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Comparative Study on Stable Isotopes of Different Occurrence Waters in China Southern Taihangshan Mountainous Region in Spring Season

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Abstract:

Environmental isotope characteristics of different occurrence waters are the main basis for the application of stable isotope technique to regional water cycle. Based on detection data of 2020 by L2130-i liquid water/water vapor isotope analyzer, this study analysed stable isotopes composition characteristics of six kinds of water samples at the Piedmont Alluvial Plain of China Southern Taihangshan Mountainous in spring and the water phase transition relationship indicated by them. The results show that the stable isotope values of different occurrence waters are as follows, atmospheric precipitation, lake water, artificial river water, natural river water, reservoir water, and groundwater. Among them, the atmospheric precipitation is similar to the lake water while the reservoir water is close to the groundwater. The lakes in study area are relatively wide and closed in the water surface and have undergone a long period of surface evaporation fractionation in both winter and spring, which constitutes the main source of atmospheric precipitation. So the heavy isotopes of both atmospheric precipitation and lake water are more relatively enriched. The water in reservoir is mainly replenished by groundwater and little from other sources, which resulted to that the heavy isotopes of both reservoir water and groundwater were depleted obviously. These conclusions not only revealed the stable isotopic environmental characteristics of different occurrence waters in spring, but also provided stable isotopic evidences for regional water cycle.

Keywords*: Different occurrence waters, Water cycle, Stable isotopes composition characteristics, China Southern Taihangshan Mountainous, In spring.*

I. INTRODUCTION

Isotopes are different atoms of one element with the same number of protons and different numbers of neutrons. For example, ^{1}H, ^{2}H and ^{3}H all belong to the hydrogen element with one proton, but their

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neutron numbers are 0, 1 and 2, respectively. As we see ^{3}H is unstable, there are two stable isotopes hydrogen as ^{1}H and ^{2}H. And the percentage of the former is higher than 99.98% in nature and the latter only accounts for slightly over 0.01%. There are 17 kinds of oxygen isotopes, whose number of protons is 8, but only three of them are stable, which have 8, 9 and 10 neutrons, respectively. The percentage of ^{16}O is higher than 99.76%, while the ^{18}O is only about 0.20%. As is known to all, stable isotopes are important media for studies on the mutual transformation of various water bodies in nature [1,2]. Therefore, stable isotopes of water in geological studies generally refer to ^{2}H and ^{18}O [3]. Although their proportion is small, they can respond quickly or sensitively to changes in environmental factors [4,5]. So, stable isotope components can be used to track the source of water vapor or to indicate the conversion process between water bodies [6,7].

Numerous studies have shown that both environmental effects of precipitation and water phase changes in water cycle are the most important parameters to cause the variation of stable isotopes between different occurrence waters [8]. Firstly, various environmental effects, such as temperature effect, rainfall effect, altitude effect, continent effect and latitude effect, are the basic reasons for isotope difference of precipitation between regions [9]. Secondly, thermal and dynamic fractionation resulted from phase changes between water bodies are the main causes of isotope differences within a region [10]. In various water bodies, the stable isotope composition of atmospheric precipitation is mainly closely related to the initial conditions of water vapor source, large-scale circulation situation, and meteorological conditions of rainfall [11,12]. And the stable isotopes of groundwater are mainly controlled by geological and hydrological conditions while the isotopes of lake water are mainly affected by amounts and percentages of all water recharge kinds, including atmospheric precipitation, river water and groundwater [13,14]. Moreover, the isotope composition of river water is affected by multiple factors, such as regional climate, geology, hydrology, etc. [15]. Because there are complementary hydraulic connections between various water bodies, the process of mutual transformation between water bodies can be explored according to the composition of stable isotopes, to a certain extent [16].

Up to present, most studies on water isotopes are focused on the spatiotemporal patterns of stable isotopes in atmospheric precipitation, and regional comparisons on characteristics of stable isotopes among water bodies. For example, Xu et al. (2007) have analysed the spatiotemporal pattern of $\delta^{18}O$ in precipitation and their correlation with vapour sources [17], based on stable isotopes data of rainfall from August to October of 2005 in Namco of Tibet Autonomous Region of China. Gao et al. (2018) have found that the water evaporation of Hulunhu Lake in Inner Mongolia Autonomous Region of China is stronger and its stable isotopes are more abundant than that of other river water nearby [18]. Yao et al. (2016) also have found that stable isotopes of river water around the Yuelushan Mountain in Hunan Province were slightly higher than those of soil water, groundwater and atmospheric precipitation during the same period, which revealed that the river water was stronger influenced by water surface evaporation than the other three water bodies [19]. So in this study, the isotope compositions of various water bodies in the southern foot of Taihangshan Mountain in Henan Province of China were comparatively analyzed to reveal the main recharging relationship between different occurrence waters in spring, the dry period of a year.

