Characteristics of Hydrogen and Oxygen Stable Isotopes of Different Water Bodies in Peixian Coal Mining Subsidence Area in Jiangsu Province, China

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Abstract. As a result of long-term well mining activities, a large area of coal mining subsidence has formed in the mining area in Peixian County, Jiangsu province, an important energy base in eastern China. This subsidence filled by water made the local water cycle become more complicated and severe geological hazards easy to occur. Oxygen-stable isotope, playing an important role in the study on water-cycle mechanism, is a substantial way to track different sources of water in nature. In this study, we took samples from different water bodies of soil water, the surface waters (river, lake and collapse pit) and the groundwater (well water) seasonally in a year. The analyses of $\delta^D$ and $\delta^{18}O$ were further conducted to trace the transforming relationships between these water bodies. The findings are as follows: (i) precipitation is the main charge source of soil water, along with significant evaporation processes; (ii) with soil depth increasing, $\delta^D$ and $\delta^{18}O$ of soil water showed a trend like that first decreasing to a certain value and then stabilizing and finally increasing to the bottom of soil profile; (iii) when the reclamation soil experienced longer time, the values of soil water $\delta^D$ and $\delta^{18}O$ increased in the whole profile, and this character was more obvious in deeper layers than in shallower and in surface layers; (iv) indicated from the isotopic characters of different water bodies and precipitation that precipitation was the main source of recharge of collapse pit water, and the infiltrated soil water and ground water experienced mixing with river water and precipitation by the water pathways conducted through the entire Cenozoic coal seam by mining.

1. Introduction
Owing to stable water isotopes are very sensitive to water environments, $^1\text{H}^{16}\text{O}$ and $^1\text{H}^{18}\text{O}$, the composition of oxygen and hydrogen elements of water have been approved to be good tracers for water transition processes[1]. Isotopic fractionation occurs during evaporation and condensation processes in water cycle, the characteristics of $\delta^D$ and $\delta^{18}O$ from different water bodies, such as atmospheric water vapor, precipitation, surface waters, soil water and groundwater can be consequently used to trace recharge sources, migration path and retention time of water bodies[2]. Research on stable isotope technology research started from 1961, and the Global Network of Isotopes in Precipitation (GNIP) has been established (currently there are over 800 sampling stations in the world) under the co-sponsorship of the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO). Based on these monitoring data sets from the GNIP, Dansgaard[3] analyzed the temporal and spatial characteristics of stable isotopes in precipitation globally, and put
forward the concepts of temperature effect, precipitation effect and excessive deuterium. So far in China, a number of researches have been carried out in different areas, such as the Qinghai-Tibet Plateau, the Loess Plateau, the southwestern region, the eastern monsoon region, the Urumqi basin, and the Inner Mongolia’s Hetao Plain. However, there are few researches on characteristics of hydrogen and oxygen stable isotopes of different water bodies in coal mining subsidence reclamation area, for example, Lei Zhang et al. (2015)[4] analyzed the source of different water bodies in the subsidence of Huainan coal mining area through hydrogen and oxygen stable isotopes techniques, Junjie Liu et al.(2009)[5] and Tao Ge et al.(2014)[6] made use of the stable hydrothermal isotopes to trace deep groundwater sources in mining areas.

China, as a large coal production country, accounting for half production over the world[7]. Coal mining often leads to the surface deformation and forms a large elliptical subsidence, inducing the destruction of original cultivated land, the disturbances of surface water systems, potential geological hazards and so on, which can pose a serious and negative impacts on local people’s economics and life. As a large subunit of the China Coal Group, the Datun Coal Electricity Company, located at Weishan Lake at the junction of Jiangsu and Shandong provinces, covering area of 245 km², outputs 9,055,900 tons of raw coal and 3,906,700 tons of cleaned coal a year. Long-term coal mining activities have led to severe and contiguous surface subsidence in the large-scale coal mining area, forming a large area of water.

