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Quantitative Analysis and Prediction of Correlation between Xintan Landslide Displacement, Reservoir Water Level and Rainfall

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***Abstract:** In order to study the influencing factors of Xintan landslide deformation and the growth law of cumulative displacement, this paper discusses the correlation between displacement and reservoir water level and rainfall through qualitative and quantitative analysis. The conclusions are as follows: 1 Through qualitative analysis, it can be preliminarily considered that the rise of reservoir water level is the main influencing factor of landslide displacement; 2. The correlation between Xintan landslide displacement and reservoir water level and rainfall is quantitatively calculated and analyzed by using Spearman correlation coefficient method. The calculation results show that the correlation coefficient is 0.5 ≪ρ ≪0.8, the cumulative displacement of each monitoring point of Xintan landslide has a positive correlation with the reservoir water level, and the correlation coefficient at the stage when the water level drops to low water level is 0.1<| ρ|< At the same time, the absolute value of the correlation coefficient between landslide displacement and rainfall is 0.448, and the correlation is not close; To sum up, Xintan landslide deformation has the most obvious response to the rise of reservoir water level. 3. According to this characteristic, the displacement monitoring data from July to September, which is the most serious landslide deformation every year from 2007 to 2016, are selected, and the time is fitted by univariate linear regression with the cumulative displacement as the objective function. The results show that the cumulative displacement from July to September has a linear relationship with time, and the error of the predicted value of cumulative displacement in 2017 is less than 1%, with high prediction accuracy.*

***Keywords:** Xintan landslide displacement, Reservoir water level rise, Rainfall, Spearman correlation coefficient, Univariate linear regression fitting*

1. Introduction

Landslide is one of the common adverse geological phenomena in nature, and also the key object of national disaster prevention and reduction. The occurrence process of landslide is long and complex. In addition to engineering geological conditions, rainfall, earthquake, reservoir water level change, human activities, etc. are also external factors inducing landslide deformation [1,2]. Zigui County has a variety of landforms, with numerous landslides distributed, and more than 500 landslide points have been identified (Figure 1). The Yangtze River basin runs through the whole Zigui County [3]. As one of the bank slopes of the Three Gorges Reservoir Area, Xintan landslide has always been a hot research object. On June 12, 1985, Xintan Landslide collapsed with huge accumulation layer. The volume of the landslide reached an astonishing 30 million m3, and the millennium old town Xintan Town was destroyed in an instant. After this painful lesson, many domestic scientific researchers began to do a lot of research on Xintan Landslide and go to the field [4]. For example, Wang Shangqing and others concluded that the landslide development process has gone through four stages of initial deformation - uniform deformation - accelerated deformation - rapid deformation according to the comprehensive analysis of the field investigation results and the monitoring data in recent years before the Xintan landslide disaster occurred [5]. Yin Kunlong and others conducted numerical simulation on the whole deformation stage of Xintan landslide based on the basic principle of discontinuous deformation analysis. The simulation results show that Jiangjiapo area slides first and plays a leading role in the whole landslide movement. It is precisely because it pulls the upper ancient landslide mass and simultaneously compresses the lower ancient landslide mass that led to large-scale overall sliding of Xintan landslide [6]. Xia Yuanyou and others discussed the sliding mechanism of Xintan landslide through shaft exploration and mechanical experiments. They believed that the infiltration and saturation of the groundwater generated by rainfall on the weak rock stratum made the slope weak rock stratum more vulnerable. In addition, the water level of the Yangtze River is closely linked with the groundwater on the slope. The backwater of the Gezhouba Dam raised the groundwater level in this area and accelerated the arrival of slope instability [7]. Taking Xintan Landslide as an example, Zhou Bin et al. discussed the application of the correlation between the monthly displacement variable, deformation acceleration and monthly rainfall in the early warning and prediction of landslide imminent sliding [8]. Liu Wenjun and others preliminarily studied the displacement vector of landslide based on observation data using R/S analysis method widely used in fractal theory, and found that the displacement vector can be well applied to landslide prediction [9].

