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Hydrogeochemical and isotope evidence of groundwater evolution and recharge in Minqin Basin, Northwest China

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Summary A hydrochemical investigation was conducted in the Minqin Basin to identify the groundwater evolution and recharge in the aquifer. The mBr/Cl ratio is strongly depleted (average 0.000451) compared with sea water (0.0035), indicating an evaporite origin. The ionic ration plot, saturation index (SI), and chloro alkaline indices (CAI) suggest that the dissolution of halite, the glauberite, gypsum, dolomite and calcite determine Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and HCO_3^- chemistry, but other processes, such as Na^+ exchange for Ca^{2+} and Mg^{2+}, and calcite precipitation also contribute to the water composition. The $\delta^{18}O$ and δ^2H in precipitation near the study area are linearly correlated, similar to that for the world meteoric water line (WMWL), with an equation of $\delta^2H = 7.49\delta^{18}O + 5.11$ ($r^2 = 0.97$). According to radiocarbon residence time estimates, the deep groundwater is approximately 40 ka old, and was recharged during a period when the climate was wetter and colder. The radiocarbon content of shallow groundwater shows a clear evolution along the groundwater flow path. From the beginning of the groundwater flow path to ~31 km the radiocarbon values are >73.6 pmc, whereas beyond this point the values are <42.9 pmc. Based on radiocarbon content, the shallow groundwater is older than 1 ka, and represents palaeowaters mixed with a limited quality of modern recharge.

The rain-fed groundwater direct recharge was estimated by chloride mass balance (CMB) method to range from 1.55 to 1.64 mm yr^{-1}, with a mean value of 1.6 mm yr^{-1}. This value represents about 1.5% of local rainfall. The direct recharge volumes is about 0.666×10^8 m^3 yr^{-1}.

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Indirect recharge volumes by the surface water is about $0.945 \times 10^8\ m^3\ yr^{-1}$. The total natural recharge in the Minqin Basin is $1.6 \times 10^8\ m^3\ yr^{-1}$, whereas the groundwater abstraction has reached $11.6 \times 10^8\ m^3\ yr^{-1}$, far exceeding the groundwater natural recharge.

Introduction

Northwest China, including the whole Xingjing autonomous region, the Hexi Corridor in Gansu Province, and the area west of Helan Mountains in Inner Mongolia, is one of the driest regions in the world (Shi and Zhang, 1995). This area is an ecologically fragile area, which is characterized by low and irregular rainfall, high temperatures and evaporation, and notable drought periods (Ma et al., 2005). In such arid and semi-arid environments, groundwater is a significant part of the total water resource, and plays an important role as a water supply both for drinking and irrigation. Because of rapid economic growth and lack of precipitation, the use of groundwater resources has increase dramatically. Substantial over-exploitation of groundwater has created serious consequences, for example, intense mineralization of groundwater, lowering of the regional water table, land desertification and salinization, degeneracy of vegetation and a heightened frequency of sand storms (Feng et al., 2005). If such a situation continues, further deterioration of the environment and ecosystem of the vast area is unavoidable. Some safeguarding measures for groundwater resource protection must been undertaken.

The Minqin Basin is located in the lower reach of the Shiyang River Basin. Already the water in the Shiyang River is over-used for irrigation and little or no surface water now reaches the Minqin Basin itself. As a result, farms in the Minqin Basin are now depending on the pumping of groundwater for both irrigation and drinking water. Recently, groundwater has begun to be exploited in the vicinal desert region, e.g. the Tengger desert. There can be little doubt the groundwater is being extracted much more rapidly than it is being replaced. Further more, the quality of groundwater may change as volume decline. Also this is an issue that faces the whole region of arid China (Ma et al., 2005).

Knowledge on the quality of groundwater and rate of recharge is important. During the last decades environmental isotope techniques have been commonly and largely used in the overall domain of water resources development and management (Fritz and Fontes, 1980). In fact, the application of these relatively new techniques has played an important role in solving the envisaged hydrological problems that cannot be solved by conventional methods alone. Stable isotopes, oxygen-18 (^{18}O) and deuterium (^{2}H) are commonly used for flow-system tracing and climate reconstruction. The chloride-mass balance (CMB) is used for groundwater recharge because of its conservative nature. Furthermore, the application of these techniques in the case of arid and semi-arid zones, where the available water resources are often limited to groundwater, has proved to be an attractive tool for the identification of recharge and the quantitative evaluation of groundwater system (IAEA, 1980, 1983). In recent years, the Chinese government and scientists have carried out much research on the assessment and utilization of water resources in the Shiyang River Basin. Many researches focus on the quantity assessment of natural water resources, understanding of the relationships between water and environment, and recognizing how to practice sound water management (Liu et al., 1998; Ye et al., 1998). However, study of the hydrochemistry (especially isotopic geochemistry) of water resources is rather sparse, and efforts to use the geochemistry data available to solve particular problems are even fewer or non-existent. This study combines the systematic analysis of the hydrochemical analysis and hydrogeologic features of the Shiyang River Basin with isotopic geochemical method for rainfall, surface water and groundwater in the Minqin Basin. The first goal of this study was to use minor elements (Br, B, Sr), environmental stable isotopes (^{18}O, ^{2}H, ^{13}C) and radiocarbon to determine the evolution and age of the groundwater in the natural conditions. The major-ion chemistry (Cl^-, HCO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+} and Mg^{2+}) were employed to determine the predominant geochemical processes that take place along the groundwater flow path. Secondly, in order to determine the safe yield of the aquifer in Tengger desert, the chloride mass balance (CMB) method was used to calculate the recharge flux. The results of this study provide essential information and a theoretical basis for effective design of water resource management in northwest China in the new century.

The study area

The Minqin Basin is the lower reach of the Shiyang River system, which is located in the east Hexi Corridor of Gansu province (Fig. 1). It is approximately between latitudes 38°20′ to 39°18′ North and longitudes 102°52′ to 103°50′ East. The basin covers an area of $41.6 \times 10^3\ km^2$. The Hongyashan Mountains, the tail of Longshou Shan Mountains, separate the Wuwei Basin and the Minqin Basin, where a reservoir was built in 1958 and is the only surface water in the Minqin Basin. Although the discharge of the Shiyang River at the mouth of mountain valleys has remained near $15.8 \times 10^8\ m^3\ yr^{-1}$ since the 1950s, the flow into the lower reaches at the Hongyashan reservoir has decreased by 74% over the same period. In the 1950s, the discharge of the Shiyang River at Hongyanshan reservoir in the Minqin Basin was $5.73 \times 10^8\ m^3$; in the 1960s, $4.45 \times 10^8\ m^3$; in the 1970s, $3.22 \times 10^8\ m^3$; in the 1980s, $2.25 \times 10^8\ m^3$; and in the 1990s, only about $1.48 \times 10^8\ m^3$ (Ma et al., 2005). As a result, groundwater recharge has greatly decreased by 75% from $0.48 \times 10^9\ m^3\ yr^{-1}$ in the 1950s to $0.12 \times 10^9\ m^3\ yr^{-1}$ in the 1990s (Li, 1983).

The Minqin Basin borders the Wuwei basin to the south, the Tengger desert to the east and north, and to the west