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Distribution and transportation of mercury from glacier to lake in the Qiangyong Glacier Basin, southern Tibetan Plateau, China

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ABSTRACT

The Tibetan Plateau is home to the largest aggregate of glaciers outside the Polar Regions and is a source of fresh water to 1.4 billion people. Yet little is known about the transportation and cycling of Hg in high-elevation glacier basins on Tibetan Plateau. In this study, surface snow, glacier melting stream water and lake water samples were collected from the Qiangyong Glacier Basin. The spatiotemporal distribution and transportation of Hg from glacier to lake were investigated. Significant diurnal variations of dissolved Hg (DHg) concentrations were observed in the river water, with low concentrations in the morning (8:00 am–14:00 pm) and high concentrations in the afternoon (16:00 pm–20:00 pm). The DHg concentrations were exponentially correlated with runoff, which indicated that runoff was the dominant factor affecting DHg concentrations in the river water. Moreover, significant decreases of Hg were observed during transportation from glacier to lake. DHg adsorption onto particulates followed by the sedimentation of particulate-bound Hg (PHg) could be possible as an important Hg removal mechanism during the transportation process. Significant decreases in Hg concentrations were observed downstream of Xiao Qiangyong Lake, which indicated that the high-elevation lake system could significantly affect the distribution and transportation of Hg in the Qiangyong Glacier Basin.

Introduction

Mercury (Hg), a highly toxic trace metal, is considered to be a global pollutant due to its long-range transport via the atmosphere and biomagnification in ecosystems (Selin, 2009). Inorganic Hg species in aquatic systems can be converted into toxic methylated forms, such as methylmercury (MeHg), a bioaccumulative and neurotoxic form of Hg, which poses a

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potential threat to human health after bioaccumulation and biomagnification through food chains (Li et al., 2015a, b; Zhang et al., 2010a). The consumption of aquatic products, especially fish, is an important pathway of Hg exposure for humans and wildlife around the world (Zhang et al., 2014; Mergler et al., 2007). Hg contamination and its biogeochemical cycles in the aquatic ecosystem have become a hot topic in scientific research.

The Tibetan Plateau, or “Third Pole”, is one of the most remote and pristine areas in the world, with an area of approximately 2,500,000 km^2 and an average elevation of more than 4000 m above sea level (a.s.l.) (Qiu, 2008). This region is the most glacier-concentrated region at low- and mid-latitudes (Kang et al., 2010a; Yao et al., 2012). Known as the “Water Tower of Asia”, the Tibetan Plateau is the source region of the fresh water for more than one-third of the world’s population through its 10 largest rivers, including the Yangtze River, Yellow River, Yarlung Tsangpo (Brahmaputra), Salween River, and Indus River (Huang et al., 2014; Immerzeel et al., 2010). However, in recent decades, several studies have shown that pollutants, such as Hg, originating from outside the Tibetan Plateau could be transported over a long range via atmospheric circulation and eventually be deposited onto the glaciers, endangering ecosystems and human health in the downstream regions of the glacier-fed river basins (Huang et al., 2014; Huang et al., 2012a; Zhang et al., 2014). This becomes more significant for the downstream ecosystems in the light of ongoing global warming, as the accumulated pollutants will largely be released due to accelerated glacier melting (Bogdal et al., 2009; Zhang et al., 2015). The study of Hg distribution and its transportation processes from the glacier to its downstream on the Tibetan Plateau is thus imperative for further understanding its potential downstream impact. However, due to the difficulty of sampling, there have been few studies to date on the subject, and therefore, the transportation process of Hg from the glaciers to its downstream areas in glacier basins in the Tibetan Plateau is still poorly understood. Currently, very limited studies on Hg distribution have been conducted in the aquatic systems of Nam Co Basin, which lies at the foot of the Nyainqêntanglha Mountain in the southern Tibetan Plateau, and is the second largest saline lake on the Tibetan Plateau with an area of approximately 1960 km^2; and in the Yarlung Zangbo River, which is the highest river in the world with an average elevation of over 4000 m a.s.l., originates from the Gyaimanezong Glacier in the northern foothills of the Himalayas, flows from west to east through the southern part of Tibetan Plateau, and has a total length of 2057 km and a drainage area of 239,228 km^2 (Wang et al., 2012b; Zheng et al., 2010). A previous study on the Hg distribution and transportation in the Zhadang Glacier Basin on the south shore of Lake Nam Co, southern Tibetan Plateau, has revealed that total mercury (THg) in the melt water was dominated by PHg, and decreased significantly during the transportation from the supraglacial streamwater to the downstream. Moreover, a significant positive relationship was found between THg concentrations and total suspended particulates (TSPs) in the meltwater, indicating that particulates played an important role during the transportation process (Guo, 2012).

