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Stable isotopic and geochemical characteristics of groundwater in Kherlen River basin, a semi-arid region in eastern Mongolia

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Summary Inorganic solute ion concentrations and stable isotopes of oxygen and hydrogen in groundwater, river water and precipitation were investigated to gain insight into the groundwater recharge process in the Kherlen River basin, a semi-arid region in eastern Mongolia. The solute constituents in the river water (main stream) were of Ca–HCO_3 type, spatially invariant and low in concentration. Groundwater in the upstream region was also characterized by a Ca–HCO_3 type, though all ion concentrations were higher than in the river water. On the other hand, the chemical composition of the groundwater in the midstream region (southern and eastern) was spatially variable and the Na^+, Mg^{2+}, Cl^- and HCO_3^- concentrations were considerably higher than in the river water and upstream groundwater. The stable isotopic compositions showed an evaporation effect on the groundwater and river water, as well as an altitude effect in the precipitation and river water. Preferential recharge by relatively large rainfall events is thought to have caused the depleted isotopic ratio in the groundwater in the dry regions. The stable isotope, chemical and hydrological data suggest that the main stream water of the Kherlen River is recharged by precipitation that falls in a

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headwater region at an altitude of more than 1650 m, and that the interaction between the groundwater and river water is not dominant in the midstream and downstream regions of the river basin.

Introduction

In arid and semi-arid regions, domestic noncommercial, industrial and agricultural water uses depend largely on the amount of groundwater (Wang and Cheng, 1999). However, due to unsuitable management of water resources, several problems related to groundwater use have arisen such as extraordinary decline of the groundwater level in the High Plains, United States, the North China Plain, and the Delhi area, India (Brown and Halweil, 1998; Datta et al., 1996; Kondo et al., 2001; Rodell and Famiglietti, 2002; Tase, 2000). Sustainable control of water resources with sufficient understanding of the groundwater situation is therefore essential. In Mongolia, a semi-arid region of northeast Asia, more than 90% of the total population use groundwater for daily necessities (Sugita, 2003). Moreover, no management of the water resources has been carried out since destatization was established in 1990. Accordingly, it is highly probable that potential problems with groundwater resources will occur. In order to develop an effective water use system, it is first necessary to scientifically understand the behavior of groundwater. However, very few studies have previously documented groundwater resources in northeast Asia (Chelmicki, 1984).

The multi tracer approach using the isotopes and solute concentrations in water has been used for elucidating the origin of groundwater and the interaction between groundwater and river water in semi-arid and arid regions. Onodera (1996) suggested that preferential and partial infiltration under conditions of high rainfall intensity is a major mechanism of groundwater recharge in a tropical semi-arid region in Tanzania. In addition, Taniguchi et al. (1995), based on stable isotope and solute concentration data, clarified that in the Heife river basin, northwestern China, the groundwater originates from a mountain region. Moreover, Kabeya et al. (2002) compared the stable isotopic compositions of the groundwater between sand dunes and grassland in the Nu Us desert, China, and concluded that the stable isotopes of the groundwater in the grassland were concentrated as a result of evapotranspiration. Understanding the effect of evaporation on stable isotopes is an important factor in discussing the relationship between precipitation and groundwater (Boronina et al., 2005), and geochemical weathering is also known to affect the chemical compositions of groundwater and river water (Sami, 1992). Previous studies suggest the importance of temporal and spatial heterogeneity in infiltration, evaporation and groundwater recharge processes in arid and semi-arid regions (De Vries and Simmers, 2002; Gee and Hillel, 1988; Vogel and Van Urk, 1975). In other words, groundwater recharge is affected by site-specific conditions in these regions.

In the Kherlen River basin, eastern Mongolia, the spatial distribution of vegetation shows a clear change along the river. Mountain forest is distributed upstream in the basin while grassland, known as steppe, without any tall trees can be seen downstream. In addition, a discontinuous permafrost zone is also observed in the upstream region (Sharkhuu, 2001). Thus, there are many factors to be considered when discussing the hydrological processes in this basin. Hirabaru et al. (1999) described the geochemical composition of the groundwater in a central area of Mongolia and warned against a worsening of groundwater quality, while Davaa et al. (2002) investigated $\delta^{18}O$ and δD in the Tuul River, which flows into Ulaanbaatar, the capital city of Mongolia, and reported seasonal changes in the groundwater recharge system. Few studies, however, have investigated the isotopic and chemical characteristics of groundwater and discussed the recharge and flow system of groundwater on a catchment scale including multiple vegetation cover. The purpose of this study is to clarify the groundwater recharge and flow system in the Kherlen River basin, eastern Mongolia, using a multi-tracer approach.

Study area

The study area was located approximately 120 km east of Ulaanbaatar, the capital city of Mongolia (Fig. 1). The altitude of the main study area ranges from 1484 m at Mongenmorit (MNG) to 985 m at Underhaan (UDH), and the total length of the main stream of the Kherlen River is approximately 300 km from MNG to UDH. Mesozoic and Paleozoic granite and Carboniferous granite are dominant from the mountainous upstream area to Kherlenbayan-Ulaan (KBU) (Mineral Resources Authority of Mongolia, 1999). From KBU to UDH, the right bank of the Kherlen River mainly consists of Mesozoic sandstone, while Cenozoic sandstone or siltstone is distributed around the Darhan (DH) region and along the river. Sharkhuu (2001) showed that the southern boundary between the discontinuous permafrost region and no-permafrost region is found around Baganuur (BGN). Conifer trees such as larch are dominant in the mountainous region, upstream of MNG, whereas the flat plain downstream of BGN is dominantly covered by grass with a height of 5—10 cm during the growing season.

As summarized by Sugita et al. (2006) (Table 1) based on data obtained by the Institute of Meteorology and Hydrology (IMH), Mongolia, from 1993 to 2003 and aridity index data (AI; Budyko, 1974), it is relatively humid in the upstream regions of the Forest Site (FOR), MNG, BGN, and KBU, but relatively dry in the midstream region of DH and UDH. The discharge rate of the Kherlen River observed by the IMH at BGN, UDH and CHB from 1990 to 2000 is shown in Fig. 2. All gauging stations observe a high flow in the summer, with a slight decrease in the discharge rate as the river flows down from BGN to CHB, though the rate of decrease is small.