Characteristics and Significance of Environmental Isotopes and Hydrochemistry in Surface Water and Groundwater in Jixi Wetland, East China

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Abstract. The interaction between surface water and ground water (SW-GW) is an important mechanism affecting wetland hydrological process and its ecological environment. Jixi Wetland, located in the western part of Jinan City, East China, was selected as the study area. The surface water bodies include Yuqinghu Reservoir, Yellow River, Yufu River, Jiping Trunk Channel and Xiaoqing River. Groundwater includes shallow pore water and deep fracture karst water. To strengthen water management and protection and understand different water exchange in the Jixi Wetland, ion composition, stable isotopes ($\delta^{18}O$ and $\delta^2H$) and deuterium excess were studied. The result shows that the characteristic cation is Ca$^{2+}$, and the characteristic anion is HCO$_3^-$ . The main hydrochemical types of wetland water, Sedimentation Basin water and groundwater are HCO$_3^-$ · Cl$^-$ · Ca$^{2+}$ · Mg$^{2+}$ water, the water of Jiping Trunk Channel is HCO$_3^-$ · Cl$^-$ · Na$^+$ · Mg$^{2+}$ type, the water of Yufu River is HCO$_3^-$ · Cl$^-$ · Ca$^{2+}$ · Na$^+$ type, and the water of Yellow River is HCO$_3^-$ · Cl$^-$ · Na$^+$ · Ca$^{2+}$ type. There is a hydraulic connection between SW-GW. The evaporation is strong in the surface water, while it plays a weak role in the groundwater. The dominant hydrogeochemical processes in the study area are lixiviation and cation alternating adsorption.

1. Introduction
Wetlands have great benefits for human being. The existence and function of wetlands is crucial for adjacent terrestrial and aquatic ecosystems. And the most wetlands provide important functions such as nutrient cycling and climate change mitigation [1]. Wetland destruction is one of the biggest environmental problems, and the wetland ecosystem is decreasing gradually [2]. Although the interaction between SW-GW is limited to water cycle, it also has a great impact on material circulation and ecosystem [3]. In 1998, Restrepo presented a conceptual model for SW-GW interaction in wetlands. As this concept is put forward, more and more people are involved in the research in this field [4]. Rushton [5] have carried on the detailed research and discussion to the different forms of SW-GW interaction. Winter and Thomas (2015) organized it according to landscape types, and the research on the interaction between SW-GW increased greatly [6].

The interaction between SW-GW will guide the ecological restoration and protection of wetlands. And characteristics of environmental isotopes and hydrochemistry are the premise of revealing the interaction between SW-GW. Studying the characteristics of environmental isotopes and
hydrochemistry plays a critical role in understanding the connection of different water bodies in study area. The characteristic of environmental isotopes reflects the sources of different water bodies and hydrochemical reactions in study area. In addition, the characteristic of hydrochemistry determines the hydrochemical types and the conversion relationship of different water bodies. Due to the increasingly serious ecological problems of wetlands, this paper aims to study the characteristics of environmental isotopes and hydrochemistry in Jixi Wetland, Shandong, East China. Then the relationship of various water bodies will be revealed in the future, and the ecosystem of Jixi Wetland is protected better.

2. Methods

2.1. Study area and samples
The study area is located at the junction of main urban area and western urban area of Jinan City, Shandong Province. It is the multi-water source gathering place of Yangtze River, Yellow River and Yufu River. Its geographic coordinates are 116°45′10″~116°52′41″ east longitude and 36°37′46″~36°42′63″ north latitude (Figure 1).

![Distribution map of sampling points of Jixi Wetland.](image)

Based on the investigation of water system connection of Jixi Wetland, the Yellow River, Yufu River, Jiping Trunk Channel, Xiaqing River and groundwater were sampled. A total of 26 water samples (20 surface water samples, 6 groundwater samples) were collected. The blue dot represents the sampling location for groundwater, the yellow for Yellow River water, the red for surface water in Jixi Wetland, the green for Jiping Trunk Channel water, the purple for Yufu River water and the white for Sedimentation Basin water.

2.2. Methodology
Water body in nature is in the evaporation and condensation stage, because the physicochemical properties of H and O isotopes in the constituent water molecules are different, the isotope content in water body changes, that is the isotope fractionation effect. Stable isotopes are widely used to study the
relationship between different water bodies [7,8]. In general, the composition differences of isotopes in nature are expressed by relative values, that is isotope ratios ($\delta$). The formula is:

$$\delta(\%) = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000$$

(1)

Where, $R$ is the isotope ratio of $^{18}O/^{16}O$ and $^2H/^1H$, $R_{\text{sample}}$ is the isotope ratio of the sample, $R_{\text{standard}}$ is the isotope ratio of the standard sample.

