沙漠研究 **24**-1, 97-100 (2014)
Journal of Arid Land Studies

Groundwater Recharge Revealed by Multi-tracers Approach and EMMA in Semi-arid Irrigated Village, Heihe River Basin, Northwest China

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Abstract: A hydrological field survey using multi-tracers was performed to identify groundwater recharge sources and those contribution rates at the village scale in an irrigated area in a semi-arid region. Groundwater, river water and irrigation water samples were taken in Pingchuan village which is irrigated by river water and groundwater in Heihe River basin, Northwest China in August 2010. Major inorganic solute compositions and Hydrogen and Oxygen stable isotopes were analyzed and End Member Mixing Analysis (EMMA) was calculated using two tracers of Cl and δD, and end members of Heihe River main stream, Liyuanhe River as branch and old groundwater outside of irrigated area. Ion compositions of groundwater in the irrigated area tended to be similar to river water as Ca, Mg - HCO_3 type and the groundwater also had similar isotope compositions to river water. Recharge contribution calculated by EMMA showed high contribution of water from the Heihe main stream and Liyuanhe River. Thus, it is suggested that groundwater in this village is not only recharged by the Heihe River main stream via irrigation activities but also by branches such as Liyuanhe River. On the other hand, a few groundwater samples had Na^+, Mg^{2+}, Cl^-, SO_4^{2-} dominant and high concentrated water quality and lower isotopic compositions. The high concentrated groundwater located along the boundary between Gobi desert area and the irrigated area tended to have relatively high contribution rates of old groundwater outside of the irrigated area which indicate low sustainability and possibility of soil salinization for irrigation farming. Our results indicate that there are significant differences between the irrigated area and marginal area in groundwater quality and recharge system even at the small village scale.

Key Words: Contribution rate, EMMA, Groundwater recharge, Heihe river basin in Northwest China, Multi-tracers

1. Introduction

Social concerns regarding the conservation of water resources have been growing for the last several years. Especially in arid and semi-arid regions, groundwater tends to be the main water resource due to lack of surface water. There are several issues to be addressed such as rapid depression of groundwater level caused by unrestricted pumping without any strategies of sustainable groundwater management based on scientific information in irrigated farm areas. Thus, it is essential to have a sustainable control of water resources with enough understanding of the hydrological cycle such as groundwater recharge and flow processes especially in arid and semi-arid regions.

Previous researches show that geochemical approaches such as stable isotopes, radio isotopes and inorganic solute concentrations are effective ways to determine groundwater recharge and flow processes in arid regions (Scanlon *et al*., 2002). Many hydrological studies observed that groundwater recharge flow processes tend to be preferential or inhomogeneous in scale and time in arid and semi-arid regions (Onodera, 1996; Tsujimura *et al*., 2007). However groundwater recharge system in relation to human effects such as in irrigation activities is not widely understood. Abe *et al*. (2011) observed local characteristics of geochemical and isotopic compositions in upper, middle and lower reach in irrigated areas in Zyangye flat plain in the center of the Heihe River basin. They also noted complex groundwater recharge processes in middle reach. Thus, there is a need to detail observations in a smaller scale.

Therefore the purpose of this presentation is to identify local characteristics of groundwater recharge resources and those contribution rates in small scale (*i.e.* village scale about 20 km) in a semi-arid irrigated region in northwest China.

2. Study Area

The study area was set in the Pingchuan region which is a village that primarily uses irrigated farmland for cultivation and is located in Heihe river middle basin, northwestern China (**Fig. 1**). The upper basin is comprised of mountains up to 4,000m in elevation called Qilian Mountains. The annual precipitation ranges from 300 to 500 mm a year and glaciers

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(Received, September 15th, 2013; Accepted, March 5th, 2014)