The above scholars' analysis and research on Xintan landslide are mainly based on the monitoring data before the landslide occurs. Most of them study the inducing factors of landslide through physical and mechanical experiments or numerical simulation. After years of adjustment after the 1985 landslide, the displacement of Xintan landslide has gradually become stable, and the landslide site has been stable enough [10]. Since the water level in front of the Three Gorges Dam reached 135m in the first half of June 2003, Xintan landslide has been monitored again and initial data have been obtained. Since the implementation of Xintan landslide monitoring work, there are few studies on quantitative calculation and analysis of landslide displacement influencing factors, so this paper uses the monitoring data of Xintan landslide from 2007 to 2017, such as measured deformation displacement, rainfall, reservoir water level, etc., and conducts quantitative analysis based on Spearman correlation coefficient method to judge the correlation between Xintan landslide displacement, reservoir water level, rainfall. Finally, on the basis of correlation analysis of landslide displacement, the cumulative displacement of monitoring points is predicted based on the linear regression model of one variable with the cumulative displacement as the objective function, which is used to test the subsequent measured values.

2. Overview of Xintan Landslide

2.1. Engineering geological conditions

Xintan landslide is located on the north bank of the Yangtze River (Figure 1), at the exit of Bingshu Baojian Gorge, 26km below the Three Gorges Dam site, and belongs to Group 2, Changjiang Village, Quyuan Town. Longitude 110 °48'32 ", latitude 30 °57'02".

The sliding body is long tongue shaped (Figure 2), with the terrain high in the north and low in the south, and it is inclined to the Yangtze River as a gentle slope with an overall gradient of 23 °. The rear edge is located at the foot of Guangjiaya slope, with an elevation of 910m, and the front edge is located below 135m water level. Its north-south length is 1600m, east-west width is 500m, average thickness is about 30m, and volume is 2400 × 104 m3。The sliding surface is the contact surface between the accumulation body and the underlying bedrock. Xintan landslide is an accumulation layer landslide, and the slope structure is a cut layer slope.

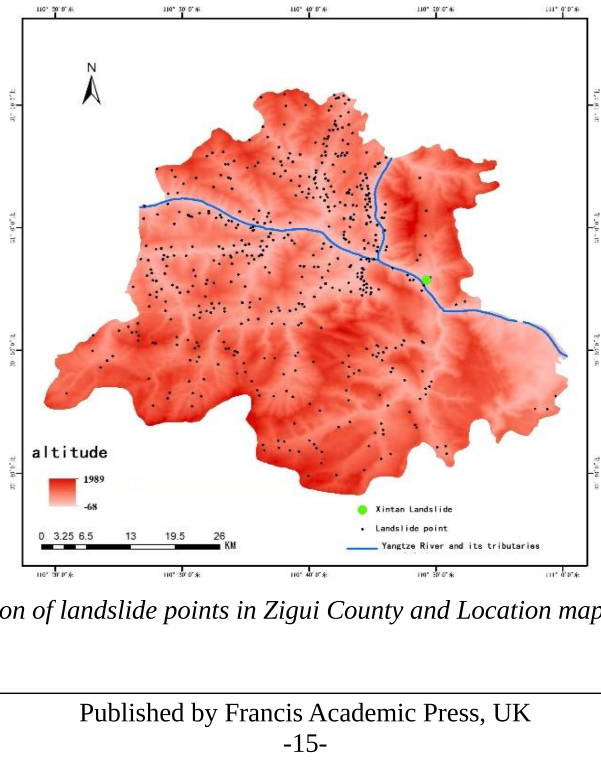

Figure 1: Distribution of landslide points in Zigui County and Location map of Xintan Landslide

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2.2. Qualitative analysis of surface displacement monitoring results

The elevation data of reservoir water level comes from the water level query platform provided by the website of China Three Gorges Project Development Corporation; Displacement monitoring data and rainfall data are from the national field of Three Gorges landslide in Hubei Five GPS displacement monitoring devices are arranged by the Scientific Observation and Research Station in the landslide body, and five GPS monitoring points are distributed on the landslide body centerline, with elevations of 625m, 575m, 508m, 409m and 285m respectively, forming a longitudinal monitoring profile (Figure 2); Monitoring point 4 has been damaged, so it is not included in the statistics. The displacement shown in the text is the horizontal displacement of the landslide.

