Groundwater recharge process in the Kherlen River basin, eastern Mongolia

TANAKA Tadashi[1], ABE Yutaka[2] and TSUJIMURA Maki[1]

[1] Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Japan
[2] Metocean Environment INC, Tokyo, Japan

Key words: semi-arid region, aridity index, stable isotope ratio, river flow system, groundwater flow system, recharge process

I Introduction

Many quantities of water resources for life and social needs in arid and semi-arid regions are often depending on groundwater. However, the management of groundwater resources is not enough and many problems related to groundwater resources such as decline of water table and salinization of groundwater are occurred in the world in recent years. No exception is true in Mongolia. The situation of water use in Mongolia, nearly 60% of population use the groundwater resources for life water and this figure reaches over 90%, if include the city water originated in groundwater (Sugita, 2003). In Mongolia, however, the Negdel organization has broken down since introduce the market system in 1990. Accordingly, the management system for maintenance of wells also broke down and it is reported that many wells about 40 to 50% of 43,000 wells in 1989 including both shallow and deep wells could not be used in 1996 (Mori, 2003). Especially, mortar driven deep wells has been collapsed or abandoned more than 80% of about 7,800 deep wells, and the source of water supply has been sifted to the former shallow wells (Hirahara and Shimotsu, 1999). On the other hand, the number of stocks which need water as well as human being increases more than 30% during the period from 1990 to 1999, and the density of the stock per unit area increases more than 80% in recent years (Mori, 2003). In addition to the mentioned above condition in Mongolia, increase of surface temperature and decrease of precipitation according to the climate change in recent years were reported (Yatagai and Yasunari, 1994).

This paper describes the groundwater recharge process in the Kherlen River basin in rangelands of Mongolia based on the observed data of water quality and stable isotope ratios in river, spring and ground waters and the continuous monitoring of soil water contents.

II Study area and methods

The study area shown in Fig. 1 is located at about 120 km east of Ulaanbaatar with an area of nearly 40,000 km^2. The altitude of the area ranges from 980 to 1,500 m a.m.s.l. The vegetation changes from taiga forest in the upper most area to the steppe through the forest steppe in the middle of study area.

Observations were carried out in twice in July and October, 2003, and collected 117 water samples in total of river, spring and ground waters. These samples were analyzed for general water quality and hydrogen and oxygen stable isotope ratios. In addition, EC, pH, depth of water table and depth of the well bottom were also measured at the time of collecting waters. Moreover, soil water contents were continuously monitored at both locations of the forest site located at the most upper observation area and the grass land site of the Kherlenbayan-Ulaan (KBU) using the TDR method.

III Results and discussion

Fig. 2 shows the δ-diagram of precipitation, river, spring and ground waters in the study area. As seen in Fig. 2, all of water samples of river water, spring water and groundwater are distributed in the range of δ-diagram of precipitation. This means that the source of these terrestrial waters is originated to the meteoric water. The slope gradient of regression lines of precipitation and river water is about 8, corresponding to those of the GMWL. On the other hand, the slope gradients of spring and ground waters are rather small than that of precipitation, indicating evaporation effect occurs.

Although the composition of water quality of both river and ground waters shows a Ca-HCO_3 type, total ion concentrations of groundwater are much higher than those of river water as seen in Fig. 3. This fact indicates that little interchange between river and ground waters occurs in the study area from the view point of water quality.

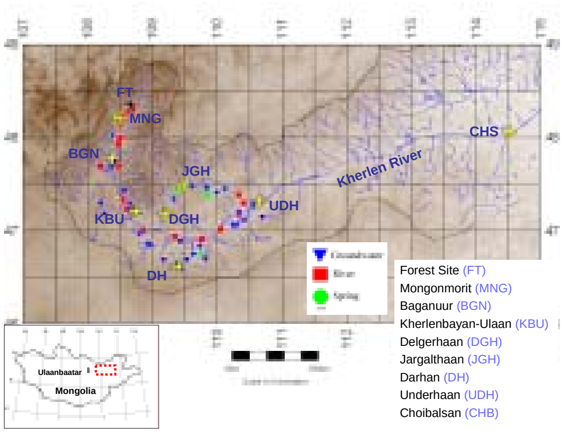


Fig. 1 Study area.