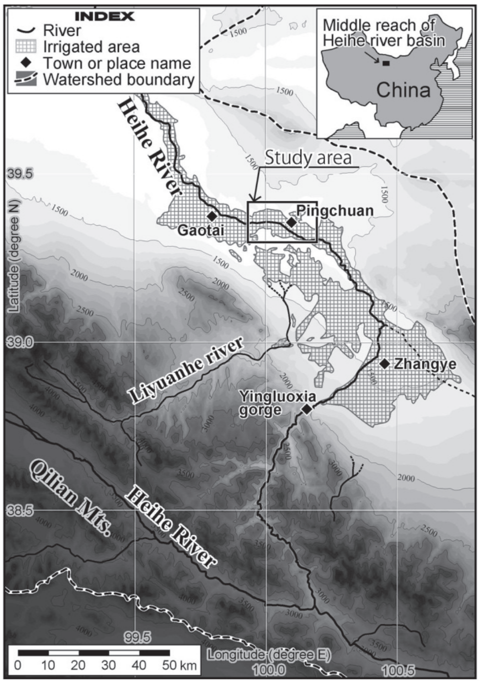

Fig. 1. Topography of Heihe river basin and location of Pingchuan region. Black lines show river line of Heihe river and their branches flowing from Qilian Mts. Study area shown by square is located in meshed irrigated region.

are present. The middle basin where Pingchuan region is located is in a semi-arid region with average precipitation of less than 200 mm a year (Wang and Cheng, 1999). In this region, people take Heihe River water from the upper mountainous region for irrigation through concrete canals widely spread in farmland to produce mainly maize and wheat from May to September. Therefore the mountainous area provides the main water source for the irrigated region in the middle basin. Because of problems such as river dry-up and decreasing groundwater levels in the lower basin caused by overuse of irrigation water in the middle basin, regulation of river water for irrigation has been enforced since the beginning of 2000. This intervention caused groundwater use to increase as the alternative water resource (Yamazaki, 2006). In such severe condition of groundwater overexploitation, it is important to understand the groundwater recharge and flow system. Abe (2012) suggested that the sources of groundwater recharge may be not only Heihe River by irritation water but also the Branch River in the middle basin of Heihe River.

The geological setting on alluvial fan and flat plain of the irrigated area is underlain by Quaternary deposit with the depth of approximately 100 m (Hu *et al*., 2007).

3. Methodology

Field work for inorganic solute concentrations and Hydrogen and Oxygen stable isotopes analysis of river and

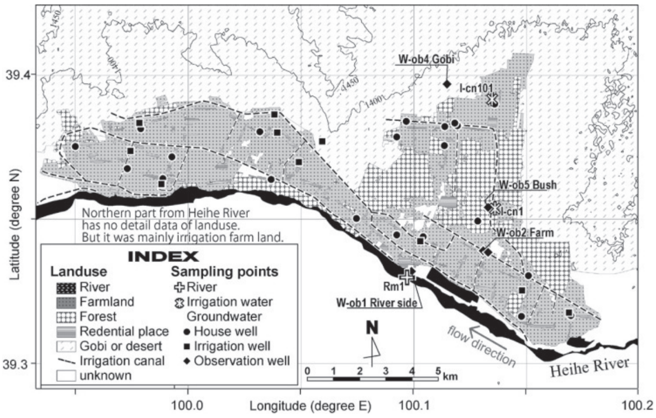

Fig. 2. Land use of study area and sampling sites in Pingchuan region in middle basin. Land use data is modified by authors after non published data of Cold and Arid Regions Environmental and Engineering Research Institute, CAS, China. Land use in Southern part of the map from Heihe river is unknown. However, it was confirmed by authors that land use in those regions is mainly irrigated farmland.

groundwater in Pingchuan village in the middle basin of Heihe River were performed from 9th to 13th August 2010. Groundwater samples from 37 sites and 1 sample from Heihe River, the source of irrigation farming, were taken in Pingchuan village (**Fig. 2**). Also, irrigation canal water in Pingchuan village and river water in Liyuanhe River which is major branch of Heihe River basin were sampled.

Groundwater samples were collected from basically 3 types of wells: house wells, farm wells, and observation wells. "House wells" are in farmer's houses for daily use with depths ranging from 5 to 20 m. "Farm wells" are for irrigation water and are relatively deeper than other wells with depths ranging from 20 to 100m. "Observation wells" are owned by Cold and Arid Regions Environmental and Engineering Research Institute, CAS, China. Their depth ranges from 10 to 15 m. Because those wells were constructed for groundwater research, they are not used daily.

