Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 21 | No. 3 | pp. 1027-1037 | 2022

Original Research Paper

https://doi.org/10.46488/NEPT.2022.v21i03.009

Open Access Journal

Dynamic Changes and Precision Governance of Soil Erosion in Chengde City Using the GIS Techniques and RUSLE Model

Xiaoping Yan*, Leixiang Wu, Jun Xie*†, Yongqian Wang***, Chencheng Wang*** and Bing Ling****
*College of Water Conservancy and Hydropower Engineering, Sichuan Agricultural University, Ya'an 625014, Sichuan, PR China
**Institute of Water Ecology and Environment, China Institute of Water Resources and Hydropower Research, Beijing 100089, PR China
***College of Resources and Environment, Chengdu University of Information Technology, Chengdu 610225, Sichuan, PR China
†Corresponding author: Jun Xie; yan1227108150@163.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 26-08-2021
Revised: 10-11-2021
Accepted: 15-11-2021

Key Words:
Soil erosion
Precision governance
RUSLE
GIS
Chengde city

ABSTRACT

Soil erosion is one of the major environmental problems facing the world. The multi-scale characteristics of soil erosion and the complexity of its influencing factors put forward higher requirements for soil erosion prevention and control. Based on GIS technology and the RUSLE model, this paper quantitatively studies the temporal and spatial variation characteristics of soil erosion intensity in Chengde City(CC) from 2003 to 2018 and analyzes the temporal and spatial characteristics of R, K, LS, C, P factors according to the model calculation results, and analyzes the formation mechanism of key units of soil erosion in CC. The results show that: The area of tolerable erosion in CC in 2018 was 35152.19 km^2 (accounting for 90.22% of the total area), which was at the level of tolerable erosion on the whole. The average soil erosion modulus of CC in 2003, 2006, 2009, 2012, 2015, and 2018 were 41.38, 45.06, 46.58, 83.66, 27.67, and 73.34 $t.km^{-2}.y^{-1}$, reaching the maximum value of 83.66 $t.km^{-2}.y^{-1}$ in 2012, showing a rising trend and then declining trend in the research period. Soil erosion deteriorated in some areas of CC and regional differences increased, which caused serious environmental problems. Fitting results showed that the R factor was one of the important factors for the increase of regional differences and average erosion modulus. According to the characteristics of the problem, a precise governance model of soil erosion prevention based on the intensity and causes of soil erosion was put forward, and a "landing" scheme of soil erosion prevention and control measures was put forward. Furthermore, the control of soil and water loss in key areas should be strengthened in the future.

INTRODUCTION

Soil erosion refers to the process of soil denudation by external forces such as water power and wind power, as well as the transport of denudated soil by wind and runoff, which eventually leads to a series of eco-environmental problems (Wang & Zhao 2020). Worldwide, prevention and control of soil erosion and other forms of land degradation caused the attention of policymakers, land managers, and politicians, and this is reflected in many global initiatives, including but not limited to the Global Land Assessment of Degradation (GLASOD), the United Nations Convention to Combat Desertification (UNCCD), and the United Nations Environment Programme (UNEP) report (Ustin et al. 2009). Water and soil conservation planning requires scientific and reasonable soil erosion assessment to clarify the intensity, area, and spatial distribution of regional soil erosion to carry out soil and water conservation activities in a targeted manner (Lin et al. 2020). In addition, after the implementation of regional soil erosion assessment, how to promote the "landing" of soil erosion assessment results and prevention measures is also an important link in soil and water conservation activities. "Landing" means that the assessment results can be "landed" on specific plots or small-scale ranges to provide decision-makers with specific soil erosion prevention and control areas (Gu et al. 2020).

At present, a variety of quantitative soil erosion assessment models have been developed all over the world, which can be mainly divided into three types: conceptual, physical process-based, and empirical statistics-based (Kwanele & Njoya 2019). Among the three models, an empirical statistical model is the simplest model with low computational requirements and easy application, so it has been widely used around the world (Antonello et al. 2015). The Universal Soil Loss Equation (USLE) was proposed in the mid-1960s. Renard et al. (1997) modified USLE and obtained the RUSLE model. Liu et al. (2002), based on the USLE model, fully considered the characteristics and geographical characteristics of slope erosion in China and proposed the Chinese Soil Loss Equation (CSLE). RUSLE model is considered to be the most commonly used empirical model for soil erosion assessment (Biddoccu et al. 2020), as a computer-based model, the rapid development of computer technology, remote sensing technology, and geographic information system greatly promoted the development and application of RUSLE (Xiao et al. 2015). It provides a clear idea for understanding the causes of soil erosion. China's ecological governance mode means that China's governance policies are usually implemented on a large scale (Wen & Zhen 2020). In the early stage of governance, large-scale governance measures can achieve rapid and obvious governance effects, but they also have certain drawbacks. For example, Chengde City(CC) has implemented large-scale environmental protection projects such as the Conversion of Cropland to Forest Project(CCFP) for many years, and its forest area has increased significantly, and the overall situation of soil erosion has improved significantly. However, from May to July 2019, sediment deposition and water quality index exceeded the standard in the Pianqiaozi section of the mainstream of Luanhe River in the territory of CC for three consecutive months, and local soil and water loss broke out. The pattern and process of geographical phenomena change with the change of measurement scale, which means that the laws observed at one scale may not be directly applied at another scale. Therefore, the effectiveness of prevention measures is closely related to regional characteristics, and policies should be adjusted according to specific geographical conditions (Wen & Théau 2020). In addition, in the existing soil erosion assessment studies based on remote sensing data, the evaluation results are usually presented in the spatial form of soil erosion modulus, soil erosion amount, or erosion intensity distribution map, and the presentation form is mostly "speckled" with great spatial variability, so the "landing" of erosion evaluation cannot be well realized (Gu et al. 2020), more reasonable "landing" options still need to be explored.