Figure 2: Xintan Landslide Engineering Geology and monitoring point plan

The relation curve between the cumulative displacement of Xintan landslide GPS monitoring point (GXT1-GXT5) and the reservoir water level and rainfall from 2007 to 2017 is shown in Figure 3. It can be seen from the figure that the water level elevation of the Three Gorges Reservoir fluctuates periodically every year. The initial displacement data has been obtained since the impoundment of the Three Gorges Reservoir reached 135m in 2003, and the increase and decrease of the water level elevation has been maintained at about 10m until the experimental impoundment of the Three Gorges Reservoir reached 175m in 2008, when the increase and decrease of the water level elevation increased to about 30m. The change trend of the cumulative displacement curve of the four monitoring points is roughly the same. As of December 2017, the cumulative displacement of each monitoring point is between 926-1256mm. With the rise of the Three Gorges water level every year, the cumulative displacement rate of almost all monitoring points will increase, that is, a "step" phenomenon occurs, which also shows that Xintan landslide has accelerated deformation and appears periodically with the rise and fall of the Three Gorges reservoir water level, but each increase in the cumulative displacement rate will lag behind the rise of the reservoir water level. During the first experimental impoundment of the Three Gorges water level to 175m in 2008, the "step" phenomenon was the most obvious (red circle in Figure 3).

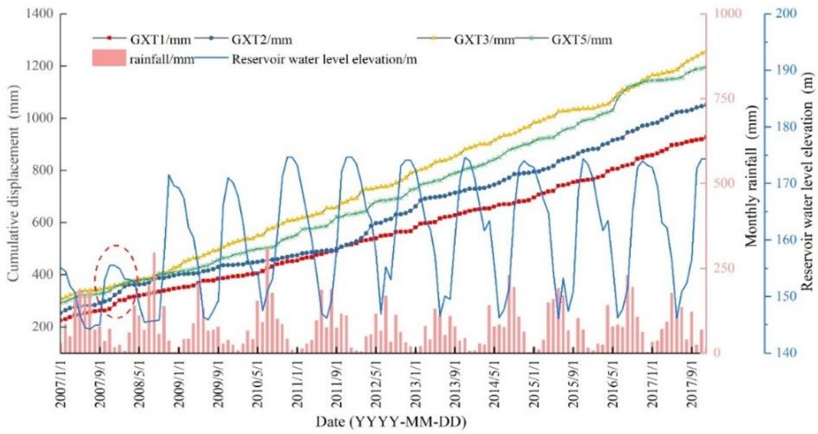

Figure 3: Relation curve between cumulative displacement of Xintan landslide monitoring points and rainfall and reservoir water level

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Figure 4 shows the relationship between the cumulative displacement curve, rainfall and reservoir water level from 2010 to 2012. In order to clearly study the displacement order, Therefore, two representative monitoring points GXT3 and GXT5 are selected. It can be seen from the figure that when the water level is low, the monthly displacement is basically less than 10mm. Later, with the elevation of the reservoir water level rising, the monthly displacement of the monitoring point starts to increase, and the cumulative displacement rate increases. When the water level elevation is at the high water level stage (165-175m), the monthly displacement exceeds 15mm; After the reservoir water level starts to drop to 165m, the monthly displacement of the monitoring point returns to within 10mm again, and the cumulative displacement curve rises gently. Therefore, it can be preliminarily considered that the rise of reservoir water level is one of the factors affecting the displacement of Xintan landslide. There is no obvious consistency between the month with large cumulative displacement rate of the monitoring point and the month with strong rainfall. In some dry seasons without rainfall, the cumulative displacement rate will still increase, so Figure 4 cannot directly reflect the correlation between the cumulative displacement of the monitoring point and rainfall.

