

Construction of Evaluation Model of Surface Soil Erodibility Factors in Black Soil Area

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Abstract: The increasing soil erosion in black soil area has caused widespread concern from all walks of life. Based on this background, the evaluation model of surface soil erodibility factor in black soil area is studied and constructed. The data of erosion gully is from the general survey data of surface soil erosion gully in black soil area. After quantifying the morphological characteristics of the data, the vector data of erosion gully are gridded by fractal theory. The number of non-empty grids is calculated by the attribute query function of ArcGIS, and the pixel size is transformed in turn to obtain different coverage grids and corresponding fractal parameters. The surface soil runoff and soil erosion process in black soil area are simulated by PESERA model. To build the surface soil erosion model of black soil area, in the process of building the user-defined model, it needs to carefully select the parameters used for modeling, and it needs to consider all the factors that may play a role in the whole process of soil erosion. The factors of surface soil erodibility in black soil area are analyzed, including spatial distribution characteristics of soil erodibility's K value, semivariance function analysis of soil erodibility's K value, and spatial distribution characteristics analysis of soil erodibility's K value. Finally, the evaluation model of surface soil erodibility factor in black soil area is constructed. By testing the quantitative performance and evaluation accuracy of erodibility factors, it is proved that this method has good quantitative performance and evaluation accuracy of erodibility factors, and has strong practicability.

Keywords: Black soil area; Surface soil; Erodibility factor; Evaluation model

Tob Regul Sci.™ 2021;7(6): 6283-6302

DOI: doi.org/10.18001/TRS.7.6.104

1. Introduction

Black soil has been known as "Grain warehouse" since ancient times for its good

properties, high fertility and rich organic matter. In recent decades, the aggravation of unreasonable development and utilization of

black soil has led to more and more serious soil erosion, the decline of land productivity and the deterioration of ecological environment in black soil area. Especially with the development of erosion gully, farmland is cut and devoured. At present, the phenomenon of soil parent material exposed on the surface is common in many areas. The unique natural environment and human activities make the black soil area one of the areas with the greatest potential risk of soil erosion in China [1]. From the formation, development and limit state, the erosion gully has some quantitative parameters. In the process of erosion development, the changes of gully volume, length and width with time reflect the soil erosion status of the area to a certain extent. The soil erosion monitoring results of the second national water conservancy census show that the soil erosion area of black soil area in China is $27.59 \times 104 \text{ km}^2$, accounting for 27% of the total area of black soil area. Rainfall, soil, topography and human activities jointly drive the development of erosion gully. The loose texture and unique physical properties of black soil are the main reasons for its weak anti erodibility. In the black soil area, erosion gullies develop seriously under the adverse natural conditions, such as concentrated rainfall in summer and alternation of freezing and thawing cycles in spring thawing period. Gully erosion is becoming more and more serious under the action of water and freeze-thaw, which leads to the destruction of soil structure, the reduction of land productivity and the deterioration of ecological environment. It seriously restricts the sustainable and healthy development of regional social economy and poses a serious threat to the food production security in China. The ecological environment damage caused by the development of gully erosion and the harm of people's production and life cannot be ignored [2]. The increasing soil erosion in black soil area has caused widespread concern from

all walks of life. Based on this background, the surface soil erodibility factor evaluation model in black soil area is studied and constructed.

2. Materials and Methods

2.1. Basic data acquisition

The data of erosion gully is derived from the general survey data of surface soil erosion gully in black soil area. The survey process is as follows: the survey of erosion gully is based on the main information sources including the remote sensing Orthophoto image (Panchromatic image with resolution of $2.5\text{m} \times 2.5\text{m}$), 1:50000 digital line graph (DLG), 1:50000 digital elevation model (DEM with $25 \text{ m} \times 25 \text{ m}$ resolution), the data of administrative division, watershed boundary and water system, issued by the leading group office of the first national water conservancy survey of the state council. The data satellites used mainly include ZY (Resource Satellite) and ALOS (Japan Earth Observation Satellite). Before interpreting the erosion gully, radiometric correction, strip and spot removal, geometric correction, image mosaic and image fusion are performed on the basic remote sensing image to ensure the good quality of the impact [3]. In addition, the remote sensing Orthophoto Image is registered based on DEM data, and the coordinate system and projection transformation are carried out for each remote sensing image, so that the coordinate system and projection mode of remote sensing image data are consistent with the projection information of DEM data.

The interpretation of erosion gully is based on GIS software platform, which combines man-machine interaction, remote sensing image prediction and field review. With the help of remote sensing image, a line is drawn along the gully bottom from the gully head to the gully mouth, and the gully line is used as a ruler along the gully edge (The deviation is not more than 5 m), each erosion gully is coded, and the length, area and other indicators of

erosion gully are obtained by topological analysis; then the type of erosion gully is judged by combining with vegetation coverage, and the vegetation coverage of development gully is defined as less than 30%. Finally, the digital line drawing (DLG) is imported to read the elevation and geographical location of gully head and gully mouth combined with remote sensing image, calculate the ratio of the elevation difference of gully head and gully mouth to the length of gully, and determine the longitudinal ratio and geographical spatial location (longitude and latitude) of gully, so as to obtain the data of gully length, quantity, area, type, longitudinal ratio and geographical location [4]. The monitoring process of erosion gully can be divided into four stages: basic data collection, erosion gully extraction, field verification and data collection. The specific interpretation process is shown in Figure 1.

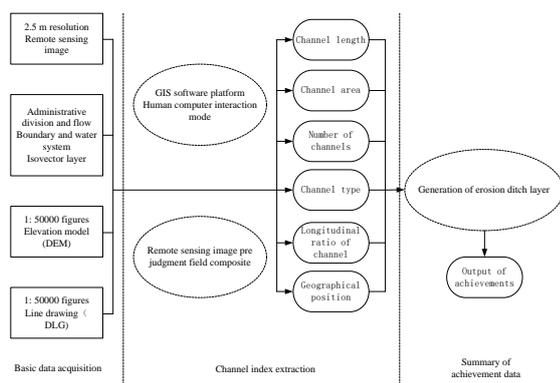


Figure 1. Flow chart of remote sensing interpretation of erosion gully

2.2. Quantitative method and data processing of morphological characteristics

2.2.1. Quantification of morphological characteristics

Fractal dimension is an important parameter to quantify the morphological characteristics. According to the similarity between the local and the whole to a certain extent, it can quantitatively describe some non-differentiable, fragmented and complex objects in nature, reflecting the complexity of fractal to a certain extent. The calculation process of

fractal dimension of erosion gully is shown in Figure 2 [5].

