Study on Soil Moisture Temporal-Spatial Variation and Stability in Loess Plateau of China

Yanpeng Wang※¹, Ying Zhou², Xueyong Liu³
Henan Xinxiang Hydrology and Water Resources Survey Bureau
Xinxiang, 453000, Henan, China
Email address: zying8608@163.com

Abstract: Soil moisture temporal-spatial distribution and stability are important factors influencing soil pollutant transport, material migration, regional climate change, hydro-ecological environment as well as agricultural production patterns. According to soil moisture distribution features on the loess plateau, the paper selected three different kinds of surface slopes on the typical experiment sites to carry out soil moisture measurement. The variation coefficient and rank correlation method are proposed to calculate the longitudinal and vertical soil moisture distribution characteristics. The temporal-spatial dynamic features of soil moisture are studied. The present findings show that the soil moisture in the Loess Plateau varies greatly at different soil depths during the period from April to June. The maximum soil moisture appears at the depth of 40-60 cm. The variation coefficient of soil moisture increases with the soil depth. It was discovered that there exist temporal stability at the depth of 20-80 cm. The correlation coefficient of soil moisture in different slopes is significant during the period of April-June. The results would play an important support in theoretical research and ecological environment planning, optimization of agricultural planting pattern and comprehensive management of Loess Plateau.

1. Introduction
In recent years, climate change influences the social and economic development (Bekele D. et al. 2018). The study of soil moisture temporal stability has attracted attention of many scholars (Deng C et al. 2018, Ersahin S, Brohi A R. 2006). A lot of relevant findings are applied in ecosystem restoration, agricultural planning and environment management (Fu Bojie et al. 2001, Gerhards M et al. 2018, Madadgar S et al. 2017). The temporal stability of soil moisture in hilly area of Sichuan Basin was studied by Wang (Wang et al. 2009, Bai Ru, Shao Mingan. 2011), which provided scientific basis for local agricultural management. Zhang et al. (Zhang et al. 2017, Xing et al. 2015) analyzed the temporal stability of soil moisture at a depth of 0-20 cm in the oasis-desert transition zone. The results concluded that there exists the possibility of water resources development in the region, which could strongly support the local economy. Zhu et al. (Zhu Xuchao et al. 2017, Pan et al. 2009) studied the temporal stability of water in the surface soil of alpine meadow ecosystem, the research findings play an important role in solving water shortage.

At present, the study of soil moisture in the small gully watershed of the Loess Plateau is mainly concentrated on the dynamic changes and distribution characteristics of soil moisture. Unfortunately, there is shortage of deep exploration on the temporal stability of soil moisture distribution in the region of loess plateau (Li et al. 2010, Li et al. 2014).

The Loess Plateau of China is a typical semi-arid ecologically fragile area with a small furrow
basin as the main terrain, which accounts for 50-60% of the total area (Zhang et al. 2017, Tang 2004). Soil moisture is a major limiting factor for plant growth and vegetation restoration in the region (Chien H. et al. 2013, Vanderlinden et al. 2012). The strong temporal-spatial variation characteristics significantly affect the rational allocation of regional vegetation and the effective utilization of soil moisture (Li et al. 2014, Zhao et al. 2019). Due to lack of reasonable assessment for the soil moisture temporal stability in the furrow basin, and unreasonable vegetation selection and plant pattern, the problems of soil drying and low development efficiency in the region seriously affect local social and economic development (Fu et al. 2001, Williams D G. 2005). Therefore, the study of soil moisture temporal stability in Loess Plateau could provide important basic theory and technical support for ecological planning and construction, optimization of agricultural planting pattern and comprehensive management of Loess Plateau (Wang et al. 2012, Xing et al. 2015).

In this study, through comparative analysis, a typical small watershed was selected in the Loess Plateau. In the experiment area, the representative slopes were selected and soil moisture monitoring works were carried out in different slopes using Trime-TDR instruments. The temporal stability of soil moisture in this area was calculated and analyzed by using both variation coefficient and Spearman rank correlation methods. The study result is crucial in providing important reference for local ecological environment planning, agricultural production and comprehensive management of the Loess Plateau.