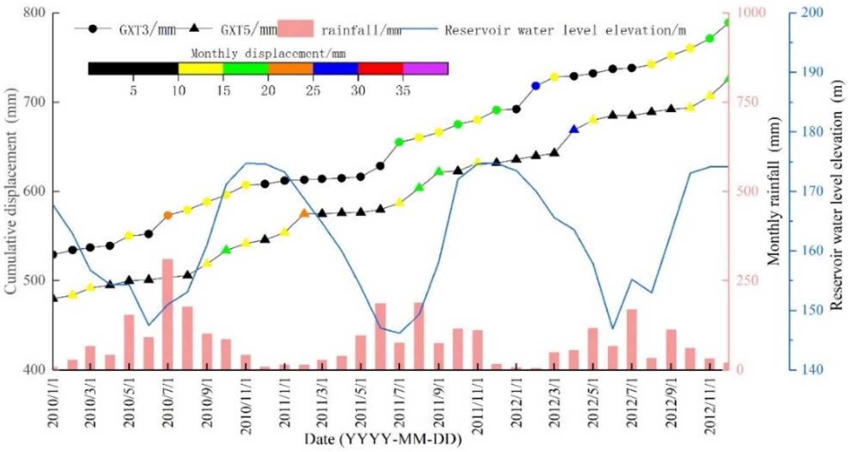

Figure 4: Relation curve between cumulative displacement of monitoring point gxt3 / gxt5 of Xintan Landslide and rainfall and reservoir water level

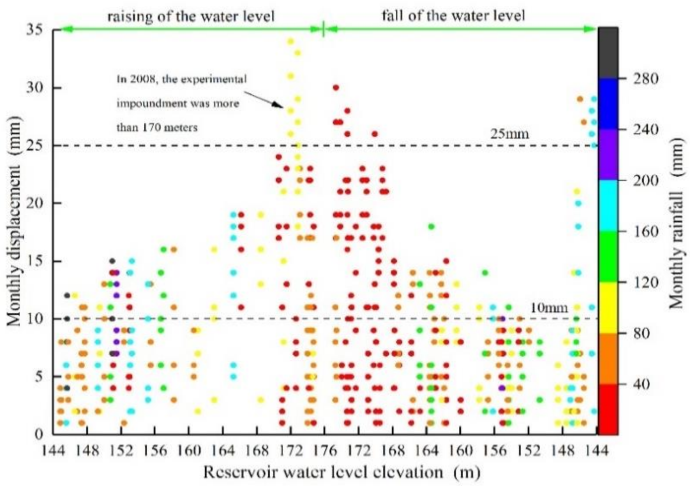

Figure 5: Relationship between monthly displacement, reservoir water level and monthly rainfall

Figure 5 shows the relationship between the monthly displacement of the four monitoring points from 2007 to 2017 and the reservoir level elevation and monthly rainfall. It can be seen from the figure that in the dry season when the monthly rainfall is less than 40mm, the monthly displacement of the four monitoring points within the range of 165-175m of the reservoir water level elevation is more than 10mm in most cases, especially in 2008, when the Yangtze River was first impounded for 175m, the monthly displacement of the monitoring points was more than 25mm after the reservoir water level rose to 170m, but the monthly rainfall at this stage is still less than 80mm. On the other hand, when the elevation of the reservoir water level is low, the monthly rainfall exceeds 195mm, or even when the monthly rainfall in the rainy season is more than 230mm, a large number of monitoring points have a monthly displacement of less than 10mm. In particular, the monthly displacement of a large number of monitoring points in the high water level stage of the Three Gorges at 165-170m is concentrated between 10-25mm or even more than 25mm. To sum up, it can be preliminarily judged that the displacement of Xintan landslide is mainly related to the rise of water level of the Three Gorges Reservoir, and has no obvious correlation with rainfall.

