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Study on the contribution of cryosphere to runoff in the cold alpine basin: A case study of Hulugou River Basin in the Qilian Mountains

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ABSTRACT

Global warming would inevitably lead to the increased glacier–snow meltwater and mountainous discharge. Taking an example the Hulugou River Basin in the Qilian Mountains, this study confirmed the contribution of cryosphere to runoff by means of the isotope hydrograph separation. The hydro-geochemistry and the isotope geochemistry suggested that both the meltwater and rainwater infiltrated into the subsurface and fed into the river runoff of the Hulugou River Basin in the form of springs. The isotopic composition of river water and underground water was close to the Local Meteoric Water Line, and the $\delta^{18}O$ and δD ranged among precipitation, glacier–snow meltwater and frozen soil meltwater. The results indicated that 68% of the recharge of the Hulugou River water was the precipitation, thereinto, glacier–snow meltwater and frozen soil meltwater contributing 11% and 21%, respectively. For tributary-1, precipitation accounted for 77% of the total stream runoff, with frozen soil meltwater accounting for 17%, and glacier–snow meltwater only supplied 6%. During the sampling period, the contribution of surface runoff from precipitation was 44% to tributary-2, and glacier–snow meltwater had contributed 42%; only 14% from frozen soil meltwater. For tributary-3, precipitation accounted for 63% of the total runoff, and other 37% originated from the frozen soil meltwater. According to the latest observational data, the glacier–snow meltwater has accounted for 11.36% of the total runoff in the stream outlet, in which the calculation has been verified by hydrograph separation. It is obvious that the contribution of cryosphere has accounted for 1/3 of the outlet runoff in the Hulugou River Basin, which has been an important part of river sources. This study demonstrated that the alpine regions of western China, especially those basins with glaciers, snow and frozen soil, have played a crucial role in regional water resource provision under global warming.

1. Introduction

The latest Intergovernmental Panel on Climate Change (IPCC) (2013) report firstly specified that the global average temperature showed a warming of 0.85 °C covering the period 1880 to 2012. The average rate of ice loss from glaciers around the world, excluding glaciers on the periphery of the ice sheets, was very likely 226 Gt/a over the period 1971 to 2009, and very likely 275 Gt/a over the period 1993 to 2009 (IPCC, 2013). Global mean sea level rose by 0.19 m during 1901–2010. From 1993 to 2010, global mean sea level was rising, which was consistent with the sum of the observed contributions from changes in glaciers (0.76 mm/a). In China, glacier thickness had decreased by 10.56 m from 1980 to 2005 owing to the accelerating mass loss (CMA, 2006). Glacier area had decreased by 15% from 1970 (53,005.11 km^2) to 2008 (45,045.2 km^2), and 5797 glaciers had disappeared in China (Yao et al., 2012, 2013); Permafrost in the Qinghai–Tibetan Plateau had experienced significant temperature increases and a widespread degradation during the last several decades, and the trend of snow-covered areas had also been decreasing in the past 50 years (Yao et al., 2013). With temperature rising, the area of the snowing and snow cover critical state had been greatly increased, resulting in the delay of the beginning time and ahead of the end date of the snow cover period in the Qinghai–Tibetan Plateau. Glacier ablation was accelerating, and the melting water had been increasing year by year, which caused the changes in the spatial and temporal distribution of water resources and the water cycle under climate warming (Li et al., 2010a, b,c, 2011, 2012; Yao et al., 2013; You et al., 2013, 2014). Based on the calculation by Ren et al (2011), the average meltwater runoff was 630 × 10^8 m^3 during 1961–2006 in China, and it increased from 518 × 10^8 m^3 in the 1960s to 795 × 10^8 m^3 during 2001–2006, which had contributed 0.12 mm/a to the global mean sea level rise.

As mentioned above, global warming would inevitably lead to the increased volume of glacier–snow meltwater and mountainous discharge, which would obviously give a profound impact on hydrologic process and water resources, especially in inland river basins. To some

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extent, it highly depended on the contribution of cryosphere system towards climate change, which has a significant influence on water resources management and flood control in alpine basins. However, the magnitude and variability of water system response to cryosphere impacts have not been assessed and are unclear. Qilian Mountains and Hexi corridor region are located in the northwestern China, and the three inland rivers directly sourced from glaciers, snow and frozen soil. The water shortage and low efficiency of water use made the people and agriculture very thirsty in the arid region. However, mountain-front discharge has increased about 10% in recent decades (Shi et al., 2003). In order to predict future changes in regional water resources, it is necessary to gain a good understanding of the contribution of cryosphere on mountainous discharge in Qilian Mountains.

Isotope hydrograph separation now is often used for analyzing possible source area contributions to stream flow (Hooper et al., 1990; Hooper, 2003). The method involves graphical analysis in which chemical and isotopic parameters are used to represent the designated end members. Tracer concentrations are constant in space and time. Essentially, the composition of the water changing can be looked as a result of intersections during its passage through each landscape zone. Tracers can be used to determine both sources and flow paths. Hydrograph separation can also be implemented to define the origin and composition of runoff by isotopes or the combination of isotopic and chemical tracers. Recently, the isotope hydrograph separation has been used to identify the recharge sources of stream water in different catchments (Buttle et al., 1995; Han and Liu, 2004; Huth et al., 2004; Gibson et al., 2005; Eckhardt, 2008; Liu, 2008; Liu et al., 2008; Peng et al., 2010, 2012a,b; Vanderzalm et al., 2011; Zhao et al., 2011; Kong and Pang, 2012; Ma et al., 2012; Pu et al., 2013). Nevertheless, these studies did not involve the contribution of cryosphere system and did not emphasize the importance of its meltwater.

