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Soil erosion in the Xiangxi River Basin based on the RUSLE model

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Abstract

The Xiangxi River basin is the largest branch in the upper reaches of Three Gorges Reservoir located in the Hubei province of China, and it has a significant effect on the storage of the Three Gorges Reservoir. However, soil erosion of the Xiangxi River basin often leads to a series of problems. To minimize the impact of soil erosion on crop production and ecological life, the objective of this study was to evaluate soil erosion of the study area based on the soil and water loss model (RUSLE) with average monthly rainfall data for many years, land-use maps, soil maps, and the remote sensing (RS) images of the Xiangxi River basin and to analyze the spatial characteristics of soil erosion of the study area by geographic information system (GIS) methods in ArcGIS 10.2. The results showed that the areas of a lower grade of erosion increased dramatically while the number of the areas of a higher erosion grade decreases relatively compared with the previous study in 2011. This conclusion illustrated that the engineering measures taken by relevant departments affect high grade soil erosion. However, the slope zone of [30, 40) still suffered from high erosion due to mountains with heavy rainfall. It is suggested that more attention should be paid to reduce erosion in mountains, because the Xiangxi River basin belongs to early karst development and large areas of soil are covered with limestone soil. Existing measures to enclose the land for reforestation were not strong enough, thus other measures like planting grass in mountainous areas to alleviate soil erosion should be taken. Meanwhile, for the yellow-brown soil with high erosion, it is necessary to protect soil from stagnant water.

Zusammenfassung

Das Einzugsgebiet des Xiangxi-Flusses ist das größte im Oberlauf des Drei-Schluchten-Stausees in der chinesischen Provinz Hubei und hat einen erheblichen Einfluss auf den Speicher des Drei-Schluchten-Stausees. Die Bodenerosion im Einzugsgebiet des Xiangxi-Flusses führt jedoch häufig zu Problemen. Um die Auswirkungen der Bodenerosion zu minimieren, war das Ziel dieser Studie, die Bodenerosion im Untersuchungsgebiet auf Grundlage der überarbeiteten allgemeinen Bodenabtragsgleichung (RUSLE) mit durchschnittlichen monatlichen Niederschlagsdaten auf Basis einer langen Zeitreihe, der Landnutzungskarte, der Bodenkarte und Fernerkundungsaufnahmen (RS-Daten) des Xiangxi-Einzugsgebiets zu bewerten und die räumlichen Muster der Bodenerosion im Untersuchungsgebiet mithilfe eines geographischen Informationssystems (GIS), d.h. der Software ArcGIS 10.2,

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zu analysieren. Die Ergebnisse zeigen, dass der Anteil von Flächen, die von geringer Bodenerosion betroffen sind, dramatisch angestiegen ist, während der Anteil von Flächen mit höheren Erosionsraten im Vergleich zu einer vorherigen Studie aus dem Jahr 2011 zurückging. Dies veranschaulicht, dass die von der zuständigen Behörde ergriffenen technischen Maßnahmen gegen eine hochgradige Bodenerosion wirken. Die Hangzone von [30, 40) litt jedoch immer noch unter starker Erosion aufgrund von starken Regenfällen im Gebirge. Es wird vorgeschlagen, dass der Verringerung der Erosion in Gebirgen mehr Aufmerksamkeit geschenkt werden sollte. Das Einzugsgebiet des Xiangxi-Flusses gehört zur frühen Karstentwicklung, und große Teile des Gebietes sind mit Kalksteinböden bedeckt. Die bestehenden Maßnahmen zur Sperrung von Flächen für die Wiederaufforstung reichen nicht aus, so dass andere Maßnahmen wie die Begrasung in Berggebieten ergriffen werden sollten, um die Bodenerosion zu verringern. In der Zwischenzeit ist es für die gelbbraunen Böden mit starker Erosion notwendig, den Boden vor stehendem Wasser zu schützen.