Aiming to make up for the inadequate research on the characteristics of hydrogen and oxygen stable isotopes for the mining areas in China, and to find out the relationships between the different water bodies and the impact of the time of after reclamation activity on the characteristics of hydrogen and oxygen stable isotopes in the mining areas of Peixian county, this study analyzed and tracked the sources of subsidence pit water in the research mining-areas of Longdong Coal Mine, Yaoqiao Coal Mine, Xuzhuang Coal Mine, Kongzhuang Coal Mine in the western part of Weishan Lake in Xuzhou, Jiangsu province. We took samples from the farmland soil water of with varied reclamation years, using a “space replacing time” method, and then analyzed the characteristics of hydrogen and oxygen stable isotopes to detect the impacts of different reclamation years on the characteristics of soil water hydrogen and oxygen stable isotopes. We also measured and compared the isotope characteristics of precipitation, surface waters (river, lake, and subsidence pit water) and groundwater to explore the relationship among these water sources.

2. Research Area Overview

The study area (116.8°E, 34.9°N, Figure 1), located in the western part of Weishan Lake, belongs to the warm temperate zone and semi-humid monsoon continental climate with characteristics of hydrothermal synchronization. Its multi-year average annual temperature is 13.7°C, with the minimum and maximum monthly mean temperature of 0.4°C in January and 27.1°C in July. The muti-years average annual total precipitation is 760 mm, with characteristics of extremely uneven distribution (about 60% in summer and only 5% in winter). The muti-years average wind speed is 2.7 m/s~3.8 m/s, with dominant wind direction from southeast wind and secondary wind direction from northwest in winter. A network of waterways developed well with shallow groundwater and porous alluvial soil type which is suitable for cultivation.

There are several coal mining areas. The Longdong coal mining area located at Longgu Town, which annual production was 1.2 million tons and was put into operation from 1987; the Yaoqiao coal mining area located at Yangtun Town on the western of Weishan Lake was put into operation in 1976 with geological mine reserves of 540 million tons and original designed reserves of 1.2 million tons, and in 1990, it was reconstructed to extend its production capacity of reaching to 360 million tons, which made it to be the largest mining area in Jiangsu Province. The Datun coal mining area, as one of the earliest mining area located at Datun in Peixian County, was put into operation in 1979 with annual designed production of 900,000 tons, actually from 1980 to 2004, the total production of raw coal in this mine was 21.926 million tons. The Kongzhuang coal mining area, located at the southernmost part of
Datun town, covering an area of approximately 570,000 square meters, with annual production capacity of 1.05 million tons.

![Location of the study area](image)

**Figure 1.** Location of the study area

### 3. Sampling and Experimental Methods

#### 3.1. Sampling Methods

3.1.1. **Sampling of precipitation.** During experimental period, precipitation was collected by precipitation collector which was placed on sample plot randomly. Precipitation was collected in a standard rain bucket, and a round funnel was installed above it to collect rain or snow, with a ping pong ball above the funnel mouth to avoid losses of experimental accuracy that evaporation could occur. The collected, precipitation was re-filled to a 30-ml plastic centrifuge tube and sealed with parafilm making sure no air leaching. The tubes were stored in a refrigerator keeping temperature at 4 degrees immediately to prevent moisture from evaporating. By the way, if there were two precipitation samples one day, the averaged value of these two samples was taken as the stable isotope ratio of precipitation on that day. In total, 38 precipitation samples were collected during the study period.

3.1.2. **Sampling of soil.** According to the method of “space instead of time”, this study conducted sample collection from the reclaimed plots with 0, 1, 2, 3, 4, 5, 9, 10 and 12 years old, as well as one from no-reclaimed plot and one from no-collapsed plot for comparison purpose. The field sizes of these reclamation series were 4.4689, 4.1354, 4.2688, 4.7357, 4.6023, 4.4022, 4.8691, 4.3355, 4.5356, 4.0687 and 4.6690 Mu (Mu = 0.0667 hectares). 3 plots were randomly distributed on each plot, and the soil samples were collected at the depth of 0-100 cm soil profile with 10 cm intervals, which were sealed in bags for a physical and
chemical properties analysis and for isotope analysis. Totally, 300 soil samples were collected.

