

## Response to Editor

Journal: HESS

Title: Influence of environmental factors on spectral characteristic of chromophoric dissolved organic matter (CDOM) in Inner Mongolia Plateau, China

Author(s): Z. D. Wen et al.

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We thank the editor for the patient and careful suggestions for revision. And we are very sorry for the many improper words and ambiguous expressions. We have adopted your suggestions and rewritten some sentences, the related revisions were listed in the manuscript with yellow highlight. Thank you again for the comments.

Some specific comment and our response are listed as following:

Comment 1: Is this necessary in the abstract, it seems technical and a site specific fact not of general interest: “Page 1, Line 29. In most sampling locations, CDOM was the dominant non- water light-absorbing substance. Light absorption by non-algal particles often exceeded that by phytoplankton in the plateau waters.”

**Response 1:** We thank the editor for the good comment. This sentence was the conclusion of the relative contributions analysis of CDOM, phytoplankton and non-algal particles to the total non-water light absorption in the Hulun Buir Plateau waters. In our opinion, it is necessary in the abstract.

Comment 2: Page 2, Line 11-12. This sentence is about coastal waters, which seems not relevant to this study. Perhaps better to reword, by saying that the rivers serve to connect the terrestrial cycling of carbon with the marine carbon cycle, and supply some recent reference from biogeosciences journal.

CDOM is principally contributed by terrestrial inputs and river discharge in coastal waters.

**Response 2:** We thank the editor for the good suggestions for revision. We have rewritten the sentence according to the suggestion, and supply some recent references ([Page 2, Line 10-12](#)).

Alvarez-Cobelas, M., Angeler, D. G., Sanchez-Carrillo, S., and Almendros, G.: A

worldwide view of organic carbon export from catchments, *Biogeochemistry*, 107, 275-93, doi: 10.1007/s10533-010-9553-z, 2012.

Guo, L., Cai, Y., Belzile, C., and Macdonald, R. W.: Sources and export fluxes of inorganic and organic carbon and nutrient species from the seasonally ice-covered Yukon River, *Biogeochemistry*, 107, 187-206, doi: 10.1007/s10533-010-9545-z, 2012.

Para, J., Coble, P. G., Charriere, B., Tedetti, M., Fontana, C., and Sempere, R.: Fluorescence and absorption properties of chromophoric dissolved organic matter (CDOM) in coastal surface waters of the northwestern Mediterranean Sea, influence of the Rhone River, *Biogeosciences*, 7, 4083-103, doi: 10.5194/bg-7-4083-2010, 2010.

Comment 3: Page 2, Line 13-14. This sentence is not accurate as terrestrial inputs are the dominant source. I think this sentence is referring to internally generated sources, in which case you should be more clear.

**Response 3:** We accept your comment, and we have rewritten the sentence as the following (Page 2, Line 10-12): Terrestrial allochthonous inputs are the dominant CDOM source in aquatic ecosystems (Nelson and Siegel, 2013; Zhou et al., 2015). Phytoplankton excretion, zooplankton and bacterial metabolism are the major autochthonous CDOM sources (Coble, 2007).

Nelson, N. B., and Siegel, D. A.: The Global Distribution and Dynamics of Chromophoric Dissolved Organic Matter, *Annual Review of Marine Science*, Vol 5, 5, 447-76, doi: 10.1146/annurev-marine-120710-100751, 2013.

Zhou, Y., Zhang, Y., Shi, K., Niu, C., Liu, X., and Duan, H.: Lake Taihu, a large, shallow and eutrophic aquatic ecosystem in China serves as a sink for chromophoric dissolved organic matter, *J. Great Lakes Res.*, 41, 597-606, doi: <http://dx.doi.org/10.1016/j.jglr.2015.03.027>, 2015.

Comment 4: Page 4, Line 32. I don't think your analysis assesses any system dynamics of these aquatic systems and therefore cannot aim to answer if there is a stable state or tipping points.

**Response 4:** We do agree with the comment of editor, and we have deleted the sentence "And is this absorption pattern a stable state?".

Comment 5: Page 6, Line 12. Create a new paragraph- currently the site description is

merged with the sampling approach.

**Response 5:** This is a good suggestion. We have merged the site description with the sampling approach ([Page 6, Line 18-30](#)).

Comment 6: Page 14, Line 3. Do you mean US rivers?

**Response 6:** Thank you for the question. This does not only mean US rivers but also UK, northern Europe, and central Europe (Evans et al., 2005; Monteith et al., 2007).

Evans, C. D., Monteith, D. T., and Cooper, D. M.: Long-term increases in surface water dissolved organic carbon: Observations, possible causes and environmental impacts, *Environ. Pollut.*, 137, 55-71, doi: 10.1016/j.envpol.2004.12.031, 2005.

Monteith, D. T., Stoddard, J. L., Evans, C. D., de Wit, H. A., Forsius, M., Hogasen, T., Wilander, A., Skjelkvale, B. L., Jeffries, D. S., Vuorenmaa, J., Keller, B., Kopacek, J., and Vesely, J.: Dissolved organic carbon trends resulting from changes in atmospheric deposition chemistry, *Nature*, 450, 537-U9, doi: 10.1038/nature06316, 2007.

Comment 7: Page 14, Line 18. Compared to what? Cant this ref jusy br added to your earlier statement (ln 13).

**Response 7:** Prior research has shown that inland saline lakes always contain higher concentrations of DOC than freshwater lakes in semi-arid region. The reference of Arts et al., 2000 could not be added to the earlier statement (line 13), because this article focused on the effect of the UV radiation penetration on DOC concentration in freshwater and saline water bodies. This is inappropriate for the earlier statement.

Comment 8: Page 14, Line 18. higher than what?

**Response 8:** We have rewritten this sentence ([Page 14, Line 14-15](#)).

Comment 9: Page 14, Line 20-21. The discussion should be focused on your results, not more literature review. This ref is cited her and Line 13. Instead you should explain the reasons - is it evapoconcentration of high molecular weight material than is slow to breakdown? ie evapoconcentration rate is faster than breakdown rate..

**Response 9:** We thank the editor for the good comment, and we have rewritten this part according to the comment ([Page 14, Line 16-21](#)).

Comment 10: Page 15, Line 10. Needs rewording. “In this study, the ratios in the most water samples accord with the degradation condition. ”

**Response 10:** We have rewritten the sentence. In this study, the values of C:N and C:P in most the of water samples satisfy the degradation condition of DOC. ([Page 15, Line 3-4](#)).

Comment 11: Page 16, Line 7. Currently there is no connection between the data in this analysis and the general information in this paragraph. In other words, I can’t see how the carbon budget numbers here are connected to any data from this study (other than plateau area).

This must be made clear, otherwise this is just general lit review that is not substantiated by the present analysis.

**Response 11:** This is a good comment. We have done a rough count of carbon budget based on the area of Inner Mongolian Plateau inland waters ([Page 16, Line 1-3](#)). And we have given an estimation of CO<sub>2</sub> emissions from these inland waters based on the mean CO<sub>2</sub> emission rate from saline lakes ([Page 16, Line 11-14](#)).

## List of all relevant changes made in the manuscript

1. We have checked and revised some troubles in the grammar (for example, Page 1, Line 13, 17, 19, 20; Page 2, Line 23; Page 3, Line 1, 6, 12, et al.). We have adopted reviewer's suggestions and rewritten some sentences, the related revisions were listed in the manuscript., such as Page 2, Line 4-6, Line 10-15, Line 26-27; Page 6, Line 18-25, Line 29-30; Page 14, Line 14-21; Page 15, Line 6-7; et. al.

2. We have adjusted a paragraph position in order to highlight the purpose and structure of the study (Page 15, Line 15-24).

3. Some references were added to the reference list.

# **Influence of environmental factors on spectral characteristic of chromophoric dissolved organic matter (CDOM) in Inner Mongolia Plateau, China**

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## **Abstract**

Spectral characteristics of chromophoric dissolved organic matter (CDOM) were examined in conjunction with environmental factors in the waters of rivers and terminal lakes within the Hulun Buir plateau, northeast China. Dissolved organic carbon (DOC), total nitrogen (TN), and total phosphorous (TP) were significantly higher in terminal lakes than rivers waters ( $p < 0.01$ ). Principal component analysis (PCA) indicated that non- water light absorption and anthropogenic nutrient disturbances were the likely causes of the diversity of water quality parameters. CDOM absorption in river waters was significantly lower than terminal lakes. Analysis of the ratio of absorption at 250 to 365 nm ( $E_{250:365}$ ), specific UV absorbance ( $SUVA_{254}$ ), and the spectral slope ratio ( $S_r$ ) indicated that CDOM in river waters had higher aromaticity, molecular weight, and vascular plant contribution than in terminal lakes. Furthermore, results showed that DOC concentration, CDOM light absorption, and the proportion of autochthonous sources of CDOM in plateau waters were all higher than in other freshwater rivers reported in the literature. The strong evapoconcentration, intense ultraviolet irradiance and landscape features of Hulun Buir plateau may be responsible for the above phenomenon. Redundancy analysis (RDA) indicated that the environmental variables total suspended matter (TSM), TN, and electrical conductivity (EC) had a strong correlation with light absorption characteristics, followed by TDS and chlorophyll a. In most sampling locations, CDOM was the dominant non- water light-absorbing substance. Light absorption by

1 non-algal particles often exceeded that by phytoplankton in the plateau waters. Study  
2 of these optical-physicochemical correlations is helpful in the evaluation of the  
3 potential influence of water quality factors on non-water light absorption in cold  
4 plateau water environments. The construction of a correlation between DOC  
5 concentration and water quality factors may help contribute to regional estimates of  
6 carbon sources and fate for catchment carbon budget assessments.

