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Hydrogen and oxygen isotopic records in monthly scales variations of hydrological characteristics in the different landscape zones of alpine cold regions

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ABSTRACT

Monthly scale variations in stable isotopic composition in precipitation and various water bodies were analyzed in this study using data collected from a field station. Experimental observation was performed to analyze processes in the glacier-snow zone, alpine cold desert zone, marsh meadow zone, alpine shrub zone, and mountain grassland zone based on the isotopic and hydrochemical analyses of glacier, snow, frozen soil, groundwater, and other water sources in the headwater catchment of the alpine cold region. $\delta^{18}O$ and δD values of precipitation and various water bodies in Mafengou River Basin exhibited strong seasonal variations. Precipitation and various water bodies were rich in $\delta^{18}O$ and δD during the wet season and relatively negative in $\delta^{18}O$ and δD during the dry season. The isotopic content of various water bodies in Mafengou River Basin was dependent on temperature, elevation of the recharge area, and amount of precipitation. Lower temperatures were typically associated with lower $\delta^{18}O$ and δD values and are believed to be mainly responsible for the seasonal patterns observed in the isotopic values of various water bodies in Mafengou River Basin in the alpine cold region. Seasonal variations were larger in streams where recent precipitation is the main source of the flow and smaller in streams where groundwater is the dominant source of water.

1. Introduction

Many international hydrological research programs have focused on water basins. The combined study of oxygen and hydrogen isotopes in water is a powerful and promising tool for conducting hydrological research at the basin scale. Isotopic tracers can provide valuable information and data on the origin of streamflow components and runoff processes and yield insights that can help identify hydrological source areas or flow paths under different flow conditions (Catherne et al., 2010; Stumpp et al., 2009; Dmitry et al., 2007). Yang et al. (2012a) studied hydrological processes in the different landscape zones of alpine cold regions by combining isotopic and hydrochemical tracers. Many investigators have used the variable isotopic signatures of glacier, snow, precipitation, surface water, and groundwater to address complex hydrological questions, including evaporative rate calculations from the surface of a forested area and $\delta^{18}O$ and δD isotope analysis of natural waters around an active volcanic area. Stable isotopic tracers have been used to identify runoff pathways, residence times, the origin and contribution of each runoff component, and the characteristics of hydrological systems (Kevin et al., 2010; Andrew, 2009; Longinelli et al., 2008; Subyani, 2004).

Variations of $\delta^{18}O$ and δD in various water bodies have been used in a variety of hydrological, ecological, and climate studies. Many investigators have studied the variable abundances of $\delta^{18}O$ and δD in atmospheric moisture to determine short and long-term climatic variations in different geographic locations (Yang et al., 2011; Liu, 2007; Mul et al., 2008). An important issue that can be addressed by isotopic ratio analysis of precipitation samples involves the primary and secondary processes that control the evaporation–condensation cycle in a particular region. Some investigators have found that Iowa and its surrounding areas demonstrate significant seasonal variations in isotopic precipitation (MacKinnon et al., 2011; Emma et al., 2010; Iqbal, 2008; Liu et al., 2008). Simpkins (1995) reported isotopic variations between the Pacific moisture source and the Gulf of Mexico moisture source in central Iowa and attributed these differences in composition to seasonal variations in temperature. Harvey and Welker (2000) found substantial seasonal variations between winter and summer precipitation in the US north-central Great Plains. Yoshimura et al. (2003) used a Rayleigh-type isotope circulation model to quantitatively analyze short-term $\delta^{18}O$ and δD variability.

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Performing long-term stable isotope monitoring studies is important to improve our understanding of the hydrological characteristics in the different landscape zones in the river continuum (Yang et al., 2012a,b; Nives et al., 2008). To date, isotopes in catchments have been useful in assisting the conceptualization of runoff generation models (Kuczera and Mroczkowski, 1998). Diagnostic tools of mixing models and end member mixing analysis were combined to determine the water sources that contribute to stream flow (Liu et al., 2008), and is help to structure and validate hydrological models(Yao et al., 2009; Yamanaka et al., 2007; Weyhenmeyer et al., 2002).

Mafengou River Basin is an important and ideal region for the study of hydrology and water resources in alpine cold regions. A diversity of vertical vegetation zones and fragmented ecosystem landscape patterns exist in this basin with the distribution of glacier, snow, and frozen soil. However, limited research on the hydrogen and oxygen isotopic records of monthly scale variations in hydrological characteristics in the different landscape zones of alpine regions has been performed. Moreover, the influences of glacier, snow, and frozen soil on mountain runoff remain unclear.

This paper investigates glacier, snow, frozen soil water, precipitation, groundwater, and surface water in different landscape zones using isotopic tracers. The aims of this paper are (1) to document the spatial and temporal variations in the stable isotopic composition of Mafengou River Basin, and (2) to characterize hydrogen and oxygen isotopic records of monthly scale variations in hydrological characteristics in the different landscape zones of alpine regions. This paper provides a scientific basis for water and ecological management in the basin.