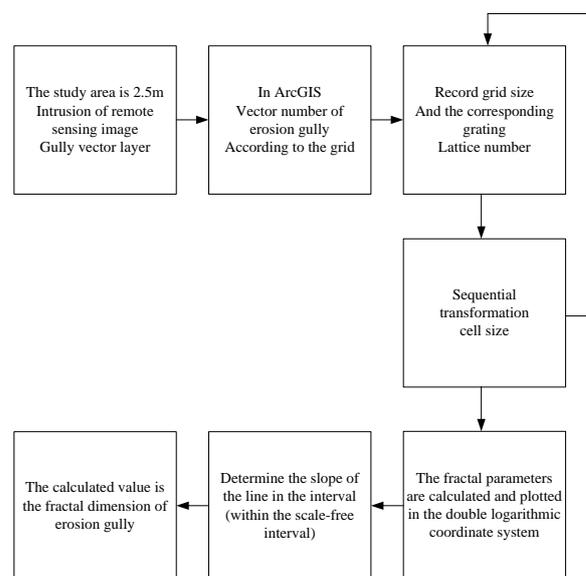


Figure 2. Calculation process of fractal dimension of erosion gully

The calculation formula of the corresponding fractal parameters is as follows:

$$N(r_i) = f(r_i^{-D_i}) \quad (1)$$

In formula (1), $N(r_i)$ is the corresponding fractal parameter; r_i is the covering grid; D_i is the fractal dimension; $f(\cdot)$ is the fractal function.

2.2.2. Index extraction and processing

The vector data of erosion gully are gridded by fractal theory. The number of non-empty grids is calculated by the attribute query function of ArcGIS. The pixel sizes are transformed in turn to obtain different coverage grids and corresponding fractal parameters. When the pixel size is selected, the fractal accuracy of erosion gully will be reduced if the scale is too large, and the amount of data will increase geometrically if the scale is too small, which will affect the operation speed.

Therefore, the pixel size (unit: m × m) is 0.2 × 0.2, 0.4 × 0.4, 0.6 × 0.6, 0.8 × 0.8, 1.0 × 1.0, 1.2 × 1.2, 1.4 × 1.4, 1.6 × 1.6, 1.8 × 1.8, 2.0 × 2.0, 2.2 × 2.2, 2.4 × 2.4, 2.6 × 2.6, 2.8 × 2.8, 3.0 × 3.0, 3.2, 3.4 × 3.4, 3.6 × 3.6, 3.8, 4.0 × 4.0, totally 20 grid gradients [6].

2.3. Simulation of runoff generation and soil erosion process

The process of runoff and soil erosion in black soil area is simulated by building PESERA model. The process of runoff and soil erosion is simulated by PESERA model with month as time step, and the interaction between vegetation growth and hydrological and erosion processes is considered. The PESERA model generalizes the land surface into a series of slopes, and assumes that each slope is directly connected to the river channel (regardless of the process of soil erosion, sediment transport and sedimentation in the river channel), which is convenient for its application in large spatial scales such as regional and global [7]. PESERA model has two operation modes: balance mode and time series mode. In the balanced model, the hydrological process is balanced by enough

cycles, and the input climate data and output results are the monthly average of the study period. In the time series model, the input climate data and output results are the time series from the first month to the last month in the study period. PESERA model consists of three parts: hydrological module, erosion module and plant growth module [8].

The input parameters of PESERA model mainly include climate, land use / cover, terrain and soil, which need 128 layers of input data. Climate data is the most important input parameter to drive PESERA model, with 96 layers in total. Other input data mainly describe land use / cover, crops and planting date, soil water storage, soil erodibility and topographic relief in the study area. The output of the model mainly includes monthly total amount of erosion and runoff, monthly soil water shortage, monthly vegetation interception, monthly vegetation coverage, monthly vegetation biomass and monthly total amount of soil organic matter. The specific parameters and requirements of PESERA model are shown in Table 1.

Table 1. Specific parameters and requirements of PESERA model

Parameter	Value range	Company	Definition	Category
Meanrf130	0-300	mm	Monthly total rainfall	Climate
Meanrf2	0-50	mm	Rainfall days average rainfall	
Cvrf2	1-10	-	Coefficient of variation of rainfall days (standard deviation)	
Mtmean	-32.4-37.3	°C	Monthly average temperature	
Mtrange	2.4-18.4	°C	Monthly mean temperature difference	
Meanpet30	0-300	mm	Monthly total evaporation	
Mtd_eudem2	-	m	Topographic relief factor	Topography and land use
Use	-	-	Types of land use	
Eu12crop	-	-	Main crop types	
Itill	1-12	-	Sowing month of main crops	
Mitill	0/1	-	Sowing date of main crops	
Cov	0-100	%	Initial vegetation coverage	
Rough0	0,5,10	mm	Initial surface roughness	Soil
Rough_red	0,50	%	Attenuation rate of surface	

			roughness
Rootdepth	10-1000	mm	Root depth
Crusting	1-5	mm	Crust depth
Erodibility	1-5	mm	Soil Erodibility
Swsc_eff_2	0-205	mm	Soil available water capacity
P1xswap1	0-90	mm	Soil water is available for vegetation more than 300 mm deep
P2xswap2	0-154	mm	Soil water available for 300-1000mm deep vegetation
Zm	5,10,15,20,30	mm	TOPMODEL soil scale parameters

PESERA requires climate data, terrain data, soil data and land use / cover data to operate. Meteorological data (i.e. daily meteorological data) is provided by the national meteorological science data sharing service platform of China Meteorological Administration. The 30 m SRTM DEM is provided by the international science and technology data mirror station of the computer network information center of the Chinese Academy of Sciences. Soil type map and soil characteristics (such as texture, organic matter content) are provided by the ecological environment database of black soil. The land use / cover dataset is derived from 30 m Landsat images downloaded from the USGS case data sharing infrastructure. Based on supervised classification, seven types of black land are identified, including farmland,

grassland, forest, residential land, sandy land (i.e. desert like land) and undifferentiated land. Then the LUCC is obtained by overlaying the land classification map with Arc GIS 10.2 [9].