3.1.3. Sampling of the surface waters (river, lake, and subsidence pits) and groundwater (well water). Water samples from river and subsidence pit were taken a few centimeters below the surface to ensure the sampled river water being fully mixing and no isotope fractionation impaction by the possible surface water evaporation. One part of the sampled water was sealed in centrifuge bottles (30 ml) for isotope analysis, and the other part was stored in polyethylene bottles (100 ml) for physico-chemical properties analysis. The sampling method groundwater was same as the surface water. Total 58 water samples were collected.

3.2. Experimental Methods
All samples were processed and analyzed in the Isotope Analysis Laboratory, China University of Mining and Technology.

(1) Soil moisture extraction
Based on the theory of vacuum distillation, the L1-2000 vacuum distillation device for plants and soil moisture was used to extract soil moisture, the extraction time was at least 2 hours long to ensure soil moisture was entirely extracted to avoid experimental errors from incomplete extraction. In addition, the extraction process was conducted once more time in the case of the amount of extracted water was less than 1 ml).

(2) Liquid water analysis
In this study, the LGR908-0008 Liquid Water Isotope Analyzer was used to detect the content of $\delta^2$D and $\delta^{18}$O. As for the precision of this instrument, $^{18}$O/$^{16}$O and D/H are above 0.1‰ and above 0.3‰, respectively.

4. Results and Discussion

4.1. Isotopic Composition in Precipitation
As shown in Figures 2 and 3, precipitation was the main source of soil water, surface waters (river, lake and collapse pit), and underground water (well water). Analysis of $\delta^2$D and $\delta^{18}$O in precipitation is the basis for studying on the interaction between different water bodies. Tab. 1 shows that the value of $\delta^2$D in precipitation ranged from -92.5‰ to -3.5‰, with average of -50.0‰ and standard deviation of 0.43‰; the $\delta^{18}$O ranged from -13.1‰ to -2.1‰, with average of -7.96‰ and standard deviation of 0.32‰; the value of d-excess ranged from -2.25‰ to 29.29‰, with average of 13.62‰ and standard deviation of 0.5. Table 1 also shows the seasonal variation of $\delta^2$D, $\delta^{18}$O that higher isotopic values were found in winter, whereas lower values in summer in general. There are two main factors can be attributed to this trend as follows: (i) On a large scale, isotopic fractionation caused by the source of vapor as well as transportation process while vapor transferring. Our study area is located in the east part of China, which is affected by monsoon severely. During summer monsoon, maritime air mass often condenses into rain times as it goes inland, which depletes the content of heavy isotope. Consequently, the values of $\delta^2$D and $\delta^{18}$O in precipitation in the research area were lower. By contrast, during winter monsoon, continental air mass carried by westerly zone was dry and cold. Besides, the atmosphere during this season was stable and this makes it hard to form rain which causing isotopic fraction. Therefore, a small amount of heavy isotope depletes in winter; (ii) regional factors were also responsible for this trend, including temperature, rainfall, relative humidity. It is found that temperature was low in winter and spring while higher in summer and autumn, and rainfall mainly occurred in summer (from June to August. The values of $\delta^2$D and $\delta^{18}$O of precipitation in summer were lower than those in winter, indicating the isotope fractionation effects of rainfall and of converse temperature. Similar phenomenon was also seen in other monsoon areas, such as Yunnan[8], Nanjing[9]and Xiamen[10]. Different results were also reported by Vodila[11], Fadong Li[12], Catherine E[13], Congjian Sun[14]because of different atmospheric circulations in their research areas.
Figure 2. Characteristic distribution of δD and δ18O of rainwater, mining subsidence cracks and underground water

