Temporal variation of soil water and its influencing factors in hilly area of Chongqing, China

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Abstract: The paper studied the temporal variation of soil water content and its influencing factors in hilly area of Chongqing by the yearly data of 2006 and 2007. According to precipitation anomaly percentage, the year 2006 was a dry year and 2007 a normal year. In the dry year 2006, the variations of soil moisture in all three layers (0-10 cm, 10-20 cm, 20-40 cm) were medium (10%<CV<30%); in the normal year 2007, the variation in the layer of 0-10 cm was strong (CV>30%), and those of the two deeper layers were weak (CV<10%). Hence, the seasonal variation of soil moisture in the humid area was large in the dry year and small in the wet year. The probability distributions of soil moisture in all three layers in both dry and normal years showed single-peak shapes. However, peak locations and values varied with different layers and years. Among factors affecting the temporal variation of soil moisture in the 0-10 cm layer, during March to May, the meteorological factors including temperature, sunshine and precipitation were all inversely correlated with soil water content variation. The correlations with average temperature and accumulated temperature were both highly significant $P<0.01$ ($P=0.00$). The inverse correlations with sunshine and precipitation were significant $P<0.05$ ($P=0.01$). Among soil physical properties, except for bulk density which was inversely correlated with soil moisture, all other properties were positively correlated. Organic material was positively correlated with soil moisture, which suggested that organics had the sponge effect and contributed to soil water storage and movement. During the period of June to September, there was no significant correlation between soil water content and total storage. The meteorological factors of temperature, accumulated temperature and sunshine were all inversely and highly significantly correlated with soil water content $P<0.01$ ($P=0.00$).

Keywords: soil water, temporal variation, influencing factors, hilly area

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1 Introduction

Rainfed crops cover more than 80% of global cropped area and account for 60%-70% of global crop production, but the yields of rainfed crops are frequently limited by drought and soil moisture stress[1]. Soil moisture is an important element in the hydrological cycle which is closely related to water and energy transfer between soil, vegetation, and atmosphere. Understanding the spatial and temporal variations of soil moisture is crucial to the parameterization of soil moisture characteristics of land surface components in the atmospheric and hydrologic models. It is known that soil moisture variations in time and space are controlled by many factors, such as soil texture, vegetation, and topography. Soil moisture affects the partitioning of incoming solar radiation into sensible heat flux and latent heat flux and the partitioning of incoming rainfall into surface runoff and subsurface

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infiltration. Thus soil moisture is one of the key parameters governing interactions among atmosphere, land surface, and groundwater[2]. It plays a critical role in controlling the distribution of rainfall into surface evapotranspiration, infiltration, and runoff in the hydrological cycle in a strong and non-linear way[3,4]. Soil water dynamics relates to precipitation, air disturbance, heterogeneous characteristics, topography, accumulation of organics, rooting depth, etc. These variables are associated with complex physical and biological processes of crops. There is a fundamental need to understand the eco-system and hydrological process through an in-depth inspection of soil water dynamics at various temporal and spatial scales[5]. Besides, soil moisture information also has the potential to improve prediction of seasonal precipitation[6].

As the most serious soil erosion area in the Yangtze River Basin, soil moisture in the Chongqing hilly area is a limiting factor of land productivity and crop yields[7]. The 2006 drought in Chongqing and the 2010 drought in the five provinces in Southwest China caused huge economic loss. In general, droughts are characterized by their severity (average water deficiency), magnitude (cumulative water deficiency) and duration. Definitions vary for droughts of different causes and consequences: agricultural, hydrologic, meteorological, and socioeconomic[8]. Several drought indices have been defined for the characterization of droughts including the use of soil moisture.

Variations in drought, flood, and surface temperature are linked to soil moisture dynamics, a determinant parameter in climate modeling. A negative water balance in some key phases during plant growth may affect potential crop yields. Soil water content is an essential parameter for crop growth and yield forecasting in deterministic models, as well as for water stress detection and irrigation management[9]. Due to the poor eco-environment in this area, especially the high temperature in summer which leads to strong evaporation, crop yields can be very seriously affected when droughts happen. The 2006 drought and the relatively balanced precipitation in 2007 had serious impact on the agricultural sector of Chongqing. Hence, through the data acquired every 5 days, the research analyzed the temporal variation of soil moisture. The results have the important theoretical and practical sense for sustainable agricultural development.

2 Materials and methods

2.1 Description of the study area

This study focused on the soil moisture condition of Chongqing in Southwest China. With an area of 82 300 km^2 Chongqing is located at 28°10'~32°13' N, and 105°17'~110°11' E on the north of the Yunnan-Guizhou Plateau and the east of the Sichuan Basin. Chongqing is intersected by the Jialing River and the upper reaches of the Yangtze River. The annual average temperate is 17.7℃, and annual precipitation at 1 140 mm, the total annual length of sunshine at 1 060 hours. It has the Daba Mountains on the north, the Wu Mountains on the east, the Wuling Mountains on the southeast, and the Dalou Mountains on the south.

Chongqing is hilly with more than 50% of the arable land under the slope of 150, and 807 944 hm^2 having a slope between 150 and 250, which accounts for 31.4% the total arable lands, and 415 256 hm^2 above 250, accounting for 16.1%. These slope lands make farming difficult and soil erosion easy. Due to its unique geographic location, the climate in Chongqing is mild with plenty of precipitation which comes with summer heat. However, extreme meteorological disasters such as high temperature, droughts and floods, hails also occur occasionally. For example, the drought in 2006 and the flood in 2007 were both the largest in the past century, which brought huge economic and social losses for Chongqing.