Keywords soil degradation, GIS, soil loss, soil erosion, soil management, RUSLE

1. Introduction and framework

Soil resources are an important part of maintaining ecosystems on the earth's surface. Without human intervention, soil erosion will also occur, but affected by unreasonable human activities, soil erosion not only destroys the original land resources but also leads to soil degradation and reduces soil productivity (*Zhang* et al. 2002: 336). It poses a great threat to soil structure, agricultural production, water quality and environment, and regional sustainable development. Soil erodibility is the sensitivity of the soil to erosion, that is, the degree of difficulty for the soil to be dispersed and transported by the effects of raindrops and runoff erosion (*Borselli* et al. 2012: 85; *Yang* et al. 2017: 158) and is also an important index for evaluating soil quality. Soil erosion and its induced environmental problems have been one of the largest geological environmental problems in the world and have received widespread attention (*Qiao* and *Qiao* 2002: 85).

Xiangxi River is a branch of the Three Gorges Reservoir area in Hubei province, which eventually flows into the Yangtze River. The level of soil and water loss in the Xiangxi River basin will affect the regional soil quality and reduce crop yield and quality, and, what is more important, it will lead to ecological imbalance, frequent drought, and flood disasters eventually. Meanwhile, because of the increase in the amount of silt flowing into the river, the river carries silt through the reservoir and rivers which will cause sediment settlement converted to silt in the future. In the end, the Three Gorges Reservoir will be reduced in capacity because of silted shallow, and the river will be blocked resulting in shorter mileage. The results will seriously affect the Three Gorges project and the shipping business around the basin. Therefore, it is very important to evaluate the annual average amount of soil erosion in the Xiangxi River basin.

To quantitatively study soil erosion and its environmental problems, researchers have established a large number of empirical statistical models like the USLE model, RUSLE model, and physical process models such as the WEPP model (*Laflen* et al. 1991), EUROSEM model (*Morgan* et al. 1998), and LISEM model *(De Roo* 1996). These models serve to describe the characteristics of soil erosion at different temporal and spatial scales and the development of soil erosion. Compared with the physical model, the empirical statistical model has the characteristics of simple structure and strong applicability. The USLE (Universal Soil Loss Equation) model was originally established in 1965 by *Wischmeier* and *Smith* based on a large number of community observation data and artificial rainfall simulation data (*Wischmeier* and *Mannering* 1969). Since its establishment, the USLE model has been widely used in erosion prediction and water and soil conservation planning in the United States and other countries and has achieved huge economic and social benefits. With the continuous development of technology, based on the USLE model, the group of *Renard* et al. (1996) proposed a modified soil loss equation RUSLE which solved the problem of not considering factors closely related to soil erosion in the USLE model. Compared with USLE, the erosion factor measurement method has been improved, and in each factor, the influence factor considered is very comprehensive and more complicated. Therefore, it has been widely used in the research of soil erosion in some areas (*Ouadja* et al. 2021; *Duulatov* et al. 2021; *Kashiwar* et al. 2021; *Sandeep* et al. 2021; *Eniyew* et al.

2021) and has become the mainstream soil erosion research method. To further improve the applicability of the RUSLE model in China, a large number of domestic researchers have improved the RUSLE model according to the actual situation in China like *Jiang* et al. (2005), *Tian* et al. (2015) and *Yin* et al. (2018). These researches provide effective technical methods for the evaluation of soil erosion in different regions of China.

Based on remote sensing (RS) and geographic information system (GIS) technology, the objective of this study is to analyze the characteristics of soil erosion factors of the Xiangxi River basin applying the RUSLE model with selected factors such as rainfall, land use type, vegetation coverage, slope, soil erodibility, and sloping fields distribution characteristics, and obtain the spatial differentiation and influencing factors of soil erosion in different areas. Meanwhile the results of soil erosion are compared with a previous study in 2011 (*Wang* et al. 2012: 60), to explain the effectiveness of the measures by the government. The novelty of this study lies in comparing soil erosion in 2019 with the results in 2011 and finding out the changes of soil erosion in the Xiangxi River basin and the key factors influencing them. Secondly, the distribution and reasons of the soil erosion were analyzed according to slope, soil types, and land use respectively, and several suggestions were given for high grade erosion.

