Spatial distribution and influencing factors of stable hydrogen and oxygen isotopes in river water during rain period in Shiyang River Basin

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Abstract: *Understanding the stable hydrogen and oxygen isotope composition of river water in the basin is of great significance for identifying the evolution mechanism of water cycle and the composition of water source. Based on the test results of δD and δ18O of river water and precipitation samples collected from Shiyang River in August 2020, this paper analyzed the composition characteristics of δ18O and δD of river water in Shiyang River Basin during rainy period, and further revealed the spatial evolution characteristics and influencing factors. The results show that the δ18O and δD values of the main and tributaries of Shiyang River are gradually enriched along the river, showing an increasing trend, while the excess deuterium is decreasing along the river. The effect of δ18O and δD in river water is significant, and the variation of δ18O altitude gradient is smaller than that of local precipitation and global precipitation. Using the evaporation loss calculation model, it can be seen that evaporation fractionation has an obvious effect on the water isotope change of Shiyang River, and the main stream of Shiyang River has the greatest effect, followed by Jinta River and Zamu River. The evaporation of reservoir water is more intense than that of river water. Precipitation is the main source of river water, and the isotope is mainly affected by the isotopic composition of river water in tributaries, and is controlled by the elevation effect, the continuous evaporation effect along the direction of runoff, and the higher degree of evaporation effect in the rainy season.*

Keywords: *Hydrogen and oxygen isotopes, Elevation effect, Evaporation loss*

1. Introduction

There is a serious water shortage problem in the arid and semi-arid areas of inland China [1]. As the most important fresh water resource that can be directly utilized, the study of river water is of great significance [2]. River systems play an important role in the water cycle in inland regions [3-4], and the investigation of river systems can provide insights into the status of relevant ecosystems and water resources [4-5]. As a natural tracer of water, stable hydrogen and oxygen isotopes are very useful in hydrological studies, such as labeling and determining the characteristics, source, composition and evaporation loss of water [5-7]. At present, a number of studies have been carried out on river basins, but most of them focus on investigating the characteristics of stable hydrogen and oxygen isotopes in precipitation [8], water cycle [9-10], groundwater and surface water interaction [11-12], and plant water sources [12-14].

The stable isotopes in river water have a complex change process, because the changes of stable hydrogen and oxygen isotopes in river water are affected by many factors [8], such as precipitation [15-17], altitude [8,18], evaporation [19-20], groundwater recharge and human activities, etc. As a result, the spatial distribution and variation characteristics of stable hydrogen and oxygen isotopes in river water in different regions are different, and these differences can well explain regional hydrological processes [21]. Zheng et al. analyzed the stable isotope characteristics of the Yarlung Zangbo River and found that deuterium excess and $\delta^{18}O$ showed a spatial change trend of first decreasing and then increasing, which was affected by multiple factors such as temperature and altitude [22]. Fan et al. studied the spatial distribution changes of stable hydrogen and oxygen isotopes ($\delta^{18}O$ and δD) in the water source and river of the Tizinaphe river in North Kunlun, and evaluated the response of hydrogen and oxygen isotopes and deuterium excess to evaporation through correlation analysis [23]. Wang et al. analyzed the variation characteristics of $\delta^{18}O$ and δD in the Kaidu River in the arid region of Northwest China and found that the spatial variability of $\delta^{18}O$ in the main stream river showed an "increase-decrease-increase" change due to intense evaporation [24]. Sun et al. found that the increasing trend of $\delta^{18}O$ and δD in the river water of Tarim River basin along the river is related to the intense evaporation in this area and the construction of reservoir [25]. However, there are relatively few studies focusing on the spatial changes of stable hydrogen and oxygen isotopes of river water in the whole basin, especially in small rivers in arid and semi-arid areas deep in the interior. Therefore, it is of great significance to study the changes of stable hydrogen and oxygen isotopes in small rivers in arid and semi-arid areas. These studies on stable hydrogen and oxygen isotopes of surface water in river basins provide important information for understanding regional hydrological processes.

The spatial variation characteristics of stable hydrogen and oxygen isotopes in river water are different [26], which are controlled by the effect of elevation [18,27-28], the continuous evaporation effect along the direction of runoff [29], and the high degree of evaporation effect in rainy season [30]. Arid and semi-arid areas are particularly affected by evaporation, which enrichis the isotopic composition of surface water [31]. The fractionation effect of hydrogen and oxygen isotopes leads to a certain degree of differences in the natural abundance of hydrogen and oxygen isotopes in different water sources in river ecosystems [32]. Water from different sources has different hydrogen and oxygen isotope characteristics [33]. For the main stream of a river, there will be a large number of tributaries flowing into it, and the differences in geographical conditions of each small watershed affect the composition of stable isotopes in these tributaries, thus affecting the changes of stable isotopes in the main stream river [34]. Therefore, when studying the isotopic changes of river water in the whole basin, the movement trajectory of water body can be traced by comparing the hydrogen and oxygen isotopic compositions of water bodies from different sources, and the contribution ratio of tributary water systems to the main stream water can be quantitatively estimated.

The Shiyang River basin originates in the eastern part of the Qilian Mountains and is located in the arid and semi-arid regions of the interior. It consists of eight tributaries (Dajing River, Gulang River, Huangyang River, Zamu River, Jinta River, Xiying River, Dongdahe River and Xidahe River). The runoff of the downstream basin mainly depends on the upstream tributaries, which has a great influence on the regional hydrological process. In order to better understand the whole Shiyang River basin, through the investigation of stable hydrogen and oxygen isotope data of water samples, the content and spatial distribution characteristics of hydrogen and oxygen isotopes in the whole Shiyang River basin are analyzed, the altitude effect of water isotopes in the Shiyang River basin is studied, and the evaporation loss of the main tributaries in the basin is explored, as well as the contribution rate of tributaries in the basin to the main stream is explored. The aim of this study is to improve the understanding level of hydrogen and oxygen isotope characteristics in Shiyang River basin and improve the understanding of water resources in inland arid and semi-arid areas.

