A Study on the Response of Surface Water and Groundwater Interaction to River Runoff in the Taoer River Alluvial Fan

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Abstract: Understanding the transformation mechanisms of surface water and groundwater positively impacts the rational utilization of water resources and the more scientific allocation of their uses. Many factors affect surface water and groundwater interaction (SGWI), among which river runoff is the most critical variable. Studying the response mechanism of SGWI under changes in river channel volume can help understand the essence of SGWI. Using the Taoer River alluvial fan as the research area, daily runoff data from hydrological stations in the study area from January to March 1961, 1971, 1981, 1991, 2001, and 2011 were collected. The daily SGWI was calculated using the water balance and flow speed difference methods. The results show that river runoff is the main factor controlling the SGWI, and the interaction quantity (IQ) is more stable when the IQ is relatively small.

1 Introduction

The world is currently facing the problem of water scarcity, and better management and utilization of water resources are particularly important [2, 8]. The clean water cycle is significant for the comprehensive management and utilization of water resources [1, 10], and the surface water and groundwater interaction (SGWI) is an integral part of the water cycle [4, 7]. There are many influencing factors on the SGWI, such as basin geology and geomorphology, riverbed characteristics, river runoff, groundwater level, evaporation, rainfall, and human exploitation [3]. The above factors not only have complex impacts on the SGWI, but also have cross effects within each other, making the study of the transformation mechanism of surface water and groundwater challenging [6, 9]. According to reports, in the Taoer River area, the river runoff is directly proportional to the conversion amount of surface water and groundwater. River runoff is usually a key factor affecting the conversion relationship and amount of surface water and groundwater and significantly impacts surface water and groundwater [5]. In this article, we innovatively attempt to calculate the daily SGWI from January to March 1961, 1971, 1981, 1991, 2001, and 2011, excluding other factors. We study the impact of river runoff on the SGWI without the influence of artificial water diversion and exploitation and draw specific rules and conclusions, providing a basis for human control and comprehensive management of surface water and groundwater.

2 Case study and materials

2.1 Case study

The research area is located in the western region of Jilin Province, China, and belongs to a typical alluvial fan with an area of approximately 2920 km^2. The research area belongs to an arid and semi-arid region. According to the analysis of precipitation and evaporation from 1956 to 2014, the average annual precipitation was 395.0mm. The precipitation from January to March was 1.3mm, 1.5mm, and 4.4mm, respectively, accounting for 1.8% of the year. The main rivers in the research area include the Taoer River and Jiaoliu River (a primary tributary of the Taoer River). The Taoer River flows into the research area from the Zhenxi Hydrological Station in the northwest, and the Jiaoliu River flows into the research area from the Wuben Hydrological Station. (Fig. 1).

