C) | DO (mg/L) | pH | TDS (g/L) | ORP (mv) | EC (mS/cm) |
|------|--------|-----------|----|-----------|----------|-----------|
| Mean | 16.5   | 6.9       | 8.8| 1.66      | 171.4    | 2.60      |
| Min  | 15.7   | 6.3       | 8.5| 0.32      | 93.9     | 0.33      |
| Max  | 17.3   | 7.5       | 9.0| 3.70      | 237.4    | 4.71      |

Figure 2. Chart of physical and chemical properties of waters in the Bangong Lake

From the vertical distribution (Table 2), the temperature, DO and ORP potential of the water showed a decreasing trend from the surface to the bottom of the water. The rule of the vertical temperature of the lake was consistent with the survey results in August 2012 [7]. The conductivity had the opposite tendency. There was no significant change in salinity.
The nitrate ion and fluoride ion concentration in the lake water was below the detection limit and could be ignored. The average concentration of main cations were Na\(^+\)>Mg\(^{2+}\)>K\(^+\)>Ca\(^{2+}\) (Table 3), the average concentration of main anions were Cl\(^-\)>SO\(_4^{2-}\)>HCO\(_3^-\)>F\(^-\). Na\(^+\) was the main cation, the concentration range was 40.70–1111 mg/L, the average concentration was 548.8 mg/L. Cl\(^-\) was the main anion, the concentration range was 41.22–1061 mg/L, and the average concentration was 536.4 mg/L.

**Table 3. Main anion and cation concentration of Bangong lake water (mg/L)**

| Term       | Ca\(^{2+}\) | Mg\(^{2+}\) | Na\(^+\) | K\(^+\) | HCO\(_3^-\)+CO\(_3^{2-}\) | SO\(_4^{2-}\) | Cl\(^-\) |
|------------|-------------|-------------|----------|--------|-------------------------|-------------|--------|
| Mean       | 11.69       | 114.5       | 548.8    | 50.08  | 101.6                   | 447.8       | 536.4  |
| Min        | 4.54        | 11.68       | 40.70    | 2.29   | 18.21                   | 64.38       | 41.22  |
| Max        | 25.37       | 237.5       | 1111     | 163.8  | 268.1                   | 898.7       | 1061   |

The ions triangle diagram was used to analyze the water chemical types of lakes in different regions. Figure 3 demonstrated the lake water was divided into two categories, most of the sampling points were SO\(_4^-\)-Cl-Na type, only point 5 was SO\(_4^-\)-Cl-Ca-Mg type, and the sampling points were inclined to the end of (K\(^+\)+Na\(^+\)), accounting for about 70%–80% of the cations, indicating that the research area of Banggong Lake was mainly affected by evaporative salts[10].

**Figure 3. Triangle diagram of anion and anion in bangong lake**

### 3.2 Source analysis of major ions
Gibbs analyzed the chemical composition of the world's surface water (water, rain, river, water, etc.) and its formation reasons (atmospheric precipitation, rock weathering, evaporation-crystallization) by the TDS-$\text{Na}^+/(\text{Na}^++\text{Ca}^{2+})$ and TDS-$\text{Cl}^-/(\text{Cl}^-+\text{HCO}_3^-)$ chart[11]. The ion concentration values of the Bangong Lake almost all fall within the dotted line in Figure 4. The middle sampling points 1, 2 and 3 all in the area of evaporation-crystallization, while the eastern sampling points 5 and 6 fall in the area of rock weathering. It was indicated that the soluble ions in the central waters of Bangong Lake were mainly controlled by evaporation and concentration, while the soluble ions in the water of the eastern part were mainly controlled by rock weathering.

Ions in rivers or lakes were mainly come from atmospheric transport of Marine salt, rock weathering and dissolution, and human activities[5, 6]. Bangong Lake area residents were scarce, traffic inconvenience, less affected by human activities. The ratio of Na/Cl in all sampling points of lake water was higher than that of seawater (0.86), indicating that the contribution of sea salt carried by long-distance transport air mass in Bangong Lake could be neglected, and Na$^+$ and Cl$^-$ may be mainly caused by surrounding runoff [12]. Under natural conditions, water HCO$_3^-$ mainly come from the dissolution of carbonate, SO$_4^{2-}$ and Cl$^-$ mainly come from the dissolution of evaporite. Na$^+$ and K$^+$ were primarily derived from the weathering of evaporite and silicate [13]. Ca$^{2+}$ and Mg$^{2+}$ mainly come from carbonate, evaporite and silicate.

**Figure 4.** Plots of the major ions within the Gibbs for waters in the Bangong lake

In the closed lakes, if dolomite weathering, Mg$^{2+}$, and Ca$^{2+}$ completely entered into the lake, and the ratios of Ca$^{2+}$/Mg$^{2+}$ would not exceed 1[14], but for the molar ratio of the most part in our study sample point (1, 2, 3, 4, 6) were greater than 1, mainly due to the solubility of calcium salt in the water was less than the magnesium salt, Ca$^{2+}$ was preferred to the situation of calcium carbonate precipitation settling to the bottom [8].

The ratios of (Mg$^{2+}$+Ca$^{2+}$)/(Na$^+$+K$^+$) in the water of the eastern part in Bangong Lake (point 5-6) were near the equivalence line, while the middle water body sample point (1, 2, 3, 4) were below the equivalence line (Figure 5a), indicating that the lake water in the eastern part of Bangong Lake might be mainly affected by silicate, but the middle lake was mainly controlled by evaporated Rock[15]. The ratios of (Mg$^{2+}$+Ca$^{2+}$)/(HCO$_3^-$+SO$_4^{2-}$) in most of the Bangong Lake were distributed near the equivalence line (Figure 5b), indicating that Mg$^{2+}$,
Ca$^{2+}$ and SO$_4^{2-}$ in the lake water were mainly derived from the dissolution of evaporite[6]. The ratios of (SO$_4^{2-}$+Cl$^-$/HCO$_3^-$ at all sampling points were located below the equivalence line (Figure 5c), indicating that SO$_4^{2-}$, Cl$^-$ and HCO$_3^-$ were mainly derived from the dissolution of evaporite. The ratios of Cl$^-$/[(Na$^+$+K$^+$) at all sampling points were located below the equivalence line (Figure 5d), and Except for point 5, the ratios of(Na$^+$-Cl$^-$/TZ(=Na$^+$+K$^+$+2Ca$^{2+}$+2Mg$^{2+}$)) were 20%-40%, indicating that silicate rock weathering contributes significantly to the cation in the lake [16].

**Figure 5.** Proportions of major ions for the water of the Bangong lake

4. Conclusions

The lake water to bangong lake was weakly alkaline. The central part was mainly brackish water, and the eastern part was mainly fresh water. From the west to the east, the conductivity and salinity of surface water show an obvious decreasing tendency. From the surface to the bottom of the water, the T, DO and ORP potential showed a decreasing tendency, while the electrical conductivity showed a rising trend. The main cation of Bangong Lake was Na$^+$, and the principal anion was Cl$^-$. Water chemistry types of lake water in different regions were altered, and the main chemical type was SO$_4$-Cl-Na. The soluble ions in the central water of Bangong lake were mainly controlled by evaporation-crystallization, while the soluble ions in the eastern water were controlled by rock weathering. The cations in the water mainly come from the weathering of silicate rock and evaporite rock, and the anions mainly originated in the dissolution of evaporite rock.

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