However, the above analysis is qualitative analysis based on the relationship curve between variables. In order to further determine the influence of reservoir water level and rainfall on Xintan landslide displacement, quantitative calculation and analysis will be conducted with the help of correlation coefficient.

3. Quantitative calculation and analysis of influencing factors

Correlation analysis refers to the analysis of two or more Quantitative calculation and analysis shall be carried out for variable elements of sex to measure the closeness of correlation between variable elements [11]. In correlation analysis, the most commonly used analysis methods are Pearson correlation coefficient method and Spearman correlation coefficient method [12]. Pearson correlation coefficient method is the most appropriate and efficient method when the data of variable elements are continuous and conform to normal distribution and linear relationship; When any of the above three conditions is not met, Spearman correlation coefficient is required and Pearson correlation coefficient is no longer applicable [12, 13]. The rainfall and reservoir level elevation data in the monitoring data in this paper are not satisfied with the normal distribution. Therefore, Spearman correlation coefficient method is selected as the quantitative calculation and analysis method.

3.1. Spearman correlation analysis principle

Spearman correlation coefficient is to convert the original data of variables into grade data, and use monotone equation to calculate the grade difference of two variables. The calculation expression is [12, 13]:

$$\rho = 1 - \frac{6\sum d^2}{n(n^2-1)} \tag{1}$$

In formula (1) ρ Is Spearman correlation coefficient, d is the difference of data order of two variables, and n is the number of samples. The value range is (- 1, 1). Spearman correlation coefficient indicates the correlation direction between independent variable X and dependent variable Y. When X increases, Y also increases ρ Is a positive value; When X increases, Y decreases ρ Is a negative value; When Y does not tend to change with X, it indicates ρ Is 0. When $|\rho| \leq 0.2$ indicates very weak correlation or no correlation, $0.2<|\rho| \leq 0.4$ indicates weak correlation, $0.4<|\rho| \leq 0.6$ indicates moderate correlation, $0.6<|\rho| < 0.8$ indicates strong correlation $|\rho| \geq 0.8$ indicates very strong correlation [12].

3.2. Correlation analysis of monthly displacement, reservoir water level and rainfall

Since the cumulative displacement rate of monitoring points is different during the two stages of rising and falling of reservoir water level, the correlation analysis of cumulative displacement and reservoir water level is calculated separately according to the two stages of rising and falling of water level, and the calculation results are shown in Table 1.

Table 1: Spearman correlation coefficient between cumulative displacement and reservoir water level

Stage (reservoir level)	Time/month	Spearman correlation coefficient between cumulative displacement and reservoir level ρ			
		GXT1	GXT2	GXT3	GXT5
fall of the water level	January	-0.659	-0.615	-0.676	-0.63
	February	-0.583	-0.434	-0.597	-0.551
	March	-0.223	-0.195	-0.287	-0.303
	April	-0.201	-0.168	-0.227	-0.199
	May	-0.095	-0.113	-0.164	-0.202
	June	0.108	0.174	0.226	0.197
raising of water level	July	0.344	0.376	0.403	0.382
	August	0.794	0.772	0.823	0.806
	September	0.668	0.697	0.711	0.691
	October	0.721	0.678	0.732	0.694
	November	0.589	0.552	0.585	0.552
	December	0.585	0.548	0.601	0.558

It can be seen from Table 1 that no matter whether the reservoir water level is in the rising or falling stage, the correlation coefficient between the cumulative displacement of the four monitoring points and

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the reservoir water level has little difference in the same month, which is consistent. It is obvious that the cumulative displacement is positively correlated with the water level of the Three Gorges Reservoir in the rising stage, and the correlation coefficient ρ From July to August, the mutation increased to the maximum, and then in September ρ The value decreases by 0.5 ° ρ ≪0.8。 It can be seen from Figures 2 and 3 above that the cumulative displacement curve of the landslide occurs a "step" phenomenon in July September when the reservoir water level rises, and the cumulative displacement rate of the landslide is the highest in July September. In January and February (water level elevation 165-175m), 0.5<| ρ|< 0.7, the cumulative displacement is moderately related to the reservoir water level, indicating that the response to landslide displacement is relatively high in the rising stage and high water level fluctuation stage, and the cumulative displacement rate increases. Basically 0.1 in the drawdown stage of reservoir water level<| ρ|< 0.3. The correlation between the cumulative displacement and the drawdown stage of the reservoir water level is weak, and the landslide displacement tends to be stable.