The major soil types in Chongqing are Regosols, Gleysols, Ferralsols, Cambisols, Acrisols and Fluvisols. Most of soils with the PH value are greater than 7, being alkaline soils.

2.2 Soil sampling and monitoring

Distribution of soil water monitoring sites is illustrated in Figure 1. There were about five sites in each district or county, which were a total of 169 sites in Chongqing. From March to September of 2006 and 2007, soil samples were taken from 0-10 cm, 10-20 cm, and 20-40 cm deep under the ground surface in 5-day intervals. Soil water content was measured by microwave oven method[10] and expressed as relative percentage, which means "Soil water content (%) = Soil moisture/Field moisture capacity × 100%". The location is determined by GPS.

Figure 1 Distribution of monitoring sites

According to soil water monitoring sites, 30 other soil samples were taken between March and September of 2006 and 2007 from above sampling network by stochastic spotting, see Figure 2. These 30 soil samples were used for testing the physic-chemical and hydraulic properties. The samples were taken by sampling tube from three layers: 0-10 cm, 10-20 cm, and 20-40 cm under the ground surface to get the retention curve. At the same time, soil was collected by a plastic bag at each layer for indoor experiment of diffusion rates.

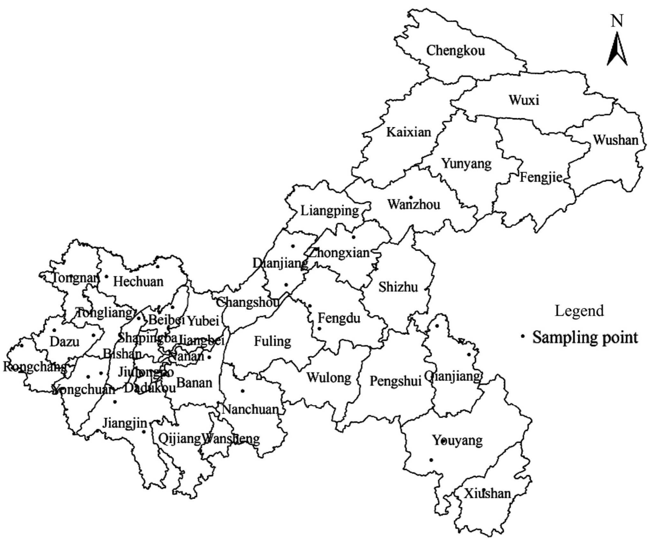


Figure 2 Distribution of stochastic soil sample sites in research area

2.3 Measurements and analysis

The retention curve was measured by No.1500 15Bar Pressure Extractor to measure the water content under 0.33×10^5 par, 1×10^5 par, 3×10^5 par, 10×10^5 par, and 15×10^5 par. Put the saturated samples (24 hrs imbibition) into the container, then gradually increasing the pressure. Under low pressure, the water in the macro pores was drained, with the increasing pressure, the water was gradually drained from micro pores and soil water content decreased. After the drainage stopped, the exerted pressure equals the suctions of soils, which corresponds to soil water content.

The particle distribution of soil was measured by Hydrometer method, bulk density by tube method and total porosity by calculation.

3 Results

3.1 Temporal variation of soil water

Several studies have looked at the temporal variability of soil moisture. A research was done on the characterization of temporal relations between soil moisture and precipitation at a very short time scale, i.e. from 1 h to 2 weeks based on seven soil moisture time series[9]. The research showed that for the 1–48 h scale, soil moisture was linked to precipitation occurrence, intensity and duration, while for the 48 h to 1 week scale soil moisture was related to the periodicity of rainfall events, and for the 1–2 weeks scale to the duration of the dry spells. Tuttle and Salvucci (2014) examined the temporal function of soil moisture, and suggested that it was related to infiltration, cloud coverage, precipitation, and drainage[11]. Soil moisture deficit resulted in more infiltration and little runoff when followed by precipitation. Knowledge of soil moisture within the root zone where active roots reside in soil is essential not only for crop water absorption and crop yields, but also for estimation of fundamental hydrological and atmospheric processes. Soil moisture may be characterized by auto-correlation in time, which means that the lagged effects in inputs or losses can be as important as those occurring at the time when impacts are actually observed[12]. Usually trend analysis is needed for long term soil moisture analysis. There are at least three prevailing methods of the trend analysis. The first method is to draw the linearly regressive trend line over the time series of data to see if it is in upward (increasing) or downward (decreasing) trend[13]. The second is to perform the nonparametric Mann-Kendall (M-K) trend test[14,15] and judge the trend by the value of the M-K statistic[16]. The third method is to compare soil moisture averaged among each of the decades, which is broadly used in the related studies in China[17]. According to the temporal stability, soil moisture site in Mudong can best represent Chongqing's average soil water status[18]. Hence the study will focus on this site to analyze its temporal variation. Time series plots not only provide an increased understanding of the temporal variations of soil moisture, but also allow inter-comparisons of drying and wetting trends and differences between different soil depths. Thus, time series plots were used in this study.