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II. OVERVIEW OF STUDY AREA AND SAMPLE COLLECTION

2.1 Overview of Study Area

The study area is located in the alluvial plains in the south of Taihangshan Mountain and on the northern bank of Huanghe River in China. The climate type belongs to the warm temperate continental monsoon, with cold winters and hot summers, and four distinct seasons. Relatively, it is cold and dry in winter, mainly controlled by continental air masses while it is warm and humid in summer, mainly affected by ocean air masses. The multi-year average precipitation and evaporation are 573.4 mm and 1928.1 mm, respectively, and the multi-year average of active accumulated temperature ≥10 ℃ is about 4800 ℃, all which resulted to almost study area belonging to the semi-humid zone in climate dry or wet condition.

In terms of hydrology, because both the west and the north of study area are Taihangshan Mountain or Shanxi Plateau, it is rich in groundwater with relatively shallow water level. There are abundant in surface water resources and many rivers, such as Qinhe River, Danhe River, Luanhe River and Shahe River, belong to the Huanghe River water system or the Haihe River water system respectively. In addition, large or medium-sized reservoirs, such as Maanshi Reservoirs e, Baiqiang Reservoirs and Hongqi Reservoirs, as well as lakes, such as Qunying Lake and Longyuan Lake, are distributed in this study area. And the middle section of China’s South-to-North Water Diversion Project passes by, from which the artificial river water samples described below are taken.

2.2 Sample Collection

All samples were collected from April 6th to 30th, 2020. Sample types include atmospheric precipitation, natural river water, artificial river water, lake water, reservoir water and groundwater. During the collection process, a 10 ml disposable syringe was used to draw a water sample first. Then, the sample was transferred into a 4 ml brown glass reagent bottle before it was tightened and sealed to avoid isotope fractionation due to the evaporation. All samples had been stored in the refrigerator in a timely manner after the sample was marked with sampling number, location, occurrence type, sampling time, weather conditions and other related information. Three samples of each type water body were collected with a total of 18 samples (Table I).

III. LABORATORY DETERMINATION AND DATA PROCESSING

3.1 Laboratory Determination

In order to ensure the maximum reliability of the connection of the autosampler, evaporator and analyzer, and to prevent small solid particles in the water from clogging the syringe needle, we use a filter with a pore size of 0.45 μm to remove impurities, such as soluble particles and suspended particles in the samples to meet the test sample requirements. Then, the pre-treated samples were handed over to the full-time professionals at the Hydrology Laboratory in Henan Polytechnic University. They used the L2130-i liquid water/water vapor isotope analyzer to continuously and automatically obtain the original

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values of δ^2H and $\delta^{18}O$ of various water bodies with the existing program. The analyzer can ensure that the accuracy of δ^2H and $\delta^{18}O$ reaches to ± 0.10‰ and ± 0.20‰ respectively, which meets the analysis needs of this study.

3.2 Data Processing

The original data were extracted, classified, sorted and error-checked to obtain the stable isotope proportions of hydrogen and oxygen in different water types. And δ was expressed as the thousandth difference (‰) relative to the Vienna standard mean ocean water (VSMOW for short) (Table I).

$$\delta = \left(\frac{R_{sample}}{R_{VSMOW}} - 1\right) * 1000 \tag{1}$$

In the formula, R_{sample} and R_{VSMOW} are the stable isotope ratio of sample and the Vienna standard mean ocean water, respectively. Here, when the δ^2H or $\delta^{18}O$ of each sample is "+", it indicates that the sample is more enriched than the standard sample; otherwise, it indicates that it is depleted [20].

