Temporal and Spatial Distribution and Fluorescence Spectra of Dissolved Organic Matter in Plateau Lakes – A Case Study of Qinghai Lake

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Abstract

Dissolved organic matter (DOM) has a great influence on the main pollution indexes of lakes (such as COD). Therefore, DOM research is the basis for understanding the water environmental quality and the law of pollutant migration and transformation in the basin. In this study, the water quality monitoring data of Qinghai Lake water body and 8 rivers around the lake from 2010 to 2020 were collected, and the dissolved organic matter (DOM) was synchronously sampled in May, September and October 2020. The optical characteristics of DOM, the temporal and spatial distribution of CDOM and the fluorescence spectrum and fluorescence component characteristics of FDOM were analyzed and studied. The results show that: (1) From 2010 to 2020, the annual mean value of COD_{Cr} of Qinghai Lake water body fluctuates in the range of Class III to Class V according to the environmental quality standard of the surface water, and shows a downward trend first and then an upward one. In general, the mean value of COD_{Cr} concentration in Qinghai Lake water body is at a high level and varies slightly among different months. (2) The mean value of COD_{Cr} concentration of the eight main rivers entering Qinghai Lake from 2010 to 2020 can be sorted from lowest to highest as follows: Ganzi River, Buha River, Jilmeng River, Hargai River, Shaliu River, QuANJI River, HeMa River, and DaoTang River. (3) The concentration of CDOM in Qinghai Lake shows not only obvious seasonal variation (October, September and May, in the descending order) but also spatial variation. (4) The three-dimensional fluorescence spectrum matrix data of DOM in Qinghai Lake were analyzed by PARAFAC model, and four DOM fluorescence components with single maximum emission wavelength were analyzed.

Introduction

Dissolved organic matter (DOM) is ubiquitous in soil, rivers, lakes and oceans in nature. It is an important organic component in water (Fig. 1) (Battin et al., 2009). DOM is a complex organic mixture composed of different functional groups and molecular structures (Rizzuto et al., 2021), which usually includes humus, carbohydrates and proteins, and it plays an important role in the global carbon cycle (Xiao et al., 2019). In natural water bodies, DOM may be derived from the decomposition of plant substances and extracellular substances released by aquatic organisms by microorganisms, or the transportation of degraded organic substances from the surrounding terrestrial environment by rivers and groundwater (Song et al., 2019; Wang et al., 2019).

(DOC is dissolved organic carbon; CDOM is colored dissolved organic matter; FDOM is fluorescent dissolved organic matter; DBC is dissolved black carbon.)

CDOM is the main light absorbing substance in dissolved organic matter (DOM) in natural water, which can affect the migration and transformation of heavy metals and organic pollutants (Patidar et al., 2015). The part with fluorescence characteristics in CDOM is called fluorescent dissolved organic matter (FDOM), which is of great significance to aquatic ecosystems (Mostofa et al., 2013). As an important part of DOM, its important role in natural water environment has long been concerned. At present, ultraviolet, visible and fluorescence spectra are mainly used to study CDOM of water bodies from different sources

at home and abroad. Foreign studies on CDOM have been carried out earlier, and the research fields include CDOM origin, destination, distribution, migration and transformation, and spatio-temporal changes. The Tibet Plateau is the highest plateau on earth and has always enjoyed the reputation of "Asian water tower" and "third pole". Its high terrain and unique geographical location have a significant impact on the global climate (Yang., 2009; Wang et al., 2003). Qinghai Lake is an important water body to maintain the ecological security of the Tibet Plateau. It plays a great role in improving and regulating climate and promoting a virtuous cycle of Regional Ecology (Xinhua news agency., 2020). However, there are few investigations or regional environmental studies on the water environment of Qinghai Lake Basin. In recent years, with the acceleration of urbanization and the rapid development of tourism, Qinghai Lake Basin is facing great ecological pressure. Therefore, the investigation on the water quality of Qinghai Lake and the study on the temporal and spatial distribution and optical characteristics of dissolved organic matter in the water body are helpful to deeply understand the current situation of the water environment of Qinghai Lake, the carbon cycle process within the basin and its potential impact on water quality, and can provide background data support for lake water environment analysis and water body assessment.

