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The chemistry of river–lake systems in the context of permafrost occurrence (Mongolia, Valley of the Lakes) Part II. Spatial trends and possible sources of organic composition

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ABSTRACT

The chemistry of river–lake systems located in Central Mongolia near the southern border of permafrost occurrence has not been well studied. The main aim of this paper is to summarize patterns in water chemistry in supply springs, rivers and lakes in relation to permafrost occurrence, as well as other natural and anthropogenic impacts. The analyses involved water samples taken from two river–lake systems: the Baydrag River–Böön Tsagaan Lake system and the Shargalyuut/Tuyn Rivers–Orog Lake system. Total organic carbon (TOC) and polycyclic aromatic hydrocarbons (PAHs) were detected and quantified. Other organic compounds, such as organic halogen compounds, phthalates, and higher alkanes were also noted. The main factors which influence differences in TOC concentrations in the water bodies involve permafrost occurrence, mainly because compounds are released during active layer degradation (in the upper reach of the Tuyn river), and by intensive livestock farming in river valleys and in the vicinity of lakes. In relation to the concentrations of PAHs, high variability between samples (>300 ng L^{-1}), indicates the influence of thermal water and local geology structures (e.g., volcanic and sedimentary deposits), as well as accumulation of suspended matter in lakes transported during rapid surface runoff events. The monitoring of TOC as well as individual PAHs is particularly important to future environmental studies, as they may potentially reflect the degradation of the environment. Therefore, monitoring in the Valley of the Lakes should be continued, particularly in the light of the anticipated permafrost degradation in the 21st century, in order to collect more data and be able to anticipate the response of river–lake water chemistry to changes in permafrost occurrence.

1. Introduction

Permafrost is widespread in the Arctic and boreal regions of the Northern Hemisphere (e.g., Petrone et al., 2006; Frey et al., 2007; McClelland et al., 2007; Kokelj et al., 2009; Stotler et al., 2009; Douglas et al., 2013; Olefeldt et al., 2014; Manasypov et al., 2015), including China and Mongolia (Yang et al., 2010) and several mountain regions (e.g., Cheng and Dramis, 1992; Zhao et al., 2010; Dobinski, 2011). The distribution of permafrost is controlled by air temperature and, to a minor extent, by vegetation and soil properties (Schaefer et al., 2011). As temperature rises, permafrost degradation can be identified as one of the key cryosphere indicators of global climate change (Yang et al., 2010). The extent of permafrost degradation is indirectly reflected in the changes in freshwater conditions. The hydrochemical status of fresh water in the Northern Hemisphere is believed to be greatly affected by permafrost degradation. This phenomenon is observed as seasonal fluxes of nutrients and carbon (e.g., Petrone et al., 2006; Frey et al., 2007; McClelland et al., 2007; Zhang et al., 2008; Kokelj et al., 2009; Stotler et al., 2009; Bagard et al., 2011; Douglas et al., 2013; Olefeldt et al., 2014; Manasypov et al., 2015).

The study area (Valley of the Lakes, Mongolia) is located at the border of permafrost occurrence, which reaches its southernmost latitude in the Northern Hemisphere. According to predictions, climate in Mongolia will continue to change over the 21st century (Dagvadorj et al., 2009), with an increase in annual temperatures from 3.5 to 4 °C across Mongolia over the next 100 years (Christensen et al., 2007), which may lead to significant permafrost degradation over a considerable area (Lawrence and Slater, 2005; Guo et al., 2012). We can assume that in the southern range of permafrost occurrence, changes will be most severe and will eventually lead to complete degradation of the permafrost. Hence, the better thermal characterization and spatial distribution of permafrost degradation in this region would greatly contribute to improving the prediction of global climate change impacts.

