Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 18 | No. 3 | pp. 825-833 | 2019

Original Research Paper | Open Access

Variations of Environmental Isotopes in Precipitation and Surface Water in Plain Area Influenced by Summer Monsoon: A Case Study in Jinjiang River Basin, Chengdu, China

Chengcheng Xia, Jie Mei, Wen Liu, Jing Zhou and Guodong Liu†
State Key laboratory of Hydraulics and Mountain River Engineering, Sichuan University, Chengdu, 610065, China
†Corresponding author: Guodong Liu

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 21-01-2019
Accepted: 08-04-2019

Key Words:
Environmental isotopes
Temporal-spatial variations
Monsoon activity
Water vapour source

ABSTRACT

Monsoon is a typical wind system, which influences a quarter of continental area on the earth and is closely bound up with the life of one half of the earth's population. Therefore, it is important to explore the information on monsoon activities. In the present study, samples of precipitation and surface water collected in the summer of 2018 were analysed to reveal the variation of stable isotopes influenced by summer monsoon and its relationship with the sources of water vapour. The temporal variation of stable isotopes in precipitation is great during the monsoon period, which is primarily the result of the varying proportions of water vapour from continental and oceanic sources. The heavy isotopes in precipitation grew gradually as the proportion of ocean-source water vapour increased from May to August. The meteorological parameters of temperature and precipitation amount are not the main factors that influence the isotopic composition in precipitation, for the determination coefficient (R^2 value) is low. The isotopic characteristics of river water are similar to those of precipitation, indicating that the rivers are mainly recharged by precipitation. The temporal-spatial variations of isotopes surface water are complex for the joint influence of the distribution of isotopes in precipitation, isotopic compositions of the river source, rainfall amount and evaporation, which can be considered as the indirect effects of monsoon activities.

INTRODUCTION

As an important natural tracer, environmental hydrogen and oxygen isotopes have been widely used in multidisciplinary research in recent years due to their unique physical and chemical properties (Martinelli et al. 2014, Yeh et al. 2014, Chang et al. 2016, Oyebanjo et al. 2018). In hydrological research, stable isotope technique has been used as a complementary tool, and played a significant role in the area of indicating the source of atmospheric precipitation, analysing the sources and components of surface water, tracking the water sources of plants, exploring the laws of groundwater movement, and indicating the sources and migration mechanisms of pollutants (Bowen et al. 2012, Li et al. 2014, Mezga et al. 2014, Balagizi et al. 2018, Ogrinc et al. 2018).

The research on environmental isotopes began in the 1960s. Since 1961, the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO) have jointly established the Global Network of Isotopes in Precipitation (GNIP), which has established more than 1,000 monitoring sites in 125 countries around the world to collect global-scale precipitation isotope samples and determine the spatial and temporal changes of stable isotopes and tritium isotopes in precipitation. Geographical location of the sites (i.e., longitude, latitude and elevation) and meteorological data (temperature, precipitation amount and water vapour pressure) have been recorded together. The monitoring data of GNIP are free for researchers around the world. Craig (1961) collected and analysed the hydrogen and oxygen stable isotope composition of more than 400 precipitation and surface water samples from around the world, and found the linear relationship between ^{2}H and ^{18}O. The equation of Global Meteoric Precipitation Line (GMWL) was first proposed as: $\delta^{2}H = 8\delta^{18}O+10$. Dansgaard (1964) proposed that the four factors affecting the stable isotope composition in precipitation are temperature, precipitation, elevation and distance from the sea. For the first time, the parameter deuterium excess (d-excess= $\delta D - 8\delta$), which was sensitive to the dynamic fractionation process of isotopes was defined. Since 1980s, with the improvement of instrumental analysis accuracy, the theoretical and applied research on hydrogen and oxygen stable isotopes has been rapidly developed, and the research object has expanded from precipitation to various water bodies. For example, Forstel & Hutzen (1983) obtained the regional distribution

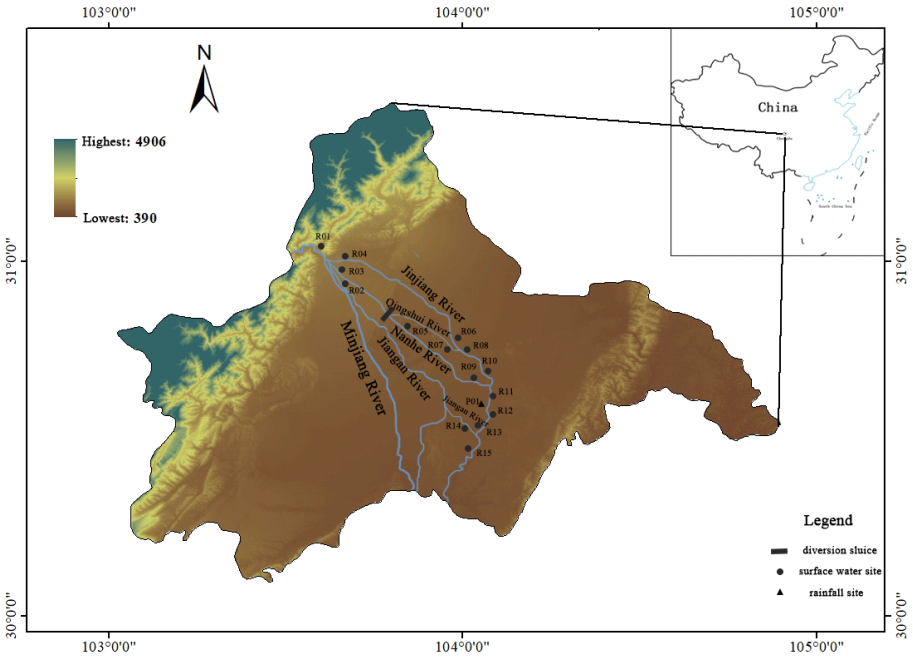

Fig. 1: Location and sampling sites in the Jinjiang River region.