Methodology

Study area

Qinghai Lake is located in the northeast of Qinghai Tibet plateau at the junction of Gangcha County, Gonghe County and Haiyan County. It is the largest inland salt water lake in China. In 2019, the lake area reached 4519 km². The lake water is weakly alkaline, low oxygen content and salt content is 14.1 g L⁻¹, transparency below 3M. Qinghai Lake Basin is between 97°50'~101°20' E and 36°15'~38°20' N, with a drainage area of about 29661 km²(Yu et al., 2021). The overall outline is oval, and the terrain is high in the northwest and low in the northeast. It is located at the intersection of the East Asian monsoon, the northwest arid region and the alpine region of the Qinghai Tibet Plateau. It belongs to the semi-arid and alpine climate of the plateau, and the precipitation is unevenly distributed throughout the year(Yu et al., 2021). Qinghai Lake is located in the southeast of the basin and is mainly supplied by rivers and precipitation. Most of the rivers entering the lake are seasonal rivers and concentrated in the West and north of the lake. The main supply rivers are Buha River, Shaliu River, Quanyi River, Hargai River, Ganzi River and HeMa river.

In this study, Qinghai Lake Basin is taken as the research object, 14 sampling points are set, and the layout of sampling points is shown in Figure 2-1. In May, September and October 2020, Qinghai Lake Basin was comprehensively sampled three times, and 2.5L surface water samples (0 ~ 0.25m from the water surface) were collected, stored in brown glass bottles (constant 4 ° C) and sent back to the laboratory for testing.

Sample Method

Seawater samples are collected by Niskin water collector, and the parameters such as water depth, temperature and salinity are measured synchronously by CTD sensor during seawater collection. The river water samples are taken manually, and the parameters such as temperature, salinity and pH value of the on-site river water are synchronously measured in the river by the portable water quality analyzer. DOM and CDOM use filtering devices to filter the water samples to be collected in the shortest possible time, and the filtered samples can be frozen and stored. Thaw in the laboratory before measurement, and transfer sufficient samples to DOC measurement sample bottle (24 ml or 40 ml) with burned Pasteur glass pipette (Corning). If the sample cannot be measured immediately, add acid to the sample (pH<2) and store it in cold storage for measurement.

Sample Analysis

In order to facilitate the examination of the instruments used in the experiment and the experimental process, the instruments used for parameter determination correspond to Table 1, and the process corresponds to the back.

Table 1
instrument used for parameter determination.

Measurement index	Instrument / method	Model	Origin / manufacturer
Water temperature (T), pH, and dissolved oxygen (DO)	Multi parameter water quality monitor	YSI 6600V2	USA
potassium bichromate (COD _{Cr}) and permanganate (COD _{Mn})	Titrimetric method	(MEP of PRC 1989)	China
TOC(DOM)	Total organic carbon analyzer	TOC-V	Shimadzu, Kyoto, Japan
CDOM	(UV-Vis) Ultraviolet visible spectrophotometer	UV-2600PC	Shimadzu, Kyoto, Japan
FDOM	Fluorescence spectrum	Hitachi F-7000	Hitachi, Tokyo, Japan

DOM and CDOM before analysis, the water samples were filtered using pre-combusted (450°C for 5 h) glass fiber filters (0.7µm, GF/F, Whatman).

The absorption coefficient of CDOM at 254 nm (α_{254} , m⁻¹) was used as a proxy for CDOM concentration. The value of α_{254} was calculated by the following equation (Song et al. 2019): $\alpha_{254} = 2.303A_{254}/L$ where A_{254} is the absorbance at 254 nm and L is the path length of the cuvette (0.1m). Fluorescence EEMs-PARAFAC analysis Fluorescent DOM (FDOM) with a 150 W Xe lamp as the excitation light source and a 9PMT voltage of 700 V. The excitation wavelength (Ex) and emission wavelength (Em) scanning range were from 200 to 450 nm and 250 to 600 nm, respectively. The increments of excitation and emission wavelength were all set to 2 nm. The slit width and the scanning speed were set as 10 nm and

12,000 nm·min⁻¹, respectively. In order to reduce the influence of instrument conditions and Raman scattering on fluorescence spectra, the ultrapure water blank was used as a reference. Before PARAFAC analysis, the EEM fluorescence data should be preprocessed as the method used by Wang et al. (2018). PARAFAC modeling was performed using MATLAB (The MathWorks, Natick, MA, USA) with the DOM Fluor toolbox. The number of components was determined based on a core consistency test and split-half validation. The fluorescence index (FI) is the fluorescence intensity ratio of the fluorescence emission spectrum at 450 and 500 nm with an excitation light wavelength of 370 nm (McKnight et al. 2001; Stedmon and Bro 2008; Stedmon and Bro 2008).

