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Difference of SPAC composition and control factors of different vegetation zones in north slope of Qilian Mountains

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Abstract: Understanding the differences and controlling factors of stable water isotopes in the soil-plant-atmosphere continuum of different vegetation zones has important guiding significance for revealing the hydrological processes and regional water cycle mechanisms.This study selected three different vegetation zones (alpine meadows, forests, and arid piedmont zones) in the Shiyang River Basin for study. This paper's analysis results show that: (1) In SPAC, precipitation isotope has the main controlling effect. From alpine meadows to arid foothills, as the altitude decreases, the temperature effect of precipitation isotopes increases. (2) From the alpine meadow to the arid foothills, the soil water isotope is gradually enriched, indicating that the evaporation is gradually increasing. (3) Alpine meadow plants are mainly supplied by precipitation in the rainy season; forest plants mainly utilize soil water in the dry season and precipitation in the rainy season. The soil water in the arid mountain foothills is mainly recharged by groundwater, and the evaporation and fractionation of plant isotopes are very strong.This research will help understand the SPAC system's water cycle at different altitudes and climates on high mountains.

Keywords: Shiyang River Basin; Stable isotope; Precipitation; Soil water; Plant water

1 Introduction

The relative abundance changes of isotope technology in water can indicate the water cycle and water use mechanism in plants, so isotope technology has become an increasingly important method for studying the water cycle (Gao et al. 2009; Song et al. 2002; Coplen, 2013; Shou et al. 2013). The

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stable isotope composition of water is considered to be the "fingerprint" of water, which records a large amount of environmental information that comprehensively reflects the geochemical process of each system and links the composition characteristics of each link (Darling et al., 2003; Rac et al., 2013; Gaj et al., 2014; Nlend et al., 2020). Moreover, it is used in the research of the analysis of water sources, migration and mixing, and other dynamic processes and played an increasingly important role (White et al., 2013; Bowen et al., 2015). In particular, D and 18O are considered conservative and stable in the absence of high-temperature water-rock interaction and strong evaporation conditions. They are the ideal environmental isotopes for tracing the actual dynamic process of water (William et al., 2013). The application of isotope tracers directly relies on isotopic labeling of atmospheric vapor or the resulting precipitation (Welker et al., 2000; Konstantin et al., 2008). As an effective tool, stable isotope technology can not only show the relationship between environmental factors and the water cycle (Araguas-Araguas et al., 1998; Cristhor et al., 2009), water transport and distribution mechanisms (Gao et al., 2011), and can also deepen the way plants use water (Detjen et al., 2015). And the understanding of the influence of plant characteristics provides a new observation method for revealing the water cycle mechanism in the hydrological ecosystem (Nie et al., 2004; Yu et al., 2007; Wang et al., 2019), and the connection between water use efficiency and water sources (Ehleringe, 1991; Sun et al., 2005; Chao et al., 2019). Therefore, the application of stable isotope technology provides a new tracer method for the study of the SPAC hydrological cycle (Zhang et al., 2012; Wen et al., 2017; Pan et al,. 2020). The content of the SPAC hydrological cycle research are dramatically enriches and expands (Dawson et al., 2002; Ma et al., 2019).

The changes of stable isotopes of soil water are affected by various factors such as atmospheric precipitation, surface evaporation, soil water migration and vertical movement (Gazi and Feng 2004; Araguas-Aragua et al., 1995; Jennifer et al., 2015). Also, for desert vegetation, soil water is an essential water source (Murdock, 1963). Because the isotope ratio in soil moisture obviously changes with depth, when water is transported between plant roots and stems, it reaches the leaves or young unbolted branches before its isotopic composition has not changed (Porporato, 2001; Meissne et al., 2014). Therefore, the content of stable isotopes in soil moisture directly affects the isotopic composition of water in plants'xylem (Dawson, 1993; Rothfuss et al., 2017). In this way, only by measuring the δD and δ18O characteristics of plant xylem moisture and soil moisture at different levels can the source of plant water use be determined (Wu et al., 2015; Meissner et al., 2014; Yang et al., 2014). Precipitation

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is an important input factor in the hydrological cycle. The study of the temporal and spatial changes of its isotope characteristics is not only helpful to explore the source of precipitation water vapor and corresponding meteorological and climatic information (Edwards et al., 2010; Daniele et al., 2013; Timsic et al., 2014; Evaristo et al., 2015; Négrel et al., 2016), reflect the historical changes of natural geographic elements (Wei et al., 1994; Speelman et al., 2010; Steinman et al., 2010; Hepp et al., 2015) and climate reconstruction (Thompson et al., 2000; Yao et al., 2008; Xu et al., 2014; Li et al., 2017), but also helpful to determine the hydraulic connection between water bodies (Yao et al., 2009). And combined with the changes of surface water, soil water, and groundwater isotopic composition, can determine the precipitation infiltration and runoff generation process (Bam and Ireso, 2018; Hou et al., 2008), groundwater replenishment, and renewal capacity (Smith et al., 1992; Cortes and Farvolden, 1983), and then lay the foundation for the study of the deep mechanism of the water cycle (Gao et al., 2009). As an important part of the global water cycle, plants control 50-90% of ecosystem evapotranspiration (Jasechko et al., 2013; Coenders-Gerrits et al., 2014; Schlesinger and Jasechko, 2014). Plant roots do not undergo isotopic fractionation when they absorb water (White et al., 1985; Song et al., 2013). Therefore, the water isotope composition of plant roots and stems reflects the isotope composition of water available for plants (Dawson et al., 1991).

We took three different vegetation zones (alpine meadows, forests, and arid foothills) in the Shiyang River Basin as the research object, took the period from April 2018 to October 2019 as the research time, and selected 3 sampling points to analyze the differences and controlling factors of SPAC in different vegetation zones. This research helps to clarify the water use mechanism and local water cycle mechanism of different vegetation zones in tall mountains, and can provide a certain theoretical basis and guiding suggestions for the efficient and reasonable utilization of water resources in arid areas.

2 Materials and methods

2.1 Study area

The Shiyang River Basin is located at the northern foot of the Qilian Mountains, east of the Hexi Region of Gansu Province (Zhu et al., 2019) (Fig. 1). The Shiyang River originates from the snow-capped mountains on the north side of the Lenglongling in the eastern section of the Qilian

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Mountains. The total length of the river is about 250 km, with a basin area of 4.16×104 km^2. The annual average runoff is about 15.75×108 km^3. The river supply comes from meteoric mountain precipitation and alpine ice and snow meltwater. The runoff area is about 1.1×10^4 km^2, and the drought index is 1 to 4. The soil is divided into grey-brown desert soil, aeolian sand soil, salinized soil, and meadow soil. The Shiyang River Basin is located in the hinterland of the mainland. It belongs to a continental temperate arid climate, with strong solar radiation, sufficient sunshine, short hot summers, long cold winters, large temperature differences, little precipitation, and strong evaporation. The upper reaches of the basin is an alpine, semi-arid and semi-humid area, with annual precipitation of 400-600 mm, annual evaporation of 700-1200 mm, and an annual average temperature of 0-4 ℃; the lower reaches of the basin is a warm and arid area with annual precipitation of 200-400 mm. The annual evaporation is 1300 ~ 2000 mm, and the annual average temperature is 4 - 8 ℃ (Wen et al., 2013). The vegetation coverage in the upper and middle alpine areas is relatively good, with trees, shrubs, and Grassland coverage. The downstream vegetation coverage is poor under the strong influence of long-term human production and life, mainly desert vegetation.