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Thus far relatively few studies have investigated the chemistry of Mongolian reservoirs (e.g., Williams, 1991; Egorov, 1993; Bignall et al., 2003; Puntsag et al., 2010; Hofmann et al., 2015). Moreover, only a few papers attempted to provide a description of water chemistry and organic components (e.g., Baek et al., 2013; Free et al., 2014). The characteristics of inorganic chemistry of two studied river–lake systems in the Valley of the Lakes (the Baydrag River–Böön Tsagaan Lake system and the Shargalyuut/Tuyn Rivers–Orog Lake system) was discussed by Szopińska et al. (2016). Overall findings of this study suggest that the rivers and their sources have low mineralization and constitute a "background" for the lakes' water chemistry. Moreover lake water is considerably modified by evapotranspiration as well as by seasonal drying out of the lakes (e.g., Lake Orog). Based on Szopińska et al. (2016), two categories of factors that affect water chemistry can be distinguished: natural factors, such as permafrost occurrence, intensive water evaporation and mineralogical background; and anthropogenic factors, including agriculture. These factors can also potentially influence the spatial trends and shape of organic composition in both river–lake systems.

The main aim of this paper is to summarize patterns at organic composition variation (mainly total organic carbon – TOC, and polycyclic aromatic hydrocarbons – PAHs) of rivers located in the vicinity of permafrost occurrence. TOC was selected as a priority parameter to indicate general changes in water organic composition. PAH determination and identification of volatile and semi-volatile organic compounds were used to offer a precise description of water chemistry. Permafrost degradation may mainly affect the organic solute chemistry of upper river reaches (Baydrag, Shargalyuut and Tuyn). Volcanic and sedimentary deposits as well as hydrothermal minerals can also contain dispersed bituminous materials enriched with PAHs (Geptner et al., 2005). Hence, volcanic deposits and numerous hot springs (near the Shargalyuut river) in the study area can potentially affect PAH levels. Moreover, the impact extent of the volcanic factor on water chemistry in river–lake systems could be better understood, if we compare the chemical characteristics of water samples taken from an area subject to the influence of earlier volcanic activity with water chemistry of the lake formed in a volcanic caldera (Togo volcano area).

2. Study area

2.1. Hydrological setting

The study involved two river lake systems located in the Valley of the Lakes: the Baydrag River–Böön Tsagaan Lake system (Baydrag–Böön Tsagaan System) and Shargalyuut/Tuyn Rivers–Orog Lake system (Shargalyuut/Tuyn–Orog System) (Fig. 1A). The basins of the analyzed river–lake systems cover an area of 45,020 km^2 and 14,929 km^2 for the Baydrag–Böön Tsagaan system and the Tuyn–Orog system, respectively (Lehner et al., 2008). Both rivers have their source zones in the Khangai mountains (one of the Mongolian "runoff-forming areas") (Davaa and Oyunbaatar, 2012; Kwadijk et al., 2012), flow to the south, across the uplands to the Valley of the Lakes, where they feed two large lakes (Fig. 1A).

Total precipitation in the study area decreases southwards, from 300 to 350 mm in the Khangai mountains, where the river source zones are found, to 50–150 mm in the Valley of the Lakes, where they flow into the lakes of Böön Tsagaan and Orog (Davaa and Oyunbaatar, 2012; Kwadijk et al., 2012). Mean sum of annual precipitation in the analyzed basins in the years 1974–2013 was 205 mm and mean annual temperature was −0.3 °C (Fig. 2A).

In this region river runoff is shaped by rainfall, groundwater and snowmelt (Davaa and Oyunbaatar, 2012). Groundwater resources in both basins are spatially varied, but more than 90% of the area is characterized by scarce groundwater resources with a yield at less than 0.3 $L\ s^{-1}\ km^{-2}$ (Jadambaa and Batjargal, 2012). Annual specific runoff in the Baydrag and Tuyn basins tends to decrease southwards with the river course and ranges from 2.5–3.0 $L\ s^{-1}\ km^{-2}$ in the vicinity of the Khangai slope to less than 1.0 $L\ s^{-1}\ km^{-2}$ in the Valley of the Lakes (Glazik, 1995; Batsukh et al., 2008; Davaa and Oyunbaatar, 2012). Data collected at two gauges in Tuyn (1970–2008) show a downstream decrease in specific runoff from 1.22 $L\ s^{-1}\ km^{-2}$ for the Tuyn in Bayankhongor to 0.302 $L\ s^{-1}\ km^{-2}$ for the Tuyn in Bogd (Davaa and Oyunbaatar, 2012).