2. Materials and methods

2.1 Description of the study area

The Xiangxi River basin is located between 110°25′E-111°06′E and 30°57′N-31°34′ N in the west of Hubei Province of China (*Fig. 1*). It derives from the Shennongjia district (about 20%), and then flows across Xingshan County (nearly 70%) from north to south and finally into the Yangtze River in Xiangxi Town of Zigui County (approximately 10%). The basin is about 66 km from east to west and about 67 km from north to south, with a length of about 94 km and a total drainage area of 3221.19 km^2. From west to east, there are three tributaries of Nanyang River, Gufu River, and Gaolan River included in the basin. The Xiangxi River basin belongs to the remaining veins of the Daba Mountain. It is dominated by deep or medium-deep cutting middle-low mountains. The natural slope angles are mostly 30°-45°. The Xiangxi River basin is a strong denudation middle-low mountain area with a strong effect of vertical downward cutting.

As one of the rainfall centers in western Hubei of China, the basin has had an average runoff depth of 723.3 mm, rainfall of 1015.6 mm, and runoff of 1.955 billion m^3 for many years. About 70% of the annual rainfall is concentrated from April to September, dominated by heavy rains. During this period, the soil erosion of the Xiangxi River basin is very serious because the basin is characterized by loose soils such as woodland with medium to high coverage, yellow-brown soil, and others, resulting in a serious loss of soil nitrogen and reduced water conservation capacity.

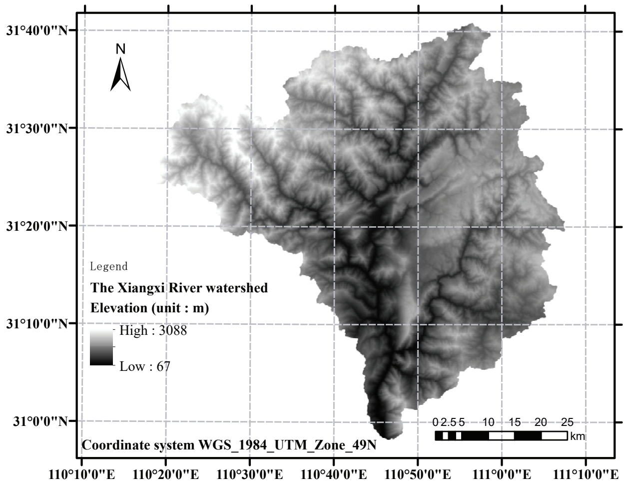


Fig. 1 *The Xiangxi River basin location map. Source: own elaboration*

2.1 Data collection and source

To evaluate soil loss in the Xiangxi River basin, primary and secondary data sources in 2019 were used and all of the data sources were projected to 'WGS UTM Zone 49N' uniformly before being calculated. *Table 1* shows more detail of these data sources. This research mainly used five kinds of data sources of the Xiangxi River basin which were satellite images, DEM (Digital Elevation Model) with 30 m resolution, landuse map, annual average rainfall data (*Table 2*), and soil map, respectively.

Table 1 Data sources and description. Source: own elaboration

Year	Data name	Data accuracy	Data sources
2019	satellite images: Landsat 8	spatial resolution: 30 m	Geospatial Data Cloud (http://www.gscloud.cn/)
2019	DEM	spatial resolution: 30 m	Geospatial Data Cloud (http://www.gscloud.cn/)
2019	land-use map	spatial resolution: 30 m	Yichang Bureau of Natural Resources and Planning
1952-2010	rainfall data	average monthly rainfall data over many years	Hydrological yearbook by Changjiang Water Resources Commission (CWRC) in 2010
2010	soil map	1:200000	Yichang Bureau of Natural Resources and Planning

Table 2 Annual rainfall data of the Xiangxi River basin in 2019. Source: own elaboration

Location of the monitoring station in the Xiangxi River basin	Coordinates (m) X	Coordinates (m) Y	Rainfall (mm)	Location of the monitoring station in the Xiangxi River basin	Coordinates (m) X	Coordinates (m) Y	Rainfall (mm)
Xiakou	479332.61	3443931.01	971.41	Zheng Jiaping	476219.93	3473504.19	936.48
Xingshan	476182.22	3456872.89	979.44	Zhongyangya	476236.74	3480896.00	1128.82
Hiddensi	406331.19	3459110.85	1052.81	Fruit Garden	469963.98	3503088.31	1128.78
Hua bridge	485632.17	3399573.19	1155.83	Qingshan	488910.49	3480874.84	1047.23
Nanyang river	469857.30	3466128.76	1076.52	Yuan'an	561091.74	3437925.46	1100.21
Honghua	450871.65	3477288.51	1259.47	Badong	437108.19	3435862.65	1500.27

2.3 Data preprocessing

All of the processes on data of this research were handled in ArcGIS 10.2 software (Environmental Systems Research Institute ESRI, https://www.esri.com). Firstly, all of the data sources were projected to 'WGS_1984_UTM_Zone_49N' uniformly before being calculated and each raster map was processed into 30*30 of cell size to be calculated conveniently and accurately.

