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Influence of land cover on riverine dissolved organic carbon concentrations and export in the Three Rivers Headwater Region of the Qinghai-Tibetan Plateau

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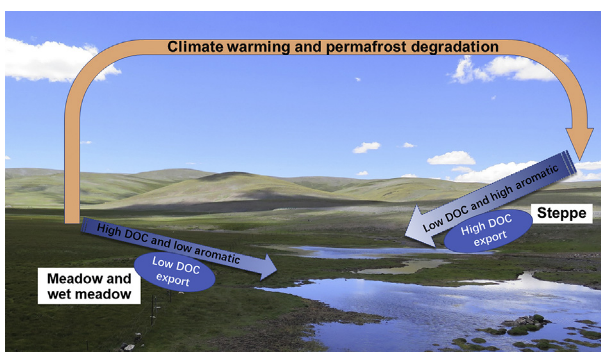
HIGHLIGHTS

- The riverine dissolved organic carbon on the Qinghai-Tibetan Plateau was examined.
- Land cover type (i.e., meadow or steppe) controls DOC concentrations and exports.
- Permafrost degradation may increase riverine organic carbon transport.

GRAPHICAL ABSTRACT



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ABSTRACT

The Qinghai-Tibetan plateau (QTP) stores a large amount of soil organic carbon and is the headwater region for several large rivers in Asia. Therefore, it is important to understand the influence of environmental factors on river water quality and the dissolved organic carbon (DOC) export in this region. We examined the water physico-chemical characteristics, DOC concentrations and export rates of 7 rivers under typical land cover types in the Three Rivers Headwater Region during August 2016. The results showed that the highest DOC concentrations were recorded in the rivers within the catchment of alpine wet meadow and meadow. These same rivers had the lowest total suspended solids (TSS) concentrations. The rivers within steppe and desert had the lowest DOC concentrations and highest TSS concentrations. The discharge rates and catchment areas were negatively correlated with DOC concentrations. The $SUVA_{254}$ values were significantly negatively correlated with DOC concentrations. The results suggest that the vegetation degradation, which may represent permafrost degradation, can lead to a decrease in DOC concentration, but increasing DOC export and soil erosion. In addition,

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some of the exported DOC will rapidly decompose in the river, and therefore affect the regional carbon cycle, as well as the water quality in the source water of many large Asian rivers.

1. Introduction

Dissolved organic carbon (DOC) transport by rivers has been recognized as an important component of the global carbon cycling (Raymond and Bauer, 2001). Rivers receive approximately 2.9 Pg C from terrestrial ecosystems annually of which 0.6 Pg C is buried, 1.4 Pg C is released as greenhouse gases into the atmosphere, and 0.9 Pg C is transported to oceans (Cole et al., 2007; Tranvik et al., 2009). Under global warming scenarios, the riverine transport of carbon in permafrost regions may play a vital role in the carbon cycle and global change feedbacks since permafrost regions store a large quantity of carbon (Hugelius et al., 2014; Mu et al., 2015; Schuur et al., 2015).

The Qinghai-Tibetan Plateau (QTP) is a middle-low latitude permafrost region with a permafrost area of 1.06×10^6 km^2 (Qin et al., 2016; Zou et al., 2017). Similar to the circum-Arctic regions, the permafrost region on the QTP has high soil organic carbon (SOC) content, and stores about 28 Pg C in the upper 2 m of soil (Mu et al., 2015). The QTP is the head water region for several large rivers in Asia including the Yangtze River, the Yellow River, and the Lancang-Mekong River, and the area is known as the Three-Rivers Headwater Region. These rivers are important sources of drinking water to billions of people in Asia and, as such, water quality is very important.

Water quality parameters and carbon transport can be affected by many factors such as temperature, precipitation, topography, weathering and soil erosion, and land cover types (O'Donnell et al., 2012a; O'Donnell et al., 2016). Although the process is complicated (Fig. 1), the relationship between the water chemistry, DOC export and its relationship to land cover types is extremely useful because land cover types are easily accessible via satellite images. Based on the fact that SOC contents are closely associated with land cover types (Wu et al., 2017), we hypothesized that the land cover type controls the DOC and total suspended solids (TSS) concentrations in the river water. Furthermore, since DOC in the rivers of permafrost regions can experience rapid decomposition, we hypothesized that the DOC in large rivers is more degraded than other rivers, which can be demonstrated by the concentration-normalized UV absorbance at 254 nm ($SUVA_{254}$). We also hypothesized that the basic water quality parameters including riverine DOC concentration, pH, turbidity, and TSS concentration are closely associated with one another. To test these hypotheses, we collected water samples from rivers with different types of land cover within the river's catchment area, and examined the relationship between DOC concentrations and exports rates, and water parameters in the eastern QTP.