Major inorganic solute concentrations (HCO_3^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Mg^{2+}, Ca^{2+}, Si) and Hydrogen and Oxygen stable isotopes (δD, $\delta^{18}O$) were measured in water samples at the University of Tsukuba, Japan.

End Member Mixing Analysis (EMMA) is an effective way to identify the contribution rates on discharge of each resource from geochemical data. Contribution rates are calculated using tracers such as inorganic solute concentrations and isotopes on the condition that discharge consists of only mixing from groundwater and soil water in the catchment (e.g. Hooper *et al*., 1990). Contribution rates "f" are calculated by following mass balance equations.

$$\begin{aligned} & f_a + f_b + f_c = 1 \\ & C1_a f_a + C1_b f_b + C1_c f_c = C1_{gw} \\ & C2_a f_a + C2_b f_b + C2_c f_c = C2_{gw} \end{aligned} \qquad (1)$$

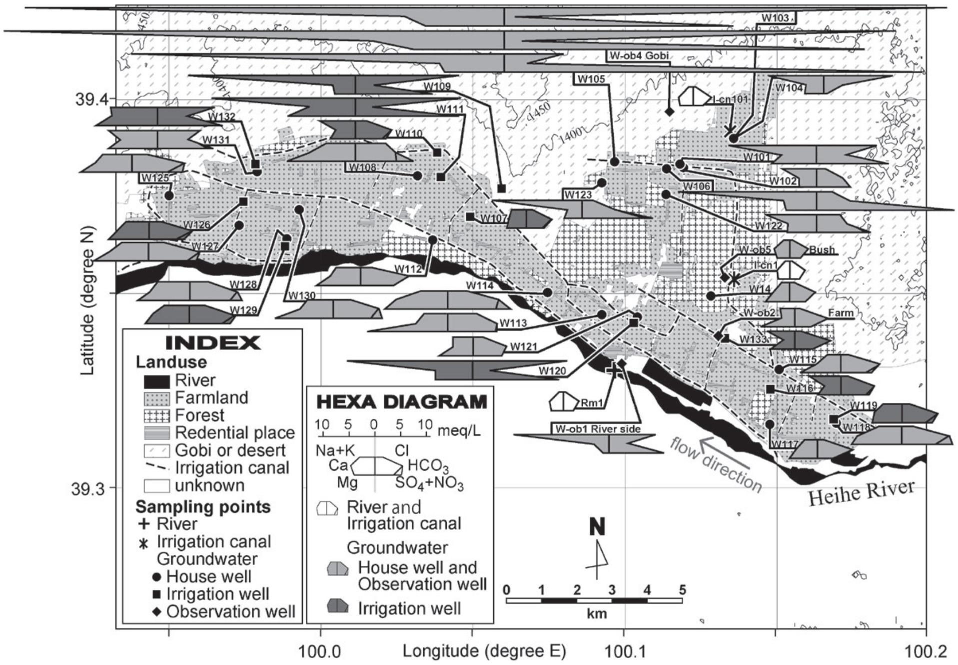

Fig. 3. Spatial distribution of water quality of groundwater and river water with hexa-diagram in Pingchuan village.

Where C1 and C2 are concentrations of tracers and a, d, c are component of end members. In this study, we endeavored to calculate which source water contributes to each groundwater.

According to previous research of groundwater recharge resource (Abe, 2012), Heihe river main stream water and branches which infiltrate into irrigated area from NE side of Qilian Mountains are important sources of groundwater in the irrigation flat plain. Third End member should be identified from an area outside of the irrigated area which does not seem to have interaction between river or irrigation water. It was observed that the groundwater outside of the irrigated area has longer residence time (before 1950) than other groundwater using Tritium analysis. Thus, site Rm.3 as “Heihe River main stream” which can be irrigation water, site Rb.102 as “Branch from NE side of Qilian Mountains” (Liyuanhe River) and site W-ob.4 gobi as “old water outside of irrigated area” were decided as end members. Chloride concentrations and δD were chosen as tracers.

