Linkages between precipitation cycle and slope stability: A case study in the Caijiapo landslide among Weihe River Basin

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Abstract. It is of great importance to forecast landslide in future certain time interval. Hence, this study proposed a method combination precipitation period with variety of slope stability factor based on macro scale. This study designed 5 grades of rainfall strength simulation and corresponding 5 grades of slope state using Markoff prediction technique analysis change of slope factor K in the short time. Results indicated that: (1) the rainfall in Baoji area has three periods of 5a, 13a and 25a, in which 5a is the primary period; (2) the slope safety factor K has a similar fluctuation trend compared to precipitation state, thus division slope factor K of 5 grade as safety state, basically safety state, stable state, partial risk state and risk state, respectively; (3) in the previous year if slope in the safety, basically safe and stable state, in the next year slope factor K above 1.15 has 60%, 75% and 72% probability, respectively; (4) when the previous year at partial risk or risk situation, there is high probability that value of the K is always more than 1.15, it is means to a great extent the landslide have already occurred, thus defined a concept which between “the safety state after destruction” and “safety state have no destruction”.

1. Introduction
Slope instability is a geologic hazard that usually occurs after earthquake, and the water content of soil is one of the major factors for this, thereby continuous precipitation leads to engineering landslide is very common. Landslide is one of the most costly non repetition natural hazards, causing greatly disadvantageous economic, life and property and social influences. So research of linkages between precipitations with slope stability is very meaningful.

A large number of experiments and data show that [1-3], main effect of landslide is rainfall, because infiltration leads to soil water content of slope increasing and farther results decline in shear strength. Rainfall from the slope surface to inside, and additional penetration is generated by percolation which increases landslide sliding force. In the rainy season, temporary additional water and groundwater movement are instability factors for strength of unsaturated soil. However, in fact, precipitation will reduce the shear strength, so this is another important factor to influence slope stability. But the previous researches focus on seepage in rock/soil, adverse mechanical property cause by seepage, slope failure mechanism and so on [4-6]. The traditional research program is an effective method to evaluate stability of slope but the calculations and analysis on slope coefficient are ignoring rainfall accumulation of time and space.
Based on above understanding, this paper combines the rainfall cycle and probability of precipitation in the study area with assessment risks of project, and predicts the probability of landslide. It is viewing from macro long time sequence to explore the slope stability evaluation. The primary objectives of this study are to (1) obtain the rainfall cycle in the study area; (2) reveal linkages between precipitation state with safety factor K of slope from macro long time sequence.

2. The study area and data
The landslide is located in North village area in Shaanxi province. Geographic coordinates of landslide center is about N34°36′, E107°28′. Landslide is mainly composed of Quaternary sedimentary rock, one county highway through the slope leading edge in its bottom. Affected by long-term rainfall of historical the landslide boundary produced deformation and trailing edge appears as tensile cracks. At present, the slope has not produced large sliding, slope is in stage of creep deformation, if it is not treated timely, it will be direct threat to the safety of residents in north village and more than 100000 square meters region will be in danger. The maps of study areas are shown in figure 1.

![Figure 1. The Weihe River Basin and the location of the slope.](image)

3. Methods

3.1. Analysis of regional precipitation patterns
Based on data of Boji meteorological station, this study is from annual and inter-annual scale to analyze precipitation time series in 1960-2006, in order to evaluation possibility of landslide in engineering. The precipitation results of annual and inter-annual scale are shown in figure 2.

![Figure 2. Precipitation time measured curve.](image)
frequency and cycle of precipitation, thus, this paper uses wavelet transform to study precipitation time series [7], because it can convert time domain description of series to frequency domain description that can effectively find the period. Wavelet transform is continuation and development of Fu Liye transform, the basic theory is through translation and scaling basic wavelet to approximation function or signal.

If basic wavelet function is \( \psi(x) \), then wavelet function family \( \psi_{ab}(x) \) is defined as follow:

\[
\psi_{ab}(x) = \frac{1}{\sqrt{a}} \psi\left(\frac{x - b}{a}\right) \quad a, b \in \mathbb{R}, a \neq 0
\]

(1)

Where \( a \) is telescop factor, \( b \) is translation factor, \( x \) is variable.