## 8 1 Introduction

9 Chromophoric dissolved organic matter (CDOM) is the colored component of  
10 dissolved organic matter (DOM) in the natural waters environment. The rivers serve  
11 to connect the terrestrial cycling of carbon with the marine carbon cycle  
12 (Alvarez-Cobelas et al., 2012; Guo et al., 2012; Para et al., 2010). Terrestrial  
13 allochthonous inputs are the dominant CDOM source in aquatic ecosystems (Nelson  
14 and Siegel, 2013; Zhou et al., 2015). Phytoplankton excretion, zooplankton and  
15 bacterial metabolism are the major autochthonous CDOM sources (Coble, 2007). As  
16 an important constituent of DOM, which is the largest reservoir of organic carbon on  
17 Earth, CDOM plays a vital role in the global carbon cycle (Gonnelli et al., 2013;  
18 Mopper & Kieber, 2002). CDOM is one of the major light absorbing constituents in  
19 natural waters, it can absorb solar radiation in the UV and visible ranges of the light  
20 spectrum to shield biota from harmful UV radiation. As a consequence of its optical  
21 behavior, CDOM is also largely responsible for the bio-optical properties of natural  
22 water, and has a potential effect on the productivity of the water column (Organelli et  
23 al., 2014). The absorption characteristics of CDOM also influences the inversion  
24 accuracy of remote sensing of chlorophyll a (*Chl a*) and other suspended solids  
25 (Siegel et al., 2005; Song et al., 2014).

26 Spectral analysis of CDOM (absorption and fluorescence) has been used to trace  
27 its origin, chemical composition, and photochemical reaction (Stedmon et al., 2000;  
28 Vodacek et al., 1997; Xie et al., 2014). Understanding the spectral characteristics of  
29 CDOM could help to understand DOM cycling in aquatic ecosystem. According to  
30 previous studies, the light absorption of CDOM often decreases in a near-exponential  
31 manner with increasing optical wavelength (Coble, 2007; Zhang et al., 2010). In order  
32 to characterize the properties of CDOM from absorption spectra, several spectral

1 indices have been previously developed. The ratio of absorption at 250 to 365nm  
2 ( $E_{250:365}$ ) is used to track changes in the size of DOM molecules (De Haan & De Boer,  
3 1987); specific UV absorbance ( $SUVA_{254}$ ) is found to have strong correlation with  
4 DOM aromaticity as measured by  $^{13}C$ NMR spectroscopy (Weishaar et al., 2003); Two  
5 optical parameters, the absorption coefficient at specific wavelengths  $\lambda$  nm ( $a_{CDOM\lambda}$ )  
6 and CDOM spectral slopes (S), are generally recognized proxies of CDOM  
7 concentration and molecular origin (Helms et al., 2008). Furthermore, S may also  
8 correlate with the ratio of fulvic acid (FA) to humic acid (HA). In fact, the use of S is  
9 dependent on the calculated wavelength intervals, and the ratio of the slope ( $S_r$ ), as a  
10 dimensionless parameter, could avoid the limitations of spectral wavelength  
11 measurements (Helms et al., 2008; Spencer et al., 2012). The analysis of these  
12 spectral indices is therefore useful for understanding spatial and temporal CDOM  
13 variations in the aquatic environment.

14 Recent studies have proven that CDOM in aquatic ecosystems exerts an impact  
15 on ecosystem productivity, optical properties of water, and biochemical processes  
16 (Zhang et al., 2007). However, regional CDOM characteristics are still not thoroughly  
17 understood in diverse aquatic environments because of various physico-chemical  
18 parameters of water (Findlay & Sinsabaugh, 2003). Many water quality parameters  
19 have been proposed to affect the temporal and spatial variation of CDOM, and some  
20 correlations among them have been established; a significant positive correlation was  
21 found between dissolved organic carbon (DOC) and CDOM absorption coefficients,  
22 and a series of different models were established based on this correlation in Lake  
23 Taihu (Zhang et al., 2007), the Yangtze River (Zhang et al., 2005), and the Georgia  
24 river in the USA (Yacobi et al., 2003). CDOM strongly absorbs in the blue spectral  
25 region, which interferes with the determination of *Chla* concentration by remote  
26 image sensing (Siegel et al., 2005), therefore the relationship between the spectral  
27 characteristics of CDOM with *Chla* concentration has received widespread attention.  
28 A significant linear relationship between  $a_{CDOM(300)}$  and *Chla* concentrations was  
29 identified in the central eastern Mediterranean Basin (Bracchini et al., 2010), the  
30 Atlantic Ocean (Kitidis et al., 2006), and the Baltic Sea (Kowalczyk et al., 2006), but  
31  $a_{CDOM(440)}$  was loosely related to pigment concentrations in the 0- 400 m depth layer  
32 of NW Mediterranean Sea (Organelli et al., 2014). Furthermore, the relationship  
33 between  $a_{CDOM(\lambda)}$  and other physico-chemical parameters of water, such as total



1 nitrogen (TN), total phosphorous (TP), salinity, and extracellular enzyme activities  
2 (Gonnelli et al., 2013; Kowalczyk et al., 2006; Niu et al., 2014; Phong et al., 2014),  
3 were all investigated in different aquatic environments. However, these studies  
4 reached different conclusions due to regional variations in water quality.

5 Studies published to date have focused on the relationship between CDOM  
6 properties and environmental factors; results indicate that salinity, solar radiation, and  
7 watershed characteristics all have important effects on CDOM optical properties  
8 (Graeber et al., 2012; Gueguen et al., 2011; Mavi et al., 2012; Song et al., 2013b). The  
9 properties of CDOM in plateau water at high altitude have attracted interest due to the  
10 unique natural environmental and climatic features of these waters. The DOM  
11 composition in two Tibetan alpine lakes showed a limited terrigenous DOM and  
12 exhibited a high biolability of DOC (Spencer et al., 2014). The analysis of CDOM  
13 parameters in three intermontane plateau rivers in western U.S. indicated that  
14 autochthonous DOM or DOM derived from anthropogenic sources dominated the  
15 DOM pool (Spencer et al., 2012). However, the relationship between CDOM and  
16 environmental factors in plateaus area has been less well studied. Analysis of these  
17 optical-physicochemical correlations is critical for understanding the source and  
18 distribution of CDOM in plateau water environments and evaluating the potential  
19 influence of water quality factors on non-water light absorption.

20 **The** Inner Mongolia Plateau in China is located in an arid and cold climate zone  
21 with sparse annual rainfall. The plateau is covered with numerous lakes surrounded  
22 by vast grasslands and forest. These lakes are located far away from the ocean and are  
23 supplied with water by precipitation and river runoff, and most of them are  
24 noncontributing lakes (Tao et al., 2015). The unique geographical environment and  
25 climatic factor in arid and cold plateau regions altered CDOM properties, when  
26 compared with the bulk of inland water. Moreover, over 80% of the lakes are saline,  
27 which allows higher carbon storage levels than fresh water lakes (Duarte et al., 2008;  
28 Song et al., 2013b). The plateau lakes therefore play an important role in global  
29 carbon balance estimation.

30 Based on the above studies, we address the following issues: (1) Whether  
31 CDOM properties in **this** cold plateau region differ within the plains or not? And is  
32 this difference related to water quality of **the** terminal lakes? (2) Under the unique  
33 climatic and hydrological conditions of **the** boreal plateau, which is the main

non-water light absorption component in water?” We expect that the information obtained in this study can answer all these questions. **Answers to these questions** can enhance our understanding of the non-water light absorption characteristics of inland waters in arid and cold plateau **regions**. The results of CDOM source and constitute analysis are also helpful **for** carbon storage estimation in **these catchments**. The optical-physicochemical correlation analysis could contribute to **an** improved understanding and interpretation of satellite remote sensing imagery **for** this area.

## **2 Material and methods**

### **2.1 Study sites**

**The** Inner Mongolia Autonomous Region is located in the north of China with an area of about 1.18 million km<sup>2</sup> (37°24'- 53°23' N, 97°12'- 126°04' E). The average altitude of the whole region is over 1000 m, and it is basically a plateau landform composed of Hulun Buir, XilinGol, Ulanqab, Bayannur, Alxa, and Erdos plateaus. Rivers, lakes, reservoirs and other surface water areas account for 0.8% of the whole area. All the collected water samples were taken from Hulun Buir Plateau (Fig. 1). **The** Hulun Buir plateau is located in the northeast of **the** Inner Mongolia plateau with the **topography being high** in the east and low in the west. The east side of the plateau is connected to Daxing'anling mountains, and the geology composition is mainly the Paleozoic granite, **Mesozoic andesite**, quartz trachyte, and tuff. Most of the overlying rock has weathered away into loess. The central regions are undulating rolling plains, and are made up of the loose river and lacustrine sedimentary sand. The western regions are mainly low **hills** composed by volcanics. The physico-geographic zone of **the** whole Hulun Buir plateau is **divided** into chernozem zone with forest and steppe and chestnut earth zone with steppe. This plateau is characterized by a typical semi-humid and semi-arid continental monsoon climate with intensive solar radiation throughout the year. **The** Hulun Buir Plateau has distinct seasons with a dry spring, a hot and rainless summer, a windy and short autumn, and a cold dry winter (Zheng et al., 2015). Based on long-term meteorological data (1961-2010), the average annual temperature

1 is 0.8 °C. The average annual wind speed is 3.5 m/s. The average annual rainfall is  
2 273.9 mm, 70%- 80% of which falls in May- August (Bai et al., 2008). There is  
3 greater than three-quarters days of each year with direct sunlight. In this area, the  
4 average sunlight per day is over 8.2 h. The average annual evaporation is 1615.3 mm,  
5 which is far greater than precipitation, resulting in water scarcity. The soils of the area  
6 are Mollisols, and the topography consists of gently rolling hills and tablelands.