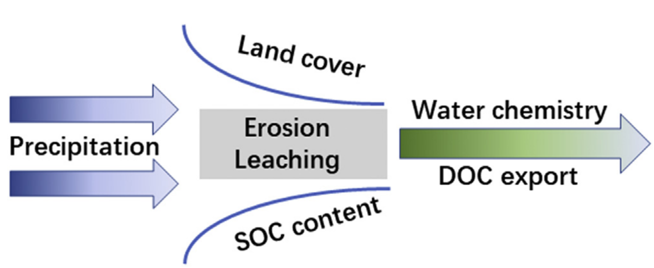

Fig. 1. Conceptual diagram for the river chemistry and DOC (dissolved organic carbon) export.

2. Materials and methods

2.1. Area description

The study areas are located in the Three Rivers (i.e., Lancang-Mekong River, Yangtze River, and Yellow River) Headwater Region, which is the largest National Natural Reserve in China, covering an area of 36.3×10^4 km^2. The study area is within the continuous permafrost zone on the QTP (Fig. 2). The mean annual precipitation varied considerably over the reserve, and about 80% of the annual precipitation falls during the summer, with the highest precipitation occurring in August (Yi et al., 2013). There are few reports of soil taxonomy on the QTP, and the soil orders are largely Gelisols, Aridisols, Entisols and Inceptisols (Li et al., 2015; Wu et al., 2016a). Although the mountainous areas have great heterogeneities in environmental factors such as soil texture, soil parent materials, and topographic conditions, there are four typical land cover types in this area (i.e., alpine wet meadow, alpine meadow, alpine steppe, and alpine desert) (Wang et al., 2016). According to the distribution of land cover types, we selected 7 rivers (Fig. 2) to investigate the riverine DOC concentrations and export rates under different land cover types within the permafrost region. The geographical coordinates and environmental factors for these rivers were summarized in Table 1.

The catchment boundaries were delineated with the hydrologic tools in ArcGIS 10.4, based on the data of ASTER Global Digital Elevation Model (ASTER GDEM). The areas of land cover and permafrost distribution were also extracted using ArcGIS 10.4 from the literature (Wang et al., 2016; Zou et al., 2017).

2.2. Sampling and analysis

Since the maximum precipitation in this area occurs in August, the field work was conducted from August 10 to August 20, 2016. River flows are dynamic properties since they change along with precipitation. Therefore, to avoid possible effects of heavy rainfall, we collected water samples after there had been no storm events during the previous three days. The water quality parameters, including water temperature, turbidity, dissolved oxygen content, conductivity, and pH were recorded at a water depth of 30 cm using multi-parameter water quality sonde (YSI 6600 V2, Yellow Spring Instruments, USA). The water samples (3 L for each) were also collected at a depth of 30 cm and filled into the pre-acidified polyethylene bottles. The samples were kept in a dark refrigerator at 4 °C during transport to the laboratory. The DOC and $SUVA_{254}$ were measured within 1 week of collection.

Water flow in the large rivers (YMR, HLH, XSH and WQ) was measured with a stream Pro ADCP (2.0 M Hz, Teledyne RD Instruments, Poway, CA, USA) during sample collection. For the three small streams (ZD1, ZD2, and FHS), flow transects with uniform depth were selected, and then the flow rates were measured using a Flowtracker (San Diego, CA, USA).

For the laboratory analysis, water samples were filtered through weighted, pre-ashed 0.45 μm glass fiber filters (450 °C for 4 h). The DOC concentrations were measured using a Vario EL elemental analyzer (Elementar, Hanau, Germany), and the glass fiber filters were oven-dried and weighted to calculate the concentration of TSS. The absorbance of water samples at 254 nm were analyzed with a UV-160A spectrophotometer (Shimadzu, Tokyo, Japan) in 1 cm quartz cuvettes. Using absorbance and concentration values, we calculated the concentration-normalized UV absorbance at 254 nm ($SUVA_{254}$), which is a