Hence, one signal or function such as \( f(x) \in L^2(\mathbb{R}) \) which wavelet transform is defined as follow:

\[
w_f(a,b) = \int_{-\infty}^{\infty} f(x) \psi_{ab}(x) dx = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(x) \psi\left(\frac{x - b}{a}\right) dx
\]

(2)

Where \( w_f(a,b) \) is wavelet transform coefficients.

Mexican hat wavelet is one commonly basic wavelet, which has two order derivative of Gauss function. Mexican hat wavelet is often written as MHF and expressed as follows:

\[
\psi(x) = \frac{1}{\sqrt{2\pi}} (1 - x^2) e^{-\frac{x^2}{2}}
\]

(3)

Combine (2) and (3), and to change parameter \( a \) and \( b \) can get wavelet transform coefficients \( w_f(a,b) \). Take \( b \) as abscissa and \( a \) as ordinate, we can get two-dimensional isoline which is called coefficient diagram of wavelet transform. By wavelet transform coefficient diagram can get evolution characteristics and mutation characteristics of time series: the positive wavelet coefficients correspond to partial multi periods and the negative wavelet coefficients correspond to partial less periods and zero point correspond to mutation-point. The larger absolute value of wavelet coefficients the more significant change in corresponding time scale, hence, wavelet coefficients can display time series with multi-resolution.

To integral wavelet coefficients get wavelet variance and expressed as follows:

\[
\text{var}(a) = \int_{-\infty}^{\infty} [w_f(a,b)]^2 db
\]

(4)

Wavelet variance can show scale of wave energy distribution and determine the scales of main time series, which is main cycle.

This paper studies 1960-2006 precipitation series in Baoji meteorological station by MEF wavelet time scale analysis. To choice MEF wavelet is based on precipitation evolution process which has characteristics of multi time scale and continuously changing. Thus, it should use continuous wavelet transform (such as MEF) to analysis this case.

Because observed precipitation data are limited time series, both initial boundary and trailing end of this series may have a boundary effect [8], in order to eliminate or reduce this effect, this paper extended both boundary of the data and to abandon the minor coefficients after wavelet transform, in this case the scale factor is 1/2 of the data length.

3.2. Analysis of regional precipitation cycle
The result of MEF wavelet analysis in regional precipitation is shown in figure 3, wavelet coefficients has upper and lower isoline distribution, the upper contour corresponding long time periodic
oscillation (low frequency oscillation) and lower contour corresponding short time periodic oscillation (high frequency oscillation), it shows from time distribution that oscillation is not uniform, hence, precipitation has different cycle, in this case, different precipitation cycle lead to landslide has similar cycle as precipitation. In figure 3, there is no strong vibration in the center and cycle can divide into 5a, 13a, 25a. In the smaller time scale (less than 5a) the change is complex that study is not considered.

![Contour map of wavelet transform](image)

**Figure 3.** Contour map of wavelet transform.

In trends of one series, the zero point of wavelet coefficient transform is the series variation points. Thus in figure 3 the zero point is the inflection point of the precipitation, so it can judge mutation point of precipitation under different time scales and get the law of variation. Further from figure 3, the precipitation cycle of the area shows a law as alternate of two less and one more, where the 60-74 is less period and 74-84 is more period and after 1984 is less period. Quantitative research of rainfall plays a very important role to safety evaluation of landslide hidden danger engineering.

Wavelet variance result shows rainfall sequence in 1960-2010 has maximum fluctuations as 5a, which has strongest shock, it’s shows in this interval that variation characteristics of precipitation is significantly which 5a is mainly period. In addition, although the rest of years have vibration and less energy, they can be divided into auxiliary periods. The precipitation cycle judgment is basic index for evaluation landslide hazard in Engineering.