Because the original rainfall data consisted of many dispersion points, these data should be processed into a raster map by using a specific interpolation method. There are a variety of interpolation methods in ArcGIS developed to simulate precipitation spatially (*Ly* et al. 2013; *Xu* et al. 2015), such as Inverse Distance Weighting (IDW) and Kriging. According to the research of *Fan* et al. (2014) the Kriging interpolation method is better than the IDW interpolation method in the months with abundant rainfall, while the IDW interpolation method is better than the Kriging interpolation method in the dry seasons. Meanwhile, the number of known stations affects the spatial interpolation of rainfall data in the basin. Compared with two different tests of Kriging and IDW, the IDW method was more suitable for the rainfall data of the Xiangxi River basin which is characterized by a large data range. During the process of IDW, the extent of rainfall data was extended according to the extent of the basin because IDW generated the result directly by the coordinates of the meteorological station and the extent of the result was smaller than that of the basin.

2.4 Soil erosion model (RUSLE)

Based on the revised universal soil loss equation (RUSLE) widely used in the study of soil loss in small and medium basins or regions in the world, a quantitative assessment of soil erosion in the Xiangxi River basin was conducted. The RUSLE model fully considers the factors that induce soil erosion and is used to calculate regional soil erosion. Through the calculation and analysis of the data, various factors affecting the soil erosion model were extracted, and the soil erosion level of the study area was measured scientifically and systematically. Every factor was obtained according to the technical process (*Fig. 2*).
RUSLE equation:

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

where:
A = average annual soil erosion (unit: tons·ha^{-1}·year^{-1}).

R = rainfall erosivity factor (unit: $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot year^{-1}$). R factor is an indicator that reflects the impact of rainfall on soil erosion and is an important factor for soil erosion prediction. It is a function of rainfall, rainfall intensity, rain pattern, and raindrop kinetic energy.

K = soil erodibility factor (unit: $tons \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$). K factor is an indicator of how easy the soil is to be separated, eroded, and transported by rainfall erosivity.

LS = L*S, topographic factor, L is slope length factor and S is the slope factor. L factor represents the effect of slope length on soil erosion and the S factor reflects the effect of slope on soil erosion.

C = crop cover and management factor (ranges from zero to one). C factor is not only related to crop coverage, management, and control measures, but also related to erosive rainfall during different growth periods of crops.

P = conservation practice factor (ranges from zero to one) (*Tessema* et al. 2020: 5). P factor is a mixed model based on experience and physical process. It is the ratio of the amount of soil loss after taking special measures to the amount of soil loss when planting downhill (*Xu* et al. 2013), and its value is between 0 and 1. 0 represents an area where no soil erosion occurs at all, and 1 represents an area where no conservation measures have been taken.

2.4.1 Rainfall erosivity (R) factor

The *Ma* (1989) algorithm and the algorithm proposed by *Wu* (1992) can be used to calculate the R factor. The basic datas of *Ma's* algorithm comes from Hebei Province and those of *Wu's* algorithm come from the Dabie Mountain area in Anhui. Therefore, *Wu's* algorithm is more suitable for the climatic environment of the complex middle region in China.

R equation:

$$R = \sum_{i=1}^{12} 0.0125 P_i^{1.6295} \tag{2}$$

where:
P = average monthly rainfall over many years (MJ mm ha^{-1} h^{-1} $year^{-1}$)

After interpolation preprocessing by IDW toolset in ArcMap software, an estimated surface was generated by rainfall point data. Then the raster calculator toolset was used to generate the R factor from the result of IDW according to the R equation.