In this paper, high-precision RS data and the RUSLE model were used to quantitatively study the spatial-temporal variation characteristics of soil erosion in Chengde City(CC) and accurately identified the regional coordinates with large soil erosion modulus and the influencing factors of soil erosion. In view of the above scale and "landing" problems, a town-scale soil erosion control planning model was proposed, and a "landing" scheme was proposed.

MATERIALS AND METHODS

Study Area

Chengdu City (CC) is located in the northeast of Hebei Province, with Inner Mongolia grassland in the north and Beijing and Tianjin in the south, and Liaoning Province to the east. The city ranges from 115°54'-119°15' E and 40°12'-42°37' N. The total area of CC is 39519 km², it is a temperate continental monsoon climate with an annual rainfall of 402.3-882.6 mm and an annual average rainfall of 530.13 mm. The main river in CC is the Luanhe River, which is one of the main water systems in the Haihe River Basin. It not only supports the economic and social development in the region but also serves as the water conservation area and ecological protection area of Beijing and Tianjin. Fig. 1 gives the details on Pianqiaozi town and the study area.

Data Source

(1) Daily precipitation data of Chengde, Fengning, and other

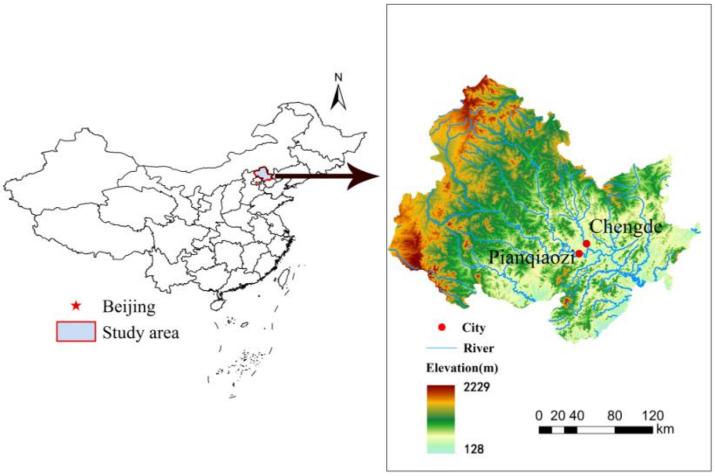

Fig. 1: Study area.

rainfall stations from 2003 to 2018. (2) The soil type map of CC extracted from the national soil data types includes the data on the physical and chemical properties of all soil types. (3) 30 m resolution GDEM data. (4) 30 m resolution Landsat5 TM/Landsat8 OLI data (5) 500 m resolution MODIS level 3 land cover types data set. 500 m MOD12Q1 data and 1000 m soil physical and chemical data were resampled to 30 m to keep consistent with the spatial scale of TM data for subsequent processing.

RUSLE MODEL

In this study, based on the Revised Universal Soil Loss Equation (RUSLE), combined with GIS technology and RS data source, the numerical values of five factors (R, K, LS, C, P) affecting soil erosion in CC were calculated by ArcGIS10.2 software and the spatial distribution maps were drawn. The expression equation of the RUSLE model is as follows:

$$A = R \times K \times LS \times C \times P \quad \ldots(1)$$

Where *A* is the soil loss (t.km-2.y-1). *R* is the rainfall erosivity factor ($\mathrm{MJ.mm.hm^{-2}.h^{-1}.y^{-1}}$). *K* is the soil erodibility factor $[\mathrm{t \cdot ha \cdot h \cdot (ha \cdot MJ \cdot m)^{-1}}]$. *LS* is the slope length and steepness factor (dimensionless). *C* is the vegetation cover and management factor (dimensionless). *P* is the conservation practice factor (dimensionless).

(1) Rainfall erosivity factor R

Rainfall is the direct driving force of soil erosion, as raindrops splash and separate soil particles, and runoff formed by rainfall will further scour and denude the soil and carry the soil, thus forming soil erosion. Richardson et al. (1983) first proposed the daily rainfall erosivity model. Zhang et al. (2002) modified Richardson's daily rainfall erosivity model by using the daily rainfall data of 71 representative weather stations in China. This revised Richardson daily rainfall erosivity model was used in this study to calculate rainfall erosivity R, with the formula as follows:

$$R = \alpha \sum_{j=1}^{n} P_{dj}^{\beta} \quad \ldots(2)$$

$$\alpha = 2.239 \times \beta^{-7.3967} \quad \ldots(3)$$

$$\beta = 0.6243 + \frac{27.346}{P_{d12}} \quad \ldots(4)$$

Where P_{dj}^{β} is the actual rainfall on the day when the daily rainfall is greater than 12 mm. α, β are the model parameters, which needs to be calculated according to the regional precipitation characteristics. P_{d12} is the average rainfall with daily rainfall greater than 12 mm.

(2) Soil erodibility factor K

K is a necessary parameter in the soil loss model. Soil erodibility refers to the ease with which soil can be dispersed and transported under the action of erosive forces such as raindrop impact and runoff scour. Soil physical properties, including soil structure, texture, organic matter, and soil infiltration ratio, determine soil erodibility and soil erosion resistance. However, soil structure and soil infiltration ratio are often difficult to obtain. Therefore, this study adopted the calculation method of K value developed by Williams et al. (1990) based on the EPIC model, which mainly considered soil organic carbon and particle size composition data. Formula:

$$K = \left\{0.2 + 0.3\exp[0.0256SAN(1-\frac{SIL}{100})]\right\} \times \left(\frac{SIL}{CAL+SIL}\right)^{0.3} \times \left[1-\frac{0.25C}{C+\exp(3.72-2.95C)}\right] \times \left[1-\frac{0.7SN1}{SN1+\exp(-5.51+22.9SN1)}\right] \quad \ldots(5)$$

Where, $\mathrm{SN1} = 1 - \frac{\mathrm{SAN}}{100}$, *SAN* (0.05-2.0 mm)is gravel content (%). *SIL* (0.002-0.05 mm) is silt content (%). *Cal* (<0.002 mm) is the clay content (%). *C* is the organic carbon content (%). The unit of K value calculated by the formula is the American system. In this paper, the K value is converted to an international system for analysis.

