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RESEARCH ARTICLE

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The impact of natural vegetation restoration on surface soil moisture of secondary forests and shrubs in the karst region of southwest China

Jia Chen[1,2] | Lin Zhang[1,2,3] | Xianli Cai[1,2,3] | Weijun Luo[1,2] | Yina Lyu[1,2] | Anyun Cheng[1,2] | Shijie Wang[1,2]

[1]State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, China
[2]Puding Karst Ecosystem Research Station, Chinese Academy of Sciences, China
[3]University of Chinese Academy of Sciences, Beijing, China

Correspondence
Weijun Luo, State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, 550081, China.
Email: luoweijun@vip.gyig.ac.cn

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Abstract

Soil moisture is crucial to vegetation restoration in karst areas, and climate factors and vegetation restoration are key factors affecting changes in soil moisture. However, there is still much controversy over the long-term changes in soil moisture during vegetation restoration. In order to reveal the changes in soil moisture during vegetation restoration, we conducted long-term positioning monitoring of soil moisture at 0–10 and 10–20 cm on secondary forests sample plot (SF, tree land) and shrubs sample plot (SH, shrub land) in karst areas from 2013 to 2020. The results showed that the aboveground biomass of SF and SH increased by 50% and 240%, respectively, and the soil moisture of the SF and SH showed an increasing trend. When shrubs are restored to trees in karst areas, the soil moisture becomes more stable. However, the correlation coefficients (R^2) between the annual rainfall and the annual average soil moisture of SF and SH are 0.84 and 0.55, respectively, indicating that soil moistures in tree land are more affected by rainfall. The soil moisture of shrubs and trees are relatively low during the months of alternating rainy and dry seasons. Rainfall has a very significant impact on the soil moisture of tree land, while air temperature and wind speed have a significant impact on the soil moisture of tree land, but the soil moistures of shrub land are very significantly affected by rainfall and relative humidity. Therefore, during the process of vegetation restoration from shrubs to trees, the main meteorological factors that affect soil moisture changes will change. The results are important for understanding the hydrological processes in the ecological restoration process of different vegetation types in karst areas.

KEYWORDS
climate factors, karst, rainfall, soil moisture, vegetation restoration

1 | INTRODUCTION

Soil moisture plays an important component of the soil-plant-atmospheric hydrological continuum, which affects ecosystems by regulating the growth and development of vegetation (Heathman et al., 2003; Legates et al., 2011; Wang et al., 2018; Yu et al., 2018; Yu et al., 2020; Zhang et al., 2021), and also playing a key role in the hydrological cycle. (Pierdicca et al., 2015). Soil moisture is influenced by climate factors, but the impact of vegetation change on soil moisture cannot be ignored (Niether et al., 2017; Peng et al., 2022).

Jia Chen and Lin Zhang are co-first authors.

Especially in recent years, changes in human activities in karst areas have led to significant changes in vegetation (Niether et al., 2017). Therefore, it is necessary to conduct long-term, localized and continuous soil moisture monitoring of different vegetation types, to understand more detailed and continuous soil moisture change data, which is of great significance in revealing the impact of vegetation restoration on soil moisture.

There are many factors affecting changes in soil moisture. Precipitation characteristics (such as quantity, intensity and duration) also have a significant impact on soil water movement (Albertson & Kiely, 2001; Chang et al., 2016; Hardie et al., 2011; Jing et al., 2020; Li et al., 2013). What's more, vegetation can affect soil moisture and response to precipitation through many complex and interactive hydrological processes (Canton et al., 2016; Chen et al., 2007; Rivera et al., 2014). However, from a long-term perspective, climate factors and vegetation restoration are two important factors leading to changes in soil moisture (Soonthornrangan & Lowry, 2021; Yang et al., 2022).

Some studies in semi-arid and semi-humid areas have shown that vegetation restoration leads to a decrease in soil moisture (Cao et al., 2018; Liang et al., 2018; Liu et al., 2018; Zhang et al., 2020). However, the impact of vegetation restoration on soil moisture varies under different environmental conditions (Hiltbrunner et al., 2012; Van Hall et al., 2017). Studies have also pointed out that vegetation restoration in karst areas leads to a slight decrease in forest soil moisture (Zhou et al., 2022), and the soil moisture was dominated by a drying trend in karst areas (Wei et al., 2021). But, the another research had pointed out that vegetation restoration in the subtropical humid karst region causes only a slight increase in soil moisture, although this change differed from season to season (Peng et al., 2022). Therefore, there is still much controversy over the changes in soil moisture after vegetation restoration in karst areas. The above are all regional-scale studies based on remote sensing or data reanalysis. However, at a long-term scale, the seasonal and interannual changes in soil moisture under different vegetation types are still unclear.

Because of the special geological conditions and fragile ecosystem in the karst region of southwest China (Chen et al., 2022; Li et al., 2017; Peng et al., 2013), soil moisture deficiency is one of the main influencing factors for ecological restoration in the karst region. Considering the shallow soil layer in karst areas and the more significant response of surface soil moisture to climate factors and vegetation changes (Yang et al., 2018; Zhang et al., 2022), long-term monitoring of surface soil moisture and analysing soil moisture change characteristics can better reveal the response of soil moisture to climate and vegetation changes. The purpose of this study is to confirm whether the surface soil moisture content and stability change through long-term positioning observations, what is the relationship among soil moisture, vegetation and climate factors. So, this study conducted long-term positioning observations on the surface soil moisture (0–10, 10–20 cm) of two typical natural restoration vegetation types, secondary forest sample plot (SF) and shrubs sample plot (SH), from January 2013 to December 2020.

2 | MATERIALS AND METHODS

2.1 | Study site

The study site (Figure 1) was located in the Chenqi catchment (26°14′–26°15′ N, 105°42′–105°47′ E), about 100 m east of Chenqibao Village, Puding County, Guizhou Province, China. The catchment area is about 1.3 km^2, with an elevation of 1316–1524 m, belong to a humid subtropical monsoon climate with uneven temporal and spatial distribution of rainfall. The rainy season mainly concentrated from May to October, accounting for over 80% of the annual rainfall. The annual average rainfall is 1338 mm, and the multi-year average temperature is 14.3°C (−7.6°C–34.3°C). The lithology consists mainly of gently dipping carbonate rocks of the Middle Triassic Guanling Formation. Limestone overlies marl and shale interbeds, which form an essentially impermeable base (Cao et al., 2020).