The input parameters of PESERA model include meteorological parameters, terrain, land use / cover. PESERA needs six meteorological parameters: monthly total precipitation, average rainfall of rainfall days, coefficient of variation of rainfall days, monthly average temperature, monthly average temperature difference and monthly total evaporation. The input parameter of terrain is the degree of relief, which is the standard deviation of elevation. It is calculated by Arc GIS software. The input parameters of land use / cover are based on the assignment of PESERA user manual, as shown in Table 2.

Table 2. Assignment of land use / cover parameters

Input parameter	Grassland	Woodland	Residential area	Sand	Unused land	Cultivated land
Use	334	310	400	100	334	210
Eu12crop1	-9999	-9999	-9999	-9999	-9999	6
Maize_210c	-9999	-9999	-9999	-9999	-9999	210
Eu12crop2	-9999	-9999	-9999	-9999	-9999	6
Itil_crop1	-9999	-9999	-9999	-9999	-9999	5
Itil_crop2	-9999	-9999	-9999	-9999	-9999	5
Itil_maize	-9999	-9999	-9999	-9999	-9999	5
Mitill_1	-9999	-9999	-9999	-9999	-9999	0
Mitill_m	-9999	-9999	-9999	-9999	-9999	0
Mitill_2	-9999	-9999	-9999	-9999	-9999	0
Cov_	-	-	-	-	-	-
Rough0	5	5	0	0	5	10

Rough_red	0	0	0	0	0	50
Rootdepth	300	1000	10	10	10	200
_ The parameter assignment is the true value of vegetation coverage calculation, and - 9999 means that there is no such attribute value in this field						

The soil property parameters are calculated from the soil property parameters of black soil.

2.4. Construction of surface soil erosion model in black soil area

To build the surface soil erosion model of black soil area, in the process of building the user-defined model, it needs to carefully select the parameters used for modeling, and it needs to consider all the factors that may play a role in the whole process of soil erosion. Relying on the technology platform of remote sensing and geographic information system, it can collect the data of all aspects affecting erosion as comprehensively as possible, reduce the errors caused by spatial heterogeneity and timeliness as far as possible, and improve the available value of parameters [10].

Generally speaking, the richer the model parameters are, the closer the final model fitting results are to the real situation. However, there is also the problem of functional duplication or feature redundancy between parameters, which increases the unnecessary running load of the model. Therefore, in addition to using all database parameters, we also use a variety of feature selection algorithms to reduce the dimension of the original model parameters, and then compare the model accuracy under different optimized parameter combinations, in order to obtain a relatively efficient parameter subset. Finally, a soil erosion model based on different subset parameters is established by combining the selected subset parameters.

Firstly, according to the characteristics of environmental factors, the specific variable parameters are divided into the following categories: climate factor (C: climatic), soil factor (s: soil), terrain factor (T: topography), vegetation factor (V: vegetation) and

management factor (M: management).

There are six types of representative parameters of climate factors [11]. Among them, the calculation method of temperature spatial distribution map is the same as that of precipitation in RUSLE model, while the co Kriging spatial interpolation method is selected for wind speed interpolation. The rainfall erosivity is based on the parameter calculation results of RUSLE equation. The climate area is a new climate regionalization scheme based on the data of 609 meteorological stations in China from 1970s to 1990s.

Soil factors mainly come from a series of surface soil attributes of black soil area in HWSD, including water pH, organic carbon content, carbonate content, texture, classification, sand content, silt content, clay content, available water content in soil, etc. The surface soil attributes in the data set are selected, that is, the depth range of 30 cm from the surface. Soil texture is the classification of soil particles according to the proportion of particle size, including rough, medium, fine and no data. The soil is classified as 13 kinds based on the percentage of sand, silt and clay in the soil. The data of soil freezing and thawing come from national long series surface freezing and thawing data set of cold and arid area scientific data center. The data set is calculated by using the daily passive microwave data processed by the National Snow and Ice Data Center (NSIDC) of the United States combined with the decision tree method. The data is incomplete from 1987 to 2020. Therefore, the complete year data is selected, and the freezing days are counted according to the multi day maximum synthesis method to reflect the degree of soil affected by freezing and thawing

in the study area. Finally, the soil erodibility factor K in the general soil loss equation is also included in the soil factors.

Terrain factors mainly include a kind of parameters which mainly reflect the characteristics of land surface fluctuation. DEM is the record of surface elevation, through which a series of terrain parameters including altitude, slope, aspect and slope length can be obtained. In addition, there is a set of geomorphic type data as one of the terrain factor parameters [12].

The vegetation type and vegetation type group of topsoil in black soil area of 1:1 million vegetation data set in China are selected as vegetation type parameters. NDVI and enhanced vegetation index are two parameters that can be used to detect vegetation growth according to the reflectance characteristics of vegetation in visible and near-infrared bands, which can be obtained from remote sensing data. Both of them are derived from MODIS land product MOD13A2. The concept and algorithm of vegetation cover and management factor C refer to the general soil loss equation.

Finally, the land use type maps are the surface soil land use and land cover map of black soil area in IGBP, the surface soil data of black soil area in global land cover plan and the surface soil land cover data of black soil area in China. Among them, GLC2000 data is a subset of global land cover data in China based on SPOT4 remote sensing data of the global land cover plan, and China's regional land cover data is based on the 1:10 data organized and implemented by the Chinese Academy of Sciences based on the results of land resources survey in 2000, the land use data products of the whole country are obtained by merging and vector grid transformation (area maximum method) [13].

