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Using stable isotope to identify impact of evaporation from mountainous reservoirs on local precipitation

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Using stable isotope to identify impact of evaporation from mountainous reservoirs on local precipitation

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Abstract: Due to the increase in industry, agricultural production and domestic water consumption, a common practice is to improve water use efficiency by building reservoirs. However, the construction of reservoirs has the effect of an increase in the evaporation area of the water surface. Observations show that due to the evaporation effect of the reservoir, the precipitation and precipitation distribution will change in some area. The Xiying Reservoir is a typical manmade mountain reservoir in the Qilian Mountains in the upper reaches of the Shiyang River Basin. Based on the data collected by the multi-water body stable isotope observation network in the Shiyang River Basin, the study under discussion here used the isotope mixture model to quantify the impact of reservoir evaporation in this region. It was found that the advected water vapor of the Xiying reservoir mainly comes from southeast, northeast and northwest. The *d*-excess value of precipitation around the Xiying reservoir is significantly higher than that of other regions in the Xiying River Basin, which is characterized by the mixing of water vapor generated by the evaporation of surface water and advected water vapor, indicating that the evaporation water vapor of the reservoir has a certain impact on local precipitation. It was calculated that 3.86-11.86% of the precipitation around the Xiying reservoir comes from the evaporation of reservoir water and that about 4.39% (8.06×10^6 m^3) of the Xiying river water was consumed by evaporation. The

background of atmospheric water vapor content is the main influencing factor responsible for reservoir evaporation. The local atmospheric movement determines the influence range of reservoir evaporation on precipitation.

Key words: Qilian Mountains, Reservoir evaporation, Linear mixing model, Precipitation, Deuterium excess

1 Introduction

Due to the equilibrium and kinetic fractionation of stable hydrogen and oxygen isotopes in water from different sources during the hydrological cycle process, stable hydrogen and oxygen isotopes will exist in different proportions in the natural water body, different isotopic composition characteristics will be embodied (IAEA, 1983; Mook, 2000; Gat, 1996). In recent years, the stable isotope technique has been widely used in tracer basin hydrological process and lake water volume change and balance process; these tasks are difficult to achieve through traditional hydrological methods (Liu et al., 2009; Cui et al., 2016) . Evapotranspiration, an important part in the hydrological cycle process, is the aspect most directly affected by climate change and is the main water expenditure item. Terrestrial moisture produced by evapotranspiration is called recycled moisture. Some researchers have divided local water vapor sources into advection water vapor, surface water evaporation and vegetation transpiration, and have used the three-end-member linear mixing model to estimate the contribution rate of each of these sources (Peng et al., 2011; Wang et al., 2016; Li et al., 2016). But in arid areas with sparse vegetation or lakes with a large water surface area, the effect of vegetation transpiration is mostly excluded since it is considered that the precipitating water vapor above the lake is mainly composed of the advection water vapor and lake evaporation, and the contribution rate of each source is estimated by using the linear mixing model with deuterium excess parameter(Gat and Matsui, 1991; Gat et al, 1994; Xu et al., 2011; Kong et al., 2013; Aemisegger et al., 2014). For a lake in a relatively stable state, the ratio of evaporation to inflow can be determined by using the method of stable isotopic mass equilibrium, and the evaporation situation of external water inflow can also be determined (Cui et al., 2016; Dinçer, 1968; Zuber, 1983; Gonfiantini, 1986; Gibson and Edwards, 2002; Gibson et al., 2002; Liu et al., 2009).

The construction of reservoirs in the Basin under discussion here will increase the total water area, which will lead to a change in the water and heat conditions between the land and the water, and the transfer and exchange of water vapor and heat between the earth and atmosphere. And local aerodynamic characteristics will also be changed. All these changes will have a certain impact on the local climate of the reservoir and its surrounding area (Straškraba et al., 1993). The reservoir contributes water vapor to the atmosphere by evaporation, and this process has an important impact on the regional climate. The Xiying Reservoir is a typical reservoir in the Eastern Qilian Mountains situated on the northeast edge of the Qinghai-Tibet Plateau and serves as the main water supply for production and livelihood for the Wuwei and the Minqing Oasis. The local atmospheric circulation system is diverse, and the local hydrological cycle process is relatively unique. The isotope technique has been widely used in Basin hydrology in recent years; the influence of strong evaporation background on water bodies such as lakes, reservoirs and wetlands in arid areas has often been neglected in the relevant research undertakings.