7 The plateau is dotted with numerous lakes surrounded by vast grasslands and  
8 forests, and the two largest freshwater lakes (Hulun Lake and Buir Lake) of Inner  
9 Mongolia are located in this area. Most lakes in this area are inland terminal lakes.  
10 Several rivers flow through Hulun Buir Plateau, including the Kerulen, Ergun,  
11 Wuexun, Hailar, and Zhadun Rivers. Wuexun River originates from Buir Lake's  
12 northern shore, flows north and empties into Hulun Lake. Kerulen River flows east  
13 through Hulun Lake, and finally into the Ergun River. The Zhadun River flows into  
14 the Hailar River, flowing north to join the Ergun River. A total of 46 surface waters  
15 were collected in this study with respect to both watershed characteristics and lake  
16 size.

## 17 2.2 Water Sampling and water quality measurement

18 Water samples were taken from the Hulun Buir Plateau, China, during September  
19 2012 (Fig. 1), and the sample numbers for each water body are listed in Table 1 and  
20 marked in Fig. 1. Based on the salinity and EC (salinity threshold value = 0.5 PSU,  
21 EC threshold value = 1000 ms/cm), these waters were divided to 22 river waters and  
22 24 saline waters. Particularly, the saline waters were collected from lakes without  
23 outflow or the terminal-flow of rivers. Hulun Lake and Buir Lake are connected with  
24 rivers, so the water samples collected from these lakes are classified as river water  
25 samples in the subsequent analysis in this study. The saline lakes size in this study  
26 ranged from 1 km<sup>2</sup> to 42.5 km<sup>2</sup>, with the average depth of 0.4- 2.8 m. The related  
27 hydrological data of rivers and freshwater lakes have shown in the Table 2, including  
28 rivers (or freshwater lakes) names, sampling numbers, basin area, width, Length, max  
29 water depth, elevation. The surface water (0.5-1 m) was collected into a sample bottle  
30 with at least 4 L in every sampling point, and kept in a portable refrigerator before

they were returned to laboratory. Chemical and physical parameters, e.g., pH, total dissolved solid (TDS) and electrical conductivity (EC) were determined in sampling situ by a portable multi-parameter water quality analyzer (YSI6600, U.S). Concentrations of DOC, TN, and TP were measured with unfiltered water samples by a standard procedure (APHA et al., 1998). Total suspended matter (TSM) was determined by gravimetric analysis (Song et al., 2013a). Water turbidity (Turb) was determined by a UV spectrophotometer in 680 nm (Shangfen, 7230) with Milli-Q water as reference at room temperature (20±2°C). Chlorophyll-a (*Chla*) was extracted from water samples by 90% buffered acetone solution, and the concentrations were determined with a UV spectrophotometer (Shimadzu, UV-2600PC) by the method detailed in Song et al. (2013a).

### 2.3 Non- water light absorption analysis

CDOM was extracted from the collected water samples by filtering through a 0.7 µm glass fiber membrane (Whatman, GF/F 1825-047) and then was further filtered through 0.22 µm polycarbonate membrane (Whatman, 110606). The filtering process was finished within two days in dim light in order to avoid alteration by microbial activity. Filtered samples were kept refrigerated and warmed at room temperature at the time of the analysis. CDOM absorption was analyzed within 12 h using UV-2600 spectrophotometer equipped with 1-cm quartz cuvette. Absorbance scans were performed from 200 to 800 nm, and Milli-Q water was used as reference. Between each sample, the quartz cuvette was flushed with Milli-Q water, and the cleanliness was checked according to the optical density of reference water. The bubbles should be avoided during the measurement. In order to eliminate the internal backscattering, the absorbance at 700 nm was used to correct absorption coefficients (Bricaud et al., 1981). The absorption coefficient ( $a_{CDOM}$ ) was calculated from the measured water optical density (OD) following the Eq. (1).

$$a_{CDOM}(\lambda) = 2.303 \times OD_{\lambda} / L \quad (1)$$

Where L is the cuvette path length (0.01 m) and 2.303 is the conversion factor.  $OD_{\lambda}$  is the average optical density. The absorption coefficients at wavelengths 335 nm ( $a_{CDOM335}$ ) and 440 nm ( $a_{CDOM440}$ ) were selected to express the CDOM concentration (Miller, 1998). CDOM absorption ratio ( $E_{250:365}$ ) was calculated using

absorbance at 250 nm and 365 nm.  $SUVA_{254}$  values were calculated by dividing the UV absorbance at 254 nm by the DOC concentration ( $mg\ L^{-1}$ ) (Weishaar et al., 2003).

CDOM spectral slopes ( $S_{275-295}$  and  $S_{350-400}$ ) between wavelengths 275-295 nm and 350- 400 nm were both calculated using a nonlinear fit of an exponential function to the absorption spectrum according to the Eq. (2) by Origin 8.0 software (Bricaud et al., 1981; Jerlov, 1968).

$$a_{CDOM}(\lambda) = a_{CDOM}(\lambda_0) \times e^{S(\lambda_0 - \lambda)} \quad (2)$$

Where  $a_{CDOM}(\lambda)$  is the CDOM absorption at a given wavelength, and  $a_{CDOM}(\lambda_0)$  is the absorption at a reference wavelength (440 nm). The spectral slope ratio ( $S_r$ ) was calculated as the ratio of  $S_{275-295}$  to  $S_{350-400}$ .

Particulate absorption was determined by quantitative membrane filter technique (QFT) (Cleveland & Weidemann, 1993). A certain volume of water was filtered through 0.7  $\mu m$  glass fiber membrane (Whatman, GF/F 1825- 047), and the filter membrane was subsequently stored in laboratory at  $-80^\circ C$  until analysis. The light absorption of total particulate trapped on the filter membrane was determined by UV spectrophotometry (Shimadzu, 2660) from 280 to 800 nm with virgin wet membrane as reference. After correction of the path length with path length amplification factor ( $\beta$ ), the measured optical densities were transformed into total particulate absorption coefficients according to the Eq. (3) (Bricaud & Stramski, 1990).

$$a_{PB}(\lambda) = 2.303 \times \frac{S}{V} \times OD_s(\lambda) \quad (3)$$

Where  $a_{PB}(\lambda)$  is the total particulate absorption at a given wavelength (nm),  $S$  is the effective area of the deposited particle on the fiber membrane ( $m^2$ ), and  $V$  is the volume of the filtered water ( $m^3$ ).  $OD_\lambda$  is the optical density at the given wavelength (nm).

The above fiber membranes loaded with total particulate were soaked in the sodium hypochlorite solution in order to remove the pigments, and the light absorption coefficient of non-algal particles ( $a_{NAP}\lambda$ ) was determined and calculated as the  $a_{PB}(\lambda)$ . The phytoplankton light absorption coefficient ( $a_{phy}\lambda$ ) was the difference between  $a_{PB}(\lambda)$  and  $a_{NAP}(\lambda)$  according to the Eq. (4).

$$a_{phy}(\lambda) = a_{PB}(\lambda) - a_{NAP}(\lambda) \quad (4)$$

## 2.4 Statistical analysis

The contributions of CDOM, phytoplankton, and non-algal particles (NAP) to non-water light absorption at 440 nm were calculated using Origin 8.0 software (Ortega-Retuerta et al., 2010). The variation of water quality parameters in different sampling locations was assessed by principal component analyses (PCA) using CANOCO 4.5 for Windows with centered and standardized variables. Correlations between water quality parameters and light absorption characteristics were determined by Redundancy analysis (RDA) using CANOCO 4.5, light absorption characteristics were defined as species variables, and water quality parameters were selected as explanatory variables. The Pearson Correlation Coefficient ( $r_p$ ) was calculated using SPSS 5.0. Because the responding variables may exist in the high autocorrelation, they were first screened through Canonical Correspondence Analysis (CCA) using CANOCO 4.5 to remove the variables with an inflation coefficient greater than 20 (Leps and Smilauer, 2003). A Monte Carlo permutation test was conducted with CANOCO 4.5 and indicated that the selected environmental variables were significantly related to light absorption characteristics (499 permutations under the reduced model,  $p \leq 0.05$ ).

## 3 Results

### 3.1 Water quality

The collected river and terminal lake samples exhibited large variations in water quality (Table 1). A significant difference of DOC was also observed between these two water types ( $p < 0.001$ ). The DOC concentration ranged from 8.44 - 39.74 mg L<sup>-1</sup> in river waters, and exhibited higher values in the terminal lakes (23.03 - 300.5 mg L<sup>-1</sup>). Further, the terminal lakes also had higher alkalinity and EC than river waters. We have redone the statistics after log-transformation of the data and normal distribution test. A positive relationship between DOC and alkalinity was established in the Hulun Buir Plateau waters (Fig. 2a,  $R^2 = 0.87$ ). Regression analyses were also conducted, and a linear relationship between EC and DOC was shown based on the collected data (Fig. 2b;  $R^2 = 0.72$ ). The average nutrient concentrations for TN ( $1.33 \pm$

0.63 mg L<sup>-1</sup>) and TP (0.11 ± 0.04 mg L<sup>-1</sup>) in river waters were both lower than in terminal lakes, and significant differences were observed for TN ( $p < 0.001$ ) and TP ( $p < 0.01$ ). Strong linear relationships were shown between TN and DOC in Hulun Buir Plateau (Fig. 2c;  $R^2 = 0.67$ ). A positive correlation between DOC and TP was found in surface water in this area (Fig. 2c;  $R^2 = 0.66$ ).