### 3.3. Division of the precipitation state

Not all rainfall affects the stability of the slope, when the rainfall intensity is lightly because of too little water infiltrate that rainfall can not influence slope stability. Southwest Jiao Tong University Professor Huang Tao [9] based on similar slope rainfall designed one simulation experiment that result shows the observing horizontal displacement $Y$ of slope leading edge and water infiltration index $X$ has relationship of exponential function, the expressed as following:

$$Y = ae^{bx}$$  \hspace{1cm} (5)

Huang’s research showed that infiltration of water reaches a certain state then slope will be instable. Based on this, it puts forward the concept of dangerous slope infiltrate critical volume: in the actual engineering that whether landslide has occurred is irrespective form of infiltration and time of infiltration. As long as the infiltration amount reached threshold value, the slope may cause damage. This theory provides a favorable method for forecast slope collapse by continuous rainfall.

Hence, amount of rainfall determines dangerous level of slope, based on this, use mean standard deviation method to study 5a precipitation cycle, this paper divided the 5 state respectively: $[0, \bar{x} - 1.0s]$ , $(\bar{x} - 1.0s, \bar{x} - 0.5s]$ , $(\bar{x} - 0.5s, \bar{x} + 0.5s]$ , $(\bar{x} + 0.5s, \bar{x} + 1.0s]$ , $(\bar{x} + 1.0s, +\infty)$; The $\bar{x}$ is mean of precipitation sequence and $s$ is variance of precipitation sequence.
3.4. Establishing and solving of the model calculation

Field sampling survey shows that slope layers approximately composed of 5 kinds of soil: the upper slope overburden is Quaternary Pleistocene alluvium $Q_{4\text{al}}$, Middle Pleistocene soil and slide accumulation layer $Q_{3\text{del}}$, the lower slope overburden Pleistocene alluvium soil $Q_{2\text{al}}$ and contains part of artificial fill $Q_{1\text{al}}$, the bottom of slope is third Ji mudstone bedrock $N$. In this study, calculation selection 3-3 profiles have decisive effect to landslide body stability state. 3-3 profiles are shown in the second section, and parameters of slope soil are shown in table 1.

Table 1. The finite element calculation parameter table.

| Soil/parameters | $E$  | Poisson | $C$  | $\phi$ | $C'$ | $\phi'$ | Bulk density | Buoyant density | Saturation density | $K$   |
|-----------------|------|---------|------|--------|------|--------|--------------|-----------------|-------------------|------|
| $Q_{1\text{al}}$ | 15   | 0.3     | 22.5 | 10.5   | 15   | 9.5    | 16.73        | 7.75            | 17.56             | 0.0035 |
| $Q_{2\text{al}}$ | 8    | 0.3     | 24.5 | 14     | 13.5 | 11     | 17.14        | 8.97            | 18.78             | 0.0040 |
| $Q_{3\text{del}}$ | 24   | 0.3     | 16.5 | 12.4   | 14.3 | 11.7   | 17.99        | 9.18            | 18.99             | 0.002  |
| $Q_{4\text{al}}$ | 24   | 0.3     | 25   | 15     | 15   | 14.8   | 17.28        | 8.93            | 18.74             | 0.001  |
| $N$             | 8000 | 0.2     | 30   | 15     | 27   | 13     | 18.44        | 9.63            | 19.44             | 0.000  |

According to the mean standard deviation method, this study design artificial rainfall which has simulation 5 different states of rainfall intensity All different rainfall intensities are shown in table 2. It is known by stochastic hydrology [10] that precipitation is positively related to rainfall intensity. According to the meteorological department divide 5 kinds of state on rainfall intensity, this research hypothesis 5 grades rainfall status (measured daily rainfall data). For limit equilibrium principle that simulation applying finite element software to calculation, which result shows no effect on the slope stability factor in the lightly rainfall state, therefore this study only selected 4 states to calculate, the rainfall duration is 48 h and the results are shown in figure 4. The purpose of this experiment is numerical simulation variety of safety factor $K$ under different rainfall state.

