Analysis of Jingyu Natural Mineral Water Recharge Mechanism

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Abstract. Jingyu county of jilin province is located in the core area of Changbai Mountain Nature Reserve. It belongs to the Changbai Mountain mineral water group and has a daily total flow of 151,000 m³. It is one of the most important mineral water producing areas in Northeast China and has nongfu spring, Evergrande ice springs, Master Kong and other well-known production bases. Therefore, it is of great significance to the local government and society to clarify the mineral water recharge mechanism in Jingyu Nature Reserve and ensure that the mineral water in the protected area is sufficient. In summary, in order to ensure the sustainable scientific development and utilization of mineral water in this area, this paper takes into account the local geological and hydrogeological structural characteristics, and uses the environmental isotope method to compare the hydrogen and oxygen isotopes of mineral water in the study area with atmospheric precipitation in the area. According to the isotope change law, the origin, formation conditions and recharge mechanism of the local groundwater were revealed. The conclusions are as follows: the main source of mineral water in Jingyu Nature Reserve is atmospheric precipitation, and the cycle time is 20 to 40 years.

1. Introduction
Natural mineral water, as a precious mineral resource, is rich in various trace elements and is very beneficial to human health. With the continuous improvement of people's living standards, people have formed a lifestyle of drinking mineral water. Jingyu natural mineral water is an important component of the natural mineral spring group in Changbai Mountain (one of the world's three high-quality mineral water producing areas). Because of its rich metasilicate and strontium ions, it has become a rare high-grade mineral water at home and abroad. At present, there are 17 proven mineral springs in Jingyu Nature Reserve with a daily flow of 151000 m³. Because of its huge flow and excellent water quality, Jingyu Nature Reserve has attracted many mineral water manufacturers such as Nongfu Spring, Evergrande Ice Spring, and Master Kong to build factories here. Based on this, mineral water has become a local pillar industry. Therefore, it is of great significance to study the recharge source and mechanism of natural mineral water for the sustainable development and utilization of Jingyu mineral water and the sustainable development of the local economy.

Since the mid-1980s, research on groundwater recharge mechanisms has gradually risen and reached its peak. At present, there are 10 main methods for studying groundwater recharge mechanisms in the academic world: Water balance method, Base flow segmentation method, Watershed numerical simulation method, Zero flux surface method, Evapotranspiration method, Darcy's law method,
Chlorine element conservation method, Environmental isotope method, Groundwater level dynamic method, Stable isotope method\(^{[2-3]}\). Among them, the environmental isotope method is widely used to identify the origin, recharge source, age and recharge elevation of groundwater due to its accuracy and ease of use\(^{[4-5]}\). Therefore, based on the geological structure characteristics of the study area, the environmental isotope method was used to analyze the recharge source and recharge ways of Jingyu natural mineral water, providing a scientific basis for the sustainable development and utilization of local mineral water.

2. Study Area

2.1. Physical Geography

Jingyu National Nature Reserve is located in the southeast of Jilin Province, southwest of Jingyu County, the hinterland of Changbai Mountain, and the upper reaches of Songhua River. The geographical coordinates are \(126^\circ 34'58" \sim 126^\circ 48'38"\) E, and \(42^\circ 10'49" \sim 42^\circ 22'02"\) N. The study area belongs to a temperate continental humid climate, with climatic characteristics of cold and humid, abundant rainfall, short frost-free period, and moderate light. The annual average precipitation in the region is 750–850mm, mainly concentrated in June to August\(^{[6]}\).

2.2. Regional Geology and Hydrogeology

The neotectonic movement in the study area is intense, active faults are developed, volcanic activity is frequent, and basalt is widely exposed. The study area is located in the eastern slope of the northern part of the Longgang Mountains in the Changbai Mountains. It belongs to the middle-low mountain landscape, with the southwest high and the northeast low. The lower mountains are mainly distributed around the southwestern boundary of the study area, while the lava plateaus are mainly distributed in the central and northeastern regions. 90% of the groundwater in the study area is basalt fissure water, which is mainly found in the basalts of the Junjianshan Formation of the Pleistocene in the Quaternary. The main source of groundwater recharge is atmospheric precipitation, which is mainly horizontal movement, and is mostly discharged to nearby rivers in the form of spring groups. The spring flow rate is generally >10L/s, the maximum up to 449L/s.