PCA was performed for all the sampling locations with ten water environment variables (Fig. 3A). The first two principal components (PC) of the PCA explained 61.0% of the variability in all the selected variables (PC1, 36.4%; PC2, 24.6%). Relatively high loadings on PC1 were TSM and Turb, whereas DOC and CDOM showed high negative loadings. The second PCA axis revealed gradients of nutrients (TN and TP). These all had positive loadings on PC2. Furthermore, TDS and Chl $a$  showed high negative loadings on PC2. A clear difference was found between river waters and terminal lakes (Fig. 3B). Terminal water samples clustered in close proximity to each other and were distributed on the negative side of PC2 (with the exception of one point) in Fig. 3B, and river waters clustered almost exclusively on the positive side of PC2.

### 3.2 Spectral characteristics of CDOM

CDOM absorption spectra of the waters collected from Hulun Buir Plateau decreased as the classical near-exponential manner with increasing wavelengths from the ultraviolet to the visible spectral region. This near-exponential CDOM absorption spectra has been observed in many natural waters (Bricaud et al., 1981; Spencer et al., 2009; Xie et al., 2014). The comparative analysis was conducted in two types of sampling waters in the study, and the mean values of  $a_{\text{CDOM}}(335)$  and  $a_{\text{CDOM}}(440)$  both showed that the terminal lakes exhibited significantly higher CDOM light absorption than river waters (Table 1).

$E_{250:365}$  values in the waters examined ranged from 5.43 to 20.73, and the mean values were  $7.80 \pm 2.30$ , and  $8.02 \pm 3.48$  in the river and terminal lakes respectively. The majority of the  $\text{SUVA}_{254}$  values in the river waters ranged from 1.09 - 3.56 L mg C<sup>-1</sup> m<sup>-1</sup>, and the mean  $\text{SUVA}_{254}$  was clearly higher in river waters ( $2.74 \pm 1.08$  L mg C<sup>-1</sup> m<sup>-1</sup>) than the terminal lakes ( $1.90 \pm 0.57$  L mg C<sup>-1</sup> m<sup>-1</sup>), and this was significant ( $p < 0.01$ ). In order to confirm the source and composition of CDOM in different types of waters, the spectral slopes in the 275-295 nm ( $S_{275-295}$ ) and 350-400 nm ( $S_{350-400}$ )

ranges were both calculated as the indicators (Table 1).  $S_{275-295}$  values showed a wide variation in the river water samples ranging from  $14.80 \times 10^{-3}$  to  $26.79 \times 10^{-3} \text{ nm}^{-1}$  (mean =  $19.25 \pm 4.05 \times 10^{-3} \text{ nm}^{-1}$ ), and the majority of river waters in the study exhibited  $S_{275-295}$  between  $17.11 - 17.82 \times 10^{-3} \text{ nm}^{-1}$ . There was not a significant difference when compared with terminal lakes.  $S_{350-400}$  values also showed no significant difference between the two types of waters. Furthermore, the mean values of  $S_{275-295}$  and  $S_{350-400}$  in Hulun Lake were both lower than Buir Lake.

### 3.3 Light absorption of CDOM and particulates

Detailed knowledge regarding the relative contributions of CDOM, phytoplankton and non-algal particles to the total non-water light absorption are essential in bio-optical and biogeochemical models, and the relative contributions at 440 nm are shown in Fig. 4. There was no obvious difference in the relative contributions of CDOM, phytoplankton and non-algal particles between river waters and terminal lakes ( $p > 0.5$ ). At all the sampling locations, the mean contribution of CDOM to the total non-water light absorption was 52.78% with the range varied from 2.87% to 97.23%, and the relative contribution of non-algal particles was on mean 39.84%, ranging from 2.01% up to 97.13%. Phytoplankton absorption played a minor role in total non-water light absorption with the mean 7.61%. In most water samples examined in this study, CDOM was the dominant non-water light-absorbing substance.

To assess the distribution of light absorption in the waters of Hulun Buir Plateau, levels of light absorption due to CDOM, phytoplankton and non-algal particles were plotted based on the numbers of sampling locations and their contributions to total light absorption at 440 nm using a Pareto-Lorenz curve (Lorenz, 1905). The relative contributions were arranged from high to low. Subsequently, the cumulative sampling points are represented on the abscissa axis, and the cumulative contributions plotted on the vertical axis. The more the curve deviated from the theoretical perfect evenness line ( $45^\circ$  diagonal), the more inhomogenous light contributions were observed (Fig. 5). According to the Pareto principle, the value of vertical axis was in accordance with 20% abscissa axis, being used to interpret the Pareto- Lorenz curves. From the degree of curve deviation (Fig. 5), it was observed that the light absorption of optically active substances in Hulun Buir Plateau area presented inhomogenous phenomena. Among



1 them, CDOM absorption was the most representative relative to other non-water  
2 absorption components. CDOM light absorption by 20% of the samples corresponded  
3 with 5.03% of the cumulative CDOM contributions to non-water absorption. For  
4 non-algal particles and phytoplankton, 20% of the samples corresponded with 1.46%  
5 and 0.51% of cumulative light absorption contributions, respectively. Thus, for all the  
6 non-water absorption types, it was observed that CDOM light absorption was  
7 numerically dominant compared with non-algal particles and phytoplankton.

### 8 **3.4 Correlations between water quality parameters and light absorption**

9 The RDA data showed that the forward selected explanatory variables could explain  
10 the variability of light absorption characteristics with species-environment  
11 correlations of 0.781 (Fig. 6). The first two axes of RDA explained 43.7% of total  
12 variability in light absorption characteristics of all the collected water samples (axis  
13 one, 34.3%; axis two, 9.4%). Coefficients between environmental variables with axes  
14 in RDA indicated that TSM, TN, and EC had a strong correlation with light  
15 absorption characteristics, followed by TDS and Chla. TDS, TP, and DOC were most  
16 closely corrected to CDOM light absorption (Fig. 6). TSM, TN, and Chla were best  
17 correlated to light absorption of phytoplankton, non-algal particulates, and total  
18 particulates at 440 nm (Fig. 6). EC and pH were related to the CDOM spectral slope  
19 ( $S_{275-295}$ ) (Fig. 6).

20 The Pearson correlation coefficients ( $r_p$ ) between water quality and light  
21 absorption characteristics presented in Table 3 indicate that CDOM light absorption  
22 ( $\alpha_{CDOM335}$  and  $\alpha_{CDOM440}$ ) showed a significantly positive correlation with TN, TP, TDS,  
23 and DOC ( $p < 0.01$ ), but had no correlation with Chla concentration ( $p > 0.05$ ,  $n=46$ ).  
24 There was also no correlation between  $S_{275-295}$  and Chla concentration. However,  
25  $S_{275-295}$  presented a significantly positive correlation with DOC, pH, and EC in this  
26 plateau water ( $p < 0.01$ ,  $n = 46$ ). Light absorption of pigments at 440 nm showed a  
27 significantly positive correlation with TN ( $r_p = 0.377$ ,  $p < 0.01$ ,  $n = 46$ ) and TSM ( $r_p =$   
28  $0.515$ ,  $p < 0.01$ ,  $n = 46$ ), and there was also no linear relationship with Chla  
29 concentration. The light absorption at 440 nm of total particulates and non-algal  
30 particulates both had a significant positive correlation with TSM ( $r_p = 0.985$ ,  $p < 0.01$ ,  
31  $n = 46$ ).

## 4 Discussion

### 4.1 Dissolved organic carbon in river and terminal lakes

Previous studies showed that DOC concentrations in inland waters always decrease with the prolongation of water residence times due to biodegradation and photobleaching in humid regions (Curtis & Adams, 1995). However, terminal lakes with long water residence times exhibited higher DOC values than the river waters in this study. The most likely explanation for the opposite pattern of DOM concentration is that the most refractory DOC is diluted in humid regions and evapoconcentrated in semi-arid regions (Song et al., 2013b). Further, the higher alkalinity and EC in the terminal lakes compared with river waters may explain the inverse pattern (Table 1). The sodicity of water could also increase DOM solubility. Increasing EC (salt concentration) would result in decreased osmotic potential, which has negative effects on microbial activity (Mavi et al., 2012). DOM along with other nutrients come from soil via runoff and leaching, and can accumulate in terminal lakes due to lower microbial activity. Furthermore, the average DOC concentration in rivers ( $25.99 \pm 6.64 \text{ mg L}^{-1}$ ) is higher than in many rivers reported in other studies (Alvarez-Cobelas et al., 2012; Evans et al., 2005; Findlay and Sinsabaugh, 2003; Song et al., 2013b; Spencer et al., 2012; Spencer et al., 2010; Worrall and Burt, 2004). DOC levels in rivers are linked to climate and watershed landscape characteristics (Alvarez-Cobelas et al., 2012; Jiang et al., 2014). The elevated DOC concentrations in these plateau rivers could be attributed to evaporation, which would be expected to be extreme in the arid environment of Inner Mongolia Plateau (Hao et al., 2007). Furthermore, Inner Mongolia region is located in semiarid climatic zones with low rainfall, and the impoundment of these plateau waters mainly depended on surface runoff. The land use types around the sampling locations were mainly grassland and forest (Bai et al., 2008). The high DOC concentration in the waters highlights the organic-rich nature of these ecosystems (Zheng et al., 2015).