2. Materials and Methods
2.1. The study Area
The North-West Loess Plateau of China is situated in the north-west region of China, which is also the most concentrated loess plateau in the world. The total area amounts to 640,000 km² and spans seven provinces (Qinghai, Gansu, Ningxia, Inner Mongolia, Shannxi, Shanxi and Henan). The experiment area was selected in the Nanxiaohe small watershed, which is situated in Qingyang County, Gansu Province, and belongs to a branch ditch on the left bank of the Puhe River, a tributary of the Jinghe River. Average altitude of the experiment area is 1050-1423 m, and the experiment area is 36.3 km², in which plateau land accounts for 57%, gully area accounts for 43%.

2.2. Sample collection and test methods
2.2.1. Observation site selection and measuring methods
The observation points were located on the slopes with direction from north to south, and the slope degree is from 15° to 20°. Three different slopes (upper, middle and lower) were selected. 3 monitoring points were designed for each slope, therefore, totally 9 measurement points were arranged. Soil moisture measurements are continuously carried out for 3 months from April to June. The slope surface vegetation is all natural secondary shrubbery and wasteland.

2.3. Calculation methods
In this study, two methods were used to calculate and analyze soil moisture variation, i.e. variation coefficient and rank correlation. The variation coefficient, also called standard deviation rate, is a statistic indicator to measure the variation degree of soil moisture samples.

Rank (Spearman rank) correlation is a nonparametric (independent distribution) statistic variable calculation method, proposed by Spearman in 1904, to measure the relationship between two variables. Spearman rank correlation coefficient can be used for R test, and it can also be used as a measurement of the relationship between variables when the data distribution is not linear correlation or leads to wrong conclusions by using other methods.

2.3.1. Variation coefficient method
Discrete degree of random variables can be reflected by variation coefficient CV, the formula is:
in which, CV refers to variation coefficient, which illustrates the sample dispersion and also indicates the variation degree of calculated variables; s is standard deviation; m represents the mean value of samples.

Classification could be made according to variation degree. i.e. CV<10% (weak variation); 10%≤CV≤100% (middle variation); CV≥100% (strong variation.).

2.3.2. Rank correlation
Spearman rank correlation coefficient method (Wan Li, Mao Bingqi. 2008) was used to calculate the soil moisture time stability, which reflects the sample similarity in spatial patterns at different observation times. Calculation method of rank correlation coefficient is as follows,

\[
r_s = 1 - \frac{6\sum_{i=1}^{N}(R_{ij}-R_{ij+1})^2}{N(N^2-1)}
\]

in which, \(r_s\) is rank correlation coefficient; \(R_{ij}\) is the rank of measured soil moisture at the point i and at time j; \(R_{ij+1}\) is the rank of measured soil moisture at the point i and at the time j+1. N is the number of measured soil moisture samples.

If \(r_s\) is close to 1, it indicates that the spatial distribution pattern of soil moisture is similar in different time periods, that is, the time stability of soil water is stronger.

3. Temporal and spatial stability analysis on soil moisture.

3.1. Temporal and spatial dynamics of soil moisture at different depths
It can be seen from Fig.1 that the mean soil moisture, standard deviation and variation coefficient show different variation trend at different soil depths.

![Fig.1 Mean, standard deviation and variation coefficient of soil moisture at different depths from April to June](image)

It can be seen from Fig.2 that the soil moisture variation coefficient fluctuates greatly at different depths and has a large amplitude. The standard deviation and mean values remain relatively stable.

3.2. Temporal and spatial dynamics of soil moisture at different slopes
It can be seen from Fig.2 that the distribution of mean soil moisture, standard deviation and variation coefficient were different at the different slope locations.
Fig. 2 Mean, standard deviation and variation coefficient of soil moisture from April to June at different slopes

It is clear from Fig. 3 that the mean value of soil moisture at different slopes shows the trend of upper < middle < lower. The soil moisture content was 10.50%, 11.58% and 16.66% at the upper, middle and lower slope respectively.