(3) Slope length and steepness factor LS

Slope length and steepness factor LS include slope length

Table 1: Data source table.

Data	Format	Source	Spatial resolution	Time span
MODIS land use/cover data	Raster	https://lpdaac.usgs.gov/	500 m	2003-2018
GDEM	Raster	http://www.gscloud.cn/	30 m	N/A
Soil data	Raster	http://vdb3.soil.csdb.cn/	1000 m	N/A
Rainfall data	Text	Hydrological stations in CC	N/A	2003-2018
Landsat5 TM/ Landsat8 OLI data	Raster	http://www.usgs.gov/	30 m	2003-2018

Note: N/A means not applicable.

factor L and steepness factor S. Slope length factor L affects the velocity of surface runoff, and steepness factor S affects the scale and intensity of material flow and energy conversion. For gentle slope and steep slope, the formula proposed by Liu et al. (2002) was adopted respectively for calculation, and the formula is as follows:

$$S=\begin{cases}10.8\times\sin\theta+0.036 & \theta<5^{\circ}\\ 16.8\times\sin\theta-0.5 & 5^{\circ}<\theta<10^{\circ}\\ 21.9\times\sin\theta-0.96 & \theta\geq10^{\circ}\end{cases} \quad \ldots(6)$$

Where S is the steepness factor, and the unit is radian; θ is the slope, and the unit is the angle. The slope length factor L was extracted by using the modified formula proposed by Wischmeier et al. (1960). Formula:

$$L = (\lambda \div 22.13) \quad \ldots(7)$$

$$m=\begin{cases}0.2 & \theta\leq1^{\circ}\\ 0.3 & 1^{\circ}<\theta\leq3^{\circ}\\ 0.4 & 3^{\circ}<\theta\leq5^{\circ}\\ 0.5 & \theta>5^{\circ}\end{cases} \quad \ldots(8)$$

Where, λ is the slope length, and m is the slope length index.

(4) Vegetation coverage and management factor C

C refers to the ratio of soil loss on the land with specific vegetation cover or field management to the soil loss on the bare fallow land with clear tillage or no vegetation cover under the same soil, slope, and rainfall conditions. The higher the value of C, the greater the amount of soil erosion caused by this kind of land use. In this study, the most widely used Normalized Difference Vegetation Index (NDVI) was used to estimate vegetation coverage. Vegetation coverage f (Equation 10) was calculated based on NDVI data, and then the C factor value was calculated based on the model established by Cai et al. (2000). Formula:

$$NDVI=(NIR-R)/(NIR+R) \quad \ldots(9)$$

$$f=(NDVI-NDVI_{\min})/(NDVI_{\max}-NDVI_{\min}) \quad \ldots(10)$$

$$C=\begin{cases}1 & f=0\\ 0.6508-0.3461\times\lg f & 0<f<78.3\%\\ 0 & f\geq78.3\%\end{cases} \quad \ldots(11)$$

Where NIR is the near-infrared band, R is the red band, f is the vegetation coverage, and C is the vegetation coverage and management factor.

(5) Conservation practice factor P

P is a quantitative index reflecting the influence degree of soil and water conservation measures on soil and water loss. By referring to previous research results on P value, this paper assigned the value of 1 to the land use types that can be considered as having not taken any measures, such as forest, shrub lands, grassland, and unused land. Land use types that in principle will not produce soil erosion, such as water bodies, and urban and construction land, were assigned as 0, while other land use types were assigned according to the empirical P value formula proposed by Lufafa et al. (2003). Formula:

$$P = 0.2 + 0.03S \quad \ldots(12)$$

Where P is the factor of conservation practice, and S is the percentage slope.

RESULTS AND DISCUSSION

Spatial and Temporal Characteristics of Soil Erosion in CC

From the perspective of space, the overall soil erosion in CC was good, at a tolerable erosion level, and soil erosion mainly occurs in local areas. To accurately identify the area where soil erosion occurs, the areas with a soil erosion modulus of 0 are defined as the area where no erosion occurs. At the regional scale, researchers are usually more concerned about the characteristics of soil erosion areas. The ArcGIS 10.2 software was used to make statistics on the erosion area data of CC. In 2018, it was found that the area of tolerable and below erosion was 35152.19 km^2, accounting for about 90.02% of the total area of CC. And its area proportion was the largest, it showed a trend of decreasing first and then increasing. The area of light erosion was 3736.77 km^2, accounting for 9.57%, and the area of moderate erosion was 138.87 km^2, accounting for 0.36%. The area of severe erosion was 20.37 km^2, accounting for about 0.05% (Fig. 2, 3, and Table 3). During the study period, the area of very severe erosion occurred for the first time in 2018, with an area of about 0.71 km^2, indicating that local soil erosion had worsened. In 2018, the areas with large soil erosion modulus in CC were mainly distributed in Wulingshan Forest Park, Yingshouyingzi Mining Area of Xinglong County, and Luanping County. In addition, soil erosion modulus along the Luanhe River was also high, which was related to the local

Table 2: P factor value table.

Land use type	Forest	Shrub lands	Grassland	Unused land	Waterbody	Urban and Construction land	Other
P	1	1	1	1	0	0	0.2+0.003S

agricultural planting along the river area and the high slope of the hillside along the river. The light and above erosion areas in CC were mainly concentrated in the Wuling Mountain Forest Park in the northeast of Xinglong County, Kuancheng County, Weichang County, and Fengning County (Fig. 2). In the study of soil erosion, light and above erosion areas are generally considered as soil erosion areas, so the above areas are the key areas for soil erosion control.