2. Materials and methods

2.1 Overview of the study area

Shiyang River is the third largest river in the Hexi Corridor of Gansu Province. It originates from Daxue Mountain on the north side of Lenglong Mountain in the eastern part of Qilian Mountains. Its geographical coordinates are 101°22'-104°04' east longitude and 37°07'-39°27' north latitude(Figure 1). It includes eight tributaries, namely Dajing River, Gulang River, Huangyang River, Zamu River, Jinta River, Xiying River, East River and West River. According to the different river flow and pooling areas can be divided into three major water systems, the Dajing River system includes the Dajing River, the West River system includes the West River, the six river system includes the other six tributaries. The Shiyang River originates in the cold, humid and semi-arid Qilian Mountains at an altitude of 2000-5000 m, flows into the middle temperate zone at an altitude of 1400-2000 m in the Wuwei Basin, and then continues to flow into the lower warm temperate zone at an altitude of 1000-1400 m in the Minqin Basin. The drought index increased from the upper reaches to the middle reaches to the lower reaches. The river is mainly fed by rainfall, snowmelt and glacial meltwater from the Qilian Mountains. The average annual runoff of Shiyang River is 1.591 billion cubic meters, with a runoff producing area of 11,100 square kilometers. According to records from 1971 to 2021, the combined annual average runoff of the eight tributaries is 1.396 billion square meters, about 181.7 million square meters in the Caiqi area in the middle reaches and about 217.4 million square meters in the lower reaches. There are 15 large reservoirs in the whole basin, of which the downstream Hongyashan reservoir is the most famous.There are 15 large reservoirs in the whole basin, of which the downstream Hongyashan reservoir is the most famous.

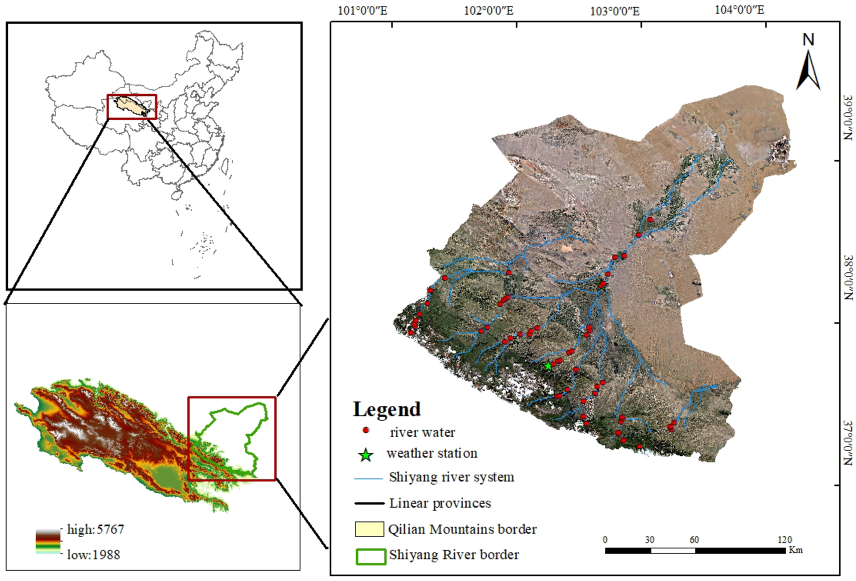

Figure 1: Geographical location of the study area.

2.2 Sample collection and experimental analysis

From August 7 to August 12, 2020, 57 sampling sites were selected in eight tributaries and main streams of the Shiyang River. Eight times of precipitation were collected at Binggou River meteorological station and Caiqi meteorological station in August. Before sampling, clean a 5mL glass sample bottle three times with sampling water and fill it with water. Each vial is immediately sealed with Parafilm to prevent evaporation. All samples were sealed in glass bottles immediately after collection and stored in a cryogenic laboratory at −18°C. Just prior to analysis, samples are stored in a 4°C refrigerator to gradually melt and avoid evaporation. The samples were pre-processed and determined in Isotope Laboratory, College of Geography and Environmental Sciences, Northwest Normal University. All water samples were analyzed using the DLT-100 liquid water isotope analyzer developed by Los Gatos Research. The microliter syringe was used to inject all samples and isotope reference materials successively for six times, and the first two injections were discarded. The average of the four injections results was taken as the final value. The analytically derived δD and $\delta^{18}O$ are expressed in terms of the difference of one thousandth of Vienna Standard mean Seawater (VSMOW) :

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

In the formula, Rsample is the ratio of heavy to light isotopes in the water sample. δD and $\delta^{18}O$ are D/H and $^{18}O/^{16}O$, respectively. The measurement uncertainties were 0.6‰ and 0.2‰, respectively.

2.3 Excessive deuterium in river water

In order to compare the differences between global and regional atmospheric precipitation, Dansgaard proposed the concept of deuterium excess (d-excess), defined by the formula:

$$\text{D-excess}=\delta D-8*\delta^{18}O \tag{2}$$

D-excess is associated with source moisture and evaporation process, and this value has been frequently used in precipitation and groundwater studies. D-excess can also be used in the study of surface water, and its characteristics can reflect the influence of surface water on evaporation. The d-excess value in surface water can directly reflect the degree of evaporation enrichment and the source of inter-water recharge.

2.4 Evaporation loss calculation model

Rayleigh distillation is a phase equilibrium process based on an open system, assuming that when evaporation occurs, the water-vapor interface is always in equilibrium between the two phases, and the river water is sufficiently mixed and affected by evaporation. The calculation of river evaporation using Rayleigh distillation equations represents the mean hydrological characteristics, even if the river is a

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dynamic system. In this paper, Rayleigh equilibrium fractionation equation is used to calculate the evaporation ratio. According to this equation, the isotopic composition of residual water during evaporation can be calculated by (3):

$$\delta^{18}O = F^{\frac{1-\alpha O}{\alpha O}}[(\delta^{18}O)_0+1000]-1000 \tag{3}$$

Where, F is the proportion of residual water; $\delta^{18}O$, $(\delta^{18}O)0$, are isotopic components of residual water and initial water, respectively. αO is the fractionation coefficient of $\delta^{18}O$ in condensation process, and they are equal to the reciprocal of fractionation coefficient in evaporation process, respectively. Since fractionation in evaporation involves equilibrium fractionation between water and steam and dynamic fractionation between steam and boundary layer at the evaporation interface, the fractionation factor can be expressed as:

$$\alpha_o = \alpha_1 + \alpha_2 \tag{4}$$

According to, the relationship between the fractionation coefficient α1 and temperature (T) of liquid-gas phase transition system deduced by theory is as follows:

$$10^3 \text{In}\alpha O = 1.137 * (10^6 * T^{-2})-0.4156*(10^3*T^{-1})-2.0667 \tag{5}$$

Relative humidity plays the most important role among the surface temperature, wind speed, salinity and relative humidity that affect dynamic fractionation, describes kinetic fractionation at relative humidity (h) using the following equation:

$$\alpha_2 = (h-1) * 14.2‰ \tag{6}$$

Infiltration or transpiration may not strongly affect the isotopic composition of water, so its effects are not considered for the time being.