Table 1. Seasonal variability of δD, δ18O and d-value in precipitation

| Date       | δD(‰)  | δ18O(‰) | d-excess(‰) | Date       | δD(‰)  | δ18O(‰) | d-excess(‰) |
|------------|--------|---------|-------------|------------|--------|---------|-------------|
| 2016.11.7  | -56.46 | -9.44   | 19.08       | 2017.7.15  | -66.19 | -10.22  | 15.61       |
| 2016.11.9  | -4.58  | -1.17   | 20.79       | 2017.7.26  | -52.65 | -7.18   | 4.83        |
| 2016.11.22 | -73.96 | -11.54  | 18.38       | 2017.8.2   | -92.53 | -13.05  | 11.87       |
| 2016.12.1  | -42.94 | -7.05   | 13.43       | 2017.8.7   | -30.32 | -5.49   | 13.57       |
| 2016.12.21 | -70.37 | -9.22   | 3.4         | 2017.8.12  | -45.73 | -6.83   | 8.9         |
| 2016.12.25 | -31.79 | -7.25   | 26.22       | 2017.8.18  | -60.05 | -8.36   | 6.83        |
| 2017.1.6   | -49.59 | -8.77   | 20.59       | 2017.8.19  | -60.07 | -8.41   | 7.17        |
| 2017.1.7   | -52.18 | -8.77   | 17.98       | 2017.8.29  | -31.36 | -6.26   | 18.7        |
| 2017.1.29  | -13.33 | -5.1    | 27.45       | 2017.8.3   | -46.53 | -7.69   | 15          |
| 2017.1.31* | -51.79 | -8.07   | 12.74       | 2017.9.3   | -76.22 | -11.28  | 13.99       |
| 2017.2.8*  | -47.1  | -8.39   | 20.03       | 2017.9.4   | -41.95 | -7.09   | 14.73       |
| 2017.4.9   | -19.11 | -2.11   | -2.25       | 2017.9.6   | -86.12 | -12.19  | 11.41       |
| 2017.5.3   | -3.5   | 2.45    | 16.13       | 2017.9.25  | -68.17 | -9.85   | 10.66       |
| 2017.6.5   | -13.95 | -5.4    | 29.28       | 2017.9.26  | -63.37 | -8.8    | 7.06        |
| 2017.6.1   | -26.59 | -5.21   | 15.13       | 2017.9.3   | -76.62 | -11.16  | 12.63       |
| 2017.6.23  | -55.9  | -7.35   | 2.92        | 2017.10.4  | -37.46 | -5.41   | 5.82        |
| 2017.7.6   | -68.34 | -10.54  | 15.96       | 2017.10.5  | -34.57 | -6.07   | 13.96       |
| 2017.7.7   | -56.52 | -7.93   | 6.94        | 2017.10.1  | -53.46 | -9.38   | 21.54       |
| 2017.7.13  | -73.1  | -10.42  | 10.26       | 2017.10.11 | -67.16 | -9.51   | 8.94        |

Figure 3. Variations in d-value of precipitation
The phenomena of d-excess reflect the thermodynamic condition and vapor equilibrium state when the precipitation vapor forms [15], and also reflect their climatic conditions and geographic characters where precipitation forms. Kinetic fraction intensifies evaporation under arid conditions, this would increase the value of d-excess in precipitation [16]. For example, the d-excess value exceeds 10‰ in Koster (1993) [17], Gat (1994)[18] and Machavaram’s [19] studies, and this suggests that evaporation plays an important role in regional water cycle. The distribution of d-excess for a year round sampling in this study can be seen in Figure 3 which presents the values of d-excess vary from -2.25‰ to 29.3‰, with average value of 13.6‰, which is well high compared to the global weighted mean d-excess of +10‰[20]. Among these 38 precipitation samples collected during the study year, 6 and 28 samples had d-excess values above 20‰ and 10‰, respectively, suggesting that evaporation was very important in the study area. There were 26 samples collected during May to October (warm half year), their average value was 12.15‰, and of which 17 samples’ d-excess >10‰ and 9 samples’ d-excess <10‰.