The Xiying Reservoir was selected as the case to carry out an analytical research based on the stable isotope technique to determine the effect of evaporation on the reservoir water and the precipitation of the around reservoir. The research results can provide reference and can be a source of accumulated raw data for the lake water balance and hydrological cycle in this area. It also has the potential to improve the level of local water resources management and utilization.

2 Materials

2.1 Study area

The Qilian Mountains form a huge marginal mountain range in the northeastern section of the Qinghai-Tibet Plateau (94°E~104°E, 36°N~39°N). The Shiyang, Heihe, and Shule Rivers which originated on the north slope of the Qilian Mountains, are the three inland rivers of the Hexi Corridor. The surface water resources in the upper reaches of the Shiyang River are characterized by unequal distribution annually The Qilian Mountains are the main runoff areas for inland rivers (Fig. 1). In recent years, reservoirs have been built near the exit of each tributary, including the Xiying Reservoir, the Nanying Reservoir, the Huangyang Reservoir and so forth (Fig. 1). The existence of reservoirs in the eastern section of the Qilian Mountains and the stability of their water volume have a direct impact on the industrial and agricultural production and the improvement of ecological conditions for the Wuwei and Minqing Oasises the Minqing Oasis being one of the oases with the largest ecological function in the eastern section of the Hexi Corridor.

The Xiying Reservoir is an important and typical reservoir in the region which has irrigation as its main function and plays an important role in flood control and power generation. The total storage capacity is 2.35×107 m_3, and the effective irrigation area is 252.33 km_2.

Figure 1. Location of the research area

2.2 Sampling and laboratory analysis

From April 2015 to October 2017, the researchers conducted monthly multi-water bodies sampling work in the Xiying River Basin (Fig.1; Table1). The 655 precipitation, reservoir water and river water were collected for this research (Fig.1; Table1).

For reservoir water sampling, the bottles were first flushed with runoff water 3 times, then each bottle was placed under the water surface until three quarters of the volume of the bottle was filled. The two sampling bottles were continuously collected by means of the above method. Before the experiment, all the collected samples were stored in the freezer (-5℃). The researchers installed a precipitation collection device to collect samples from the collection device at 20.00 (Beijing time). If the precipitation was snow, it was filled into the vial after it had naturally melted at room temperature indoors in the laboratory. All the samples were analyzed using a liquid water isotope analyzer DLT-100 (Los Gatos Research, Inc.) in the Stable Isotope Laboratory, College of Geography and Environmental Science, Northwest Normal University. The precision of measurement is ±0.6% for δD and ±0.2% for δ^{18}O, respectively. The isotope ratio of the samples was expressed as parts per mil (&) relative to the Vienna Standard Mean Ocean Water (V-SMOW): δ (‰) = $(R_S/R_{V\text{-}SMOW}-1)$ ×1000.

Table 1 Date for sampling station

3 Methods

3.1 Contribution rate of reservoir evaporation

Precipitation in the lake area is generally considered as coming from evaporation and advection water vapor, of which evaporation is an important part of the lake hydrological cycle. The value of δ^{18}O and δD in oceanic water vapor becomes poorer as the air mass moves inland, due to continuous precipitation. The equilibrium fractionation of hydrogen and oxygen stable isotopes is destroyed by the kinetic fractionation of water in the process of evaporation. There is a difference in the relationship between δD and δ^{18}O in precipitation, which is called deuterium excess (Dansgaard, 1964). If there is continental water vapor input during this period, the value of deuterium excess in the water vapor will change, and if there is no continental water vapor input, the deuterium excess will remain unchanged (Craig, 1961). The deuterium excess of precipitation formed by surface water evaporation is often higher than the advection water vapor (Gat, 1994). Therefore, the contribution ratio of surface water evaporation to precipitating water vapor can be estimated according to the variation of *d* in precipitating water vapor (Gat and Matsui, 1991; Vallet-Coulomb et al., 2008; Ingraham and Taylor, 1991).

Assuming that the contribution rate of local evaporation is f_{ev} ($0<f_{ev}<1$), the contribution rate of the water vapor input from the upwind direction to the precipitating water vapor (advected water vapor) is $1-f_{ev}$. The deuterium excess value of water vapor produced by local evaporation is d_{ev}. The deuterium excess value of the advection water vapor is d_{adv}. The deuterium excess in precipitating water vapor (d_{pv}) can be expressed in the following formula (Xu et al., 2011).