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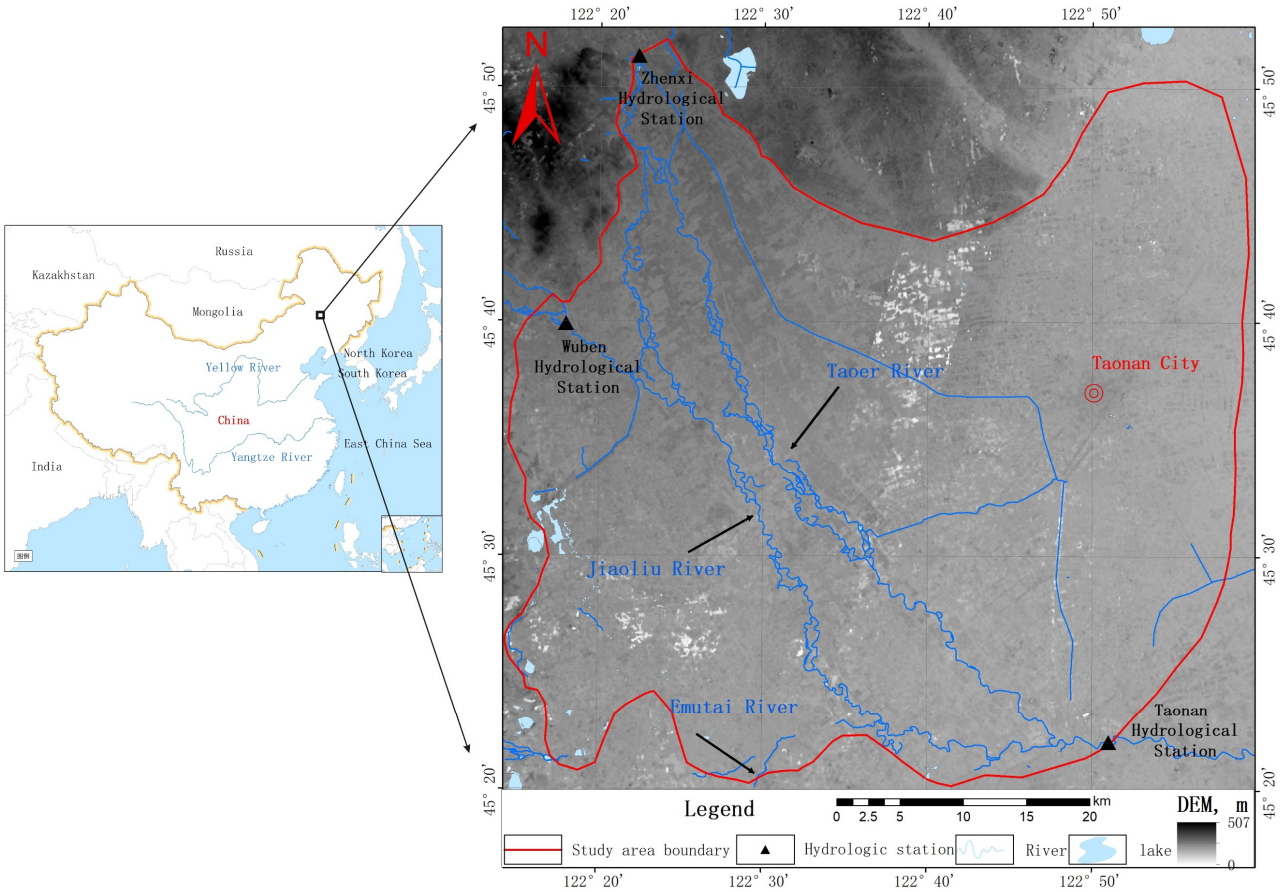

Fig.1. Location map of the study area.

2.2 Materials

We collected daily river runoff data from Zhenxi Hydrological Station, Taonan Hydrological Station, and Wuben Hydrological Station from January to March 1961, 1971, 1981, 1991, 2001, and 2011. These three hydrological stations measure the river runoff entering and exiting the Taoer River alluvial fan. From January to March, there was no irrigation and water diversion, and the precipitation appeared in the form of snow and did not melt. The impact of rainfall, evaporation, and artificial exploitation on the SGWI was ruled out, and the groundwater level was relatively stable during this period, which can better reflect the runoff and the transformation rules of surface water and groundwater.

3 Methods

The SGWI calculations were based on the principle of surface water balance. This principle is an application of the conservation of matter in hydrology. In a particular region, the changes in the water quantities obey the protection of water quantity:

$$Q_{S\text{-}G}=(Q_{ZX}+Q_{WB}+Q_H+Q_{RI})-(Q_{TN}+Q_E+Q_C) \quad (1)$$

Where $Q_{S\text{-}G}$ is the SGWI in 10^4m^3, Q_{ZX} is the actual measured runoff at the ZhenXi Hydrological Station in 10^4m^3, Q_{WB} is the actual estimated runoff at the WuBen Hydrological Station in 10^4m^3, Q_H is the runoff of the Emutai River in 10^4m^3, Q_{RI} is the direct recharge of rainwater to the river in 10^4m^3, Q_{TN} is the actual measured runoff at the TaoNan Hydrological Station in 10^4m^3, Q_E is the evaporation from the river surface in 10^4m^3, and Q_C is the water diversion from the canal in 10^4m^3.