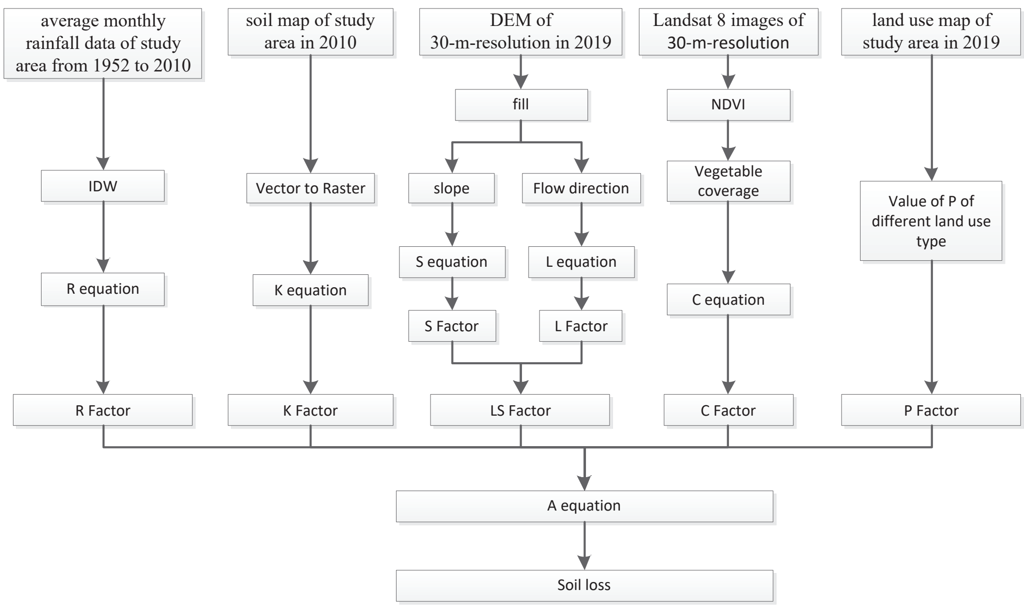


Fig. 2 The technical route of calculating soil erosion. Source: own elaboration

2.4.2 Soil erodibility (K) factor

The erosion productivity impact calculator (EPOC) model was proposed by *Sharpley* and *Williams* (1990) and was used to calculate the K factor.

K equation:

$$K = \left\{0.2 + 0.3 * exp^{\left[-0.0256*SAN\left(1-\frac{SIL}{100}\right)\right]}\right\} * \left[\frac{SIL}{CLA + SIL}\right]^{0.3} * \left[1.0 - \frac{0.25 * C}{C + exp^{(3.72-2.95*C)}}\right] * \left[1.0 - \frac{0.7 * SN}{SN + exp^{(-5.51+22.9*SN)}}\right] \quad (3)$$

where:
SAN = sand (0.05-2 mm, unit: %)

SIL = silt (0.002-0.05 mm, unit: %)

CLA = clay (less than 0.002 mm, unit: %)

C = organic carbon (unit: %)

SN = 1-SAN/100

The soil map which included the elements of soil with the shape format was converted to a raster map. Then the values of the K factor were calculated using the raster calculator toolset in ArcMap software, according to the K equation.

2.4.3 Topographic (LS) factors

The change of slope has a greater effect on soil erosion than that of slope length: the longer the slope length, the steeper the slope, and the larger the LS value. The DEM data of the study area are used to analyze the topographic features in GIS as a technical method which is to extract the slope and length data. Slope length can be defined as the projection length of the maximum ground distance from a point on the ground along the direction of water flow to its starting point on the horizontal plane (*Pan* 2009: 616). The slope length factor calculation of the area uses the formula of *Liu* et al. (2002: 23). The slope factor calculation of the area below 10° adopts *McCool's* formula (*McCool* et al. 1987), and the calculation of the slope factor of the area above 10° adopts the formula improved by *Liu* et al. (1994: 1837) based on the steep slope of the Loess Plateau.