1       Most monitoring data indicate that DOC concentration in rivers shows a  
2 tendency to increase year by year, potentially due to recovery from acid deposition  
3 (Evans et al., 2005; Monteith et al., 2007). DOC concentrations in surface water are  
4 depressed when acid anion concentrations are high, and increase as acidic anion  
5 concentrations decrease (Evans et al., 2005). The response of water parameters to acid  
6 deposition would be apparent in the alkalinity measurements. In this study, the  
7 positive relationship between DOC and alkalinity indicated that an empirical model  
8 might be established in Hulun Buir Plateau waters for estimating DOC storage based  
9 on water alkalinity, with calibration by a comprehensive dataset. Within semi-arid  
10 regions, DOC is always related to salinity, which could reflect the water residence  
11 times and dissolved organic matter accumulation (Curtis and Adams, 1995; Song et al.,  
12 2013b). A positive correlation between DOC and EC was established based on the  
13 collected data (Fig. 2b;  $R^2 = 0.72$ ). More than 80% of lakes in the Inner Mongolia  
14 Plateau are saline lakes, and the prior research has shown that inland saline lakes  
15 always contain higher concentrations of DOC than freshwater lakes in semi-arid  
16 region (Arts et al., 2000). There are probably several reasons: saline lakes are  
17 hydrologically terminal, organic matter received and produced by saline lakes largely  
18 remain within the basin and are not exported downstream; DOC in the saline lakes  
19 accumulated with much higher rates than those in fresh waters; Saline lakes  
20 commonly support highly active biological communities, which can actively break  
21 down refractory organic matters into DOC.

22       Relationship between CDOM properties and nutrients (TN and TP) may be used  
23 to track the plant-derived source fraction. Strong linear relationships were shown  
24 between nutrients (TN and TP) and DOC in the surface waters (Fig. 2c, Fig. 2d). The  
25 types of land use around the water sampling locations may be a crucial to the nutrient  
26 levels in the waters. The main land types in Hulun Buir Plateau were grassland and  
27 forest with high nitrogen and organic matter export rates. A similar relationship  
28 between TN and DOC was also shown during rainfall in agricultural and forested  
29 wetlands in the Shibetsu watershed, Japan (Jiang et al., 2014). Studies have indicated  
30 that DOC concentration in the natural water environments is closely related to the  
31 phytoplankton production and biological activity. Phytoplankton can convert  
32 dissolved inorganic carbon (mainly means  $\text{CO}_2$ ) to DOM through the photosynthesis,  
33 and part of the DOM in the water can be degraded to the  $\text{CO}_2$  by heterotrophic

1 microorganisms. TN and TP concentrations affect the respiration and reproduction of  
2 microbes and phytoplankton, which could have a pronounced influence on the  
3 conversion between DOC and CO<sub>2</sub>. The respiration is often assumed to be conducted  
4 according to the Redfield ratio (C: N: P= 106:16:1) under aerobic conditions  
5 (Redfield et al., 1963). When C:N >20 and C:P >100, the biodegradation of DOC  
6 cannot be fully performed. In this study, the values of C:N and C:P in most the of  
7 water samples satisfy the degradation condition of DOC. We suspect the above  
8 relationships (Fig. 2c, Fig. 2d) may be connected with the escape of CO<sub>2</sub> from the  
9 waters. Furthermore, CO<sub>2</sub> flux in lakes is negatively correlated with lake size  
10 (Raymond et al., 2013). If the flow and size of lakes in the study is reduced by the  
11 construction of reservoirs, irrigation, and landuse, the higher carbon emissions may  
12 develop. Furmore, DOC concentration and CO<sub>2</sub> escape from the waters are both  
13 affected by season and watershed characteristics (Organelli et al., 2014; Tranvik et al.,  
14 2009; Riera et al., 1999).

15 PCA was performed in order to explain the variations in water quality in the  
16 different sampling waters (Fig. 3). From the locations of the variables in Fig. 3A, PC1  
17 could be involved in the non-water light absorption, which may be one important  
18 factor that distinguishes particulate light absorption from CDOM light absorption. TN  
19 and TP with positive loadings on PC2 indicated that PC2 may be related to  
20 anthropogenic nutrient disturbance. The close juxtaposition of TDS and Chl<sub>a</sub> shown  
21 in Fig. 3A indicated that TDS concentration may be linked to phytoplankton  
22 metabolism. The PCA also indicated that non-water light absorption and  
23 anthropogenic nutrient disturbance might be the causes of the diversity of water  
24 quality in different sampling locations.

25 The surface area of global inland waters is 3,624,000 km<sup>2</sup> based on the  
26 calculation of Raymond et al. (2013), it is 2.47% of the Earth's land surface  
27 (Raymond et al., 2013). They play a substantial role in the global carbon (C) cycle,  
28 and about 2.9 Pg C/yr is migrated, transformed, and stored via inland water ecological  
29 system (Tranvik et al., 2009). DOM is the major component of organic matter during  
30 the process of terrestrial organic matter transport to lakes and the coastal zone, and it  
31 represents an essential link between terrestrial and aquatic ecosystems (Cole et al.,  
32 2007; Harrison et al., 2005). Based on the revision of the 'active pipe' hypothesis, the  
33 total current emissions from inland waters to atmosphere as CO<sub>2</sub> and CH<sub>4</sub> may be as

high as 1.4 Pg C/yr, the carbon burial in inland waters sediments may amount to 0.6 Pg C/yr, and the annual transport of 0.9 Pg C from inland waters to the ocean (Tranvik et al., 2009). The inland waters area in Inner Mongolian Plateau is about 9,843 km<sup>2</sup>, which is 0.27% of the global inland waters surface. So a rough count in this study would be 3.8 Tg C for annual emissions, 1.6 Tg C for annual sediment burial, and 2.4 Tg C the annual transport from Inner Mongolian Plateau inland waters. Furthermore, over 80% of lakes in Inner Mongolian Plateau are saline lakes and salt lakes. Previous studies have showed that saline lakes emitted more substantial carbon to the atmosphere and contained higher DOC concentrations than freshwater (Anderson and Stedmon, 2007; Duarte et al., 2008; Osburn et al., 2011). The dissolved inorganic C concentrations was about 10-15 times greater than in freshwater lakes (Cole et al., 2011; Duarte et al., 2008; Tranvik et al., 2009). Therefore the above estimation possibly underestimated the contribution of Inner Mongolian Plateau inland waters to the global carbon cycle. The mean CO<sub>2</sub> emission rate from saline lakes of the world is 81- 105 mmol m<sup>-2</sup> d<sup>-1</sup> (Duarte et al., 2008). When applied to the inland waters area in Inner Mongolian Plateau of 9,843 km<sup>2</sup>, the calculated CO<sub>2</sub> emissions to the atmosphere from these inland waters amounts to 3.49-4.53 Tg C/yr.

## 4.2 Analysis of CDOM spectral characteristic

Terminal lakes exhibited significantly higher CDOM light absorption than river waters (Table 1). Terminal lakes in the study all had high EC values (>1000 µs cm<sup>-1</sup>) (Song et al., 2013b). Researchers reported that the structure and composition of DOM alters obviously after flowing into saline lakes (Waiser & Robarts, 2000). The use of E<sub>250:365</sub> for the tracking of changes in CDOM molecule size has been practically demonstrated by many researchers (Helms et al., 2008; Song et al., 2013b). Increasing E<sub>250:365</sub> values indicate a decrease in aromaticity and molecular weight (MW) of CDOM, and the results of this study showed that CDOM in river waters had higher aromaticity and MW than terminal lakes. The relatively low CDOM MW in terminal lakes implied that chromophores associated with high MW CDOM were destroyed by photolysis with the prolongation of hydraulic retention time and irradiation. In terminal lakes, the change of molecular structure in high MW

1 CDOM caused by bond cleavage, resulted in its transformation to a low MW pool.  
2 Furthermore, previous studies showed that the bulk of  $E_{250:365}$  mean values in 30 U.S.  
3 rivers ranged from 5.00 to 6.50 (Spencer et al., 2012), and in the Elizabeth River and  
4 Chesapeake Bay estuary ranged from 4.33 to 6.23 (Helms et al., 2008). Compared  
5 with the reported river waters, the plateau rivers in the study presented significantly  
6 higher mean  $E_{250:365}$  values. The intense solar irradiance in this region potentially  
7 enhances the photochemical degradation of allochthonous DOM and high MW  
8 CDOM, causing an increase in the  $E_{250:365}$  values with the production of low MW  
9 CDOM. Two rivers in the intermontane plateaus of the western U.S. with intense  
10 solar irradiance also presented higher  $E_{250:365}$  values ( $9.05 \pm 1.47$ ,  $7.38 \pm 0.84$ ) than  
11 other plain rivers (Spencer et al., 2012).

