Design and Implementation of Soil Loss System Based on RUSLE

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*Abstract:*Soil erosion is a serious hazard that causes damages to environment and causes other problems. To compute soil loss, a system that merges with geographic information system(gis) is developed. This program uses the model of Revised Universal Soil Loss Equation (RUSLE).It is built on Microsoft.NET Framework 4, combined with integrated secondary development tool ArcGIS Engnie 10.1.This program can compute the six RUSLE factors, namely rainfall erosivityfactor,vegetation cover management factor, soil erodibility factor, slope length factor, slope angle factor and conservation practice factor by inputting corresponding layers. The system provides visualization interface and it is easy to use .We use the data of Beijing as an example for application. The spatial distribution map of soil erosion is generated and it is classified into five levels, which can monitor the distribution of soil erosion patterns. The results are in line with the soil erosion tendency. The soil erosion map will facilitate the allocation of conservation resources and the enacting of relative regulations.

*Key words:*soil erosion, RUSLE, interpolation, slope length, ArcGIS Engnie, NDVI

1 Introduction

Soil erosion and degradation of land resources are significant problems in a large number of countries[1].It not only causes damage to cultivated soils, but also affects water quality and is responsible for sediment transport, causing many remote problems such as mud floods[2]. Therefore, an effective way of calculating soil erosion amount can facilitate relevant management. There exist many models and programs predicting and calculating soil losses such as European soil Erosion Models,EUROSEM/KINEROS,ANSWERS and CREAMS. However, some of these models are too sophisticated to use, some lack of sufficient verification and some need data that are hard to obtain. Fortunately, the Universal Soil Loss Equation, simple and easy to use, has been extensively used all over the world since it was developed by Wischmeier and Smith in 1956.This equation was put forward according to statistical analysis of erosion data from a large number of plot studies under different conditions[3]. Revised Universal Soil Loss Equation (RUSLE) and modified Universal Soil Loss Equation (MUSLE) has improved the algorithm and expanded its application scopes.

Though some programs applicating the Universal Soil Loss Equation has been developed, in case of The Universal Soil loss Equation Computer Program developed by Wisconsin-Madison[4] which requires strict data forms and is difficult to manipulate. Geographic information system has been integrated with RUSLE to evaluate soil erosion. Many commercial GIS products such as ArcGIS Desktop and SuperMapDeskpro have been used in many studies. Nevertheless, their applications are limited for high cost, complex installation, too large memory space and other factors[5].Due to these problems, we develop a Soil Loss System based on revised Universal Soil Loss Equation.

This program can display results as maps with many pixels showing its spatial distribution.In consideration of the applicability in different regions and scales, easy acquisition methods are used in the calculation of each factor. RUSLE is integrated into the program and it use the digitized data estimate soil erosion amount. It has light graphic user interface and geographical spatial data is easily utilized and in contact with users with different professional knowledge. Spatial query is realized by inputting corresponding search criteria.

Data management、data browse and results output are also implemented in this program. User can wander in the soil loss region and zoom in and out the region.

2 System Design and development

2.1 System structure

The development of this program is built on Microsoft.NET Framework 4. C# was used to create the program under the platform of Microsoft Visual studio 2010 by embedding ArcGIS Engnie 10.1. And Microsoft.NET Framework 4 is a technology that supports building and running the generation of applications and XML Web services. C□ is a simple object-oriented programming language which can improve the efficiency of system development. ESRI issued ArcGIS Engine 10.1 in 2012 which is the component of the packaged ArcObjects. ArcGIS Engine contains GIS components that allows developers to build custom mapping applications. It is convenient to develop applications by using ArcGIS Engnie which saves time and cost. The programs developed by ArcGIS Engine can run on client computer after installing ArcGIS Engine Runtime. Our program can be installed on windows 8/7/xp. It requires Microsoft.NET Framework 4 except for windows 8 which has already got .NET Framework 4.