According to the target model, there are 33 environmental factors with or potential to affect the surface soil erosion in black soil area,

among which environmental factors refer to the parameters that can participate in the calculation of prediction model. Feature selection is the application of mathematical algorithm based on machine learning to eliminate the poor correlation or redundant parameters, reduce the operation time and operation difficulty of the model through parameter filtering, improve the interpretability and accuracy of the model, prevent over fitting, and ensure the universal adaptability of the model. The feature selection methods used in this paper are five representative methods: Boolean total correlation feature selection method, single variable filtering method, simulated annealing algorithm, genetic algorithm and recursive feature exclusion method. Five parameter subsets for modeling are obtained. According to the principle of feature selection, these five methods can be divided into filtering method (single variable filtering method) and packer method (ERTA total correlation feature selection method, simulated annealing algorithm, genetic algorithm, recursive feature exclusion method).

The characteristic of filtering method is that no matter what type of model they belong to, their operation is only based on general characteristics, such as the correlation between variables and predicted values. In order to shorten the calculation time, prevent over fitting and improve the calculation efficiency, the residual variables are used to build the prediction model. The calculation of filtering method is less, but its operation process is completely independent of the prediction system. It is more regarded as a preprocessing and ignores the performance of variable subset in the final prediction result, which is also the biggest disadvantage of filtering method.

The method of Boolean total correlation feature selection is a method to evaluate the correlation between environmental parameters and predicted values. The judgment of

nonlinear correlation is as accurate and effective as the judgment of linear correlation. It belongs to the wrapper algorithm of search strategy. For each given attribute, each decision tree in the forest in the calculation process is operated independently, and then the accuracy loss is compared according to the average and standard deviation results, so as to measure the importance of the attribute. The detailed algorithm is seen as Feature Selection with the BorutaPackage [14].

The calculation idea of simulated annealing algorithm is to simulate the gradual cooling process of heated solid, in which molecules release energy gradually from free and disordered state to form natural and orderly arranged crystals, so as to reach an equilibrium state with minimum energy value, that is to seek the optimal parameter combination. From another point of view, simulated annealing algorithm is also an optimized greedy algorithm which is not limited to the local optimal solution. In order to find the optimal solution under the temperature change, iterative calculation is often needed, which leads to the disadvantages of large amount of calculation and slow operation speed of simulated annealing algorithm.

Genetic algorithm is a kind of optimization method which imitates Darwin's natural selection theory. Multiple populations (progenies) are obtained through repeated iterations to obtain evolution. In the process of feature selection, an individual is equivalent to a prediction subset, and fitness is the evaluation index of model performance, such as root mean square error or classification accuracy.

Recursive feature exclusion method is suitable for all prediction parameters, and the importance of each prediction parameter to the model should be calculated and evaluated. At first, the model is trained with the initial data set of all parameters to evaluate the accuracy of the model and the importance of variables.

Then, the feature parameters with the least importance are removed from the current data set, and a sequence sorted by feature importance is obtained by iterative calculation.

The specific data processing process is divided into the following two steps. Firstly, raster package () of R software is used to integrate parameters and sample data. Then, Boruta () and caret () function packages are used to filter the parameters of the five methods.

How to establish the relationship between multivariate independent variables and observations is the core problem to be solved in modeling, and it is also the significance of the application of machine learning method. Whether the modeling method is appropriate or not directly affects the running results of the model. Regression analysis is an important statistical analysis method used to estimate the erosion modulus, which is widely used in the study of the interaction between various phenomena and factors. It is widely used in the study of the interaction between various phenomena and factors. Through the comparison of various models, four representative models under the framework of machine learning method are selected to simulate and calculate soil erosion. They are generalized linear model and Cubist model based on linear regression, advance tree model and random forest model based on ensemble classifier. The method selection of the four user-defined models is based on the multiple selection results of different stages of the development process of machine learning methods and the thinking framework of different machine learning computing methods [15].

According to the results of parameter selection method, the parameters are selected. By using mboost-package (), bst-package (), plyr-package (), cubist-package (), and random forest-package (), the distribution maps of surface soil erosion in black soil area are

completed based on the push tree model, generalized linear model, cubist model and random forest model of total parameter subset, burta total correlation feature selection method subset, single variable filtering method subset, simulated annealing algorithm subset, genetic algorithm subset and recursive feature exclusion method subset.

The R software function packages of different models are shown in Table 3.

Table 3. R software function packages of different models

Model name	Model parameter values	Model type	Function package
Propulsion tree model	Bsttree	Classification / regression	Bst, plyr
Generalized linear model	Glmboost	Classification / regression	Mboost
Cubist model	Cubist	Regression	Cubist
Random forest model	RF	Classification / regression	RandomForest

According to the selection of five feature selection methods, including Boolean total correlation feature selection method, single variable filtering method, simulated annealing algorithm, genetic algorithm and recursive feature exclusion method, five parameter optimization combinations are generated from the original parameter set by R software to construct the model.

Among them, 29 parameters are selected by Boolean total correlation characteristics, which are slope aspect, soil available water content, vegetation coverage and management factors, soil carbonate content, vegetation coverage, soil clay content, China regional land cover data, altitude, enhanced vegetation index,

water flow direction, frozen soil days, landform type, GLC2000 land cover data, soil erodibility, slope length factor, normalized vegetation index, soil organic carbon content, soil pH, annual average temperature, annual precipitation, annual average wind speed, rainfall erosivity, soil sand content, soil silt content, slope, soil moisture characteristics, soil quality classification, soil texture, vegetation type group. It covers almost all the parameters in the original parameter set, especially all the parameters in soil properties and terrain factors.

There are 23 parameters selected by univariate filtering method, which are slope aspect, soil available water content, vegetation coverage and management factors, soil carbonate content, vegetation coverage, China regional land cover data, altitude, enhanced vegetation index, water flow direction, GLC2000 land cover data, slope length factor, normalized vegetation index, soil organic carbon content, soil pH, annual average temperature, annual average precipitation, rainfall erosivity, annual average wind speed, slope, soil classification, soil texture, vegetation type group.

