

Research on Early Warning Method of Plough Layer Thickness of Cultivated Land in Black Soil Driven by Rainfall Events

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ABSTRACT

The thinning of the arable layer causes soil quality degradation, seriously affecting crop growth and even threatening national food security. This article focuses on the problems and needs of poor timeliness, high cost, and inability to dynamically warn about the thinning of the tillage layer in black soil farmland, and conducts research on corresponding warning methods. Based on daily rainfall data, the percentile method is used to calculate the threshold for erosive rainfall event driven warning. Based on erosive rainfall event driven coupling of external soil erosion stress meteorological elements and influencing processes, as well as the connotation of geographic events, the concept definition of geographic events for thinning warning of arable layer thickness is given. The semantic description and discovery method of geographic events are provided, and geographic event driven rules and the technical process of thinning warning of arable layer thickness are formulated. There is a significant correlation between rainfall and topsoil thickness, with a correlation coefficient of 0.83. A soil thickness thinning warning simulation was conducted based on the daily rainfall data of Hailun City, Heilongjiang Province in 2020. On June 14, 2020, when the daily rainfall exceeded the event threshold, an automatic warning for thinning of the plow layer was triggered, achieving a dynamic warning process for thinning of the plow layer. The research results indicate that this method is helpful in solving the problem of thinning warning of the cultivated layer thickness in black soil farmland, and can provide technical support for the quality construction, protection, and management of black soil farmland.

KEYWORDS

Rainfall; event-driven; cultivated land; plough layer thickness; warning.

1. INTRODUCTION

Black soil is a precious arable land resource and plays an irreplaceable role in ensuring national food security. Long term high-intensity utilization, coupled with soil erosion, results in an overall thinning of black soil thickness[1]. The thickness of black soil has degraded from 60-70cm at the beginning of cultivation to 20-30cm now, and it is decreasing at a rate of 0.3-1.0cm per year[2-4]. Soil erosion leads to a decrease in productivity, endangering national food security and ecological security.

Currently, foreign scholars have conducted research on soil warning, including Luo[5] using a combination of soil probes and electrical resistivity tomography, analyze the distribution of soil

thickness. Khaledian[6] using principal component analysis and multivariate statistical methods to predict soil quality in cultivated land. The formation and variation of topsoil thickness are influenced by various factors and processes such as topography, climate, vegetation coverage, and land use patterns. This influence is closely related to geographic space and elements, and is dynamically changing. Domestic scholars have also conducted extensive research on soil thickness, Chen Yulan^[7]based on machine learning methods, predicting soil thickness around plain and mountainous elements can better reflect the distribution of soil thickness. Liu kai^[8]study the trend of changes in the thickness of black soil layers in water eroded areas and analyze the reasons for the changes in the thickness of black soil layers. Dai Liangliang^[9]utilizing field measured topsoil thickness data and using mathematical statistical methods to comprehensively overlay influencing factors based on weights, the distribution of topsoil thickness in the study area can be obtained. To monitor changes in topsoil thickness, traditional techniques mainly rely on soil profile surveys and use multi period soil survey data for monitoring and early warning of changes in topsoil thickness^[10-12], no further research has been conducted on the impact of soil erosion on the thickness of the cultivated layer.

In terms of soil water erosion, existing research mainly focuses on spatiotemporal analysis of soil erosion intensity, and cannot simulate the impact of a single rainfall on the thickness of the cultivated layer. In recent years, with the rapid development and application of ground observation and Internet of Things technology, the use of three-dimensional monitoring technology in space, space, and space can monitor real-time changes in geographical elements such as meteorology and terrain environment, providing the possibility of automatic warning of changes in arable layer thickness. Based on this, this article addresses the issues and demands of poor timeliness, high cost, and inability to dynamically warn about changes in the thickness of the cultivated layer in black soil, Thoroughly analyze the natural environmental factors such as meteorology and terrain closely related to the thickness of the cultivated layer, and their impact processes, coupled with soil erosion processes, propose an automatic warning method for changes in topsoil thickness driven by rainfall events, aiming to solve the problem of thinning warning for black soil topsoil thickness and serve the construction, protection, utilization, and management of farmland quality.

2. MATERIALS AND METHODS

2.1. General Situation

Hailun City is located in Suihua City, Heilongjiang Province, with geographical coordinates of 46°58'-47°52' N and 126°14'-127°45' E. The overall terrain is low in the southwest and high in the northeast, with the highest elevation of 470m and the lowest elevation of 146m. The slope is within 5°, making it a typical black soil area of Manchuan Mangang[13]. Affected by the terrain, rainfall gradually increases from southwest to northeast, mainly concentrated from June to August, with an average annual precipitation of 500-700mm. Severe soil erosion and soil erosion, with over 70% of the area affected by erosion[14]. The land use type in the research area is mainly farmland, with uniform soil parent material texture, mainly composed of fine silt and clay particles[15].

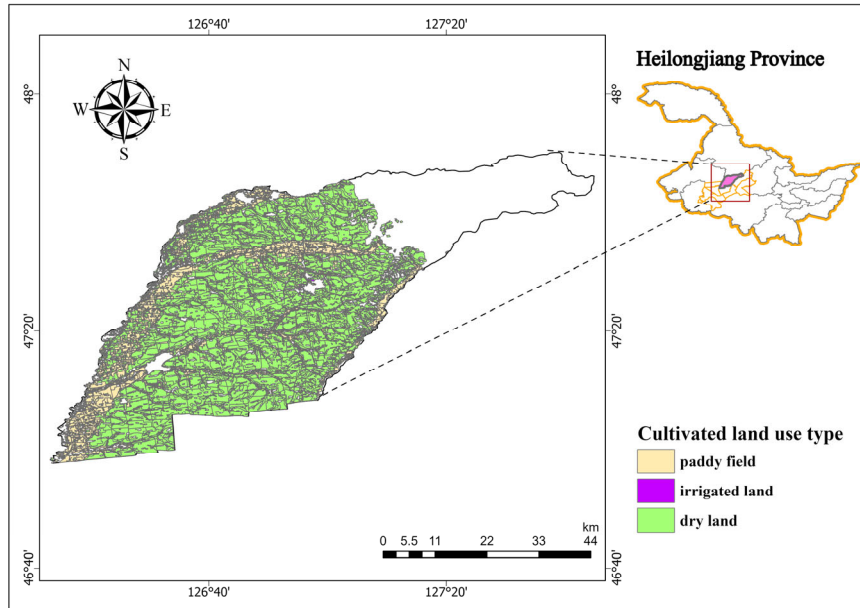


Figure 1. Land use type map of study area

2.2. Data sources

The data for conducting research on the thickness of cultivated land mainly includes terrain and geomorphology, meteorological, soil, land use data, etc, according to the data, including: 1) 2015 Hailun City 1:10000 cultivated land resource unit data (excluding Hailun Farm); 2) 12.5m resolution DEM data, sourced from geospatial data clouds; 3) daily precipitation data from 2010 to 2020, sourced from the European Centre for Medium Range Weather Forecasts; 4) 1: 1000000 soil texture data, from the Data Center of Resources and Environment Science, Chinese Academy of Sciences; 5) 1:100000 soil data (including soil organic carbon and soil bulk density), sourced from the World Soil Database (HWSD); 6) the thickness data of the cultivated layer is sourced from the second soil survey sampling point data in the Northeast region; 7) The 30m land use type remote sensing monitoring data is sourced from the National Earth System Science Data Center.