3. Research Method

In this paper, observation data from Qiqihar, Harbin, Changchun and Jinzhou in northeast China in the Global Atmospheric Precipitation Isotope Observation Network GNIP were selected. Observation point data mainly include monthly averages of \(\delta D\) and \(\delta^{18}O\) in precipitation, as well as temperature, water vapor pressure, precipitation, latitude, longitude and elevation. The information of each site is shown in table 1.

| Meteorological station | Latitude | Longitude | Altitude | Sampling time  | Number of data |
|------------------------|----------|-----------|----------|----------------|----------------|
| Qiqihar                | 47.38    | 123.92    | 147      | 1988–1992      | 48             |
| Harbin                 | 45.68    | 126.62    | 172      | 1986–1998      | 34             |
| Changchun              | 43.90    | 125.22    | 237      | 1999–2001      | 22             |
| Jinzhou                | 41.13    | 121.10    | 66       | 1986–1989      | 12             |

Because the standard is VSMOW, in 1993, Rozanski\(^{[7]}\) improved the accuracy of the Craig line based on long-term average regression lines of \(\delta^{18}O\) and \(\delta D\) of the atmospheric precipitation measured by the monitoring network of 219 stations, and obtained the Global Meteoric Water Line (GMWL) is:

\[
\delta D = 8.138^{18}O + 10.8\%_VSMOW
\] (1)

\(\delta^{18}O-\delta D\) curves are drawn based on the collected of hydrogen and oxygen isotopes values in the northeast of precipitation. Although the difference between the \(\delta^{18}O\) and \(\delta D\) values at these stations is large, \(\delta D\) is \(-271.3\%\) to \(81.3\%\), and \(\delta^{18}O\) is \(-33.46\%\) to \(14.14\%\). However, it is very close to the GMWL
line, and δD and δ\(^{18}\)O are relatively enriched, which indicates that evaporation from the rainy season in the northern arid region caused deviation from GMWL, as shown in Figure 1, and the relevant equation is the Local Meteoric Water Line (LMWL):

\[
\delta D = 7.14\delta^{18}O - 3.22\% VSMOW \quad (R^2=0.965)
\]

\[\text{Figure 1. GMWL and LMWL.}\]

Due to the lack of isotope data of local atmospheric precipitation in the study area, and the study area is located in the southeast of the Northeast region, the meteoric water line in the northeast region is used as the meteoric water line in the study area. The slope and intercept of the LMWL in this area deviate from the global average and are small, but still maintain a linear relationship, indicating that the precipitation in the study area has already had a strong evaporation effect when it reaches the surface. A slope less than 8 indicates that the water vapor of area precipitation comes from sources with different hydrogen-oxygen stable isotope ratios \[8\]. The intersection of GMWL and LMWL in Figure 1 can approximately reflect the original average hydrogen-oxygen stable isotope composition of the water vapor source.

### 4. Results and Discussion

#### 4.1. Stable Isotope Characteristics of Hydrogen and Oxygen

The samples of mineral water isotopes used in this study were 10 mineral water samples collected in the wild during the dry period in May 2011 and the wet period in September 2011, and samples at three different depths in a scientific experiment well (see Figure 2). The items of measurement of the samples were \(^{18}\)O, D and \(^{3}\)H, and the measurement results are shown in table 2.

The isotope test values of the collected groundwater samples were combined with Figure 1 to get Figure 3. It can be seen from Figure 3 that the collected test values of groundwater samples fall near the meteoric water line, indicating the origin of the atmosphere. The isotopic composition of groundwater is close to the mean annual composition of meteoric precipitation, but its isotopic composition is different from that of meteoric precipitation, which is usually formed by the water cycle that meteoric precipitation goes through in the process of recharge of groundwater.