characteristics of oxygen isotopes in groundwater in Germany by investigating the oxygen isotope ratio ($^{18}O/^{16}O$) in more than 900 groundwater samples and the main factors affecting the ratio were identified as the elevation and the distance from the sea. Kendall & Coplen (2001) collected more than 4800 river water samples at nearly 400 points across the United States during a three-year period, and the stable isotope distribution of the river water was analysed. Using the hydrogen and oxygen stable isotopes combined with soil water potential, Song et al. (2009) studied the migration mechanism of soil water in the unsaturated zone of the North China Plain and its impact on water distribution and circulation process. West et al. (2014) analysed the isotopic distribution characteristics of groundwater and tap water in South Africa and compared the differences in isotopic composition between groundwater, tap water and simulated precipitation based on the nearly 800 groundwater and tap water samples collected in South Africa. Xu et al. (2014) analysed the isotopic characteristics and dynamic processes of throughfall in two vegetation types in Adelaide, a coastal city of Australia, and compared the differences in the isotopic composition of throughfall and precipitation.

The variation of isotopes in natural water bodies is the result of a combination of equilibrium fractionation and kinetic fractionation, which depends on a variety of processes and factors, including the generation and transport of water vapour, climatic conditions at the source of water vapour, rainfall history during the water vapour transportation, and sub-cloud processes. In many previous studies, geographic location (longitude, latitude and elevation) and environmental variables (temperature, precipitation and relative humidity) have been shown to be strongly correlated with isotope changes at annual and seasonal scales. However, for monsoon climate regions where the direction of prevailing wind changes with seasons, the model of large-scale atmospheric circulation determines the source of water vapour, which in turn determines the basic composition of regional water isotopes.

Monsoon climate has a wide impact on the whole world. In the monsoon climate region, the spatial distribution patterns and seasonal distribution characteristics of precipitation are directly determined by the monsoon circulation. Precipitation is controlled by air masses from different directions in different seasons, carrying water vapour from different sources. Due to the complex climatic conditions of the sources of water vapour, stable isotopes tend to have large time and space changes. In abnormal years, extreme weather events such as floods and droughts will occur frequently, due to the change of precipitation pattern caused by monsoon activities. Therefore, it is of great significance to explore the relationship between isotope variations and monsoon activities for coping with droughts and floods and improving the predictive capabilities. Recently, many scholars have focused on the relationship between isotopic changes and water vapour sources in the monsoon region. For example, Qu et al. (2018) compared the characteristics of stable

Table 1: The geographic location of the sampling points (BC means "before confluence" and AC means "after confluence").

Number	Water Type	Location	Longitude (°E)	Latitude (°N)
R01	River water	Minjiang River	103.61	31.00
R02		Jiangan River(upstream)	103.62	31.00
R03		Nanhe River(upstream)	103.62	30.99
R04		Jinjiang River(upstream)	103.62	30.98
R05		Qingshui River(upstream)	103.86	30.79
R06		Jinjiang River(BC)	104.03	30.66
R07		Qingshui River(BC)	104.03	30.65
R08		Jinjiang River(AC)	104.04	30.66
R09		Nanhe River(BC)	104.08	30.65
R10		Jinjiang River(BC)	104.08	30.64
R11		Jinjiang River(AC)	104.09	30.64
R12		Jinjiang River (BC)	104.09	30.61
R13		Jiangan River(BC)	104.06	30.49
R14		Jinjiang River(BC)	104.05	30.49
R15		Jinjiang River(AC)	104.06	30.48
P01	Precipitation	Sichuan University	104.08	30.63

Table 2: Rainfall amount, number of samples and average values of precipitation isotopes from May to August, 2018.

Month	Rainfall Amount (mm)	Number of Samples	Arithmetic mean Value		Weighted Average Value		$\delta D_{(WA)}$-$\delta D_{(AA)}$	$\delta^{18}O_{(WA)}$-$\delta^{18}O_{(AA)}$
			δD	$\delta^{18}O$	δD	$\delta^{18}O$		
May	115.3	7	-39.8	-6.5	-37.3	-6.3	2.5	0.2
June	204.3	12	-54.7	-7.4	-63.7	-8.7	-9.0	-1.3
July	566.0	30	-85.2	-11.9	-86.0	-12.1	-0.8	-0.2
August	156.0	3	-78.6	-10.8	-81.2	-11.1	-2.6	-0.3

isotopes and d-excess in Hemuqiao watershed under the influence of typhoon and plum rain. Chengcheng et al. (2018) obtained the temporal and spatial distribution of stable isotopes in the tropical monsoon climate region of Asia, using the monthly precipitation data from the GNIP dataset. Guan et al. (2013) analysed the effect of synoptic weather system and water vapour source on d-excess in precipitation events in South Australia. For the same area, the isotopic compositions of different water bodies may be different. The isotopic variation of precipitation isotope is large and the isotopic characteristics of surface water can reflect the cumulative effect of precipitation isotopes on the seasonal scale. However, previous studies have mostly focused on precipitation samples on regional or continental scales, there have been few studies on the temporal and spatial variation characteristics and migration mechanisms of isotopes in precipitation and surface water in small basins. The accuracy of the isotopic space-time distribution model is limited by the insufficient density in space and the long interval in time. In this study, the study area was confined to a small basin on a city scale. During the monsoon period, continuous sampling and isotopic measurements of precipitation and rivers were carried out and the spatial and temporal characteristics of hydrogen and oxygen stable isotopes of two different water bodies were obtained. The relationship between sources and environmental variables and the isotopic compositions were also analysed. The obtained isotopic information would be useful to study the response of different water body isotopes to monsoon activity in the southwest monsoon region of China.