2.3. Research method

2.3.1. Concept and semantic description of geographic events

"Event" refers to the occurrence or possibility of extreme phenomena related to natural environmental factors, including sudden changes between natural phenomena and geographic spatial elements. Through "event", changes in the world can be discovered[16]. The concept of geographic events was initially proposed in the study of spatio-temporal data models[17], to this day, there is still no unified concept[18].

This article is based on the connotation of thinning the thickness of the cultivated layer, starting from natural environmental factors such as climate and terrain, and defining events that affect geographical objects due to abnormal changes in geographical phenomenon attributes within a certain time and space range as geographical events. The content includes the phenomena, time, geographical location, and causes of geographical events, described using a set of quadruples<E, T, L, A>, Among them: E refers to the phenomenon of geographical events, such as water erosion; T refers to the time when a geographical phenomenon occurred in a geographical object, such as year/month/day; L refers to the location of geographical objects in space where geographical phenomena occur, such as longitude and latitude coordinates; A refers to the cause of geographical phenomena, such as rainfall.

2.3.2. Geographical Event Discovery Methods

When rainfall exceeds the range of soil bearing capacity, it will cause soil waterlogging and erosion, resulting in changes in attributes such as topsoil thickness, which can damage the quality of cultivated land and endanger its production capacity. Therefore, this article sets rainfall event thresholds based on rainfall data to discover geographical events. The selection of event thresholds is a crucial step in discovering geographic events. Currently, methods for determining thresholds include fixed threshold method[19], standard deviation method[20], percentile method[21], climate anomaly method [22], etc, however, rainstorm in Heilongjiang Province is characterized by short duration, paroxysmal and local characteristics[23-24], this paper will use the percentile method to calculate the threshold[25], the calculation method is that the effective values of meteorological elements are n , and in ascending order $X_1, X_2, \dots, X_m, \dots, X_n$, a certain value $\leq X_m$, the probability of is $P = (m - 0.31) / (n + 0.38)$, in the formula, m is the sum of X_m , n is the number of valid samples. The 99th percentile value is the X_m value corresponding to $P = 99\%$, which is defined as the threshold for geographic event recognition and triggering, providing discrimination rule mechanism data for geographic event triggering.

2.3.3. Geographic event driven design

Event driven is a core concept in modern industrial information technology[26], with the main idea that events will only be triggered when a pre-defined threshold is exceeded. It is a triggering mechanism that executes according to user needs[27]. Unlike traditional periodic control methods, it converts prior knowledge into geographic events[28], and determines whether to issue warnings based on set triggering conditions, which can reduce the number of database traversals and improve data utilization.

Rainfall is a natural factor affecting water erosion, and rainstorm has the greatest destructive effect on the thickness of the plough layer[29-30], in order to achieve early warning of changes in the thickness of the plough layer caused by soil erosion caused by rainfall, it is necessary to organize data on meteorological monitoring data and rainfall event data, and monitor the rainfall monitoring data in real time. The entity relationship between meteorological monitoring data and rainfall event data is shown in Figure 2.

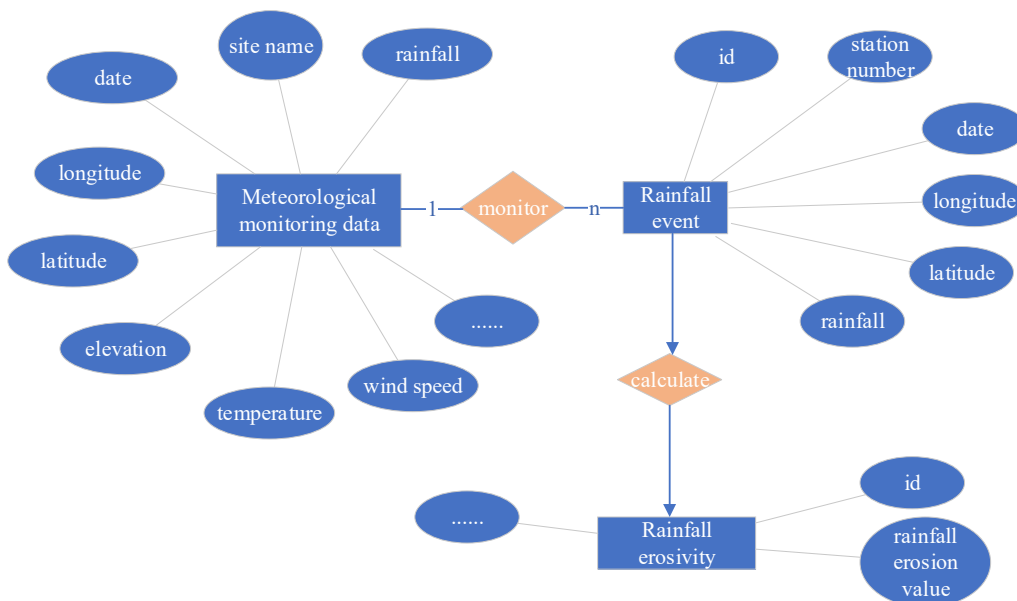


Figure 2. E-R chart of meteorological data and rainfall event data

Geographic event driven data analysis is automatically achieved through service flow engine technology. Integrate real-time monitoring rainfall data into the system, filter the data by setting thresholds, and determine whether to conduct thinning warning for the tillage layer based on the threshold. Firstly, determine the filtering range. This article sets the filtering range to 46°58'-47°52', 126°14'-127°45'. Secondly, set the rainfall threshold. Then, this article sets a 24-hour interval for automatic filtering, defining a continuous sampling time of $i \in \mathbb{N}$ for the driving sequence t_i . Afterwards, the user activates the automatic warning function module, and based on the triggering mechanism of rainfall geographic events, the conditions are represented as $\| D(t)-X(t) \| > 0$, $D(t)$ is the value of rainfall at time t , and $X(t)$ is the event threshold. If the triggering mechanism conditions are not met, the current activity will no longer continue and filtering will automatically stop; if the triggering mechanism conditions are met, the next step of soil erosion modulus calculation will be carried out, and the event driven application process is shown in Figure 3.