3. Results and analysis

3.1 Stable hydrogen and oxygen isotope composition of Shiyang River water

The minimum and maximum $\delta^{18}O$ values of stable hydrogen and oxygen isotopes in Shiyang River water are -9.80‰ and -8.41‰, and the fluctuation range is small; the minimum and maximum δD values are -68.61‰ and -58.93‰,and the fluctuation range is large. The average values of δD and $\delta^{18}O$ are -65.20‰ and -9.28‰, and the coefficient of variation is 0.31‰ and 2.11‰, respectively. The coefficient of variation of δD is larger than that of $\delta^{18}O$, and the degree of dispersion of $\delta^{18}O$ is lower than that of δD, and the change is stable. The equation of river line from Shiyang River basin can be obtained from Figure 2: $\delta D=6.74\delta^{18}O-2.66$ ($R^2=0.93$).The equation shows a significant linear correlation, and its slope and intercept are smaller than that of the global atmospheric water line reported by Craig (GMWL, $\delta D=8\delta^{18}O+10$). It can be seen that the slope and intercept of the river line obviously deviate from the atmospheric precipitation line and are located at the lower right of it, because surface water is mainly affected by precipitation, and after being recharged by atmospheric precipitation, it undergoes evaporative fractionation, which leads to the accumulation of stable isotopes in surface water. The equation of atmospheric precipitation line of Shiyang River proposed by Zhu $\delta D=7.65\delta^{18}O+9.75$ ($R^2=0.94$).

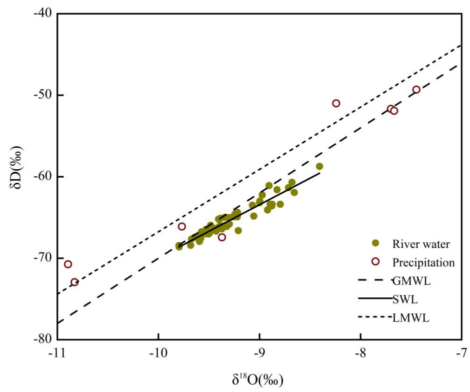

Figure 2: Relationship between river water and precipitation δD and δ18O in Shiyang River Basin.

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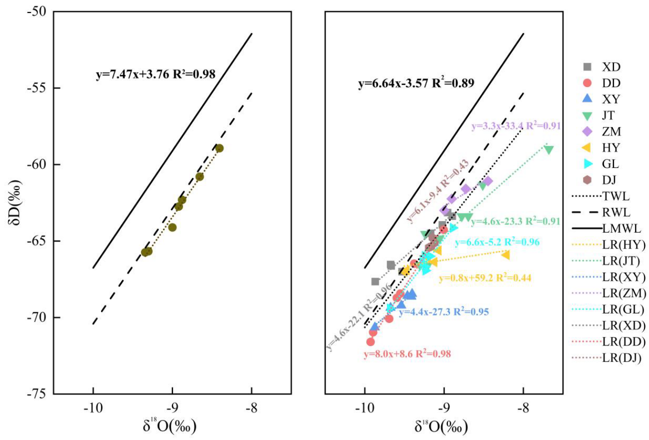

Figure 3: The relationship between δD and δ18O values of main stream river and tributary river.

Table 1: Isotopic compositions of $\delta^{18}O$ and δD in river water of main tributaries.

Rivers	Number of samples	$\delta^{18}O$			$\delta^{2}H$		
		Minimum value	Maximum value	Mean value	Minimum value	Maximum value	Mean value
Xida River	8	-9.53	-9.07	-9.31	-67.00	-63.49	-65.48
Dongda River	7	-9.80	-9.25	-9.59	-68.61	-64.80	-67.19
Gulang River	7	-9.68	-9.37	-9.48	-68.41	-65.97	-66.78
Huangyang River	6	-9.50	-9.22	-9.37	-67.01	-64.91	-66.04
Jinta River	8	-9.24	-8.68	-8.93	-66.60	-60.68	-63.51
Xiying River	6	-9.67	-9.48	-9.58	-67.65	-66.36	-67.00
Zamu River	4	-9.00	-8.83	-8.93	-63.00	-61.07	-61.97
Dajing River	4	-9.40	-9.34	-9.38	-65.21	-64.97	-65.10
Main stream	7	-9.34	-8.41	-8.93	-65.74	-58.93	-62.43

$\delta^{18}O$ ranges from -9.34‰ to -8.41‰ and the average value is -8.93‰; δD ranges from -65.99‰ to -58.93‰ and the average value is -62.43‰; and $\delta^{18}O$ ranges from -9.80‰ to -8.83‰ and the average value is -9.21‰ in tributary rivers(Table 1). The value of δD ranges from -68.61‰ to -60.68‰, with an average value of -65.50‰. The δD and $\delta^{18}O$ values of each tributary river are roughly the same, and the fluctuation range of their composition is small. Because the main stream is in the middle and lower reaches of the Shiyang River basin and the evaporation is intense, the $\delta^{18}O$ and δD values of the main stream of the Shiyang River are smaller than those of the tributaries, and the variation range is larger than that of the tributaries. It can be seen that the hydrogen and oxygen isotopes of the main stream of Shiyang River are obviously larger, while those of the tributaries are relatively smaller. Figure 3 shows the surface water lines of the main stream and eight tributaries (main stream: $\delta D=7.47\delta^{18}O+3.77$; Tributaries: $\delta D=6.64\delta^{18}O-3.57$), among which the waterline slope of Dongdahe River is greater than that of the main stream, and the slopes of other tributaries are smaller than that of the main stream. The slope intercept of the main stream river line and the precipitation line is similar, and the deviation between the tributary river line and the precipitation line is large, which indicates that the main stream is more affected by precipitation recharge.

3.2 Change characteristics of excess deuterium

The average value of deuterium excess parameters in global precipitation is 10‰, and that in China is close to 8‰.