Table 2. Finite element calculation of precipitation strength design value.

| Rainfall intensity | year | less   | M-less | Middle  | M-more | more   |
|--------------------|------|--------|--------|---------|--------|--------|
| LV                 | Light rain | Less rain | Middle rain | Heavy rain | Rainstorm |
| 4.9 mm/d           | 16.9 mm/d  | 24.9 mm/d  | 49.9 mm/d  | 74.9 mm/d  |
3.5. Based on the precipitation state to evaluation of landslide

The specification [11, 12] shows slope is on safe when safety factor \( K \geq 1.15 \), slope is on critical state when \( K \in [1,1.15] \), and slope is in dangerous state when \( K \leq 1 \). Based on the specification, combination stability factor and precipitation state, calculate result divided stability factor \( K \) to 5 grades such as safe, less safe, stable, dangerous and too dangerous. Then choose the minimum \( K \) in every state (72 hours after the rainfall) as calculated value. Calculate results are shown in table 3.

| Precipitation state | Stability coefficient | Evaluation grade |
|---------------------|-----------------------|------------------|
|                     | less | M-less | middle | M-more | more |
| Safety              | 1.477 | 1.373 | 1.168 | 1.107 | 1.032 |

4. Result

4.1. Analysis method

Each kind of precipitation state corresponds to a certain year that accords rainfall to calculate safety factor, in this way, slope factor \( K \) evaluation grade and precipitation state are linked. This paper uses the Malco J prediction technique [13] to predict slope stability factor \( K \) in the different precipitation condition, moreover, this method can judge the stability of the slope in different years. Because landslide prediction has complexity characteristic, this study is only for short-term forecast.

Markoff prediction technology is the method to study the time series of which basic principle is variation of Markoff chain. Markoff chain linked change of future and present, thus it can accord present state or past state to estimating future trends. If the time series is expressed a finite function such as \( N \), then from the state of \( i \) by one step state transition to the state of \( j \), in the process of transfer that has different state may be occur, if using \( P_{ij} \) shows this possibility, which \( P_{ij} \) is called one step state probability. These probabilities are arranged in order and formed a matrix that called one step state transition probability matrix. Denoted \( P \) as follow:

\[
P = \begin{bmatrix}
P_{11} & P_{12} & \cdots & P_{1N} \\
P_{21} & P_{22} & \cdots & P_{2N} \\
\vdots & \vdots & \ddots & \vdots \\
P_{N1} & P_{N2} & \cdots & P_{NN}
\end{bmatrix}
\]

The matrix has two characteristics: one is the matrix elements sum of each row equals to 1; the second is non-negative element in the matrix. Therefore, if the sequence at time \( T_0 \) is in state \( i \), after \( n \) step transition to time \( T_N \) that state change to \( j \), the possibility of this transfer quantity index called \( n \)
step transition probability, denoted \( n \) step transition probability as follow:

\[
P(t_n = j | t_0 = i) = P_{ij}(n)
\]  

(7)

The \( n \) step transition probability matrix is denoted:

\[
P = \begin{bmatrix}
P_{11}(n) & P_{12}(n) & \cdots & P_{1N}(n) \\
P_{21}(n) & P_{22}(n) & \cdots & P_{2N}(n) \\
\vdots & \vdots & \ddots & \vdots \\
P_{N1}(n) & P_{N2}(n) & \cdots & P_{NN}(n)
\end{bmatrix}
\]  

(8)

Base on this theory, if the current state of the slope were known, one step state transition probability matrix can be used for prediction slope stability in the coming year and \( n \) step state transition probability matrix can be used to prediction slope state of next \( n \) year. This study is only about statistics element value on one step state transition probability matrix, to predict change of slope stability in the next year (short-term). This method belongs to probability application in prediction of slope stability.

Use mean standard deviation method, precipitation data corresponding slope stability factor of \( K \) respectively as follow: lightly rainfall→safety, less rainfall→safe table, moderate rainfall→critical state, more rainfall→dangerous, heavy rainfall→too dangerous, in this paper five levels respectively labeled as 1, 2, 3, 4 and 5, each state appears year as shown in table 4.

| Table 4. Study area slope state statistics. |
|---|---|---|---|---|---|---|---|
| year | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 |
| state | 1 | 4 | 3 | 4 | 4 | 3 | 3 | 4 |
| year | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
| state | 4 | 1 | 3 | 3 | 3 | 3 | 3 | 5 |
| year | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 |
| state | 3 | 1 | 3 | 1 | 4 | 5 | 2 | 5 |
| year | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| state | 4 | 2 | 2 | 3 | 4 | 4 | 4 | 3 |
| year | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
| state | 3 | 3 | 1 | 1 | 2 | 1 | 4 | 3 |
| year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| state | 3 | 1 | 1 | 5 | 1 | 3 | 3 |