Meanwhile, Spearman correlation coefficient between cumulative displacement of landslide and rainfall is shown in Table 2.

Table 2: Spearman correlation coefficient between cumulative displacement and rainfall

Time/month	Spillman correlation coefficient between cumulative displacement and rainfall ρ			
	GXT1	GXT2	GXT3	GXT5
January	-0.086	-0.112	-0.984	-0.045
February	-0.288	-0.181	-0.299	-0.301
March	-0.113	-0.235	-0.092	-0.096
April	0.07	0.081	0.054	0.079
May	-0.274	-0.219	0.263	-0.255
June	0.083	0.124	0.047	0.079
July	0.425	0.448	0.401	0.447
August	0.219	0.135	0.229	0.111
September	-0.349	-0.328	-0.298	-0.349
October	-0.014	-0.037	-0.01	0.015
November	0.286	-0.141	0.102	0.225
December	0.009	-0.211	-0.181	-0.235

It can be seen from Table 2 that the correlation coefficient between the cumulative displacement and rainfall of the four monitoring points cannot be consistent with the reservoir water level in Table 1, because the monthly rainfall is affected by geographical and climatic factors, which is different from the periodicity of the reservoir water level rise and fall, and the rainfall is random. Only Spearman coefficient in June, July and August ρ There is consistency, especially the correlation coefficient in July ρ> 0.4 shows a moderate positive correlation, which is also because the rainfall peaks in June, July and August each year, resulting in a low response relationship between the cumulative displacement of the landslide and rainfall. There is basically negative correlation or no correlation between the cumulative displacement of each monitoring point and the rainfall in other months. Even the positive and negative correlation coefficients of some months are not consistent, which is because the monitoring points are distributed at the center line of the landslide mass, and the elevation is inconsistent, leading to subtle differences in the rise and fall of the reservoir water level on each monitoring point. In addition, the randomness of rainfall will also have an impact. To sum up, in July September, when the landslide displacement is the most serious, the landslide displacement has a strong correlation with the rise of the reservoir water level, and a weak correlation with the rainfall, indicating that the Xintan landslide displacement is mainly caused by the rise of the Three Gorges reservoir water level.

4. Prediction of cumulative displacement based on unitary linear regression model

It can be seen from the previous article that the cumulative displacement of Xintan landslide will occur a "step" phenomenon in July September every year, and the cumulative displacement rate will increase significantly; After the water level drops to the low water level, the displacement curve will rise gently (Fig. 3 and 4). As a whole, the cumulative displacement of the landslide is linear with the time. Therefore, the prediction of cumulative displacement based on the quantitative analysis of the factors affecting the landslide displacement and deformation mentioned above can be used as the inspection basis for the measured values of subsequent monitoring points.

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4.1. Univariate linear regression modeling

Regression is a mathematical model, usually used as a tool to predict future values. The research object is mainly measurable variables [14]. The commonly used regression analysis methods are mainly one variable linear regression and multiple regression [15]. Because the cumulative displacement in this paper has a linear relationship with time, we use the one variable linear regression model to fit the displacement data. The regression equation expression is [16]:

$$Y = A + BX + \varepsilon \tag{2}$$

Where A and B are regression parameters, ε Is the error term, X is the independent variable,Y is the dependent variable, where the regression parameter:

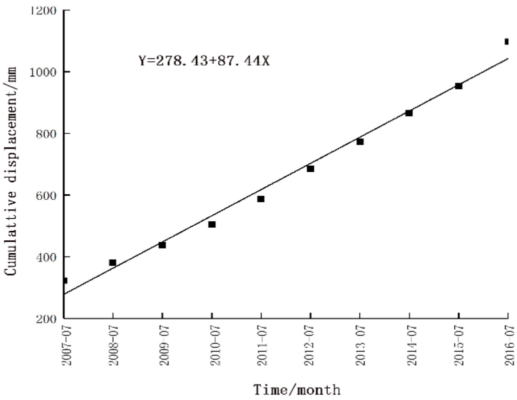
$$B = \frac{\sum_{i=1}^{n} X_i Y_i - n\overline{XY}}{\sum_{i=1}^{n} X_i^2 - n\overline{X}^2} \tag{3}$$

$$A = \overline{Y} - A\overline{X} \tag{4}$$

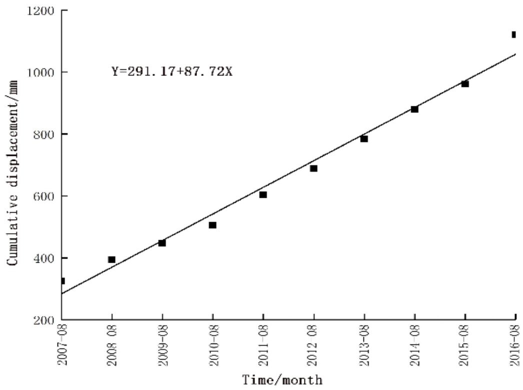
Based on the analysis of the factors affecting the displacement of Xintan Landslide, this paper selects the cumulative displacement data of July, August and September of each year from 2007 to 2016, monitoring point GXT5 as the research object, and conducts regression fitting analysis on the displacement data with origin and spss software. The regression equation is shown in Table 3, and the cumulative displacement and time of Xintan Landslide are fitted with origin software. The results are shown in Figure 6.

Table 3: Regression equation of cumulative displacement of gxt5 monitoring point from July to September

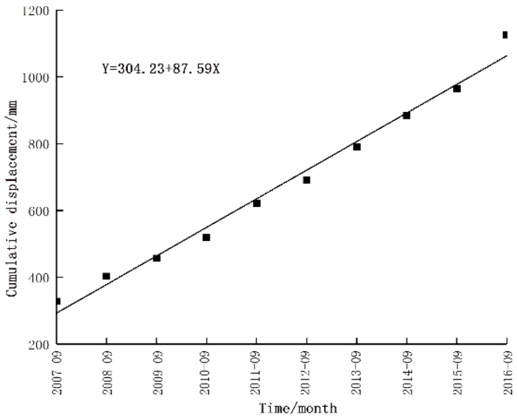
month	regression equation
July	Y=278.43+87.44X
August	Y=291.17+87.72X
September	Y=304.23+87.59X



(a) Fitting Straight line in July



(b) Fitting straight line in August



(c) Fitting Straight Line in September

Figure 6: Linear diagram of cumulative displacement and time fitting of gxt5 monitoring point of Xintan landslide from July to September

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From Table 3 and Figure 6 alone, it can be seen that the cumulative displacement in July September is highly consistent with the time fitting straight line, and the dispersion of the scattered points of the cumulative displacement is low. In order to further verify the linear correlation between the cumulative displacement and time, the goodness of fit test and significance test were conducted on the regression equation in July September. The results are shown in Table 4 and Table 5.

Table 4: Goodness of fit test of regression equation

month	DF (freedom)	Pearson's r (R)	R-Square (R^2)	Adj. R Square (adjustment R^2)
July	9	0.993	0.987	0.985
August	9	0.992	0.985	0.983
September	9	0.993	0.987	0.985

According to Table 4 and Table 5, R2=0.987 in July, the sum of regression squares is 595212.803, and the sum of residual squares is 7853.297, P=0.874 ×10-11 ＜ 0.05, so the cumulative displacement in July is highly correlated with time and the regression equation is significant.