Since the study period is from January to March, the effects of precipitation, evaporation, and artificial exploitation on the SGWI have been excluded, and the tributaries have dried up. Therefore, formula (1) can be simplified as:

$$Q_{S\text{-}G}=Q_{ZX}+Q_{WB}-Q_{TN} \quad (2)$$

When the water balance method is used to calculate the daily SGWI, the time to reach the downstream hydrological station is calculated by dividing the river length and runoff velocity. The corresponding river flow is subtracted to obtain the daily SGWI.

4 Result

4.1 The results of daily conversion calculation

The water balance method calculates the daily interaction quantity (IQ) from 1956 to March 2014. The calculation results show that the daily IQ is stable when the IQ is relatively small. As the IQ gradually increases, a dispersion phenomenon begins to appear. From Fig.2, it can be seen that when the IQ is greater than 50, it begins to show significant dispersion. When the IQ is less than 50, the IQ is basically in a stable and gentle state. Starting from March, the IQ gradually increased, and the range of change began to grow.

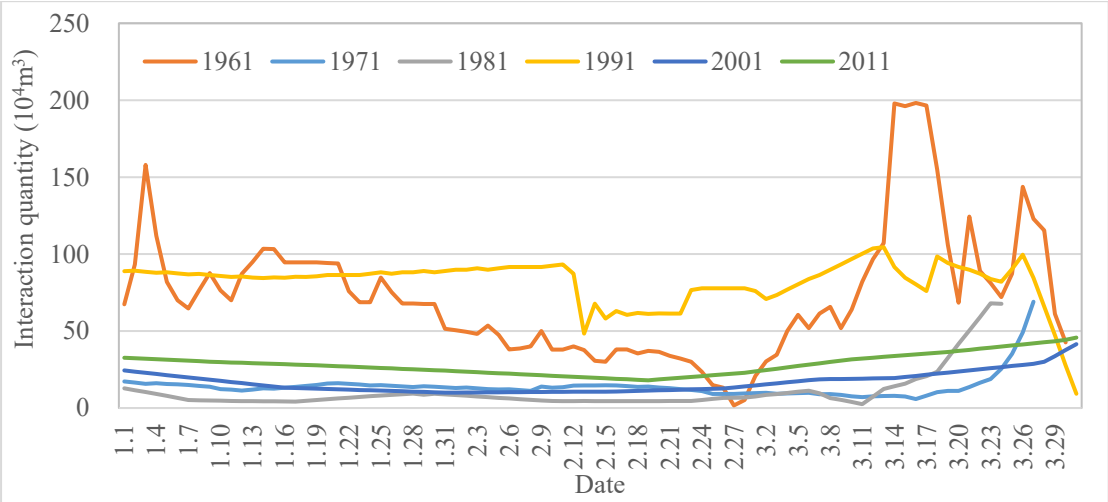

Fig.2. Calculated SGWI from January to Mar.

4.2 Regularity of SGWI

According to the water balance method, the daily SGWI was calculated from January to March 1961, 1971, 1981, 1991, 2001, and 2011. The relationship curve and scatter plot between the SGWI and the net flow of the river were compared and analyzed by adding them up in 10-day steps, as shown in Fig.3 and Fig.4. The results show that from January to March, the runoff of the Taoer River alluvial fan channel is the main driving force for the SGWI, with a correlation coefficient of 0.8425.