2.2 Sample collection

We have collected samples of precipitation, groundwater, soil, and plant at Lenglong (alpine meadow), Hulin (forest), and Xiying (arid foothills) in the Shiyang River Basin from April 2018 to October 2019 (Table 1).

Collection of precipitation samples: Collect precipitation with a rain bucket. The rain measuring cylinder is composed of a funnel and a storage part. After each precipitation event, the collected liquid precipitation is immediately devolved to a 100 ml high-density sample bottle. The sample bottle is sealed with a sealing film, and stored at low temperature. Simultaneously, put a label on the polyethylene bottle sample, telling the date, types of precipitation (rain, snow, hail, and rainfall). For the case of multiple precipitation events in one day, multiple sampling is required.

Collection of soil samples: The soil samples are collected with a soil drill at a depth of 100 cm in

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the soil at intervals of 10 cm. Put part of the soil sample into a 50 ml glass bottle. The mouth of the bottle was sealed with parafilm and transported to the observation station for cryopreservation within 10 hours after sampling. It would be used for the determination of stable isotope data. The rest of the soil sample was placed in a 50 ml aluminum box, and used the drying method to measure the soil moisture content.

Collection of plant samples: Firstly, collect the xylem stem of the plant with a sampling shear. Then peel the bark, and put the stem into a 50 ml glass bottle. Lastly, seal the mouth of the bottle and keep it frozen until the experimental analysis.

Collection of groundwater samples: The groundwater was collected in polyethylene bottles, and the samples were brought back to the refrigerator at the test station for cryogenic preservation within 10 hours.

2.3 Sample treatment and analysis

All the water samples collected are tested with a liquid water analyzer (DLT-100, Los Gatos Research Center, USA) in the Northwest Normal University laboratory. Each sample and isotope standard were analyzed by continuous injection six times. To eliminate the memory effect of the analyzer, we discarded the values of the first two injections and used the average of the last four injections as the final result value. Isotope measurements are given with the symbol "δ" and are expressed as a difference of thousandths relative to Vienna Standard Mean Ocean Water:

$$\delta_{(‰)} = \left(\frac{\delta}{\delta_{-smow}} - 1\right) \times 1000 \qquad (1\text{-}1)$$

Where, δ is the ratio of $^{18}O/^{16}O$ or $^{2}H/^{1}H$ in the collected sample, $\delta_{v\text{ - }smow}$ is the ratio of $^{18}O/^{16}O$ or $^{2}H/^{1}H$ in the Vienna standard sample.

Due to the methanol in plant samples, it is necessary to modify plant samples' original data. Using different concentrations of pure methanol and ethanol mixed deionized water, combined with Los Gatos' LWIA-spectral pollutant identification instrument V1.0 spectral analysis software, the establishment of $\delta^{2}H$ and $\delta^{18}O$ spectral pollutant correction method, determine methanol (NB) and ethanol (BB) pollution degree (Meng et al., 2012; Liu et al., 2015). The configuration mode of methanol and ethanol solution concentration in the correction process is similar to Meng's relevant experiments (2012). For the broadband metric value NB metric of the methanol calibration result, its

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logarithm has a significant quadratic curve relationship with $\Delta\delta^2$H and $\Delta\delta^{18}$O, and the formulas are respectively,

$$\Delta\delta^2\mathrm{H} = 0.018(\ln NB)^3 + 0.092(\ln NB)^2 + 0.388\ln NB + 0.785(R^2 = 0.991，p > 0.0001) \quad (2\text{-}1)$$

$$\Delta\delta^2\mathrm{O} = 0.017(\ln NB)^3 - 0.017(\ln NB)^2 + 0.545\ln NB + 1.356(R^2 = 0.998，p < 0.0001) \quad (2\text{-}2)$$

Its broadband measurements for ethanol correction results in BB metric $\Delta\delta^2$H and $\Delta\delta^{18}$O a quadratic curve and linear relationship, respectively, are:

$$\Delta\delta^2\mathrm{H} = -85.67BB + 93.664(R^2 = 0.747, p = 0.026)(BB < 1.2) \quad (2\text{-}3)$$

$$\Delta\delta^2\mathrm{O} = -21.421BB^2 + 39.935BB - 19.089(R^2 = 0.769，p < 0.012) \quad (2\text{-}4)$$

3 Results

3.1 The relationship between water stable isotopes in different vegetation zones

According to the definition of global atmospheric waterline (GMWL) (Craig, 1961), the linear relationship of δ^{18}O and δD in local precipitation, soil water, plant water, and groundwater is defined as LMWL, SWL, PWL, and GWL, respectively. By comparing different waterline equations and analyzing changes in various water bodies, regional meteorological and hydrological conditions can be determined. The contribution of various environmental factors can be evaluated (Hua et al., 2019).

As shown in Fig. 2, from April 2018 to October 2019, there are certain differences in the atmospheric waterline equations of different vegetation zones. The slopes of the atmospheric waterline equations of alpine meadows, forests, and arid foothills are all smaller than that of GMWL. This is because the study area is located in the northwestern China's arid area, which is weakly affected by the monsoon, the climate is dry, and the isotopes have undergone strong fractionation. Among them, the slopes of the atmospheric waterline equations of alpine meadows, forests, and arid foothills are all smaller than that of GMWL. This is the same as the study area is located in northwestern China's arid area, which is weakly affected by the monsoon, the climate is dry, and the advection is strong, and the isotopes have undergone strong fractionation. The slope of the soil waterline in the alpine meadow is the largest (6.07), and the slope of the soil waterline in the forest (5.10) is greater than the slope of the soil waterline in the arid foothills (3.94). The intercept has the same characteristics, indicating that the arid foothills's soil evaporation is the largest. The degree of soil evaporation in alpine meadows is the smallest. The vegetation coverage area of alpine meadows is larger than that of arid foothills, and the

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water retention capacity is better, and soil moisture is not easy to evaporate. The slope of the vegetation waterline equation in the arid foothills is the largest (2.45), and the slope of the vegetation waterline in the alpine meadow (1.90) is greater than that of the forest (1.69). The vegetation coverage of the forest is large, the evaporation is strong, and the evaporation of the vegetation in the arid foothills is relatively weak.

According to the weighted average of each water body's stable isotope (Table 2), the isotopes of soil water in alpine meadows are the most depleted and are the closest to the isotopic values of precipitation. The average isotopic values of groundwater are located between plants and precipitation, indicating that precipitation is the primary source of replenishment for alpine meadows. The precipitation isotope of the forest is the most depleted, and the average isotope of groundwater is between soil water and precipitation but close to precipitation, indicating that forest groundwater is replenished by soil water and precipitation. The mean isotopic values of soil water in the arid foothills are between precipitation and groundwater but closer to groundwater, indicating that the soil water in the arid foothills is mainly supplied by groundwater.