Deuterium can be used as an artificial tracer [9]. Dansgaard (1964) proposed the concept of deuterium surplus parameter [10]. When the water is strongly evaporated, isotope fractionation will occur, resulting in the decrease of deuterium surplus. The formula for calculating the deuterium surplus is:

$$d = \delta^2H - 8\delta^{18}O$$

(2)

3. Result

3.1. Abundances of anions and cations
The abundances of anions and cations in SW-GW in the study area are the same, the abundances of cations are $\text{Ca}^{2+}>\text{Na}^+>\text{Mg}^{2+}$, and the abundances of anions are $\text{HCO}_3^->\text{Cl}->\text{SO}_4^{2-}$. The $\text{Ca}^{2+}$ content of Yufu River is the highest. This is due to the fact that Yufu River originates from the southern mountainous area and flows through the Cambrian-Ordovician limestone area. The riverbed sand gravel layer has good water permeability conditions. There are many surface water seepage points along the river, which are closely related to the interaction with groundwater. The $\text{NO}_3^-$ content in the water of the Yellow River is much higher than that of other water bodies and is closely related to the influence of human life on both sides of the Yellow River. The average levels of $\text{Na}^+$, $\text{Cl}^-$, $\text{SO}_4^{2-}$ in the water samples of Jiping Trunk Channel are higher than those of other water bodies, especially $\text{Na}^+$, $\text{Cl}^-$, which is related to strong evaporation and concentration during the transmission process of the East Route of the South-to-North Water Transfer Project.

3.2. Total dissolved solids
Total dissolved solids (TDS) of SW-GW in the study area is generally high. As a whole, TDS in surface water is 517.62 and 989.48 mg/L. TDS of Jiping Trunk Channel is 953.36-989.48 mg/L, followed by Yufu River, 745.47-747.05 mg/L; Yellow River and wetland water are relatively low. TDS of groundwater ranges from 517.21 to 1030.20 mg/L. pH value of surface water is between 7.36-8.94, which is weakly alkaline. pH of groundwater ranges from 7.07 to 7.69 with an average value of 7.27.

3.3. Characteristic of hydrochemistry and water types.
The ion test expresses major anions, cations and composition of different water bodies. The molecule in water consisting of major anions and cations is the water type. The similar water type indicates existing connection of two or more water bodies. Trilinear diagram of Hydrochemical Types can better explain the anions and cations and relationship of different water bodies.

The water types of different water bodies are variety (Figure 2). The wetland water types covering $\text{HCO}_3^->\text{Cl}->\text{SO}_4^{2-} - \text{Ca}$, $\text{HCO}_3^->\text{Cl} - \text{Ca-Mg}$, $\text{HCO}_3^->\text{SO}_4^{2-} - \text{Ca-Na}$ and $\text{HCO}_3^->\text{Cl} - \text{Ca-Mg}$. Jiping Trunk Channel water belongs to $\text{HCO}_3^->\text{Cl} - \text{Na-Mg}$ type, Yufu River water belongs to $\text{HCO}_3^->\text{Cl} - \text{Ca-Na}$ type, Sedimentation Basin water belongs to $\text{HCO}_3^->\text{Cl} - \text{Ca-Mg}$ type, Yellow River water belongs to $\text{HCO}_3^->\text{Cl} - \text{Na-Ca}$ type. The chemical type of groundwater is mainly $\text{HCO}_3^->\text{Cl} - \text{Ca-Mg}$ with medium and high mineralization, and it evolves from $\text{HCO}_3^->\text{SO}_4^{2-} - \text{Ca-Mg}$ water to $\text{HCO}_3^->\text{Cl} - \text{Ca-Mg}$ water from southeast to northwest.
3.4. Change range stable isotopes

Stable isotopes are used widely for the research of water exchange, water cycle and flow paths [11-13]. The change range of $\delta^{18}O$ in wetland water is -7.41‰ to -4.08‰, with an average value of -5.22‰; and the change range of $\delta^2H$ is -55.82‰ to -37.93‰, with an average value of -45.02‰. The average values of $\delta^{18}O$ and $\delta^2H$ in Jiping Trunk Channel are -4.97‰ and -40.08‰. The variation range of $\delta^{18}O$ in groundwater is -9.29‰ to -7.46‰, with an average value of -8.51‰; and that of $\delta^2H$ is -66.90‰ to -57.27‰, with an average value of -62.17‰. The variation range of $\delta^{18}O$ in Yufu River water is -7.07‰ to -6.58‰; and that of $\delta^2H$ is -51.29‰ to -49.12‰. The variation range of $\delta^{18}O$ in Yellow River water is -9.61‰ to -2.68‰; and that of $\delta^2H$ is -67.56‰ to -32.72‰.