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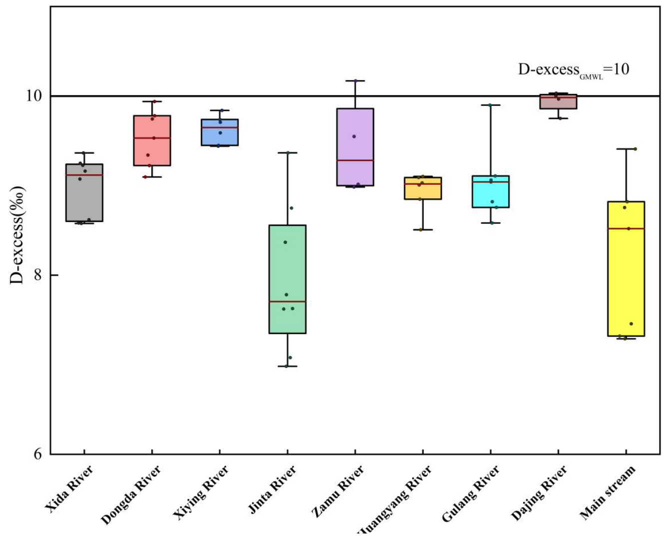
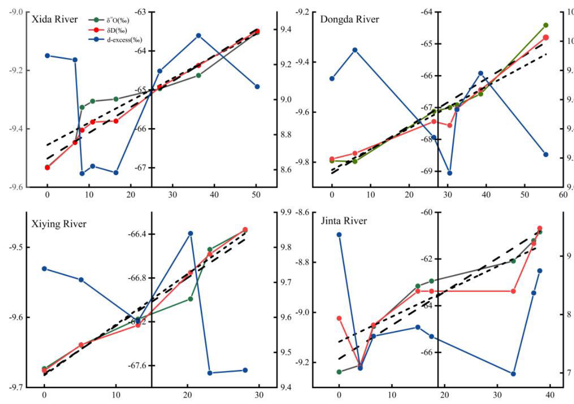


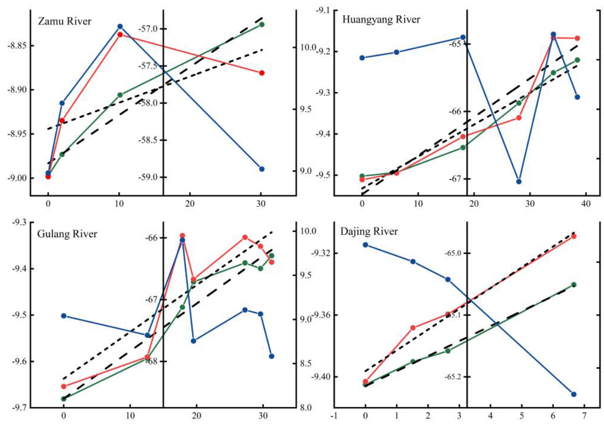
Figure 4: d-excess values of the eight tributaries and main streams, with the squares representing the percentiles of 25%-75%, the lines in the boxes representing the median (50th percentile), the required lines representing the 90th and 10th percentiles, and the dots representing the 95th and 5th percentiles.

Deuterium excess in precipitation depends on the source vapor conditions as well as the water cycle in the area, and the excess deuterium value reflects the characteristics of the source. It can be seen from Figure 4 that the variation range of excess deuterium value in river water is 6.98‰~10.17‰, and the variation range of excess deuterium value in river water of major tributaries is different, and the average difference is not obvious.The box diagram of excess deuterium value shows that the data of excess deuterium value in the main stream of Jinta River, Zaamu River and Shiyang River show a wide range, which indicates that the evaporation intensity of the sampling points of the river is very different. The variation range of Dajing River, Xiying River, Huangyang River and Gulang River is narrow, which indicates that the difference of evaporation intensity of each sampling point of the river has little change. The excess deuterium value in the global precipitation is 10‰, and the excess deuterium value in the rivers of the main tributaries is roughly around 10‰, and most of the excess deuterium value is under 10‰ (only about 5.26% of the samples have a value greater than 10‰). Among them, the excess deuterium value in the main stream and the Jinta River is relatively small, and the excess deuterium value in the Dajing River is most close to 10‰. In general, the composition of excess deuterium value from small to large is: Gan Liu, Jinta River, Huangyang River, West River, Gulang River, East River, Xiying River, Zaamu River and Dajing River. It shows that during the sampling period, there is a high level of evaporation in all the main and tributaries of Shiyang River basin, in which the main stream evaporation is the strongest, followed by the Jinta River, and the Dajing River evaporation is the least.

3.3 Spatial distribution characteristics of isotopes along the flow path



(a)



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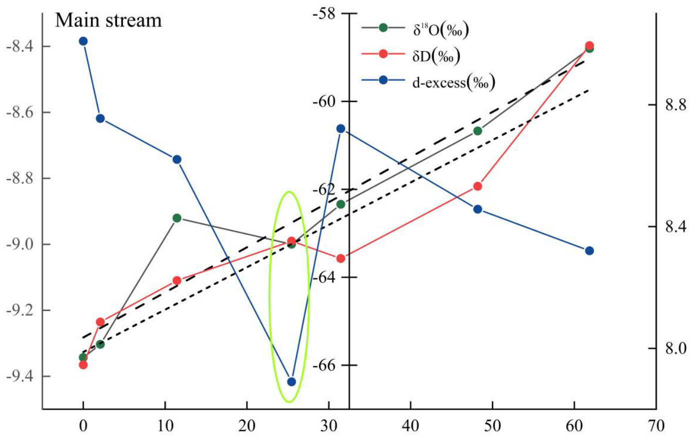

(c)

Figure 5: (a)(b)(c) Variation of $\delta^{18}O$ and δD values along the distance of the main tributaries of Shiyang River Basin (horizontal axis distance represents the distance between each sampling point and the westernmost sampling point on the flow path of each river).

Table 2: Correlation between $\delta^{18}O$ and δD and distance in main and tributary rivers.