This system mainly consists of seven functions including rainfall calculation, slope length calculation, slope calculation, soil erodibility acquisition, cover and management practices factor calculation, support practice calculation and statistics, as is shown in figure 1. System includes data layer, plug-in layer and application layer. Personal Geodatabase spatial data model is used in the program and ArcSDE spatial data engine is used to manage spatial data and attribute data in data layer including raster data, vector data and tables. Plug-in layer links the data in the database with user, including data storage and data reading. Application layer interacts with user and it can implicate basic functions, render map, calculate soil loss and query spatial data.

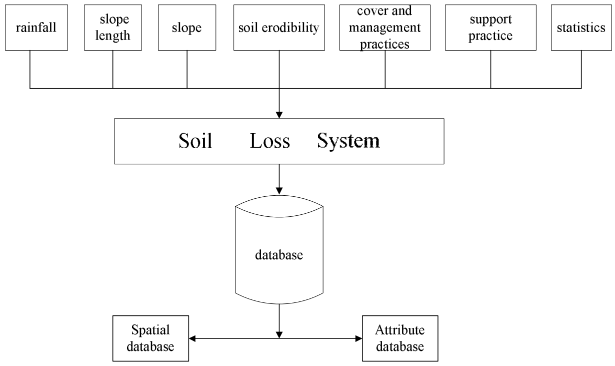

Fig. 1 The system architecture

2.2 Soil Erosion Model

Types of erosion generally take place in varied stages of an erosion process, including raindrop erosion, gully erosion, the deposition of soil particles and so on[6].RUSLE considers these processes and the factors that affect soil loss, which is expressed in the following:

$$A = R * K * L * S * C * P \qquad (1)$$

A is annual soil loss (t $ha^{-1}\cdot a^{-1}$); R is rainfall erosivity factor (MJ mm $ha^{-1}h1\cdot a^{-1}$); K is soil erodibility factor (t $ha^{-1}MJ^{-1}mm-^{1}$); L, S, C,P are dimensionless factors respectively representing slope length, slope angle, vegetation cover and management practices and supporting practices [7][8].

The data required by R includes rainfall records, DEM,NDVI, soil map, land use map as is shown in figure 2.After interpolation, rainfall of the region's envelop is produced, then mask it with the research area's extent and C factor will be created. Topographic factors, slope angle and slope length, are calculated from DEM by several steps.NDVI is adopted to create C factor. Soil map and land use map are vector maps which will be converted to raster maps. At last multiply the six factors and the soil loss map is created.

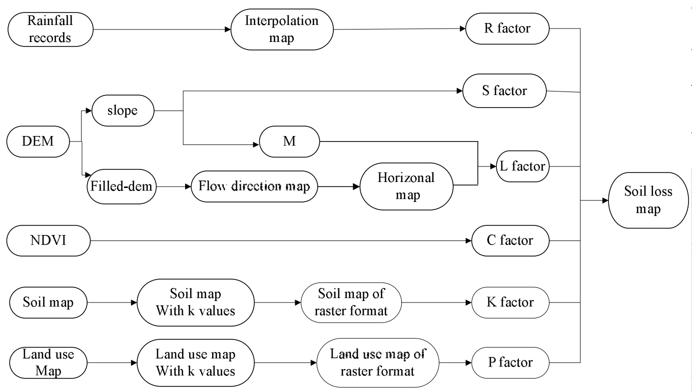

Fig.2. Overall Data Structure

2.3 Basic functions and the main interface

Microsoft Visual studio 2010 and AcrGIS Engine 10.1 have many controls. Add ToolbarControl、MapControl、TocControl、MenuStrip et al. The tools in the ToolbarControl are added by right-click and Zoom in、Zoom out、Pan and other tools are seletcted. These tools can perform well without writing codes. Some functions can also be realized by clicking the submenu of File, including saving file, opening .mxd-format file exiting etc. The format of the six factors are GRID, but the tool Add Data can't add the format of GRID.GRID format contains a series of files with different formats, all of which are put in a folder. The Add GRID function are in the submenu of File too. The basic functions include adding different kinds of vector data and raster data, zooming in and zooming out the map, pan the map by dragging, zooming to the full extent of the map, identifying geographical features, opening and saving all the layers as format of .mxd.