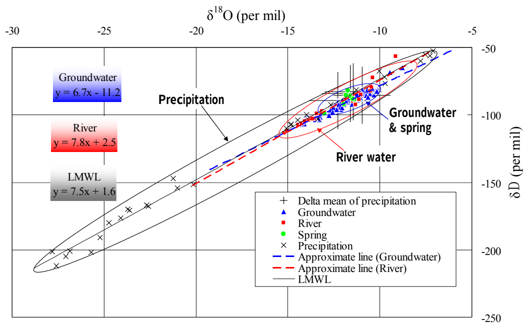
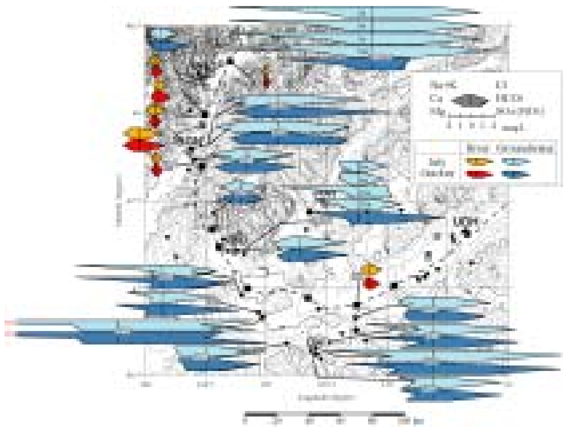


Fig. 2 δ-diagram of precipitation, river, spring and ground waters.



(July and October, 2003)

Fig. 3 Composition of water quality of river and ground waters.

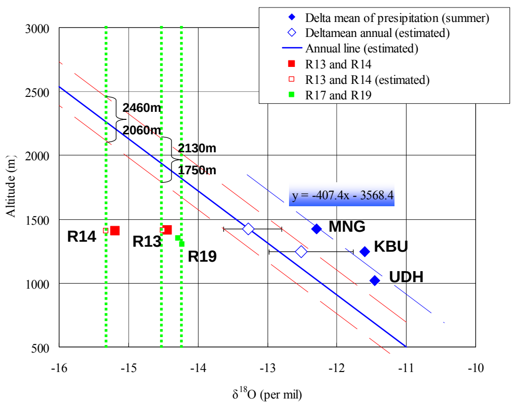


Fig. 4 Recharge altitude of Kherlen River water estimated from the altitude effect of $\delta^{18}O$ of precipitation.

Recharge altitude of Kherlen River water was estimated based on the data of altitude effect of stable isotope ratios of precipitation and those of river water as shown in Fig. 4. Estimated recharge altitude of Kherlen River water ranges from 1,750 to 2,500 m a.m.s.l., indicating that the main stream water of Kherlen River is recharged by the precipitation fallen in the upper most area of the Kherlen River basin. The inter-annual change of Kherlen River discharge from 1990 to 2003 indicates that there is no increase of discharge in the lower reach from the Baganuur (BGN) station at where the altitude is about 1,350 m a.m.s.l. In addition to the fact mentioned above, changes of $\delta^{18}O$ and d-value of river water along the main stream reach of about 300 km distances in the study area indicate that discharge loss occurs due to the evaporation from the river water surface. These facts mean that the interchange between river and groundwater in the study area is not so much actively.

The relationship between Cl^- concentration and the d-value of groundwater shows that the Cl^- concentration increases with the decline of d-value, indicating there occurs the condensation of Cl^- ion due to the evaporation effect. Furthermore, the relationship between the concentrations of HCO_3^- and the tritium of river and ground waters shows the trend that the concentration of HCO_3^- increases according to the decrease of tritium concentrations. These relationships among water qualities mean that every data of Cl^- concentration, HCO_3^- concentration and d-value could be used as a good tracer for considering the groundwater flow system in the study area.

Fig. 5 shows the groundwater flow system along the cross section of northeast-southwest direction originating from the Kherlen River at near the Darhan east based on the data of spatial distribution of water quality and stable isotope ratios. This figure shows that the relationship of interchange between river and ground waters in the study area is restricted to a very narrow extent of 2 to 10 km distances from the river channel. Furthermore, the flow system of shallow groundwater in the grass land of the study area prevails local flow system depending on the relief of the topography with a few components of the regional groundwater flow system over the entire grass land. Many wells distributed on the grass land are usually ducked in a small depression area with several 100 m scales in distance. Therefore, in those sallow wells the possibility is high to use the water supplied from these very narrow areas.