3.2 Variation of isotope and SWC between different vegetation zone

The average variation of $\delta^{18}O$ (δD has the same interpretation as $\delta^{18}O$) and SWC in soil water along the vertical soil profile is shown in Fig. 3. Along the three vegetation zones of alpine meadow-forest-arid foothills, soil water isotope gradually enriched.The coefficient of variation of the arid foothills is the largest. The coefficient of variation of the forest is the smallest, indicating that from forest to arid foothills, it tends to be arider in regions, the greater the coefficient of variation, the greater the instability of stable isotope soil water. The soil water isotopes of different vegetation zones showed the same characteristics as the soil depth changed, that is, they were all depleted in May and August, and enriched in October.

The soil water content of alpine meadows is higher than that of forests and arid foothills, and the soil water content of alpine meadows increases with the soil depth, while the soil water content of forests decreases with the soil depth. Forest soil moisture content is caused by the transpiration of the forest canopy and large water consumption. Compared with forests, plants in alpine meadows have shallower root systems and smaller canopies, so transpiration and water consumption are lower, and soil water content is higher. With the continuous progress of vegetation restoration, the vegetation coverage of alpine meadows will continue to increase, which will reduce soil water evaporation and increase soil infiltration and water retention capacity. The soil moisture content of alpine meadows and forests is the largest in August, while the arid foothills's soil moisture content is the smallest in August. This is because the northern foot of the Qilian Mountains is a windward slope. In August, there is a lot of rain, and a lot of precipitation falls on the high-altitude alpine meadows and forests. The dry and dry foothills have little precipitation and low soil water content.

3.3 Relationship between soil water and plant water in different vegetation zone

For plants in general, water is absorbed by the root system and moves from root to leaf without hydrogen and oxygen isotope fractionation (Zhao et al., 2008; Lin et al., 1993). Therefore, by analyzing the isotopic composition of soil moisture and plant xylem, it is possible to preliminarily determine whether there is an overlap between soil moisture and plant moisture at different depths (Javaux et al., 2016; Dawson et al., 2002; Rothfuss et al., 2017; Tetzlaff et al., 2017; McCole et al., 2007; Zhou et al., 2015; Schwendenmann et al., 2015). Precipitation, surface runoff, and most groundwater are "initial" sources absorbed by plants after converting into soil water. Before being absorbed by plants, soil water may undergo evaporation to produce isotopic enrichment, resulting in an increase in the $\delta^{18}O$ and δD value of soil water (Chen et al., 2014). Therefore, it can be well explained that the surface soil water in Fig. 4 is more affluent than the deep soil water.

According to the study area's precipitation, the study area is divided into two time periods: dry season (October-May of the following year) and the rainy season (June-September) for analysis (Fig. 4). In the dry season, alpine meadow plants have the most abundant water isotope. There is no overlap between soil water and plant water. The isotopic values of groundwater and precipitation are similar, indicating that alpine meadow plants do not directly use soil water in the dry season. In the rainy season, plant water isotope is the most abundant, and the surface and deep layers of groundwater and soil water intersect, which indicates that the soil water of the alpine meadow in the rainy season is mainly recharged by groundwater. In the dry season, due to the low temperature (average temperature of 0.30°C), there is a large amount of melted ice and snow in the alpine meadow, which is rich in precipitation and meltwater, and plants do not directly use soil water. In the rainy season (average temperature 8.72°C), as the temperature increases, plant water isotopes experience intense evaporative fractionation and are most enriched in isotopes. With the increase of precipitation, runoff, and formation of groundwater increase, and groundwater supplements soil water. Forest plant water

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intersects with deep soil during the dry season and intersects with the soil surface during the rainy season. This indicates that forest plants mainly use deep soil water during the dry season and shallow soil water during the rainy season. This is related to the lack of rainfall in the dry season and more rainfall in the rainy season. During the drought and rainy seasons, the soil water in the arid piedmont intersects with the groundwater, plant water is enriched, indicating the replenishment relationship between the soil water and the plant water in the arid piedmont is not apparent. High temperature is related to groundwater level exposure.

4 Discussion

4.1 The influence of temperature on SPAC

$\delta^{18}O$ changes significantly with seasons. As shown in Fig. 5, with the changes in the water cycle of precipitation-soil water-plant water, the $\delta^{18}O$ of forests gradually accumulates, while the soil water isotopes of arid foothills and alpine meadows are the most depleted in summer. In other seasons, along precipitation-soil-water-plant water, $\delta^{18}O$ are gradually enriched. In summer, alpine meadows have a lot of precipitation and large soil water content, but due to low temperature (average temperature in summer is 9.8°C) and low evaporation, the soil water isotope of alpine meadows is relatively depleted in summer. In the arid foothills, in summer, especially in August, although the temperature is relatively high (the average summer temperature is 23.92°C), the soil water content is low, evaporation is weak, and isotopes are relatively depleted. This phenomenon shows that precipitation plays a major control role in the water cycle of precipitation-soil-plants. Previous studies have shown that local factors, especially local temperature mainly control the stable isotope changes of precipitation in mid-latitudes. If the temperature is below 0°C, the air will expand adiabaticly and the water vapor will change adiabatic cooling (Rozanski, 1992). When the temperature is between 0°C and 8°C, the influence of local water vapor circulation is greater. When the temperature is below 8°C, the secondary evaporation under the clouds is very strong (Ma et al., 2018). Therefore, the temperature is divided into three

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gradients (below 0°C, between 0°C and 8°C and above 8°C) to analyze the relationship between precipitation isotope and temperature. From alpine meadow to arid foothills, the correlations between temperature and soil are 0.41, 0.30, and 0.19, respectively, and the correlations with plants are 0.24, 0.27, and 0.25, respectively. Compared with precipitation, the temperature effect is not significant. As shown in Table 3, from the alpine meadow to the arid foothills, the temperature effect of the precipitation isotope is enhanced, and there is a significant positive correlation with temperature, and all have passed the significance test. With the increase of temperature, the temperature effect of precipitation isotope in each vegetation area weakens, and the linear relationship decreases.When the temperature is lower than 0°C, the correlation between the isotope of precipitation in the arid mountain foothills and the temperature fails the significance test.When the temperature is between 0°Cand 8°C, as the temperature increases, the temperature effect of precipitation weakens, which may be related to the weakening of the local water cycle and the enrichment of precipitation isotopes when the temperature rises. When the temperature is above 8°C, there is no correlation between the precipitation isotope and the temperature, but the precipitation isotope value is the most enriched, which may be related to the isotope enrichment caused by the secondary evaporation under the cloud.