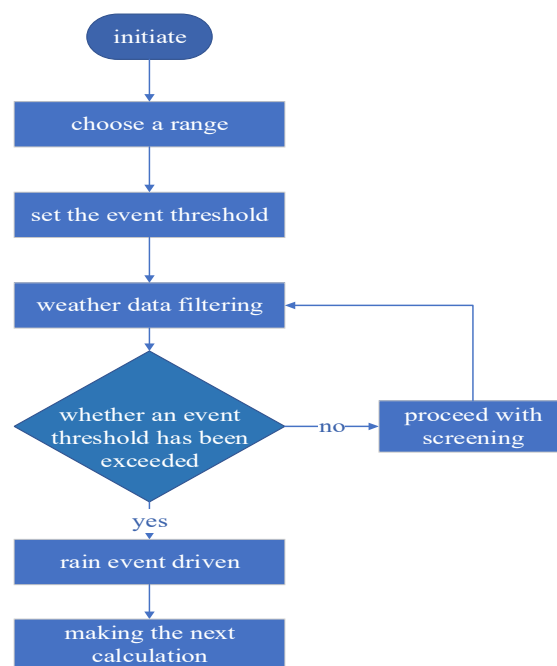


Figure 3. Event-driven process

2.3.4. Calculation method for soil erosion modulus and soil loss thickness

(1) Method for calculating soil erosion modulus

Soil erosion seriously affects the natural environment and agricultural production. In order to quantitatively evaluate soil erosion in China, the Universal Soil Loss Model (USLE) proposed by Wischmeier [31] was introduced, later, Liu Baoyuan proposed the Chinese Soil Loss Equation (CSLE), both of which require more than 20 years of rainfall data to calculate the average annual rainfall erosive force, however, Renard[32] improved the USLE model and proposed the Revised Universal Soil Loss Model (RUSLE), which has now become an important calculation model in the field of soil erosion. Combining the availability and applicability of model data, they use it to calculate the soil erosion modulus. The formula is:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (1)$$

In the formula: A is the soil erosion modulus, R is the rainfall erosion factor, K is the soil erosion factor, L is the slope length factor, S is the slope factor, C is the vegetation coverage and management factor, and P is the soil and water conservation measure factor (L, S, C, P are all dimensionless).

1) Rainfall erosion factor (R). The rainfall erosion factor is the dominant factor of soil erosion, reflecting the magnitude of the impact of rainfall intensity on soil erosion capacity. This article uses a method that can better reflect the rainfall intensity and daily rainfall erosion factor based on daily rainfall data^[33] to improve the accuracy of rainfall erosion factor estimation. The formula is as follows:

$$\begin{aligned} R_i &= \alpha(p_i)^\beta \\ \alpha &= 21.586\beta^{-7.182} \\ \beta &= 0.836 + 17.144P_{d12}^{-1} + 24.455P_{y12}^{-1} \end{aligned} \quad (2)$$

In the formula, R_i is the erosion factor of rainfall on the i -th day, and P_i is the daily rainfall on the i -th day, α and β the statistical coefficient of rainfall erosion factor, P_{d12} is the daily average rainfall with a daily rainfall of ≥ 12 mm, and P_{y12} is the annual average rainfall with a daily rainfall of ≥ 12 mm. If monthly and annual rainfall erosion need to be calculated, they only need to be accumulated separately.

2) Soil erosion factor (K). The soil erosion factor reflects the resistance of soil's physical and chemical properties to soil erosion, and is calculated based on various soil attribute data. This study adopted the EPIC model proposed by Williams and Sharply^[34], with the following formula:

$$\begin{aligned} K &= \{0.2 + 0.3 \exp[-0.0256 SAN(1 - \frac{SIL}{100})]\} \times (\frac{SIL}{CLA + SIL})^{0.3} \times \\ &[1 - \frac{0.25C}{C + \exp(3.72 - 2.95C)}] \times [1 - \frac{0.7SN1}{SN1 + \exp(-5.51 + 22.9SN1)}] \end{aligned} \quad (3)$$

$$SN1 = 1 - \frac{SAN}{100} \quad (4)$$

In the formula: K is the soil erosion factor, and SAN is the sand content (%); SIL is the powder content (%); CLA is the content of clay particles (%); C is the organic carbon content (%).

3) Terrain factors (L and S). Slope length and slope factor are important parameters of soil erosion. Considering the geographical conditions of the study area, the calculation of slope length and slope factor is carried out using the formula proposed by Wischmeier, as follows:

$$S = \begin{cases} 10.8 \sin \theta + 0.03 (\theta < 5^\circ) \\ 16.8 \sin \theta - 0.50 (5^\circ \leq \theta < 10^\circ) \\ 21.9 \sin \theta - 0.96 (\theta \geq 10^\circ) \end{cases} \quad (5)$$

$$L = \left(\frac{\lambda}{22.1} \right)^m \quad (6)$$

$$m = \frac{B}{B+1} \quad (7)$$

$$B = \frac{\sin\theta/0.0896}{3.0 \times (\sin\theta)^{0.8} + 0.56} \quad (8)$$

In the formula: λ is the slope length (m), θ is the slope, m is the slope length index, the dimension is 1, and B is the slope correction value.

4) Vegetation coverage and management factors (C). Vegetation coverage and management factors are based on the impact of different vegetation cover on soil erosion on the ground, with values ranging from 0 to 1^[35].

5) Factors of soil and water conservation measures (P). The factor of soil and water conservation measures refers to the ratio of soil loss under certain specialized measures to soil loss under slope planting, with a value between 0 and 1^[36-37].

(2) Calculation method for soil erosion thickness

In order to more accurately express the degree of soil erosion, it is necessary to convert the soil erosion modulus into the soil loss thickness. Existing research suggests that the thickness of soil erosion can be calculated by converting the soil erosion modulus and soil bulk density^[38], using the following formula:

$$V = \frac{W \cdot A}{Q} \quad (9)$$

In the formula, V is the daily average soil loss thickness, A is the soil erosion modulus, Q is the soil bulk density, and W is the conversion coefficient of 0.001.