The SF were weakly disturbed by humans, with a slope of 35° and an area of about 300 m^2. The arbours are mainly *Platycarya longipes* and *Quercus fabri* Hance, with a small amount of shrubs such as *Akebia trifoliate* and *Rosa cymosa* Tratt., etc. The herb layer is mainly composed of a variety of *Carex spp* and *Synotis wallichii*, etc., and the soil is calcareous soil. The SH was affected by grazing in the early stage, and the degree of vegetation damage was relatively serious, the grazing decreased in the later stage, the slope of 31° and an area of about 200 m^2. The vegetation is mainly composed of *Zanthoxylum planispinum* and *Pyracantha fortuneana*, etc. The herb layer is mainly composed of *Artemisia dubia* and *Deyeuxia scabrescens*, and the soil is calcareous soil. We sampled and analysed the physical properties (Table 1) of 0–10 and 10–20 cm of soil layer of SF and SH in 2020.

2.2 | Data collection

In order to study soil moisture dynamics, soil moisture sensors (HOBO, S-SMD-M005) were installed at representative fixed locations within the SF and SH in this study, respectively. The observation time was from January 2013 to December 2020. The HOBO (H21-002) Micro data acquisition system was used to collect soil moisture at 10 and 20 cm in the surface, with a monitoring time resolution of 5 min. The sensor has a measurement accuracy of ±0.03 cm^3 cm^{-3} and a resolution of ±0.0008 cm^3 cm^{-3}. In order to study the impact of rainfall on soil moisture dynamics, a small HOBO meteorological station was installed on the SH to monitor rainfall and temperature. The observation period was from January 2013 to December 2020. The variation trend of monthly rainfall and monthly average temperature over the years is shown in Figure 2. It is heavy rainfall and high temperatures from May to October. At the same time, the wind speed and relative humidity from 2014 to 2020 were also monitored (Figure 3). The results show that the wind speed is lower and the relative humidity is lower in the rainy season, while the changes are opposite in the dry season.

To understand the changes in vegetation biomass of the two sample plots. The diameter at breast height (DBH, D) or diameter at basal

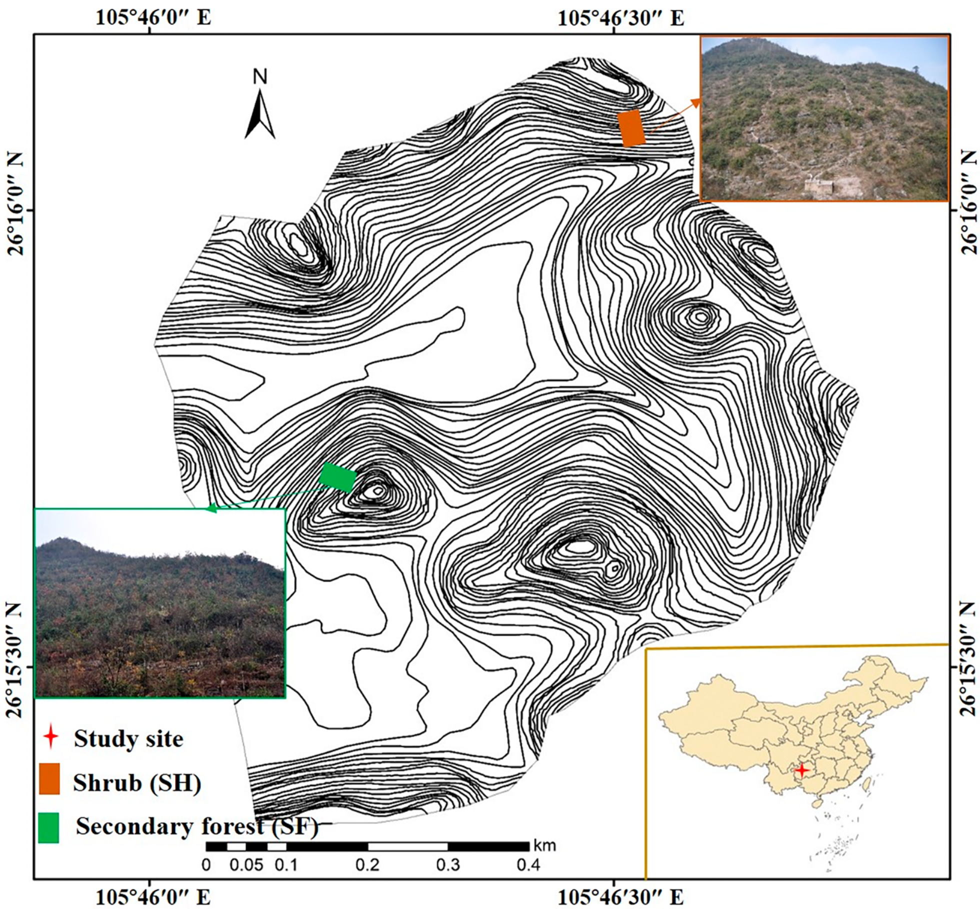

FIGURE 1 Location of the Chenqi catchment, and the relative locations of secondary forest sample plot (SF) and shrub sample plot (SH) within the catchment.

TABLE 1 Physical properties of soil in the different vegetation types sample plots.

Physical properties	pH	SOM (g/kg)	Bulk density (g/cm^{-3})	Clay (<0.002 mm)	Silt (0.002–0.05 mm)	Sand (0.05–2 mm)
SF-10	6.9	79.0	1.1	57.2	34.2	8.7
SF-20	7.1	52.2	1.2	44.2	47.5	8.3
SH-10	7.5	92.4	1.2	42.2	42.9	14.8
SH-20	7.5	71.0	1.2	43.9	43.8	12.3

Note: SF-10, SF-20: 0-10 cm and 10-20 cm of the secondary forest soil layer, respectively; SH-10, SH-20: 0-10 cm and 10-20 cm of the shrub soil layer.

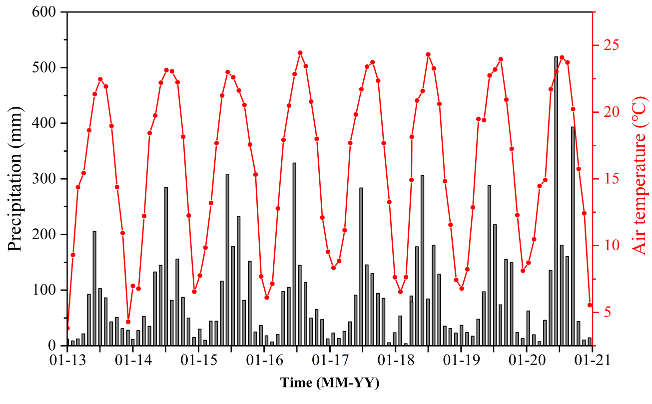

FIGURE 2 The monthly rainfall and monthly average temperature over the years in the study area.

height (d) and height in the two sample plots were investigated in 2013, 2015 and 2020, respectively. We divided the SF into three quadrats, and the SH into two quadrats, each with an area of 10 m × 10 m. The plants within each sample plot were investigated and measured, including plant number, plant height and DBH (or d). Then, by calculating the average biomass of plants within the sample plots and extrapolating the plant biomass per unit area based on the area of the sample plots. When the DBH of the plant is greater than or equal to 1 cm, record the value of the DBH, and when the DBH is less than 1 cm, record the value of the diameter at basal height (d). At the same time, randomly selected two small quadrats of 2 m × 2 m within each quadrat, and the herbaceous plants were harvested and weighed. The plant biomass obtained was then divided with the area of the surveyed area to obtain the plant biomass per unit area.