4.2 The influence of altitude on different vegetation zones

To analyze the relationship between precipitation isotope and altitude, the study area is divided into summer half-year (May-September) and winter half-year (October-April of the following year). As the water vapor mass rises along the hillside, the temperature continues to decrease, and the precipitation isotope values continue to deplete. As shown in Fig. 6, from the arid foothills to the alpine meadow, the altitude rises from 1467m to 2097m, and the mean values of precipitation isotopes $\delta^{18}O$ and δD have changed from -7.33‰, -48.62‰ to -9.10‰ and -54.93‰, respectively, and the rate of change was respectively -7.10‰ , -54.93‰ and -0.08‰ $(100m)^{-1}$, -0.29‰ $(100m)^{-1}$, this rate of change is within the globally recognized altitude gradient of precipitation $\delta^{18}O$ is-0.28‰$(100m)^{-1}$ (Poage and

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Chamberlain, 2001). In the summer half of the year, the correlation between $\delta^{18}O$ in precipitation and altitude is -0.97, R^2 is 088, and the rate of change is -0.12‰ $(100m)^{-1}$, indicating that there is a significant negative correlation between $\delta^{18}O$ in precipitation isotope and altitude. And every time the altitude increases by 100 meters, the $\delta^{18}O$ value of the precipitation isotope changes 0.12‰. In the winter half of the year, the correlation between $\delta^{18}O$ in precipitation and altitude is -0.95, R^2 is 0.79, and the rate of change is -0.18‰ $(100m)^{-1}$. The correlation between altitude and soil water isotope and plant water isotope is -0.53 and -0.61, respectively, and their correlation is not as strong as that of precipitation.

5 Conclusion

This paper uses the hydrogen and oxygen isotope method to study the differences and control factors of SPAC in different vegetation zones. From alpine meadows to forests to arid foothills, as the altitude decreases, the temperature effect of precipitation isotope increases, and the influence of temperature increases. When the temperature is lower than 0℃, the temperature effect of the vegetation zone is the strongest. As the depth increases, soil water isotopes are gradually depleted. The soil water content of alpine meadows is the largest and increases with the soil depth, while the forest soil water content decreases with the soil depth, and the soil water content of the arid mountain foothills is the least in August. In the rainy season, plants mainly use precipitation, while in the dry season, forest plants mainly use soil water, while alpine meadow plants do not directly use soil water due to the abundant precipitation and meltwater in the growing season. Exposure of the groundwater level in the arid mountain foothills can provide water for plants in the dry season. Because forests and grasslands have the effect of intercepting rainfall, they delay or hinder the formation of surface runoff, and convert part of the surface runoff into soil flow and groundwater, which can provide part of water resources' role for plants. To better understand the water cycle of SPAC at different temperatures and altitudes in high mountain areas, long-term observations of different plants are needed to provide a theoretical basis for the rational and practical use of water resources in arid mountainous areas.

Data Availability

The data that support the findings of this study are openly available in Zhu (2021) at "Data sets of Stable water isotope monitoring network of different water bodies in Shiyang River Basin, a typical arid river in China", Mendeley Data, V1, doi: 10.17632/t87pm4b5dx.1

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Author contributation

Guofeng Zhu and Yuwei Liu conceived the idea of the study; Zhuanxia Zhang analyzed the data; Zhigang Sun and Leilei Yong were responsible for field sampling; Liyuan Sang participated in the experiment; Kailiang Zhao participated in the drawing; Yuwei Liu wrote the paper; Liyuan Sang and Lei Wang checked and edited language. All authors discussed the results and revised the manuscript.

Competing interests

The authors declare no competing interests

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References

Araguas-Araguas, L., Rozanski, K., Gonfiantini, R., and Louvat, D.: Isotope effects accompanying vacuum extraction of soil water for stable isotope analyses. Journal of Hydrology Amsterdam. 168(1–4), 159-171, doi:10.1016/0022-1694(94)02636-P,1995.

Araguás-Araguás, Luis, Froehlich, K., and Rozanski, K.: Stable isotope composition of precipitation over southeast asia. Journal of Geophysical Research Atmospheres, 103(D22), 28721-28742, doi:10.1029/98JD02582,1998.

Bam, E., and Ireson, A. M.: Quantifying the wetland water balance: a new isotope-based approach that includes precipitation and infiltration. Journal of Hydrology, 570, doi:10.1016/j.jhydrol.2018.12.032, 2018.

Bowen, G. J., Kennedy, C. D., Liu, Z., and Stalker, J.: Water balance model for mean annual hydrogen and oxygen isotope distributions in surface waters of the contiguous united states. Biogeosciences, 116(G4), 105-12, doi:10.1029/2010JG001581, 2015.

Chao, C., Huang, M. S., Liu, J., and Shuping.: Isotope-based water-use efficiency of major greening plants in a sponge city in northern China. PloS one, 14(7), doi:10.1371/journal.pone.0220083, 2019.

Chen, X. L., Chen, Y. N., and Chen, Y. N P.:Water use relationship of desert riparian forest in lower reaches of Heihe River. Chinese Journal of Eco-Agriculture, 22(08):972-979. (in Chinese), doi:10.1007/s11430-013-4680-8,2014.

Christopher, T., Solomon, J, J., and Cole.:The influence of environmental water on the hydrogen stable

https://doi.org/10.5194/bg-2021-127
Preprint. Discussion started: 2 June 2021

isotope ratio in aquatic consumers. Oecologia, 161(2), p.313-324, doi:10.1007/s00442-009-1370-5, 2009.

Coenders-Gerrits, A. M, J., van der Ent, R.J., Bogaard, T. A., Wang-Erlandsson, L., Hrachowitz, M., Savenije, and H. H. G.: Uncertainties in transpiration estimates. Nature. 506, E1–E2, doi:10.1038/nature12925, 2014.

Coplen, T.: Stable isotope hydrology: deuterium and oxygen 18 in the water cycle. Eos Transactions American Geophysical Union, 63(45), 861-862, doi:10.1029/EO063i045p00861, 2013.

Cortes, A., and Farvolden, R. N.: Isotope studied of precipitation and groundwater in the sierra de las cruces, Mexico. Journal of Hydrology, 107(s 1–4), 147-153, doi:10.1016/0022-1694(89)90055-3,1989.

Craig, H.: Isotopic variations in meteoric water. Science, 133, 1702–1703, doi:10.1126/science.133.3465.1702,1961.

Daniele, P., Omar, O., Rick, A., and Giancarlo, D. F.: Tracing the water sources of trees and streams: isotopic analysis in a small pre-alpine catchment. Procedia Environmental Sciences, 19(6), doi:106-112, 10.1016/j.proenv.2013.06.012, 2013.

Darling, W. G. , Bath, A. H. , and Talbot, J. C.: The O and H stable isotope composition of freshwaters in the british isles. 2, surface waters and groundwater. Hydrology and Earth System Sciences, doi:10.5194/hess-7-183-2003, 2003.

Dawson, T. E.: Water sources of plants as determined from xylem-water isotopic composition: perspectives on plant competition, distribution, and water relations stable isotopes and plant carbon water relations. Stable Isotopes and Plant Carbon-water Relations, 465-496, 1993.

Dawson, T. E., and Ehleringer, J. R.: Streamside trees that do not use stream water. Nature, 350(6316), 335-337, doi:10.1038/350335a0, 1991.

Dawson, T. E., Mambelli, S., Plamboeck, A. H., Templer, P. H., and Tu, K. P.: Stable isotopes in plant ecology. Ann. Rev. Ecol. System. 33(1), 507–559, doi.:10.1146/annurev.ecolsys.33.020602.095451, 2002.

Detjen, M., Sterling, E. , and A Gómez.: Stable isotopes in barnacles as a tool to understand green sea turtle (chelonia mydas) regional movement patterns. Biogeosciences, 2015.

Edwards, T. W. D., Birks, S. J., St Amour, N. A., Buhay, W. M., Mceachern, P., and Wolfe, B. B., Progress in isotope tracer hydrology in Canada. Hydrological Processes, 19(1), 2010.