The lakes of Böön Tsagaan and Orog constitute remnants of a former larger lake that covered the greater part of the Valley of the Lakes (Komatsu et al., 2001). The surface area of the lakes in the middle of the 20th century amounted to 252 km^2 in the case of Böön Tsagaan, and 140 km^2 for Lake Orog, with a volume 2.355 km^3 and 0.42 km^3, and mean depth at 10 m and 3 m, respectively (Davaa et al., 2007). However, the surface area of both lakes decreased in the period 1974–2013 by 14% in the case of the Böön Tsagaan Lake and 51% in the case of Lake Orog. Due to the fact that the lakes are located at the border between an arid steppe and a semi-desert, the water bodies are characterized by marked water table fluctuations. Lake Orog is subject to considerably greater fluctuation, both on an annual and interannual bases (Szumińska, 2016), which is a result of three times smaller discharges in the Tuyn river in comparison to the Baydrag river (Davaa and Oyunbaatar, 2012). In 1974–2013, Lake Orog dried out on several occasions (in 1989 and later between 2006 and 2011), which may have significantly affected the current chemical status of the lake water.

2.2. Weather conditions at the time of sampling

Samples were collected in late August and early September 2013. Average daily temperatures in that period ranged from 10 to 17 °C (Fig. 2B). It rained from June to the second half of August, but total daily precipitation did not exceed 20 mm. Average daily temperatures in July and August reached 15–20 °C, however the maximum daily temperatures at the beginning of July were up to 30 °C. Data analysis shows that several consecutive years before 2013 featured low total precipitation (apart from the years 2010 and 2011) and high air temperatures (Fig. 2A). The most dominant directions of wind in the research area are northeast (40% — NE, NNE) north (10–15%) and northwest (25% — NW and NNW) (Fig. 2C).

2.3. Permafrost occurrence and geological conditions

Permafrost occurrence in the research area tends to diminish to the south, hence in the Khangai mountains permafrost is variously continuous and discontinuous, at the southern slopes of the Khangai it is insular or sparsely insular and disappears completely further down south (Sharkhuu, 2000; Sodnom and Yanshin, 1990) (Fig. 1). The Valley of the Lakes is classified as a zone with seasonally frozen ground, where the depth of freezing ranges from 2.0 to 4.5 m (Sodnom and Yanshin, 1990).

The researched basins have highly varied lithology and tectonics, which may potentially be a reason of considerable contamination of surface water with different elements and compounds. The source areas of sediments for both river–lake systems mainly consist of Paleozoic granites, Khangai flysch clastic rocks, exposed fragments of Early Proterozoic basement, and Precambrian Bayankhongor ophiolite with a complex of ultrabasic rock formations, mélange of volcano–sedimentary complexes (basaltoids, sandstones, mudstones, metasedimentary shales, limestones), and criss-crossed with quartz and chalcedony veins (Tomurtogoo et al., 2002; Tomurtogoo, 2004; Machowiak and Stawikowski, 2012). Furthermore, Central Mongolia features numerous volcanic areas of Miocene, Pliocene, Pleistocene and Holocene ages (Chuvashova et al., 2007; Yarmolyuk et al., 2007) (Fig. 1). Some well-preserved volcanic cones include the Togo volcano (Pleistocene) and the Khorgo volcano (Holocene). In the watershed zones and southern part of the study area, the Baydrag and Tuyn rivers flow through a Neogene system of sedimentary–volcanic rocks with the prevalence of