The simulated annealing algorithm screens the least parameters, only 13, which are slope aspect, China regional land cover data, CSCS grassland classification, soil erosivity factor, slope length factor, soil organic matter content, annual precipitation, rainfall erosivity, annual wind speed, slope, soil classification, normalized vegetation index, vegetation type group [16]. Although the number of parameters is small, it also includes various types of erosion factors.

The 26 parameters screened out by genetic algorithm are slope aspect, vegetation coverage and management factor, vegetation coverage, soil clay content, climate area, China regional land cover data, CSCS grassland classification, altitude, water flow direction, frozen soil days,

landform type, GLC2000 land cover data, land use type, vegetation group, slope length factor, normalized vegetation index, soil organic carbon content, soil pH, annual precipitation, rainfall erosivity, annual wind speed, soil sand content, slope, soil moisture characteristics, soil texture, vegetation type group. And the proportion of terrain factor is the highest.

21 parameters screened by recursive feature exclusion are slope aspect, soil available water content, land cover data in China, vegetation cover and management factor, enhanced vegetation index, vegetation coverage, altitude, water flow direction, frozen soil days, slope length factor, normalized vegetation index, soil pH, annual average temperature, annual average precipitation, annual average wind speed, rainfall erosivity, sand content, clay content in soil, slope, moisture characteristics and vegetation type group.

Generally speaking, climate factor and terrain factor account for the largest proportion of the selected parameters. The probability of soil, vegetation and land use type being selected is low.

2.5. Erodibility factor analysis

The factors of surface soil erodibility in black soil area are analyzed, including spatial distribution characteristics of soil erodibility's K value, semivariance function analysis of soil erodibility's K value, and spatial distribution characteristics analysis of soil erodibility's K value.

The spatial distribution characteristics of soil erodibility's K value are analyzed by descriptive statistical characteristics and normal distribution test. According to the classical statistical analysis method, the characteristic value of K value of surface soil erodibility in black soil area is counted, as shown in Table 4. It can be seen from Table 4 that the K value of soil erodibility varies from 0.05 to 0.44, and the maximum value is 8.8

times of the minimum value, which shows that the measured value varies greatly.

Table 4. Theoretical model of descriptive statistical characteristic value and semivariance function of soil erodibility's K value and its related parameters

Parameter	K value of Soil Erodibility	Parameter	K value of Soil Erodibility
Minimum value	0.05	Model type	Spherical model
Maximum	0.44	Nugget	0.003
Average value	0.27	Abutment value	0.008
Median	0.26	Nugget value / abutment value (%)	37.3
Standard deviation	0.08	R2	0.685
Skewness	-0.02	RSS	4.227×10^{-6}
Peak value	2.43	Range (km)	440
Coefficient of variation (%)	29.63	Step length (km)	23
K-S test	0.577		

The normal distribution of data is the premise of spatial analysis of soil erodibility's K value by geostatistics. It can be seen from the descriptive statistical results that the kurtosis is 2.43 and the skewness is - 0.02, which basically conforms to the normal distribution. In order to further clarify its distribution type, the nonparametric Kolmogorov-Smirnov test is carried out, and the goodness of fit is 0.557 ($P > 0.05$). It can be seen that the K value of soil erodibility conforms to the normal distribution and meets the hypothesis of geostatistical

analysis.

Semivariance function analysis of soil erodibility's K value: semivariance function is the theoretical basis of geostatistics to explain the spatial variation structure of soil erodibility's K value. It has three important parameters: nugget value, range and abutment value. The range reflects the spatial variability of soil erodibility's K value, which is correlated within the range and independent outside the range. The nugget value is caused by the measurement error and random factors of soil properties (fertilization, tillage measures, etc.) within the minimum sampling interval. The base value reflects the degree of influence of structural factors (soil type, parent material, topography, climate, etc.) on the regionalized variables. The spatial correlation of soil erodibility's K value can be divided according to the ratio of nugget value to abutment value. When nugget value / abutment value is $< 25\%$, the variables have strong spatial correlation; when nugget value / abutment value is between 25% and 75% , the variables have medium spatial correlation; when nugget value / abutment value is $> 75\%$, the variables have weak spatial correlation. The choice of semivariance function model is the key to analyze the spatial variation structure of soil erodibility's K value. In this study, the spherical model is used as the semivariance function theoretical model of soil erodibility's K value. When the semivariance theoretical model of soil erodibility's K value is spherical model, the nugget value is 0.003, the abutment value is 0.008, and the nugget / abutment value is 37.3% , indicating that there is a moderate spatial correlation within the range. The step length is 23 km and the range is 440 km, which is much larger than the step length. It shows that there is a good spatial correlation in the small watershed scale, and Kriging interpolation can get more accurate results [17].

Spatial distribution characteristics of K

value of soil erodibility: for K value of surface soil erodibility in black soil area. The spatial variability caused by soil structural factors (soil type, parent material, topography, climate, etc.) is the main reason affecting the spatial distribution of soil erodibility. The spatial correlation of soil erodibility is enhanced by random factors (fertilization, cultivation measures, planting system, etc.). The difference of underlying surface and human disturbance degree in different areas are the main random factors causing the distribution characteristics of K value of surface soil erodibility in black soil area. The main factor affecting soil erodibility's K value in vegetation coverage area is the difference of vegetation type, the growth and distribution of soil roots of different plants are different, and the accumulation of soil organic matter is also different, which leads to the difference of soil anti erosion ability.

2.6. Construction of erodibility factor evaluation model

Finally, the evaluation model of surface soil erodibility factor in black soil area is constructed. The constructed evaluation model of surface soil erodibility factor in black soil area comprehensively considers natural factors such as slope gradient of closed section, erosion base level depth, balanced section, slope catchment area, test data and field measurement data, as well as the effect of human activities on surface soil erodibility factor in black soil area. The potential growth of gully length, area and quantity and the activity of erodibility factors in the process of erosion are systematically analyzed, and the soil erodibility factors are evaluated.