Fig. 6 shows the δ-diagram of groundwater in each region. This figure indicates that values of δD and $\delta^{18}O$ of groundwater in each region distribute in a rather round range on the diagram. To indicate the aridity condition of each region, the Aridity Index (AI) is shown on the figure. AI is defined as,

$$AI = P / RET \qquad (1)$$

where P is the mean annual precipitation (mm) and PET the Penman mean annual potential evapotranspiration (mm) (UNESCO, 1979; Simmers, 2003), viz.:

$AI < 0.03$: hyper-arid region
$0.03 < AI < 0.20$: arid-region
$0.20 < AI < 0.50$: semi-arid region

In this study, the figure of AI in each region shown on the figure was determined by the corresponding data of mean monthly value in 1988. It is obvious that the study area is defined as a semi-arid region and the aridity condition in south regions of the study area such as the Darhan (DH) and the Underhaan (UDH) is more stronger than those of the north regions. Furthermore, Fig. 6 indicates the fact that the stable isotope ratio in the region with high aridity condition shows relatively low value comparing with those in the region showing the opposite aridity condition. In general, stable isotope ratios of soil and ground waters have a tendency to shift in more high value due to the condensation effect of evaporation according to increase the aridity condition. However, the result represented in Fig. 6 shows the reverse tendency of the relationship between the stable isotope ratio and the aridity condition in the study area. The results suggest that there is a possibility to occur the different recharge process depending on the degree of the aridity condition even within the same semi-arid region.

Figs. 7 and 8 show the time variation of soil water contents in July and August, 2003 at the forest site (FT, AI: 0.81) and the grass land site (KBU, AI: 0.51), respectively. Time variation of soil water contents was determined based on the data of 6 hours' average value in a day. At the forest site, it can be seen the increase of the soil water content to a depth of about 1 m following after the total rainfall amounts of 20-30 mm, indicating the percolation process will occur to reach deep depth corresponding to the measure of above mentioned rainfall amounts. On the other hand, at the grass land site of KBU, where the aridity condition is relatively high, the measure of total rainfall amounts of 20-30 mm could not cause the percolation to reach more deep depth, but affect increasing the soil water contents only in a very shallow surficial layer as seen in Figs. 7 and 8.

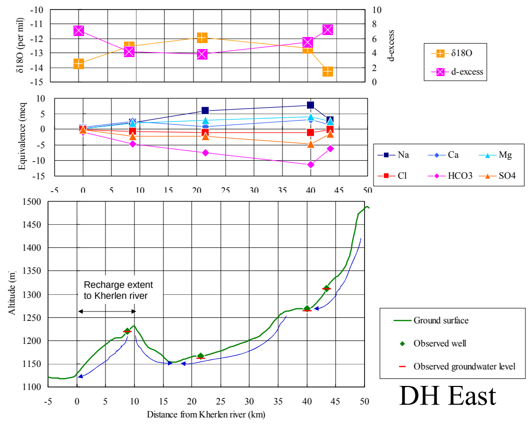


Fig. 5 Estimated groundwater flow system in around the Darhaan east.