2.3.5. Automatic warning method

The term early warning originated in the military field^[39]. Early warning is defined as sending warning signals to relevant departments and reporting the situation beyond the existing human understanding before a disaster occurs, in order to avoid disasters without knowledge or insufficient preparation, and thus minimize losses. The basic elements of early warning include warning element, warning situation, warning source, warning sign, and warning degree. The process includes: determining the warning situation, searching for the warning source, analyzing the warning sign, predicting the warning degree, and making early warning decisions^[40]. Based on this, this article will refer to the factor indicators of thinning of the plow layer, such as rainfall, as warning factors; The phenomenon of thinning the thickness of the cultivated layer is called a warning situation; The meteorological changes that cause changes in the thickness of the cultivated layer are called warning sources, such as water erosion caused by rainfall; The characterization indicators of the warning situation, such as the thickness of the plow layer, are called warning signs, and the quantitative analysis of the warning signs is called warning degree.

(1) Automatic alert data organization

In order to support the warning of thinning of the plow layer, a data table consisting of four types of information, including warning units, warning situations, warning sources, and warning signs, was designed to organize and store warning related information. The warning unit data table includes: warning unit number, warning unit land class name, warning unit land class number, rainfall erosivity factor (R), soil erosion modulus (A), and soil loss thickness. The alarm data table includes: alarm number, time of occurrence of the alarm, geographical location (longitude and latitude) of the alarm, and cumulative rainfall within 24 hours (mm). Alarm source data table includes: meteorological station number, rainfall monitoring date, station geographic location (latitude and longitude), cumulative rainfall within 24 hours (mm). The warning data table includes: warning number, warning method, warning value, and warning degree.

(2) Automatic warning process

The process of warning for thinning of arable layer thickness is as follows: first, access real-time monitoring data of meteorological elements; Secondly, real-time analysis and calculation of monitoring data are carried out according to pre-defined geographic event triggering rules. Once the geographic event triggering rules are met, an automatic warning of thinning of the plow layer is triggered, and a semantic description model of geographic events is used to construct geographic event data. Then, based on geographic event data and soil erosion model data, the modified universal soil loss equation (RUSLE) model is used to calculate the soil erosion modulus, and the soil loss thickness calculation model is used to calculate the soil loss thickness; Finally, based on the warning threshold, soil loss thickness and soil loss thickness change rate are warned, and the warning results are visually displayed. The detailed process is shown in Figure 4.

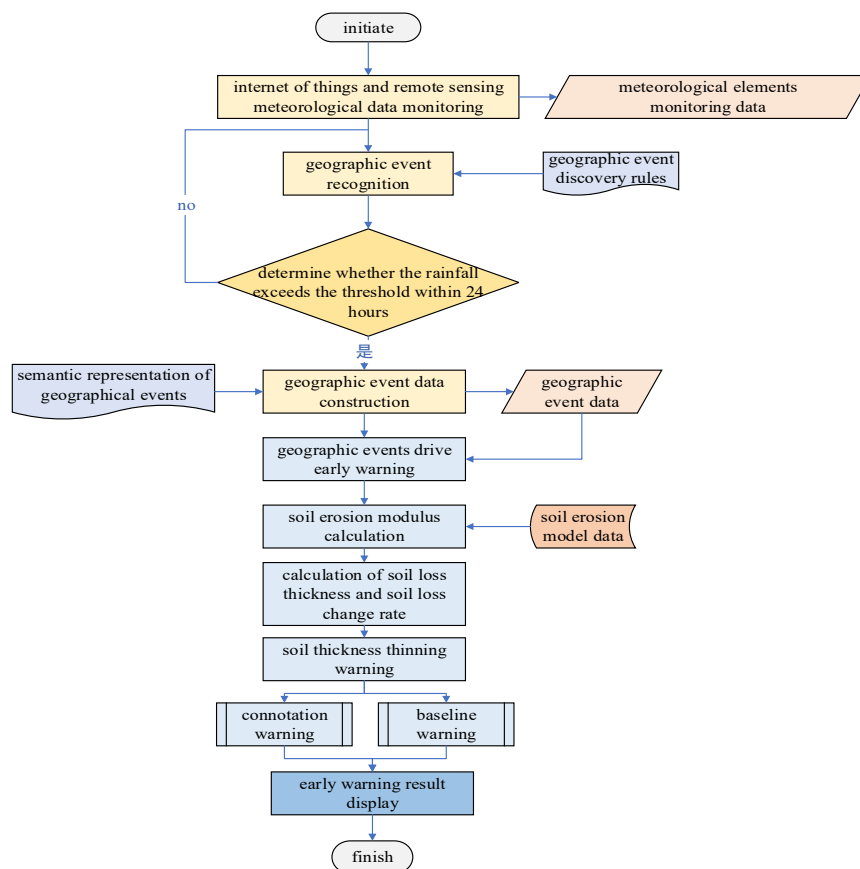


Figure 4. Flow chart of soil thickness early warning method for rainfall events

3. CASE ANALYSIS

Rainfall, especially rainstorm, is easy to cause soil erosion, leading to water and soil loss, and then causing changes in the thickness of cultivated layer. This article combines the application requirements of thin layer warning for black soil farmland, taking Hailun City as an example, to introduce the implementation process of thin layer warning for black soil farmland driven by rainfall events.

3.1. Soil erosion model data preprocessing

To achieve the calculation of soil erosion modulus and soil loss thickness, it is necessary to preprocess the data related to the model. Among them, the warning unit data is 1:10000 cultivated land resource unit data; the thickness data of the plow layer is based on 277 soil profile points from the second general survey, and then obtained through ordinary Kriging spatial interpolation, as shown in Figure 5a; the slope length and slope factor (L and S) are based on DEM data and processed using tools such as filling, flow direction, and flow rate in ArcGIS software. The L and S values are determined using formulas (5) to (8), as shown in Figures 5b and 5c; soil erosion factor (K) data, based on soil texture data and soil organic carbon data, were calculated using formulas (3) and (4) through the grid calculator of ArcGIS software, as shown in Figure 5d; the vegetation coverage and management factor (C) was assigned using the empirical assignment method. Based on the land use type data in the study area, the value was assigned through the reclassification function of ArcGIS software. The C value for paddy fields was 0.18, and the C value for dry and irrigated fields was 1, as shown in Figure 5e; the factor of soil and water conservation measures (P) was assigned to different land use types using the empirical assignment method. The reclassification function of ArcGIS software was used to assign values, with a P value of 0.03 for paddy fields, 0.35 for dry lands, and 1 for irrigated lands, as shown in Figure 5f.