MATERIALS AND METHODS

Study area and sample collection: The study area is located in the Jinjiang River Basin in Chengdu, the capital of China's Sichuan Province, which is one of the largest city in western China, seated in the transition zone of the northwest Sichuan Plateau to the Sichuan Basin (geographical coordinates: 103.61°-104.10°E, 30.60°-31.00°N), with an altitude of 390-4906 m (Fig. 1). The Chengdu Plain is a subtropical monsoon climate zone with an annual average temperature of 16°C and an annual rainfall of about 1000 mm. The precipitation was concentrated from June to September. According to the long-term monitoring data from the Tianqi Website (https://www.tianqi.com/qiwen/city-chengdu-1/) and the data in 2018 from Chengdu Public Meteorological Service Website (http://pcc.scqx.gov.cn/sc_cd/fwcp/qhpj/), the precipitation and temperature distribution in Chengdu are shown in Fig. 2. Jinjiang River is a tributary

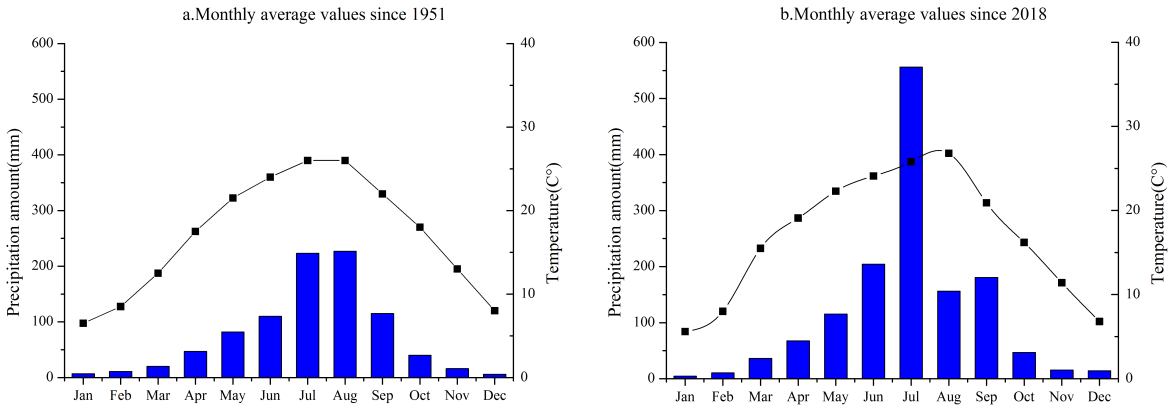

Fig. 2: Monthly values of average precipitation amount and daily average temperature in Chengdu. (a. data of long-term monitoring; b. data of 2018)

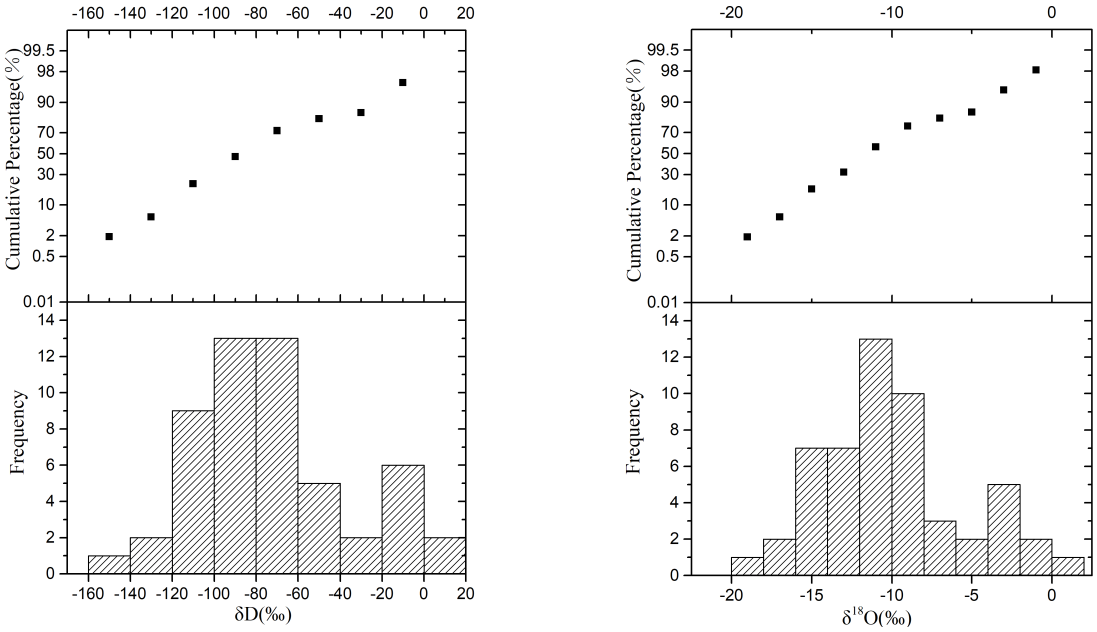

Fig. 3: Histograms, representing the frequency and cumulative percentage of δD and $\delta^{18}O$ in each range in precipitation samples of Chengdu.

of Minjiang River, which is an important upstream tributary of the Yangtze River. It is called the "Mother River" of Chengdu because it flows through the urban area of Chengdu, and is the main source of tap water for Chengdu for its good water quality.