According to the test, the average value of δD and δ\(^{18}\)O in the mineral water is -86.47‰ and -12.21‰ respectively, and the slope is 3.94. As can be seen from Figure 3, the δD and δ\(^{18}\)O of the mineral water deviate from the LMWL, which is affected by the interaction between water and rock and evaporation. Because the groundwater in the study area is shallow, the evaporation phenomenon is obvious, which is consistent with the conclusion of isotope method.

The study area is not large, and the distances between the sampling points are also small. The test results of isotopic test points distributed in the direction of the flow line change relatively gently, which indicates that the source of groundwater recharge is single and the atmospheric precipitation is the main source. Although not prominent, the values of δ\(^{18}\)O are gradually increasing from the recharge area to
the discharge area. The reason may be that the groundwater is shallower and shallower, and the influence of evaporation in the process of precipitation infiltration is more and more obvious, so that isotopes are gradually enriched. The sampling points are mostly arranged in the middle of the study area, and the dense area with spring distribution is relatively lower than the north, south and west. They are springs formed by groundwater drainage outlets, and their evaporation is obvious.

![Figure 2. Isotopic water distribution in the study area.](image)

| Number | Samples no. | Sampling position | Sample depth (m) | Sample elevation (m) | Measurement items | Age of groundwater (a) |
|-------|-------------|-------------------|------------------|----------------------|-------------------|------------------------|
| 1     | Q1-1        | Shenhua Spring    | 0                | 621                  | \( ^{18}\)O/SMOW | -12.01                 | 21.04                  |
| 2     | Q3-1        | Linhai Spring     | 0                | 640                  | \( ^{18}\)O/SMOW | -12.20                 | 20.40                  |
| 3     | Q3-5        | Julong Spring     | 0                | 690                  | \( ^{18}\)O/SMOW | -12.38                 | 23.93                  |
| 4     | Q3-5-2      | Yinlon Spring     | 0                | 664                  | \( ^{18}\)O/SMOW | -12.25                 | 37.00                  |
| 5     | Q3-6        | Luming Spring     | 0                | 689                  | \( ^{18}\)O/SMOW | -12.23                 | 48.98                  |
| 6     | Q4-1        | Xuelong Spring    | 0                | 592                  | \( ^{18}\)O/SMOW | -12.42                 | 26.18                  |
| 7     | Q4-2        | Qinglong Spring   | 0                | 634                  | \( ^{18}\)O/SMOW | -12.36                 | 24.59                  |
| 8     | Q4-3        | Julong Spring     | 0                | 690                  | \( ^{18}\)O/SMOW | -12.38                 | 36.16                  |
| 9     | Q4-4        | Laiya Spring      | 0                | 692                  | \( ^{18}\)O/SMOW | -12.17                 | 32.25                  |
| 10    | Q4-5        | Feilong Spring    | 0                | 716                  | \( ^{18}\)O/SMOW | -12.38                 | 48.98                  |
| 11    | D1-11-1     | Scientific        | 0-43             | 617-660              | \( ^{18}\)O/SMOW | -11.93                 | 32.93                  |
| 12    | D1-11-2     | Scientific        | 43-83.6          | 576-617              | \( ^{18}\)O/SMOW | -11.98                 | 26.37                  |
| 13    | D1-11-3     | Scientific        | 86-123.3         | 537-576              | \( ^{18}\)O/SMOW | -12.07                 | 32.93                  |
It can be seen from the isotopic data of the scientific experimental well in Figure 3 that the δ¹⁸O and δD of the groundwater are stratified vertically. With the increase of the groundwater burial depth, the δ¹⁸O and δD values in the groundwater decrease, that is, the hydrogen and oxygen stable isotope values of the shallow groundwater are higher than those of the deep groundwater. Generally speaking, in the aquifer far from the recharge area, the concentration of isotopes in the groundwater is very low. When receiving recharge from the upper phreatic, the groundwater in the recharge area will reflect a considerable concentration of isotopes. This abnormal changes are often referred to as a sign of aquifer recharge[9]. The changes of the hydrogen and oxygen stable isotopes between different aquifers in this study area are small and not very obvious, so the vertical hydraulic connection of groundwater between the aquifer groups in the study area is weak.

