Surface Water and Groundwater Interaction with Hydro-chemical Processes in Tuul River Basin, Mongolia

(モンゴル・トゥール川流域における地表水ー地下水の交流と水質形成過程)

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Abstract

Groundwater and surface are hydraulically connected with each other. Therefore, a good understanding between groundwater and surface water interactions could provide important scientific insights for integrated water resources management. The most processes are influenced by the connection between these two water bodies. This means that the interactions between groundwater-surface water need to be evaluated and combined into the management response to a range of water quantity and quality issues.

Hydro-chemical and stable isotope tracing approaches, and multivariate statistics, and End Member Mixing Analysis (EMMA) were applied to groundwater and surface water (rivers, springs, canals, and wastewater) to study the spatiotemporal geochemical and stable isotope characteristics, groundwater and surface water interactions, the main processes and controlling factors within the system.

δD and $\delta^{18}O$ results showed spatial variation among sampling sites, indicating different isotopic fractionation through physical and chemical processes along different water flow paths and different water sources. The slight temporal changes observed in the flood plain area groundwater (municipal wells) and Tuul River water, possibly related to snowmelt and precipitation runoff, and solid-state precipitation at sub-freezing temperatures. The most samples were plotted above the LMWL, possibly due to precipitation and runoff of snowmelt, therefore evaporation effect insignificant in the study area.

The analysis revealed spatiotemporal variations and interactions between groundwater and surface water. Ca-HCO_3-type water dominated the study area, representing 70.7% (summer) and 81% (winter) of the samples. The chemical and isotopic values presented some

spatial differences but minimal temporal changes, except in downstream Tuul River water. The Tuul River was mostly characterized as Ca-HCO_3-type water, but varied temporally and spatially, shifting to Ca-Na-HCO_3-type water in summer and Na-Ca-HCO_3-type in winter in the downstream region after wastewater discharge. The similarity in the stable isotopes and chemical characteristics of floodplain groundwater and river water was suggestive of interactions between alluvial groundwater and Tuul River water, whereas sampling locations far from the river had higher hydro-chemical and isotope values.

Hierarchical Cluster Analysis (HCA) classified water samples into 4 clusters (C1-C4) according to hydro-chemical facies. The samples from C1 (fresh water in upstream area), C2 (slightly polluted water in downstream area), and C4 (mineralized and polluted water in north mountain area) were Ca-HCO_3 type, and their electrical conductivity (EC) demonstrated an increasing trend following the order in both seasons. The samples of C3 (polluted water-springs, canal and wastewater) were Ca-Mix type in summer and Na-HCO_3 and Na-Ca-HCO_3 type in winter. HCA demonstrated groundwater and surface water interaction in the floodplain area, and hydrochemistry of the study area was related to human impacts in addition to hydrogeology and geology. Nitrate was a significant contribution to conductivity, and highly correlated with major ions (Ca, Mg, Na, SO_4, CI, HCO_3) indicating pollution inputs; its correlation with EC also decreased in winter (from r=0.885 to 0.575), indicating reduced dilution of runoff processes and infiltrations due to freezing of the subsurface as shown by correlation analysis.

Four principal components in summer and three principal components in winter were extracted, representing 86.9% and 83.8% of the total variance in the geochemistry. In summer, PC1 represents the pollution and mineral weathering processes and rock-water interactions. Moreover, PC2 indicates the regional flow system and mineral weathering, PC3 represents the silicate weathering and pollution, whereas PC4 indicates physical processes. In winter, PC1 and PC2 represent mineral dissolution and anthropogenic inputs, whereas PC3 indicates physical processes. In the winter season, the number of components decreased and also the cumulative variance was as low as 84%. This is because the number of processes decreased due to the freezing of the river, and solid-state precipitation. The scatter diagrams show that carbonate and silicate weathering, and ion exchange, are dominant processes controlling the water system. The oversaturation of calcite in some samples indicates that the

groundwater is discharging from an aquifer having abundant calcite mineral with enough resident time.

The results of EMMA demonstrated that the contribution ratio of the Tuul River, north mountain groundwater and south mountain groundwater to flood plain groundwater estimated to be ranging from 47% to 92%, 4% to 21%, 3% to 47%, respectively in summer season. In winter season, the contribution ratio of each components ranging from 56 to 94%, 0% to 22%, 7% to 33%, respectively. Generally, Tuul River water contributes dominantly to flood plain groundwater.

Based on the results of the multi-tracer approach and multivariate analysis concluded that there are two zones, first zone has low mineral Ca-HCO_3 type water with short residence time along and near the flood plain area dominated by carbonate weathering process. Second zone has mineralized and polluted water with long residence time representing sites in the north mountain side. In this zone, most of the samples had Ca-HCO_3 type and contained high nitrate concentrations, the dominant processes were silicate weathering and ion exchange.

Overall, this study demonstrates the usefulness of combined approaches for data interpretation, and understanding of spatial/temporal variations, pollution sources in hydrochemistry, dominant geochemical processes, recharge mechanisms and future spatial sampling plan in an optimal way; it offers a reliable classification of sampling stations in the region, especially along Tuul River. Furthermore, time series data with more detailed investigation of lithology in aquifers, and detailed hydro-chemical data such as nitrogen, sulphur, and carbonate isotopes are presented in order to obtain quantitative hydro-chemical reactions.

Keywords: Hydrochemistry, stable isotope, groundwater and surface water interaction, dominant geochemical processes, mineral weathering, Hierarchical Cluster Analysis, Principal Components Analysis, EMMA, Tuul River Basin