TABLE I. Relative proportion of stable isotopes in different occurrence waters

ID	Longitude	Latitude	Occurrence type	δ^2H	Average Value/Order	$\delta^{18}O$	Average Value/Order
P.1	113.25°E	35.18°N	Precipitation	1.26‰	1.157‰/1	-1.92‰	-1.870‰/2
P.2				1.05‰		-1.84‰	
P.3				1.16‰		-1.85‰	
NS.1	113.17°E	35.18°N	Natural river water	-52.26‰	-53.020‰/4	-6.86‰	-6.81‰3/3
NS.2				-53.52‰		-6.75‰	
NS.3				-53.28‰		-6.83‰	
AS.1	113.23°E	35.22°N	Artificial river water	-47.92‰	-47.920‰/3	-7.18‰	-7.250‰/4
AS.2				-47.58‰		-7.26‰	
AS.3				-48.26‰		-7.31‰	
L.1	113.25°E	35.21°N	Lake water	-20.20‰	-19.770‰/2	-0.72‰	-0.667‰/1
L.2				-19.65‰		-0.65‰	
L.3				-19.46‰		-0.63‰	
R.1	113.45°E	35.25°N	Reservoir water	-56.35‰	-56.927‰/5	-8.15‰	-8.387‰/5
R.2				-57.18‰		-8.44‰	
R.2				-57.25‰		-8.57‰	
G.1	113.29°E	35.20°N	Groundwater	-64.05‰	-64.223‰/6	-8.90‰	-8.977‰/6
G.2				-64.36‰		-9.08‰	
G.3				-64.26‰		-8.95‰	

IV. RESULTS AND ANALYSIS

4.1 Characteristics of Stable Isotope in Different Occurrence Waters

4.1.1 Atmospheric precipitation

The isotope composition of atmospheric precipitation is mainly affected by two kinds of factors,

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regional climatic background and local environmental conditions. The former mainly includes vapor source and atmospheric circulation, and the latter refers to meteorological factors, including precipitation, temperature and humidity, as well as geographical factors, such as latitude, altitude, distance from sea and other surface conditions, etc. In this study, δ^2H and δ^{18}O were 1.167‰ and -1.870‰, respectively; among the six types of water bodies, the former was the first highest and the latter was the second highest only to that of lake water. In spring, it is dry with limited rain in the study area, and it is drizzle if being rainfall. So the recharging from atmospheric precipitation to surface water and groundwater is very limited. Because atmospheric moisture comes mainly from evaporation of surface water, dominated by lake water, the values of δ^2H and δ^{18}O in atmospheric precipitation are relatively higher because of rarely isotopic depletion way. In a word, the heavy stable isotope of atmospheric precipitation in spring is more relatively enriched, while both surface water and groundwater still retain the depletion characteristics resulted from low stable isotopes of precipitation replenishment in the summer season.

4.1.2 Lake water

Dry air and strong winds are the most important climatic characteristics of spring in the study area, so there are few ways and less quantity of lake water replenishment. The δ^2H and δ^{18}O of the lake water in this study were -19.770‰ and -0.667 ‰, respectively, and the numerical values were the second highest and the first highest among the six types of water bodies. That meant the stable isotope of lake water was more enriched than that of river water, reservoir water and groundwater, and was equivalent to that of atmospheric precipitation. There are two reasons to be explained for the higher stable isotope values of lake water. Firstly, the water surface evaporation of lake was much stronger than that of other surface bodies or groundwater, and at the same time its water body replacing cycle was longer. Secondly, the sampling lake water with weak fluidity had no direct exchange with large rivers. Both of them caused the light isotopes of the lake water to evaporate in large quantities, and the heavy isotopes to accumulate. So the stable isotopic value of this lake water is higher rather than that of other surface water bodies or groundwater.

4.1.3 River water

In this study, river water included natural river water and artificial river water. The former is a regular or periodic flowing water body on the earth, whose surface has been constantly evaporated to varying degrees due to the effects of temperature difference between water and air, wind speeds and humidity. And its sources of replenishment are diverse, including precipitation, lake water, reservoir water, groundwater, and so on. The latter in this study was diverted from Danjiangkou Reservoir which was 500 km away. Its isotopic composition was obviously controlled by the reservoir water, but it is also inevitably with the imprint of the geographical environment background along its running route, because its main source of supply was atmospheric precipitation and shallow groundwater. In this study, the values of δ^2H and δ^{18}O of natural river water samples were -53.020‰ and -6.813‰ while those of artificial river water were -47.920‰ and -7.250‰ respectively. Therefore, the values of stable isotopes of natural river water and artificial river water were close to each other, which were more depleted than those of both atmospheric precipitation and lake water, and more enriched than those of both reservoir water and groundwater in the

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following article.