Rivers	Correlation between $\delta^{18}O$ and distance	Correlation between δD and distance
Xida River	y=0.0076x－9.4551 R^2=0.86	y=0.0662x－66.762 R^2=0.98
Dongda River	y=0.0094x－9.8438 R^2=0.95	y=0.0654x－69.957 R^2=0.91
Xiying River	y=0.0068x－9.6804 R^2=0.94	y=0.0462x－67.687 R^2=0.98
Jinta River	y=0.0134x－9.1855 R^2=0.91	y=0.1075x－65.542 R^2=0.75
Zamu River	y=0.0055x－8.9833 R^2=0.96	y=0.0353x－62.348 R^2=0.35
Huangyang River	y=0.0078x－9.5323 R^2=0.96	y=0.0573x－67.227 R^2=0.90
Gulang River	y=0.0102x－9.6792 R^2=0.84	y=0.0758x－68.287 R^2=0.72
Dajing River	y=0.0097x－9.4060 R^2=0.99	y=0.0336x－65.191 R^2=0.98
Main stream	y=0.0137x－9.2824 R^2=0.92	y=0.0964x－65.699 R^2=0.90

Treat each tributary as a unit and then divide the river into units based on where it was sampled. Sampling points are set from west to east along the flow path of each major river, and the westernmost sampling point is considered the starting point when calculating distances. Due to the existence of strong evaporation, the composition of stable hydrogen and oxygen isotopes in the river has significant spatial variation characteristics. The $\delta^{18}O$ and δD values of the eight tributary rivers show the same trend along the runoff direction, and some values occasionally decrease, but generally increase with the increase of distance. The d-excess value of the tributary river along the runoff direction is opposite to the trend of $\delta^{18}O$ and δD values, and decreases with the increase of distance.

The variation trend of d-excess in river water is exactly opposite to the variation trend of $\delta^{18}O$ in river water, showing "N" and inverse "N" type changes (Figure 5(c)). The rise or fall of some values that do not follow enrichment may be related to precipitation recharge, groundwater recharge, etc.

The variation rate of $\delta^{18}O$ and δD values in river water is not completely consistent, which is mainly caused by the different degrees of $\delta^{18}O$ and δD fractionation (Table 2). The $\delta^{18}O$ and δD of the main tributaries of Shiyang River showed a trend of increasing with the increase of the distance along the river, and the linear correlation was significant ($P<0.05$), most of the linear correlation coefficients were higher, and the linear correlation coefficient between the δD and the distance of the Zaomu River was lower ($R^2=0.35$). The correlation equation of $\delta^{18}O$ changes along the Shiyang River main stream is $y=0.0137x-9.2824$, and the correlation equation of δD changes along the Shiyang River main stream is $y=0.0964x-65.699$, indicating that $\delta^{18}O$ increases by 1.37‰ and δD increases by 9.64‰ with the increase of 100km along the main stream. Among the eight tributaries, the order of increment of $\delta^{18}O$ value is Jinta River > Gulang River > Dajing River > Donghe River > Huangyang River > Xihe River > Xiying River > Donghe River > Huangyang River > Xiying River > Donghe River > Huangyang River > Xiying River > Zamu River > Dajing River, and the order of increment of δD value is Jinta River > Gulang River > Xihe River > Donghe River > Huangyang River > Xiying River > Zamu River > Dajing River. The change rate of $\delta^{18}O$ and δD values in Jinta River is the largest, which is 1.34‰/100km and 10.75‰/100km, respectively; the change rate of $\delta^{18}O$ values in Zamu River is the smallest, which is 0.55‰/100km; and the change rate of δD values in Dajing River is the smallest, which is 3.36‰/100km. The change rate of hydrogen and oxygen isotopes along the main stream is different from that of the eight tributaries, but the increase of δD is stronger than that of $\delta^{18}O$. In general, the change rates of $\delta^{18}O$ and δD vary with distance, but the difference is relatively large. Stable hydrogen and oxygen isotopes have different degrees of accumulation and evaporation in the tributaries and main streams of Shiyang River.

4. Discussion

4.1 Evaporation loss

The accuracy of temperature and relative humidity depends on the distribution of weather stations, and deviations in measurements may induce greater computational errors. Temperature is a very important factor affecting evaporation loss, but in this study, the sampling time is concentrated, and the temperature is slightly different, which has been calculated in the calculation, so it is not considered as the main reason analysis here. It can be seen that the evaporation loss of river water is not only related to meteorological factors, but also to its runoff, and human activities also affect its evaporation loss. The results of $\delta^{18}O$ are mainly used in this study.

Table 3: Evaporation ratio of eight tributaries.

Rivers	Head to tail distance(km)	Average annual runoff(10^8 m^3)	reservoires	Amount of evaporation loss(%)
Dongda River	55.473	3.071	Jinchuanxia Reservoir	35.49%
Gulang River	31.298	0.644	Caojiahu Reservoir	25.36%
Dajing River	6.664	0.118	Dajing reservoir	6.04%
Huangyang River	38.462	1.270	Huangyang reservoir	23.37%
Jinta River	38.034	1.309	Nanying reservoir	40.40%
Xida River	50.26	1.601	Xidahe Reservoir	31.79%
Xiying River	28.052	3.194	Xiying reservoir	17.84%
Zamu River	30.152	2.367	none	15.69%

Due to different river characteristics, different rivers show different evaporation proportions. The distance between the first and last sampling points of the West River and the East River is similar (more than 50km), and the evaporation loss ratio is also similar, both of which are higher than 30%. Kinta River has the highest evaporation ratio, and the first and last sampling points of Kinta River are far apart, and some sampling points are located in Wuwei Basin in the middle of the river, so its evaporation loss is greater, about 40.40%(Table 3). The distance between the first and last sampling points of Huangyang River and Jinta River is similar, but the evaporation ratio of Huangyang River is only 23.37%. The average annual runoff of Zamu River is 2.367, which is higher than that of Gulang River when the distance between the first and last sampling points is close, but the evaporation ratio of Gulang River is higher than that of Gulang River, which may be because the sampling points of Gulang River are more affected by reservoir evaporation. The evaporation ratio of Dajing River is the lowest, about 6.04%, but due to the limitation of sampling distance, the evaporation loss ratio of Dajing River

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is of little reference significance.