Sampling of precipitation and surface water is carried out during May 2018 and August 2018. A sampling site for precipitation samples was set up in the testing ground of the College of Water Resources and Hydropower, Sichuan University. A rainfall event was sampled, when its hourly precipitation amount was greater than or less than 0.1 mm. The water collection device was made according to the method recommended in the IAEA/GNIP precipitation sampling guide (http://www-naweb.iaea.org/napc/ih/IHS_resources_gnip.html). There are 15 sampling points for surface water located in the upper, middle and lower reaches of the Jinjiang River, and the confluences between Nanhe River, Qingshui River and Jiangan River, which are also tributaries of Minjiang River, and Jinjiang River. The surface water sample was taken at the river bank, with a depth of more than 15 cm. After the river meets, it is sampled at the 1000 m downstream to ensure that the river water is fully mixed. A total of

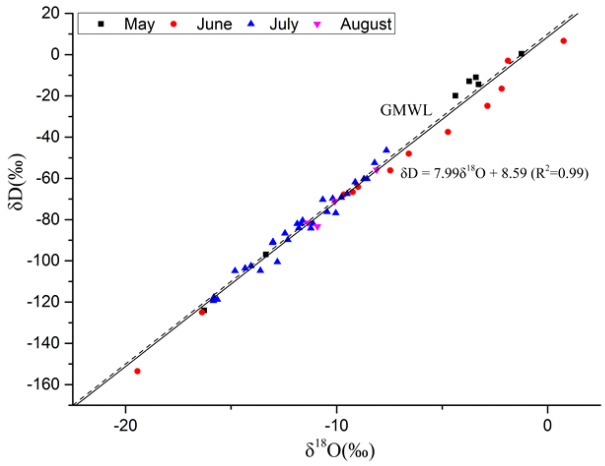

Fig. 4: Relationship between δD and $\delta^{18}O$ of precipitation samples during the study period.

9 sampling campaign were carried out, including 2 in May and June, 4 in July, and 1 in August. During the sampling processes, the sample bottle was washed 3 times with the water to be taken and then filled with water. All the samples were collected in a 20 mL white PE bottle, and the cap of bottle was sealed immediately after the sampled water was filtered twice with a 0.45 μm filter. The bottle mouth was wound with a PARAFILM sealing film to avoid bubbles, which may be a cause of evaporation. Geographic information for sampling points is shown in Fig. 1 and Table 1.

Stable isotopes analysis: Isotopic analysis of all water samples was performed at the Isotope Hydrology Laboratory of Sichuan University, using the T-LWIA-45-EP Triple-Liquid Water Isotope Analyser developed by Los Gatos Research (LGR). The measurement results are expressed as the thousand deviation of Vienna Standard Mean Ocean Water (V-SMOW), and the calculation formula is as follows:

$$\delta^{2}H_{sample}(‰)=\left(\frac{\left(^{2}H/^{1}H\right)_{sample}-\left(^{2}H/^{1}H\right)_{V\text{-}SMOW}}{\left(^{2}H/^{1}H\right)_{V\text{-}SMOW}}\right)\times 1000 \quad ...(1)$$

$$\delta^{18}O_{sample}(‰)=\left(\frac{\left(^{18}O/^{16}O\right)_{sample}-\left(^{18}O/^{16}O\right)_{V\text{-}SMOW}}{\left(^{18}O/^{16}O\right)_{V\text{-}SMOW}}\right)\times 1000 \quad ...(2)$$

The measurement accuracy is δD < 0.3‰, $\delta^{18}O$ < 0.08‰, and $\delta^{17}O$ < 0.08‰. In order to eliminate the effect of the sample memory effect, each sample was measured 6 times in the isotopic analysis, and the measurement data of the first two samples were removed, and the average values of the last four measurements were taken as the measured isotope value of the sample.

RESULTS AND DISCUSSION

Distribution characteristics of environmental isotopes in precipitation: During the study period, a total of 52 precipitation samples were recorded, and the histogram and cumulative percentage chart presenting the number and percentage of δD and $\delta^{18}O$ values of the samples in each interval are shown in Fig. 3. The δD value varies from -152.50‰ to 6.65‰, with the arithmetic mean of -71.35‰ (precipitation amount weighted average is -78.89), and $\delta^{18}O$ varies from -19.43‰ to 0.76‰, with the arithmetic mean of -10.01 ‰ (the precipitation amount weighted average is -11.11 ‰). During the study period, the summer monsoon prevailed, and the arithmetic mean and precipitation amount weighted average of δD and $\delta^{18}O$ of precipitation in Chengdu were significantly lower than those in the southeastern coastal areas of China (Liu et al. 2008), but higher than the northern inland regions (Wang & Wang 2001, Wen et al. 2010, Wu et al. 2010). This is because Chengdu is located in the southwest of China and is far away from the ocean. The tropical air masses, which are enriched in water vapour, are transported from the ocean to the inland by the monsoon. The precipitation continues to occur along the transporting path, resulting in the heavy isotopes in Chengdu being depleted than the southeast coast but enriched than the northern regions which are farther away from the sea.