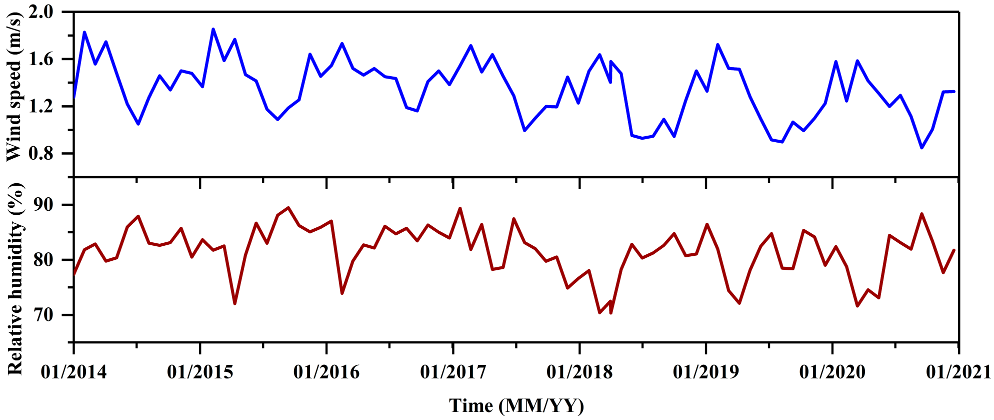

FIGURE 3 The monthly average wind speed and relative humidity over the years in the study area.

TABLE 2 Regression models for biomass of main tree species and different DBH classes.

Species	DBH classes (cm)	Regression models
Platycarya longipes	1.0 ≤ D ≤ 22.6	$y = 1.9611(D^2H)^{0.8921}$
Machilus cavaleriei	1.0 ≤ D ≤ 19.9	$y = 2.6211(D^2H)^{0.8565}$
Zanthoxylum planispinum	0.6 ≤ d ≤ 1.4	$y = 0.2876(d^2H) + 22.075$
Myrsine africana	0.2 ≤ d ≤ 0.8	$y = 0.5757(d^2H) + 18.309$
DBH classes	D < 1.0	$y = 0.5418(d^2H) + 17.287$
	1.0 < D ≤ 5.0	$y = 0.5834(D^2H)–8.151$
	D > 5.0	$y = 2.0141(D^2H)\ 0.889$

Abbreviations: D, diameter at breast height (cm), d, diameter at basal height (cm); H, height (cm) (Liu et al., 2009).

2.3 | Data analysis

Soil water data were used to estimate the coefficient variation (CV). The CV was calculated using the following equation:

$$CV = \frac{\bar{x}}{\sigma} \times 100\%, \quad (1)$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n}\theta_i, \quad (2)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(\theta_i - \bar{x})^2}{n} - 1}, \quad (3)$$

where CV is coefficient variation (%); *x* is the mean of soil water content (%); σ is the standard deviation of soil water content; θ_i is volumetric soil water content (%) for the number of measurements *i* and *n* is the total number of measurements.

In order to estimate the aboveground biomass of tree and shrub layers, a regression model for biomass (Liu et al., 2009) suitable for different diameter class groups (Table 2) was selected for estimation in this study. When the DBH of a plant was greater than or equal to 1 cm, the DBH (D) was used as a regression parameter when using the model, and when the DBH was less than 1 cm, the base diameter (d) is used as a regression parameter. Based on the results of the quadrat survey, and the regression model for biomass of 15 common vegetation types established by Liu et al. (2009), the corresponding aboveground biomass of each tree species was calculated. For 15 common species and other tree species that exceed the applicable range, the aboveground biomass of the entire sample site's tree layer and shrub layer was calculated based on the regression model for biomass of the three diameter class groups (Table 2).

3 | RESULTS

3.1 | Variation in vegetation biomass

The biomass of trees, shrubs and herbs in the SF and SH are shown in Figure 4. In the surveys conducted in 2013, 2015 and 2020, in the SF, the surface biomass of SF increased by about 50%, and the biomass of trees increased by 60%, the biomass of shrubs decreased by 20% and the biomass of herbs increased by 24%. This indicates that SF were mainly dominated by trees, which are growing and also inhibiting the growth of underlying shrubs. In contrast, surface biomass in SH increased by 240%, with its tree biomass increasing by 640%, shrub biomass by 60% and herbaceous biomass by 61%. This indicates that shrubs were originally dominant in the SH. Trees have significantly increased at after several years of restoration, while shrubs and herbs are also increasing, but their growth rate is significantly lower than that of trees.

3.2 | Monthly characteristics of changes in soil moisture

The monthly average soil moisture and rainfall variation characteristics of SF and SH during the observation period are shown in Figure 5. The changes in soil moisture under the two vegetation types fluctuate