One thing should not be ignored that the value of d-excess should be less than 10‰ during the warm half year considering the study area is located in the eastern monsoon region which is affected by summer monsoon. However, the higher value of d-excess occurred many times in our precipitation samples, which may be attributed by the strong evaporation fractionation caused by regional evaporation and long-distance transportation from lower latitudes to the study area. The mean value of d-excess is 16.46‰ during the cold half year, especially in January and February when the value reached 20‰. The high value of d-excess may be due to the non-equilibrium evaporation caused by the vapor transport process and secondary evaporation in winter when the weather was rather dry[21]. This research result coincides with theirs’, i.e. Huawu Wu[22], Zongxing Li[23], and J Wu’s[24].

The relationship between δD and δ18O is defined as local water meteoric water line (LWML) which is useful for analyzing physical geography, meteorological condition, historical climate, and the sources of vapors[25]. In 1961, Craig[26] proposed a global meteoric water line (GMWL) at the first time when he found the linear relation between δD and δ18O during reaching precipitation in North America. GMWL can directly reflects the non-equilibrium extend of evaporation and condensation in precipitation, this line has been consequently widely used in analyzing regional geography, climatic conditions and interactions between different water bodies. We can see from Figure 2 that the local LMWL is δD = 8.11δ18O+14.48 (R2=0.9). Obviously, the values of both the slope and intercept of the LMWL were higher than that of the global GMWL. This is because under the Rayleigh isotope fractionation condition, the fractionation rate of δD is eight times higher than δ18O, and this rate increases with lower air temperature. Owing to the characteristics of moist and rainy in the study area and air temperature is lower when condensation and the secondary evaporation is not weak, leading to higher values of slope and intercept of LWML. LWML in the study area was similar to those areas, such as Tengchong [27], Changsha[28], Yichang29, Guilin[30] because of these areas have similar water sources, climatic characters, and the influence of monsoon. In addition, the LMWL line of cold half year (May to October, δD =7.34δ18O+11.61, R2=0.85) and of warm half year (November to April in the next year, δD = 8.33δ18O+15.01, R2=0.93) were quite different: the values of the slope and intercept of LWML were higher in the warm half year than those in cold half year, which is attributed from different monsoon in the different seasons (marine vapor is the main source in the warm half year while continental air mass prevails in the cold counterpart).

4.2. Isotopic Composition in Soil Water with Different Reclamation Ages

Soil water links the surface water, groundwater and plant water in the atmosphere-soil-plant system. Table 2 shows the δD and δ18O characteristics of soil moisture at different soil depths. It shows that the values of δD and δ18O with different reclamation ages ranged from -92.03‰ to -43.26‰ and -13.13‰~5.56‰, with average of -13.13‰ and -8.93‰ and standard
deviation of 0.16‰ and 0.17‰. The values of mean and standard deviation of δD and δ18O in soil moisture were much lower than that of δD and δ18O in atmospheric precipitation of -50.00‰ and 0.43‰, -7.96‰ and 0.32‰, respectively. The characteristics of soil moisture with lower negative values of δD and δ18O and low standard deviation values reflects that the soil moisture was not purely from the precipitation in the current season but affected by mixture of old soil water with previous precipitation. From figure 4, it can be seen that the δD and δ18O values of soil water were mostly at the right-bottom of the local atmospheric water line, indicating that precipitation was the recharge source of soil water. The linear regression relationship between δD and δ18O of soil water is δD = 6.34 δ18O+8.31 (R²=0.95, n=210), and the values of slope and intercept are both lower than that of LMWL, with an average d-excess of 6.53‰ which is lower than the global average of 10‰. This suggests that soil water experienced evaporation and fractionation during infiltration process, which was mainly related to the dry season with drought and low air humidity during the study period.