3.1.1 Annual dynamics of soil water variation

From historical records, there was a serious droughts hitting Chongqing in 1936, with very little rainfall from May to August. A similar drought occurred in the year 2006. Table 1 lists the minimum monthly rainfall values from 1891 to 2000 and the year with the minimum values. The rainfall of 1936 and 2006 is also shown in the table[19]. From the table, the rainfall between May to August was similar in 1936 and 2006, both of them were very low. The low rainfall directly affected soil water moisture and hence agricultural production.

Table 1 May to August minimum precipitation during 1891-2000 and the comparison of precipitation between 1936 and 2006 in Chongqing[19]

	Month				
	May	June	July	August	Sum
Min (mm)	51.0	17.3	14.5	3.9	324.2[a]
Year of Min	1994	1961	1899	1976	1930[b]
1936 (mm)	93.7	76.1	208.3	89.1	467.2
2006 (mm)	154.5	129.0	111.6	30.5	425.6

Note: a. The minimum sum precipitation from May to August between 1936 and 2006 was 324.2 mm.

b. The minimum sum precipitation from May to August between 1936 and 2006 happened in 1930.

According to precipitation anomaly percentage of 2006-2007's, 2007 (-5%<P'≤5%) is a normal year and 2006 (P'<-15%) a dry year. Table 2 shows the statistics of soil water in the year 2006 and 2007.

Table 2 Statistics of soil moisture dynamics in 2006 and 2007 at different soil depths

Layer		Min/%	Max/%	Average/%	Median/%	S	k-s	CV/%	Skewness	Kurtosis	amplitude
2006	0-10 cm	38.00	93.00	67.76	70.70	16.15	0.50	22.84	-0.31	-1.08	55.00
	10-20 cm	46.00	114.00	81.19	82.00	16.86	0.63	20.56	-0.21	-0.82	60.00
	20-40 cm	60.00	111.50	84.46	87.25	11.66	0.35	13.36	-0.23	0.10	51.50
2007	0-10 cm	52.00	93.00	79.88	83.00	8.77	0.22	10.57	-1.08	1.49	41.00
	10-20 cm	75.00	104.00	88.57	89.00	5.71	0.23	6.42	-0.01	0.52	29.00
	20-40 cm	82.50	106.00	92.02	88.50	5.16	0.21	5.83	0.87	0.64	23.50

Note: The yearly soil moisture is expressed as relative percentage.

From the table, the average soil water content for 2007 was greater than that in 2006, and both the coefficient of variance (CV) and the amplitude of 2006 were much bigger than those of 2007 at all three depths. CV can reflect the seasonal variation of soil moisture, with CV>30% as strong variation, 10%≤CV≤30% as medium and CV<10% as weak variation. According to these criteria, the variations in all three layers in 2006 were medium. For 2007, the variation for 0-10 cm being strong and the other two layers weak. Hence, in the humid region, the seasonal variation was large during the dry year and relatively small in the wet year. The k-s values for normal distribution test were all greater than 0 for all layers, which suggested that they all fitted well for normal distribution. Except for the 20-40 cm layer in 2007, the skewness values for the shallower layers were negative, which meant a less than average situation. The kurtosis refers to the extent of peak or flatness of probability distribution in comparison with the normal probability distribution. For the 0-10 cm and the 10-20 cm layers' water content in 2006, the kurtosis was -1.08 and -0.82, respectively, which meant a relatively smaller concentration of probability near the mean. However, the values for the 0-10 cm layer and the 20-

40 cm layer in the year of 2007 were both greater than 1, which illustrated the steepness of the peak and meant a relatively bigger concentration of probability near the mean.

3.1.2 Monthly dynamics of soil water variation

Through a t distribution test, with the significance of $p \leq 0.01$, a significant difference was found. Table 3 shows soil water content changes with month. It could be seen that in 2006, from March to May soil water content decreased in a row and from May to June it experienced slight recovery; from June to September, soil water contents decreased rapidly. Furthermore, from June to July, the contents in the layers of 0-10 cm, 10-20 cm, and 20-40 cm decreased by 14.5%, 8.67%, and 11.25%, respectively. From July to August, it decreased by 12.17%, 18.00%, and 6.75% in the three depths, respectively. However, from August to September, water content in the layer of 20-40 cm dropped drastically, while in the layer of 10-20 cm, it dropped rather slowly, and in the layer of 0-10 cm, it had a slow increase. Actually there was a severe drought occurred in Chongqing, with much less rainfall from mid-May to September than regular years. The drought had a huge effect on soil moisture. From Table 3 which shows the comparison of May to August rainfall between 1936 and 2006, it could be seen that the rainfall in May and June of 1936 was 60% of the value of 2006, whereas the rainfall in July and August in 2006 was half of the value of 1936. This was because during the period of May to August which usually has the highest temperature of a year, strong evaporation caused soil moisture to decrease rapidly, and meanwhile agricultural water requirement was very high. As a result, the affected area and the degrees of the drought of these two years were similar. However, the effects of the drought were quite different, with the losses from the 1936's drought being much higher than that of 2006. The reason probably was the less rainfall in May and June of 1936 when it was the key period of crop planting, transplanting and growing. Some other reasons probably included the social and political turmoil in 1936[20] as well as backward technologies.