Ehleringer, L.: Stable isotope composition of stem and leaf water: applications to the study of plant

https://doi.org/10.5194/bg-2021-127
Preprint. Discussion started: 2 June 2021

water use. Functional Ecology, 5(2), 270-277, doi:10.2307/2389264,1991.

Evaristo, J., Jasechko, S., and Mcdonnell, J. J.: Global separation of plant transpiration from groundwater and streamflow. Nature, 525(7567), 91, doi:10.1038/nature14983, 2015.

Gaj, M., Beyer, M., Hamutoko, J., Uugulu, S., Wanke, H., and Koeniger, P.: How do soil types affect stable isotope ratios of 2H and 18O under evaporation: A Fingerprint of the Niipele subbasin of the Cuvelai - Etosha basin, Namibia.EGU General Assembly Conference Abstracts, 2014.

Gao, J., Yao, T., Tian, L.D., Risi, C., and Hoffmann, G.: Precipitation water stable isotopes in the south tibetan plateau: observations and modeling. Journal of Climate, 24(13), 3161-3178, doi:10.1175/2010JCLI3736.1, 2011.

Gao, J., Tian, L, D., Liu, Y, Q., and Gong, T. L.: Oxygen isotope variation in the water cycle of the yamzho lake basin in southern tibetan plateau. Chinese Science Bulletin, (16), 2758-2765, 2009.

Gazis, C., and Feng, X.: A stable isotope study of soil water: evidence for mixing and preferential flow paths. Geoderma, 119(1-2), 97-111, doi:10.1016/S0016-7061(03)00243-X, 2004.

Hepp, J., Tuthorn, M., Zech, R., Mügler, I., and Zech, M.: Reconstructing lake evaporation history and the isotopic composition of precipitation by a coupled δ18O-δD biomarker approach. Journal of Hydrology, 529, 622-631, doi:10.1016/j.jhydrol.2014.10.012, 2015.

Hou, S. B., Song, X. F., Jie, Y. J., Liu, X., and Zhang, G. Y.: Stable isotopes characters in the process of precipitation and infiltration in taihang mountainous region. Resources Science, 2008.

Hua, M. Q., Zhang, X. P., Yao, T. C., and He, X. G.: Dual effects of precipitation and evaporation on lake water stable isotope composition in the monsoon region. Hydrol.Process, 33, 2192–2205, doi:10.1002/hyp.13462, 2019.

Jasechko, S., Sharp, Z. D., Gibson, J. J., Birkes, S. J., Yi, Y., and Fawcett, P. J.: Terrestrial water fluxes dominated by transpiration. Nature, 496 (7445), 347–351, doi:10.1038/nature11983, 2013.

Javaux, M., Rothfuss, Y., Vanderborght, J., Vereecken, H., and Brüggemann, N.: Isotopic composition of plant water sources. Nature, 536 (7617), E1–E3, doi:10.1038/nature18946, 2016.

Jennifer, D., Knoepp, R., Scott, T., Lindsay, R., Boring., and Chelcy, F. M.: Influence of forest disturbance on stable nitrogen isotope ratios in soil and vegetation profiles. Soil Sci Soc amj, 79(5), 1470-14, doi:10.2136/sssaj2015.03.0101, 2015.

Konstantin, S., Claudio, M., Ulrich, S., Elisabeth, L., and Uwe, T.: Reassessing hydrological processes that control stable isotope tracers in groundwater of the atacama desert (Northern Chile). Hydrology, 5

(1), 3-3, 2018.

Lin, G. H., and Sternberg, L.: Hydrogen isotopic fractionation by plant roots during water uptake in coastal wetland plants. Stable Isotopes and Plant Carbon-Water Relations. Boston: Academic Press Inc, 497–510, 1993.

Liu, W., Wang, P., Li, J., Liu, W., and Li, H.: Plasticity of source-water acquisition in epiphytic, transitional and terrestrial growth phases of Ficus tinctoria. Ecohydrology, 7 (6), 1524–1533, doi:10.1002/eco.1475, 2015.

Ma, X. J., Jin, J. J., Si, B. C., and Wang, H. X.: Effect of extraction methods on soil water isotope and plant water source segmentation. Chin. J. Appl. Ecol, 30, 1840–1846 (in Chinese), 2019.

McCole, A. A., and Stern, L.A.: Seasonal water use patterns of Juniperus ashei on the Edwards Plateau, Texas, based on stable isotopes in water. J. Hydrol, 342, 238–248, doi:10.1016/j.jhydrol.2007.05.024, 2007.

Meissner, K., Schwendenmann, H., and Dyckmans.: Soil water uptake by trees using water stable isotopes (δD and δ18O)-a method test regarding soil moisture, texture and carbonate. Plant Soil, 376, 327-335, doi:10.1007/s11104-013-1970-z, 2014.

Meng, X. Q., Wen, X. F., Zhang, X. Y., Han, J. Y., Sun, X. M.., and Li, X. B.: Influence of organics on the determination of δ18O and δD of plant leaves and stalk water by infrared spectroscopy, Chin J Eco-agri, 20, 1359-1365, 2012.

Murdock, W.: Soil moisture and temperature survey of a desert vegetation mosaic. Ecology, 44(4), 821, doi:10.2307/1933043,1963.

Négrel, P., Petelet-Giraud, E., Millot, R.: Tracing water cycle in regulated basin using stable δ18O-δ2H isotopes: the ebro river basin (spain). Chemical Geology, 422, 71-81, 2016.

Nie, Y. P., Chen, H. S., Wang, K, L., and Ding, Y. L.: Rooting characteristics of two widely distributed woody plant species growing in different karst habitats of southwest China. Plant Ecol, 215(10),1099-1109, doi:10.1007/s11258-014-0369-0, 2014.

Nlend, B., Celle-Jeanton, H., Risi, C., Pohl, B., and Ketchemen-Tandia, B.: Identification of processes that control the stable isotope composition of rainwater in the humid tropical west-central Africa. Journal of Hydrology, 584, 124650, doi:10.1016/j.jhydrol.2020.124650 2020.

Pan, Y. X.: The stable isotopic composition variation characteristics of desert plants and water sources in an artificial revegetation ecosystem in northwest China. Catena, 189(4),

https://doi.org/10.5194/bg-2021-127
Preprint. Discussion started: 2 June 2021

Biogeosciences
Discussions

doi:10.1016/j.catena.2020.104499, 2020.

Poage, M. A., Chamberlain, C. P.: Empirical relationships between elevation and the stable isotope composition of precipitation and surface waters: considerations for studies of paleoelevation change. American Journal of Science, 1–15, doi:10.2475/ajs.301.1.1, 2001.

Porporato, L.: Plants in water-controlled ecosystems: active role in hydrologic processes and response to water stress. Advances in Water Resources, 24(7), 725-744, doi:10.1016/S0309-1708(01)00005-7, 2001.

Raco, B., Dotsika, E., Feroni, A. C., Battaglini, R., and Poutoukis, D.: Stable isotope composition of italian bottled waters. Journal of Geochemical Exploration, 124, doi:10.1016/j.gexplo.2012.10.003, 2013.