LS equation: $LS = L * S$ (4)

L equation: $L = \left(\frac{\lambda}{22.13}\right)^m$ (5)

m equation: $m = \begin{cases} 0.5 & \tan\theta > 5\% \\ 0.4 & 3\% < \tan\theta < 5\% \\ 0.3 & 1\% < \tan\theta < 3\% \\ 0.2 & \tan\theta < 1\% \end{cases}$ (6)

S equation: $S = \begin{cases} 10.8 * \sin\theta + 0.03 & \theta < 5° \\ 16.8 * \sin\theta - 0.5 & 5° \leq \theta < 10° \\ 21.91 * \sin\theta - 0.96 & \theta \geq 10° \end{cases}$ (7)

θ equation: $\theta = \frac{slope * 3.1415926}{180}$ (8)

where:
L = slope length factor

S = slope factor

λ = slope length (unit: m)

θ = slope (unit: degree)

m = slope length index

During the process of L factor calculation, the m parameter was calculated first. In m equation, 'tanθ < 1%' means that the numeric value of 'tanθ < 1%' is less than 0.01 converted by 1%, thus 0.01 should be applied to the m equation. When θ was used in the trigonometric function, θ was calculated first by 'slope * 3.1415926 / 180' to get a number with degree unit because θ in the slope map was just a numeric value without unit.

Based on DEM with 30 m resolution of the study area, λ was extracted by a special method. Then m was calculated according to the m equation by using the raster calculator toolset in ArcMap software. With the same toolset, the S factor was calculated after obtaining no depression DEM.

2.4.4 Crop cover and management (C) factor

With the rapid development of remote sensing (RS) technology, it is easy to extract vegetation coverage quickly using remote sensing images. By calculating the correlation between sediment yield and vegetation coverage according to previous research, the function of annual average C and vegetation coverage (c) was obtained (*Cai* et al. 2000: 23).

C equation:

$$C = \begin{cases} 1 & c = 0 \\ 0.6508 - 0.3436 * lg^{c} & 0 < c \leq 78.3\% \\ 0 & c > 78.3\% \end{cases} \quad (9)$$

c equation: $$c = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (10)$$

where:
C is crop cover and management factor. c is vegetation coverage and its unit is a percentage. *NDVI* is the normalized difference vegetation index. $NDVI_{min}$ is the minimum *NDVI* and $NDVI_{max}$ is the maximum *NDVI* of the study area. Thus, c should be converted to the percentage system before being calculated in the equation if the values of *c* are just numerical values on a scale of ten.

Initially, the land use land cover map of the study area was prepared by Landsat 8 satellite image of 30 m resolution in 2019 (*Table 1*). Then, the normalized difference vegetation index (*NDVI*) was calculated from the land use land cover map by using the image analysis toolset in ArcMap 10.2 software. During this process, the red band and infrared band could be found from the metadata of satellite images in the layer properties function of ArcMap software. According to the maximum value and the minimum value of *NDVI*, vegetation coverage (c) could be obtained from the c equation and the range of c was from 0 to 1. Thus, the values of c multiplied by 100 using the raster calculator toolset and the result could be applied to the C equation.

2.4.5 Conservation practice (P) factor

Due to the many sub-factors of the P factor, it is difficult to quantify the P factor. Therefore, only the main conservation measures are considered in reality. According to the research of *Cai* et al. (2000) and *Bu* et al. (1997), the values of the P factor in natural vegetation areas and sloping farmland can be 1, wherever horizontal terraces have been built, it is 0.01, and in other situations between the two, a value between 0.02 and 0.7 can be taken. Thus, in complex areas, the values of the P factor can be made based on the results of previous experience and combined with the conservation measures in the study area.

Initially, there were several fields in the attribute table of the land use land cover map of the study area, such as OID (object identifier), value, count. Based on the constituent of the land use land cover map of the study area, the attribute table had added a field named P and set a value for this field relying on previous experience under the pattern of edit in ArcMap software. Then, the P factor map of the study area was generated using the lookup toolset after selecting the P field as the lookup field.

3. Results

3.1 Rainfall erosivity (R) factor

From *Table 1*, the annual average precipitation of the study area is nearly 1111.44 mm per year, varying from 936.48 mm per year to 1500.27 mm per year. Meanwhile, the northern part and northwestern part of the Xiangxi River basin experience higher rainfall, resulting in high rainfall erosivity (R) factor with approximately 302 to 359 MJ mm ha^{-1} h^{-1} $year^{-1}$ (*Fig. 3a*). By contrast, in the middle part and the southern part of the study area, the values of rainfall erosivity (R) factor are generally low between 229 and 284 MJ mm ha^{-1} h^{-1} $year^{-1}$.