3.3 Temporal stability of soil water content at different depths

Temporal stability of soil moisture was analyzed with Spearman rank correlation method. The Spearman rank correlation coefficient of soil moisture between 0-100 cm is shown in Table 1.

| Table 1 | Spearman rank correlation coefficient of soil moisture at the depth of 0 - 100 cm |
|---------|---------------------------------------------------------------|
| depths | Dates       | 27,April | 21,May | 24,Jun |
| 0-20cm  | 27,April    | 1        | 0.810*  | 0.976** |
|         | 21,May      | 1        | 0.881** |
|         | 24,Jun      | 1        |         |
| 20-40cm | 27,April    | 1        | 0.405   | 0.786*  |
|         | 21,May      | 1        | 0.857** |
|         | 24,Jun      | 1        |         |
| 40-60cm | 27,April    | 1        | 0.595   | 0.905** |
|         | 21,May      | 1        | 0.786*  |
|         | 24,Jun      | 1        |         |
| 60-80cm | 27,April    | 1        | 0.643   | 0.738*  |
|         | 21,May      | 1        | 0.952** |
|         | 24,Jun      | 1        |         |
| 80-100cm| 27,April    | 1        | 0.381   | 0.595   |
|         | 21,May      | 1        | 0.905** |
|         | 24,Jun      | 1        |         |

Note.: *the correlation coefficient is significant at the P<0.05 level; ** significant correlation coefficients at the P<0.01 level.

3.4 Soil moisture temporal stability at different slopes

Spearman rank correlation coefficient of soil moisture at different slope locations can be seen in Table 2.

| Table 2 | Spearman rank correlation coefficient of soil moisture at different slopes |
|---------|---------------------------------------------------------------|
| slopes | dates       | 27,April | 21,May | 24,Jun |
| upper  | 27,April    | 1        | 0.406   | 0.782** |
|         | 21,May      | 1        | 0.855** |
| Date   | Depth  | Correlation Coefficient | Correlation Coefficient |
|--------|--------|--------------------------|--------------------------|
| 27, Apr | middle | 0.696**                  | 0.856**                  |
| 21, May | middle | 0.922**                  |                          |
| 24, Jun | middle | 1                        |                          |
| 27, Apr | downhill | 0.738**                | 0.918**                  |
| 21, May | downhill | 0.932**                |                          |
| 24, Jun | downhill | 1                        |                          |

Note: * the correlation coefficient is significant at the P<0.05 level; ** significant correlation coefficients at the P<0.01 level.

It is clear from Table 2 that except the soil moisture correlation coefficient at the upper slope from April to May, the soil moisture at the most other slopes are significantly correlated with time, which indicates that the soil moisture has strong similarity during the observation period.

4. Conclusions
In this study, a typical experiment area was selected in the small watershed of the Loess Plateau to carry out soil moisture measurement. Through continuous observation, a series of dependable soil moisture samples were obtained.

It is shown through analysis that soil moisture varies largely with the different soil depths, while the standard deviation and mean value remain relatively stable. The largest soil moisture appears at the depth of 40-60 cm. The variation coefficient of soil moisture initially shows an increasing and then decreasing trend with the soil depth. The largest soil moisture variation was discovered at the depth of 20-40 cm. Soil moisture variability in the depth of 60-100 cm is weak. But in other soil depths, the soil moisture variation was moderate. Standard deviation is below 5%. On the whole, in the same depth, the soil moisture temporal variation is relatively small.

The Loess Plateau is an ecological fragile region. Soil moisture is an important limiting factor for ecosystem restoration and eco-environment improvement in the region. This paper focused on the research of soil moisture measurement, soil moisture calculation, and soil moisture temporal and spatial variation analysis. The study results should provide theoretical basis, scientific and technological support for soil moisture utilization and management in Loess Plateau.

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Declaration of Competing Interest
The author declare that there should be no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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