$d_{pv}=d_{ev}\times f_{ev}\times d_{adv}\times(1\text{-}f_{ev})$ *(1)*

Formula 2 can be obtained by transforming formula 1.

$$f_{ev}=\frac{d_{pv}-d_{adv}}{d_{ev}-d_{adv}} \quad (2)$$

According to the definition of deuterium excess *(d)*, its calculation can be seen in the following formula (Dansgaard, 1964).

$d=\delta D\text{-}8\times\delta^{18}O$ *(3)*

For $\delta^{18}O_{pv}$ and δD_{pv}, the hydrogen and oxygen isotopes in precipitating water vapor is difficult to measure directly because of the dynamic nature of the local atmosphere and strong seasonality impact. In this study, this was calculated by means of formula 4 (Xu et al., 2011; Gibson et al., 2008), the vapor–precipitation balance method, which has been successfully employed in many research studies for many districts (Gat et al., 1994; Zuber, 1983; Gonfiantini, 1986; Gibson and Edwards, 2002).

$$\delta^{18}O_{pv}\cong(\delta^{18}O_p-\in_{eq}^{18})/(a_{w-v}^{18}) \quad (4a)$$

$$\delta D_{pv}\cong(\delta D_p-\in_{eq}^{2})/(a_{w-v}^{2}) \quad (4b)$$

The water vapor equilibrium fractionation coefficient (a_{w-v}^{18} and a_{w-v}^{2}) of lake water during evaporation can be calculated on the basis of the empirical formula of water vapor interface temperature (in Kelvin, *K*) (Horita and Wesolowski, 1994). $\in_{eq}^{18}$ and $\in_{eq}^{2}$ are the equilibrium enrichment coefficients of $\delta^{18}O$ and δD, respectively, reflecting the isotopic enrichment effect of water vapor entering the saturated water vapor layer at the water-gas interface (Craig and Gordon, 1965).□$\in^{18}$ and□$\in^{2}$ are the kinetic fractionation factor of $\delta^{18}O$ and δD, respectively, calculated from empirical formulas based on atmospheric boundary layer conditions and humidity conditions. The above calculation can be seen in equation 5.

$$10^3*\ln a_{w-v}^{18}=-7.658+(\frac{6.7123*10^3}{T})-(\frac{1.6664*10^6}{T^2})-(\frac{0.35041*10^9}{T^3}) \quad (5a)$$

$$10^3 * \ln a_{w-v}^2 = -161.04 + (\frac{794.84 * T}{10^3}) - (\frac{1620.1 * T^2}{10^6}) - (\frac{1158.8 * T^3}{10^9}) + (\frac{2.9992 * 10^9}{T^3}) \quad (5b)$$

$$\in_{eq}^{18} = a_{w-v}^{18} - 1 \quad (5c)$$

$$\in_{eq}^{2} = a_{w-v}^{2} - 1 \quad (5d)$$

$$\Delta \in^{18} = 14.2 * (1-h) / 1000 \quad (5e)$$

$$\Delta \in^{2} = 12.5 * (1-h) / 1000 \quad (5f)$$

Stable isotope values of water vapor are produced by the evaporation of surface water bodies ($\delta^{18}O_{ev}$ and δD_{ev}) and the simplified Craig-Gordon Water Evaporation Model can be used to estimate their values (Craig and Gordon, 1965). See formula 6 for details.

$$\delta^{18}O_{ev} \cong \frac{(\delta^{18}O_s - \in_{eq}^{18}) / a_{w-v}^{18} - h * \delta^{18}O_{adv} - \Delta \in^{18}}{1 - h + \Delta \in^{18}} \quad (6a)$$

$$\delta D_{ev} \cong \frac{(\delta D_s - \in_{eq}^{2}) / a_{w-v}^{2} - h * \delta D_{adv} - \Delta \in^{2}}{1 - h + \Delta \in^{2}} \quad (6b)$$

$\delta^{18}O_s$(δD_s) and $\delta^{18}O_{adv}$ (δD_{adv}) are the stable isotopic values of the local surface water and advection water vapor, respectively, and h is the relative humidity of the surface atmosphere.