In August, R2=0.990, the sum of regression squares was 610256.003, and the sum of residual squares was 9344.097, P=1.103 ×10-11 ＜ 0.05, so the cumulative displacement in August is highly correlated with time and the regression equation is significant.

In September, R2=0.987, the sum of regression squares was 604421.603, and the sum of residual squares was 8152.897, P=3.101 ×10-11 ＜ 0.05, so the cumulative displacement in September is highly correlated with time and the regression equation is significant.

Table 5: Significance test of regression equation

month		**Sum of squares**	**freedom**	**mean square**	**F**	**Significance P**
	regression	595212.803	1	595212.803	606.332	0.874E-11
July	residual	7853.297	8	981.662		
	total	603066.100	9			
	regression	610256.003	1	610256.003	522.474	1.103E-11
August	residual	9344.097	8	1168.012		
	total	619600.100	9			
	regression	604421.603	1	604421.603	593.086	3.101E-11
September	residual	8152.897	8	1019.112		
	total	612574.500	9			

In conclusion, the goodness of fit test and significance test of regression equation prove that the cumulative displacement of Xintan landslide has a high degree of linear correlation with time, so it can be fitted to predict and test the future value.

4.2. Verification of cumulative displacement prediction

In order to verify the applicability of the unitary linear regression equation between the cumulative displacement of monitoring points and time in landslide displacement prediction, the cumulative displacement of GXT5 monitoring point in 2017 was predicted by using the regression equation and compared with the actual value. The results are shown in Table 6.

Table 6: Comparison between predicted value and actual value of cumulative displacement of regression equation

month	**predictive value/mm**	**actual value/mm**	**relative error/%**
July	1152.820	1156.900	0.353
August	1168.370	1172.900	0.386
September	1180.130	1181.900	0.150

It can be seen from Table 6 that the difference between the predicted cumulative displacement of monitoring point GXT5 in July September 2017 and the actual value is small, basically within 5 mm, and the relative error is also less than 1%. Therefore, it is feasible to establish a regression model for Xintan landslide monitoring point to predict the cumulative displacement. Especially in the rising stage of the Yangtze reservoir water level, the most serious landslide deformation from July to September can also be used as a reference for correcting the cumulative displacement.

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5. Conclusion

According to the qualitative analysis of Xintan landslide monitoring point, the cumulative displacement of the monitoring point is linear with time, "step" phenomenon occurs in July September every year, and there is a lag effect with the water level rise of the Three Gorges Reservoir. The accelerated deformation of monitoring points basically occurs in the dry season when the water level of the Three Gorges Reservoir rises and there is less rainfall, and in the rainy season when the monthly rainfall exceeds 200 mm, the monthly displacement of most monitoring points is within 10 mm. It can be preliminarily considered that the displacement of Xintan landslide is mainly caused by the rise of the reservoir water level, and the response to rainfall is not high.

The Spearman correlation coefficient method is used to quantitatively calculate the cumulative displacement of landslide, reservoir water level and rainfall. During the rising stage of reservoir water level, the cumulative displacement of each monitoring point is positively correlated with the reservoir water level, and the correlation coefficient reaches the maximum value of 0.8 in August, while the correlation coefficient with rainfall is basically negative. The correlation coefficient with the most concentrated rainfall is only 0.4 in June and July, It shows that the rise of reservoir water level is the main factor causing the displacement and deformation of Xintan landslide.

On the basis of qualitative and quantitative analysis of the factors affecting the displacement and deformation of Xintan Landslide, taking the cumulative displacement as the objective function, the displacement data of GXT5 monitoring point in July, August and September of each year are selected as a linear regression model to predict the cumulative displacement of the landslide. The fitting results conform to the growth trend of the sliding slope displacement, and the error between the predicted results and the actual values is within 1%, with good accuracy, It can be used as a reference for landslide displacement monitoring data collection.

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