Research Article

Field Monitoring-Based and Theoretical Analysis of Baota Mountain Landslide Stability

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Received 17 December 2020; Revised 4 March 2021; Accepted 11 March 2021; Published 23 March 2021

Academic Editor: Jian Xu

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Landslide is one of the most widely distributed surface morphological landscapes, and it can cause a series of major economic and human losses. Field monitoring and limit equilibrium methods were applied to investigate Baota Mountain landslide stability, and soil volumetric water content, different scales of rainfall data, and landslide displacements were monitored using various equipment. The theoretical factor of safety was also calculated for the landslide. Finally, the theoretical results were validated by monitoring data in the field. The results demonstrate that soil volumetric water content experienced the greatest change with time at a depth of 0.2 m and then 1 m; however, the change in soil volumetric water content was relatively small with time at a soil depth ranging from 2.0 m to 4.0 m. Soil volumetric water content also did not change with time at a soil depth of 5.0 m and below. In addition, the retardation effect was found in different depths of volumetric water content for continuous rainfall. The safety factors were 2.713 and 1.133 for landslide No. 1 and landslide No. 2, respectively. These results indicate that landslide No. 1 is relatively stable, but there is a probability of the occurrence of movement in landslide No. 2. The monitoring displacement data indicate that landslide No.1 was in a relatively stable state between 2008 and 2013, and this result was in accordance with the value of theoretical calculation. This study provided relevant parameters for numerical simulation of landslides in loess areas.

1. Introduction

Landslides are one of the most widely distributed surface morphological landscapes and can cause a series of major economic and human losses [1–3]. Landslides also constitute the most important disaster type that can influence surface geomorphology processes [4, 5]. Therefore, research that focuses on landslide stability is both significant and worthwhile [6, 7].

The landslide stability problem has been developed for evaluating the safety of hillslopes [8]. Some researchers studied and discussed current methods, which included physical models, field monitoring, and numerical analysis for slope stability analysis in detail [9–11]. When physical models were used to simulate slope stability, the soil structure usually changed during the construction of artificial slopes [12]. Some researchers also utilized field surveys and the freeze-thaw cycling theory to elucidate the mechanisms of natural and

artificial slope failures in the Loess Plateau, China [13, 14]; however, these approaches cannot directly reflect the deformation processes of the landslide prototype. Subsequently, a series of pieces of equipment have been widely applied to monitor landslide displacement, which constitute direct and efficient ways to determine landslide stability and calculate its threshold, especially for single landslides [15, 16]. Field monitoring of landslide stability from 2013 to 2016 in the Three Gorges Reservoir, China, was performed with different types of equipment, and the results demonstrated that landslide deformation reverted to seasonal stepwise cumulative displacements influenced by cycles of reservoir draw-down and rainfall [11]. It is worth noting that the monitoring data could be obtained each hour and in even shorter units of time. Tecca et al. (2003) applied various apparatuses to measure pore water pressure and volumetric water content for a landslide in Acquabona, Italy, and found that an

instantaneous and vertically upward pore water pressure and volumetric water content were increased in a shallow slope [17]. Uhlemann et al. (2016) assessed ground-based monitoring techniques for landslide investigations in Hollin Hill landslides, UK, and demonstrated that the global positioning system (GPS) network of markers can offer a higher temporal and spatial resolution for landslide stability analysis [18]. Vassallo et al. (2020) implemented a system of inclinometers and GPS to determine landslide displacement in southern Apennines, Italy [19]. The above-mentioned achievements indicated that field monitoring and measurements are highly effective ways to obtain the stability of single landslides. However, monitoring of volumetric water content regarding landslide stability was performed relatively less frequently; in fact, volumetric water content is a key factor to analyze landslide stability [20]. With technological advancements, a large number of numerical methods were applied to calculate the stability of landslides. The basic approach is to determine a safety factor or stability threshold to prevent sliding failure of a given slope, but these methods vary markedly in simplification and accuracy [21, 22]. Meanwhile, conventional methods of slope analysis based on the concept of limit equilibrium have been broadly implemented, due primarily to their simplicity and applicability [8]. The main difference was in assumptions made about the shape of the slide surface (circular, plane, and logarithmic) for different limit equilibrium methods, and equilibrium equations were applied [9]. Subsequently, the slip surface would be divided into a series of slices with the process of computation, and the implemented limit equilibrium methods included simplified Bishop's, Janbu's, Spencer's, and Morgenstern-Price methods [22]. These methods are commonly employed to calculate the safety factor of slope stability in geotechnical engineering applications [23]. Zolkepli et al. (2019) used the modified Fellenius' and Bishop's methods to calculate the safety factor of slopes located at Pahang Matriculation College, Malaysia, and the results showed that the theoretical calculated values were highly similar to the monitoring data [24]. Limit equilibrium methods were also carried out to simulate the whole process of a landslide, particularly in the large deformation of soils during the landslide [22]. Above all, the values of landslide stability can be obtained conveniently by limit equilibrium methods.

