A Multi-tracer Approach to Characterize Hydrological Process in Kherlen River Basin, Eastern Mongolia

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1. Introduction

The purposes of this study focusing on hydrological processes in Kherlen River basin, eastern Mongolia, are to elucidate flow path and residence time of water using isotope tracers of ^{2}H, ^{18}O and ^{3}H, to determine the origin of precipitation, river water, groundwater and atmospheric water vapor, to investigate plant water use strategy using ^{18}O, and to investigate the soil erosion and overland flow processes using ^{137}Cs and ^{210}Pb. Modeling approach is also applied to support the results by tracer approach regarding atmospheric water vapor source and groundwater flow system.

2. Where does water vapor come from?

The stable isotopes of ^{2}H (D) and ^{18}O in precipitation, atmospheric water vapor and subsurface water were investigated at forest and grassland sites. Atmospheric water vapor was sampled at heights of 0.5–1000 m from the ground surface (throughout atmospheric boundary layer: ABL) using an aircraft and aboveground observations, and soil water was sampled at depths of 0.1–1.5 m by digging a trench and using suction lysimeters from June to October 2003. The δD and $\delta^{18}O$ of 230 water samples were determined (Tsujimura et al., 2006).

The $\delta^{18}O$ of precipitation in the forest and grassland sites showed clear seasonal variation from October 2002 to September 2003, with higher values in summer and lower values in winter. The $\delta^{18}O$ values in the atmospheric water vapor decreased from June to October 2003, parallel to those of precipitation. The vertical profile of $\delta^{18}O$ in the water vapor tended to show a gentle decrease with altitude in the atmospheric boundary layer at both the forest and grassland sites. This was caused by evapotranspiration and mixing with air in the free atmosphere over the atmospheric boundary layer.

Using the $\delta^{18}O$ of water vapor in the free atmosphere and evapotranspired water vapor on the 21st and 23rd August 2003, the contribution of free atmospheric water vapor in the water vapor in the ABL was evaluated as approximately 54–70% at forest site and 56–75% at grassland site. These estimated values suggest that evapotranspired water vapor is not dominant in the water vapor of the ABL especially above KBU. Thus, local recycling of water vapor does not play a significant role in the formation of water vapor in the ABL in the grassland region of the Kherlen River basin under a steady atmospheric condition. Yamanaka et al. (2006) showed that the isotopic composition of precipitation is primarily controlled by rainout history during transportation from the region outside of Mongolia as the ultimate origin to eastern Mongolia, and that continental recycling has a generally minor effect on isotopes in precipitation. Sato et al. also (in preparation) suggests inner Eurasia, Siberia and eastern China as source areas causing the atmospheric water vapor to eastern Mongolia by using regional climate model including isotope transport process.

We separated evaporation and transpiration components by Keeling plots analysis using the $\delta^{18}O$ of atmospheric water vapor and soil water. Accordingly, the ratio of transpiration rate to evapotranspiration rate was estimated to be 60–73% at the forest site and 35–59% at the grassland site.

3. Where are groundwater and river water recharged?

Inorganic solute ion concentrations and the stable isotopes 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 (Tsujimura et al., 2006). 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 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.

The ^{3}H concentration was used to estimate the residence time of groundwater. Groundwater in the upper stream region showed the similar ^{3}H value as recent precipitation. Thus, residence time of this groundwater was estimated to be relatively short after infiltration, less than 30 years. On the other hand, the ^{3}H concentration of groundwater in the mid and lower stream region showed very low values, suggesting long residence time of groundwater recharged before 1900, age more than 100 years. The results of three-dimensional simulation of groundwater flow also supported the evaluation of residence time by ^{3}H.

We also focused on the interaction between the groundwater and Kherlen River water considering the stream runoff and stable isotope data. The stream base flow discharge was measured in main stream and tributaries flowing into the main stream during a dry period in June 2004. The main stream runoff rate increased from 10.8 m^3/s to 12.6 m^3/s during a flow of 300 km. A simple mass balance model including runoff rate and stable isotope ratio in the stream was used to estimate the inflow rate of the groundwater into the main stream. The inflow rate was estimated to be 1.0 m^3/s/58km in the upper stream, whereas that of lower stream was estimated to be 2.6 m^3/s/247km. Thus, approximately 10 % of the stream runoff was recharged by groundwater in the upper stream in the Kherlen River.

The available volume of groundwater in specific wells was estimated using a simple mass balance method shown in the following equation.

$$A(P-E)-G_{out}-U=\Delta S$$

where A: area of watershed gathering the groundwater in a specific well, P: precipitation, E: evapotranspiration, G_{out}: discharge of groundwater, U: pumping volume of groundwater, ΔS: change of storage (change of water table). Suppose steady state, the change of water table in a well should be minimum for sustainable use of the well. The available groundwater volume in the specific wells was estimated to be 20 to 200 m^3/day. Given the water use volume by a nomadic man to be 30 L/day, 670 to 6230 nomadic people can depend upon the well. Considering the inter-annual variation of precipitation in Mongolia, these values seem to be not enough, and the water resource in the grassland is fragile depending on the groundwater.

4. Summary

In the present study, the hydrological process was clarified qualitatively and quantitatively by multi-tracer approach combining with the numerical simulation technique in Kherlen River basin, eastern Mongolia. This is a first scientific research to apply the multiple tracers to a specific basin throughout the hydrological and mass transport processes in an inland region of northeastern Eurasia, and every finding should be referred internationally not only in the field of hydrology but also meteorology, hydro-geomorphology and eco-hydrology in future.

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