In terms of time, the average soil erosion modulus in CC increased at first and then decreased, and its value reached the maximum value of 83.66 t·km^{-2}·a^{-1} in 2012 (Table 4). The area of light and above soil erosion area in CC increased firstly and then decreased, reaching the maximum value of 6386.93 km^2 (accounting for 16.45%) in 2012 and then decreased gradually (Table 3 and Fig. 3), which was consistent with the changing trend of average soil erosion modulus, indicating that the overall soil erosion situation in CC gradually improved in recent years. According to the statistics of the variation range of soil erosion modulus in each year, the maximum soil erosion modulus in CC showed a trend of decreasing first and then increasing and reaching the maximum value of 12202.2 t.km^{-2}.y^{-1} in 2018 (Table 4). The standard deviation is the arithmetical square root of the statistical variance of a data set, which can reflect the degree of dispersion of a data set. The standard deviation of soil erosion modulus in CC from 2003 to 2018 was calculated, and it was found that the standard deviation in the study area first decreased and then increased, and the value reached the maximum value of 232.38 in 2018 (Table 4), which was significantly larger than that in other years. These two sets of data indicated that in recent years, the dispersion of soil erosion modulus in the study area has increased and the difference in soil erosion status between regions has become larger. Compared with the data for 2012 and 2018 in Table 3, it was found that the light erosion area and moderate erosion area of CC in 2018 were smaller than that of 2012, but the severe erosion area was larger than in 2012, and the very severe soil erosion area appeared for the first time. By the same token, comparing the data of 2003 and 2018, it was found that the areas of light and above erosion in 2018 are larger than that in 2003. The reason was that the condition of some tolerable-erosion areas deteriorated and developed into higher-grade soil erosion areas. To sum up, after the implementation of large-scale soil and water conservation measures in CC, the soil erosion situation had gradually improved in recent years, but due to the scale characteristics

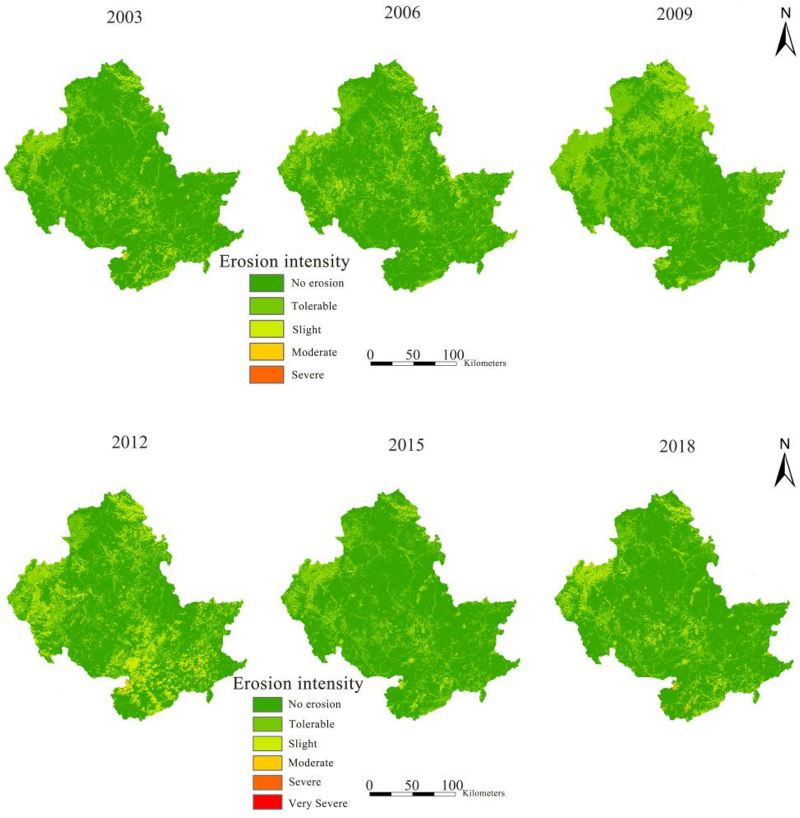

Fig. 2: Interannual variation of soil erosion in CC from 2003 to 2018.

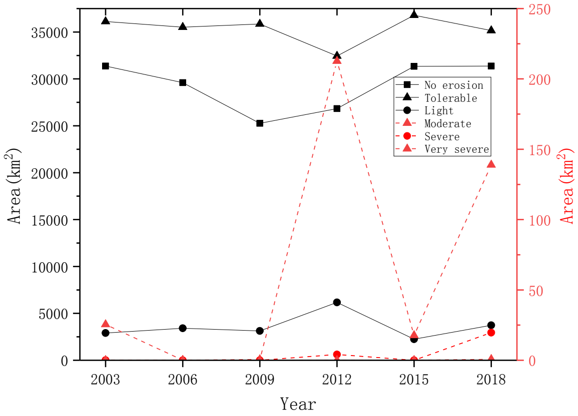

Fig. 3: Interannual variation of soil erosion intensity area in CC from 2003 to 2018.

of geographical phenomena, the causes of soil and water loss in some areas did not match with large-scale environmental protection measures. As a result, the difference in soil erosion between local areas was gradually increasing, and the local condition was deteriorating.