![Figure 3. The relationship between δD and δ¹⁸O of groundwater in the study area.](image)

4.2. Analysis of Groundwater Renewability

Because the tritium value in the atmospheric rainfall of the nuclear test in 1960 suddenly increased, and the tritium value in the atmospheric rainfall gradually decreased after the nuclear test, the tritium value in the groundwater formed around 1960 differs greatly. The tritium before the nuclear test had basically decayed, while the tritium value after the nuclear test was high, which can be used to determine the age of groundwater formation. The groundwater with a tritium value less than 1TU is formed before 1960; groundwater with a tritium value of 1~5TU is mixed with a small amount of groundwater formed after 1960; groundwater with tritium value of 5~30TU is a mixture of groundwater formed before 1960 and after 1960; groundwater with a tritium value greater than 30TU is formed after 1960[10].

The tritium content of Luming Spring and scientific experiment well of 0~43m is relatively low(≤3TU), which should be mixed with a small amount of groundwater after 1960. The tritium content of remaining springs is 5~15TU, which should be a mix of recharged water before 1960 and modern water. Use the change of radioisotopes in groundwater to calculate the age of groundwater, mainly based on the law of radioactive decay[11]:

\[
N = N_0e^{\lambda t} \quad (3)
\]

Where \(N\) is the concentration of radioisotopes at time \(t\) (TU), \(N_0\) is the initial \((t=0)\) concentration of a radioisotope (TU), \(t\) is the time (a), \(\lambda\) is the decay constant, dimensionless, has the following relationship with half-life \(T\):

\[
\lambda = \frac{\ln 2}{T} = \frac{0.693}{T} \quad (4)
\]

Sorting out the above two formulas:

\[
t = \frac{T}{0.693} \ln \left( \frac{N_0}{N} \right) \quad (5)
\]

The age of groundwater was measured with the isotope tritium (³H), and the half-life period of tritium \((T=12.43a)\) was substituted into equation (5) to obtain the relationship between the concentration of tritium \((N)\) and the age of groundwater, that is, the average detention time of groundwater \((T)\):
With reference to the “Groundwater and Environmental Geological Survey and Evaluation Report of Changbai Mountain Area of Jilin Province” prepared by Jilin Province Geological Survey Institute in 2003, the groundwater tritium values of Jingyu basalt low platform subregion are 45~47TU. Taking 46TU here as the initial input concentration (N₀) of tritium in groundwater, the mineral water tritium value in this study area is brought into formula (6), and the results are shown in Table 2.

According to Table 2, the circulation time of groundwater in rocks is 20~40 years, which provides a time guarantee for the full development of water-rock reaction and the formation of mineral water.

5. Conclusions
In this paper, the origin and formation conditions of groundwater, and the mechanism of recharge are revealed by comparing the differences and changes in the hydrogen and oxygen isotopic composition of water samples and atmospheric precipitation in the study area. Concluded as follows:

(1) The δD and δ¹⁸O in mineral water are not much different from the δD and δ¹⁸O in atmospheric precipitation, indicating that groundwater in this area mainly receives recharge from atmospheric precipitation. The tritium isotopes in mineral water is generally 5~15(TU). It can be roughly estimated that the circulation time of groundwater in rocks is about 20~40 years.

(2) Jingyu natural mineral water recharge mechanism is as follows: the atmospheric precipitation infiltrate into basalt structural fissures, through long-term cycle, the cycle time is 20~40 years. The constant components and trace components in the water-bearing medium are leached by water-rock reaction. Basalt provides the necessary material source for the formation of natural mineral water.

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