12 SUVA<sub>254</sub> values in the river waters in this study were lower than the following  
13 rivers: Mean SUVA<sub>254</sub> values in 30 U.S. rivers examined ranged from 1.31 to 4.56 L  
14 mg C<sup>-1</sup> m<sup>-1</sup> (Spencer et al., 2012), while SUVA<sub>254</sub> in the Songnen Plain waters ranged  
15 from 2.3 ( $\pm 0.14$  SD) to 8.7 ( $\pm 2.8$  SD) (Song et al., 2013b), in the tropical Epulu river  
16 ranged from 3.08 to 3.57 L mg C<sup>-1</sup> m<sup>-1</sup> (Spencer et al., 2010). A possible driver of this  
17 CDOM characteristic in these plateau rivers is coupled evapoconcentration,  
18 photo-degradation and photobleaching with strong plateau ultraviolet radiation  
19 (Spencer et al., 2014; Spencer et al., 2009). SUVA<sub>254</sub> values have been proven to have  
20 a correlation with DOM aromaticity as determined by <sup>13</sup>C-NMR (Weishaar et al.,  
21 2003). In this study, the lower SUVA<sub>254</sub> measurements in terminal lakes indicated that  
22 the aromatic moieties of CDOM in this environment were lower compared within  
23 river waters due to the effect of photodegradation and microbial degradation with  
24 prolonged water residence times. From the conclusions of some studies on SUVA<sub>254</sub>  
25 and hydrophobic organic acid fraction (HPOA), the SUVA<sub>254</sub> values were always  
26 comparable to HPOA, and the conjecture could be reached that low SUVA<sub>254</sub> values  
27 indicate that the aquatic systems with little vascular plant input, and the  
28 autochthonous sources (algal or microbial) dominated the organic matter content  
29 (Spencer et al., 2008; Weishaar et al., 2003). Conversely, high SUVA<sub>254</sub> values  
30 indicated that the organic matter in aquatic systems was dominated by allochthonous  
31 sources with significant vascular plant inputs (Cory et al., 2007; Spencer et al., 2012).  
32 In this study, the SUVA<sub>254</sub> revealed that the contribution of vascular plant matter to

DOM in rivers might be greater than the terminal lakes, and the high MW DOM was more abundant in fresh waters than terminal lakes. Shorter residence time of DOM in river waters and the quick exchange rates of flow water shortened the photo-oxidation of DOM, which could be responsible for the phenomenon (Song et al., 2013b; Spencer et al., 2012).

The majority of river waters in the study exhibited significantly higher  $S_{275-295}$  values than allochthonous-dominated fresh waters which include the majority of U.S. rivers ( $13.00 - 16.50 \times 10^{-3} \text{ nm}^{-1}$ ) (Spencer et al., 2012), and the Congo River ( $12.34 \times 10^{-3} \text{ nm}^{-1}$ ) (Spencer et al., 2009), which indicated the proportion of autochthonous sources CDOM and photolysis of allochthonous CDOM in plateau waters was higher than freshwater rivers. The ratio of spectral slopes ( $S_R$ ), an indicator of CDOM molecular weight and source (Helms et al., 2008; Spencer et al., 2010), indicated that river water samples with lower  $S_R$  values contained greater allochthonous and higher MW DOM than terminal lakes. Previous studies have proven that  $S$  values were inversely proportional to CDOM MW, with a steeper spectral slope signifying decreasing aromaticity, and a shallower spectral slope signifying an increasing aromatic content (Gonnelli et al., 2013; Helms et al., 2008).  $S$  values in this study indicated that the percentage of high MW humic acid in CDOM in Hulun Lake was greater than in Buir Lake, whereas the proportion of fulvic acid and aromatic compounds showed the reverse trend. Furthermore,  $S_{275-295}$  could be used as indicator for terrigenous DOC percentage in bodies of water (Gonnelli et al., 2013). Our results indicate that the percentage of terrigenous DOC is higher in Hulun Lake than Buir Lake. From the known geological history of the region, Buir Lake is a throughput lake with inflow from the Halaha river and outflow from the Wuerxun river to Hulun Lake. Also, the land use pattern in Buir Lake watersheds shows potential desertification. Hulun Lake not only accepts the Wuerxun River flowing from Buir Lake, but also receives the water from the Kerulun River. Natural grassland with the fresh organic rich layers was dominant in Hulun Lake watersheds. The geographical location and land use pattern together account for the larger percentage of terrigenous DOM in Hulun Lake.

### **4.3 Correlations between water quality parameters and light absorption**

Strong positive correlations between CDOM absorption coefficients and TN, TP, and

DOC concentrations in all water samples indicated that CDOM light absorbance could be explained by variations in nutrients and DOC concentration to a greater extent. Previous studies have shown that CDOM absorption in a range of spectra could be used as a proxy for DOC in many inland water bodies, including the Kolyma river basin (Griffin et al., 2011), the Epulu river (Spencer et al., 2010), as well as many U.S. rivers (Spencer et al., 2012), and our results once again support this relationship in the aquatic environment of Hulun Buir Plateau.  $S_{275-295}$  and Chl *a* concentration had no correlation; a similar phenomenon has been identified in the Ligurian Sea (BOUSSOLE site) and the Mediterranean Sea (central eastern basin) (Bracchini et al., 2010; Organelli et al., 2014). These results indicated that CDOM in natural waters did not originate entirely from the release and dissociation of the phytoplankton, and that terrestrial input and microbial activities all play an important role in the generation and properties of CDOM (Ogawa et al., 2001; Rochelle-Newall & Fisher, 2002). Furthermore, strong solar radiation in the plateau area and the open ocean enhanced the photobleaching of CDOM, resulting in variation in the structural composition of CDOM. Inner Mongolian Plateau has high levels of wind and dust, and a number of lakes in the region have shrunk remarkably in recent decades (Tao et al., 2015). The shrinkage and resuspension of lakes as a result of climatic conditions may seriously influence the optical characteristics and Chl *a* concentration. The significant positive correlation between light absorption with TSM may be related to the unique climate of Hulun Buir Plateau with alternating of windy, rainless, and frigid conditions, which need to be further studied.

#### **4.4 Contribution of CDOM to light absorption**

At all the sampling locations, phytoplankton absorption played a minor role on total non-water light absorption (Fig. 4). The low levels of phytoplankton in the Hulun Buir Plateau lakes with higher salinity may be responsible for this phenomenon. Previous studies also showed that light absorption by non-algal particles often exceeds that of phytoplankton in shallow, inland lakes and coastal waters (Carder et al., 1991; Frenette et al., 2003). In most water samples examined in this study, CDOM was the dominant light-absorbing substance even when the CDOM absorption was minimal due to photobleaching in summer. The large contribution of CDOM to total absorption (approximately 50% at 440 nm in the surface layer) was also shown in the



1 Sepik River (Parslow et al., 1998). The large contribution of CDOM was also  
2 identified in other water environments, such as a fluvial lake (Frenette et al., 2003),  
3 the equatorial Pacific area (Bricaud et al., 2002), and the Ligurian Sea (Organelli et al.,  
4 2014). The above analysis indicated that the waters in Hulun Buir Plateau were  
5 Case-2 water with CDOM present in all the water samples (Morel & Prieur, 1977).  
6 According to the optical classification of surface waters (Prieur & Sathyendranath,  
7 1981), the majority of the collected river and terminal water samples in Hulun Buir  
8 Plateau could be classified as “CDOM-type” water, and others were “NAP-type”.  
9 Different catchment properties and water quality parameters could be responsible for  
10 the variation in optical classification of these waters. Other studies have shown that  
11 CDOM absorption was related to the EC of water (Sieczko & Peduzzi, 2014). EC  
12 values in rivers and lakes of Hulun Buir Plateau showed a wide range, which may  
13 affect the agglomeration or dissociation of particles and CDOM in the waters and  
14 indirectly influence light absorption. In addition, in lakes located near the paddy field  
15 and built-up areas, water quality is greatly influenced by human activities (Graeber et  
16 al., 2012).

17 The light absorption of optically active compounds (OACs) determines the  
18 inherent optical properties of waters. In our opinion, the pattern showed in Fig.4 is not  
19 invariable, and it may change with season and some extreme climate events. First, as  
20 a constituent of DOM, CDOM inputs to lakes are the mixture of allochthonous  
21 organic substances delivered by river discharge and metabolites produced by  
22 metabolic activities of autochthonous heterotrophic bacteria (Dillon and Molot, 1997;  
23 Zhou et al., 2015). Terrestrial CDOM leached from the soil to the rivers and flowing  
24 to the lakes is subject to diverse processes: physical flocculation and adsorption,  
25 chemical photobleaching, and microbial degradation (Li et al., 2014). It is widely  
26 recognized that CDOM loading and composition in aquatic environment are regulated  
27 by ambient hydrology, landscape features, climate and aquatic organisms activity, and  
28 vary seasonally and interannually (Dillon and Molot, 2005; Spencer et al., 2012;  
29 Worrall and Burt, 2004; Griffin et al., 2011). For example, studies have indicated that  
30 highly seasonal variability of DOC has been observed in high-latitude rivers,  
31 characterized by rising concentration significantly with increasing discharge of these  
32 rivers; spring snowmelt and winter freeze both have effect on DOC concentration  
33 (Raymond et al., 2007). Photobleaching in summer dramatically altered the optical

properties of the surface waters with the CDOM absorption and fluorescence lost (Vodacek et al., 1997). Hulun Buir plateau is characterized by a typical semi-humid and semi-arid continental monsoon climate with intensive solar radiation (especially in summer) and long frozen period. The temperature, snowmelt, solar radiation, water quality, and plankton and microbes activity all have unnegligible effect on CDOM photo-absorption characteristic. Secondly, in shallow, inland lakes, light absorption of non-algal particles often exceeds that by phytoplankton. The light absorption of CDOM and non-algal particles often decreases in a near-exponential manner with increasing optical wavelength, which will not be benefit for the growth of phytoplankton. In Hulun Buir plateau, phytoplankton growth is very slow even in the warm season, the high pH, salinity and alkalinity of water may be responsible for the phenomenon. So the relative contributions of phytoplankton to non-light absorption in Hulun Buir plateau may be difficult to improve due to the depressed algae growth. Non-algal particles concentration is related to the TSM (Table 2), the sediment suspension caused by strong winds in late autumn and winter, the increase of surface runoffs in spring with snowmelt, and the change of land use pattern, these factors may cause the increase of TSM concentration, resulting the increasing of the light absorption by non-algal particles. Above all, many factors could affect the relative contributions of OACs to total non-water light absorption, and the issue should be discussed upon the local environment and climate.