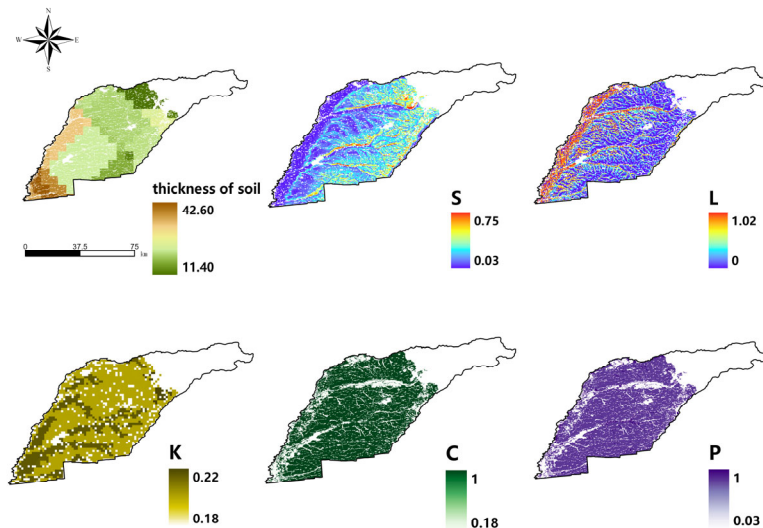


Figure 5. Soil erosion model data

3.2. Rainfall geographic event driven

According to the percentile method, the threshold for rainfall events is calculated. The daily rainfall data from 2010 to 2020 are calculated as a set of independent data for each year, and the 99th percentile value for each year is calculated. A total of 11 data points are obtained, namely 40.39, 39.12, 39.88, 100.84, 47.00, 42.67, 63.75, 48.51, 98.55, 57.91, and 70.10. Due to the inability of a

single data to quantitatively characterize the rainfall threshold, this article calculates the average of 11 data as the rainfall event threshold, with a threshold $X(t)$ of 59.

This study used daily rainfall data from 2020 for rainfall geographic event driven early warning simulation. According to the geographical event discovery rule set in 1.3.3, a geographical event driven approach was initiated to analyze the connected rainfall data. On June 14, 2020, the rainfall exceeded 59mm, resulting in rainfall event driven data. The results are shown in Table 1. A geographic event data table was generated based on rainfall event driven data, as shown in Table 2.

On June 14, 2020, an automatic warning for thinning of the topsoil layer was triggered, and the rainfall erosion factor R data was synchronously calculated after the warning was triggered. Due to the fact that rainfall data is point data, this article uses ordinary Kriging spatial interpolation to create surface data, calculate the R factor, and then associate it with warning units, as shown in Figure 6.

Table 1. Rainfall events drive data table

serial number	identification code	station number	year	month	day	latitude	longitue	rainfall/mm
1	01	507560	2020	6	14	126.87	47.45	59

Table 2. Geographic event data table

serial number	geographical event phenomenon	year	month	day	latitude	longitue	reason
1	water erosion	2020	6	14	126.87	47.45	降雨

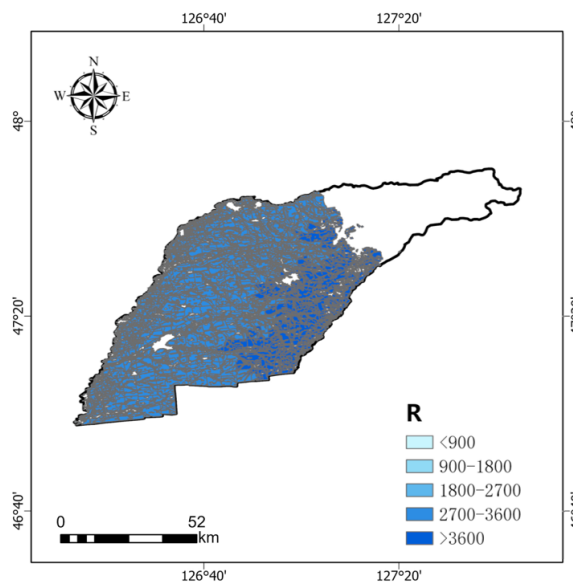
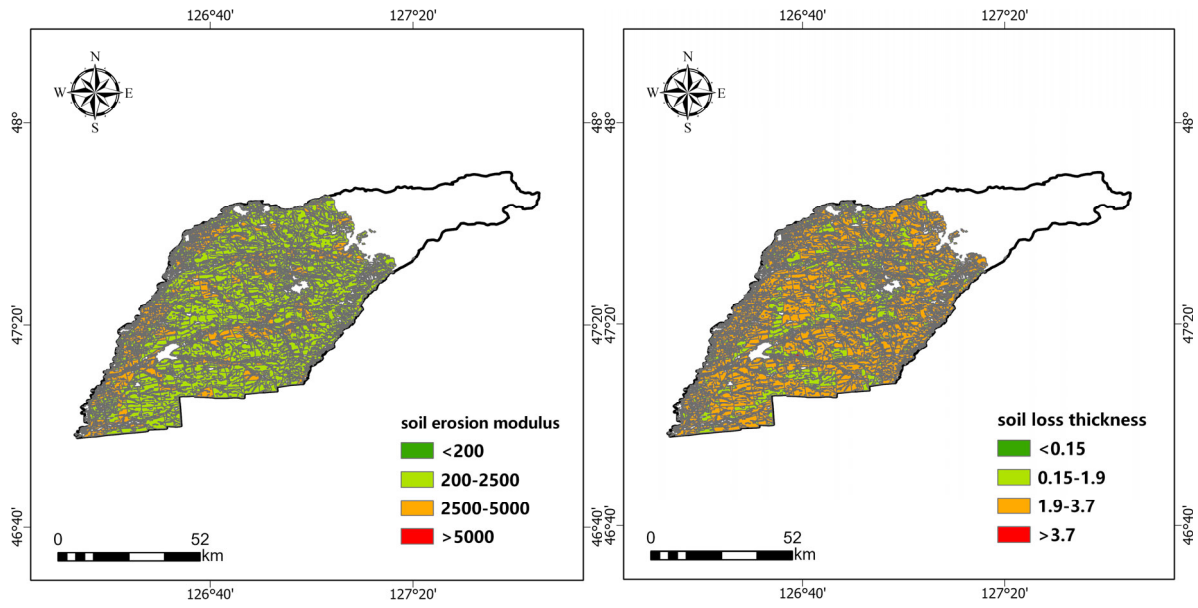