It shows that the values of $\delta^{18}O$ and $\delta^2H$ in Jiping Trunk Channel are highest, followed by wetland water, Yufu River water and Yellow River water. The isotopes $\delta^{18}O$ and $\delta^2H$ are obviously enriched in the water of Jiping Trunk Channel, which indicates that the evaporation of water in Jiping Trunk Channel is the strongest, which is related to the long water transmission path, slow flow and less hydraulic interaction along Jiping Trunk Channel. The values of $\delta^{18}O$ and $\delta^2H$ in groundwater are lower than those in surface water, indicating that the evaporation of groundwater is weaker than surface water.

3.5. Analysis of the Local Meteoric Water Line

Craig (1961) established Global Meteoric Water Line (GMWL) as $\delta^2H=8\delta^{18}O+10$ [14]. The Local Meteoric Water Line (LMWL) in the eastern monsoon area of China where the study area is located is $\delta^2H=7.46\delta^{18}O+0.9$. According to the data of samples, the Surface Water Line (SWL) and Groundwater Line (GWL) equation were modeled as $\delta^2H=5.1194\delta^{18}O-17.6694$ and $\delta^2H=4.6740\delta^{18}O-22.3773$. The LMWL is less than that of GMWL, which indicates that the evaporation is strong and the local precipitation has undergone an obvious fractionation process. The slopes of SWL and GWL are closed to each other, which further indicates the hydraulic connection of SW-GW. Furthermore, the slopes of SWL and GWL less than that of LMWL, implying SW-GW are subject to strong evaporation.

3.6. Deuterium excess

Deuterium excess of water samples in the research area is analyzed. The average of deuterium surplus value in wetland, Jinping Trunk Channel, Yellow River, Yufu River and groundwater are -3.25‰, -
0.30‰, 2.37‰, 3.39‰ and 5.94‰, respectively. It can be seen that the deuterium excess of wetland water is the smallest and deviates severely from the deuterium excess of global atmospheric precipitation (10‰), indicating that wetland surface water is strongly evaporated during the slow cycle.

The relationship between deuterium excess and TDS is used to distinguish the effects of evaporation and leaching on water [15]. If evaporation concentration is the dominant factor in water body, the deuterium excess decreases and TDS rises with the continuous evaporation. There is a negative correlation between TDS and deuterium excess. It can be found that the deuterium excess increases with the increase of TDS in groundwater. It can be considered that evaporation and transpiration play a weak role in the salinization mechanism of groundwater in the study area. The dominant hydrogeochemical processes are lixiviation and cation alternating adsorption. Although concentration plays a general role, it has a significant influence on the formation of groundwater in the study area and contributes to the higher TDS value of groundwater in the study area.

4. Discussion
The characteristics of hydrochemistry and environmental isotopes are applied widely to understand hydraulic connection, origin and evolution of different water bodies. Hydrochemistry and water types show the relationship of different water bodies, which is helpful for this study. The environmental isotope is a good method that reflects local reaction and water source.

There are many deficiencies in this study, such as uneven distribution of sampling sites, the lack of important local atmospheric precipitation hydrogen and oxygen isotope data. These may lead to the experimental results are not representative, and further research will be needed to obtain the actual results. With the impacts of climate change and human activities, wetland hydrological processes become more and more complex. People pay more and more attention to ecological problems. Understanding the SW-GW interaction mechanism is of great help and guidance significance for the construction of Jixi Wetland, as well as the similar area in the other region.

5. Conclusion
The conversion relationship between surface water and groundwater is the focus and frontier topic of water science research, which can be indicated by hydrochemistry characteristics and environmental isotopes. In this paper, surface water (Yellow River, Yufu River, Jiping Trunk Channel and Jixi Wetland water) and groundwater are research objects and the results show that the hydraulic connection of different water bodies is close. It is found that the shallow pore water in the area is recharged by atmospheric precipitation, surface rivers, and replenished by deep fractured karst water. The upper pore water overflows the surface to form surface discharge. It overflows into the wetland around the Yuqinghu Reservoir. Deep groundwater is discharged to the east and northeast through slow runoff. Understanding the interaction between SW-GW in Jixi Wetland will support its ecological restoration and protection.

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