In 2007, soil water content fluctuated in a W curve. From March to May, due to active growth of crops, soil water consumption was rather large and soil water content decreased rapidly. Up to May, soil water content in the three layers of 0-10 cm, 10-20 cm and 20-40 cm decreased to 74.17%, 83.50% and 86.5%. Crop water requirement went down from May, so did the evaporation, and with the increasing rainfall, soil water content started to recover. In July, soil water contents went to the highest point on average. The relative soil water contents in the three layers rose to 84%, 93.83% and 96.17%, respectively. During the period from July to August, there was a rapid decrease; the rate was 10.91%, 9.24% and 3.81% each. From August, benefiting from rainfall, it started to increase again.

Table 3 Monthly soil water content variation in Mudong (%)

Month	2006			2007		
	0-10 cm	10-20 cm	20-40 cm	0-10 cm	10-20 cm	20-40 cm
Mar	87.83	97.67	93.42	83.33	89.83	92.25
Apr	76.83	90.83	93.92	80.50	89.83	89.08
May	71.33	88.17	87.08	74.17	83.50	86.50
Jun	76.50	89.17	92.50	83.00	88.00	92.58
Jul	62.00	80.50	81.25	84.00	93.83	96.17
Aug	49.83	62.50	74.50	74.83	85.17	92.50
Sep	50.00	59.50	68.58	79.33	89.83	95.08

Note: The monthly soil water content is expressed as relative percentage.

According to the above description, the monthly variation can be divided into crop water consumption period (March to May) and fluctuation period (June to September), coinciding with the separation of implicit periods.

3.1.3 Ten-day dynamics of soil water variation

A month can be divided into three parts, the first ten days, the middle ten days and the last few days (also about ten days). Table 4 shows the ten-day soil water content variation characteristics in the site of Mudong, Banan district of Chongqing in the year 2006 and 2007. From these two figures, it can be seen that no matter it was a normal year or a dry year, there was a drastic fluctuation of soil water content. The first one came from the last ten-day period of March to the second ten-day of April, due to gradually warming weather; the crop water evapotranspiration was very strong which caused drastic change of soil moisture. The second came from the last ten-day period of April to the last ten-day period of June. Due to the uneven distribution of rainfall and high evaporation, the summer dry spells occurred frequently. The third came from the second ten-day period of July to the last of August. During the forty two days, the rainfall changed drastically which led to the substantial fluctuation of soil moisture. From the first ten-day period of September, soil moisture started to recover because of the relatively less crop water evapotranspiration and accumulated rainfall recharge. This was a rather stable period of soil water content variation.

Table 4 Ten-day soil water content variation in Mudong (%)

Month	Ten-day	2006			2007		
		0-10 cm	10-20 cm	20-40 cm	0-10 cm	10-20 cm	20-40 cm
Mar	Frist	84.5	93	92	88	89	91.25
	Mid	93	100	88.25	83	93	94.25
	Last	86	100	100	79	87.5	91.25
Apr	Frist	74	89	99.5	83	87.5	88.5
	Mid	75.5	91	91	74	91	89.25
	Last	81	92.5	91.25	84.5	91	89.5
May	Frist	69	84	86.5	72.5	82.5	87.5
	Mid	72.5	93	90.25	79.5	87.5	88.5
	Last	72.5	87.5	84.5	70.5	80.5	83.5
Jun	Frist	86	101.5	97	76	84	91.25
	Mid	84.5	89.5	93	83	89	93.25
	Last	59	76.5	87.5	90	91	93.25
Jul	Frist	65.5	79	85.5	81	93	93.25
	Mid	60.5	73.5	78	90	96	97
	Last	60	89	80.25	81	92.5	98.25
Aug	Frist	46.5	64.5	82.25	84.5	89	96
	Mid	43	59	71.25	79.5	86	94
	Last	60	64	70	60.5	80.5	87.5
Sep	Frist	52	50	66.25	81	95	97
	Mid	48	60.5	66.25	84.5	89	100
	Last	50	68	73.25	72.5	85.5	88.25

Note: The ten-day soil water content is expressed as relative percentage.

Due to the impact of meteorological drought of 2006, the fluctuation of soil moisture in this year was much bigger than that in 2007. All three layers had ups and downs in moisture. In this year, there were to troughs in soil moisture. The first occurred from the second 10 days of March to the second 10 days of May. In this period, it was not only a duration of high crop water consumption, i.e. the spring dry spell period, but also the latent period of summer dry spell and the dog-day dry spell. It directly threatened crop yields. The second trough was from the last 10 days of June to the late September, mainly due to the uneven distribution of rainfall, which had the most serious damage to agriculture. In 2007, the ten-day soil water change was rather smooth. During the period between the last ten days of July to late August, affected by both rainfall and evapotranspiration, the relative soil water contents continuously decreased, almost to the lower limit of the most suitable soil water availability. In September, benefited from rainfall, soil moisture started to restore. Hence, the seasonal variation of rainfall directly affected the distribution of soil moisture with time.

3.1.4 Five-day interval dynamics of soil water variation

In order to know the short time variation of soil moisture, it is necessary to perform daily analysis of soil water content layer by layer (see Table 5).