The aim of this study is to determine the stability of Baota Mountain landslides for Yan'an City, Shaanxi Province, China. Field monitoring and limit equilibrium methods were used to study landslide stability, soil volumetric water content, and landslide displacements. In addition, the theoretical factor of safety was calculated for landslides. Finally, the different results were compared, and the theoretical results were validated by monitoring data. This study provided relevant parameters for numerical simulation of landslides in loess areas.

2. Study Area

2.1. Baota Mountain Landslide. Baota Mountain is located in the Baota District, Yan'an City, Shaanxi Province, in the northern part of Xi'an City (Figure 1(a)). The study area is

approximately 320 m long and 30–50 m wide and constitutes typical loess beam topography, which is surrounded by deep valleys and gulleys. In addition, Baota is located at the top of Baota Mountain (Figure 1(b)) and was built during the Tang Dynasty. Baota is 44 m high, with nine floors, and is a well-known symbol of the historic Yan'an City.

There are two landslides (landslide No. 1 and landslide No. 2) on Baota Mountain. Landslide No. 1 is distributed in the western part of the loess slope and is 85 m long from east to west and 95 m wide from north to south, and its main sliding direction is NW 65°. The maximum thickness of the landslide is approximately 20 m, and its total volume is $9.4 \times 10^4 \text{ m}^3$. The elevation of the trailing edge of the landslide is 1,040 m, and the escarpment of the trailing edge ranges from 1 m to 3 m, within 2.5 m–4 m and 1 m–2 m in the north and south, respectively. Therefore, a concave slope with three sides of steep slope was formed, which exhibits typical landform characteristics of landslides. The shear outlet of the landslide is 974 m, and the height of the slope is approximately 66 m. The surface morphology of the landslide alternates with steep slopes and gentle slopes. Vegetation is comparatively better in the sliding area, especially in the middle of the landslide (Figure 1(c)).

Landslide No. 2 is distributed in the eastern part of Baota Mountain. It is a small landslide that was developed in loess areas. The elevations of the trailing and the leading edge are approximately 1,040 m and 1,015 m, respectively, and the main sliding direction is NE 80°. The landslide is approximately 17 m long from east to west and approximately 25 m wide from north to south, and its total volume is approximately 975 m^3 . There are a series of steep walls in the three sides of the landslide (north, west, and south), within 1 m and 3 m high. An artificial retaining wall 2 m–3 m high is in the front of the landslide (Figure 1(d)). The soil mass of the landslide is fractured into pieces, and many fissures exist. Moreover, the vegetation is well developed on the landslide, and it is in a generally stable state. However, the slopes are becoming increasingly steep due to the construction of roads, which has led to a rising risk of local slides.

2.2. Geologic and Climatic Settings. The lithology of Baota Mountain is Jurassic sandstones underlying Quaternary loess, which are interspersed with lenticular sand-gravel layers of Early Pleistocene in the middle (Figure 2(b)). The maximum thickness of the Upper Pleistocene loess is 12.5 m, among which the components of particles of the Upper Pleistocene loess are largely silt, and with a loose structure and large pores [25, 26]. The maximum thickness of the Pleistocene loess is 63.6 m, with relatively high clay content, and the average thickness of the loess is between 20 m and 30 m. The thickness of Jurassic sandstone is relatively thick in the Yan'an region. The top surface of the basement rock of Baota Mountain is a pale-eroded terrain that slopes slightly northeast. There is no groundwater within 5 m below the bedrock surface.