The steps of constructing the evaluation model of erodibility factors of surface soil in black soil area are as follows:

A. Based on the potential evaluation model of gully network, the indexes of density, concentration and land loss ratio are established to explore the potential limit degree of the

development of erodibility factors of surface soil in black soil area. It is assumed that when the development of erosion gully reaches the limit state, the change of erosion gully index is reflected in the increase of the length, the potential development length of erosion gully is determined, and the density development potential index is obtained by the length of erosion gully per unit area; the ratio of current density and current density of erosion gully is defined as the average length of regional erosion gully, and the erosion gully index is defined when the development of erosion gully reaches the limit state [18]. The target change is reflected in the increase in the number of erosion gullies, the potential development number of erosion gullies is determined, and the density development potential index is obtained by the number of erosion gullies per unit area; the potential development area of erosion gullies is obtained by combining the significant correlation between the current length of erosion gullies and the current area, and the development potential index of land loss ratio is obtained. The development space of erosion gully density, concentration and land loss ratio reflects the development space of soil erodibility factors.

B. In the potential model of gully network, there are obvious regional differences in the black soil area, and the diversity of geomorphic types leads to great regional differences. Considering the applicability of the model, the empirical value of the model is not directly used, but the slope factor and the slope of the watershed closed section are corrected before application. The LS factor model program is used for slope factor correction, and the 1:50000 DEM of black soil area is used to extract slope factor and slope length factor in ArcGIS, and the slope length is calculated on the basis of slope factor and slope length factor; Watershed closed section gradient is based on watershed DEM, with the help of ArcGIS

technology to extract watershed, and get the closed section gradient by the ratio of elevation difference and slope length of upstream and downstream watershed. Finally, the calculation results of the two methods are applied to the potential model of gully network to improve the applicability of the model in black soil area.

C. To determine the development potential and risk level of erodibility factors of surface soil in black soil area: based on the difference between potential index and current index of density, concentration and land loss ratio of erosion ditch obtained above, the potential risk evaluation index of erodibility factors of surface soil in black soil area is established, and the development potential and potential risk level of erodibility factors of surface soil in black soil area are determined.

3. Results

The evaluation model of surface soil erodibility factor in black soil area is tested. The black soil area in the experiment is northeast black soil area, which is based on the administrative division of northeast black soil area in the first national water conservancy census. The research scope covers 36 cities (prefectures, leagues and prefectures) and 171 counties (cities, districts and banners) in Heilongjiang, Jilin, Liaoning and inner Mongolia, with a total area of $94.49 \times 10^4 \text{ km}^2$. There are Songhua River, Heilongjiang River, Liaohe River, Tumen River, Yalu River and some rivers flowing into the sea. Water erosion and freeze-thaw erosion are all over the black soil area, while wind erosion is serious in the western area.

The regional soil is mainly composed of dark brown soil, black soil and chernozem in temperate zone, brown forest soil and cinnamon soil in warm temperate zone, brown coniferous forest soil, mountain tundra soil and dark gray forest soil in cold temperate zone, and albic soil, meadow soil and swamp soil are distributed in some areas. The black soil is

loose and weak in anti-erodibility. The black soil area is surrounded by mountains in the East, West and North, and a wide Songliao Plain is formed in the middle and south. There are various types of landforms in the territory, mainly distributed in overtopped hills, low mountains, low mountains and plains. The climate types of the black soil area in Northeast China are mainly temperate and cold temperate continental monsoon climate. The long and cold winter and short and hot summer lead to the great change of interannual temperature difference in the black soil area. The spatial and temporal distribution of precipitation in the black soil area is extremely uneven, with the average annual precipitation of 300-950 mm, 700-950 mm in the East, and more than 1000 mm in some areas. The average precipitation in Sanjiang Plain is 500-600 mm, and that in the west of Great Xing'an Mountains and Liaohe Plain is only 300-400 mm. The monthly precipitation is concentrated distribution, which accounts for more than half of the annual precipitation in this period. The rainstorm occurs frequently from June to September, accounting for more than 70% of the annual precipitation. The precipitation varies greatly from year to year, with the alternation of more rain and less rain for several consecutive years. There is little difference in sunshine hours between the north and the south in the whole year, which is 110-150 days in the north and 150-180 days in the south. The average annual wind speed is generally 3 ~ 5 m / s, the maximum wind speed from March to May can sometimes reach 20 ~ 25 m / s, and the maximum instantaneous wind speed can reach more than 40 m / s. The zonal distribution of vegetation is obvious, mainly distributed in the mixed forest region of Korean pine and broadleaf in eastern mountain, larch forest area in Great Xing'an Mountains, *Stipa Grandis* grassland area in Hulunbeier plateau and *Pinus Tabulaeformis*-oak forest area in Liaoning hilly

mountain.

General situation of surface soil erosion in black soil area of Northeast China: concentrated rainfall, frequent freezing and thawing, poor soil anti-erodibility and uncontrolled human activities are aggravating the process of soil erosion in this area. The results of the second national remote sensing survey of soil erosion show that the area of soil and water loss in the black soil area of Northeast China is about $27.59 \times 10^4 \text{ km}^2$, accounting for 27% of the total area of the black soil area, and the area of slope farmland accounts for 59.38% of the total area of cultivated land. Slope farmland is the main source of soil and water loss in this area. Loose soil and weak anti-erosion ability are the main characteristics of the soil in this area. The unique characteristics of black soil determine that it is easy to cause soil erosion. The annual soil erosion area of slope farmland is 46.39% of the total area of soil erosion in black soil area. At present, the soil erosion in black soil area is still aggravating, the erosion area is increasing year by year, and the soil layer is thinning year by year. With the continuous development of gully erosion and the continuous expansion of gullies, the number and density of gullies continue to increase, the soil nutrients are seriously lost, and the black soil resources are decreasing year by year. During the 40 years from 1965 to 2005, the total area of some erosion gullies increased from 16.77 km^2 to 102.04 km^2 , about 6.08 times; the total length of erosion gullies increased from 1318.11 km to 7501.81 km, about 5.69 times; the total number of erosion gullies increased from 1318 to 14486, about 10.99 times.

The location of the study area is shown in Figure 3.