Table 5 Daily soil water content variation in Mudong (%)

Day	2006			2007		
	0-10 cm	10-20 cm	20-40 cm	0-10 cm	10-20 cm	20-40 cm
3-3	86	93	90	86	89	92
3-8	83	93	94	90	89	90.5
3-13	93	100	88	76	93	88.5
3-18	93	100	88.5	90	93	100
3-23	86	93	111.5	79	86	92.5
3-28	86	107	88.5	79	89	90
4-3	79	82	108.5	83	86	88.5
4-8	69	96	90.5	83	89	88.5
4-13	79	89	92	72	89	88.5
4-18	72	93	90	76	93	90
4-23	79	89	88.5	79	89	88.5
4-28	83	96	94	90	93	90.5
5-3	66	86	88.5	83	86	88.5
5-8	72	82	84.5	62	79	86.5
5-13	79	104	96	76	89	88.5
5-18	66	82	84.5	83	86	88.5
5-23	69	82	84.5	62	75	82.5
5-28	76	93	84.5	79	86	84.5
6-3	86	107	98	69	79	86.5
6-8	86	96	96	83	89	96
6-13	90	93	96	83	89	96
6-18	79	86	90	83	89	90.5
6-23	66	82	90.5	90	93	90.5
6-28	52	71	84.5	90	89	96
7-3	59	79	80.5	83	93	92.5
7-8	72	79	90.5	79	93	94
7-13	69	79	82	90	96	100
7-18	52	68	74	90	96	94
7-23	72	114	80	76	96	102.5
7-28	48	64	80.5	86	89	94
8-3	45	68	90.5	93	96	98
8-8	48	61	74	76	82	94
8-13	38	57	78	83	86	94
8-18	48	61	64.5	76	86	94
8-23	48	64	68	52	79	88.5
8-28	72	64	72	69	82	86.5
9-3	38	54	70	76	86	90
9-8	66	46	62.5	86	104	104
9-13	48	57	62.5	86	82	94
9-18	48	64	70	83	96	106
9-23	41	54	60	79	89	86.5
9-28	59	82	86.5	66	82	90

Note: The daily soil water content is expressed as relative percentage.

The upper layer (0-10 cm), being the most sensitive one due to the effect of rainfall and evapotranspiration, changed drastically. The lowest point occurred on August 13th and September 3rd of 2006 and August 23rd of 2007, reached the value of 38% and 52%, respectively. The highest point occurred on March 13th and 18th of 2006 and August 3rd of 2007 when the relative water content went to 93% on the three dates.

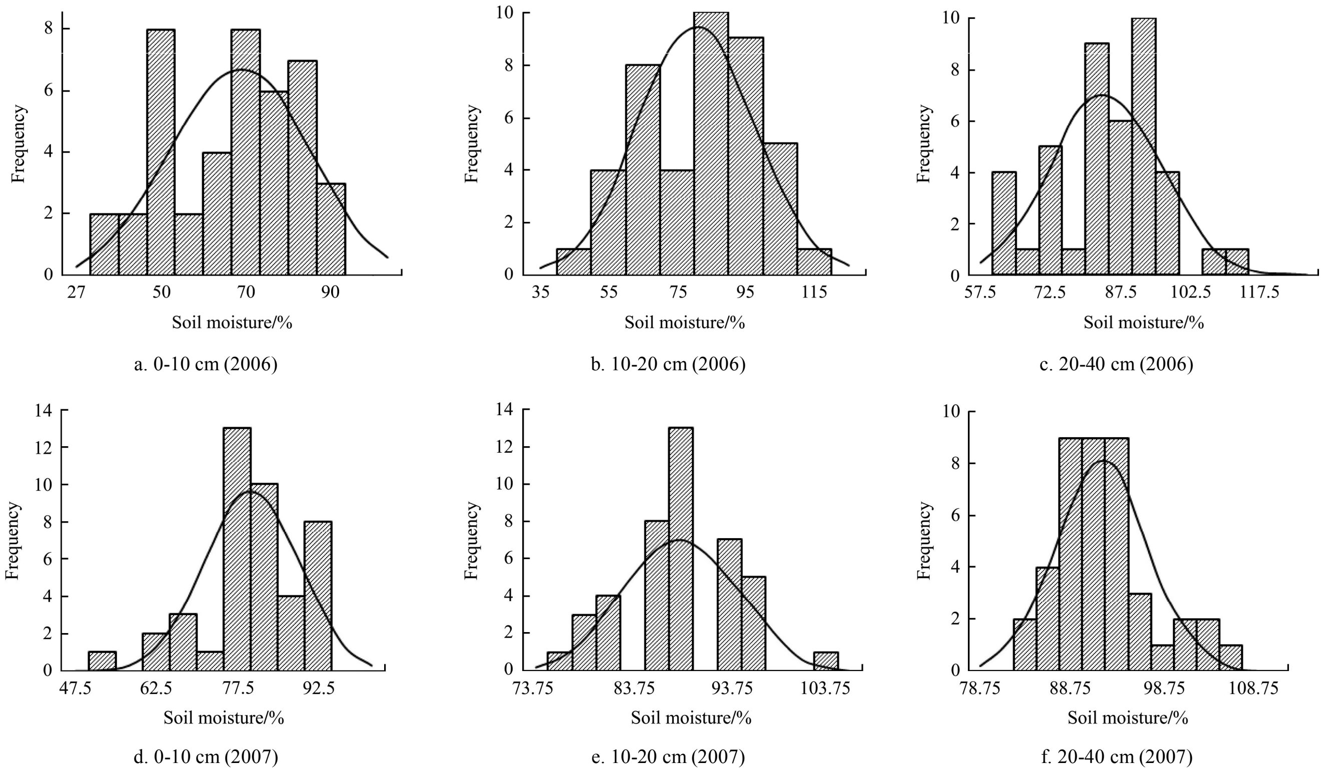
For the 10-20 cm layer, the lowest point occurred on 8th September in 2006 and 23rd May in 2007 with the relative content of 46% and 75% each. The highest point was on 23rd July 2006 and 8th September 2007 with the value of 114% and 104% each.