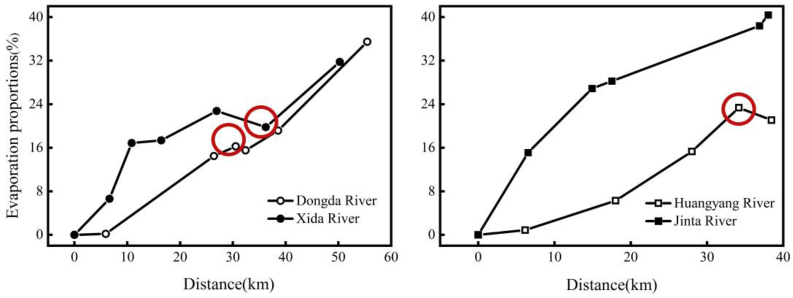

Figure 6: Change of evaporation ratio of four tributaries of Shiyang River (West River, East River, Yellow Sheep River and Kinta River). The red circle indicates that the sampling points did not follow the trend of increasing evaporation along the flow path. Horizontal headings indicating the distance between each sampling point and the westernmost sampling point along the flow path in each river.

The excess deuterium and hydrogen oxygen isotopes in river water vary due to precipitation recharge, groundwater inflow, and cumulative evaporation loss from river water. Under the condition that evaporation is dominant, the isotopic composition increases linearly with the increase of distance along the channel. Among the factors that cause evaporation rates not to follow the increasing trend closely along the flow path, recharge is probably the most important influencing factor. The evaporation ratio increases along the flow path of the river, but it may be replenished by precipitation, and groundwater recharge makes the isotopic composition of a sampling point low, so the evaporation ratio of the river does not increase along the flow path (Figure 6). Since there is a lot of precipitation in this area around August, the precipitation should be used as the supply source of the river in the rainy season. During the dry season, groundwater recharge is a critical component in semi-arid regions.

4.2 Altitude effect

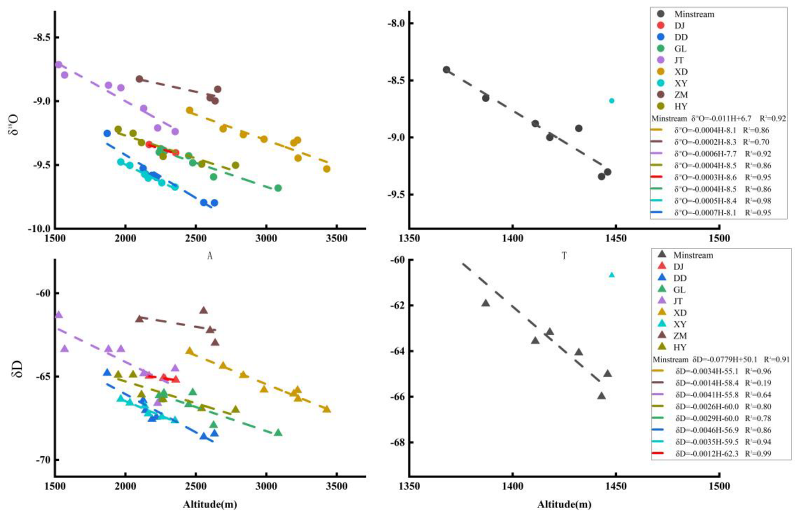

Figure 7: Eight tributaries of Shiyang River (DJ: Dajing River; DD: East River; GL: Gulang River; JT: The Kinta River; XD: West River; XY: Xiying River; ZM: Chamu River; HY: Huangyang River) and the altitude effect of $\delta^{18}O$, δD in the main stream river.

The phenomenon that $\delta^{18}O$ and δD values in water gradually decrease with the increase of altitude is the "altitude effect" of stable isotopes of hydrogen and oxygen. In order to better analyze the relationship between hydrogen and oxygen stable isotopes of Shiyang River water and altitude, the sample data of Shiyang River water were divided into two groups(Figure 7). The first group was set in the range of altitude greater than 1500m. The region has steep terrain, and the stable isotope values of hydrogen and oxygen in the river water showed a significant "altitude effect". The $\delta^{18}O$ values of Dongdahe River, Gulang River, Huangyang River, Xiying River, Xidahe River, Zamu River and Jinta River decrease with altitude in the order of -0.7‰/km, -0.4‰/km, -0.4‰/km, -0.5‰/km, -0.4‰/km, -0.2‰/km and -0.6‰/km. δD value with/km -4.6‰, respectively -2.9/km, -2.6/km, -3.5‰/km, -3.4/km, -1.4‰/km and a rate of about 4.1‰/km - with the lower altitude. The second group is set in the range below 1500m above sea level, that is, the middle and lower reaches of the river, where the terrain is relatively flat and open. It can be seen that the stable isotope values $\delta^{18}O$ and δD of the Shiyang River show a significant negative correlation with the altitude, with a slope of −11‰/km, showing a significant "altitude effect". According to the precipitation data of two meteorological stations (Binggou and Caiqi) in Shiyang River basin, the precipitation elevation gradient of $\delta^{18}O$ value in Shiyang River is 1.66‰/km. The $\delta^{18}O$ gradient values of the tributaries of the Shiyang River are all lower than the global precipitation $\delta^{18}O$ gradient values (2.8‰/km) and lower than the precipitation elevation gradient values of the Shiyang River basin, while the $\delta^{18}O$ gradient values of the main stream of the Shiyang River are greater than the $\delta^{18}O$ precipitation gradient values of the main stream of the Shiyang River, indicating that the tributaries are greatly affected by precipitation, and the main stream water is mainly fed by the precipitation of the upstream tributaries. And is affected by strong evaporation.

Generally speaking, precipitation and river water from the same water vapor source have a higher elevation effect[11]. The $\delta^{18}O$ and δD values of precipitation always decrease gradually with the increase of altitude[21]. However, the eight tributaries of Shiyang River basin all show obvious elevation effect, which indicates that the main source of river water in the whole basin is precipitation, and there may be meltwater recharge and groundwater recharge.

4.3 Human Activities

With the development of society, human's demand for water resources and hydropower resources is increasing day by day, which accelerates the development and utilization of rivers, and the construction of water conservancy projects is developing rapidly. Currently, about 70 percent of the world's rivers are covered Dam interception[10]. At present, 15 large reservoirs have been built in the whole basin of Shiyang River, among which Hongyashan reservoir in the lower reaches is the most famous. In the water samples collected from the reservoir area, the hydrogen and oxygen isotope values of the water body in front and behind the dam have changed. In the middle and lower reaches, irrigation drainage and reservoir leakage also affect the variation of isotope values.