The main interface is shown in figure 3.Menu is on the top, below which is toolbar. The submenus execute the calculation of R、L、C、S factor and other processings. Submenu soil lossscauculation calculate the amount of soil loss. TocControl is on the upper-left corner, which manage map layers.Values of K and P are calculated by right clicking the layer on the TocControl. The MapControl is on the middle, which display maps. On the left bottom is Eagle Eye, whose function is to locate the main map. The bottom shows the current coordinate of x and y whose unit is defined by the user.

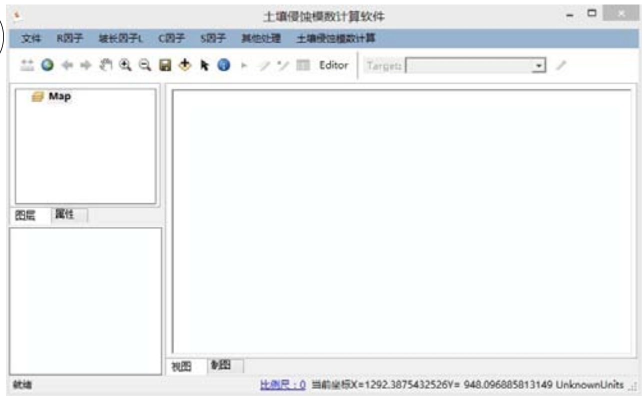

Fig.3 The main interface

2.4 Implementation of R

R represents the potential capacity of rainfall to cause erosion. We adopt the empirical equation of Wischmeier's [9]:

$$R = \sum_{i=1}^{12} 1.735\times 10^{1.5\times\lg\frac{p_i^2}{p}-0.8188} \quad (2)$$

Where R is the erosivityvalue(MJ mm $ha^{-1}h^{-1}\cdot a^{-1}$), p_i is the monthly precipitation amounts which can produce soil erosion and p is the average precipitation of the year. The rain records should have monthly precipitation and average annual precipitation will be calculated with R.

GE Zhong- qiang use another equation with a different parameter to estimate soil lose in Beijing[14] .

$$R = \sum_{i=1}^{12} 1.2157\times 10^{1.5\times\lg\frac{p_i^2}{p}-0.8188} \quad (3)$$

We provide these two equations in our program, it depends on the regions and user can choose one to estimate this factor. The rainfall record should be shapefile format and R can be calculated by clicking corresponding button.

Precipitation mainly comes from meteorological stations which can't cover the whole area. Therefore, many unknown points exist. To obtain the soil loss amount on the whole area, known precipitation should be interpolated. We adopt Kriging interpolation in our program, which generates an estimated surface from a scattered set of points with z-values. Kriging Interpolation assumes that the spatial variation is statistically homogeneous throughout the surface in the phenomenon represented by the z-values. And the variation can be described by Semivariogram, which is expressed as following:

$$\gamma(h)=\frac{1}{2m}\sum_{i=1}^{m}\{Z(x_i)-Z(x_i+h)\}^2 \qquad (4)$$

Where m is the number of pairs of sample points, and$Z(x_i)$ and $Z(x_i+h)$ are spatial locations. There are five models to model the Semivariogram, namely Exponential, Spherical, Circular, Gaussian, and Linear. These models can be set as parameter in the program. We choose Gaussian model to fit the Semivariogram:

$$y(h)=C\times\{1-\exp(-\frac{-3h^2}{a^2})\} \qquad (5)$$

Where h is lag distance. C represents sill which is defined as the semivariance value at which the variogram levels off. And a is range that is the lag distance at which the semivariogram reaches the sill value. Kriging interpolation can be achieved by interfacesofInterpolationOp3, IFeatureClassDescriptor,IGeoDataset,ISpatialReference, IRasterAnalysisEnvironment and IRaster.