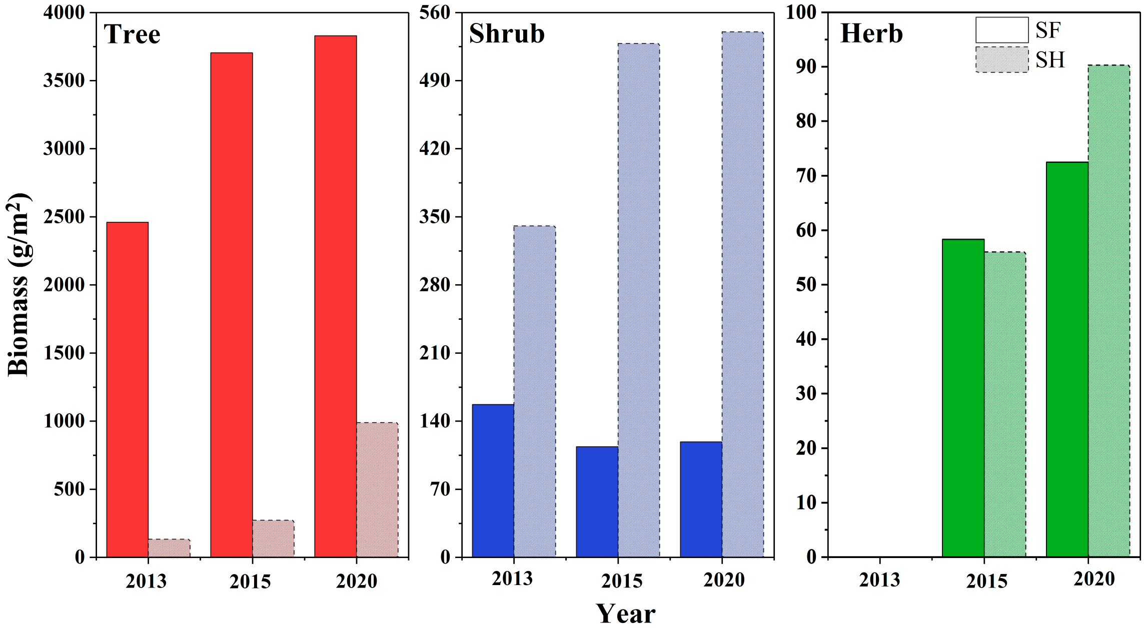

FIGURE 4 Multi-year changes in biomass of tree, shrub and herb in the two sample plots. There is no biomass investigation was conducted on the herb layer in 2013 at the initial stage of establishment of the sample plot.

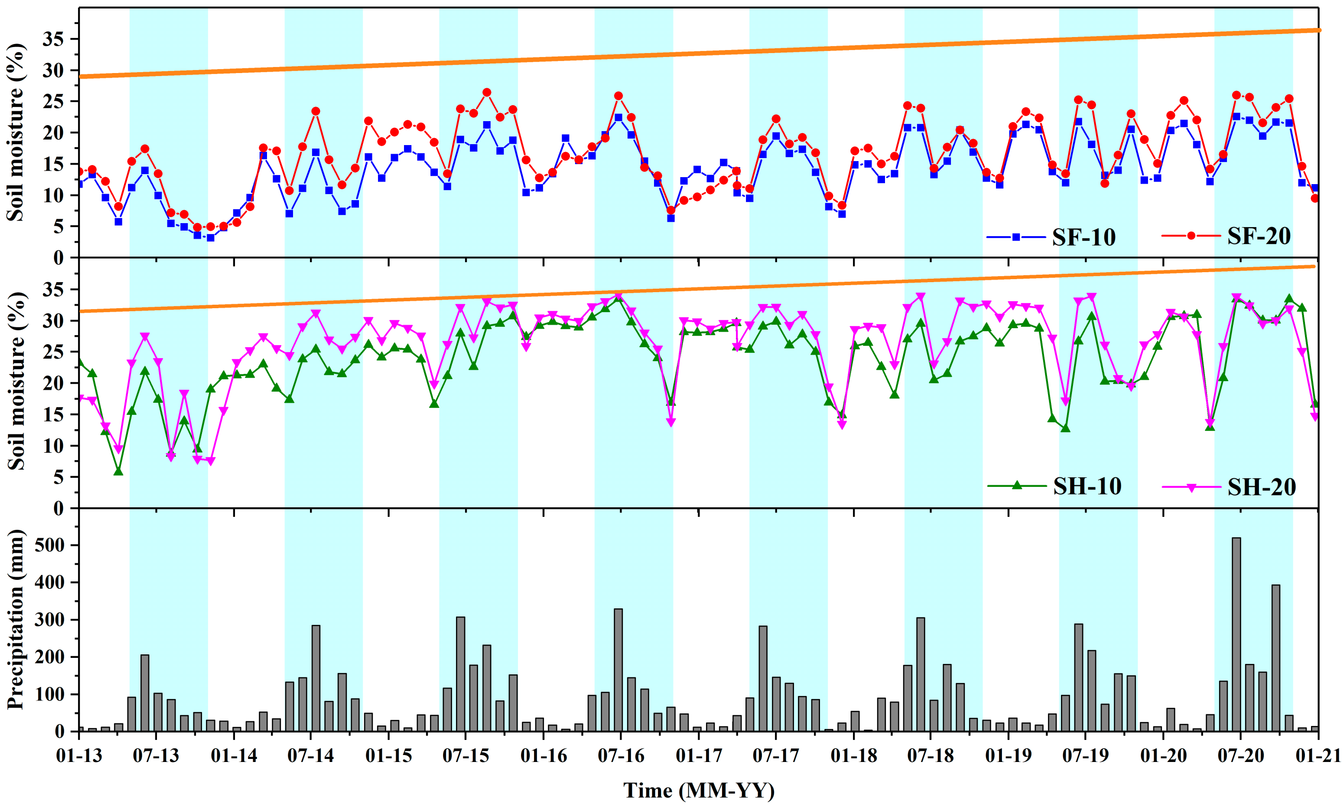

FIGURE 5 The monthly average soil moisture of secondary forest (SF) and shrub (SH) and rainfall variation characteristics during the rainy and dry season from 2013 to 2020.

to varying degrees due to the impact of rainfall. There was an increasing trend of soil moisture in SF and SH from year to year until 2017, and after 2017, the increasing trend of soil moisture in both of them decreased. However, the trend line shows that the soil moisture content of SF and SH tends to increase throughout the study period. At the same time, the monthly average soil moisture variation of SF is

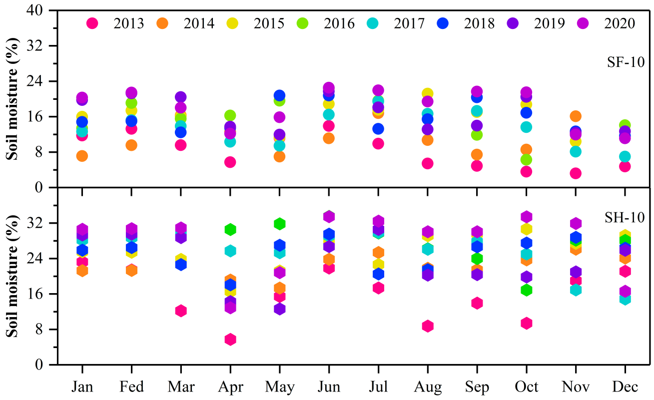

FIGURE 6 The changes in monthly soil moisture over a long time series.

smaller than that of SH, with the variation ranges of 3.2–26.4 and 5.7–34.2, respectively. Moreover, the soil moisture of SF is generally lower than the soil moisture of SH. From a long-term perspective, the difference in soil moisture between the 0–10 cm layer and the 10–20 cm layer under the two vegetation types has a decreasing trend. This may be due to the fact that the amount of vegetation in SF is higher than that in SH, and the high demand for soil moisture by plants leads to a low soil moisture in SF. At the same time, due to the restoration of vegetation, deeper soil water is utilized by plants, so the difference in soil moisture between 0–10 and 10–20 cm becomes smaller. In addition, we can discover that in the months when the rainy season and dry season alternate, the soil moisture under the two types of vegetation often decreases significantly, and the decrease in SH is even greater. The reason for this is that the temperature is relatively high in the rainy season, and the vegetation grows vigorously, and there is not much rainfall in the alternate months of the rainy and dry seasons, resulting in a large consumption of soil water.