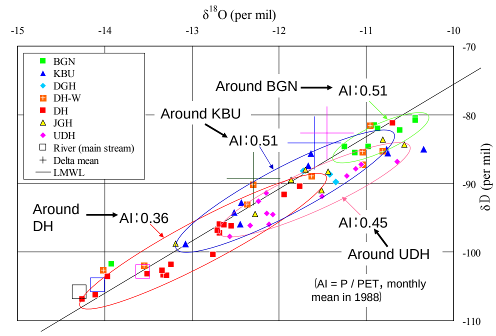
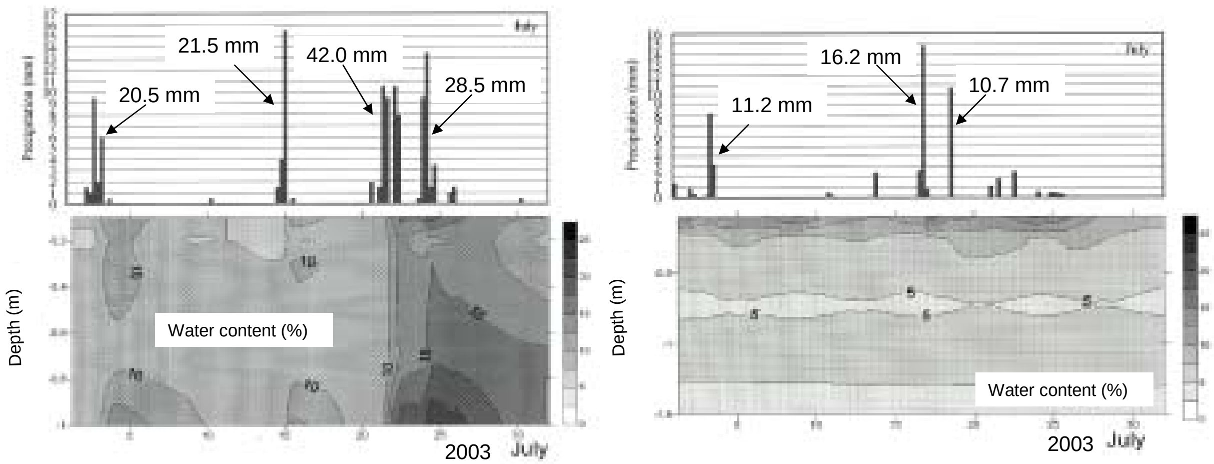
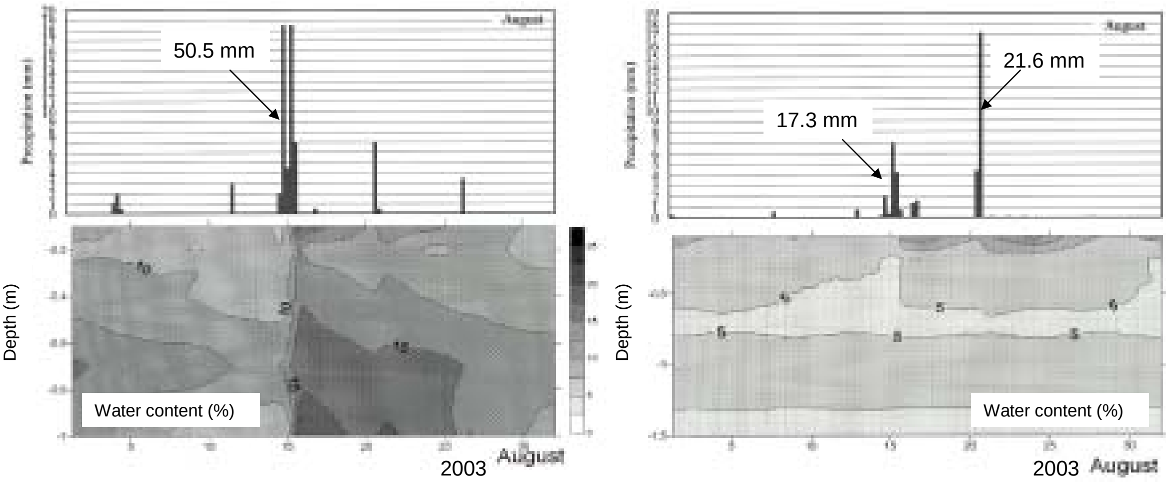


Fig. 6 δ-diagram of groundwater in each region.



Forest site (FT, AI: 0.81)　　Grass land site (KBU, AI: 0.51)

Fig. 7 Time variation of soil water contents at FT and KBU in July, 2003.



Forest site (FT, AI: 0.81)   Grass land site (KBU, AI: 0.51)

Fig. 8 Time variation of soil water contents at FT and KBU in August, 2003.

Although the infiltrated rain water into the soil layer is subjected to the evaporation effect even in the region with relatively low aridity condition, infiltrated water remains in partly in the soil layer and is pushed down by the following rainfall event, causing the groundwater recharge. Therefore, the stable isotope ratio of the groundwater shows relatively high value in these regions. On the other hand, in the region with relatively high aridity condition, infiltrated water with the low rainfall intensity evaporates entirely and the effect of the condensation due to the evaporation phenomena on stable isotope ratio in soil water does not remain in residual soil water. In these regions, groundwater recharge will be caused by only the rainfall event with high intensity and more than 30 mm of total rainfall amounts. According to the fact that the rainfall amount effect was observed in the study area, it is considered that the stable isotope ratio of infiltrated water accompanying large amount of rainfall event shows a relatively low value. Therefore, the stable isotope ratio of groundwater in these regions has relatively low value comparing with those in the region of low aridity condition.

IV Concluding remarks

The characteristic of shallow groundwater resources in the grass land covered large area in Mongolia is very vulnerable from the view point of groundwater flow system and the recharge process as mentioned in the paper. It is necessary to reinforce the management urgently for the groundwater resources in Mongolia depending on the quantitative evaluations for sustainable use as valuable resources for a life.

References

Hirahara, O. and Shimotsu, Y. (1999): *Yousui to Haisui*, **41**, 783-790. (in Japanese)

Mori, S. (2003): *Kagaku*, **73**, 594-598. (inJapanese)

Simmers, I. (2003): *IAH Int. Contri. Hydrogeol.*, **23**, 1-14.

Sugita, M. (2003): *Kagaku*, **73**, 559-562. (in Japanese)

UNESCO (1979): *MAB Tech. Note.*, **7**, 54p.

Yatagai, A. and Yasunari, T. (1994): *Jour. Meteor. Soc. Japan*, **72**, 937-957.