Results And Discussion

Time variation of COD_{Cr} and permanganate index in Qinghai Lake from 2010 to 2020

In order to make clear of the background values of the Qinghai Lake watershed, the monitoring water quality indexes were collected and analyzed to conclude the characterizations of the water quality variations. According to the historical monitoring data of water quality(Fig. 3-1), the COD_{Cr} concentration in Qinghai Lake was between 18.11 and 38.00 mg/L from 2010 to 2020, with an average of 27.10 mg/L, which was at the surface class IV level. Except for the large fluctuation of COD_{Cr} concentration in 2010 and 2011, the fluctuation of COD_{Cr} concentration in Qinghai lake water in other years is relatively small. From the mean value of COD_{Cr} at each historical monitoring point, the mean value of COD_{Cr} at Sha Dao point is relatively the highest, 43.84 mg/L.

From 2010 to 2020, the annual mean value of COD_{Cr} of Qinghai lake water body first decreased and then increased, and fluctuated greatly, fluctuating between class III ~ V levels of surface water. Among them, the average value of COD_{Cr} in 2011 is relatively the highest, close to the upper limit of class V water quality standard for surface water, and the annual average value of COD_{Cr} in 2012 is relatively the lowest; In 2020, COD_{Cr} will rise to class IV water level, with an average of 36.02 mg/L.

The on-site monitoring in May, September and October 2020 shows that(Fig. 3-2) the annual COD_{Cr} of Qinghai lake water body ranges from 31 to 48 mg/L, with an average of 39.21 mg/L. The COD_{Cr} of all point water bodies exceeds the class IV standard of surface water (threshold≤30 mg/L), and the COD_{Cr} of some point water bodies exceeds the class V standard of surface water (threshold≤40 mg/L). From the perspective of monthly variation, the range of COD_{Cr} in Qinghai lake water body is 31~45 mg/L, 32~47 mg/L and 31~48 mg/L respectively, and the average values are 40.13mg/L, 39.43mg/L and 38.09mg/L. on the whole, the difference of COD_{Cr} in Qinghai lake water body in different months is small, and the COD_{Cr} concentration is at a high level. Qinghai Lake is a large salt water lake in Western China. The population in the basin is rare. Its COD_{Cr} is mainly affected by rivers entering the lake, grassland non-point sources and surrounding human activities.

According to the historical monitoring data(Fig. 3-3), the permanganate index concentration of Qinghai lake water from 2010 to 2020 is between 2.14 and 5.53 mg/L, with an average of 3.89 mg/L, which is at the surface class II level. Except for the large fluctuation of permanganate index concentration in water body in 2012, the fluctuation of permanganate index concentration in Qinghai lake water body in other years is relatively small. From the mean value of permanganate index at each historical monitoring point, the mean value of permanganate index at Shadao point is relatively the highest, which is 5.39 mg/L.

From 2010 to 2015, the annual mean value of permanganate index of Qinghai lake water body fluctuated as a whole, but all met the class III level of surface water. From 2016 to 2020, the annual average value of permanganate index of Qinghai lake water body showed a downward trend and was basically at the class II level of surface water. Among them, the permanganate index remained at the level of 2.14 ~ 2.35 mg/L from 2018 to 2020, slightly higher than the class I water quality limit. In recent years, the average value of permanganate index in 2011 is relatively the highest, which is 5.53 mg/L, close to the upper limit of class III water quality standard for surface water, and the average annual value of permanganate index in 2019 is relatively the lowest.

Time variation of COD_{Cr} and permanganate index of rivers entering Qinghai Lake from 2010 to 2020

From 2010 to 2020, COD_{Cr} of main rivers entering Qinghai Lake Basin was 7.50~13.94 mg/L, with an average of 10.99 mg/L; The COD_{Cr} of rivers entering the lake is lower than that of lakes as a whole(Fig. 4-1).