Monthly variation rules of isotopes in precipitation during summer monsoon period: The average precipitation amount, number of samples and the arithmetic and precipitation amount weighted average of the isotopes in precipitation from May to August 2018 are given in Table 2. The monthly arithmetic mean and the weighted average of isotopes in precipitation are in the same order: July < August < June < May, indicating a significant difference in the source of water vapour for the precipitation of each month. In the monsoon climate zone far from the ocean, ocean-source water vapour is often depleted of δD and $\delta^{18}O$, while water vapour of high-latitude continental sources usually have higher isotopic values (Ren et al. 2017). Therefore, the order of the contribution rate of ocean-source water vapour to precipitation during the study period is: May < June < August < July. The absolute value of the difference between the weighted average and the arithmetic mean of the precipitation in June is significantly larger than other months, which is probably because there were more small precipitation events during this period. Being less affected by the "precipitation effect", the raindrops of small precipitation events are more susceptible to the sub-cloud processes. When the raindrops fall down from the cloud base, fractionation caused by evaporation occurs and the heavy isotopes are enriched. When calculating the arithmetic mean, each precipitation event

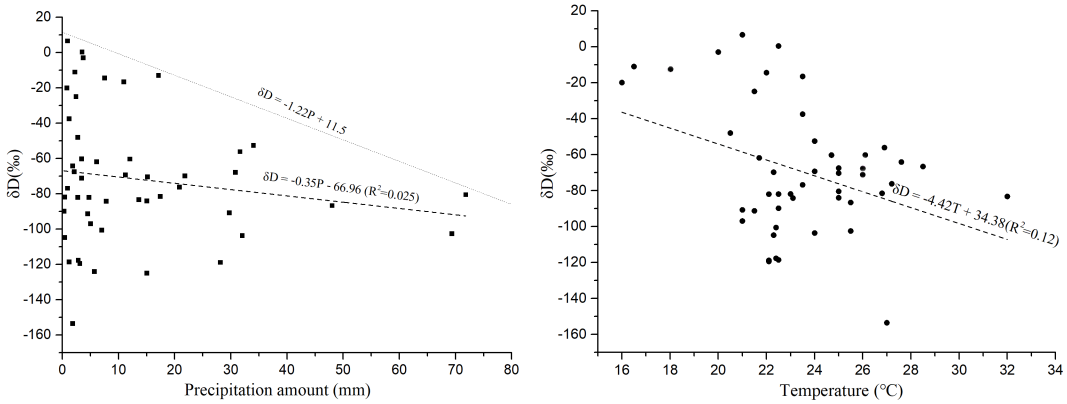

Fig. 5: The relationship between δD and meteorological parameters (precipitation amount and temperature).

has equal weight, which increases the influence of small precipitation events and the calculated values.

The seasonal variation of isotope values can reflect the water vapour source and climatic conditions in the study area. Based on the isotope data of precipitation samples, the relationship between δD and $\delta^{18}O$ of precipitation in Chengdu (Local Meteoric Water Line, LMWL) is plotted in Fig. 4. The equation is: δD = 7.99δ18O + 8.59, whose slope and intercept are close to the Global Meteoric Water Line (GMWL), indicating that the Chengdu Plain is mainly controlled by the ocean-source air masses, and the effect of evaporation is weak. During the study period, the maximum and minimum values of δD and $\delta^{18}O$ occurred in June, and the distribution range of precipitation isotopic values in June was the largest, followed by May. On the one hand, it indicates that precipitation has relatively complicated sources of water vapour in the June and May. The air masses from tropical ocean and the ones from inland areas compete with each other, and the dominant air masses change continuously, which makes the area alternately controlled by land-source water vapour and sea-source water vapour. On the other hand, temperature changes frequently in May and June, which caused more complicated fluctuations in stable isotopes in precipitation. Five of the seven precipitation events in May fall above GMWL, and the distribution is relatively concentrated, indicating that most of the precipitation air masses in May come from arid inland areas. Most of the isotopic scatter points in June fall below the GMWL, indicating that the sub-cloud processes have a great impact on precipitation isotopes during this period. In the landing processes of raindrops, the non-equilibrium fractionation occurs since the moisture in the atmosphere is unsaturated, causing the enrichment of ^{18}O and the depletion of d-excess. The scatter points in July and August are evenly distributed on both sides of the GMWL, indicating that the air masses from the ocean source are dominant. The air humidity is large in this period, and the evaporation is weak.

Correlation between meteorological parameters and isotopic composition: Precipitation and temperature have been proved to have impact of varying degrees on isotopic composition of local precipitation in many regions of the world. Since δD has a linear relationship with $\delta^{18}O$, and δD is more sensitive to environmental changes, we will discuss the correlation between meteorological parameters and δD in this chapter. As shown in Fig. 5, a linear regression equation with a very low R^2 value (0.025) between precipitation and δD was obtained: δD = -0.35P - 66.96, where P is the precipitation amount in mm. A weak negative correlation indicates that precipitation amount is not the main factor controlling the isotopic composition in Chengdu, especially for small precipitation events. However, the isotopic scatters of all precipitation samples fall below a straight line with a slope of -1.22 and an intercept of 11.5, indicating that the large precipitation events are less able to be enriched in the heavy isotopes than small ones.