Rothfuss, Y., and Javaux, M.: Reviews and syntheses: Isotopic approaches to quantify root water uptake: A review and comparison of methods. Biogeosciences, 14, 2199, doi:10.5194/bg-14-2199-2017, 2017.

Schlesinger, W. H., Jasechko, S.: Transpiration in the global water cycle. Agric Forest Meteorol, 180–190, 115–117, doi:10.1016/j.agrformet.2014.01.011, 2014.

Schwendenmann, L., Pendall, E., Sanchez-Bragado, R., Kunert, N., Hölscher, D.:Tree water uptake in a tropical plantation varying in tree diversity: Interspecific differences, seasonal shifts and complementarity. Ecohydrology, 8 (1), 1–12, doi:10.1002/eco.1479, 2015.

Shou, W. K., Hu, F. L., Alamusa., and Liu, Z. M.: Methods for studying water cycle and water sources in arid regions based on spac system. Chinese Journal of Ecology, 32(8), 2194-2202, 2013.

Smith, G. I., Friedman, I., Gleason, J. D., and Warden, A.: Stable isotope composition of waters in southeastern California: 2. groundwaters and their relation to modern precipitation. Journal of Geophysical Research Atmospheres, 97, doi:10.1029/92JD00183,1992.

Song, X. F., Xia, J., Yu, J. J., and Liu, C. M.: Application of environmental isotope techniques to study the hydrological cycle mechanism of typical watersheds in North China. Advances in Geographical Sciences, 21(6), 527-537, 2002.

Song, X., Barbour, M. M., Farquhar, G. D., Vann, D. R., and Helliker, B. R.: Transpiration rate relates to within and across species variations in effective path length in a leaf water model of oxygen isotope enrichment. Plant, Cell and Environment, 36(7), 2013.

Speelman, E. N., Sewall, J. O., Noone, D., Huber, M., Heydt, A., and Damsté, J. S.: Modeling the influence of a reduced equator-to-pole sea surface temperature gradient on the distribution of water isotopes in the early/middle eocene. Earth and Planetary Science Letters, 298(1), 57-65, doi:10.1016/j.epsl.2010.07.026, 2010.

Steinman, B. A., Rosenmeier, M. F., Abbott, M. B., and Bain, D. J.: The isotopic and hydrologic response of small, closed-basin lakes to climate forcing from predictive models: application to paleoclimate studies in the upper Columbia river basin. Limnology and Oceanography, 55(6), 2231-2245, doi:10.4319/lo.2010.55.6.2231, 2010.

Sun, S. F., Huang, J. H., Lin, G. H. , Zhao, W., and Han, X. G.: Application of stable isotope technique in the study of plant water use. Acta Ecologica Sinica, 25(9), 2362-2371. Tech. Pap, No. 96 (48 pp.), doi:10.1360/982004-755, 2005.

Tetzlaff, D., Sprenger, M., and Soulsby, C.: Soil water stable isotopes reveal evaporation dynamics at the soil-plant-atmosphere interface of the critical zone. Hydrol. Earth Syst. Sci, 21, 3839–3858, 2017.

Thompson, L. G., Yao, T., Mosleythompson, E., Davis, M.E., Henderson, K. A., and Lin, P.: A high-resolution millennial record of the south asian monsoon from himalayan ice cores. Science, 289(5486), 1916-1920, 2000.

Timsic, S., and Patterson, W. P.: Spatial variability in stable isotope values of surface waters of eastern canada and new england. Journal of Hydrology, 511(7), 594-604, doi:10.1016/j.jhydrol.2014.02.017, 2014.

Wang, S.Y., Wang, Q. L., Wu, J, K., He, X. B., and Wang, L.H.: Characteristics of stable isotopes in precipitation and moisture sources in the headwaters of the Yangtze River. Environmental Sciences, 40(6), 2615-2623, doi:10.13227/j.hjkx.201811140, 2019.

Wei, K. F., and Lin, R. F.: The influence of the monsoon climate on the isotopic composition of precipitation in China. Geochimica, 1994.

Welker, J. M.: Isotopic (δ18O) characteristics of weekly precipitation collected across the usa: an initial analysis with application to water source studies. Hydrological Processes, 14(8), 1449-1464, 2000.

Wen, P., Deng, J., Zhang, Z. J., and Shao, C.: Stable hydrogen and oxygen isotope compositions in soil-plant-atmosphere continuum (SPAC) in rocky mountain area of Beijing, China. The journal of applied ecology, doi:10.13287/j.1001-9332.201707.018, 2017.

White, J. C. , and Smith, W. K.: Water sources in riparian trees of the southern appalachian foothills,

https://doi.org/10.5194/bg-2021-127
Preprint. Discussion started: 2 June 2021

usa: a preliminary study with stable isotope analysis. Riparian Ecology and Conservation,1, 46-52, 10.2478/remc-2013-0006, 2013.

White, J., Cook, E., Lawrence, J.R., and Broecker, W. S.: The D/H ratios of sap in trees: implications for water sources and tree ring D/H ratios. Geochim. Cosmochim. Acta, 49 (1), 237–246, doi:10.1016/0016-7037(85)90207-8,1985.

William, D.: Hydrogeochemical analysis of groundwater in the sawla-tuna-kalba district of the northern region of ghana. University of Ghana, 2013.

Wu, H. W., Li, X. Y., Jiang, Z. Y., Li, J., and Zhao, D. Z.: Variations in water use for achnatherum splendens in lake qinghai watershed,based on δD and δ18O. Acta Ecologica Sinica, doi:10.5846/stxb201406231300, 2015.

Xu, Q., Hoke, G.D., Liu-Zeng, J., Ding, L., Wang, W., and Yang, Y.: Stable isotopes of surface water across the longmenshan margin of the eastern tibetan plateau. Geochemistry Geophysics Geosystems, 15(8), 3416-3429, doi:10.1002/2014GC005252, 2015.

Yang, B., Wen, X., and Sun, X.: Seasonal variations in depth of water uptake for a subtropical coniferous plantation subjected to drought in an east asian monsoon region. Agricultural and Forest Meteorology, 201, 218-228, doi:10.1016/j.agrformet.2014.11.020, 2015.

Yao, T., Duan, K., Xu, B., Wang, N., Guo, X., and Yang, X.: Precipitation record since AD 1600 from ice cores on the central tibetan plateau. Climate of the Past, 4(3), 175-180, doi:10.5194/cp-4-175-2008, 2008.

Yao, Z., Liu, J., Huang, H. Q., Song, X. , Dong, X., and Xin, L.: Characteristics of isotope in precipitation, river water and lake water in the manasarovar basin of Qinghai–Tibet plateau. Environmental Geology, 57(3), 551-556, doi:10.1007/s00254-008-1324-y, 2009.

Yu, J. J., Song, X. F., Liu, X. C., Yang, C., Tang, C. Y., and Li, F. D.: A study of groundwater cycle in yongding river basin by using δD, $\delta^{18}O$ and hydrochemical data. Journal of Natural Resources, (03), 415-423, 2007.

Zhang, C.: Contribution of soil water at different depths in profile to winter wheat in Fengqiu in huang-huai-hai plain of China. Acta Pedologica Sinica, 2012.