For the 20-40 cm layer, the lowest point was on 23rd September 2006 and 23rd May 2007 with the values of 60% and 82.5%; the highest point was on 23rd March 2006 and 16th September with the values of 111.5% and 106%.

The date for the lowest point of soil water content occurred was different from layer to layer. In the dry year, the date of the lowest point for the layer at 10-20 cm and at 20-40 cm was the same. However, in the normal year, the same lowest point happened at the layers of 0-10 cm and 10-20 cm. The substantial differences illustrated that soil moisture change was not uniform or completely correlated among layers. It was affected by rainfall and crop growth.

3.2 Characteristics of stochastic distribution of soil moisture

The research studied the probability distribution of soil water content monitored in 5 days from March to September. Figure 3 gives the probability distribution of soil moisture at different layers in 2006 and 2007. It can be seen for the dry year and the normal year, all the distribution in three layers had a single peak shape.



Note: Soil moisture is expressed as relative percentage.

Figure 3 Probability distribution of soil moisture at different layers in different year

In the dry year of 2006, the peak appeared at the location of relative contents equal to 70% for the layer of 0-10 cm. The values mainly distributed around 50%, 60%-90%, not too much around 35%-60%. For the layer of 10-20 cm, the location for the peak was higher than the location of 0-10 cm, with s=80%. The band of the peak was wider than the one at 0-10 cm, ranging from 40%-120%. The location for the layer of 20-40 cm was even higher, with s=90%. The band ranged from 60%-100%, with few around 110%. There were also some leaps in the peak area.

In the normal year of 2007, for the layer of 0-10 cm, the peak appeared at s=80%. The values mainly distributed around 60%-95%; for the layer of 10-20 cm, the peak location was at s=90% and the peak range was discrete. The values distributed at 75%-82.5%, 85%-90% and 92.5%-95%; and for 20-40 cm, the peak location peak was with s=95%, the peak band ranging from 82.5% to 107.5%.

Apparently, the location of the peaks of the distribution for different years (dry and normal years) had some difference, with the former appearing around 80% and later 90%. Also the distribution range of former was wider than the later. There were some values lower than 60% for 2006 while for the later bigger than 60%. Actually, no matter in the dry year or the normal year, Peak locations increased with layer depths. The bands of the peak became narrower with layer depths, focusing on middle to high values.

3.3 Factors affecting temporal variation of soil moisture

The spatial and temporal variability of soil moisture conditions (specifically the total amount of water contained within a given soil mass or volume) are influenced by a number of competing factors[21]. The factors include soil properties and organic material[22-24], topography[25,26], mean soil moisture content[22,27,28], depth of the water table, vegetation[29,30] and meteorological parameters, including precipitation and solar radiation[26]. Factors affecting soil moisture are different with seasons. According to the seasonal division of the study above which was March to May and May to September, this section gave the main controlling factors affecting soil moisture in these two periods. The meteorological, soil physical, land use patterns were analyzed to test the significance of their impacts on soil water content in different layers. Table 6 gives the results of correlations under P=0.05 and P=0.01 separately.

Table 6 Correlation coefficient between soil moisture and its affecting factors

Period	0-10 cm		10-20 cm		20-40 cm		0-40 cm	
	Mar-May	Jun-Sep	Mar-May	Jun-Sep	Mar-May	Jun-Sep	Mar-May	Jun-Sep
Average T	-0.42	-0.60	-0.22	-0.46	-0.15	-0.43	-0.21	-0.47
Accumulated T	-0.41	-0.59	-0.22	-0.45	-0.15	-0.42	-0.21	-0.47
Precipitation	-0.20	0.50	-0.26	0.35	-0.08	0.39	-0.16	0.39
Sunshine	-0.22	-0.55	-0.19	-0.43	-0.15	-0.38	-0.20	-0.43
Total Reservoir	0.21	0.15	0.06	0.17	0.31	0.25	0.14	0.14
Eff Reservoir	0.40	0.14	0.35	0.30	-0.06	0.06	0.11	0.10
Wilting point	0.02	0.03	-0.17	-0.05	-0.13	-0.08	-0.09	-0.04
Field capacity	0.13	0.00	0.16	0.13	-0.18	-0.01	-0.04	-0.01
Organics	0.20	-0.04	-0.07	-0.24	0.18	0.07	0.13	-0.07
Bulk Density	-0.14	-0.11	0.06	-0.02	-0.12	-0.02	-0.01	0.02
Total Porosity	0.14	0.11	-0.06	0.02	0.12	0.02	0.01	-0.02
Landuse	0.18	0.05	-0.18	0.06	0.23	0.10	0.10	0.07