4.1.4 Reservoir water

A reservoir is a relatively closed storage space of surface water. Although its water body has certain fluidity, it is more closely related to the hydraulics of groundwater. In particular, the study area was rich in groundwater, and the sampling reservoir was located in the thick forests in the southern foot of Taihangshan Mountain, so the water evaporation was quite limited. Therefore, δ^2H and δ^{18}O of the reservoir water samples in this study were -56.927‰ and -8.387‰, respectively, both ranking fifth among the six types of water bodies, which were only higher than those of groundwater. Because the amount of atmospheric precipitation in spring is small, it is not the main form of reservoir water supply, but groundwater. Here, it worth emphasizing that both reservoir water and groundwater were closely related hydraulically each other, for their stable isotope values were similar, both of more depleted.

4.1.5 Groundwater

Generally, if groundwater is mainly replenished by sufficient atmospheric precipitation to maintain water balance, the values of stable isotopes in groundwater will be slight higher than those of atmospheric precipitation, because dynamic fractionation will occur during the conversion of atmospheric precipitation to surface water, then to recharge groundwater, which will cause the stable isotope enrichment. However, the δ^2H and δ^{18}O of groundwater in this study were -64.223‰ and -8.977‰ respectively, which were the lowest among the six types of water bodies. These results should be related to weak evaporative fractionation and abundant groundwater in study area, which is why the heavy isotope content will not decrease much even if there is evaporation. So the stable isotopes of groundwater were more depleted compared with those of atmospheric precipitation and surface water bodies.

4.2 Comparisons of Relevant Studies

The combined effects of multiple factors, such as water vapor source, atmospheric circulation and local geographic environment, cause regional differentiation in the composition of precipitation isotopes, which ultimately leads to different characteristics of stable isotopes in different water bodies participating in water cycle. Generally, the response of stable isotope characteristics of both surface water and groundwater to atmospheric precipitation has a gradual lag in time, because atmospheric precipitation forms surface runoffs, and it takes time to become groundwater through infiltration.

On the one hand, the stable isotope values of atmospheric precipitation and lake water were close to each other. The spring atmospheric precipitation in study area mainly came from the evaporation of surface water dominated by lake water, so the stable isotope values of spring precipitation were more enriched than those of the summer precipitation from marine water sources, and they also were higher than those of river water, reservoir water and groundwater. And the two characteristics of extremely weak mobility and strong evaporation of lake water also led to the enrichment of heavy stable isotopes, because the multi-year average evaporation in the study area was 3.36 times that of annual precipitation, and was even higher in

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spring because of sparse rainfall relative to other seasons. This was basically consistent with the results of other related studies. For example, Li et al. (2015), Huang et al. (2016) and Sun et al. (2016) all showed that precipitation in drought conditions was subjected to relatively strong evaporation during the descent process, which led to the enrichment of heavy isotopes, higher or more positive $\delta^{18}O$ and $\delta^{2}H$ of atmospheric precipitation than those of surface water and groundwater [21-23].

On the other hand, the stable isotope composition of reservoir water and groundwater was relatively close. In all surface water bodies, the lake water and river water in the study area were suffered significantly to surface evaporation in spring, so their stable isotopic values were close to those of atmospheric precipitation, especially that of the lake water. But here more noteworthy, those of reservoir water and groundwater were relatively low. This result was basically consistent with conclusions from many scholars. Zhan et al. (2014) and Huang et al. (2016) made a comparative study on stable isotopes of different occurrence waters in Dongtinghu Lake Basin and Changsha City in Hunan Province [8,24], and found that isotope values of groundwater of spring were significantly deviated from the precipitation line because there was a significant hysteresis in the response of groundwater $\delta^{18}O$ to atmospheric precipitation characteristics. Chen et al. (2013) and Gao et al. (2018) also found that the stable isotope values of lake water of both Hulunhu Lake Basin in Inner Mongolia Autonomous Region and Poyanghu Lake Basin in Jiangxi Province were the largest, followed by those of river water, reservoir water and groundwater, successively [6, 25].