The linear relationship between temperature and δD is plotted in Fig. 5. The regression equation is: δD = -4.42T + 34.38, with a low R^2 value of 0.12, and there is an inverse correlation between δD and precipitation. The result is contrary to the well-known "temperature effect" and may be related to the unique geographical conditions and meteorological characteristics of Chengdu. Chengdu has both continental and monsoon climatic characteristics. In May and June, the prevailing wind of Chengdu is in a transitional period from winter to summer. On the one hand, due to the strong surface evaporation, in the transporting process of land-source air masses, the contribution rate of recycled water vapour is large, leading to the enrichment in δD and $\delta^{18}O$ in water vapour. On the other hand, the low temperature occurs in May and June, and the air humidity is also

Table 3: The maximum, minimum and average isotopic value and the standard deviation of each sampling campaign of surface water (the number "20180506" in the column "date" indicates the sampling campaign was performed on May 6, 2018).

Data	δ(‰)				$\delta^{18}O$ (‰)			
	Maximum	Minimum	Average	Standard Deviation	Maximum	Minimum	Average	Standard Deviation
20180506	-74.4	-82.7	-79.4	2.7	-10.3	-12.1	-11.4	0.5
20180518	-67.2	-84.4	-76.2	7.0	-9.7	-11.8	-10.9	0.8
20180608	-38.6	-81.2	-59.1	16.5	-7.1	-12.2	-9.6	1.9
20180624	-78.8	-86.9	-84.3	2.4	-11.8	-13.0	-12.4	0.4
20180706	-81.8	-85.7	-84.0	1.3	-12.1	-13.0	-12.6	0.3
20180715	-72.7	-90.7	-83.9	6.3	-10.7	-13.3	-12.3	0.9
20180721	-72.1	-91.0	-79.3	5.0	-10.9	-13.2	-11.8	0.7
20180728	-81.5	-87.1	-86.0	1.8	-11.4	-13.1	-12.7	0.5
20180810	-79.3	-95.1	-86.1	5.4	-11.1	-12.7	-12.1	0.5

low during this period. The raindrops experiences the sub-cloud secondary evaporation during the landing process, which results in the enrichment of heavy isotopes.

Temporal and spatial variations of the environmental isotopes in surface water: According to the measurement results of surface water samples, the maximum, minimum, arithmetic mean and standard deviation of δD and $\delta^{18}O$ of the 9 sampling motions are given in Table 3, respectively. It can be found that the maximum values of δD and $\delta^{18}O$ in the river water samples are -38.6 and -7.1, respectively, which are both observed in the samples collected on June 8. The minimum values of δD and $\delta^{18}O$ are -95.1 and -13.3, occurring in samples collected on August 10 and July 15, respectively. The samples with the largest average value of δD and $\delta^{18}O$ were collected in June 8, and the ones with second largest were collected on May 18, indicating that the river water samples from mid-May to mid-June are more enriched in heavy isotopes compared with samples of other periods. The sample isotopes collected on May 18 and June 8 have the largest standard deviation, reflecting the great dispersion of river water samples between mid-May and mid-June. The average values of δD and $\delta^{18}O$ of river water samples collected from June 24 to August 10 are relatively close to each other except those collected on July 21, reflecting that the source of surface water is stable and the temporal variation of precipitation isotopes during this period is not too much. The isotopic mean values of the river water samples in July 21 are small, which is probably due to the large-intensity precipitation occurring before the sampling campaign, which contributed a lot to the water volume of river. Due to the precipitation effect, the heavy isotopes are depleted in precipitation during the period influenced by typhoon, resulting in the lower δD and $\delta^{18}O$ values in the river water. Except for the samples collected on July 15, the river water samples from June 24 to August 10 have a small standard deviation, indicating that the spatial distribution of river water isotopes is relatively uniform, which reflects that the spatial variation of precipitation isotopes during this period is small, and the effect of evaporation was small, too. The standard deviation of δD in the river water samples collected on July 15 is up to 6.3 ‰, and that of $\delta^{18}O$ is up to 0.9 ‰, and the difference between extreme values of δD and $\delta^{18}O$ is up to 18.9‰ and 2.6‰, respectively, indicating the spatial variation of surface water samples is very large. This may be due to the fact that Chengdu was affected by the super typhoon Maria during this period. The intra-regional difference of precipitation amount in this region was quite large, therefore, the spatial distribution of precipitation isotopes was uneven.