3.3.1 Controlling factors affecting 0-10 cm soil moisture variation

For the 0-10 cm layer, during March to May, it can be seen from the table that the meteorological factors including temperature, sunshine and precipitation were all inversely correlated with soil water content variation, among which the average temperature and accumulated temperature were highly significant P<0.01 (P=0.00), while sunshine and precipitation were significant P<0.05 (P=0.01), both inversely. Furthermore, when the temperature, sunshine and accumulated temperature were high, the significance of other factors was rather weak. For soil physical properties, except the bulk density was inversely correlated, all other properties like total reservoir, wiling point content, field capacity and organics, total porosity were all positively correlated. Among which, total reservoir, field capacity, wilting point content and porosity were significant, where effective reservoir was highly significant. Because soil water reservoir and effective are important factor to store water and supply water plant use, the big reservoir means it can hold more water for regulation in soil water balance. Plants cannot extract of the water that is present in soil. The available moisture AM id defined as the amount of soil water that is present in the root zone between field capacity and wilting point. The water pressure in the root zone corresponding to wilting point is defined at a pressure head of 16 bar or pF 4.2. Many crops suffer from drought and show signs of wilting when the pF in the root zone reaches values higher than 2.4-3.0 in which the availability of water starts to limit plant growth. In hilly area of Chongqing, the small storage capacity of the hilly area is the most significant reason of seasonal drought in this region. For another factor of land use pattern, the table showed a positively correlation which means that soil water content in rainfed agricultural land was higher than grassland. It seems strange that the precipitation had an inversely correlation with soil water content from March to May, the reason probably is that there are very little rainfall in this period and also a period of fast crop growth leading to rapidly evapotranspiration. The organic material is positively correlated with soil water content, which showed that the organics are advantageous to soil water storage and movement, acting as a function of sponge.

During the period of June to September, there was no significant relationship between soil water content and total storage. The meteorological factors of temperature, accumulated temperature and sunshine were all inversely correlated with soil water content in a highly significant way $P<0.01$ ($P=0.00$). The correlation with precipitation in this period was highly significant. The reason should be due to more rainfall in this period and there is enough water infiltrated into soil. Total porosity had the similar relationship with the period of Mar to May.

3.3.2 Controlling factors affecting 10-20 cm and 20-40 cm soil moisture variation

For the layer of 10-20 cm, from March to May, it can be seen from the table, the meteorological properties of average temperature, accumulated temperature and precipitation were all significant, inversely correlated with soil moisture at $P<0.05$ level. The effective reservoir was highly significant at $P<0.01$ level. In this layer, no significant relationship was found between sunshine, landuse pattern, total porosity, bulk density, organics, field capacity, wilting point these properties with soil water content. For the period of June to September, similar results were as from March to May except organics had significant correlation.

For the layer of 20-40 cm, from March to May, there was no significant relationship found between meteorological factors and soil water content. A highly significant correlation was with total reservoir and a significant relationship with landuse pattern. During the period of June to September, there was highly significant correlation between the meteorological factors like temperature, accumulated temperature and sunshine with soil water content inversely. A highly significant correlation existed between precipitation and total reservoir with soil water content at the level of $P<0.01$.

4 Discussion

4.1 Soil water dynamics with time

For many application questions in the fields of crop production and agronomy, soil water dynamics are of fundamental importance. After heavy rainfall, especially prolonged rainfall, the root zone can be saturated with water. Not all of the water is available for crops. A part percolates to the subsoil or becomes groundwater before it can be taken up by plants. This drainage of excess water from the root zone is an important process since most crops suffer from oxygen deficiency when soil remains saturated for a long period of time. In this study, there is substantial difference of soil water moisture between the dry and the normal years. In the normal year of 2007, the overall water content was high, but with big variation. However, in the dry year of 2006, the overall water content was low, and the variation and amplitude were rather small. In 2007, soil water content was high due to continuous rainfall and high initial soil moisture. However, in the dry year and its following year, soil water content was low, vice versa. Similar findings were discovered by other researchers in different land use patterns. The reason probably was the frequent rainfall that recharged soil moisture by infiltration[31]. In 2006, the biggest drought in the past century hit the Chongqing area, causing prolonged soil moisture decrease. Soil water content was so low that even the subsequent rainfall could not compensate for soil water deficit. As a result, the water content in 2007 was also low. The reason could be viewed from two aspects: first, the initial soil moisture was quite low, and the dry cover hindered the infiltration and recharge; second, the winter drought in this area led to little rainfall to satisfy soil moisture.

According to the two years' variations analyzed above, monthly variations can be divided into two periods: the consumption period from March to May and drastic fluctuation period from June to September. Ten-day period variations can be summarized into four violent fluctuation periods: mid-March to mid-April, late April to mid-June, mid-July to late August, and early September to late September. The results on seasonal variations are similar to previous researches[32]. However, soil water content study must be viewed within local context, including climatic, geological and hydrological conditions and farmers' practices. Hence, for different regions and conditions there shall be unique local experiences and practices.

For the vertical variations in different layers, the minimum, maximum values did not appeared at the same time of year; there was some time lag in different years. From the 10-day period variation, no matter in a dry year or in a wet year, the effective depth from infiltration of rainfall was 0-40 cm. Monthly average data showed that the water content in the 0-10 cm was the lowest, whereas 20-40 cm had the highest water content in most months, with 10-20 cm being in the middle. The data showed that soil water content increased with depth. Statistics described soil moisture distribution in time showed a lower temporal variability at points in deeper soil layers[33].