V. MAIN CONCLUSIONS

Based on the data of 2020 by L2130-i liquid water/water vapour isotope analyzer, the stable isotope differences of atmospheric precipitation, lake water, river water, reservoir water and groundwater in spring in the Piedmont Alluvial Plain of the South Foot of Taihangshan Mountain in China, and their causes were compared and analyzed. The main conclusions are as following of three points. First of all, the stable isotope values of different types of water bodies were basically following the order as atmospheric precipitation, lake water, artificial river water, natural river water, reservoir water and groundwater. Among them, the stable isotope values of atmospheric precipitation and lake water, and those of reservoir water and groundwater, were closer to each other. In addition, the stable isotope values of atmospheric precipitation and lake water were both more relatively enriched and close to each other, which indicated that the source of atmospheric precipitation in spring was lake water-based surface water evaporation. The lakes in this study area were relatively closed and experienced strong water evaporation fractionation. Last but not least, the stable isotope composition of reservoir water and groundwater was relatively close and both more depleted, indicating that the reservoir water in study area was mainly dominated by groundwater recharging. And there was a close hydraulic connection between them. All in all, our finding not only reveals the characteristics and conversion features of $\delta^{2}H$ and $\delta^{18}O$ in different water bodies, but also provides evidence from stable isotopes for understanding the water cycle in Jiaozuo City.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

AUTHOR CONTRIBUTIONS

Y. Liu conceived and led the study and wrote the initial manuscript.

C. Hao conducted field sampling and laboratory analyses.

W. Liu reviewed and edited and formal analyses.

H. Zhang and M. Kou supervised and validated.

Both authors interpreted the data and contributed to the manuscript preparation.

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REFERENCES

[1] Hao S., Li F. D., Li Y. H., Gu C. K., Zhang Q. Y., Qiao Y. F., Jiao L., & Zhu N. (2019) Stable isotope evidence for identifying the recharge mechanisms of precipitation, surface water, and groundwater in the Ebinur Lake basin. Science of the Total Environment, 657, 1041–1050.

[2] Penna D., Geris J., Hopp L., & Scandellari F. (2020) Water sources for root water uptake: using stable isotopes of hydrogen and oxygen as a research tool in agricultural and agroforestry systems. Agriculture Ecosystems & Environment, 291.

[3] Gaj M., Beyer M., Koeniger P., Wanke H., Hamutoko J., & Himmelsbach T. (2016) In situ unsaturated zone water stable isotope (H-2 and O-18) measurements in semi-arid environments: a soil water balance. Hydrology and Earth System Sciences, 20(2), 715–731.

[4] Wang Y., Chen Y. N., & Li W. H. (2014) Temporal and spatial variation of water stable isotopes (O-18 and H-2) in the Kaidu River basin, Northwestern China. Hydrological Processes, 28(3), 653–661.

[5] Tian H. B., Liu Z. H., Rao W. B., Wei H. Z., Zhang Y. D., & Jin B. (2017) Stable isotopes of soil water: implications for soil water and shallow groundwater recharge in hill and gully regions of the Loess Plateau, China. Agriculture Ecosystems & Environment, 243, 1-9.

[6] Bowen G. J., Chesson L., Nielson K., Cerling T. E., & Ehleringer J. R. (2005) Treatment methods for the determination of delta H-2 and delta O-18 of hair keratin by continuous-flow isotope-rate mass spectrometry. Rapid Communications in Mass Spectrometry, 19(17): 2371-2378.

[7] Koehler G., & Wassenaar L. I. (2011) Realtime stable isotope monitoring of natural water by Parallel-Flow laser spectroscopy. Analytical Chemistry, 83 (3): 913-919.

[8] Meier-Augenstein W., Kemp H. F., & Hardie S. M. L. (2012) Detection of counterfeit scotch whisky by H-2 and O-18 stable isotope analysis. Food Chemistry, 133(3), 1070-1074.

[9] Tay C. K., Kortatsi B. K., Hayford E., & Hodgson I. O. (2014) Origin of major dissolved ions in groundwater within the lower Pra Basin using groundwater geochemistry, source-rock deduction and stable isotopes of H-2 and O-18. Environmental Earth Sciences, 71(12), 5079-5097.

[10] Bertrand G., Masini J., Goldscheider N., Meeks J., Lavastre V., Celle-Jeanton H., Gobat J. M., & Hunkeler D. (2014) Determination of spatiotemporal variability of tree water uptake using stable isotopes ($\delta^{18}O$, $\delta^{2}H$) in an alluvial system supplied by a high-altitude watershed, Pfyn forest, Switzerland. Ecohydrology, 7(2), 319-333.