The isotopic values of advection water vapor can be calculated by means of equation 7.

$$\delta^{18}O_{adv} \cong \delta^{18}O_{pv} + (a_{w-v}^{18} - 1) * \ln F \quad (7a)$$

$$\delta D_{adv} \cong \delta D_{pv} + (a_{w-v}^{2} - 1) * \ln F \quad (7b)$$

In this equation, F represents the water vapor pressure ratio between the beginning and the end of the water vapor mass. In the research under discussion, F is equal to water pressure ratio between the stations in the track path of the water vapor mass and the Xiying Reservoir, during summer (Wang et al., 2016).

Note that the relevant parameters in the above formula are expressed in decimal form.

3.2 Lake evaporation to inflow ratios

Assuming that the volume of lake water remains stable for a long period of time, the theoretical model of reservoir capacity and stable isotopic equilibrium can be expressed by formula 8 for lakes that are fully mixed with inflow runoff and lake water body.

$$I_L = Q_L + E_L \tag{8a}$$

$$I_L \times \delta^{18}O_I = Q_L \times \delta^{18}O_Q + E_L \times \delta^{18}O_{ev} \tag{8b}$$

I_L is the total amount of water input to the lake by precipitation, runoff, etc. The value of Q_L is the total water output from surface and underground runoff. The value of E_L is the amount of lake evaporation. The value of $\delta^{18}O_I$, $\delta^{18}O_Q$ and $\delta^{18}O_{ev}$ are the stable isotopic ratios of oxygen in the inflow runoff, the runoff out of the lake, and lake evaporation. Assuming that the oxygen stable isotope ratio of runoff out of the lake is equal to the lake water, using $Q_L = I_L - E_L$ and $\delta^{18}O_Q = \delta^{18}O_L$ to change the formula 8, we arrive at formula 9.

$$\frac{E_L}{I_L} = \frac{\delta^{18}O_I - \delta^{18}O_L}{\delta^{18}O_{ev} - \delta^{18}O_L} \tag{9}$$

The reference for the calculation of $\delta^{18}O_{ev}$ is formula 6a.

3.3 Determination of the water vapor mass trajectory

In order to better estimate the contribution rate of lake evaporation in the Xiying Reservoir, our research first judged the characteristics of the movement path of the advection water vapor which affects the precipitation of Xiying Reservoir, so as to determine the initial value of advection water vapor. Therefore, this research used TrajStat software and the global data assimilation system data for calculation of airflow backward trajectory at 500m height of the Xiying Reservoir for 72 hours during sampling period based on HYSPLIT Model. The Angle Distance algorithm was used to cluster all the air mass trajectories.

4 Results

4.1 Characteristics of stable isotope composition of water bodies in the Xiying

Reservoir during summer

The deuterium excess value of precipitation in the Xiying Reservoir is much higher than in the Wushao Mountains, Yinchuan and Zhangye (Fig. 2). The deuterium excess value of the surface water of theXiying Reservoir and the runoff of the Xiying River is also higher (Fig. 2). The deuterium excess value of the precipitation in the upper wind direction stations (Wushao Mountains, Zhangye, Yinchuan) reflects the characteristics of more moisture and less evaporation. The deuterium excess value of the precipitation in the Xiying Reservoir shows that the low moisture humidity, fast evaporation and water vapor experience a strong imbalance in evaporation. Therefore, the surface water with a high deuterium excess in the Xiying Reservoir has entered the precipitating water vapor. The phenomenon of *d*-excess in summer precipitation around the Xiying Reservoir is the result of the mixture of reservoir evaporation and advected water vapor.

Using the measured data of δD and the δ_{18}O, the Surface Water Line equation of the Xiying Reservoir was obtained (Fig.3), $\delta D=7.14\times\delta_{18}O+9.15$, $R_2=0.95$. Furthermore, applying the Local Meteoric Water Line equation as $\delta D=7.54\times\delta_{18}O+11.74$, $R_2=0.96$ reveals that the surface water points all fall near the LMWL (Fig.3), indicating that the surface water is recharged by atmospheric precipitation. However, due to the open surface of the reservoir and the slow velocity of the reservoir water, the surface water is affected ya certain of non-equilibrium evaporation. Therefore, the slope and intercept of the SWL are smaller than that of the LMWL.

In the Xiying Reservoir, $\delta_{18}O_{pv}$ and δD_{pv} in summer are -15.24 ‰, -106.20 ‰ and 15.75 ‰, respectively (Table 2). It can be seen therefore that the value is obviously higher than that of other sampling sites and lies between deuterium excess of local precipitation and surface water, it also reflects the mixing of lake evaporation and advection water vapor over the Xiying Reservoir in summer.