From the changes in monthly soil moisture over a long time series (Figure 6), it can be seen that the soil moisture at the 0–10c of SF and SH shows an overall increasing trend during the years of vegetation restoration, regardless of the amount of rainfall in each month. However, in winter, there is not much difference in soil moisture among different years, and instead, there is a significant difference in soil moisture between spring and autumn. This may be affected by rainfall, as the overall rainfall in winter is low, resulting in small differences in soil moisture between years, while there are differences in rainfall between years in spring and autumn, resulting in large fluctuations in soil moisture between years.

3.3 | Interannual variation of soil moisture

The annual average soil moisture of SF and SH are shown in Figure 7. It can be seen that from 2013 to 2020, the average annual soil moisture of 0–10 and 10–20 cm in SF showed a fluctuating trend of increase, reaching a high point in 2015 and 2020, respectively, while the average annual soil moisture of SF-20 changed more significantly. The average annual soil moisture of each layer of SH fluctuates in different situations, but on the whole, it shows an increasing trend. Compared with SH-10, the average annual soil moisture of SH-20 has a smaller change range. By comparing the monthly average soil moisture distribution of SF and SH in the Figure 5, it can be seen that the soil moisture variation amplitude of each layer of SF is significantly smaller than that of each layer of SH, and the monthly average soil moisture variation amplitude of SH-10 is higher than that of SH-20. This also indicates that in the process of vegetation restoration in karst areas, soil moisture in each layer will have an increasing trend. The soil moisture in the SF is more stable in each month, while the soil moisture of SH which is dominated by shrubs, fluctuates greatly in each month. This may be mainly related to vegetation types and soil properties. SF has more litter and less sand content than SH, so SF is stronger in soil water retention performance than SH, resulting in smaller differences in soil moisture in each month.

3.4 | Relationships between CV of monthly soil moisture and rainfall

In order to clearly evaluate the impact of rainfall on soil moisture under different vegetation restoration types, we analysed monthly rainfall and CV of soil water (Figure 8). In the SF, the CV of soil water at 0–10 and 10–20 cm presents the same trend with the change of rainfall, but the CV of soil water in rainy season was higher and fluctuates more than that in dry season. Over time, the variation range of the CV of soil water varies little in each year. The CV of soil water at 10 cm was mostly slightly higher than the CV of soil water at 20 cm before October 2017, while after October 2017, there was no significant difference in the CV of soil water between the two. In the shrub, the relationship between rainfall variation and the CV of 0–10 and 10–20 cm was the same as that in SF. However, with the passage of time, the CV showed an increasing trend, and during the entire research stage, the CV of soil water at 10 and 20 cm had no significant difference. Through comparison, it was found that during the rainy season, the variation trend of the CV of soil water in the SF and the SH is the same, but in the dry season, the CV of soil water in the SF is more susceptible to rainfall, mainly manifested in January 2019 and January 2020. This indicates that the CV of soil water is jointly affected by rainfall and vegetation type.

4 | DISCUSSION

4.1 | Impact of rainfall on soil moisture under different vegetation types

Rainfall is the main source of soil moisture, and vegetation can redistribute rainfall. In particular, some rainfall is directly retained by the vegetation canopy, while others infiltrate into the soil through plant canopy (Llorens & Domingo, 2007; Zhang et al., 2015). At the same time, seasonal changes in vegetation canopy structure can affect the

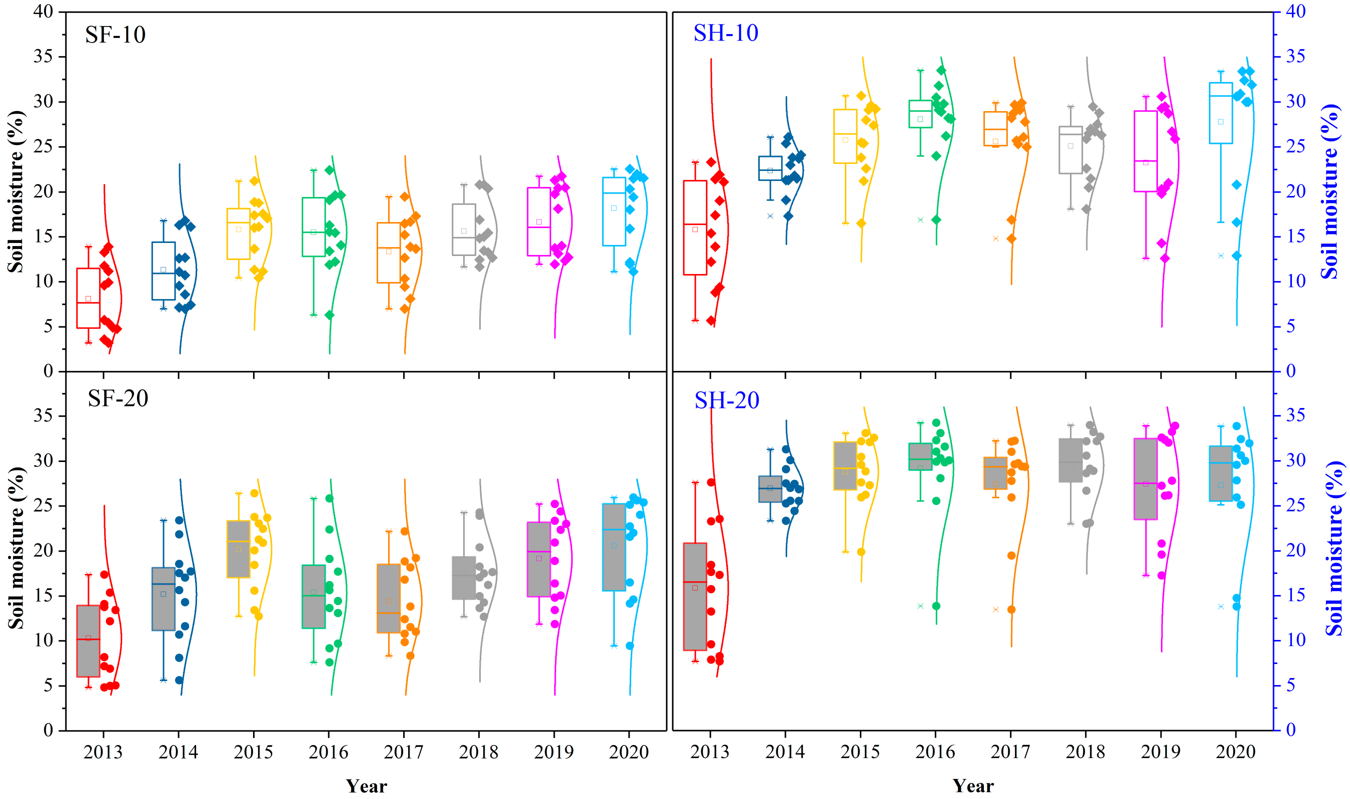

FIGURE 7 The variation characteristics of the annual average soil moisture of secondary forest (SF) and shrub (SH) during 2013–2020.