Analysis of Erosion Factors of the RUSLE Model

Analysis of R factor

The R factor was calculated by the formula (2) and the R-value was counted by ArcGIS 10.2. The annual average R-value from 2003 to 2018 was 1778.22 MJ·mm·hm^{-2}.h^{-1}.y^{-1} (Table 5). According to the research results of Liu et al. (2013), the average annual rainfall erosivity in CC ranges from 500 to 2000 MJ.mm.hm^{-2}.h^{-1}.y^{-1}, indicating that the calculated results of the R factor are reliable. The data of R factor, average soil erosion modulus, and standard deviation were input into SPSS Statistics software for processing. The statistical results showed that R had a strong correlation with standard deviation, and the coefficient of determination R^2

Table 3: Proportion (%) of different erosion intensities in CC (dimension of soil erosion modulus is t.km^{-2}.y^{-1}).

Erosion intensity	No erosion [0]	Tolerable [0-200]	Light (200-2500]	Moderate (2500-5000]	Severe (5000-8000]	Very Severe (8000-15000]
	Proportion	Proportion	Proportion	Proportion	Proportion	Proportion
2003	80.33	92.50	7.44	0.07	0	0
2006	76.03	91.22	8.78	0	0	0
2009	64.82	91.99	8.02	0	0	0
2012	69.11	83.55	15.89	0.55	0.01	0
2015	80.26	94.20	5.75	0.05	0	0
2018	80.33	90.02	9.57	0.36	0.05	0

Table 4: Characteristics of soil erosion modulus in CC from 2003 to 2018.

Year	Minimum modulus of erosion（t.km^{-2}.y^{-1}）	Maximum modulus of erosion（t.km^{-2}.y^{-1}）	Average modulus of erosion（t.km^{-2}.y^{-1}）	Standard deviation σσ Dimensionless）
2003	0	6207.87	41.38	131.55
2006	0	3170.07	45.06	119.32
2009	0	3775.75	46.58	92.63
2012	0	8520.08	83.66	215.40
2015	0	2168.74	27.67	86.40
2018	0	12002.2	73.34	232.38

Table 6: Classification and distribution area of soil erodibility K (t.ha.h.(MJ.mm.ha)$^{-1}$) value in CC.

Soil types	K ranges	Area（km^2）	Proportion（%）
High-difficult erosion soil	<0.1	0	0.00
Difficult erosion soil	0.1-0.2	7498.95	19.00
Relative-difficult erosion soil	0. 2-0. 25	5534.92	14.02
Relative-easy erosion soil	0. 25-0.3	17877.10	45.29
Easy erosion soil	0.03-0.4	6738.73	17.07
High-easy erosion soil	>0.4	1823.84	4.62

is 0.9362 (Fig.4a). There is a strong correlation between the R factor and dispersion degree of soil erosion modulus in the study area. The greater the R, the greater the difference between regions of soil erosion and the more significant problem of local erosion. The correlation between R and average soil erosion modulus is relatively strong, and the coefficient of determination R^2 is 0.6854 (Fig. 4b). R factor was not the main factor for increasing soil erosion modulus from 2003 to 2009. R factor was the important reason for increasing soil erosion modulus from 2009 to 2018. The areas with high R-values in 2018 were mainly Xinglong County and Kuancheng County in the south of CC (Fig. 5a), with the annual average values of 3902.65 MJ·mm·hm^{-2}.h^{-1}.y^{-1} and 2841.18 MJ·mm·hm^{-2}.h^{-1}.y^{-1}(Table 5). Respectively, all of them were significantly higher than the average value of 1778.22 MJ.mm.hm^{-2}.h^{-1}.y^{-1} in the study area. The soil erosion in these areas was greatly affected by rainfall erosivity factor R, so soil erosion control should pay attention to the influence of the R factor.

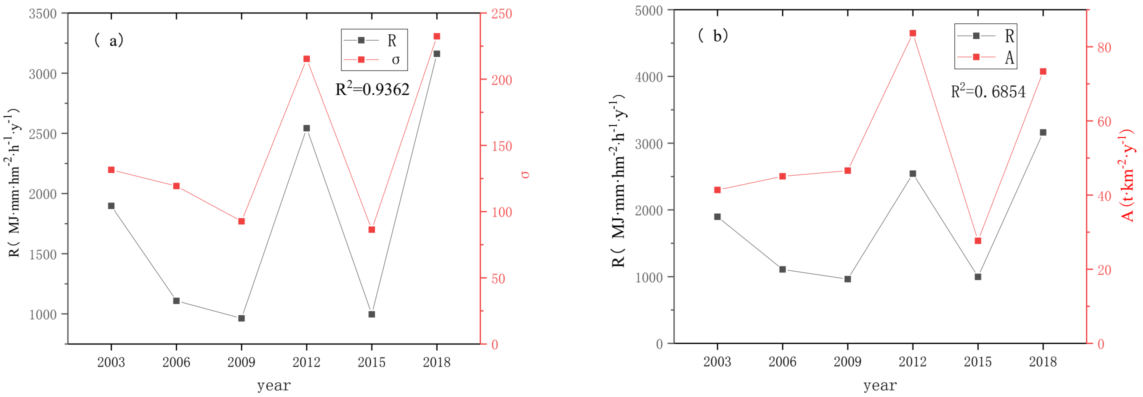

Fig. 4: Relationship map of R with standard deviation(σ) and average soil erosion modulus(A).

Table 5: Statistical table of annual average R (MJ.mm.hm^{-2}.h^{-1}.y^{-1}) value of each meteorological station in CC.