The monthly average values of δD and $\delta^{18}O$ in each river water sampling in the Jinjiang River Basin are shown in Fig. 6. It is obvious that for δD and $\delta^{18}O$, the samples with the largest fluctuation amplitude is June, followed by May. The spatial fluctuation of the isotopic composition of the samples in July and August is slight, which is similar to the variation characteristics of precipitation, indicating the isotopic variation of river water is largely affected by precipitation. In all the four months, the lower δD and $\delta^{18}O$ values are observed in the upstream sampling points (R1, R2, R3 and R4) of the Minjiang River, Jiangan River, Nanhe River and Jinjiang River, and the difference among them is small, which is probably because the distance between these four points is not far, and the river water all comes from the Minjiang River. The Minjiang River originates from the inland plateau with high altitudes and low temperature, and the concentrations of D and ^{18}O in meltwater and plateau precipitation are low. The four points have the same temporal relationship of isotopic values: May > June > July > August, reflecting the seasonal variation of precipitation isotopes in the upper reaches of the Minjiang River. In May, the region is controlled by the inland air masses, and the values of δD and $\delta^{18}O$ in the precipitation are most enriched. In

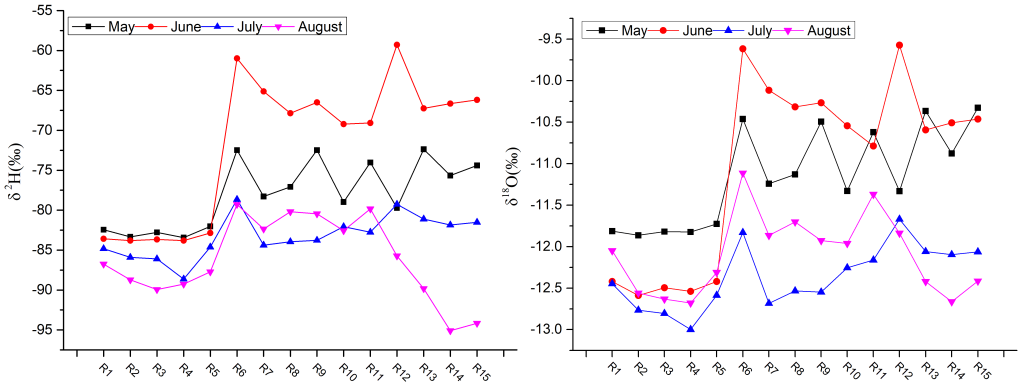

Fig. 6: Monthly average isotopic values of the surface water in Jinjiang River Basin.

June, the marine air masses and the inland air mass alternately control the area, and the isotopes show the characteristics of ocean-source water vapour to some extent and are thus depleted than those in May. In the month of July and August, the area was controlled by marine air masses and had a source of marine water vapour. Because of the remote distance from the sea, the precipitation was depleted in δD and $\delta^{18}O$. Among all the four months, the highest isotope values occur in the river water sample upstream of the confluence of Jinjiang and Qingshui River (R6), which is probably because the distance between the upper reaches of Jinjiang River and this site is long, and the riverbed is wide and the flow rate of river is relatively slow, resulting in a relatively strong evaporation fractionation as the water flew downstream, and heavy isotopic is enriched. Most sampling points in the middle and lower reaches of Jinjiang River and other rivers are enriched in heavy isotopes than the upper reaches, reflecting the influence of precipitation input on the spatial distribution of isotopes in surface water. The precipitation amount weighted averages of δD in May and June are -37.3 and -63.7, respectively, and those of $\delta^{18}O$ are -6.3 and -8.3. The heavy isotopes in May precipitation are more concentrated than June. However, in the upper reaches of the rivers, the isotopic values of samples collected in June are depleted compared to those collected in May, but enriched in the middle and lower reaches, indicating that the precipitation isotopes make greater influence on the river water isotopes in June than in May. This may be because the precipitation amount in June is much more than that in May, and the contribution rate of precipitation in June to river water is much higher than that in May.

CONCLUSION

To sum up, we confined the study area to a small basin on a city scale in this study. During the summer monsoon period in 2018, we sampled and measured the isotopes of surface water and precipitation, and analysed the variations of precipitation and surface water isotopes in the Jinjiang Basin. The results show that the isotopes of precipitation varied greatly during the study period, which was most enriched in May, and most depleted in July. This is mainly due to the changes of water vapour sources of precipitation influenced by prevailing wind of different directions. The contribution rate of ocean-source water vapour, which is depleted in heavy isotopes, to precipitation in June and August was large, and the contribution rate to precipitation in May and June was small. Isotopes in precipitation have the largest range of variations in June because of the complexity of the water vapour sources in this month, with inland air masses and oceanic air masses alternately controlling this area. The correlation between temperature and precipitation and precipitation isotope is small, indicating that these two variables are not the main controlling factors of precipitation isotope changes in Chengdu during the monsoon period.

The samples collected in surface water samples from May and June are enriched in heavy isotopes, and the isotopic compositions have large spatial fluctuations. The samples collected in July and August are depleted in heavy isotopes, and the spatial fluctuations are small. The characteristics of the variation are similar with precipitation, indicating that the river water is mainly recharged by precipitation, and the source of water vapour of the precipitation and the prevailing wind direction play a decisive role in the river water isotopes. The isotopic compositions of the sampling points in the upper reaches of each river reflect the isotope characteristics of the melt and precipitation in the upper reaches of the Minjiang River, with minor temporal changes. In addition, the spatial distribution differences of precipitation isotopes and precipitation amount have a non-negligible impact on the isotopic composition of surface water.

Compared with previous studies, this study has shortened the sampling period, reduced the spatial distances be-

tween the surface water sampling points, and investigated the response of different water bodies to atmospheric circulation systems in a small temporal-spatial scale. We expect that the results of this study will be demonstrated to contribute to the study of water cycle and climate change forecast in the southwest monsoon region of China.

ACKNOWLEDGEMENT

This study was supported by the research project from the National Natural Science Foundation of China (No. 41471084).

REFERENCES

Balagizi, C. M., Kasereka, M. M., Cuoco, E. and Liotta, M. 2018. Influence of moisture source dynamics and weather patterns on stable isotopes ratios of precipitation in Central-Eastern Africa. Sci. Total Environ., 628-629: 1058-1078.