retention capacity of vegetation canopy (Deguchi et al., 2006). Therefore, the impact of rainfall in different seasons on soil moisture will vary. It can be seen that the multi-year average CV of soil moisture in the SF and the SH has the same trend (Figure 9). In spring, autumn and winter, the CV of soil moisture shows a corresponding trend with the increase or decrease of rainfall, while in summer, with the decrease of rainfall, the CV of soil moisture actually increases. This is because the gradual increase in spring rainfall and the large supply of soil moisture, leading to an increase in the CV. In summer, the rainfall in June is the highest, and the water required for vegetation growth can be fully supplied, resulting in an increase in soil moisture with a low CV. However, with high summer temperatures and vegetation in the peak growing season, the CV of soil moisture will correspondingly increase as rainfall decreases. In addition, SF are dominated by trees, which require more water, so the CV of soil water is higher than that of SH. During the study period, there is a certain regularity between the change trend of water content in the shallow soil of vegetation and the change trend of rainfall. There is more rainfall in June, August and September, and it is also the peak period during which the shallow soil moisture is replenished by rainfall (Jing et al., 2020). In autumn, although rainfall decreases, the water required by vegetation gradually decreases, resulting in a gradual decrease in soil moisture and a gradual decrease in the coefficient of variation. In winter, with low temperatures, low vegetation water consumption and low soil moisture, soil moisture can be directly replenished after rainfall, resulting in the CV of soil moisture that change with rainfall.

Rainfall and vegetation can affect the spatial and temporal changes in soil moisture (Zhao et al., 2020). We can know that the annual average soil moisture in the two sample plots shows an increasing trend as the annual rainfall increases, and the annual average soil moisture of SF is significantly lower (Figure 10). This may be due to the rain-blocking effect of denser vegetation (Johnson & Lehmann, 2006) should greatly reduce the accumulation of soil moisture during rainfall events. This study is consistent with Zhao et al. (2020) observation and research on grasslands, shrubs and forests. In addition, the correlation coefficient between soil moisture in the 10–20 cm layer of SF and annual rainfall is the highest, reaching 0.84, while the correlation coefficient between soil moisture in the 0–10 cm layer of SH and annual rainfall is the highest, reaching 0.55 (Figure 10). Moreover, there is little difference in changes in soil moisture among months within SF (Figure 7). This is because forest diminished the effect of weather factors on soil moisture dynamics near the surface (Zhao et al., 2020). Thus, it can be seen that in the process of vegetation restoration, areas with better vegetation have more stable annual changes in soil moisture, but are more affected by rainfall.

4.2 | Effects of other climate factors and vegetation types on soil moisture

Many studies had shown that climate change, vegetation types, soil properties and human activities can all affect changes in soil moisture

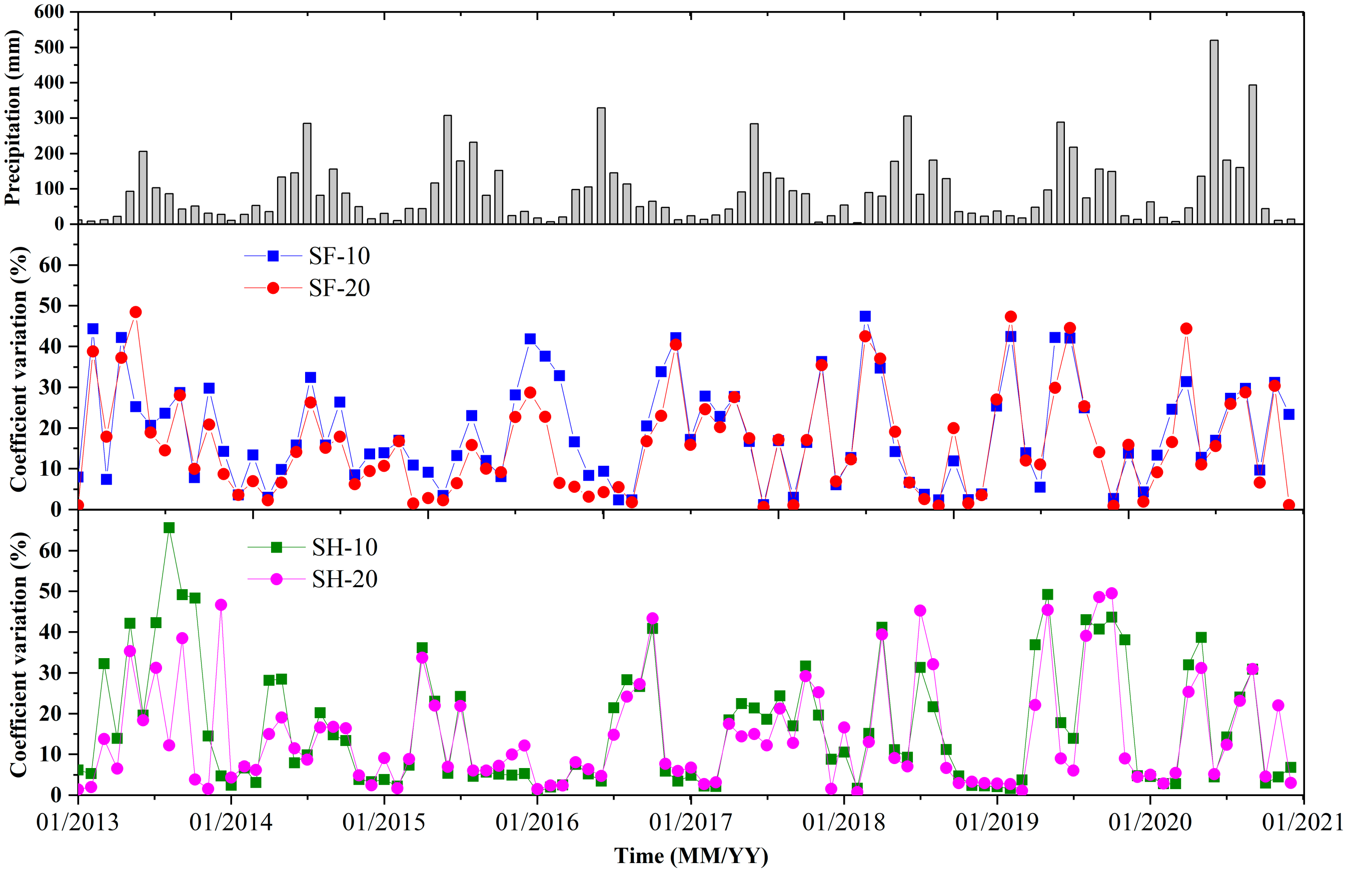

FIGURE 8 Variation trend of the coefficient variation of monthly soil water of secondary forest (SF) and shrub (SH) and monthly rainfall during 2013–2020.