Figure 6. Distribution of rainfall erosion factors

3.3. Calculation of soil erosion modulus and soil loss thickness

Based on the data from 2.1 and 2.2 and the modified universal soil erosion model (RUSLE), the six factors were multiplied using the grid calculator function of ArcGIS to calculate the soil erosion modulus in the study area. According to the Soil Erosion Classification and Grading Standard (SL190-2007), the soil erosion modulus in Hailun City was divided into four levels, with spatial distribution shown in Figure 7a. Then, the soil erosion thickness data was obtained using formula (9), as shown in Figure 7b.



a. soil erosion modulus

b. soil loss thickness

Figure 7. Soil erosion modulus and soil loss thickness distribution

3.4. Analysis of warning results

In order to better characterize the impact of rainfall on topsoil thickness, this study divides topsoil thickness warning into two types: connotation warning and baseline warning. Among them, connotation warning directly uses soil loss thickness as a warning indicator for warning, while baseline warning subtracts soil loss thickness from tillage thickness and then divides tillage thickness. The calculation formula is as follows:

$$\text{soil loss thickness changes} = \left| \frac{V - H_V}{H_V} \right| \quad (10)$$

In the formula, V represents the thickness of soil loss, and H_V represents the thickness of the cultivated layer.

In order to characterize the warning results of tillage thickness, this study divided the warning results into four levels: no warning, light warning, medium warning, and heavy warning. For connotation warning: less than 0.15 indicates no warning, 0.15~1.9 indicates mild warning, 1.9~3.7 indicates moderate warning, and 3.7 or above indicates severe warning, as shown in Table 3. For baseline warning, due to the small change in soil loss thickness in a single event, it is not easy to express the meaning of warning. Therefore, it is necessary to convert the change in soil loss thickness into the rate of change in soil loss thickness. As it is an absolute value for numerical comparison, the larger the rate of change, the smaller the degree of warning, and the smaller the rate of change. Baseline warning: If it is greater than 99.5%, it is considered no alarm, if it is between 99.5% and 98%, it is considered minor alarm, if it is between 98% and 97%, it is considered medium alarm, and if it is less than 97%, it is considered severe alarm, as shown in Table 3.

Table 3. Early warning scale table

early warning mode	no alarm	light alarm	medium alarm	heavy alarm
connotation warning	<0.15	0.15~1.9	1.9~3.7	>3.7
baseline warning	>99.5%	99.5%~98%	98%~97%	<97%

Applying the above research methods to calculation, the connotation warning and baseline warning are shown in Figure 8 and 9.

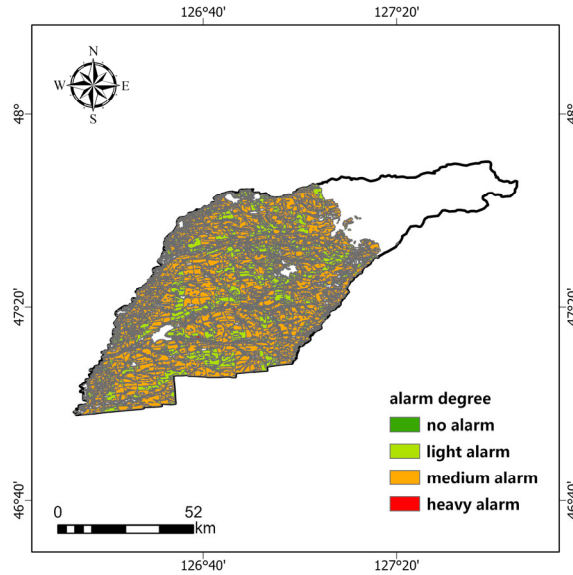


Figure 8. Connotation early warning distribution

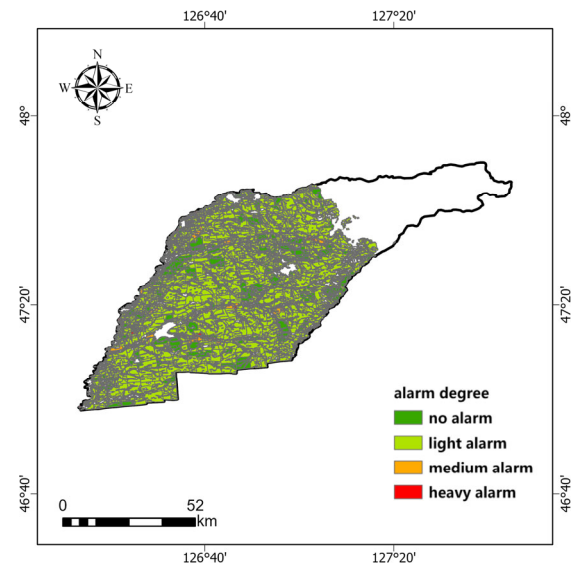


Figure 9. Baseline early warning distribution

Based on the calculation results, form an alarm warning data table (displaying partial results), as shown in Table 4.

Table 4. Warning data table

warning number	early warning mode	warning value	alarm degree
6529	connotation warning	0.12	no alarm
4713	connotation warning	1.79	light alarm
2776	connotation warning	2.15	medium alarm
4968	connotation warning	4.19	heavy alarm
2857	baseline warning	100	no alarm
1627	baseline warning	99.33	light alarm
2235	baseline warning	97.67	medium alarm
4645	baseline warning	92.51	heavy alarm

Based on the soil bulk density and soil erosion modulus, the soil loss thickness on June 14, 2020 was calculated. The connotation warning results showed that no warning accounted for 0.15% of the total cultivated land area, light warning accounted for 40.91% of the total cultivated land area, medium warning accounted for 58.70% of the total cultivated land area, and heavy warning accounted for 0.19% of the total cultivated land area. The baseline warning results show that no alarms account for 42.65% of the total arable land area, light alarms account for 54.93% of the total arable land area, medium alarms account for 1.82% of the total arable land area, and heavy alarms account for 0.16% of the total arable land area. Based on the above results, it can be seen that the overall warning is mainly light, and from the baseline warning, a single rainfall event has a certain erosion effect on the soil.