Year	Chengde station	Chengde county	Fengning	Kuancheng	Longhua	Luanping	Pingquan	Weichang	Xinglong	Study area
2003	1252.18	2438.44	405.48	2408.69	911.46	1291.86	1945.8	2038.6	4385.56	1897.56
2006	1757.29	1024.61	1943.23	559.23	667.91	879.22	877.49	1031.7	1233.38	1108.23
2009	527.77	912.19	338.8	1530.81	466.88	887.73	696.25	784.81	2522.18	963.05
2012	1655.05	2248.54	641.28	5834.3	1319.43	1653.46	2209.72	1660.27	5666.67	2543.19
2015	1273.48	819.14	984.56	1382.83	675.25	390.15	943.07	1429.1	1069.18	996.31
2018	1540.74	2905.46	940.48	5331.21	2041.46	3107.11	1182.69	2860.61	8538.94	3160.97
Muti-year average	1334.42	1724.73	875.64	2841.18	1013.73	1368.26	1309.17	1634.18	3902.65	1778.22

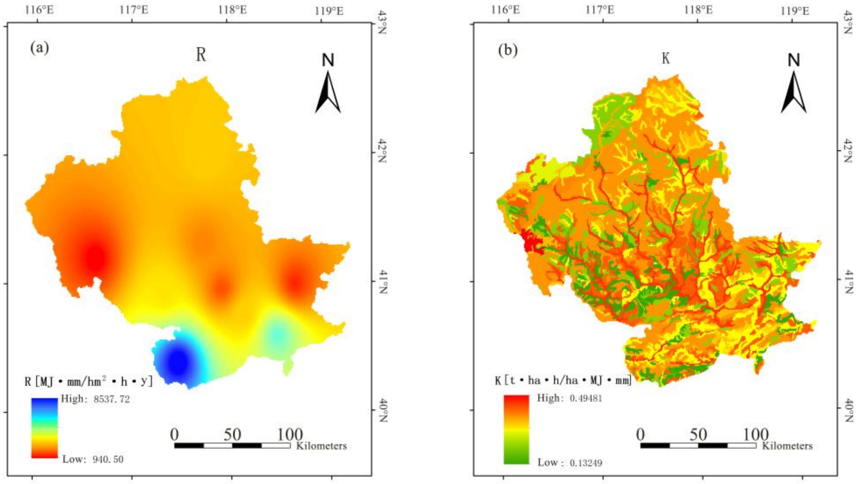

Fig. 5: Distribution of R and K in CC. R factor(a) spatial distribution of data from the data in 2018.

Analysis of K factor

The distribution map of soil erodibility in CC was obtained by model calculation, as shown in Figure 5b. Moreover, soil erodibility in CC was classified according to other soil erodibility studies, as shown in Table 6. From Table 6, the main soil type in CC is easy erosion soil (Including relative-easy erosion soil, easy erosion soil, and high-easy erosion soil), accounting for 66.98% of the area of CC, and the area of relative-easy erosion soil is 17877.1 km^2, accounting for the largest proportion, up to 45.29%, which is consistent with the research results of Men et al. (2004). According to the spatial distribution map of K value (Fig. 5b), the soil erodibility in the study area is high. The soil erodibility is high along the Luanhe River and near the urban built-up areas, and the soil erodibility is also high in Fengning County in the west of CC. The areas with a high K value are prone to soil erosion caused by the K factor, and the influence of the K value should be taken into account in the development of soil and water conservation measures.

Precision Governance Mode of Soil Erosion

At present, the quantitative evaluation results of soil erosion are usually presented in the form of soil erosion modulus distribution maps and soil erosion intensity distribution maps, most of which are “ speckled “, and cannot determine the exact location of severely eroded areas. It cannot achieve the “landing” of soil erosion assessment and treatment well, and its spatial orientation of soil and water conservation planning is not clear (Fig. 2). As a result, it is necessary to explore a more appropriate presentation mode on this basis (Gu et al. 2020). China is delimiting key areas of soil and water loss (Li et al. 2018), and key areas need to be scientifically delimited on a scale. In previous practice, the planning and management of water conservation with small watersheds as the unit has achieved remarkable results (Chen et al. 2019). Therefore, this paper proposed a town-level administrative unit scale soil erosion control model based on soil erosion intensity and causes. It is suitable for areas with prominent local soil erosion problems and few measured data, and the town-level scale is similar to the small watershed scale.

Due to the large area of CC and the sparse population of the ethnic autonomous county within the territory, there are few measured data, so it is not consistent with the actual situation to evaluate and control soil erosion by field exploration and field investigation. Based on the calculation results of the RUSLE model, the precise governance model analyzed the regional sediment source, erosion sediment-producing environment, and sediment transport process, listed the moderate and above soil erosion areas as key treatment units, and identified the precise longitude and latitude of key units. It analyzed the cause combination of key units by combining the spatio-temporal characteristics of R, K, LS, C, and P factors. The planning results and landing schemes of soil erosion prevention and control based on this model were detailed in Fig. 6 and Table 7. This paper takes the problem section (Pianqiaozi section) as the outflow point and the watershed gathered at the outflow point as the key research area to elaborate in detail. Decision-makers can develop specific small-scale soil erosion control measures based on Fig. 6, Table 7 and local conditions to effectively solve local water and soil erosion problems.

DISCUSSION AND CONCLUSION

After the implementation of large-scale ecological control projects in CC (such as CCFP), the area of no erosion increased to 31367.66 km^2 in 2018 and the average soil erosion modulus decreased from 83.66 t.km^{-2}.y^{-1} in 2012 to 73.34 t.km^{-2}.y^{-1} in 2018. The overall soil erosion improved in CC. This situation exists widely in most parts of China, such as the Loess Plateau, Shenzhen City, and so on (Zhang & Li 2018, Zhu et al. 2021). However, due to the multi-scale characteristics of soil erosion and the complexity of its influencing factors, large-scale control policies often leave some local problems at the same time. As shown by the phenomenon of sediment deposition and water quality index exceeding the standard in Pianqiaozi, the outbreak of local soil and water loss will also cause serious environmental problems. This kind of situation also exists widely in Shenzhen City, the Loess Plateau, and other areas (Zhang & Li 2018, Jin et al. 2021). Large-scale control measures are not suitable for local soil erosion, which will cost a lot of manpower and material resources, and the control effect may not meet expectations. Therefore, China is delineating the key areas of soil and water loss (Li et al. 2018) and replacing large-scale control with the way of controlling the key areas.