Table 2. Estimation of isotopic values of precipitation

Fig. 2 The track of air mass in the Xiying Reservoir in summer

Fig. 3 Relationship between δD and $\delta_{18}0$ in precipitation and surface water of the Xiying Reservoir

4.2 The path of air mass affecting the Xiying Reservoir in summer

The air masses affecting the Xiying Reservoir mainly come from the northwest, southeast and northeast (Fig.2). In June the air masses from the northwest mainly come from the southern foot of the Kunlun Mountains, the eastern section of the Tianshan Mountains and the arid area of Central Asia. The northeast air masses mainly come from the western Mongolia Plateau. The southeastern air masses come from the Sichuan Basin, the Guanzhong Plain, the Qinling Mountains and other places. In July, the air masses northwest mainly come from the eastern part of the Tianshan Mountains. The northeast air masses come primarily from the Mongolian Plateau and the Loess Plateaus. The southeast air masses come mainly from the Sichuan Basin, the Guanzhong Plain and the Qinling Mountains, but at least one of these masses can extend to the northern margin of the Yunnan-Guizhou Plateau. In August, the air masses in the northwest come from the eastern part of the Tianshan Mountains and the central Mongolian Plateau while the northeast air masses mainly come from the Loess Plateau and the eastern part of Mongolia Plateau. The air masses in the southeast mainly come from the Sichuan Basin, the Guanzhong Plain and the Qinling Mountains. According to result of the cluster analysis, the tracks of the two air masses in the southeast direction account for 51.1%, the air masses in the northwest area account for 23.9%, and the air masses in the northeast direction account for about 25% of the total number. The movement distance of westward air masses is longer, but the continental character is more obvious, and the nature of the air mass is dry. The movement distance of the air masses in the southeast direction is wetter.

In this research, the precipitation stable isotope data at the sampling site on the path of air mass movement was used to deduce the isotope value of the advected water vapor. Thereafter the contribution rate of reservoir evaporation in the research area was estimated (Table 1).

4.3 Contribution rate of the Xiying reservoir evaporation to reservoir and

reservoir around precipitation

The influence of three air mass directions of external water vapor transport on the Xiying Reservoir is now considered here respectively. The precipitation water vapor isotope data is estimated based on the precipitation isotope data of three sampling sites (equation 4), and the isotope values of advected water vapor are estimated (equation 7). The isotope value of the evaporation water vapor is estimated based the isotope value of the advected water vapor and surface water (equation 6). It was estimated that the average contribution rate of the Xiying reservoir evaporation is arouond 3.86%~11.86% in summer (Fig.4, Table 3). The contribution rate of reservoir evaporation to precipitation is relatively low when the air mass comes from the eastern direction, which is 3.86% and 6.76%, respectively. This is mainly due to the relatively abundant water vapor content in the eastern air mass, resulting in continuous precipitation and insufficient mixing with locally evaporated water vapor. When affected by an air mass from the west, the contribution rate of the recycled water vapor is 11.86%. This is mainly due to the relatively low water vapor content, which leads to the existence of adequate mixing with the local evaporation water vapor.

Table 3. The isotope value of advection water vapor, the evaporating water vapor, and the contribution rate of reservoir evaporation

Fig. 4 Contribution rate of surface water evaporation in each research area

4.4 Xiying Reservoir evaporation to inflow ratios in summer

According to the stable isotopic model of lake water balance, the ratio of runoff evaporation in the Xiying Reservoir is estimated to be 4.39%, while the remaining 95.61% of the water is stored in the Xiying Reservoir or continues to be injected into the middle and lower reaches of the Shiyang River.

The daily runoff at the entrance of the reservoir in summer is within $1\times10^6m^3$~$2\times10^6m^3$, the inflow runoff is closely related to the precipitation events in the upper reaches of the mountainous area; there are several peaks in summer (Fig. 5). The total runoff in summer is $1.84\times10^8m^3$. about 8.06×10^6 m^3 of the inflow runoff is consumed by evaporation.