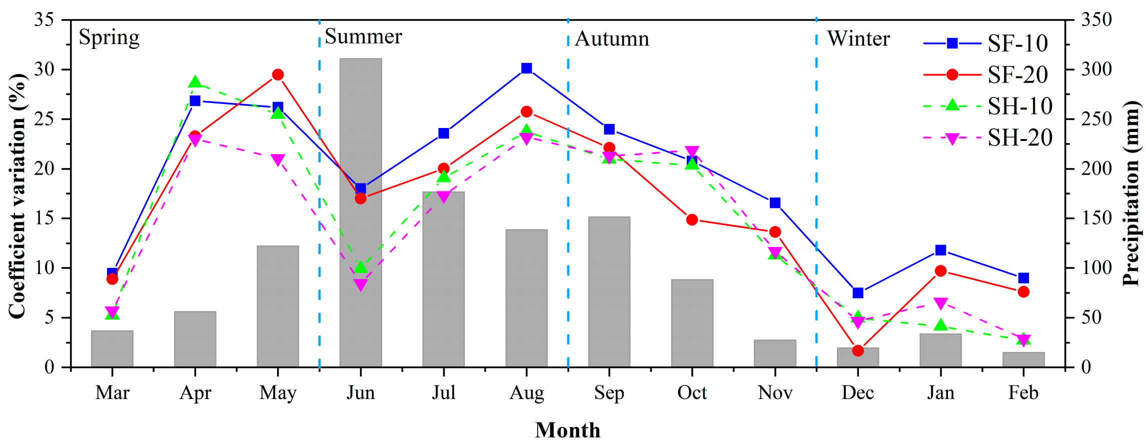

FIGURE 9 Relationships between average monthly rainfall and the coefficient variation of soil moisture in each year during the observation period.

(Yan et al., 2021; Yan et al., 2022; Zhu & Lin, 2011). From a large-scale and long-term perspective, climate change and vegetation restoration were the two most important factors leading to changes in soil moisture (Soonthornrangan & Lowry, 2021; Yang et al., 2022). However, through long-term positioning observations, this study found that changes in soil moisture in SF and SH in karst areas are very significantly correlated with rainfall, and the correlation between changes in soil moisture in 10–20 cm is higher than that in 0–10 cm (Table 3). This may be due to increased litter due to vegetation restoration, which has changed the water holding capacity of the surface soil (Yang et al., 2017; Zhang et al., 2019). The input and output of soil moisture near the surface are relatively fast, while the soil moisture below the surface is mainly utilized by vegetation. Therefore, it can be seen at a multi-year scale that the correlation between soil moisture in the 10–20 cm layer and rainfall is higher (Figure 10), and the better the vegetation condition, the higher the correlation.

Some studies had shown that temperature affects soil moisture content (Tang et al., 2019; Wang et al., 2018), with a low contribution of temperature (Wang et al., 2018). In the coupled temperature-soil moisture system, temperature affects soil moisture indirectly by influencing soil evapotranspiration, and under soil moisture limiting conditions, soil moisture also affects soil evaporation (Koster et al., 2009; Seneviratne et al., 2010). This study shows a significant correlation between temperature and soil moisture in SF, but no correlation with soil moisture in SH. Whereas monthly mean soil moisture content was significantly negatively correlated with wind speed in SF, monthly mean soil moisture content was highly significantly positively correlated with relative humidity in SH (Table 3). This may be affected by multiple factors such as rainfall, vegetation type and soil properties. The climate in the study area is characterized by simultaneous rain and heat, high temperature and good vegetation, resulting in high soil water consumption. However, there is also much rainfall, and soil water can be replenished immediately. When the temperature is low, rainfall is less, and soil moisture supply and consumption are less. Therefore, in the long-term scale, the soil moisture of the SF is significantly affected by temperature. However, due to the less of vegetation and different soil moisture holding capacity, there is no correlation between soil moisture and temperature on SH dominated by shrubs.

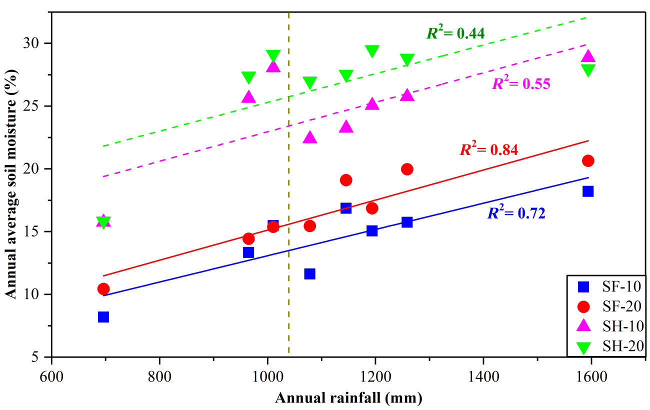

FIGURE 10 Relationships between annual rainfall and annual mean soil moisture.

In this study, principal component analysis (PCA) was conducted on the time series of rainfall, temperature, wind speed, relative humidity and soil moisture in SF and SH (Table 4), two PC are extracted for each sample plot. This indicates that at least two main processes affect changes in soil moisture in different vegetation types. Two PCs (PC1, PC2) of SF and SH explained approximately 69.9% and 71.9% of the total variance, respectively. Rainfall serves as a direct source of soil moisture (Chen et al., 2022; Zhang et al., 2015). In PC1, the correlation between soil moisture and rainfall is highest in the two plots, and there is also a high correlation between temperature, wind speed, and relative humidity and soil moisture. However, the soil moisture of SF is more affected by rainfall than SH. This indicates that the PC1 process represents the impact of the rainy season on soil moisture.