The integration of RS, GIS, and soil erosion models to make a series of maps of soil erosion changes can find the fragile areas of soil erosion from the point of view of spatio-temporal change, which is helpful to analyze the change process of regional soil erosion from emergence, development to extinction. However, most of the pictures made by this method are "speckled", which cannot determine the exact location of the serious erosion area and cannot quickly and accurately realize the "landing" of soil erosion assessment. Therefore, a precise governance model of soil erosion was proposed. It covers the calculation, assessment, identification, and cause analysis of the whole process of soil erosion prevention, which can quickly identify local soil erosion problems and put forward targeted prevention and control measures. However, the adaptability of the accurate soil erosion control model proposed in this paper to the overall areas with poor soil erosion needs to be strengthened, the key control units in the areas with poor soil erosion will be many and large, and the task of small-scale control is heavy. The study has theoretical and practical significance for soil erosion control in CC, can provide some reference for relevant research, and can also provide a supplementary treatment idea for large-scale governance mode in China.

In 2018, the area of tolerable and below erosion in CC was 35152.19 km^2, accounting for 90.22% of the total area. CC was generally at the level of tolerable erosion, but soil erosion in local areas showed a worsening trend. The average soil erosion modulus of CC in 2003, 2006, 2009, 2012, 2015, and 2018 were 41.38, 45.06, 46.58, 83.66, 27.67, and 73.34 t.km^{-2}.y^{-1}, reaching the maximum value of 83.66 t.km^{-2}.y^{-1} in 2012, showing a rising trend and then declining trend in the research period. After large-scale water and soil conservation measures were implemented in CC, the overall soil erosion situation gradually improved. However, due to the scale problem, the prevention and control measures did not consider the regional characteristics, so the local soil erosion problem aggravated and the regional differences gradually increased, which eventually led to the sediment deposition and water quality exceeding the standard in the Pianqiaozi section. Local erosion can still cause serious environmental problems with the continuous improvement of overall soil erosion. Fitting results showed that the R

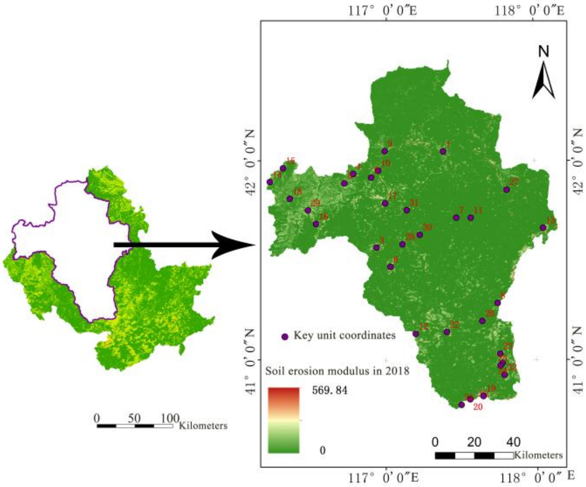

Fig. 6: Accurate location of high-value points of soil erosion modulus.

Table 7: Distribution table of key locations of soil erosion at the town scale.

Main Influencing Factors	Number	Longitude（E）	Latitude（N）	Town
R, K, LS, C, P	1	117°23′01″	42°2′59″	Yangebai town
	2	116°53′55″	41°55′07″	Xilongtou town
	3	116°56′08″	41°34′01″	Guojiatun town
	4	116°46′40″	41°56′13″	Laowopu town
	5	116°43′07″	41°53′22″	Waimengou town
	6	117°1′45″	41°28′15″	Xiguanying town
LS, R	7	117°28′15″	41°43′00″	Bugugou town
	8	117°44′39″	41°17′16″	Longhua town
	9	116°59′23″	42°3′06″	Laowopu town
	10	116°56′43″	41°57′13″	Xilongtou town
	11	117°34′04″	41°42′58″	Shanwan town
LS, C, P	12	117°11′52″	41°8′00″	Fengshan town
	13	118°3′10″	41°39′45″	Tangshanying town
K, LS, C, P	14	116°12′56″	41°53′38″	Caiyuan town
	15	116°18′13″	41°57′48″	Caiyuan town
	16	116°31′43″	41°41′05″	Sichakou town
	17	116°59′34″	41°47′22″	Nanshanzui town
C, LS	18	116°21′04″	41°48′38″	Wanshengshui town
R, LS, C	19	117°38′43″	40°49′11″	Fuyingzi town
	20	117°33′29″	40°48′14″	Fuyingzi town
	21	117°29′58″	40°46′34″	Changshanyu town
	22	117°24′14″	41°8′34″	Xigoumanzu town
K, LS, R	23	117°45′33″	41°1′57″	Xidimanzu town
	24	117°46′26″	40°59′07″	Xidimanzu town
	25	117°45′37″	40°58′21″	Xidimanzu town
	26	117°38′28″	41°11′50″	Longhua town
	27	117°48′39″	41°51′20″	Siheyon town
	28	117°6′34″	41°35′01″	Guojiatun town
P, LS	29	116°28′25″	41°45′10″	Sichakou town
	30	117°13′30″	41°37′55″	Jianfang town
	31	117°8′17″	41°45′20″	Jianfang town
	32	117°47′11″	40°55′33″	Pianqiaozi town

factor was one of the important factors for the increase of regional differences and average erosion modulus. According to the characteristics of the problem, a precise governance model of soil erosion prevention and control based on the intensity and causes of soil erosion was put forward to make up for the deficiencies of the top-down large-scale management mode in China, and a "landing" scheme of soil erosion prevention and control measures was put forward.