Figure 5. The daily and monthly potential evaporation of the Xiying Reservoir area, in summer

5 Discussion

5.1 Impact of reservoir evaporation on precipitation.

The precipitation around the Xiying Reservoir is characterized by the mixing characteristics of the reservoir evaporation water and the stratospheric transport water. The calculation results of the contribution rate of the recycled water vapor at each site of the Shiyang River show that the contribution of the ground evaporation rate around the Xiying Reservoir is more than 23% (the ground evaporation is more than 9%, vegetation transpiration is more than 15%) , which is the highest in the whole Basin (Zhu et al., 2019). Many studies have confirmed that large lake or reservoirs will increase the proportion of water vapour recirculation under certain weather conditions, with a higher recirculation rate of water vapour often being due to the contribution of large open water bodies (Edwards, 2002; Bowen et al., 2012). The Xiyingwugou site of 4.4 km from the Xiying Reservoir also clearly displays the characteristics of the mixed water of the reservoir and the transport water of the stratosphere. However, at the Huajia Town sampling point 20.48 km in the south of of Xiying Reservoir, the mixed characteristics of the reservoir evaporating water and the stratospheric transport water are greatly weakened. Furthermore, there are no mixed characteristics of reservoir evaporating water and stratospheric transport water in the Xiying Town sampling point 18.46 km to the north and at the Huling sampling point 38.22 km in the south of Xiying Reservoir. Local airflow is mainly from a low altitude to high altitude in the Xiying River Basin (Pan, 2019) and the influence range of reservoir evaporation is strongly influenced by the local water vapor movement path. Therefore, the evaporation at the Xiying Reservoir has a greater impact on high-altitude precipitation.

Ressarch in different regions of the world demonstrates that lake evaporation can increase the contribution rate of local precipitation. The contribution of lake evaporation to atmospheric precipitation is 4.6-15.7% in the Great Lakes of North

America (Gat et al., 2013) (Fig.4). Lake evaporation losses are generally greater than the 25% experienced in the Yinchuan Plain of China (Qian et al., 2013) (Fig.4). The annual contribution rate of evaporation to precipitation is 23.42% at the Qinghai Lake of China (Cui and Li, 2015) (Fig.4). Although the mountainous reservoirs generally have a small surface area, the influence range and contribution of water vapor evaporation remains limited. However, almost every mountain runoff has a built reservoir, and its comprehensive impact cannot be ignored in the arid regions. This effect may greatly increase the amount of precipitation in the Basin, thus increasing the accumulation of water resources in the high-altitude areas of the Basin.

5.2 Error estimate of the calculation result

The estimation of the contribution of reservoir evaporation to precipitation strongly depends on the exactness of parameters h (Relative humidity), T (Temperature), and d_{pv} (Deuterium excess in precipitation). The d_{pv} value was estimated employing the vapor-precipitation balance, while h and T of the reservoir water surface was substituted with the relative humidity and temperature of air recorded at the Xiying Reservoir. These parameters therefore have certain inevitable errors. Relative humidity (h) is the most critical parameter in the estimation.

Since only the influence of air mass from southwest direction (upwind station is Wushaoling) was considered (Table 4), the change of f_{ev} caused by the change of each parameter has a large range. Regarding the northwest directional air mass (upwind direction station being Yinchuan), northeast direction air mass (upwind direction station is Zhangye). This is mainly because the recycled water vapor activity varies greatly when the dominant air mass from different directions. When only the influence of the air mass from the northwest direction is considered, the variation of f_{ev} (Contribution rate of local evaporation) caused by each parameter is close to the range. At this time, the recycled water vapor activity degree is larger, and the sensitivity to the change of each parameter is low. According to the effect of air mass from different directions, d_{pv} is the main factor causing the error, followed by air temperature and relative humidity.

Table 4 Range of change in f_{ev} from the Xiying Reservoir to precipitating water vapor for a change in input parameters by ±5%

5 Conclusion

The water vapor content of the air mass has a decisive influence on the evaporation of the reservoir. The humid air mass from the southeast monsoon affects the area when the evaporation is weak, and the dry air mass from the westerly wind affects the area with strong evaporation. Evaporation from the reservoir has obviously affected the precipitation in the area around the reservoir. The impact range is related to the local atmospheric movement mode, Evaporating water vapor affects the precipitation in high altitude areas in the Xiying River Basin. Although the calculations regarding the contribution of reservoir evaporation to local precipitation still has significant uncertainties associated with the use of the stable isotope algorithm, these uncertainties will be further reduced with an increase of observation data and improvement of the algorithm itself.

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Data Availability The datasets generated and/or analyzed during the current study are available from the corresponding author on request.

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