The study area is located in the Northwest part of China, exhibits a semihumid and semiarid continental monsoon climate, and has a mean annual rainfall of 562 mm. Rainfall

(a)

(b)

(c)

(d)

FIGURE 1: Study area: (a) location of the landslide in China; (b) landslide panorama; (c) landslide No. 1; (d) landslide No. 2.

mainly occurs in the period from June to September, accounting for approximately 70% of the total annual rainfall, and thundershowers occur frequently. Daily and hourly maximum rainfalls were observed in 1981 (~139.9 mm) and 1979 (~62 mm), respectively [27]. In addition, flash and prolonged heavy rainfall events often take place in the region, thereby triggering a series of geological disasters, especially landslides and debris flows.

3. Methods

The limit equilibrium method was selected to calculate landslide stability [28], and field monitoring was applied to obtain landslide displacement. Subsequently, the results of theoretical calculation were validated by the results of field monitoring.

3.1. Theoretical Calculation of Landslide Stability. The limit equilibrium method is a crucial method to calculate the stability of landslides [29–31]. Although some theoretical shortcomings exist in this method, it has been improved after a series of researches [32, 33]. For example, the

modified Bishop's method is slightly different from the ordinary method of slices in normal interaction forces in that the adjacent slices are assumed to be collinear and the resultant interslice shear force is zero [29]. The constraint introduced by normal forces in slices makes the problem statically indeterminate. As a consequence, iterative methods should be utilized to solve the factor of safety. The method has been shown to produce a safety factor within few percents of the "correct" values. F_s for moment equilibrium in Bishop's method was given by Bishop (1955) [28]:

$$F_s = \frac{\sum [c'_i b_i + (W_i - u_i b_i) \tan \phi'_i] \zeta_i}{\sum W_i \sin \alpha_i + \sum Q_i (e_i / R)}, \quad (1)$$

where F_s is the safety factor; c'_i is the cohesive force; ϕ'_i is the internal friction angle; α_i is the slope angle of the bottom of each slice; b_i is the width of each slice; W_i is the weight of each slice; u_i is the water pressure at the base of each slice; ζ_i is the slice index; e_i is the horizontal interslice force; and R is the radius of the arc face.

The parameters were obtained from drilling data and experimental results, the specific parameters of which are presented in Table 1.

- Parking lot
- Baota
- Rainfall monitoring
- Datalogger
- ZK monitoring
- TDR monitoring
- Road
- Landslide boundary
- Scarp
- Contour line
- Building

(a)

- Late Pleistocene loess
 - Paleosol
 - Sandstone
 - Rupture and sliding direction
 - Inclinator and its depth
 - Middle Pleistocene loess
 - Calcium concretion
 - Landslide deposit
- Borehole number surface elevation (m)
 hole depth (m)

(b)

FIGURE 2: Continued.

FIGURE 2: Schematic of monitoring system in Baota Mountain landslide and vertical section of boreholes with monitoring sensors: (a) schematic of monitoring system in Baota Mountain landslide; (b) distribution of ZK; (c) distribution of TDR.

TABLE 1: Parameters for landslide No. 1 and landslide No. 2.

Soil type	Density (kN/m^3)		Cohesive force (kPa)		Internal friction angle ($^\circ$)	
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2
Q_2	17.1	17.6	50	76.2	32	18
Q_3	15.3	15.6	40	30.1	28.1	23.2
Q_4	13.6	—	26	—	24.0	—
Ancient soil	20.36	20.36	66	48.7	36.1	22.8
Medium-coarse sandstone	22.1	—	1000	—	45	—

The GEO-SLOPE module of GeoStudio software (<http://softwaretopic.informer.com/geostudio-software-for-mac/>), which embedded the Bishop method, was carried out to calculate slope stability. The height was approximately 103 m and 22 m for landslide No. 1 and landslide No. 2, and their width was approximately 200 m and 40 m, respectively. The soil types of landslide No. 1 were Late Pleistocene soil (Q_3), Holocene (Q_4) soil, ancient soil, Middle Pleistocene (Q_2) soil, and medium-coarse sandstone from the top to the bottom of landslide No. 1, respectively. The soil types of landslide No. 2 were Q_3 , ancient soil, Q_2 , ancient soil, and Q_2 , medium-coarse sandstone from the top to the bottom of landslide No. 2, respectively. The minimum depth of the sliding surface was set to approximately 0.1 m for both

landslide No. 1 and landslide No. 2, the number of soil bulks was 100, and the maximum number of convergent iterations was 5,000. The boot range of the sliding surface was set at the top loess layer of Q_3 and Q_4 , and the range of roll-out was set at the foot loess layer of Q_4 for landslide No. 1. With respect to landslide No. 2, the sliding surface was distributed in the top loess layer of Q_3 , and the range of roll-out was set at the foot of the loess layer of Q_2 . Groundwater was not considered in the process of slope stability calculation.