Except for the DaoTang River, the mean value of COD_{Cr} of major rivers is relatively similar from 2010 to 2020, and the interannual variation trend is relatively consistent. The average COD_{Cr} of the eight main rivers entering Qinghai Lake from 2010 to 2020 shows the law of Ganzi River < Buha River < jilmeng River < hargai River < Shaliu River < Quanji River < HeMa River < DaoTang river.

From 2010 to 2020, the permanganate index of main rivers entering the lake in Qinghai Lake Basin was 1.44~2.98 mg/L, with an average of 2.18 mg/L(Fig. 4-2); The permanganate index of rivers entering the lake is lower than that of lakes as a whole.

Except for Daotang River and Heima River, the mean value of permanganate index of main rivers is relatively similar from 2010 to 2020, and the interannual variation trend is relatively consistent. The average value of permanganate index of the eight main rivers entering Qinghai Lake from 2010 to 2020 shows the law of Buha River < Shaliu River < hargai River < jilmeng River < Ganzi River < Quanji River < Heima River < DaoTang river. Except Shaliu River and Ganzi River, the law of other rivers is consistent with COD_{Cr}.

Spatial distribution of COD_{Cr} and permanganate index in Qinghai Lake

There are obvious differences in the spatial distribution of COD_{Cr} concentration in Qinghai Lake(Fig. 4-3). In May, COD_{Cr} in the East is higher than that in the west, and that in the center of the lake is higher than that in the coast; In September and October, COD_{Cr} of water body showed two high areas, namely, near Jiangxi ditch wharf and Sand Island, Jiangxi ditch wharf and Qinghai Lake fishing ground wharf. From the perspective of spatial distribution characteristics, the higher values in the three months are mainly concentrated in Jiangxi ditch wharf and Qinghai Lake fishery wharf. Jiangxi ditch wharf and Qinghai Lake fishery wharf are located in the south of Qinghai Province, and the planting industry along the south coast is mainly. Therefore, the input of external sources leads to the higher concentration of COD_{Cr} in the water body in the south of Qinghai Lake than in other regions.

There are obvious differences in the spatial distribution of permanganate index concentration in Qinghai Lake(Fig. 4-4). In May, the permanganate index concentration range is 1.80 ~ 4.50 mg/L, with an average of 2.21 mg/L, in September, the permanganate index concentration range is 1.90~14.50 mg/L, with an average of 2.83 mg/L, and in October, the permanganate index concentration range is 1.80~4.50 mg/L, with an average of 2.29 mg/L. In May and September, the permanganate index in the East was higher than that in the West; In October, the permanganate index of water body showed three high areas, namely the center of the lake, the East and the west, and the shore area close to the center of the lake. From the perspective of spatial distribution characteristics, except for the center of the lake in October, the high-value areas appear in the areas close to the shore. Therefore, the external input may be the reason for the higher concentration of permanganate index in the water body of Qinghai Lake than in other areas.

Optical Properties Of Dom In Qinghai Lake

Colored soluble organic matter (CDOM) and fluorescent soluble organic matter (FDOM) are two important indicators of optical properties in DOM. CDOM is a component of DOM that can absorb ultraviolet and photosynthetic effective radiation; FDOM is a DOM component that can release fluorescent photons after absorbing light radiation. Therefore, CDOM and FDOM are commonly used to characterize the optical characteristics of DOM.

(1) Seasonal and spatial distribution of CDOM

The concentration of CDOM is characterized by its absorption coefficient a_{254} at 254 nm. The field monitoring data in May, September and October 2020 show that (Fig. 5-1)the value of a_{254} in Qinghai lake water body is between 8.80~13.29 M^{-1} , with obvious seasonal differences. Among them, a_{254} in water in May is between 8.80 ~ 9.83 M^{-1} , with an average value of 9.17 M^{-1} , which is significantly lower than that in other seasons ($P<0.01$); In September, a_{254} in the water body was between 8.73~10.64 M^{-1} , with an average value of 9.48 M^{-1} ; In October, a_{254} in the water body is between 9.14~13.29 M^{-1} , with an average value of 9.81 M^{-1} , showing the law of October>September>May. The concentration of CDOM in Qinghai Lake not only has obvious seasonal differences, but also shows different spatial differences. Among them, the highest value of CDOM at each sampling point in the water body in May, September

and October appeared near Erlangjian in the south of the lake. In addition, the value of CDOM in the water body on the West Bank of Qinghai Lake in May was also high.