2.5 Implementation of C

The cover and management factor (C) is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow land[8].We adopt normalized difference of vegetation index (NDVI) to compute C[10]. Some use the following formula[11] which is used in our program to compute C factor:

$$C=\begin{cases} 1, c=0 \\ 0.6508-0.3436\times \lg c, 0<c\le 78.3\% \\ 0, c>78.3\% \end{cases} \qquad (6)$$

Where C is the cover and management factor to be computed, c is vegetation cover. NDVI can reflect the status of vegetation cover so we substitute NDVI for c.

As the format of NDVI is raster, the execution of the above equation can be achieved by raster calculator. Raster calculator executes a map algebra expression from one raster or more rasters and outputs a raster. It supports the standard Map Algebra syntax which uses Python scripting. Some processes in our program use the raster calculator and all the map algebra expressions are integrated into our codes ,thus users don’t need to input the map algebra expression. Key codes to realize above equation are:

```
stringnn = pLayer.Name;
string    mm = "[" + nn + "]";
IMapAlgebraOprsalgebra = new
RasterMapAlgebraOpClass();
string s = "Con(" +mm + " <= 0,1,Con(" + mm+ "
  < 0.783000,0.6508 - 0.3436 * Log10(" + mm + "),
  0))";
IGeoDatasetoutGetDataset = rsalgebra.Execute(s);
```

2.6 Implementation of K and P

Soil erodibility factor is influenced mostly by soil mechanical composition and organic matter content and soil erodibility factor for most kind of soils can be obtained from table 1.

Table 1 values of K for most kind of soils[9]

Supporting practice factor(P) is calculated using land use map. P is assigned a value according to the land use type. The processing of P is similar to K.

Soil type and organic are recorded in the soil map and K can be calculated according to these two values. The attribute table will pop up by right clicking the layer on the axTOCControl(figure 4). There four buttons on the top of the interface respectively representing adding data,deleteing data, calculating K and calculating P.The attribute table form will connect to the file whose format is .dbf. The .dbf file is one of the files that make up shapefiles. And format of .dbf is the table Microsoft Visual FoxPro uses to store data. FoxPro language is used after connecting to .dbf file.

Fig.4Calculation of k and p factors

Soil map should be converted to raster after K factor is obtained such it can be calculated with other facors.User select relative layer , field and output path, then input the size of the cell(unit:pixel) and click ok, as is shown in figure 5.

Fig.5vector to raster wizard

2.7 Implementation of L and S

Topography mainly includes slope length and slope angle. They have great impact on soil erosion. As is shown in figure 2, slope length is relatively complex in out program. Wischmeier and Smith's equation[8] is used in our program:

$$L = (\lambda \div 22.1)^m \qquad (7)$$

Where L is slope length, λ is the horizonal slope length, and m is the exponent. And m is decided by the slope angle:

$$m = \begin{cases} 0.2, \Theta < 1° \\ 0.3, 1° \le \Theta \le 3° \\ 0.4, 3° \le \Theta < 5° \\ 0.5, \Theta \ge 5° \end{cases} \qquad (8)$$

Where Θ is slope angle which is extracted from DEM. Slope angle is achieved by ISurfaceOp, and its slope analyse will calculate the slope steepness after setting geodataset and other parameters. Slope angle

soil type	organic content matter for 0.5%	organic content matter for 2%	organic content matter for 4%
loam	0.38	0.34	0.29
sandy loam	0.27	0.24	0.19
light clay	0.14	0.13	0.12
loamy sand	0.5	0.13	0.12
Sand	0.05	0.03	0.02
sandy clay loam	0.27	0.25	0.21
silt loam	0.48	0.42	0.38
silty clay	0.25	0.23	0.19
clay loam	0.28	0.25	0.21

factor(S) is obtained from the slope angle Θ,and the formula proposed by by McCool and Liu[12][13]:

$$S = \begin{cases} 10.8 \times \sin\Theta + 0.036, \Theta < 5° \\ 16.8 \times \sin\Theta - 0.5, 5° \le \Theta < 10° \\ 21.9 \times \sin\Theta - 0.96, \Theta \ge 10° \end{cases} \quad (9)$$

This formula is executed by using raster calculator in our program, which is similar to the computation of C.