3.2. Field Monitoring. An integrated monitoring system was built and installed during the test pile construction. The monitoring system comprised displacement monitoring

stations, and soil volumetric water content, inclinometers (ZK), soil volumetric water content sensors (TDR) in the boreholes, and rain gauges were fixed to the test piles (Figure 2). The monitoring system consisted of displacement monitoring stations and a soil volumetric water content monitoring system, which includes inclinometers (ZK) and soil volumetric water content sensors (TDR) in the boreholes, and rain gauges were fixed to the test piles.

In 2007, three displacements monitoring sensors (ZK) were installed in landslide No. 1 (Figure 2(a)), the specific information for which is shown in Table 2 and Figure 2(b). The resolution of the equipment was 0.015 mm/h, and the monitoring period was from September 2008 to May 2013. Eight soil volumetric water content sensors (TDR) were fixed in landslide No. 2 (Figure 2(a)), the detailed information of which is presented in Table 2 and Figure 2(c). The error of TDR was less than 3%, and the monitoring data were taken from October 2008 to March 2013. Rainfall gauges were installed on landslide No. 2, and the diameter of the measuring cylinder was 20 cm. The rainfall monitoring period was from October 2008 to March 2013.

4. Results and Discussion

4.1. Volumetric Water Content (VWC)

4.1.1. Hourly Soil Volumetric Water Content. Figure 3(a) shows the relationship between VWC and daily rainfall from October 2008 to March 2013, and the trends of VWC were similar in different years. Specific examples are shown in Figures 3(b) and 3(c). The results of changes conformed to the natural phenomena, which indicated that the data were relatively reliable. The monitoring data of TDR 2-1 gradually increased during heavy rainfall, and the increase of VWC was earlier when heavy rainfall became greater. The monitoring data of TDR4-1 are shown in Figure 3(a). The VWC was at its maximum value among all monitoring points, because TDR4-1 was located at the top of landslide No. 2. The VWC of TDR 2-1 is shown in Figure 3(b). The soil VWC increased after 5 h of rainfall; however, the soil VWC of TDR 2-1 increased from 2 h after the end of the rainfall (Figure 3(c)), indicating that the changes of VWC were delayed in response to rainfall.

4.1.2. Daily Soil Volumetric Water Content. The daily change in soil VWC in different monitoring points of landslide No. 2 is presented in Figure 4. This monitoring was representative in loess regions, because the monitoring point of VWC was distributed in a natural slope [34]. The soil VWC was obviously affected by daily rainfall when the soil depth ranged from 0 m to 1 m (Figure 4); however, the VWC was stable when the soil depth was more than 2 m. In addition, the VWC of surface soil (0.2 m) was slightly increased when the daily rainfall was greater than 10 mm, but the VWC was unchanged in the soil depth of 1 m. The VWC obviously increased above the soil depth of 1 m when daily rainfall reached up to 50 mm, but the VWC was stable at the soil depth of more than 2 m.

Continuous rainfall was selected as the research object. Using monitoring data from 28 August to 26 September, the retardation effect concerning different soil depths of VWC for rainfall was analyzed. The correlation coefficient between VWC and rainfall reached a maximum in the soil depth of 0.2 m after rainfall occurred for approximately 16 d (Figure 5). With respect to the soil depth of 1 m, the correlation coefficient achieved the maximum when rainfall occurred for approximately 24 d.

4.1.3. Monthly Soil Volumetric Water Content. The relationship between monthly rainfall and VWC was constructed based on the results of the hourly and daily monitoring data. The VWC increased with the increasing of rainfall, and the retardation effect still occurred. In addition, dissimilarities of the VWC peak in different years were obvious (2008–2013). For example, the maximum peak of VWC occurred in August and September in 2009 and 2010, respectively. Dramatic differences of the soil VWC were also evident for different monitoring points and soil depths (Figure 6). The results demonstrated that the changing of soil VWC was more obvious for soil depth, which was relatively lighter with increasing rainfall. However, the changing in soil VWC was relatively stable for relatively deeper soil depth. Meanwhile, the VWC was affected by rainfall at the soil depth of 0.2 m, and a positive correlation relationship was obvious. The correlation coefficient, however, gradually decreased with increasing soil depth.