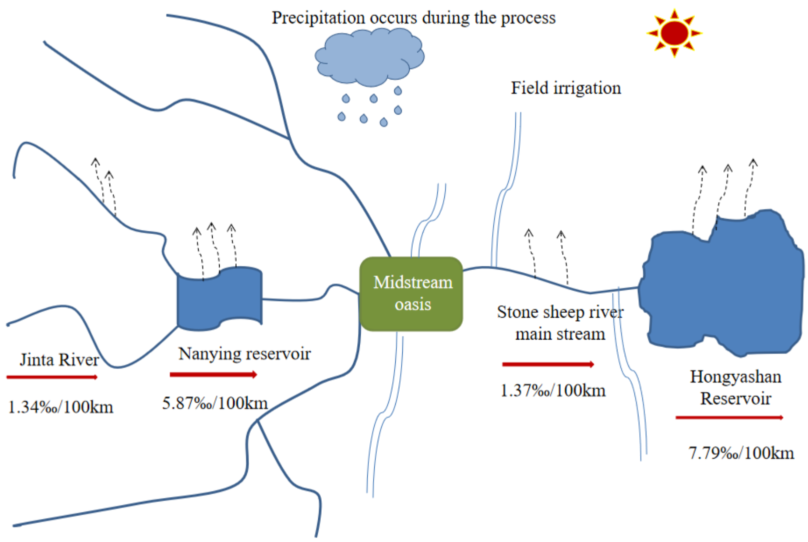

Figure 8: Variation of $\delta^{18}O$ of Jinta River, one of the main stream and tributaries of Shiyang River, along the distance (including Nanying Reservoir and Hongyashan Reservoir).

Based on the average $\delta^{18}O$ values of 66 water samples from the four sampling points of Nanying Reservoir and Hongyashan Reservoir during the 2019-2020 rainy season, the $\delta^{18}O$ values of Nanying Reservoir increased by 5.87‰ for every 100km increase of water along the dam, and $\delta^{18}O$ values increased by 7.79‰ for every 100km increase along the dam of Hongyashan Reservoir (Figure 8). The change rate is obviously higher than that of Kinta River and main stream. It is obvious that the variation trend of hydrogen and oxygen isotope composition in all water bodies is the same along the flow direction of the river, and the isotopic value of the water in the reservoir changes more strongly. The average annual runoff of Hongyashan Reservoir is about 217.4 million m^3, and the evaporation loss is nearly 9.67%, with a loss of 21.226 million m^3 and an excess loss of 17.354 million m^3. The reservoir covers an area of 30 square kilometers, and nearly 67.75mm of reservoir water is evaporated. The average annual runoff of Nanying Reservoir is 121.1 million m^3, and the evaporation loss is nearly 1.353%, with a loss of 1.638,500 m^3 and an excess loss of 1.264,500 m^3. The reservoir area is 0.36 square kilometers, and nearly 4.53mm of reservoir water is evaporated. The reason for this situation may be that the hydrogen and oxygen isotope composition of river water is to some extent affected by the action of reservoir. The main reason is that the flow rate of river slows down due to the interception effect of reservoir, the retention time of water body is prolonged and other hydraulic conditions change, which makes the evaporation time longer and the degree of hydrogen and oxygen isotope fractionation in water body is relatively high, resulting in the relative bias of water body in reservoir. Evaporation loss is also greater.

5. Conclusions

Based on the test results of δD and $\delta^{18}O$ of precipitation and river water samples collected in Shiyang River Basin in August 2020, the temporal and spatial distribution characteristics of stable isotopes in river water during rainy period in the study area were analyzed. During the whole observation period, the isotopic variation of river water is relatively small, and the isotopic variation of precipitation is large, and the slope of river water and precipitation line is similar. The relationship between δD and $\delta^{18}O$ of river water is $\delta D= 6.74\delta^{18}O-2.66$ (R^2=0.93), and the slope and intercept of river water are smaller than the global atmospheric precipitation line, indicating that the river water has been recharged by precipitation. The δD and $\delta^{18}O$ values of the eight tributaries of Shiyang River generally decrease along the distance, and the d-excess values increase along the distance. The isotopic variation trend of the main stream river is the same with that of the tributaries river. There are many factors affecting the change of the river along the main tributaries of Shiyang River. The river water of the main tributaries has undergone different degrees of evaporation fractionation, showing different evaporation proportions. The main stream of Shiyang River is the most affected by evaporation, followed by Jinta River, and the Zamu River is the least affected by evaporation, and the results of evaporation loss of Dajing River are of little reference significance because of the sampling point. The altitude effects of δD and $\delta^{18}O$ are significant in the main stream and tributaries of Shiyang River. The $\delta^{18}O$ altitude gradient line of precipitation is 1.66‰/km, the $\delta^{18}O$ gradient value of tributaries is smaller than the precipitation altitude gradient, smaller than the global precipitation altitude gradient, and the $\delta^{18}O$ gradient value of main stream is larger than the precipitation altitude gradient. It is suggested that the elevation effect and evaporation effect may be the main factors affecting the isotope accumulation along the river water of Shiyang River. The results show that the hydrological process in arid and semi-arid areas can be further studied by monitoring the characteristics of stable isotope changes of river water in the basin, and provide theoretical basis for rational utilization of water resources in arid mountain areas.

References

[1] Firmani, et al. "Evaluating recharge to an ephemeral dryland stream using a hydraulic model and water, chloride and isotope mass balance." Journal of Hydrology (2015).

[2] Xiaofei, L. I. et al. "Spatial and Temporal Variations of Hydrogen and Oxygen Isotopes in Precipitation in the Yellow River Basin and Its Environmental Significance." Acta Geologica Sinica (2013).

[3] Bosilovich, Michael G., and J. D. Chern. "Simulation of Water Sources and Precipitation Recycling for the MacKenzie, Mississippi, and Amazon River Basins." Journal of Hydrometeorology 7.3 (2006):312.

[4] Natali, C., et al. "Geochemistry of the Adige River water from the Eastern Alps to the Adriatic Sea (Italy): evidences for distinct hydrological components and water-rock interactions." Environmental Science & Pollution Research 23.12(2016):11677-11694.

[5] Ye Sheng, et al. "The Variability of Stable Water Isotopes and the Young Water Fraction in a Mountainous Catchment." Clean - Soil, Air, Water: A Journal of Sustainability and Environmental Safety 7(2022):50.