In this study, taking the Hulugou River Basin in Qilian Mountains as an example, the analysis is firstly to explore the stable isotope and chemical composition of different water types during the sampling period, including precipitation, glacier–snow meltwater, frozen soil meltwater, spring water, well water, three tributaries water and the outlet river water, and then to: (1) calculate the ratio of precipitation, frozen soil meltwater and glacier–snow meltwater in the outlet river and tributaries; (2) evaluate the influence of cryosphere on alpine basins. The results are expected to provide an insight into water resources and its management for inland river basins.

2. Materials and methods

2.1. Study area

The Hulugou River Basin is located in the Qilian Mountains at Qinghai Province of China with the domain between 38.2°–38.3° N and 99.8°–99.9° E (Fig. 1). With a catchment area of 23.1 km^2, the basin is the water source region of the Heihe River. This basin has a gourd shape with an elevation of 2960–4820 m. There are 5 glaciers with a total area of 0.827 km^2 in 2011, and these glaciers constitute the runoff area and the headwater conservation zone of the Heihe River (Chen et al., 2013). The Shiyi glacier is the largest one, with an area of 0.463 km^2. The area above 4200 m is mostly covered by mountain glaciers and seasonal snow, which accounts for 8.4% of the total basin area and is the main distribution area of ice-snow water resources. The basin has a complicated terrain and an obvious zonary with the land surface covered by glaciers, snow, frozen soil, alpine cold desert, alpine brush, and mountain meadows from high to low altitudes. The entire basin is markedly influenced by the continental climate, and the annual mean precipitation ranges from 400 mm at low altitudes to 600 mm at high altitudes and mainly concentrates on the period from July to September. Thus, the period from May to October has been defined as the wet season (it is also the ablation season), and other months are the dry season. The runoff is mainly recharged by precipitation, glacier–snow meltwater and frozen soil meltwater. Among these sources, the meltwater is important and plays a vital role in water resources under climate warming. As the representative of Qilian Mountainous, the catchment of the Hulugou River is a suitable area for researching watershed hydrology in cold alpine regions.

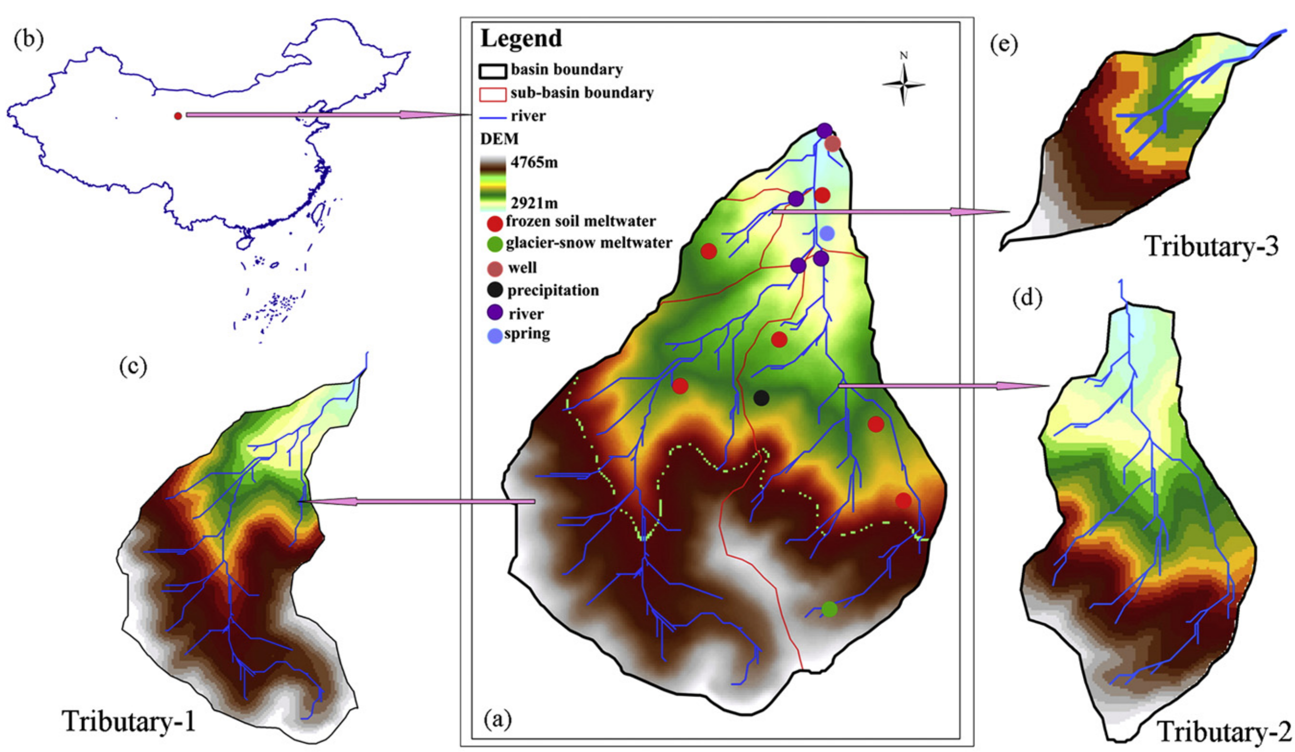

Fig. 1. Distribution of sampling sites in Hulugou River Basin (a), the location of Hulugou River Basin of China (b), tributary-1 (c), tributary-2 (d) and tributary-3 (e).