Wischmeier and Smith defined slope length as the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur[8]. Slope length can be divided into many subsections and is calculated as follows:

$$\lambda_{x_j,y_j} = \int_{x_0,y_0}^{x_j,y_j} \lambda_k dx \quad (10)$$

Where λ_{x_j,y_j} is the slope length at point (x_j,y_j), (x_0,y_0) is the original point of overland flow, λ_k is the slope length at each grid alone the flow direction.

As shown in figure 2, the DEM is filled first. Depressions exists in the DEM, which will block the flow. After the DEM is filled ,the water will flow fluently, which is shown in figure 6. A depression is the lowest cell in the grid. The method of fill in the interface of IHydrologyOp2 will execute this function.

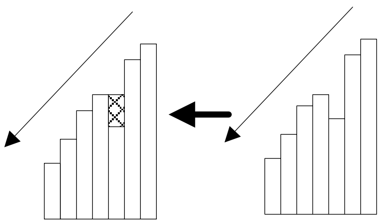

Fig.6 Fill the depression

The next step is to determine the flow direction. There are eight cells for each cell and the flow direction is determined by the steepest descent, namely the one having the maximum elevation difference. There are eight directions which are assigned 8 different values(figure 7). The method of FlowDirection in the interface of IHydrologyOp2 will realize this function.

32	64	128
16		1
8	4	2

Fig.7 value for each direction

The horizontal distance for each cell is calculated after the flow direction is determined. The horizontal distance from current cell from its neighbour cell is calculated using the following equation:

$$HD = \begin{cases} 0.5 \times G \text{ ,When flow direction is 1,4,16 and 64} \\ \sqrt{2} \times G\text{, When flow direction is 2,8,32 and 128} \end{cases} \quad (11)$$

Where G is the cell resolution and HD is the horizontal distance. Horizontal distance is achieved by the function of raster calculator in our program. Then use the function of raster calculator to calculate the horizon slope length:

$$\lambda = HD / \cos(\Theta * 3.1415926 / 180) \quad (12)$$

Factor L will be calculate according to formula 7 and 8 under the under the function of raster calculator.

2.8 Implementation of A

The estimation of soil erosion is accomplished according to formula 1.The six factors are selected in a new dialog box, as is shown in figure 8.The cell size, whose unit is meter, is set by user. Then raster analysis environment and spatial reference are automatically set in our program. At last, multiply the six factors by using the function of raster calculator. The soil erosion map is classified according to the Standards for Classification and Gradation of Soil Erosion of China[14].And the values of soil erosion can be output into .txt file. User can locate the maximum point of soil erosion in our program. The total soil erosion is calculated as :

$$TA = \sum_{1}^{m} \sum_{1}^{n} \frac{A \times \text{cell-size}_{i,j}}{10000} \quad (13)$$

Where i is the i-th row and j the j-column; m and

and n are the maximum values of row and column. Since the unit of each cell is meter, the value is divided by 10000 and it will be converted into hectare. The value of soil erosion in each cell will be added up by the iteration of formula 13.

Fig.8 Factors' selection

3 System application

3.1 General situation of trial area

We use our program to estimate the erosion of Beijing. All the data are provided by Beijing Municipal Environmental Protection Bureau and Beijing Water Authority. Precipitation, land use and soil map are shapefile type. NDVI is extracted from Landsat Thematic Mapper images in 2010 with a resolution of 30 *30 m. Topographic map is converted into DEM in advance.

The mountain area of Beijing is 10418 km2, accounting for 62% area of this city. The mountain region consists of Taihang Mountains in the West and Yanshan Mountains in the north. The mountains in the west are lofty and steep. The main rivers from the west to the east are Daqing River、Yongding River、North Canal、ChaobaiRiver and Juyun River. The average precipitation in the mountain region is 590.7 mm and the spatial distribution of precipitation is uneven within a year and between years. Rainfall concentrates on July、August and September. Water and soil loss is one of the significant ecological problems[15], which reduces soil fertility and destroys physiognomy. Moreover, waterandsoilerosion causes the contamination of surface-water. The main erosion form of Beijing is hydraulic erosion.