[6] Gabriel, et al. "Water balance model for mean annual hydrogen and oxygen isotope distributions in

surface waters of the contiguous United States." Journal of Geophysical Research Biogeosciences (2011).

[7] Gammons, Christopher H., et al. "The hydrogen and oxygen isotopic composition of precipitation, evaporated mine water, and river water in Montana, USA." Journal of Hydrology 328.1-2(2006): 319-330.

[8] Merlivat, L., &Jouzel, J. Global climatic interpretation of the deuterium-oxygen 18 relationship for precipitation. Journal of Geophysical Research Oceans, 84(1979):5029-5033.

[9] Wang Dongsheng." Application of environmental nuclides to study groundwater pollution." Survey Science and Technology 4(1993):4.

[10] Wu, Huawu, et al. "Surface water isoscapes (δ18O and δD) reveal dual effects of damming and drought on the Yangtze River water cycles." Journal of Hydrology (2022).

[11] Zhang, Lei, P. Li, and X. He. "Interactions between surface water and groundwater in selected tributaries of the Wei River (China) revealed by hydrochemistry and stable isotopes." Human and Ecological Risk Assessment 1(2021):1-21.

[12] Che, Qiaohui, et al. "Interaction between surface water and groundwater in the Alluvial Plain (anqing section) of the lower Yangtze River Basin: environmental isotope evidence." Journal of Radioanalytical and Nuclear Chemistry 329.3(2021):1331-1343.

[13] Sprenger, Matthias, et al. "Storage, Mixing, and Fluxes of Water in the Critical Zone Across Northern Environments Inferred by Stable Isotopes of Soil Water." Hydrological Processes (2018).

[14] Benettin, et al. "Effects of climatic seasonality on the isotopic composition of evaporating soil waters." Hydrology & Earth System Sciences (2018).

[15] Zhu, Guofeng, et al. "Stable water isotope monitoring network of different water bodies in Shiyang River basin, a typical arid river in China." Copernicus GmbH (2021).

[16] Ma, Jinzhu, et al. "The composition and distribution of chemicals and isotopes in precipitation in the Shiyang River system, northwestern China." Journal of Hydrology s 436–437. None(2012):92-101.

[17] Majoube, Michel. "Fractionnement en 180 entre la glace et la vapeur d'eau." Journal De Chimie Physique 68(1971):625-636.

[18] Mengyuan, Song, et al. "Characteristics of water isotopes and hydrograph separation in the Glacier No.72 of Qingbingtan,Tomur Peak." Journal of Arid Land Resources and Environment (2015).

[19] Yang, Kunhua, et al. "Spatial Variation and Controlling Factors of H and O Isotopes in Lancang River Water, Southwest China." International journal of environmental research and public health 16.24(2019):4932.

[20] Chen, Yiliang, and L. Tian. "Canal surface evaporation along the China's South-to-North Water Diversion quantified by water isotopes." Science of the Total Environment (2021):146388.

[21] Jia J, Wang L, Meng Y. Investigation of the characteristics of hydrogen and oxygen isotopes of the excess fracturing flowback fluid and calculation of groundwater content in the Jimsar Sag[J]. Hydrogeology & Engineering Geology, 2022, 49(4):10-18.

[22] Reissig, H. "Stable Isotope Hydrology. Deuterium and Oxygen-18 in the Water Cycle. Eds. J. R. GAT and R. GONFIANTINI. - 339 pp. =Technical Reports Series No 210. Vienna: International Atomic Energy Agency 1981. Östr. Schilling 550.-." Internationale Revue Der Gesamten Hydrobiologie Und Hydrographie 68.4(2010):603-603.

[23] Fan, Yuting, et al. "Characteristics of water isotopes and ice-snowmelt quantification in the Tizinafu River, north Kunlun Mountains, Central Asia." Quaternary International 380-381. SEP. 4(2015): 116-122.

[24] Zhang H, Chen Z Y, Tang C Y. Tracing runoff components in the headwater area of Heihe River by isotopes and hydrochemistry[J]. Journal of Groundwater Science and Engineering, 2022, 10(4): 405-412.

[25] Xiaofei, LI., et al. "Spatial and Temporal Variations of Hydrogen and Oxygen Isotopes in Precipitation in the Yellow River Basin and Its Environmental Significance." Acta Geologica Sinica (2013).

[26] Voss, Katalyn A.Bookhagen, BodoSachse, DirkChadwick, Oliver A. "Variation of deuterium excess in surface waters across a 5000-m elevation gradient in eastern Nepal." Journal of Hydrology 586(2020).

[27] Li, J., et al. "Characteristics of δ18O in precipitation and moisture transports in the central Hexi Corridor." Acta entiae Circumstantiae 35.4(2015):947-955.

[28] David B Rowley and Raymond T Pierrehumbert and Brian S Currie. "A new approach to stable isotope-based paleoaltimetry: implications for paleoaltimetry and paleohypsometry of the High Himalaya since the Late Miocene." Earth and Planetary Science Letters (2001).

[29] Rong, Jiang, et al. "Spatio-Temporal Variations of the Stable H-O Isotopes and Characterization of Mixing Processes between the Mainstream and Tributary of the Three Gorges Reservoir." Water

ISSN 2616-5872 Vol.6, Issue 2: 30-42, DOI: 10.25236/AJEE.2024.060205

10.5(2018):563.
[30] Joussaume, Sylvie, R. Sadourny, and J. Jouzel. "A general circulation model of water isotope cycles in the atmosphere." Nature (1984).
[31] Benettin, et al. "Effects of climatic seasonality on the isotopic composition of evaporating soil waters." Hydrology & Earth System Sciences (2018).
[32] Middelburg, and J. J. "Stable isotopes dissect aquatic food webs from the top to the bottom." Biogeosciences 11.8(2014):2357–2371.
[33] Dutton, Andrea, et al. "Spatial distribution and seasonal variation in O16/O18 of modern precipitation and river water across the conterminous USA." Hydrological Processes 19.20(2005):p. 4121-4146.
[34] Ma, J. Z., X. S. Wang, and W. M. Edmunds. "The characteristics of ground-water resources and their changes under the impacts of human activity in the arid Northwest China—a case study of the Shiyang River Basin." Journal of Arid Environments 61.2(2005):277-295.