From the monthly, 10-day period and daily water dynamics analysis, soil water distribution did not always increase with depth. In April and May 2006 and April 2007, soil water content variation in 0-10 cm, 10-20 cm, and 20-40 cm depth showed low, high, and low situation, respectively. Less water in the 20-40 cm would benefit deep percolation. For the other months, soil water content increased with soil depth. The driving force for the transport of water is the gradients of pressure head and gravitational head. The latter is constant in time and changes from zero in horizontal direction to one for vertical flow. The pressure head gradient may, however, be in several orders of magnitude larger for water infiltrating into dry soil. In this situation soil water has the potential to move upward, which prevents infiltration after rainfall. The results is not consistent with the previous research that claimed the upper layer was the first part to catch rainfall and was the most sensitive layer for infiltration and evaporation. But the results agree with previous finding on shorter duration (30 min) monitoring results. Liu et al (2007) attributed the finding to the uncertainties associated with scale transfer[34].

In addition, for the 2006 year's drought, if compared with the minimum monthly rainfall of May to August from 1891 to 2000, four-month rainfall (425.6 mm) in 2006 was even higher than the value of 1930 (324.2). Hence, if only evaluated from rainfall, 2006's drought was not the severest drought occurred. Furthermore, none of the monthly values in 2006 was the lowest compared the recorded data. Even for August 2008, the month with the least rainfall of the year, the rainfall was 30.5 mm, higher than the lowest record of 3.9 mm[20].

In summary, in all three temporal dynamics analyses, soil moisture temporal variation was obviously depth dependent. The temporal dynamics was more pronouncedly closer to soil surface, where soil was subjected to the root water uptake and rainfall events. Temporal soil moisture dynamics study was very important for understanding soil water balance and hence for agriculture, especially, rainfed agriculture. To improve the utilization of rainfall more efficiently, it is necessary to know the water storage and movement in soils. This study on temporal variation would, to some extent, help the in-situ rainfall use and RWH in the hilly area of Chongqing.

4.2 Components influencing soil water dynamics over time

The structure of soil top layers is subject to changes over time through wetting and drying, solution composition, agricultural operations, and biological activity. There are several factors influencing temporal soil water variation. For soil of 0-40 cm depth, from March to May, there was a highly significant inverse correlation between soil moisture and meteorological factors including average temperature, accumulated temperature and sunshine (P<0.01). These conditions are of critical importance for crop growth in this period. Vegetation growth, and the subsequent evapotranspiration and root water uptake play ineligible roles in temporal dynamics of observed soil moisture patterns[35]. There was a significant correlation between organic materials and soil water content, and a significant inverse correlation with precipitation. From June to September, precipitation was positively correlated with soil water content in a highly significant way (P<0.01). The other factors function similarly with those from March to May.

Hence, no matter what period (March to May, June to September) it is, meteorological factors like average temperature, accumulated temperature and sunshine significantly affect soil water content. Function of precipitation is season-dependent. From March to May, rainfall cannot satisfy soil moisture deficit. Furthermore, active growth of vegetation consumes a lot of water. From June to September, rainfall can meet soil moisture deficit.

About soil physical properties, the total reservoir and effective reservoir are important factors for soil water storage and utilization. Field capacity and wilting point directly affect the available moisture and hence determine the crop water absorption and yields. Especially, the 0-20 cm layer's water content significantly correlated with the reservoirs.

Organic materials in the 0-10 cm, 10-20 cm layers were significant correlated with soil water content. The higher organics leads to the higher water content which is because the organic materials contribute to soil's ability to store and transport water. Organic matter influences soil physical conditions in several ways. Plant residues that cover soil surface protect soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration and reducing runoff. Surface infiltration depends on a number of factors including aggregation and stability, pore continuity and stability, the existence of cracks, and soil surface condition. Increased organic matter contributes indirectly to soil porosity (via increased soil faunal activity). Fresh organic matters stimulate the activity of macro fauna such as earthworms, which create burrows lined with the glue-like secretion from their bodies and are intermittently filled with worm cast material. Over a long period, improved organic matters promote good soil structure and macro-porosity. Water infiltrates easily and keeps soil with more oxygen, which will all benefit crop growth.

The landuse pattern also has some influence on soil moisture. In this study, the land use is mainly about rain-fed agricultural and natural grassland. It can be found that the rain-fed agricultural land had higher water content than grassland. This result agreed with a former researches[36], in which soil water content was found in the following ranking: agricultural land > forest and grassland > shrubs. The finding also illustrated that with the increasing soil depth, the correlation between landuse pattern and soil water content increased[37].

Previous researchers explored the relationship between altitude and soil water content. They found that soil water content decreased with altitude[38,39]. This is probably because the low temperature and high rainfall with increasing altitude. Furthermore, agricultural activities in low altitude are more developed than in high altitude, which probably leads to more utilization of soil moisture. Soil structural properties also affect soil water variation with time. For instance, soil tillage is used to improve soil structural properties by changing soil pore-size distribution (PSD). Since these modifications are quite unstable over time, the PSD, expressed by its median pore radius, decreases after tillage[40,41]. This effect should be maximized through conventional tillage (CT) in which soil is ploughed after harvest every year.

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