As a result of precipitation infiltration, surface water evaporation, soil texture, soil moisture content and other factors, the values of δD and δ18O of soil water at different soil depths follow a certain pattern, indicating the degree of soil water affected by infiltration and evaporation[31]. Due to the interactions between environment and the human activities, there were poor regularity and significant fluctuation of water isotopes for the surface soil. There was a decreasing trend in δD and δ18O from the soil surface to 40cm depth. The effects on δD and δ18O by evaporation decrease with soil depth following the principle of Rayleigh fractionation principle that heavy isotopes would be enriched in the surface soil water. Below the depth of 40 cm, the values of δD and δ18O were fluctuated with an increasing trend in general with increasing depth, which is in the line with the findings of Chung[32] and Bristow[33]. This may be mainly because of the shallow groundwater containing high δD and δ18O content, and steady groundwater environment with weak disturbance and mixing of deep soil water and groundwater. It is noteworthy that the average values of δD and δ18O are -67.42‰ and -9.19‰ at the depth of 0-10 cm, and -64.08‰ and -8.76‰ at the depth of 50-100 cm, which is inconsistent with the results of Zimmermann et al[34] and Barnes et al[35]. This inconsistency may be mainly because their study areas and sampling frequency are different from this research. Their research area is in arid and semi-arid regions which are dry and with small amount of precipitation, precipitation is solely recharge source for soil water but is strongly affected by evaporation, while this study area is located along the Weishan lake with a humid climate. The comparatively low air temperature in the study area led to weak evaporation fractionation of δ18O at the depth of 50-100 cm, the enrichment of δ18O in soil water is not obvious compared to the δ18O. The value of δ18O of subsidence pit water was higher (average value of -5.56‰) than that of other surface waters. Located at the subsidence region of western coal mining area in Weishan lake, the study region experienced surface deformation and collapse as a result of long-term mining activities. The subsidence pits were recharged by precipitation, surface runoff and water from river and lake nearby for a long time, water gradually accumulated in the pits. And unlike flowing state of rivers, the subsidence pit is a relatively closed area, leading to weaker evaporation and fractionation[36]. The reclamation of soil cover on these subsidence pits made the subsidence pit water as a part of groundwater, therefore the δ18O value of groundwater increased. The variations in the δ18O content of soil water of with different reclamation periods ages varies were more obvious in the shallow and deep layers much more than in the middle layers, owing to obvious mixing effect and a combined influence of attributed from infiltration of precipitation, accumulated water in subsidence pit, upward groundwater and water taken by plant root.

As discussed above, soil moisture transportation, affected by many factors, is a very complicated physical-chemical process. And the surface soil is prone to be affected by other factors including human activities. However, below the depth of 60cm, the values of δD and δ18O of soil water tended to increase with longer reclamation period (Fig. 5). This is because the fractionation effects of evaporation and other processes (i.e. infiltration) became stronger
as the reclamation time was getting longer. According to the theory of isotope fractionation, lighter isotopes evaporate preferentially from the soil, leaving the heavier isotopes, allowing the fact that the longer the reclamation time, the greater the $\delta D$ and $\delta^{18}O$ content of soil water.

Table 2. Stable isotope values of soil water at different depths

| Depth/cm | N   | $\delta D$ %o | $\delta^{18}O$ %o |
|----------|-----|---------------|------------------|
|          | Max | Min | Average | Sd  | Max | Min | Average | Sd  |
| 0-10     | 33  | -55.23 | -92.03 | -67.42 | 0.15 | -12.44 | -9.19  | -9.19 | 0.18  |
| 10-20    | 33  | -48.13 | -80.35 | -68.11 | 0.13 | -11.14 | -9.29  | -9.29 | 0.15  |
| 20-30    | 33  | -48.83 | -84.44 | -68.09 | 0.13 | -13.13 | -9.60  | -9.60 | 0.16  |
| 30-40    | 33  | -46.30 | -74.77 | -62.86 | 0.15 | -10.64 | -8.78  | -8.78 | 0.17  |
| 40-50    | 33  | -43.36 | -73.08 | -62.59 | 0.12 | -10.53 | -8.65  | -8.65 | 0.13  |
| 50-60    | 33  | -47.08 | -86.37 | -63.78 | 0.17 | -11.56 | -8.90  | -8.90 | 0.17  |
| 60-70    | 33  | -43.91 | -77.20 | -60.86 | 0.14 | -10.74 | -8.43  | -8.43 | 0.15  |
| 70-80    | 33  | -46.53 | -87.35 | -68.58 | 0.16 | -12.25 | -9.34  | -9.34 | 0.17  |
| 80-90    | 33  | -45.37 | -78.71 | -63.52 | 0.18 | -11.19 | -8.59  | -8.59 | 0.17  |
| 90-100   | 33  | -43.26 | -82.51 | -63.64 | 0.19 | -11.29 | -8.55  | -8.55 | 0.18  |