ACKNOWLEDGEMENT

This work was supported by the National Natural Science Foundation of China (Grant no. 51879279).

REFERENCES

Antonello, A., Maria, A. and Filomena, C. 2015. Remote sensing and GIS to assess soil erosion with RUSLE3D and USPED at river basin scale in southern Italy. Catena, 131: 174-185.

Biddoccu, M., Guzmán, G., Capello, G., Thielke, T. and Gómez, J.A. 2020. Evaluation of soil erosion risk and identification of soil cover and management factor (C) for RUSLE in European vineyards with different soil management. Int. Soil Water Conserv. Res., 8(4): 337-353.

Cai, C.F., Ding, S.W., Shi, Z.H., Huang, L. and Zhang, G.Y. 2000. Study of applying USLE and geographical information system IDRISI to predict soil erosion in a small watershed. J. Soil Water Conserv., 14(02): 19-24.

Chen, Z.C., Ma, L.J., Guo, F.Y., Ma, X.L. and Chu, Y. 2019. Study on the influence of land use patterns on the comprehensive harnessing effects of soil and water erosion. Nature Environ. Pollut. Technol., 18(3): 919-930

Gu, Z.J, Xie, Y., Li, A., Liu, G. and Shi, Y.D. 2020. Evaluation of soil erosion in Northeast China by CSLE model. J. Agric. Eng., 36(11): 49-56.

Jin, F.M., Yang, W.C., Fu J.X. and Li, Z. 2021. Effects of vegetation and climate on the changes of soil erosion in the Loess Plateau of China. Sci. Tot. Environ., 773:145514.

Kwanele, P. and Njoya, S.N. 2019. The assessment of water-borne erosion at catchment level using GIS-based RUSLE and remote sensing: A review. Int. Soil Water Conserv. Res., 7(1): 27-46.

Li, Z.X., Zou, H.T., Zhao, H. and Qi, J.W. 2018. Delineation method of key control area of soil and water loss at the county scale. Sci. Soil Water Conserv. in China, 16(06): 56-63.

Liu, B.T., Tao, H.P., Song, C.F., Guo, B., Shi, Z., Zhang, C., Kong, B. and He, B. 2013. Spatiotemporal variation trend of rainfall erosivity in China from 1960 to 2009. Geogr, Res., 32(02): 245-256.

Liu, B.Y., Zhang, K. and Xie, Y. 2002. An Empirical Soil Loss Equation: Proceedings 12th International Soil Conservation Organization Conference. Tsinghua University Press, Beijing, China, pp:1-8.

Lin, J.K., Guan, Q.Y., Tian, J.,Wang Q.Z., Tan, Z., Li, Z.J. and Wang, N. 2020. Assessing temporal trends of soil erosion and sediment redistribution in the Hexi Corridor region using the integrated RUSLE-TLSD model. Catena, 195: 104756.

Lufafa, A., Tenywa, M.M., Isabirye, M., Majaliwa, M.J.G. and Woomer, P.L. 2003. Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. Agric. Sys., 76(3): 883-894.

Men, M.X., Zhao, T.K., Peng Z.P. and Yu, Z.R. 2004. Soil erodibility of Hebei Province Based on soil particle size distribution model. Agric. Sci. China, (11): 1647-1653.

Renard, K.G., Foster, G.R., Weesies, G.A., Mccool, D.K. and Yoder, D.C. 1997. Predicting Soil Erosion By Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook 703, United States Department of Agriculture, Washington DC, USA, pp. 1-407.

Richardson, C.W., Foster, G.R. and Wright, D.A. 1983. Estimation of erosion index from daily rainfall amount. Trans. ASAE, 26(1): 0153-0156.

Ustin, S.L., Palaciosorueta, A., Whiting, M.L., Whiting, M.L. and Li, L. 2009. Recent Advances in Remote Sensing and Geoinformation Processing for Land Degradation Assessment. CRC Press, Leiden, Netherlands, pp:1-16.

Wang, H. and Zhao, H. 2020. Dynamic changes of soil erosion in the Taohe River basin using the RUSLE model and Google Earth Engine. Water 12(5): 1293.

Wang, Z.J. and Yuan, S. 2020. Assessment of soil erosion in the Qinba mountains of the southern Shaanxi Province in China using the RUSLE model. Sustainability,12(5): 1733.

Wen, X. and Théau, J. 2020. Assessment of ecosystem services in restoration programs in China: A systematic review. Ambio, 49(2): 111.

Wen, X. and Zhen, L. 2020. Soil erosion control practices in the Chinese Loess plateau: A systematic review. Environ. Develop., 34: 100493.

Williams, J.R., Jones, C.A. and Dyke, P.T. 1990. The EPIC Model Documentation. USDA-ARS, Washington DC, pp. 3-122.

Wischmeier, W.H. and Smith, D. D. 1960. A universal soil-loss equation to guide conservation farm planning. Trans. Congr. Soil Sci., 1: 418-425.

Xiao, L.L., Yang, X.H., Chen, S.X. and Cai, H.Y. 2015. An assessment of erosivity distribution and its influence on the effectiveness of land use conversion for reducing soil erosion in Jiangxi, China. Catena, 125:50-60.

Zhang, Y. and Li, T. 2018. Study on soil erosion in Shenzhen based on GIS and RUSLE model. J. Appl. Basic Eng. Sci., 26(06): 1189-1202.

Zhang, W., Xie, Y. and Liu, B.Y. 2002. Study on the method of calculating rainfall erosivity by daily rainfall. Geogr. Sci., (06): 705-711.

Zhu, X.Y., Zhang, R.Z. and Sun, X.W. 2021. Spatiotemporal dynamics of soil erosion in the ecotone between the Loess Plateau and Western Qinling Mountains based on RUSLE modeling, GIS, and remote sensing. Arab. J. Geosci., 14(1): 33.