Zhao, L. J., Xiao, H. L., Cheng, G. D., Song, Y. X., Zhao, L., Li, C. Z., and Yang. Q.: A preliminary study of water sources of riparian plants in the lower reaches of the Heihe Basin. Acta Geoscientia

Sinica, 29(6): 709–718. 2008.

Zhou, H., Zhao, W. Z., Zheng, X. J., and Li, S. J.: Root distribution of Nitraria sibirica with seasonally varying water sources in a desert habitat. J. Plant Res, 128, 613–622, 2015.

Zhu, G. F., Guo, H.W., Qin, D. H., Pan, H. X., and Ma, X. G.: Contribution of recycled moisture to precipitation in the monsoon marginal zone: estimate based on stable isotope data. Journal of Hydrology, 569, doi:10.1016/j.jhydrol.2018.12.014, 2018.

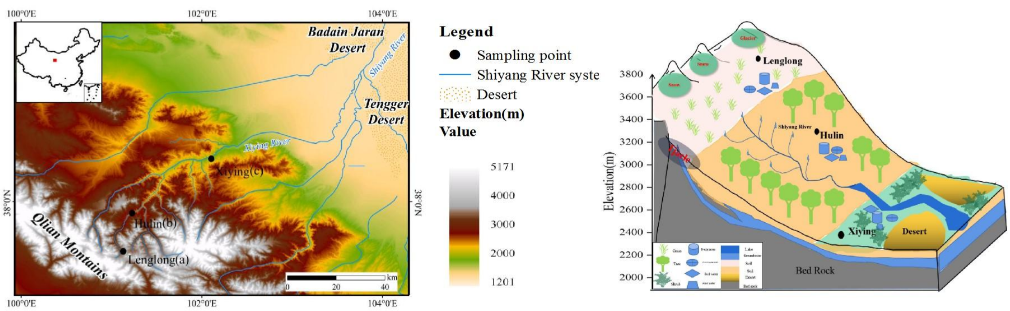

Figure. 1 Study area and observation system

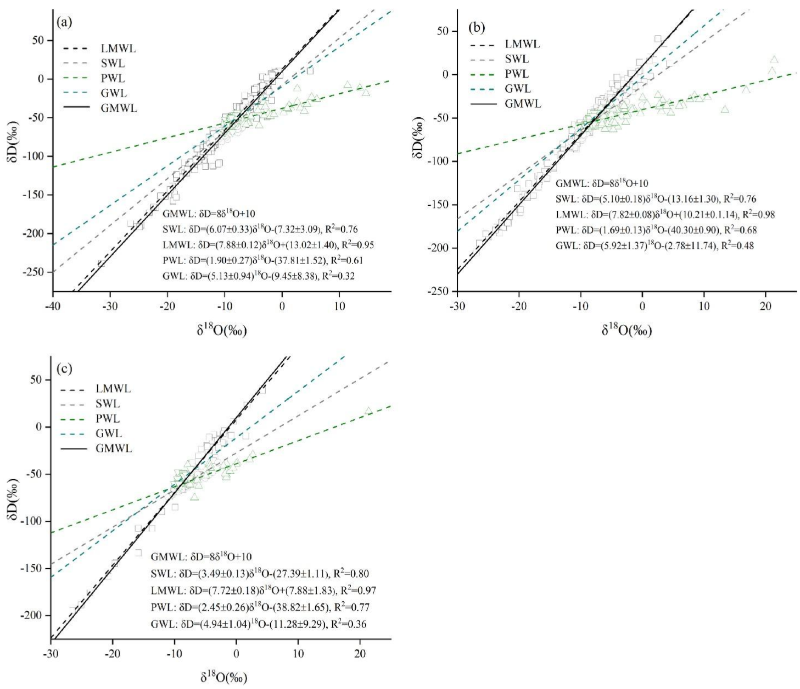

Fig. 2 Relationship of stable isotopes in different water bodies in alpine meadow (a), forest (b) and arid foothills (c).

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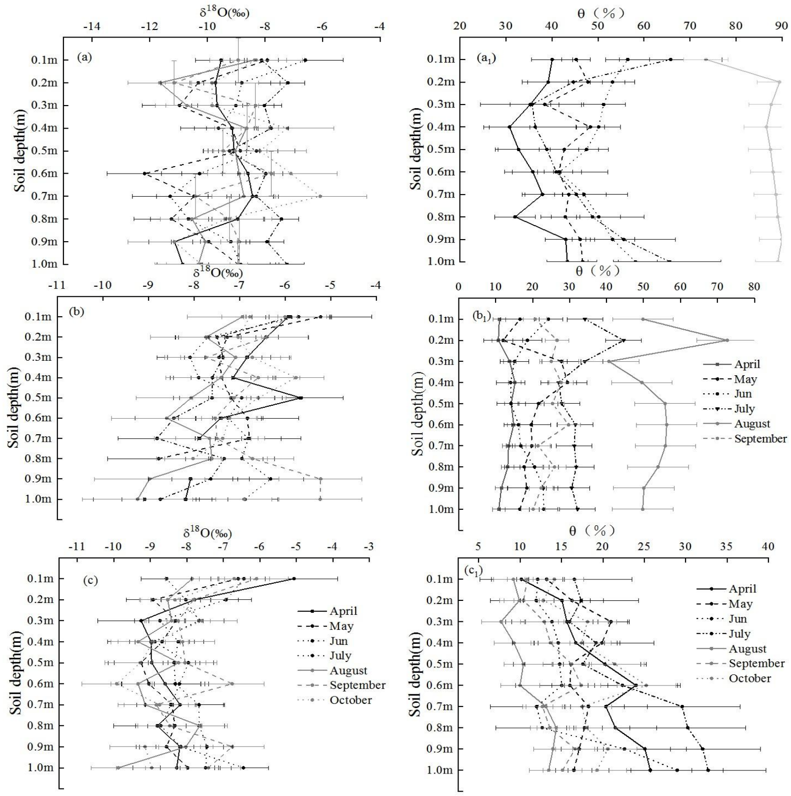

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522 **Fig. 3 The variation of δ18O and θ (%) with soil depth. (a)-(c) represent alpine meadow, forests and arid**
523 **foothills, respectively.**

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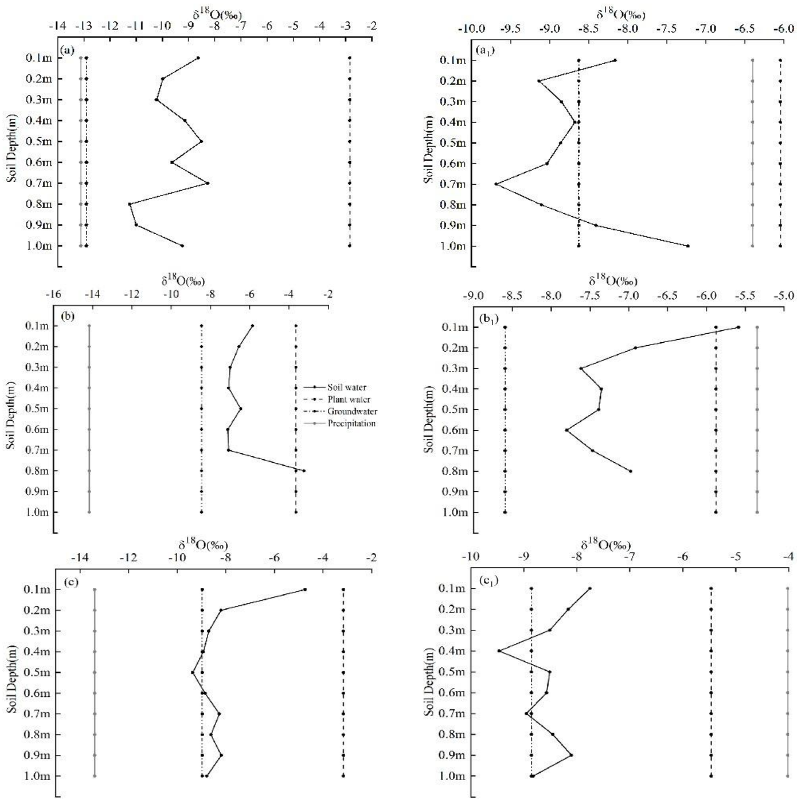