(2) Fluorescence spectrum and fluorescence component characteristics of FDOM

The three-dimensional fluorescence spectrum matrix data of DOM in Qinghai Lake were analyzed by PARAFAC model, and four DOM fluorescence components with single maximum emission wavelength were analyzed. The maximum excitation / emission wavelength distribution of the four fluorescent components and the three-dimensional fluorescence spectra of the principal components are shown in the figure below (Fig. 5-2).

The excitation wavelength of component C1 is at 242 nm and the maximum emission wavelength is near 422 nm, which reflects the land-based high molecular weight humic acid, mainly from the degradation of higher plants or soil leaching; Component C2 has two obvious excitation wavelengths at 220 nm and 272 nm, and the maximum emission wavelength is 422 nm, which reflects the low molecular weight fulvic acid like fluorescence peak, which mainly comes from the fluorescence peak formed by biodegradable organic compounds; Component C3 has two obvious excitation wavelengths at 232 and 286 nm, and the maximum emission wavelength is 338 nm. It belongs to the binding peak of protein like and fulvic acid like, which has a red shift compared with the conventional tryptophan like peak; Component C4 has an obvious excitation wavelength at 270 nm and the maximum emission wavelength is 478 nm, reflecting the fluorescence peak formed by polymer humic acid.

Overall, the proportion of each component in the total fluorescence intensity of FDOM in May and September is $C2 > C1 > C4 > C3$, and the proportion of each component in the total fluorescence intensity of FDOM in October is $C3 > C2 > C1 > C4$, which has certain seasonal differences (Fig. 5-3).

In the three sampling surveys of Qinghai Lake in May, September and October (Fig. 5-4), the average total fluorescence intensity of FDOM in the water body of Qinghai Lake was 22.20, 24.17 and 42.80 R.U., showing a significant seasonal difference law of $\text{October} > \text{September} > \text{May}$. The spatial distribution of the total fluorescence intensity of FDOM in water is also different in different seasons. The spatial difference in October is more obvious than that in May and September. However, in the three surveys, the highest value of the total fluorescence intensity of FDOM in water appears near Erlangjian in the south of Qinghai Province.

The mean values of C1 components in the overlying water of Qinghai Lake in May, September and October are 5.85, 6.86 and 7.23 R.U. (Fig. 5-5), showing the law of $\text{October} > \text{September} > \text{May}$. The spatial distribution characteristics are similar to the total amount, and the spatial difference is obvious. The highest value appears near Erlangjian in the south of Qinghai and the lowest value appears in the center of the lake.

The mean values of C2 components in the water body of Qinghai Lake in May, September and October were 6.93, 6.96 and 9.93 R.U. (Fig. 5-6), showing the law of $\text{October} > \text{September} > \text{May}$. The spatial

distribution characteristics are similar to the total amount, and the spatial difference is obvious. The highest values in May and October appear in the south of Qinghai, and the highest values in September appear in the southwest of the lake.

The mean values of C3 components in the water body of Qinghai Lake in May, September and October were 4.59, 4.96 and 20.28 R.U. (Fig. 5-7), showing the law of October>September>May. The spatial distribution characteristics are similar to the total amount, and the spatial difference is obvious. The highest values appear near erlangjian in the south of Qinghai and Hunan.

The mean values of C4 components in the water body of Qinghai Lake in May, September and October were 4.82, 5.39 and 5.36 R.U. (Fig.5-8) respectively, showing a different law from other components, that is, September>October>May. The spatial distribution characteristics are similar to the total amount, and the spatial difference is obvious. The highest values appear near erlangjian in the south of Qinghai and Hunan.

Figure 5-8 spatial distribution characteristics of C4 fluorescence intensity in Qinghai lake water in different seasons

Bioavailability Of Dom In Qinghai Lake

Both COD and BOD₅ are used to quantitatively reflect the degree of organic pollution in water. Previous studies have shown that when $BOD_5 / COD_{Cr} \geq 30\%$, it is biodegradable sewage; If $BOD_5 / COD_{Cr} < 30\%$, it is difficult to biodegrade sewage. In this study (Fig. 6), the BOD_5 / COD_{Cr} value of Qinghai Lake is between 1.90%~5.29%, with an average of 3.36%, which is obviously low, indicating that the bioavailability of organic matter in Qinghai Lake is poor and difficult to decompose. This non decomposable organic matter will continue to accumulate into the sediment over time and migrate between water and sediment under the disturbance of wind, waves and fish, which also reflects the reason for the high COD of Qinghai Lake from another aspect.