One step state transition as follows:

\[
F = (f_{ij})_{acc} = \begin{bmatrix}
1 \rightarrow 1 & 1 \rightarrow 2 & 1 \rightarrow 3 & 1 \rightarrow 4 & 1 \rightarrow 5 \\
2 \rightarrow 1 & 2 \rightarrow 2 & 2 \rightarrow 3 & 2 \rightarrow 4 & 2 \rightarrow 5 \\
3 \rightarrow 1 & 3 \rightarrow 2 & 3 \rightarrow 3 & 3 \rightarrow 4 & 3 \rightarrow 5 \\
4 \rightarrow 1 & 4 \rightarrow 2 & 4 \rightarrow 3 & 4 \rightarrow 4 & 4 \rightarrow 5 \\
5 \rightarrow 1 & 5 \rightarrow 2 & 5 \rightarrow 3 & 5 \rightarrow 4 & 5 \rightarrow 5
\end{bmatrix}
\]  

(9)

The matrix is the slope stability coefficient \( K \), which is calculated in accordance with the precipitation status in study area, by one-step transition matrix risk is divided into 5 grades
respectively as: safe state, stable state, basically stable state, partial risk state and risk state. The transition frequency matrix is calculated from formula (9) and is shown as:

\[ F = (f_{ij})_{m \times n} = \begin{bmatrix} 2 & 1 & 3 & 3 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 4 & 0 & 9 & 4 & 1 \\ 1 & 1 & 5 & 2 & 1 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix} \]  \hspace{1cm} (10)

In formula (10), \( f_{ij} \) is defined as frequency which is \( i \) state transition to \( j \) state. The transfer probability is as follows:

\[ p_{ij} = \frac{f_{ij}}{\sum_{j=1}^{n} f_{ij}} \]  \hspace{1cm} (11)

According to the formula (11), the result of one step transfer matrix shows as:

\[ P^{(1)} = \begin{bmatrix} 0.2 & 0.1 & 0.3 & 0.3 & 0.1 \\ 0.25 & 0.25 & 0.25 & 0 & 0.25 \\ 0.22 & 0 & 0.5 & 0.22 & 0.05 \\ 0.1 & 0.1 & 0.5 & 0.2 & 0.1 \\ 0.25 & 0.25 & 0.25 & 0.25 & 0 \end{bmatrix} \]  \hspace{1cm} (12)

Base on this, according to the slope stability state in a given year, we can predict slop stability state of coming year and the calculation formula as follows:

\[ P_{t+1} = P_{t}^{(1)} \]  \hspace{1cm} (13)

4.2. Results and discussion

- If the slope evaluation standards in previous year is safety state, then the unconditional probability distribution as follows:

\[ P_{last} = [1, 0, 0, 0, 0] \]

In the next year the probability of slope state may appear as follows:

\[ P_{next} = [1, 0, 0, 0, 0] \times P^{(1)} = [0.2, 0.1, 0.3, 0.3, 0.1] \]

This shows that, when a slope for safety state in this year as the next year probability for safety state is 20%, the probability for stable state is 10%, the probability for basically stable state is 30%, the probability of a partial risk state is 30%, and the probability of risk state is 10%. According to the classification standard of this study, the value of safety factor \( K \) has 60% probability above to 1.15.

- If the previous year of slope evaluation standards is stable state then the unconditional probability distribution as follow:

\[ P_{last} = [0, 1, 0, 0, 0] \]

In the next year the probability of slope state may appear as follow:
\[ P_{\text{next}} = [0,1,0,0,0] \times P^{(i)} = [0.25,0.25,0.25,0,0.25] \]

This means that when a slope for stable state in this year, in the next year probability for slope safety state is 25%, the probability for stable state is 25%, probability for basically stable state is 25%, the probability for partial risk state is 0%, and the probability for risk state is 25%. Calculation result shows that the value of safety factor \(K\) has 75% probability above to 1.15.