3.2 Results of system application

We use our system to calculate the six factors and soil erosion of Beijing. Figure 9 shows the distribution of the six RUSLE factors. Vegetation-cover management factor ranges from 0 to 1.276, which is concerned with vegetation. It is low in the north and southwest where are mountain regions. Vegetation can reduce soil erosion and mountain region has more vegetation cover so its C value is low. The calculated values for K factor is between 0.03 and 0.42 t $ha^{-1}MJ^{-1}mm^{-1}$.Slope length fluctuates from 1.06303 to 2.46851 and slope angle fluctuates between 0.036 and 20.3897. The precipitation data from 217 meteorological stations was processed and then used to interpolate the whole area. We choose formula 2 to calculate R factor and the nigger-brown area in the map presents the greater potential to cause soil erosion. Supporting practice factor is between 0.2 and 1.

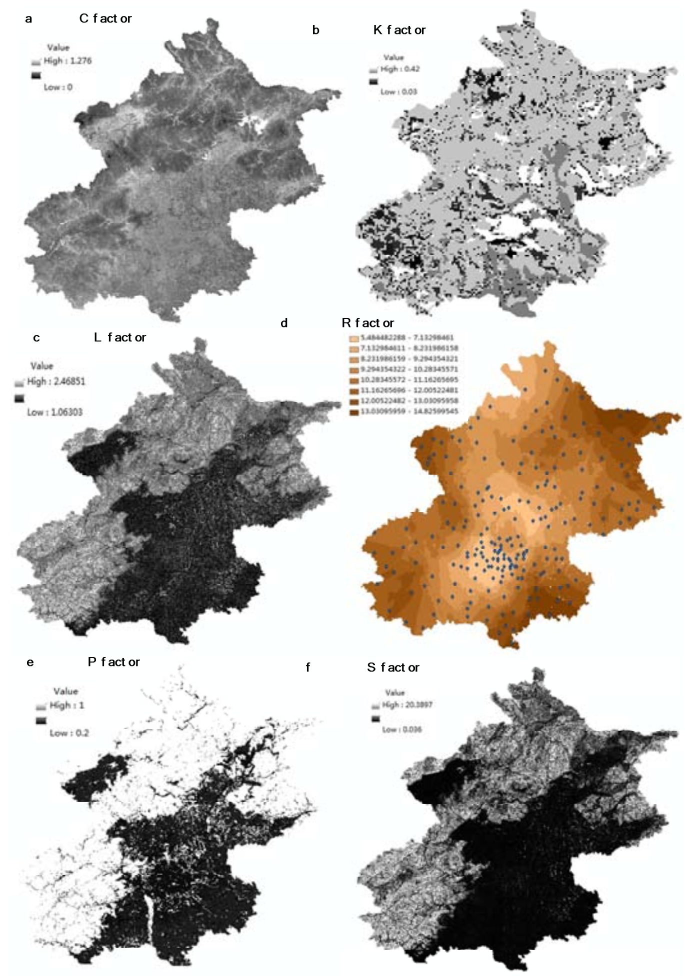

Fig.9 Distribution of RUSLE factors: (a) Vegetation-cover management factor(b) Soil erodibility(c) slope length(d) Rainfall erosivity index(e) conservation-practice factor(f) slope angle

The soil erosion distribution of Beijing in 2010 is generated after inputting the six RUSLE layers. The regions with dark brown in figure 10 are the areas where severe soil erosion occurs. The soil loss ranges from 0 $t{\cdot}ha^{-1}{\cdot}a^{-1}$to 126.1264877 $t{\cdot}ha^{-1}{\cdot}a^{-1}$. The blank areas in the map come from the soil map without soil type manly located in the water area. The maximum soil erosion point with green color is next to Zhuanghuwa Village, Mentougou District. We calculate the total soil erosion and average soil erosion in Beijing. These two values in 2010 are 13442971 t and 848 $t{\cdot}km^{-2}$ respectively and the average soil erosion excludes the blank areas. The total soil erosion in 2012 is 12273700 t according to 2012 Beijing bulletin of water and soil conservation. The average soil erosion is between 1200—1600 t /($km^2{\cdot}a$) before 2002 according to relative material. It is observed that the treatment of soil erosion in Beijing has obvious effect for years from these data. Relative governors can locate the key areas for treating soil loss by using our system.