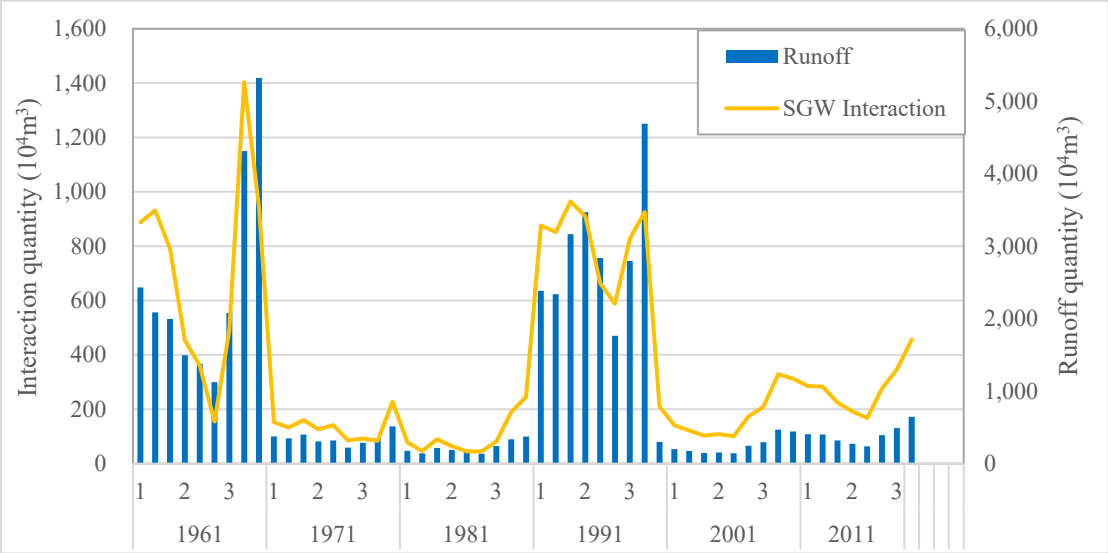

Fig. 3. Relationship between river runoff and SGWI from Jan to Mar.

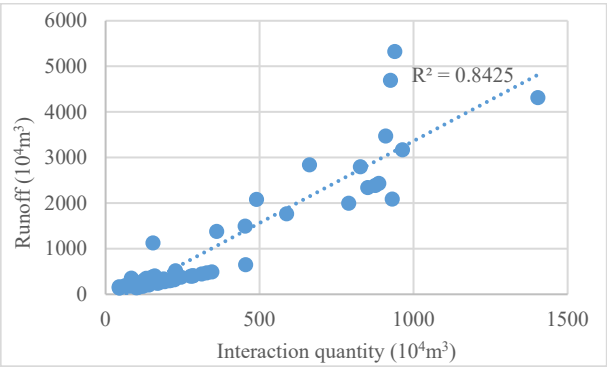

Fig. 4. Scatter plot of the relationship between river runoff and IQ.

5 Discussion

For daily IQ, when the IQ is small, the change amplitude is relatively small. There may be two possible reasons for this phenomenon: the river runoff is small and very stable. At this time, the lithology of the riverbed is uniform, and the difference in the groundwater level changes very little. The above conditions can present a very stable surface water conversion into groundwater. Secondly, when the river runoff is minimal and the groundwater level is relatively deep, all river water is converted into groundwater.

There is a positive correlation between river runoff and IQ, with a correlation coefficient of 0.8425. The correlation is strong, indicating that the size of river runoff is almost the entire driving force of IQ. Other factors, such

as riverbed lithology and groundwater level, are secondary. In future water resource management, if the goal of supplementing groundwater in the Taoer River alluvial fan is to be achieved, it is necessary to control upstream reservoirs' discharge and the appropriate flow rate and stability.

6 Conclusions

This study takes the Taoer River alluvial fan as the research area. By collecting daily runoff data from hydrological stations that entered and flowed out of the fan-shaped area from January to March 1961, 1971, 1981, 1991, 2001, and 2011, and using water balance methods, the impact of river runoff on SGWI without interference from other factors was analyzed. The results show that the river runoff from January to March is the main influencing factor for the SGWI. When the river runoff is small and relatively stable, it is more conducive to the SGWI.

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