Pareto-Lorenz curve analysis indicated that in Hulun Buir Plateau and the similar geographical aquatic environment, we could randomly select 20% of the collected water samples to analyze the light absorption, the contributions of optically active substances might be estimated based on these absorption values and the cumulative contributions in this study. Then the estimated value could be used to identify water type and evaluate regional homogeneity of non-water light absorption.

## 5 Conclusions

There has been little knowledge of CDOM properties and their relationship to environmental factors in plateau areas based on previous research results. The unique environmental conditions of plateau areas with dry and cold climates have an important effect on CDOM properties and potential implications for carbon cycling in inland waters. A preliminary study was conducted in Hulun Buir plateau which includes several freshwater rivers and numerous terminal lakes with high salinity. The

study provides information on the water quality and CDOM in these rivers and terminal lakes and provides insight into CDOM properties linked to water quality characteristics. The following conclusions were obtained: (1) A significant difference in water quality was observed between river and terminal lakes in Hulun Buir plateau ( $p < 0.01$ ). The non-water light absorption and anthropogenic nutrient disturbance might be the main causes of the wide range of water quality parameters; (2) CDOM in river waters had higher aromaticity, MW, and vascular plant contribution than in terminal lakes in cold and arid plateau regions and other fresh water rivers due to the strong evapoconcentration, intense ultraviolet irradiance and plateau landscape features; (3) Environmental variables TSM, TN, and EC had a strong correlation with light absorption characteristics, followed by TDS and Chl $a$  in the waters of Hulun Buir plateau. Study of the optical-physicochemical correlation is helpful for evaluating the potential influence of water quality factors on non-water light absorption in arid and cold plateau water environments, and it is useful for the understanding satellite remote sensing data of plateau inland waters.

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1 Table 1. Water quality and CDOM absorption parameters of water samples collected  
2 in Hulun Buir plateau

	River water (n= 22)		Terminal lakes (n= 24)	
	Mean	Min- Max	Mean	Min- Max
DOC	25.99±6.64	8.44- 39.74	83.83±68.79	23.03-300.50
TN	1.33±0.63	0.64- 3.51	4.58±3.80	1.39-19.03
TP	0.11±0.04	0.06- 0.23	1.52±1.87	0.12-6.31
TAlk	156.22±53.60	48.00- 298.56	652.70±642.15	96.00-2906.40
EC	325.95±141.64	106.70-745.00	5729.69±9715.26	1236-41000.00
TDS	163.07±70.62	53.40-372.00	743.59±483.34	93.10-1505.00
Turb	20.21±20.80	2.19- 83.84	273.79±608.75	1.75-2521.20
Chl a	4.62±3.95	0.04-11.06	6.27±11.06	0-41.07
a <sub>CDOM</sub> 335	18.29±9.87	4.71-40.07	36.16±30.27	10.47-158.24
a <sub>CDOM</sub> 440	2.68±1.68	0.60-7.14	5.60±5.10	0.83-26.21
E <sub>250:365</sub>	7.80±2.30	5.43-12.30	8.02±3.48	5.47-20.73
SUVA <sub>254</sub>	2.74±1.08	1.08- 4.79	1.90±0.57	0.79-3.74
S <sub>275-295</sub>	0.019±0.004	0.015-0.027	0.02±0.004	0.015-0.031
S <sub>R</sub>	1.00±0.17	0.73-1.35	1.05±0.09	0.91-1.25

3 TN, TP, TDS, TSM, TAlk and DOC represent total nitrogen, total phosphorus, total  
4 dissolved solids, total suspended matter, total alkalinity and dissolved organic carbon  
5 concentration, respectively (mg L<sup>-1</sup>). Turb represents water turbidity (NTU), and EC  
6 represents the electrical conductivity of water samples (μs cm<sup>-1</sup>). Chla is chlorophyll a  
7 concentration (μg L<sup>-1</sup>). The unit SUVA<sub>254</sub> was L mg C<sup>-1</sup> m<sup>-1</sup>.

1

2 Table 2 Rivers (or freshwater lakes) names, sampling numbers, basin area, width,

3 Length, max water depth, elevation in Inner Mongolia Plateau

Name	Number	Area (km <sup>2</sup> )	Max Depth (m)	Elevation (m)	Width (m)	Length (km)	Defined Type
Kerulen River	1, 11	7153	1.9	-	60-70	1264	River
Hulun Lake	5-9	2339	33	545.9	30-40 km	-	River
Hailar River	21, 31	54500	1	1100	30-130	1430	River
Yimin River	22-23	22725	2.5	-	20-50	390	River
Buir Lake	24-28	609	21.6	583	20 km	-	River
Ergun River	29	151184	>2	-	200-300	1666	River
Moegele River	36	150	2	-	1-6	319	River
Zhadun River	30, 41	3100	4	675	2-8		River
Wulannuor wetland	34	710	3.5	540	-	-	River
Qingkai River	38	-	2	580	1-10		River

4 “-”denotes without data.

Table 3. Pearson correlation coefficients for general water quality and light absorption properties

	$a_{\text{CDOM}}(335)$	$a_{\text{CDOM}}(440)$	$a_{\text{PB}}(440)$	$a_{\text{phy}}(440)$	$a_{\text{NAP}}(440)$	$S_{275-2295}$
TN	0.574**	0.548**	0.288*	0.377**	0.264	0.164
TP	0.508**	0.401**	0.078	0.194	0.062	0.151
TDS	0.483**	0.534**	-0.048	0.178	-0.068	0.015
DOC	0.527**	0.411**	-0.007	0.151	-0.024	0.377**
pH	0.192	0.129	-0.121	0.026	-0.131	0.567**
Chl a	0.021	0.084	-0.056	0.224	-0.083	0.089
TSM	0.021	0.045	0.985**	0.515**	0.985**	-0.073
EC	-0.024	-0.083	0.055	0.081	0.050	0.506**

\*  $p < 0.05$ ; \*\*  $p < 0.01$ .

Units of DOC, TN, TP, TDS, TSM, and DOC concentrations are  $\text{mg L}^{-1}$ , Chla concentrations unit is  $\mu\text{g L}^{-1}$ , EC unit is  $\mu\text{S cm}^{-1}$ .