4.1.4. Volumetric Water Content in Different Soil Depths. The changing trends of VWC were essentially the same under different times and different soil depths on the monitoring point (Figure 7). The VWC fluctuated at different soil depths on the TDR2 monitoring points, and there were three wave peaks in the soil depths of 0–8 m, which were distributed in the 3.0 m, 5.0 m, and 7.0 m soil depths, respectively. Furthermore, the changing situation of soil VWC could be summarized based on the monitoring results. The largest change of soil VWC with time occurred at the depth of 0.2 m and then 1 m. However, this change of soil VWC was relatively small with time at the soil depth ranging from 2.0 m to 4.0 m, and the VWC did not change with time at the soil depth of 5.0 m and below.

These results indicated that the soil VWC was obviously influenced by rainfall, especially in the surface soil, and these results were in accordance with extant literature. [35–37] In addition, a series of cracks were found on the Baota Mountain (Figure 8). These cracks would provide an advantageous channel for rainfall infiltration, resulting in an acceleration of the rate of rainfall infiltration and ultimately forming underground runoff [38]. This would also provide a conducive condition for the occurrence of landslide disasters. Indeed, a large number of investigations have reported that such channel can impart a marked effect on slope stability, thus leading to the occurrence of landslide disasters under the induction of rainfall [39, 40]. Consequently, the probability of a landslide in landslide No. 2 was relatively large.

TABLE 2: Distribution of TDR (landslide No. 2) and ZK (landslide No. 1) monitoring system.

Number	TDR1				TDR2					
	1-1	1-2	1-3	1-4	2-1	2-2	2-3	2-4	2-5	2-6
Depth (m)	1.0	2.0	3.0	4.0	0.2	1.0	2.0	3.0	4.0	5.0
Number	TDR2				TDR3		TDR4			
	2-7	2-8	2-9	3-1	3-2	3-3	4-1	4-2	4-3	4-4
Depth (m)	6.0	7.0	8.0	1.0	2.0	3.0	1.0	2.0	3.0	4.0
Number	ZK1				ZK2		ZK3			
	1-1	1-2	1-3	1-4	1-5	2-1	2-2	2-3	3-1	3-3
Depth (m)	10.7	14.0	19.5	25.5	34.4	3.7	9.2	10.9	5.75	11.15
										14.05

FIGURE 3: Relationship between VWC and rainfall per hour: (a) changing of VWC on the surface soil; ((b, c)) specific examples.

4.2. Landslide Stability

4.2.1. Theoretical Calculation Results. The F_s are 2.713 and 1.133 for landslide No. 1 and landslide No. 2, respectively (Figure 9). Landslide No. 1 is relatively safe based on the division standard of F_s [41]; however, landslide No. 2 is comparably instable. This result is consistent with the results of Section 4.1, in which the probability of a landslide in

landslide No. 2 with continuous rainfall or heavy rainfall is relatively large. Salmasi et al. (2019) investigated the relationship between soil material parameters (i.e., cohesive force, internal friction angle, soil specific weight, and constant slope height) and safety factor. The results showed that cohesive force and internal friction angle impart an obvious effect on the safety factor, and this safety factor gradually decreased with the slow diminishing of cohesive force and

FIGURE 4: Relationship between daily soil VWC and rainfall: (a) TDR1; (b) TDR2; (c) TDR3; (d) TDR4.

internal friction angle [42]. In this study, the values of cohesive force and internal friction angle in landslide No. 1 were apparently higher than those of landslide No. 2, and thus the F_s was different.

4.2.2. Monitoring Displacement Results

(1). *Different Monitoring Points Displacement.* Overall, the landslide displacement was almost 0 m in different monitoring points based on the daily and monthly field monitoring data (Figures 10 and 11) in landslide No. 1; and a small-level displacement occurred in part of the monitoring points, with displacement values of less than 0.05 mm.

Furthermore, landslide displacement was generally unaffected by daily rainfall (Figures 10 and 11). These results indicated that landslide No. 1 is in a relatively stable state, which was congruent with the theoretical calculation results.

(2). *Different Depth Displacement.* In general, the changing trends of displacement were essentially the same at different times and different depths of the monitoring points (Figure 12). The displacement fluctuated with different soil depth in the ZK1 monitoring point, and two wave peaks appeared in the soil depth of 0 m–35 m. However, the value of displacement was minimal, that is, less than 0.1 mm, between 2009 and 2012. In addition, a correlation relationship was not found between the displacements of

FIGURE 5: Correlation relationship between VWC and rainfall.