4. DISCUSS

This study is based on rainfall data-driven and modified universal soil loss models to conduct warning analysis on the thinning of soil thickness caused by a single rainfall, and further explore the relationship between rainfall and soil thickness. According to the calculation results of the modified universal soil erosion model, the area of soil erosion modulus < 200 (micro erosion) in Hailun City is 273331.69hm², accounting for 85.66% of the total arable land area, the area of 200~2500 (mild erosion) is 44385.31hm², accounting for 13.91% of the total arable land area, the area of 2500~5000 (moderate erosion) is 1180.66 hm², accounting for 0.37% of the total arable land area, and the area of >5000 (strong erosion) is 191.45 hm², 0.06% of the total arable land area. The above analysis indicates that the area with a soil erosion modulus of less than 200 accounts for the largest proportion in Hailun City, while the area with a soil erosion modulus of more than 5000 accounts for a relatively small proportion. This is similar to the results of Han Zilin^[41] 2020 soil erosion area proportion in Hailun City, indicating that the data is reliable.

On the one hand, by calculating the soil erosion modulus, the thickness of soil loss can be determined. The calculation results show that medium warning is the main factor, indicating that a single erosive rainfall has a certain impact on the thinning of the plow layer thickness. On the other hand, the area of no alarms in the baseline warning is 136077.45hm², the area of light alarms is 175273.24hm², the area of medium alarms is 5810.37hm² and the area of heavy alarms is 1928.05hm². According to Figure 9, it can be seen that heavy alarms are mainly concentrated in the eastern and central regions and distributed in a patchy manner.

This study mainly considers the influence of rainfall on the thickness of the cultivated layer. When rainfall is large, it is easy to erode the surface soil, leading to soil loss and erosion. In fact, the thickness of the cultivated layer is not only affected by natural factors such as climate and terrain, but also by human factors such as crop planting types, planting methods, and the use of agricultural machinery and equipment in soil utilization. In terms of planting methods, horizontal and longitudinal ridges are closely related to the total amount of soil loss, and dynamic monitoring of ridge orientation

and quantity distribution is also an important research direction. Further research will be conducted on the impact of human factors on the thickness of the cultivated layer and the dynamic monitoring and early warning of changes.

5. CONCLUSION

The Pearson analysis using SPSS software showed significant correlation between rainfall and topsoil thickness, with a correlation coefficient value of 0.83. The use of rainfall data can effectively provide early warning of thinning of arable layer thickness in the research area. In response to the shortcomings of existing warning methods for thinning of arable land topsoil thickness, this article focuses on the external environmental stress caused by thinning of arable land topsoil thickness. Based on abnormal changes in rainfall factors, the concept of geographic events for thinning of arable land topsoil thickness warning is defined, and the semantic description of geographic events and the rules for discovering and triggering geographic events are provided, And coupled with the process of soil erosion, a method and technical process for early warning of thinning of cultivated land layer thickness driven by rainfall events were proposed. The feasibility and practicality of this method were verified by simulating the thinning warning of topsoil thickness using daily rainfall data from 2020. The main conclusions of the study are as follows:

- (1) This article first calculates the values of five factors, including slope length and slope factor, soil erosion factor, vegetation coverage and management factor, and soil and water conservation measure factor, based on basic data. Then, the rainfall erosion factor is calculated through rainfall data. The rainfall erosion factor data changes with the daily rainfall data, thus achieving the purpose of warning for changes in the thickness of the cultivated layer during a single rainfall;
- (2) According to the geographical event discovery and recognition rules developed in this study, it is possible to identify and drive abnormal changes in rainfall elements closely related to changes in topsoil thickness, and dynamically generate geographical event data according to the designed semantic description;
- (3) Based on the dynamically generated rainfall geographical event data, coupled with multi-source data such as land use, topography, and soil texture, the modified universal soil loss model (RUSLE) can be used to calculate the soil erosion modulus and soil loss thickness of a single rainstorm, which provides the possibility for dynamic monitoring and early warning of thinning of tith layer thickness.

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REFERENCES

- [1] XU Y D, PEI J B, LI S Y, et al. Main characteristics and utilization countermeasures for black soils in different regions of northeast China[J]. Chinese Journal of Soil Science, 2023, 54(2): 495-504.
- [2] LIU H, WEI Y X. Influence of soil erosion thickness on soil productivity of black soil and its evaluation[J]. Transactions of the Chinese Society of Agricultural Engineering, 2014, 30(20): 288-296.
- [3] JIA Y F, WANG J N, FAN H M, et al. Effects and optimal allocation of soil and water conservation measures on the multi-agent combined soil erosion in the Mollisol region, Northeast China[J]. Science of Soil and Water Conservation, 2022, 20(5): 124-132.
- [4] ZHANG R H, XIAO Y, SHAO S G, et al. Effects of erosion gully evolution on particle size distribution and water storage properties in sloping cropland of a black soil area[J]. Bulletin of Soil and Water Conservation, 2023, 43(2): 1-8.
- [5] Zidong Luo, Jinjiao Lian, Yunpeng Nie, et al. Improving soil thickness estimations and its spatial pattern on hillslopes in karst forests along latitudinal gradients[J]. Geoderma, 2023, 441: 116749.