TABLE 4 PCA results of soil moisture and climate factors in secondary forests and shrubs.

	SF		SH	
Factors/soil moisture	PC1	PC2	PC1	PC2
Rainfall	0.84	−0.20	0.78	−0.39
Temperature	0.69	−0.45	0.59	−0.64
Wind speed	−0.61	0.51	−0.56	0.53
Relative humidity	0.47	−0.20	0.66	0.17
SM (0–10)	0.76	0.60	0.67	0.67
SM (10–20)	0.81	0.53	0.72	0.58
Explained (%)	50.38	19.61	44.34	27.56
KMO	0.66		0.63	
Bartlett (P)	<0.01		<0.01	

Note: The numbers indicate either positive or negative loadings (analogous to a correlation coefficient) of each PC for two samples. Explained (%) is the total percentage of variation in the data explained by each component. KMO is in measure of sampling adequacy. Bartlett (P) is the significance of Bartlett's test.
Abbreviations: KMO, Kaiser-Meyer-Olk; PCA, principal component analysis.

TABLE 3 The results of Pearson correlation analysis between soil moisture and climate factors.

Climate factors	Type	SF-10	SF-20	SH-10	SH-20
Rainfall	Coefficient	0.475**	0.537**	0.246*	0.334**
	p	<0.01	<0.01	0.012	0.001
Temperature	Coefficient	0.241*	0.352**	−0.011	0.136
	p	0.014	<0.01	0.459	0.109
Wind speed	Coefficient	−0.230*	−0.258*	−0.063	−0.076
	p	0.018	0.009	0.286	0.247
Relative humidity	Coefficient	0.213	0.239*	0.425**	0.375**
	p	0.026	0.014	<0.01	<0.01

**Indicates a very significant difference at the confidence level of $p < 0.01$.*Indicates a significant difference at the confidence level of $p < 0.05$.

Because of rainfall being the direct source of soil moisture, high temperatures and relative humidity result in a positive correlation with soil moisture during the rainy season. Meanwhile, as previously known, forests with better vegetation can weaken the impact of weather factors on soil moisture, but have a higher correlation with rainfall. In PC2, the correlation between soil moisture and temperature as well as wind speed exhibits a higher degree of association in the two plots, and the soil moisture of SH is more affected by temperature than that of SF. This indicates that the PC1 process represents the impact of the rainy season on soil moisture. This is mainly due to the effects of low temperatures and low relative humidity during the dry season, which results in low evaporation of surface moisture and consequently the higher of soil moisture (Figure 5). However, the vegetation coverage of SH is lower than that of SF, and there is less surface litter layer, resulting in greater influence of temperature on soil moisture evaporation. Therefore, Through PCA analysis, it is evident that soil moisture in the two sample plots is influenced by both rainy and dry seasons. Furthermore, it also indicates that the vegetation restoration process from shrubs to SF can lead to changes in the main meteorological factors that affect soil moisture changes. This helps to deepen our understanding of the ecosystem restoration mechanisms and hydrological cycle processes.

4.3 | Effects of different vegetation restoration types on soil moisture

Previous studies had shown that vegetation restoration in subtropical humid karst areas over a long time scale slightly increases soil moisture, but the increase is the most significant in spring, with an average increase of 0.019 m^3/m^3, and the maximum reduction in summer, with an average reduction of 0.010 m^3/m^3 (Peng et al., 2022). However, one study had pointed out that vegetation restoration has led to a slight decrease in soil moisture in karst areas (Zhou et al., 2022). The soil moisture tends to be mainly dry, with a variation rate of -0.0006 (cm^3/cm^3)/10a in karst areas (Wei et al., 2021). At the same time, there are differences in the impact of vegetation types on soil moisture. Due to the characteristics of shallow grassland roots, high vegetation coverage, and slow water evaporation, grassland soil water holding capacity is higher than bare land, woodland and shurb (Zhou et al., 2019). But on the slope scale, the soil moisture of forest land is higher than that of shrubs and grasslands (Chen et al., 2009).

Through 8 years of continuous monitoring research, we have shown that the soil moisture of the SF and SH shows an increasing trend (Figure 7). This may be related to the type of surface vegetation. SF are mainly dominated by trees (Figure 4), with less human damage, increased vegetation coverage and reduced surface evaporation (Li et al., 2019). At the same time, vegetation restoration makes the litter layer thicker and has more organic matter, which helps the soil form a good aggregate structure, thereby improving the water holding capacity of the soil (Yang et al., 2016; Yang et al., 2017; Zhang et al., 2019). Therefore, there is no significant difference in soil moisture at 0–10 and 10–20 cm.

However, the surface vegetation of SH is less than that of SF (Figure 5). Before we started the observation and research, the SH conducted a large amount of grazing, and then the grazing situation gradually decreased. Because of early grazing behaviour, there are fewer surface vegetation and severe soil water evaporation, resulting in low soil moisture. With the gradual decrease of grazing behaviour, surface vegetation increases, surface evaporation decreases and litter increases, which improves the water holding capacity of the soil, leading to an overall increase in the soil moisture of the SH. Our results indicate that the soil moisture of SF in karst areas, which are less affected by human activities, will slightly increase during vegetation restoration, and the average soil moisture varies slightly in each month. During the vegetation restoration process, the soil moisture of SH that were greatly affected by human activities in the early stage showed an overall increase trend, but the average soil moisture varied greatly f in each month (Figure 7). This also indicates that the restoration of karst areas from shrub with poor vegetation to tree forest will make the soil moisture more stable. This is of great significance for predicting the future evolution trend of soil moisture in ecosystems.

5 | CONCLUSION

This study conducted 8 years of continuous observation on the soil moisture of two main vegetation types in this study area, indicating an increasing trend in the soil moisture of the SF and SH. Restoring from poorly vegetated shrubs to trees in karst areas will make the soil moisture more stable. When the rainy season and dry season alternate, the soil moistures of shrubs and tree forests are relatively low, and reasonable irrigation is particularly important to ensure the water requirements of vegetation. The annual average changes in soil moisture with the variation of annual rainfall, and there are differences in soil moisture and CV between different seasons. The higher the biomass of surface vegetation, the higher the coefficient of variation in soil moisture during summer. In the process of vegetation restoration, rainfall has an extremely significant impact on soil moisture in shrubs and trees, while temperature and wind speed has a significant impact on soil moisture in trees. The impact of relative humidity on soil moisture in shrubs is extremely significant. This is highly significant in comprehending the hydrological processes during vegetation restoration in karst areas, as well as the relationship between vegetation growth and soil water supply.

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DATA AVAILABILITY STATEMENT

Research data are not shared.

ORCID

Jia Chen https://orcid.org/0009-0007-3951-4358

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