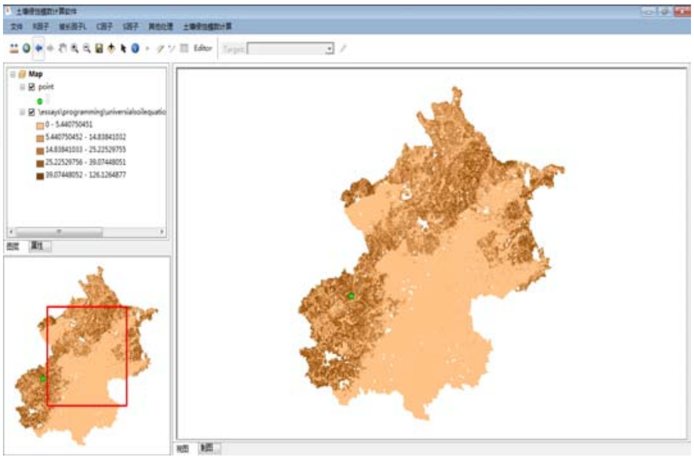

Fig.10 Map of soil erosion for Beijing

The soil erosion map is classified into 5 levels in our system(figure 11). All of the five levels, low erosion and low erosion account for 89.4% of the total soil erosion area, showing that the soil erosion in Beijing is low among most areas. The very low soil erosion areas are mainly in the urban areas which have flat cement floor. The total area of severe and very severe areas is 90.08 km^{-2} and only account for 0.56% of the total soil erosion area. These areas are the areas to be treated firstly and they are scattered in the mountain areas. Guowei used ARCGIS to calculate soil loss of Beijing in 2010[16] .He obtained six levels whose area percentage are 43.46% , 52.09, 3.66%, 0.62%, 0.16% and 0.02%.His result is similar to ours with a little difference in the calculation of P factor.

Table 2 Soil erosion levels and their areas

Soil erosion ($t\cdot ha^{-1}$)	Erosion levels	Area (km^{-2})	Area percentage (%)
<5	very low	9069.80	57.21
5-25	low	5188.74	32.73
25-50	moderate	1504.47	9.49
50-80	severe	87.96	0.55
80-150	very severe	2.12	0.01

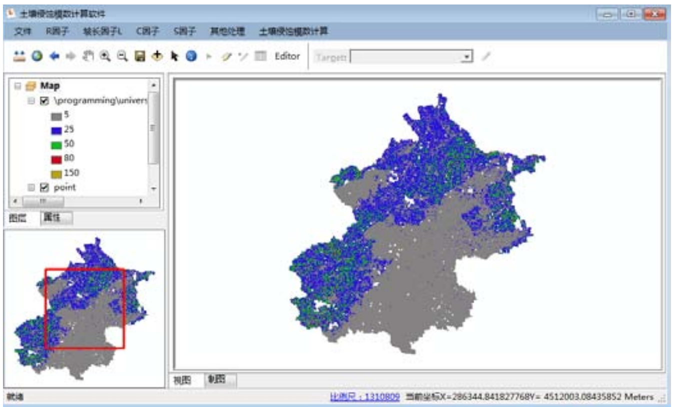

Fig.11 Soil erosion levels map

4 Conclusion

GIS is a powerful tool for editing, displaying maps and spatial analysis, and our GIS-based interface program is user-friendly , easy to operation and the results are intuitive. The RUSLE factors can be generated by inputting rainfall records, DEM, NDVI, soil map and land use map. The map of soil erosion can be generated and the total soil erosion is computed. Our system provides useful information and full view for decision-makers. It can locate the severe soil erosion areas and help decision makers in better managing soil loss and improving the environment. This program can simplify the calculation of some factors especially slope length factor and add other relative functions in the future.

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