Bowen, G. J., Kennedy, C. D., Henne, P. D. and Zhang, T. L. 2012. Footprint of recycled water subsidies downwind of Lake Michigan. Ecosphere, 3(6).

Chang, J. C., Shulmeister, J., Woodward, C. and Michalski, G. 2016. Can stable oxygen and hydrogen isotopes from Australian subfossil Chironomus head capsules be used as proxies for past temperature change? Journal Of Paleolimnology, 56(4): 331-348.

Chengcheng X., Guodong L., Jie M., Yuchuan M., Wen L. and Yue H. 2018. Characteristics of hydrogen and oxygen stable isotopes in precipitation and the environmental controls in tropical monsoon climatic zone. International Journal of Hydrogen Energy, 44(11): 5417-5427.

Craig, H. 1961. Isotopic variations in meteoric waters. Science, 133(346): 1702-1703.

Dansgaard, W. 1964. Stable Isotopes in Precipitation. Tellus, 16(4): 436-468.

Forstel, H. and Hutzen, H. 1983. Oxygen isotope ratios in German Groundwater. Nature, 304(5927): 614-616.

Guan, H., Zhang, X., Skrzypek, G., Sun, Z. and Xu, X. 2013. Deuterium excess variations of rainfall events in a coastal area of South Australia and its relationship with synoptic weather systems and atmospheric moisture sources. Journal of Geophysical Research: Atmospheres, 118(2): 1123-1138.

Kendall, C. and Coplen, T. B. 2001. Distribution of oxygen-18 and deuterium in river waters across the United States. Hydrological Processes, 15(7): 1363-1393.

Li, J., Li, F., Liu, Q. and Zhang, Y. 2014. Trace metal in surface water and groundwater and its transfer in a Yellow River alluvial fan: evidence from isotopes and hydrochemistry. Sci. Total Environ., 472: 979-988.

Liu, J. R., Song, X. F., Yuan, G. F., Sun, X. M., Liu, X., Wang, Z. M. and Wang, S. Q. 2008. Stable isotopes of summer monsoonal precipitation in southern China and the moisture sources evidence from delta O-18 signature. Journal of Geographical Sciences, 18(2): 155-165.

Martinelli, G., Chahoud, A., Dadomo, A. and Fava, A. 2014. Isotopic features of Emilia-Romagna region (North Italy) groundwaters: Environmental and climatological implications. Journal of Hydrology, 519: 1928-1938.

Mezga, K., Urbanc, J. and Cerar, S. 2014. The isotope altitude effect reflected in groundwater: A case study from Slovenia. Isotopes Environ. Health Stud., 50(1): 33-51.

Ogrinc, N., Kocman, D., Miljeviæ, N., Vreèa, P., Vrzel, J. and Povinec, P. 2018. Distribution of H and O stable isotopes in the surface waters of the Sava River, the major tributary of the Danube River. Journal of Hydrology, 565: 365-373.

Oyebanjo, O., Ekosse, G. I. and Odiyo, J. 2018. Hydrogen and oxygen isotope composition of selected Cretaceous and Paleogene/Neogene kaolins from Nigeria: Paleoclimatic inferences. Applied Clay Science, 162: 375-381.

Qu, S., Chen, X., Wang, Y., Shi, P., Shan, S., Gou, J. and Jiang, P. 2018. Isotopic characteristics of precipitation and origin of moisture sources in Hemuqiao catchment, a small watershed in the lower reach of Yangtze River. Water, 10(9): 1170.

Ren, W., Yao, T. D. and Xie, S. Y. 2017. Key drivers controlling the stable isotopes in precipitation on the leeward side of the central Himalayas. Atmospheric Research, 189: 134-140.

Song, X. F., Wang, S. Q., Xiao, G. Q., Wang, Z. M., Liu, X. and Wang, P. 2009. A study of soil water movement combining soil water potential with stable isotopes at two sites of shallow groundwater areas in the North China Plain. Hydrological Processes, 23(9): 1376-1388.

Wang, D. S. and Wang, K. 2001. Isotopes in precipitation in China (1986-1999). Science in China Series E-Technological Sciences, 44: 48-51.

Wen, X. F., Zhang, S. C., Sun, X. M., Yu, G. R. and Lee, X. 2010. Water vapor and precipitation isotope ratios in Beijing, China. Journal of Geophysical Research-Atmospheres, 115.

West, A. G., February, E. C. and Bowen, G. J. 2014. Spatial analysis of hydrogen and oxygen stable isotopes ("isoscapes") in ground water and tap water across South Africa. Journal of Geochemical Exploration, 145: 213-222.

Wu, J. K., Ding, Y., Ye, B., Yang, Q., Zhang, X. and Wang, J. 2010. Spatio-temporal variation of stable isotopes in precipitation in the Heihe River Basin, Northwestern China. Environmental Earth Sciences, 61(6): 1123-1134.

Xu, X., Guan, H. and Deng, Z. 2014. Isotopic composition of throughfall in pine plantation and native eucalyptus forest in South Australia. Journal of Hydrology, 514: 150-157.

Yeh, H.F., Lin, H.I., Lee, C.H., Hsu, K.C. and Wu, C.S. 2014. Identifying seasonal groundwater recharge using environmental stable isotopes. Water, 6(10): 2849-2861.