The Qiangyong Glacier Basin is situated on the southern part of the Tibetan Plateau, and consists of glaciers, rivers and lakes. Glacier meltwater is the main water supply for the lakes: the meltwater from Qiangyong Glacier flows toward the glacial terminus river and supplies Da Qiangyong Lake directly, which finally forms a semi-enclosed lake system (Luo et al., 2003; Owen et al., 2005). Therefore, it is considered an ideal region to investigate Hg transportation from the glacier to its downstream areas. In this study, we conducted an extensive sampling campaign and obtained successive snow, glacier melt stream water, and lake water samples in this region. The spatiotemporal distribution and transportation process of Hg from glacier to lake over the Qiangyong Glacier Basin were investigated. Moreover, the dominant factors controlling the Hg distribution and its transportation process were also discussed. This study will not only enhance our understanding of the Hg distribution and transportation mechanisms in the high-elevation glacier basins, but also be important for assessing the potential impact of Hg on downstream ecosystems as well as its environmental risks.

1. Materials and methods

1.1. Study area and sampling location

The Qiangyong Glacier Basin (28°53′N, 90°13′E) is located between the Himalayan ranges and the Yarlung Zangbo River in the southern Tibetan Plateau (Fig. 1). The annual mean air temperature in this area is approximately 2.4°C, with the lowest temperature in January at −5.5°C and the warmest in July at 10°C (Luo et al., 2003). The annual mean precipitation in the region is approximately 370 mm, with 90% of the precipitation occurring in the summer season (Li et al., 2011). The atmospheric circulation in our study region is mainly influenced by westerlies and the Indian monsoon, which prevails in the summer season from June to September (Tian et al., 2007; Tian et al., 2001; Zhang et al., 2012). Qiangyong Glacier is located on the north slope of the Himalayas, with a length of 4.6 km, a maximum width of 2.8 km and a total area of 7.7 km^2 (Luo et al., 2003). The average equilibrium line altitude of Qiangyong glacier is approximately 5600 m a.s.l. (Luo et al., 2003).

A proglacial lake is defined as a lake system that is formed not far from the glacier terminus during glacial melting and retreat and is directly supplied by glacial meltwater (Karlén, 1981). Situated at an altitude of approximately 4780 m a.s.l., Qiangyong Lake is the proglacial lake of Qiangyong Glacier and is less than 1 km from the glacier tongue (Fig. 1) (Li et al., 2011; Owen et al., 2005). Qiangyong Glacier Basin consists of two lakes: Da Qiangyong Lake, with an area of approximately 0.1 km^2 and a maximum water depth of approximately 18.5 m, and Xiao Qiangyong Lake, with an area of approximately 0.03 km^2 and a maximum water depth of approximately 4.5 m. The hydrological conditions of the two lake systems are directly affected by the melting intensity of Qiangyong Glacier. Glacier meltwater in the summer is the main water supply for the two lakes through the glacial terminus river and a river formed between the Da Qiangyong Lake and Xiao Qiangyong Lake (hereafter, the middle river). These rivers and lakes in Qiangyong Glacier Basin form a typically semi-enclosed lake system over the southern Tibetan Plateau (Owen et al., 2005). However, an outflow river formed beneath the basin of Da