Figure 4. Characteristic distribution of $\delta D$ and $\delta^{18}O$ of soil water

Figure 5. Soil water $\delta^{18}O$ profiles with different reclamation ages

4.3. Analyses $\delta^{18}O$ and $\delta D$ for Surface Waters (River, Lake and Collapse Water) and underground Water (Well Water)

$\delta D$ in river and lake varied from -53.41%o to -39.72%o, with mean value of -48.53%o, the values of $\delta^{18}O$ varied from -6.69%o to -5.67%o, with mean value of -6.09%o; the values of $\delta D$ in collapse water varied from -47.85% to -30.79%o, with mean value of -44.23%, the values of $\delta^{18}O$ ranged from -6.35%o to -7.59%o, with mean value of -5.56%o. The values of $\delta D$ of underground water (well water) varied from -56.60%o to -50.58%o, with mean value of -53.59%o, the values of $\delta^{18}O$ of underground water varied from -7.88%o to -7.59%o, with mean value of -7.64%o. All isotopic values of above mentioned water bodies fall on the right-side of the LMWL, indicating that they all received the recharge of rain with isotopic fractionation by evaporation which made higher values of $\delta D$ and $\delta^{18}O$ during the recharging processes. The values of $\delta^{18}O$ and $\delta D$ in the collapse water were higher and distributed more distractedly compared with other water bodies. Besides, the values of $\delta^{18}O$ and $\delta D$ of several river and lake water bodies are closely to that of collapse water, suggesting that the river and lake would also be the source for the collapsed pit water. The values of $\delta^{18}O$ and $\delta D$ for most of underground water samples are close to that of precipitation, and this is because that it receives recharge of rainfall. In addition, part river and lake samples have similar $\delta^{18}O$ and $\delta D$ with underground water. Therefore, it is concluded that regional cracks are likely to connect surface water and ground water in the form of infiltration of surface water.
5. Conclusion
Based on the analyses of $\delta^{18}D$ and $\delta^{18}O$ for different water bodies in Xuzhou collapse area, we draw conclusion as follows:
(i) The values of $\delta^{18}D$ and $\delta^{18}O$ of different water bodies had an overall seasonal pattern with higher values in winter while with lower values in summer. The LMWL line for the study area was that, $\delta^{18}D = 8.11 \delta^{18}O + 14.48$ ($R^2 = 0.9$). The values of the slope and intercept of LMWL were bigger than the global GMWL, indicating the local humid weather pattern.
(ii) Almost all $\delta^{18}D$ and $\delta^{18}O$ values fall on the right side of the LMWL, which reflects the effects of evaporation during replenishment course of precipitation. The values of $\delta^{18}D$ and $\delta^{18}O$ of soil water at the upper part of soil profile (0-40 cm) decreased with depth, and then increased with depth below 40cm and remained stable to 100cm depth. The variations in the upper and bottom soil profile were larger than that in the middle. In addition, the overall values of $\delta^{18}D$ and $\delta^{18}O$ of soil water samples show an increased trend with the increase in reclamation age because of the increasing in isotopic fraction effect by evaporation.
(iii) Almost all values of $\delta^{18}D$ and $\delta^{18}O$ of river, lake, collapse water and underground water (well water) also fall on the right side of LMWL, indicating that precipitation was the main source of above water bodies. Some samples from lake and river have similar values of $\delta^{18}D$ and $\delta^{18}O$ to that of collapse water, indicating that the lake and river replenish the collapse counterpart. In addition to this, similar hydrogen and oxygen isotope characteristics between river, lake and underground water suggests that the surface waters were likely to have connection with ground water in the form of surface water infiltration through cracks in the study area between river, lake and underground water.

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