3.2 Soil erodibility (K) factor

There are seven soil types in the Xiangxi River basin, and they are yellow soil, yellow-brown soil, brown soil, limestone soil, purple soil, and paddy soil, respectively (*Table 3*). The largest area is occupied by yellow-brown soil and limestone soil, with 39.42% and 38.89%, respectively. Meanwhile, the values of the

K factor in yellow-brown soil and limestone soil are 0.26 tons ha^{-1} MJ^{-1} mm^{-1} and 0.24 tons ha^{-1} MJ^{-1} mm^{-1}, respectively. Paddy soil has the highest K-factor with 0.33 tons ha^{-1} MJ^{-1} mm^{-1} and covers an extremely low area, with only 0.7% in the south of the study area. From the result of the K factor (*Fig. 3b*), the values of soil erodibility (K factor) are moderate in most areas, and the northern part and the northwestern part of the study area experience higher soil erodibility. Meanwhile, very small parts in the middle of the study area suffer from the highest soil erodibility.

Table 3 Soil group and K-factor values of the Xiangxi River basin. Source: own elaboration

Major soil group	Coverage in km^2	Coverage in %	K value
yellow soil	120.71	3.76	0.28
yellow-brown soil	1267.04	39.42	0.26
brown soil	401.99	12.50	0.29
limestone soil	1250.39	38.89	0.24
purple soil	151.85	4.72	0.21
paddy soil	22.55	0.70	0.33
waters	0.01	0.01	0
total	3214.54	100	

3.3 Topographic (LS) factors

The slope ranging from 0 to 75.1 degrees is calculated based on DEM without depression. The S factor is obtained relying on the S equation and ranges from 0 to 20.2. The values of m are between 0.2 and 0.5. In the end, the values of the LS factor in the Xiangxi River basin are between 0 and 53.27 and the highest values are observed in the northwestern parts of the study area (*Fig. 3c*). Meanwhile, the northwestern parts of the basin are characterized by steep slopes which are similar to the extended part of the basin from south to east and range from 32 degrees to 75 degrees. By contrast, the lowest LS-factor values are in the middle of the study area with relatively low slopes.

3.4 Crop cover and management (C) factor

From the result of crop cover and management (C) factor (*Fig. 3d*), the values of the C factor are relatively small on both sides of the Xiangxi River which is mainly covered by woodland. If the value of crop cover and management (C) factor is 0, it means no soil loss in the study area; on the contrary, there is the most severe soil loss when the C-factor value is 1.

3.5 Conservation practice (P) factor

There are six land-use types in the Xiangxi River basin, and they are waters, woodland, nudation (mainly refers to the residential area), garden plot, road construction, and mountain, respectively (*Table 4*). The largest area is occupied by woodland with 47.18% of the study area with the highest P-factor value. The higher the value of the conservation practice (P) factor, the fewer conservation measures were taken. Thus, 1 represents no conservation measures and 0 means good conservation measures. From the result of the P factor, most areas take no measure and get high P-factor values (*Fig. 3e*).

Table 4 Land use land cover and P-factor values of the Xiangxi River basin. Source: own elaboration