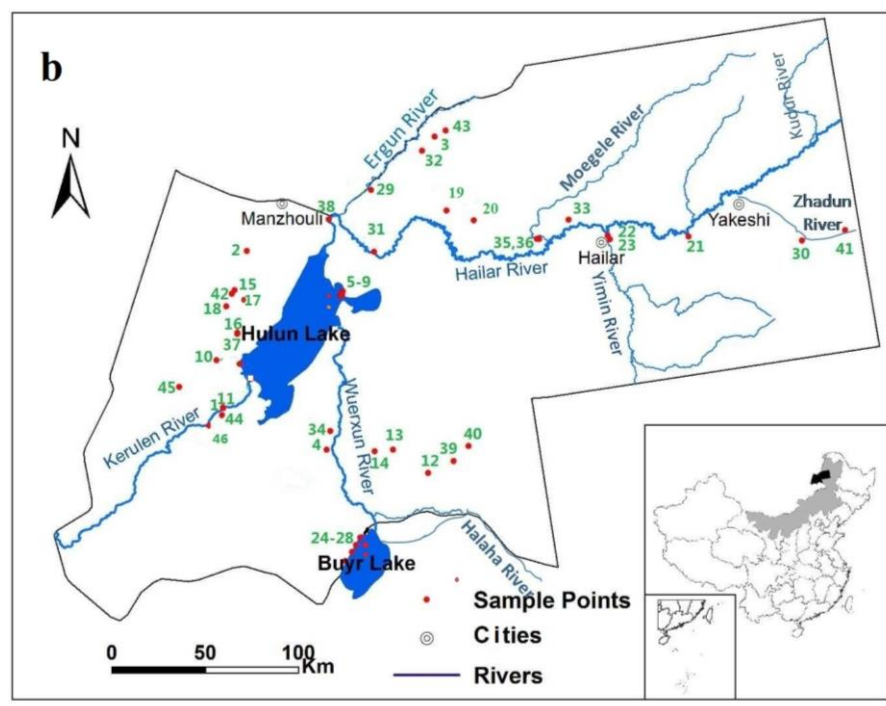
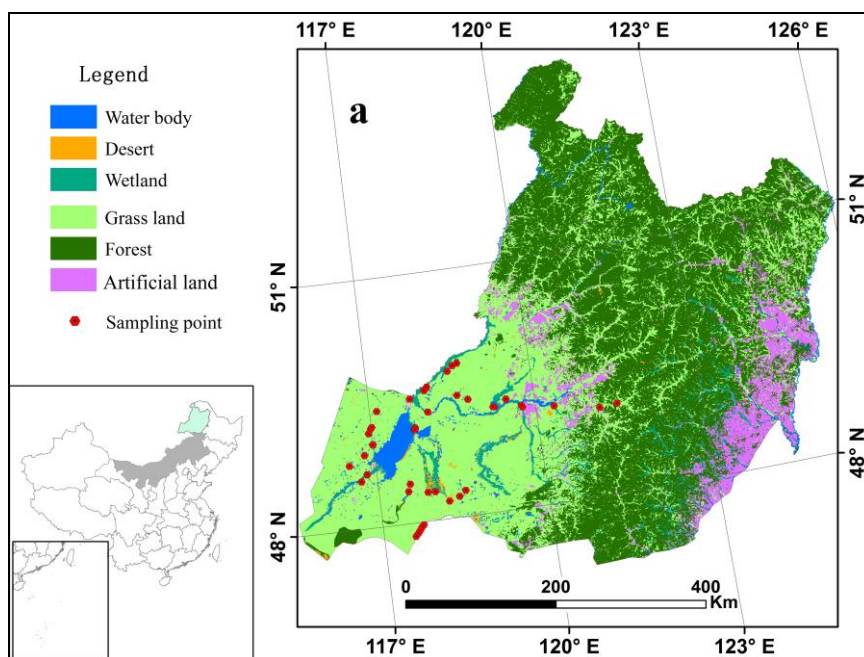
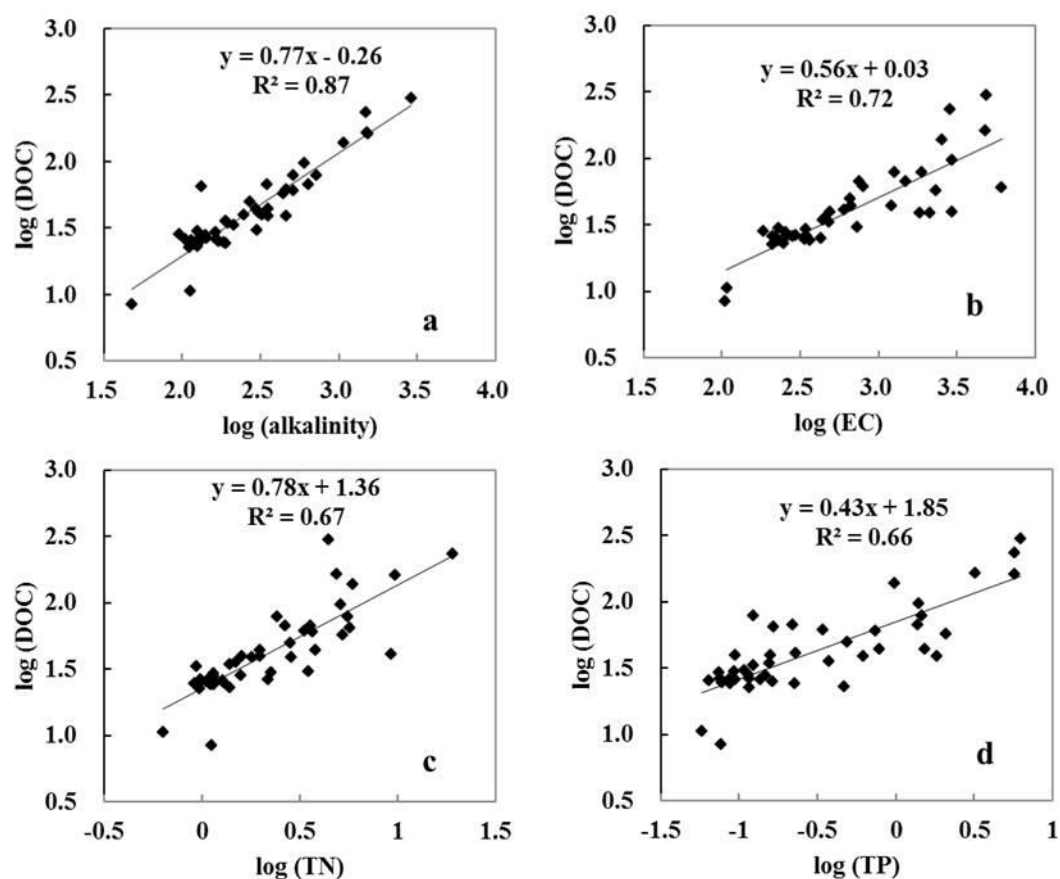


Figure 1. Study area location and sampling station distribution. The names, sampling numbers, and water types are listed in support materials (Table 1S)

1

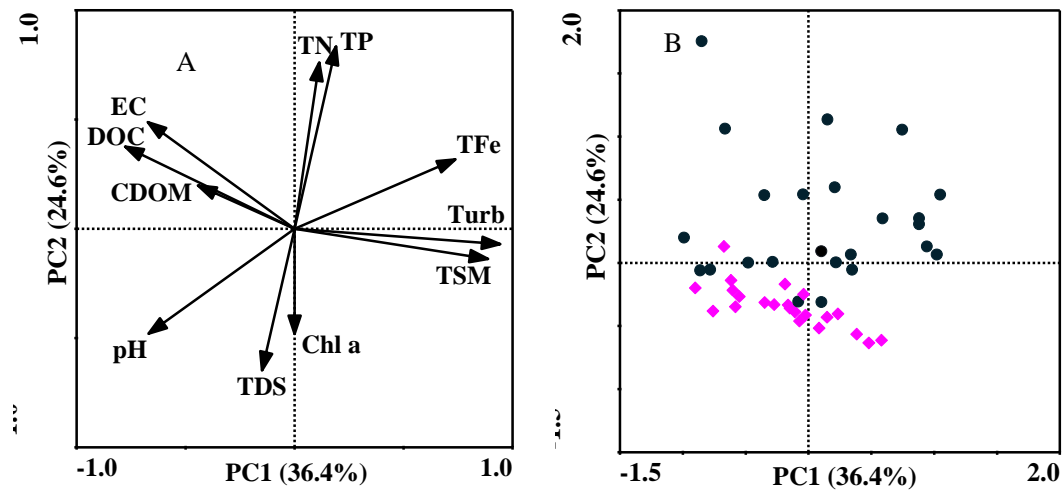


2

3 Figure 2. Correlation between DOC and alkalinity, EC, TN, and TP in Hulun Buir

4 plateau water

1



2

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4 Figure 3. PCA of the physico-chemical characteristics of all collected waters, (A)  
 5 Factors loading data, and (B) Sample scores. ● represents terminal lakes, and ◆  
 6 represents river waters.



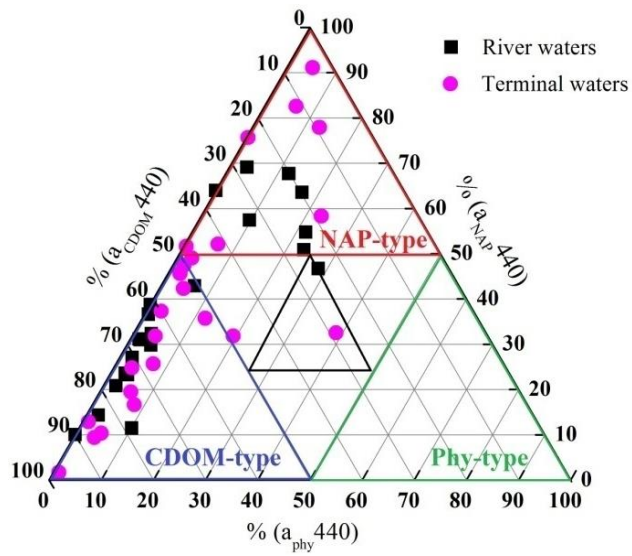
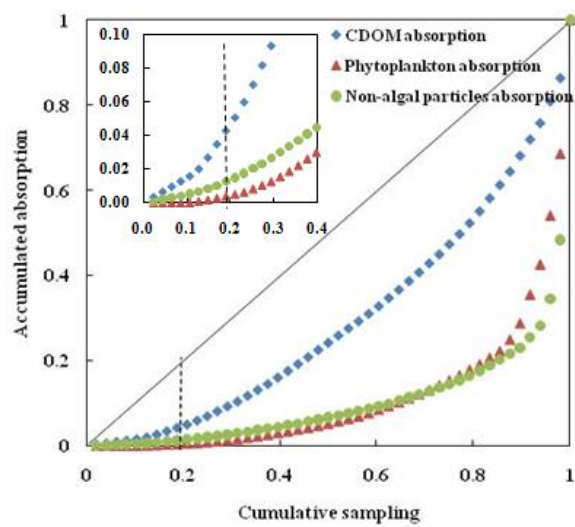


Figure 4. Relative contributions of CDOM, phytoplankton and non-algal particles to total non-water light absorption at 440 nm

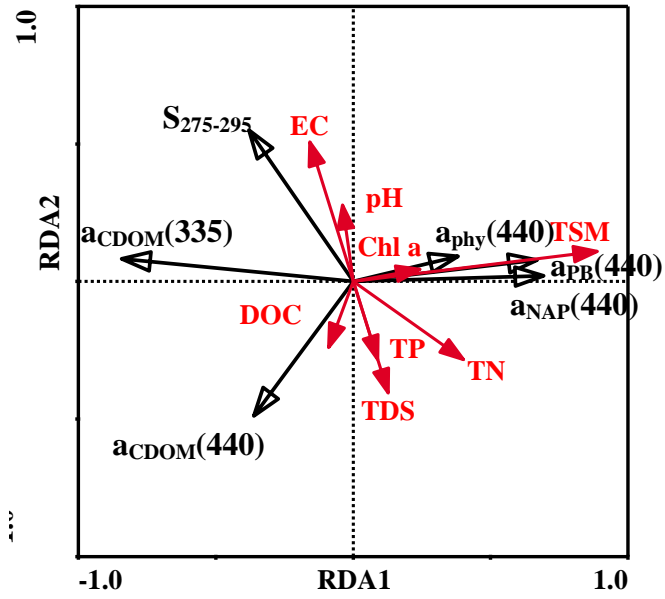
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2

3 Figure 5. Pareto- Lorenz curves derived from the total non-water light absorption at  
 4 440 nm

1



2

3 Figure 6. RDA of CDOM adsorption data and water quality parameters (n=44)