Characteristics of chemistry and stable isotopes in groundwater of the Chaobai River catchment, Beijing

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Abstract

Environmental isotopes and chemical compositions are useful tools for the study of groundwater flow systems. Groundwater of the Chaobai River catchment, Beijing was sampled for chemical and stable isotopes analyses in 2005. Geochemical signatures evolve progressively from CaMg-HCO\textsubscript{3} to NaK-HCO\textsubscript{3}, and then to Na-HCO\textsubscript{3} compositions as groundwater flows from the mountain to discharge areas. Groundwater can be divided into two groups on the basis of stable isotope compositions: ancient groundwater and modern groundwater. Modern groundwater (-9.9‰ to -6.6‰ for $\delta^{18}$O) plots along a line with a slope of 4.0 on a $\delta^{2}$H versus $\delta^{18}$O diagram, reflecting evaporation during the process of recharge, whereas ancient groundwater samples (30 to 12 Ka.) are different in isotopic composition (-11.0‰ and -68.2‰ for $\delta^{18}$O and $\delta^{2}$H, respectively), reflecting the cold and arid climate in the last glacial period. The results have important implications for groundwater management in Beijing City.

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1. Introduction

Water systems are affected by both climate change and human activities to a variable extent, so water resources and water demands are unevenly distributed spatially and temporally. Across China, water demand has increased as rapid population growth, economic development and the expanded amount of land irrigated for agriculture. As a consequence, the demand for exploitable groundwater has grown.

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concomitantly. This has led to several related problems, such as groundwater level decline, deterioration of ecological environments, and desertification. For example, heavy exploitation of groundwater by the city of Beijing has led to a 40m lowering in the position of the groundwater table and a consequent subsidence of the city by over 0.5 m [1]. Thus, it is essential to thoroughly understand relevant hydrological processes, such as groundwater recharge and flow regime, when groundwater resources are developed for use.

Under ideal circumstances, groundwater age can be ascertained by $^{14}$C dating and light stable isotopes can be used to study of hydrogeological processes such as formation of precipitation, interaction between groundwater and surface water, recharge and flow regime of groundwater [2,3]. This paper uses the spatial distributions of groundwater chemical and isotopic compositions to gain insight into the sources and evolution of groundwater in the Beijing City region, with a focus on the Chaobai River catchment.

2. Study Areas

Beijing (Fig. 1), located in the North China plain, comprises a catchment covering approximately 150,000 km$^2$ that is underlain by a thick sequence of Cenozoic sediments. The North China plain is bordered by the Yanshan Fold to the north, the Taihang swell to the west, the Yellow River in the south, and the Bohai Sea in the east. It resides in the littoral and semiarid climatic zone and has an annual temperature of 12–13°C. Mean annual precipitation ranges from 500 to 600 mm and mean potential evaporation ranges from 1100 to 1800 mm [4,5]. Generally groundwater recharge in the study area is derived from runoff originating in the Taihang and Yanshan Mountains, with groundwater flows moving south-eastwards and southward toward the Bohai Sea. The regional Quaternary aquifers in the North China plain consist of fluvial fans, alluvial fans and lacustrine deposits. Based on lithologic properties and hydrodynamic characteristics, these Quaternary sediment deposits are classified into four aquifers.

![Fig. 1. Map of the Beijing region showing the Chaobai River catchment (shaded area) and sampling locations (labeled points).](image)

3. Sampling and Analysis

Water samples were collected for isotope and chemical analyses in 2005. Samples are shown in Fig. 1. The Analytical Laboratory of Hydrogeology and Engineering Geology Team of Beijing performed major ion analyses using ion chromatography. The detection limit for analyzed constituents is 0.1 mg/L, and analytical precision is 5% of concentration based on reproducibility of samples and standards. Hydrogen and oxygen isotope analyses were carried out on a laser absorption water isotope spectrometer analyzer in
the laboratory of Institute of Geology, China Earthquake Administration. All isotopic results are reported as relative deviation of the isotopic ratio of the sample from the VSMOW standard and are cited here in the familiar $\delta$-notation. Measurements of $^{14}$C were made at the Heavy Ion Institute of Peking University by liquid scintillation counting after conversion to benzene.

4. Results and Discussion

4.1. Hydrogeochemistry

Using the Piper diagram to identify hydrochemical facies (Fig. 1), groundwater in mountain areas was readily classified as being of the CaMg-HCO$_3$ type, which has relatively low Na concentrations. Groundwater Mg$^{2+}$ contents increase with increasing distance from the mountains and Na$^+$ predominates over the remaining cations at a long distance from the mountains. Though SO$_4^{2-}$ and Cl$^-$ also exhibit gradually increases along this trend, HCO$_3^-$ remains the prevailing anion, so that the Na-HCO$_3$ hydrochemical facies is predominant in the groundwater discharge area. Several chemical processes have been identified that act to determine the major ion chemistry [6]. These include: ion exchange of Na$^+$ on the solids for Ca$^{2+}$ and Mg$^{2+}$ in solution; dissolution of carbonate minerals and gypsum in response to cation exchange; and mixing of saline water from the overlying aquifer through leakage.

Fig. 2. Piper diagram for of the Chaobai River catchment showing hydrochemical facies and predominant chemical trends in basin groundwaters.

4.2. Isotopic chemistry

The light stable isotopes of H and O are ideal tracers for estimating the recharge areas and flow path of groundwater, because they comprise the constituent water molecules and are sensitive to physical processes such as mixing and evaporation [7].

Groundwater isotopic compositions in the study area cluster into distinct groups (Fig. 3). Nine of the 27 samples (blue diamonds in Fig. 3) have an average of $-11.0\%$ for $\delta^{18}$O and $-68.2\%$ for $\delta^2$H. O-isotope compositions are plotted versus $^{14}$C ages in Fig. 3.b. Then these groundwater samples are ancient groundwater during the period from 30 to 12 Ka. Previous studies have also observed that groundwater in the deep aquifer of the North China Plain contained a paleoclimate record, with groundwater $^{14}$C ages of 25-12 Ka, and isotopic compositions ranging from $-76$ to $-85\%$ for $\delta^2$H and $-9.4$ to $-11.7\%$ for $\delta^{18}$O [8]. This group of samples plots in an array above and parallel to the present-day Global Meteoric Water Line (GMWL) of Craig (1961) [9].
Fig. 3. Plot of (a) δD and δ18O and (b) δ18O versus 14C age for groundwaters of the Chaobai River catchment

Present-day groundwaters (red circles in Fig. 3.a) have compositions that are enriched in both 2H and 18O with respect to the paleo-groundwaters, with respective average values of -61.8‰ for δ2H and -8.5‰ for δ18O. These samples plot to the right of the GMWL and define a linear trend described by the relationship δD = 4.1δ18O − 27 that is indicative of evaporation during recharge. This evaporation trend has an intercept on the local meteoric water line at -9.5‰, close to the composition of modern precipitation in this area, indicating that this groundwater is derived from modern precipitation that is subjected to evaporation during its passage through the soil and unsaturated zone to reach the water table.

5. Conclusions

Along the groundwater flow direction from the mountain to discharge areas, chemical patterns of groundwater evolve from CaMg-HCO3 to NaK-HCO3 then to Na-HCO3 compositions. Groundwater isotopic compositions and the 14C ages cluster into two groups. Ancient groundwater formed during the period from 30 to 12 Ka is more depleted in both δ2H and δ18O relative to modern precipitation derived groundwater. Modern groundwaters plot along a trend of slope of 4, reflecting evaporation during recharge.

References