2. Area descriptions

2.1. Site description

The Mafengou River Basin is located in Qilian mountainous area in China, with latitudes 38°12′14″–38°16′23″N, longitudes 99°50′37″–99°53′54″E. Mafengou River Basin, with a catchment area of 23 km^2, is located in the alpine cold region (mean temperature 3.1–3.6 °C). The altitude ranges from 2960 m to 4820 m, spanning 1860 m. The Mafengou River Basin has a complicated terrain and an obvious vertical vegetation zonation. These landscape zones include glacier-snow, alpine cold desert, marsh meadow, alpine shrub, and mountain grassland zone. The Mafengou River Basin is an important area in the study of hydrology and water resources in alpine cold regions, and the basin has received political as well as academic attention. The glacier-snow zone elevation ranges from 4200 to 4820 m. Alpine cold desert zone elevation ranges between 3700 and 4200 m, accounting for 50.06% of the total area. The alpine cold desert zone has the most precipitation in the catchment, with an average precipitation of 570 mm between June and September. The alpine shrub zone elevation ranges between 3100 and 3550 m, accounting for 19.18% of the total area. The alpine grassland zone lies in relatively flat terrain, where the elevations range between 2960 and 3100 m, and accounts for 21.17% of the total area. As one of the representative areas in Qilian mountainous area, Mafengou River Basin is suitable for an integrated observation experiment, and it can be regarded as an ideal research basin in cold and arid regions.

2.2. Hydrogeological background

The study site is an area with strong tectonic structures. The lithology is dominated by Paleozoic–Mesozoic and Cenozoic sandstone, conglomerate, shale, limestone and slate, which have degenerated to different degrees (Nie, 2005). Igneous rocks and intrusive rocks from different periods are also present. The study area is a strong geological uplifting area. Because of strong uplifting mountain and serious rock weathering, precipitation and the active tectonic movement, there are sharp cutting valleys, steep slopes, well developed tectonic fissures, and rich bedrock fissures with water in the study area. There is abundant bedrock fissure water which is characterized by metamorphic and clastic rock dating from the Paleozoic to the Cenozoic. Rock aquosity and water-rich degree are impacted by the amount of structure and fissure development (Su and Feng, 2008). Pore-fissure water occurs mainly in the Late Paleozoic to Cenozoic strata. Permian–Jurassic pore–fissure water is mainly found in high mountainous areas, where the Quaternary deposits are mostly coarse sand and gravel. The strong tectonic erosion makes mountain hydrology network well developed, which is intensive and deep, with coarse sediment particles, good permeability, steep terrain and sharply cut gullies (Feng et al., 2004). The conditions are good for recharge, which increases the supply and confluence of runoff. Glacial melt water, seasonal snowmelt, precipitation and bedrock fissure water complete the generation and confluence of runoff through the mountainous area. While flowing to the mountain's margin, groundwater mostly discharges into the nearby valley and forms a river. In the waterproof zone of the mountainous area, a small portion of the groundwater along the faults and fissures of the alluvial river valley flows out in the form of subsurface and spring water. The study area has a large supply and discharge of groundwater and surface water, and it is also an ideal site in which to research hydrological processes in different landscape zones.

3. Material and methods

3.1. Sample collection

The research was carried out in Mafengou River Basin from 2008 to 2011. Samples of glacier, snow, frozen soil, surface water and groundwater were collected in the study area, as shown in Fig. 1. Glacier and snow samples were collected from the glacier-snow and alpine cold desert zones; 'groundwater was sampled in alpine cold desert and alpine shrub meadow zones; surface waters, frozen soil and precipitation were collected in each of the landscape zones. Altogether 265 samples were collected, and sealed with parafilm. The samples were taken back to the laboratory and preserved at 4 °C, and samples of frozen soil, glacier and snow were refrigerated at −20 °C until analysis.

3.2. Laboratory analyses

Water was extracted from frozen soil and soils by cryogenic vacuum distillation. Water samples were filtered through 0.2 μm Millipore membrane for trace elements analyses. Isotopes $\delta^{18}O$ and δD were measured in the Key Laboratory of Ecohydrology and River Basin Science of Cold and Arid Region Environmental and Engineering Institute, Chinese Academy of Sciences. $\delta^{18}O$ of water samples was analyzed by a Euro-PyrOH elemental analyzer at a temperature of 1300 °C, and δD was analyzed at a temperature of 1030 °C. At both temperatures the reaction products were analyzed on a GV ISOPRIMETM continuous flow IRMS. Every sample was analyzed 6 times. The precision of δD determinations was ±1‰, and that of $\delta^{18}O$ was ±0.2‰. Isotopic concentration was expressed as δ-per million (‰) relative to the Vienna Standard Mean Ocean Water, according to the follow equation:

$$\delta^{18}O(‰) = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}} \times 1000,$$

$$\delta D(‰) = \frac{(D/H)_{sample} - (D/H)_{SMOW}}{(D/H)_{SMOW}} \times 1000$$