Conclusions

The monitoring data from 2010 to 2020 showed the high COD_{Cr} values and the high COD_{Mn} and BOD values in the Qinghai Lake. From 2010 to 2020, the annual mean value of COD_{Cr} of Qinghai lake water body first decreased and then increased, and fluctuated greatly, fluctuating between class III ~ V levels of surface water. Spatially, the COD_{Cr} mean value of sand island is relatively the highest, which is 43.84 mg/L. In terms of time nodes, the average value of COD_{Cr} in 2011 is relatively the highest, close to the upper limit of class V water quality standard for surface water, and the annual average value of COD_{Cr} in 2012 is relatively the lowest; In 2020, COD_{Cr} will rise to class IV water level, with an average of 36.02 mg/L. From 2010 to 2015, the annual mean value of permanganate index of water body in Qinghai Lake fluctuated as a whole, but they all met the class III level of surface water. It is noteworthy that the mean value of permanganate index at Sand Island is relatively the highest, which is 5.39 mg/L. From 2016 to

2020, the average annual value of permanganate index of Qinghai lake water showed a downward trend and was basically at the level of class II surface water. Among them, the permanganate index remained at the level of 2.14~ 2.35 mg/L from 2018 to 2020, slightly higher than the class I water quality limit. In recent years, the average value of permanganate index in 2011 is relatively the highest, which is 5.53 mg/L, close to the upper limit of class III water quality standard for surface water, and the average annual value of permanganate index in 2019 is relatively the lowest. The average COD_{Cr} of the eight main rivers entering Qinghai Lake from 2010 to 2020 shows the law of Ganzi River <Buha River <jilmeng River <hargai River <Shaliu River <Quanji River <HeMa River <DaoTang river(3) The concentration of CDOM in Qinghai Lake not only has obvious seasonal differences (showing the law of October>September>May), but also shows different spatial differences. The three-dimensional fluorescence spectrum matrix data of DOM in Qinghai Lake were analyzed by PARAFAC model, and four DOM fluorescence components with single maximum emission wavelength were analyzed. Component C1 reflects terrestrial high molecular weight humic acid, which mainly comes from the degradation of higher plants or the leaching of soil; Component C2 reflects the low molecular weight fulvic acid like fluorescence peak, which mainly comes from the fluorescence peak formed by biodegradable organic compounds; Component C3 belongs to the protein like and fulvic acid like binding peak, which has a red shift compared with the conventional tryptophan like peak; Component C4 reflects the fluorescence peak formed by polymer humic acid.

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Figures

Figure 1

Schematic diagram of main organic components in natural water

Figure 2

location of DOM sampling points in Qinghai Lake

Figure 3

change trend of COD_{Cr} in Qinghai Lake from 2010 to 2020 characteristics of COD_{Cr} value in Qinghai lake water body in different seasons change trend of permanganate index in Qinghai Lake from 2010 to 2020

Figure 4

Change trend of COD_{Cr} in water body of rivers entering the lake from 2010 to 2020
 Change trend of permanganate index of rivers entering the lake from 2010 to 2020
 Spatial distribution characteristics of COD_{Cr} concentration in Qinghai Lake in different seasons
 Spatial distribution characteristics of permanganate index concentration in Qinghai Lake in different seasons

Figure 5

spatial distribution characteristics of CDOM concentration (a_{254} , m^{-1}) in water body of Qinghai Lake in different seasons characteristics of DOM fluorescence components in Qinghai Lake fluorescence intensity characteristics of DOM components in Qinghai Lake spatial distribution of total fluorescence intensity of FDOM in Qinghai Lake in different seasons spatial distribution characteristics of C1 fluorescence intensity in Qinghai lake water in different seasons spatial distribution characteristics of C2 fluorescence intensity in Qinghai lake water in different seasons

fluorescence intensity in Qinghai lake water in different seasons spatial distribution characteristics of C3
fluorescence intensity in Qinghai lake water in different seasons spatial distribution characteristics of C4
fluorescence intensity in Qinghai lake water in different seasons

Figure 6

Bioavailability of DOM in Qinghai Lake