- [6] Yones Khaledian, Farshad Kiani, Soheila Ebrahimi, et al. Assessment and Monitoring of Soil Degradation during Land Use Change Using Multivariate Analysis[J]. *Land Degradation & Development*, 2016, 28: 128-141.
- [7] CHEN Y L, LIANG T B, ZHANG Y L, et al. Spatial prediction of soil thicknesses in sichuan province based on Feature-Ensemble Learning[J]. *Soils*, 2023, 55(4): 894-902.
- [8] LIU K, WEI M H, DAI H M, et al. Spatiotemporal variation of black soil layer thickness in black soil region of northeast China[J]. *Geology and resources*, 2022, 31(3): 434-442, 394.
- [9] Dai L L, Luo M X, Zhang T, et al. Method and practice of rapid evaluation of soil thickness in low mountain and hilly area based on principal component analysis--Taking Luoshan county, Henan province as an example. *South China Geology*, 2021, 37(4): 377-386.
- [10] DENG D P, LIU Q, LU Y R, et al. Spatial distribution characteristics of soil thickness in the Zhenfeng-GuanlingHuajiang karst rocky desertification area in Guizhou Province[J]. *Hydrogeology & Engineering Geology*, 2023, 50(1): 197-206.
- [11] LI X S, XU Z Q, ZHAO W, et al. Spatial heterogeneity of surface soil nutrient and soil depth in dry south-slope of North Mountain of Hebei[J]. *Journal of Hebei agricultural university*, 2018, 41(1): 24-30, 48.
- [12] QIAO L, HUANG M J, ZHANG W P, et al. Thickness and soil nutrients of typical cultivated land in Jinzhong basin: Spatial variation[J]. *Chinese agricultural science bulletin*, 2020, 36(1): 89-97.
- [13] DING C, HU W, YAN Y, et al. Gully characteristics based on observations in typical rolling-hill mollisol region of Northeast China[J]. *Bulletin of Soil and Water Conservation*, 2020, 40(5): 72-78.
- [14] QI Z, DING C, HAN X, et al. Spatial heterogeneity of soil moisture and nutrients in valley-slope erosion watershed in black soil area[J]. *Bulletin of Soil and Water Conservation*, 2020, 40(5): 79-87.
- [15] WANG H, ZHANG S L, XU W T, et al. Spatiotemporal variation of soil erosion intensity in mollisols of a small watershed-A case study of Guangrong small watershed[J]. *Journal of soil and water conservation*, 2023, 37(5): 198-206.
- [16] DU Y Y, YI J W, XUE C J, et al. Modeling and analysis of geographic events supported by multi-source geographic big data[J]. *Acta Geographical sinica*, 2021, 76(11): 2853-2866.
- [17] LI J L, CI Y Y, ZHENG K, et al. Visualized analysis framework on big geo-information data oriented spatio-temporal events[J]. *Bulletin of Surveying and Mapping*, 2019, (12): 101-104.
- [18] XING S, JIAO L, LI P C, et al. An emergency response decision method of biological-events based on Geontology[J]. *Journal of geomatics science and technology*, 2020, 37(4): 425-433.
- [19] CHEN S X, ZHANG L, KANG Z M, et al. Evaluation on indicators for heavy precipitation events[J]. *Journal of the Meteorological Sciences*, 2023, 43(4): 505-514.
- [20] SHANG S W, WANG L Z, WANG Y T, et al. Analysis of spatial and temporal evolution characteristics of extreme precipitation in Chengdu area from 1960 to 2019[J]. *Water resources protection*, 2023, 39(3): 195-204.
- [21] KONG F, SHI P J, FANG J, et al. Advances and prospects of spatiotemporal pattern variation of Extreme precipitation and its affecting factors under the background of global climate change[J]. *Journal of Catastrophology*, 2017, 32(2): 165-174.
- [22] TANG X P, LV H S. Temporal variation of main hydrologic meteorological elements in Tuotuohe river basin[J]. *Water resources and power*, 2016, 34(12): 37-40.
- [23] ZHAO N, WANG S Y, HAN B. Temporal and spatial characteristics of precipitation anomalies in 2019 flood season in Heilongjiang Province[J]. *Heilongjiang Meteorology*, 2022, 39(4): 13-15.
- [24] WANG C W, XU Y, MENG Y Y, et al. Failure analysis of heavy rain forecast in Heilongjiang Province[J]. *Heilongjiang Meteorology*, 2020, 37(3): 10-13, 35.
- [25] XU Y Q, WANG C W, LIU C S, et al. Temporal and spatial distribution characteristics of short duration precipitation in Heilongjiang Province[J]. *Heilongjiang Meteorology*, 2023, 40(3): 1-5, 18.
- [26] CHEN Z Y, HAN Q L, WU Z G, et al. Introduction to advanced technologies for event trigger control and estimation[J]. *Scientia sinica informationis*, 2020, 50(5): 777-778.
- [27] LEI Q, WEN A G. Study on consensus of discrete multi-agents with time-varying delays based on event-triggered mechanism[J]. *Journal of Central South University(Science and Technology)*, 2023, 54(7): 2705-2717.
- [28] NING M, LI H, YANG J J. The quality monitoring of marine materials based on Event-Driven technology[J]. *Ship engineering*, 2021, 43(S2): 134-140, 145.
- [29] LI P, ZHANG Y, LIANG Z J, et al. Influence of Rainstorm on Environmental Characteristics of soil and groundwater in typical area of yellow river irrigation area[J]. *Yellow river*, 2020, 42(1): 63-67, 71.
- [30] SHI Z H, LIU Q J, ZHANG H Y, et al. Study on soil erosion and conservation in the past 10 years: progress and prospects[J]. *Acta Pedologica Sinica*, 2020, 57(5): 1117-1127.

- [31] Wischmeier H W. A rainfall erosion index for a universal Soil-Loss equation[J]. Soil science society of america journal, 1959, 23(3).
- [32] G. K R, R. J F. Using monthly precipitation data to estimate the R-factor in the revised USLE[J]. Journal of hydrology, 1994, 157(1-4).
- [33] ZHENG X, BAI S Y, GAO J X. Spialial-temporal variaion of rainlall erosivity in Jiangxi province from 1961 to 2019[J]. Journal of Nanjing university of information science & technology, 2023, 15(3): 357-366.
- [34] YAN X P, WU L X, XIE J, et al. Assessment of soil erosion sensitivity and response analysis of soil erosion sensitivity to land use change in Chengde City[J]. Water Resources and Hydropower Engineering, 2021, 52(12): 221-232.
- [35] ZHAI R J, ZHAO W W, JIA L Z. A comparative study of soil erosion estimation based on RUSLE, InVEST and USPED models: A case study of the Yanhe River Bai in Northem Shaanxi[J]. Research of agricultural modernization, 2020. 41(6): 1059-1068.
- [36] ZHAO M E, YAN Q W, LIU Z T, et al. Analysis of temporal and spatial evolution and influencing factors of soil erosion in Ordos City[J]. Arid zone research, 2022, 39(6): 1819-1831.
- [37] SONG S H, LI H K, ZHANG Z W. Spatial-temporal variation of soil erosion in Dongjiang source area based on RUSLE model[J]. Journal of Earth Environment, 2022, 13(3): 344-353.
- [38] DING F, ZHANG Z X, CAI A X, et al. A discussion on the applicability of the reference index of soil erosion intensity classification[J]. Chinese Agricultural Science Bulletin, 2006, (7): 343-346.
- [39] ZHU M R, WANG Q X, ZHANG Q H. Research on adaptive technology of outburst prevention early warning index driven by multi—source data[J]. Coal Science and Technology, 2022, 50(8): 75-81.
- [40] DUAN C Y, ZHANG Y C, ZHANG J Q, et al. Design of geological disaster risk early warning system based on GIS[J]. Journal of catastrophology, 2022, 37(1): 199-204.
- [41] HAN Z L, LI Z Z, ZHANG L, et al. Temporal and spatial changes of soil erosion in Hailun city from 2000 to 2020[J]. Territory & Natural resources study, 2023, (5): 24-30.