Fig. 4 (a)-(c) represents the variation of $\delta^{18}O$ of soil, plant, precipitation and groundwater with soil depth in the alpine meadow, forests and arid foothills in the dry season, and (a_1)-(d_1) represents the variation of δ18O of soil, plant, precipitation and groundwater in the alpine meadow, forests and arid foothills in the rainy season.

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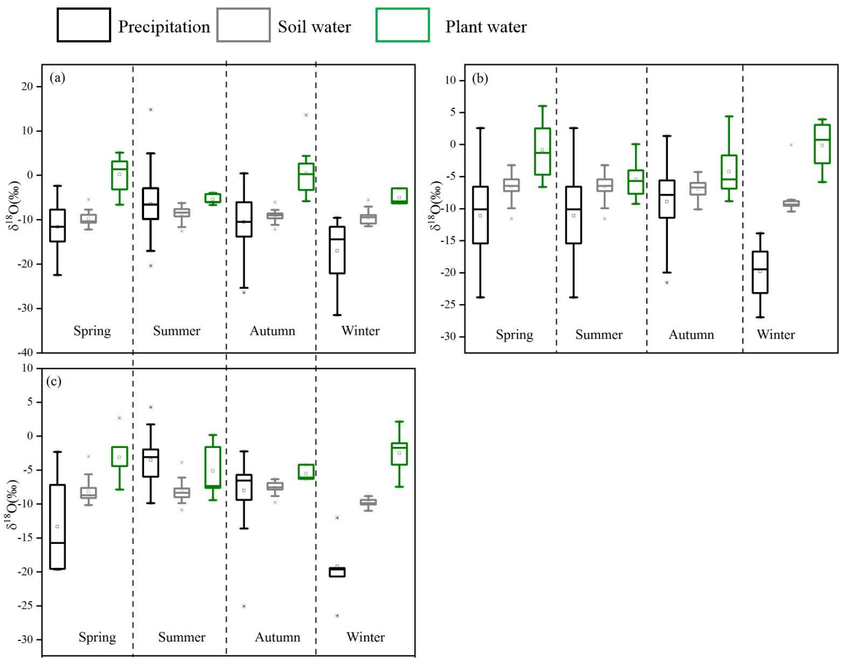

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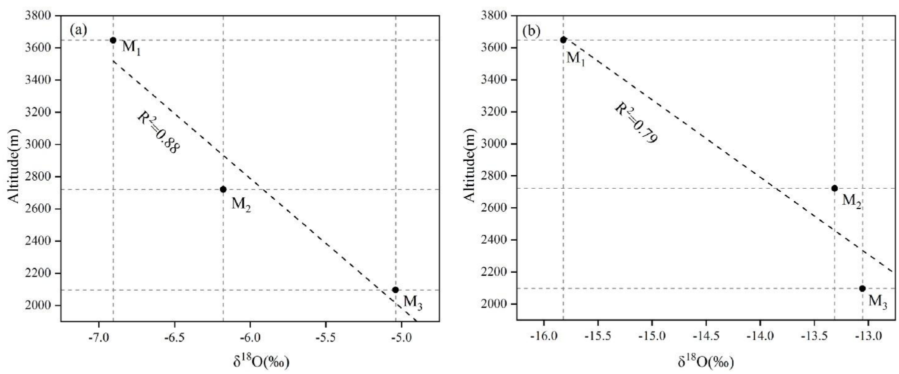
530 **Fig. 5 Seasonal variations of different water isotopes in alpine meadow (a), forests (b) and arid foothills (c).**



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532 **Fig. 6 Relationship between precipitation isotope and altitude half a year in summer (a) and half a year in**
533 **winter (b)**

534 **Table 1 Basic information table of sampling points**

Sampling Station		Geographical Parameters			Meteorological Parameters	
		Longitude (E)	Latitude (N)	Altitude (m)	Temperature (°C)	Precipitation (mm)
M1	Lenglong	101°50'	37°33'	3647	-0.20	1039.10
M2	Hulin	101°53'	37°41'	2721	3.24	469.44
M3	Xiying	102°18'	38°29'	2097	7.99	194.67

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Vegetation zone types	Water types	δ18O(‰) Min	Max	Average	Coefficient of Variation	δD(‰) Min	Max	Average	Coefficient of Variation
Alpine meadow	Precipitation	-31.49	14.79	-9.44	-0.70	-238.62	63.43	-59.43	-0.84
	Soil water	-12.62	-5.46	-9.16	-0.16	-83.86	-26.13	-62.92	-0.16
	Plant water	-6.68	5.12	-1.68	-2.18	-60.22	-12.14	-41.14	-0.28
	Groundwater	-10.07	-7.71	-8.84	-0.07	-68.55	43.72	-54.85	-0.10
Forest	Precipitation	-26.96	4.38	-8.63	-0.74	-205.40	41.35	-60.24	-0.87
	Soil water	-11.96	-0.07	-7.01	-0.25	-78.43	-18.48	-48.68	-0.21
	Plant water	-9.24	5.98	-5.44	-1.31	-63.29	-23.77	-45.12	-0.24
	Groundwater	-10.25	-7.43	-8.56	-0.09	-68.80	-43.75	-53.46	-0.12
Arid foothills	Precipitation	-26.47	4.24	-7.50	-0.87	-194.34	38.62	-48.62	-1.04
	Soil water	-10.98	-2.96	-8.23	-0.15	-74.22	-8.79	-59.17	-0.12
	Plant water	-9.41	2.67	-3.61	-0.88	-74.90	-29.39	-48.79	-0.23
	Groundwater	-10.34	-7.43	-8.88	-0.07	-71.67	-44.26	-55.12	-0.09

Table 2 Comparison of stable isotope of water in different vegetation zones

Table 3 Correlation between precipitation isotopes and different temperatures in different vegetation zones

Vegetation zone type	Correlation below 0°C (δ18O /δD)	Correlation between 0°C-8°C (δ18O /δD)	Correlation above 8°C (δ18O /δD)	Correlation during the study period
Alpine meadow	0.51*/0.59*	0.30*/0.24*	0.15/0.12	0.59*/0.61*
Forest	0.95*/0.94*	0.66*/0.69*	0.14/0.10	0.69*/0.65*
Arid foothills	0.47/0.51	0.79*/0.71*	0.31/0.14	0.83*/0.81*