[11] Liu Z. F., Bowen G. J., & Welker J. M. (2010) Atmospheric circulation is reflected in precipitation isotope gradients over the conterminous United States. Journal of Geophysical Research, 115, D22120: 1-14.

[12] Liu Z. Q., Jia G. D., Yu X. X., Lu W. W., & Zhang J. M. (2018) Water using by broadleaved tree species in

Forest Chemicals Review
www.forestchemicalsreview.com
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Article History: Received: 10 August 2021, Revised: 25 August 2021, Accepted: 05 September 2021, Publication: 31 October 2021

response to changes in precipitation in a mountainous area of Beijing. Agriculture Ecosystems & Environment, 251, 132-140.
[13] Jahanshahi R., & Zare M. (2017) Delineating the origin of groundwater in the Golgohar Mine Area of Iran using stable isotopes of H-2 and O-18 and hydrochemistry. Mine Water and the Environment, 36(4), 550-563.
[14] Jiang Z. J., Xu T. F., Mallants D., Tian H. L., & Owen D. D. R. (2019) Numerical modeling of stable isotope (H-2 and O-18) transport in a hydrogeothermal system: model development and implementation to the Guide Basin, China. Journal of Hydrology, 569, 93-105.
[15] Qian H., Wu J. H., Zhou Y. H., & Li P. Y. (2014) Stable oxygen and hydrogen isotopes as indicators of lake water recharge and evaporation in the lakes of the Yinchuan Plain. Hydrological Processes, 28, 3554-3562.
[16] Zhao W., Hao C. Y., & Xu C. Y. (2019) Environmental research on spatial pattern of hydrogen and oxygen stable isotopes of atmospheric precipitation in China influenced by both southwest summer monsoon and south sea summer monsoon. Ekoloji, 28(107), 981-988.
[17] Xu Y. W., Kang S. C., Zhou S. Q., Cong Z. Y., Chi Y. Y., & Zhang Q. G. (2007) Variations of δ18O in summer and autumn precipitation and their relationships with moisture source and air temperature in Nam Lake Basin, Tibet Plateau. Scientia Geographica Sinica, 27(5), 718-723.
[18] Gao H. B., Li C. Y., Sun B., Shi X. H., Zhao S. N., & Fan C. R. (2018) Characteristics of hydrogen and oxygen stable isotopes in Lake Hulun Basin and its indicative function in evaporation. Journal of Lake Sciences, 30(1), 211-219.
[19] Yao T. C., Zhang X. P., Li G, Huang H., Wu H. W., Huang Y. M., & Zhang W. J. (2016) Characteristics of the stable isotopes in different water bodies and their relationships in surrounding areas of Yuelu Mountain in the Xiangjiang River Basin. Journal of Natural Resources, 31(7), 1198-1209.
[20] Craig H. 1961 Isotopic variations in meteoric waters. Science, 133(3465), 1702-1703
[21] Li G., Zhang X. P, Zhang L. F, Wang Y. F., Deng X. J., Yang L., & Lei C. G. (2015) Stable isotopes characteristics in different water bodies in Changsha and implications for the water cycle. Environmental Science, 36(6), 2094-2101
[22] Huang Y. M., Song X. F., Zhang X. P., He Q H., Han Q., Fan F. D., & He W. (2016) Stable water isotopes of different water bodies in the Dongting Lake Basin. Scientia Geographica Sinica, 36(8), 1252–1260.
[23] Sun F. Q., Yin L. H., Ma H. Y., Wang X. Y., Zhang J., Wang H. Q., & Guo L. (2016) Features of hydrogen and oxygen isotopes and their indication of hydrological cycle in Sangong River Basin of Xinjiang. Yellow River, 38(12), 106–109.
[24] Zhan L. C., Chen J., & Zhang S. (2014) Characteristics of stable isotopes in precipitation, surface water and groundwater in the Dongting Lake region. Advances in Water Science, 25(3), 327–335.
[25] Chen J. S., Peng J., Zhan L. C., & Zhang S. Y. (2013) Isotope study of recharge relationships of water sources in Wuliangsuhai Lake and its surrounding areas. Water Resources Protection, 31(4), 1–7.