FIGURE 6: Continued.

FIGURE 6: Relationship between monthly soil VWC and rainfall: (a) TDR1; (b) TDR2; (c) TDR3; (d) TDR4.

FIGURE 7: Continued.

FIGURE 7: Relationship between VWC and different soil depth in different years on the TDR2 monitoring point: (a) 2009; (b) 2010; (c) 2011; (d) 2012. The other monitoring points data (DTR1, DTR3, and DTR4) are attached in supplementary files (Figures S1–S3).

FIGURE 8: Cracks on Baota Mountain.

FIGURE 9: Landslide stability results of theoretical calculation: (a) landslide No. 1 ($F_s = 2.713$); (b) landslide No. 2 ($F_s = 1.133$).

FIGURE 10: Relationship between daily landslide displacement and daily rainfall: (a) ZK1; (b) ZK2; (c) ZK3.

FIGURE 11: Relationship between monthly landslide displacement and monthly rainfall: (a) ZK1; (b) ZK2; (c) ZK3.

different depths and rainfall. These findings also indicated that landslide No. 1 was comparatively stable, and the results of the theoretical calculation were again verified to be accurate.

In general, the Baota Mountain landslide was stable, based on the results of monitoring data between 2008 and 2013. However, the closest distance was approximately 19 m between Baota and landslide No. 2. Moreover, a series of joints and fissures developed on the surface of the loess soils (Figure 8), and surface spalling always occurred. Shallow landslides will occur under the influence of continuous or heavy rainfall and once a landslide takes place, Baota would be threatened. This result was similar to the findings of other

investigations [26]. Therefore, it is urgent to take certain protective measures to prevent Baota Mountain landslides.

5. Conclusion

Loess landslides are widely distributed across the loess regions of China, and landslide disasters are common due to heavy or continuous rainfall in this region. We applied field monitoring and limit equilibrium methods to estimate landslide stability.

The relationship between soil VWC and daily rainfall from October 2008 to March 2013 and the trends of VWC were similar in different years. Daily rainfall had an obvious

FIGURE 12: Relationship between landslide displacement and different soil depth in different years in the ZK1 monitoring point: (a) 2009; (b) 2010; (c) 2011; (d) 2012. The results of other monitoring points (ZK2 and ZK3) are attached in the supplementary files (Figures S4 and S5).

impact on VWC with the soil depth from 0 m to 1 m. However, the VWC was stable when the soil depth was more than 2 m. In addition, the VWC of surface soil (0.2 m) slightly increased when the daily rainfall was greater than 10 mm; for the soil depth of 1 m, however, the VWC was

unchanged. VWC obviously increased above the soil depth of 1 m with daily rainfall of 50 mm, while VWC was stable when the soil depth was more than 2 m. Moreover, the retardation effect regarding VWC in different soil depths for rainfall was obvious.

The F_s values were 2.713 and 1.133 for landslide No. 1 and landslide No. 2, respectively. This indicated that landslide No. 1 was relatively safe, while the probability of a landslide in landslide No. 2 was greater. The results of monitoring displacement indicated that landslide No. 1 was relatively stable between 2008 and 2013, which was consistent with the value of theoretical calculation.

Data Availability

The original data are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the China Geological Survey Project (no. DD20190642).

Supplementary Materials

Figure S1: the relationship between VWC of soil and different soil depth under different years on the TDR1 monitoring point: (a) 2009; (b) 2010; (c) 2011; (d) 2012. Figure S2: the relationship between VWC of soil and different soil depth under different years on the TDR3 monitoring point: (a) 2009; (b) 2010; (c) 2011; (d) 2012. Figure S3: the relationship between VWC of soil and different soil depth under different years on the TDR4 monitoring point: (a) 2009; (b) 2010; (c) 2011; (d) 2012. Figure S4: the relationship between landslide displacement and different soil depth under different years on the ZK2 monitoring point: (a) 2009; (b) 2010; (c) 2011; (d) 2012. Figure S5: the relationship between landslide displacement and different soil depth under different years on the ZK3 monitoring point: (a) 2009; (b) 2010; (c) 2011; (d) 2012. (*Supplementary Materials*)

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