4. Results and Discussion

4.1. Inorganic solute concentrations and isotopes

Figure 3 shows spatial distribution of inorganic solute concentrations in groundwater and river water with hexa-diagram in Pingchuan village. Ion compositions of groundwater located in the irrigated area near Heihe River tended to be similar to river water as Ca, Mg - HCO_3 type. On the other hand, there were a few samples having Na, Mg, Cl, SO_4 dominant and high concentration of ion compositions. Those highly concentrated groundwaters were located along the boundary between Gobi desert area and irrigated area.

4.2. End member mixing analysis and sustainability of groundwater

Figure 4 shows spatial distribution of contribution rates of groundwater calculated by EMMA. Contribution rates showed high contribution of Heihe main stream and Liyuanhe River. It is suggested that groundwater in this village recharged by the Heihe River main stream by irrigation activities as well as branches such as Liyuanhe River via groundwater.

On the other hand, a few groundwater sites showed relatively high contribution of old groundwater outside of irrigation. This groundwater is generally located on the edge of the irrigated area and has high concentrations of ion compositions. These results indicate low sustainability of water resources for irrigation farming and possibility of soil salinization. Furthermore, there are significant differences between the irrigated area and marginal area in groundwater water quality and recharge system even on a kilometer scale.

5. Conclusion

A hydrological field survey using multi-tracers was performed to identify groundwater recharge sources and those contribution rates on a village scale in an irrigated area in the semi-arid region, Heihe River basin. Groundwater in the irrigated area was found to be recharged by the Heihe River main stream by irrigation activity and branches such as Liyuanhe River via groundwater. On the other hand, a few

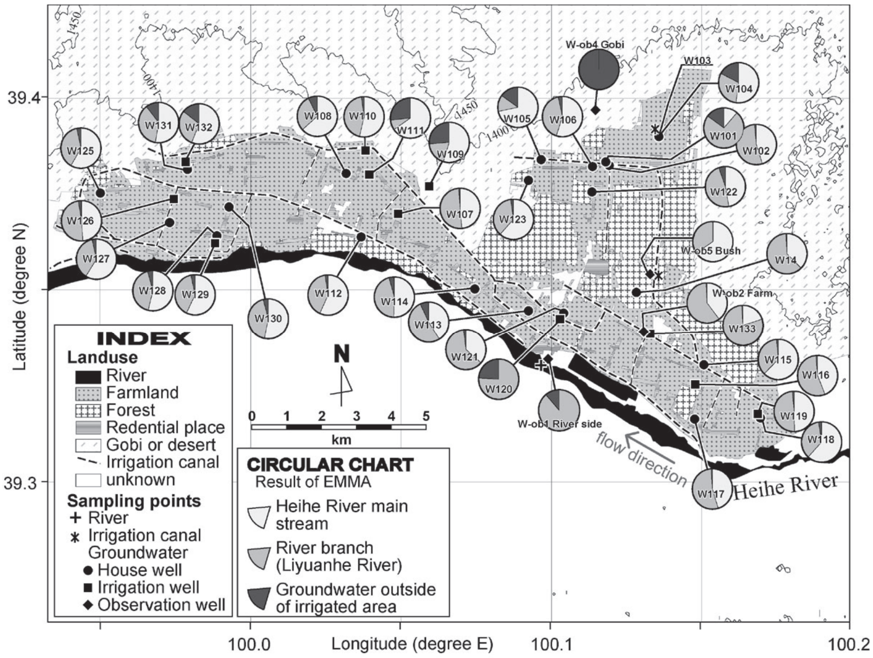

Fig. 4. Spatial distribution of contribution rates of groundwater calculated by EMMA in Pingchuan village.

groundwater sites in the marginal area showed significant difference such as high contribution rates of old groundwater outside of the irrigated area and higher concentrations of ion compositions. Those results indicate that groundwater in the marginal areas has low sustainability for irrigation farming and possibility of soil salinization exists at short distances from the irrigated area. We observed inhomogeneous groundwater quality and groundwater recharge processes even at the village scale in this semi-arid irrigated area.

Appendix

The authors would like to heartily thank Prof. Xiao HL., Dr. Zhao LJ., Dr. Ren J. and Dr. Yang Q. (Cold and Arid Regions Environmental and Engineering Research Institute, CAS, China) for all the support on field survey in China. This work was financially supported by Precipitation change in western China during Qing Era reconstructed with the official document data.

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