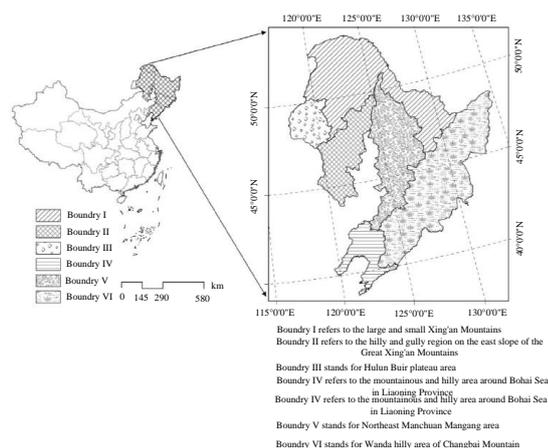


Figure 3. Schematic diagram of study area location

With large area, high vegetation coverage and abundant water resources, Great and Little Xing'an Mountains are important water conservation and ecological barrier areas in Northeast China. Good litter layer can absorb forest precipitation and weaken surface runoff with its larger surface roughness. Black soil is the main soil in the hilly and gully area on the east slope of Great Xing'an mountains. Soil structure is greatly damaged by land tillage. Grassland reclamation and overgrazing make the vegetation coverage decrease year by year. In addition, the topography of the area fluctuates greatly, so rainfall is easy to produce concentrated runoff, and the flow rate is large, and the land erosion is serious. The main soil types in Hulunbeier high plain are black soil, dark brown soil, chernozem and meadow soil, and the soil layer is thin. Water power, wind power, freeze-thaw erosion and gentle slope and hilly landform lead to large area shrinkage of surface vegetation. Frequent human activities lead to serious groundwater extraction, which leads to the premature death of grassland due to lack of water, the decrease of vegetation coverage year by year, the serious degradation of grassland ecosystem, and the increasingly severe soil and water loss. The soil texture is good and the water resources are rich in the hilly area around Bohai Sea, the eastern

part of Liaoning Province and the Liaohe plain. In Eastern Liaoning Province, the soil is mainly dark brown soil with deep soil layer and meadow soil. Good soil physical properties provide favorable soil environment conditions for the growth of trees and crops. In the West of Liaoning Province, the topography is undulating, the soil is sticky, and the wind and water erosion area is relatively serious. The wind erosion is serious in winter and spring, and the water erosion is mainly in summer and autumn. The soil texture is loose and its anti-erodibility is poor. Land use is mainly cultivated land, which is easy to cause soil damage. The topography of overtopping area in Sichuan province fluctuates greatly, with long slope and gentle slope, resulting in a large catchment area. 60% ~ 70% of annual precipitation is concentrated in July, August and September, which is easy to produce concentrated runoff. Because of the large amount of precipitation in the hilly area of Wanda Mountain in Changbai Mountain, the large-scale reclamation has had a great impact on the climate and vegetation in this area, and destroyed the balance between natural vegetation and soil. The soil is mainly albic soil, mostly light clay, with poor corrosion resistance.

Based on the fractal theory and method of erosion gully morphology, the fractal dimensions of 295663 erosion gullies in black soil area of Northeast China are calculated, and the mean value of fractal dimension of erosion gully morphology in 6 erosion gullies, i.e. the Great and Little Xing'an Mountains, the eastern slope of Great Xing'an Mountains, the Hulunbeier high plain, the mountainous and hilly area around Bohai Sea in Liaoning Province, the mountainous and hilly area in Northeast China, and the hilly area on Wanda mountainous and Changbai Mountain, are obtained as shown in Table 5.

Table 5. Statistics of fractal dimension information of erosion gully

Secondary zoning	Scale free interval	Correction factor	Pixel size and specification	Fractal dimension
	(m)	(R ²)	(m)	D _i
Great and Little Xing'an Mountains (BI)	0.2~2.4	0.997	0.2, 0.4, 0.6,...3.4, 3.6, 3.8, 4.0	1.091
Hilly and Gully Area (BII)		0.994		1.117
On the east slope of Daxing'an MountainsHulunbeier high plain (BIII)		0.996		1.127
Mountainous and hilly area around Bohai Sea in Liaoning Province(BIV)		0.9993		1.061
Manchuan Mangang District in Northeast China (BV)		0.996		1.062
Changbai mountain Wanda hilly area (BVI)		0.996		1.045

Scale free range refers to the scale range with the best correlation of fractal dimension and fractal characteristics. In the calculation of fractal dimension of erosion gully in black soil area of Northeast China, the pixel size range is selected from 0.2 m to 4.0 m. The linear regression between the pixel size and the corresponding number of pixels is made in the double logarithmic coordinate system, and the fractal scale-free range of erosion gully is determined as 0.2 m to 2.4 m. Within the scale-free range, the correction coefficient of determination (R²) of fitting straight line of erosion gully in each soil and water conservation secondary division is above 0.993 (P < 0.001), with significant correlation and scale invariance. The above analysis shows that in the scale-free range, the fractal characteristics of erosion gullies are good, and the fractal dimension Di can be used as a comprehensive index to quantify the fractal characteristics of erosion gullies.

Fractal dimension reveals the complex nature of erosion gully in different development periods. The distribution of the morphological characteristics of erosion gullies has a certain regional law, and the fractal

characteristics are obviously different between the East and the West. The overall performance is that the shape of erosion gullies in the northwest is more complex than that in the southeast, and the fractal dimension is larger. Among them, the complexity of gully morphology in different areas is shown as follows: Hulunbuir high plain > Hilly gully area on the east slope of Great Xing'an Mountains > Great and Little Xing'an Mountains > Northeast Plain > Liaoning Bohai Rim hilly area > Hilly area on Changbai Mountain and Wanda Mountain. There are obvious regional differences in the morphological characteristics of erosion gullies in black soil area. The distribution range of fractal dimension is 0.910 ~ 1.239, and the average fractal dimension is 1.067. The erosion gullies in hilly area on Changbai Mountain and Wanda Mountain are the most, but the proportion of linear erosion gullies is large, and the average fractal dimension is only 1.045; although the number of erosion gullies in Hulunbuir high plain is small, the average fractal dimension is as high as 1.127, and the shape is the most complex. To a certain extent, topographic features affect the fractal

dimension information of erosion gully. According to the analysis of the variation coefficients of elevation, slope and fractal dimension, the variation coefficients of fractal dimension in hilly area on Northeast Manchuan, Changbai Mountain and Wanda Mountain are 0.064 and 0.066 respectively. The morphological characteristics of erosion gullies are quite different, and most of them are in the early stage of development. The linear erosion gullies with single shape have great space to develop into branching type with complex shape in the future.