- If the previous year of slope evaluation standards is basically stable state then the unconditional probability distribution as follows:

\[ P_{\text{last}} = [0,0,1,0,0] \]

In the next year the probability of slope state may appear as follows:

\[ P_{\text{next}} = [0,0,1,0,0] \times P^{(i)} = [0.22,0,0.5,0.22,0.05] \]

This means that when a slope as basically stable state, slope has safety state in the next year is 22% probability, the probability for stable state is 0%, the probability for basically stable state is 50%, the probability for partial risk is 22%, the probability for risk is 5%. The value of safety factor \(K\) has 72% probability above to 1.15.

- If the previous year of slope evaluation standards is partial risk state then the unconditional probability distribution as follows:

\[ P_{\text{last}} = [0,0,0,1,0] \]

In the next year the probability of slope state may appear as follows:

\[ P_{\text{next}} = [0,0,0,1,0] \times P^{(i)} = [0.1,0,1,0.5,0.2,0.1] \]

This means that when the slope in a partial risk state, in the next year probability of safety state is 10%, stable state probability is 10%, basically stable state probability is 50%, the probability of a partial risk state is 20%, and the probability of risk state is 10%. But in this case it has different from above the situation (1)–(3), although the safety factor \(K\) above to 1.15 has 70% probability, this is likely to be a “safety after landslide”, it means if landslide occurred, adverse factors of slope accumulation will be released, thus the slope will be reach a new state of safety, so in the next year, in a certain degree safety state and stable state due to whether landslide has occurred, partial risk state and risk state due to whether the slop keep steady, but in seemingly steady state will further accumulate adverse factor, thus in the study, we must pay attention to this phenomenon.

- If the previous year of slope evaluation standards is risk state then the unconditional probability distribution as follows:

\[ P_{\text{last}} = [0,0,0,0,1] \]

In the next year the probability of slope state may appear as follows:

\[ P_{\text{next}} = [0,0,0,0,1] \times P^{(i)} = [0.25,0.25,0.25,0.25,0.25] \]

To be similar as situation (4), when slope in a risk state, in the next year the safety state, stable state, basically stable state and partial risk state have the same probability as 25%, sum of those probability is 100% meanwhile the risk state probability is 0%. It shows that the landslide may be take place already, so the adverse factors are to be consumed, hence the landslide can not occur in the next year.

5. Conclusion

To analyze long series precipitation, this paper examined rainfall period in the study area and pointed out the change in precipitation may cause geological body get more adverse factor for landslide. The main conclusions are shown as follow:

- The rainfall in the Baoji area has three periods of 5a, 13a and 25a, where 5a is the main period.
of precipitation, and it characteristic shows alternate of “two less and one more” as fluctuation.

- According to different rainfall intensities states, this paper designed different simulated precipitation, and the stability of slope is simulated by the finite element software. Simulation results show the slope safety factor $K$ has similar fluctuation trend with precipitation state. Therefore, this study based on the specification to considering the change of precipitation has similar regularity with slope factor, dividing slope factor $K$ of 5 grades, that is, safety, basically safety, stable, partial risk and risk, respectively.

- Based on periodic precipitation, this paper used Malco prediction technique, considering the stability state of the slope in the influence of precipitation factors. Results indicated that: in the previous year if the slope is in the safety state, in the next year $K$ has 60% probability that higher than 1.15; If the slope in previous year is in basically safe state, in the next year $K$ has 75% probability that higher than 1.15; If the slope in previous year is in stable state, in the next year $K$ has 72% probability that higher than 1.15.

- When the previous year slope is in partial risk state or risk state, although slope factor $K$ has larger probability than 1.15, the mechanism is different from the first three. There is high probability that stability factor $K$ is always higher than 1.15, which means to a great extent that the slope have already occurred landslide. In that case, the adverse factor accumulation has been released, thus the slope being in safety state in the next year.

The landslide system has many uncertain factors. In many cases, the prediction of safety factor $K$ is safe, but the safety state has difference means between “The safety state that after destruction” and "safety state that have no destruction". In this tow situation they are completely different in mechanism. Landslide has characteristic of complexity, openness, gradual change, mutation, and its entropy is expected to increase. Hence, to study and absolute prediction such as a chaotic system is impossible. Therefore, only at the macro scale, combine gradient with mutation and use continuous monitoring, reinforce in time, along with taking avoidance tactics when necessary, as much as possible to reduce the losses caused by landslides.

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