As a typical micro geomorphic form, the complexity and diversity of erosion gully also reflects the degree of surface fragmentation to a certain extent. The combination of average slope and average elevation expresses the frequency of terrain change. The Great and Little Xing'an Mountains and the hilly and gully areas on the east slope of the Great Xing'an Mountains have complex terrain, large slope, large and concentrated catchment area, fast catchment speed, poor soil erosion resistance and serious gully erosion. Hulunbeier high plain is an agricultural development area with loose soil, overgrazing, single vegetation community and long history, which also creates conditions for the development of gully erosion. Therefore, due to the influence of topography, soil, vegetation and human activities, the shape of erosion gullies in Northwest China is relatively complex, and the development of erosion gullies alternates in vertical and horizontal directions. The erosion results show that most of the erosion gullies are dominated by main gullies, and many branch gullies coexist. The fractal dimension is relatively large, and the average fractal dimension is 1.091, 1.117 and 1.127. Compared with the Northwest, cultivated land is the main land use in the mountainous and hilly areas around Bohai Sea in Eastern Liaoning and the mountainous and

hilly areas in Northeast China. The landform is mostly plain and hilly areas. The catchment speed is slow and the runoff is scattered, which effectively reduces the erosion of runoff on the surface and alleviates the development of erosion gullies. The stable plant communities and high vegetation coverage of forest, shrub and grass in the hilly area around Bohai Sea and Wanda mountainous area of Changbai Mountain inhibit the occurrence of partial surface erosion to a certain extent, resulting in a single regional erosion mode; in addition, the deforestation and unreasonable utilization of land resources lead to the formation of a large number of small erosion gullies dominated by linear erosion gullies in the eastern area in a short period of time. Therefore, most of the erosion gullies in the eastern area are relatively simple in shape. The main form of erosion is traceable erosion, which forms slender linear erosion gullies or simple branched erosion gullies. The fractal dimension is relatively small, with an average of 1.061, 1.062 and 1.045.

The regional distribution characteristics of fractal dimension of erosion gully are shown in Figure 4.

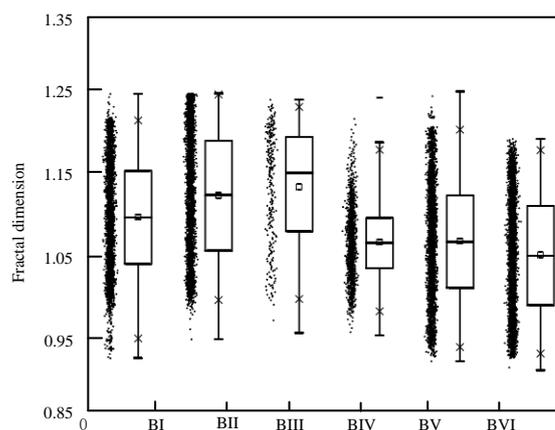


Figure 4. Regional distribution characteristics of fractal dimension of erosion gully

According to the above data of the experimental area, the surface soil erodibility factor evaluation model is constructed, and the

performance of the model is tested, including the quantitative performance and evaluation accuracy of the erodibility factor of the model.

4. Discussion

4.1. Discussion on quantitative performance of erodibility factor

The experimental data of erodibility factor quantitative performance of the model are shown in Table 6.

Table 6. Quantitative performance of erodibility factor of the model

Serial number	Secondary zoning	Quantitative proportion of erodibility factor (%)
1	Great and Little Xing'an Mountains (BI)	96.58
2	Hilly and Gully Area (BII)	98.24
3	On the east slope of Great Xing'an Mountains Hulunbeier high plain (BIII)	99.35
4	Mountainous and hilly area around Bohai Sea in Liaoning Province (BIV)	97.87
5	Manchuan Mangang District in Northeast China (BV)	98.85
6	Changbai mountain Wanda hilly area (BVI)	96.98

According to the experimental data of erodibility factor quantitative performance of the model in Table 6, the erodibility factor quantitative proportion of the surface soil erodibility factor evaluation model in black soil area is higher, and it has good erodibility factor

quantitative performance.

4.2. Discussion on evaluation accuracy

The experimental data of evaluation accuracy of the model are shown in Table 7.

Table 7. Experimental data of evaluation accuracy of the model

Serial number	Secondary zoning	Assessment accuracy (%)
1	Great and Little Xing'an Mountains (BI)	98.36
2	Hilly and Gully Area (BII)	97.36
3	On the east slope of Great Xing'an Mountains Hulunbeier high plain (BIII)	98.87
4	Mountainous and hilly area around Bohai Sea in Liaoning Province (BIV)	95.74
5	Manchuan Mangang District in Northeast China (BV)	98.87
6	Changbai mountain Wanda hilly area (BVI)	99.21

According to the experimental data of the evaluation accuracy of the model in Table 7, the evaluation accuracy of the surface soil erodibility factor evaluation model in black soil area is high, and it has good evaluation accuracy.

5. Conclusion

The research and construction of the evaluation model of surface soil erodibility factors in black soil area can improve the quantitative performance and evaluation accuracy of erodibility factors, which is of great significance to solve the problem of surface soil erosion in black soil area.

6. Acknowledgement

The Research is Supported by: National High Technology Research and Development Program 863 (Grant No.2012AA102001); Natural Science Foundation of Hainan University (Grant No. KYQD (ZR) 20058 and 1863), and Natural Scientific Foundation of Heilongjiang Province (Grant No. D201410).

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