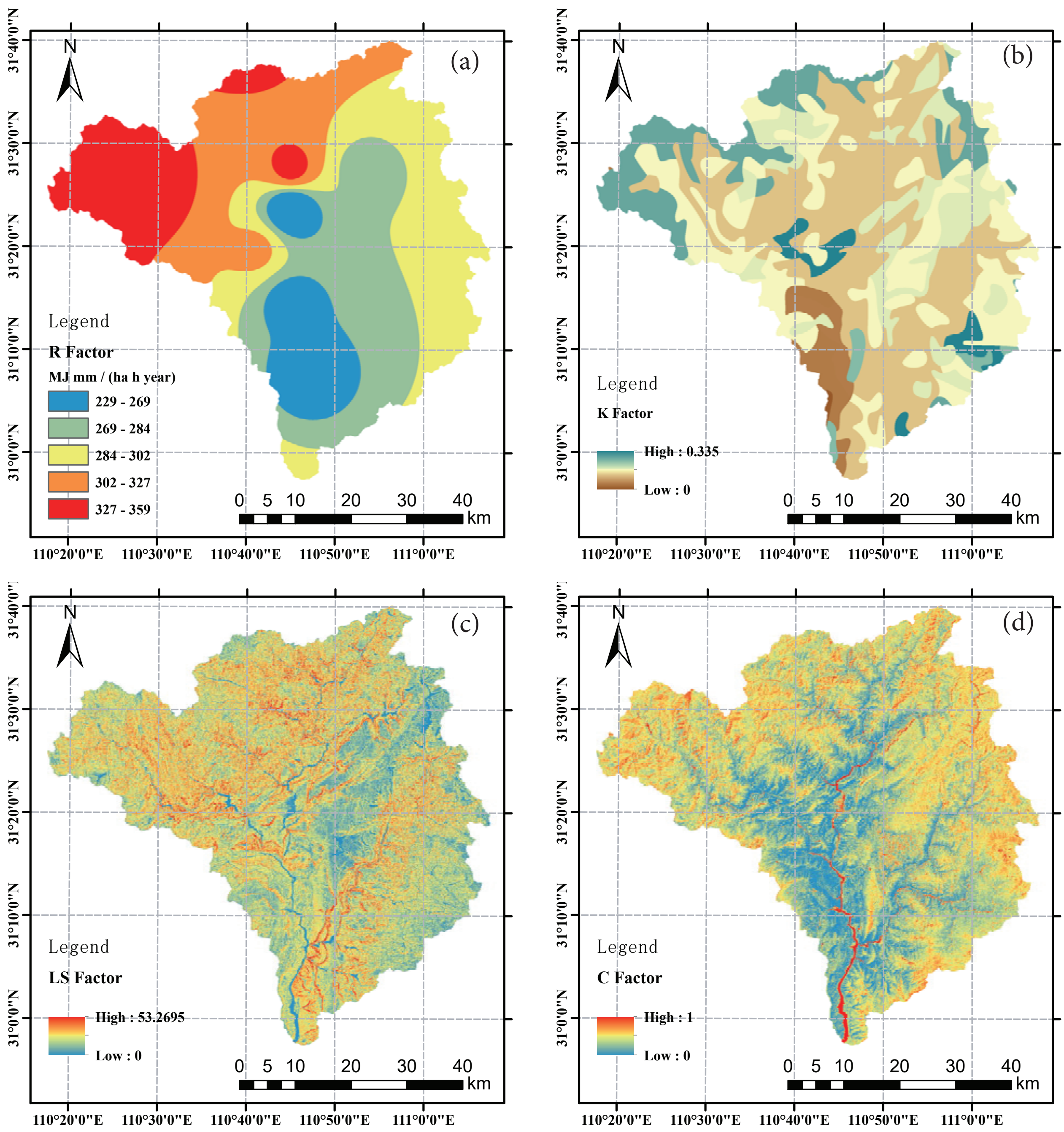
Land-use type	Coverage in km^2	Coverage in %	P value
waters	19.28	0.60	0
woodland	1517.42	47.18	1
nudation	643.35	20.01	0.01
garden plot	195.08	6.10	0.15
road construction	94.91	2.95	0.01
mountain	744.50	23.16	1
total	3214.54	100	

3.6 Soil loss potential

From the result of soil loss severity in the Xiangxi River basin (*Table 5*), about half of the area suffers from low soil loss. The intensity of soil erosion in the Xiangxi River basin is higher in the northwest and southeast, and lower in the central area. Thus, severe erosion and extreme erosion are mainly distributed in the northwest of the basin, and there is a small amount of high erosion and extreme erosion in the southeast. Low-erosion and moderate-erosion are widely distributed, of which low-erosion is the most widely distributed, with an area of 1628.39 km^2, accounting for 50.79% of the total area. It is followed by moderate erosion, with an area of 742.30 km^2, accounting for a total of 23.15% of the area. But the total area of intensive erosion, high erosion, and severe erosion is 835.24 km^2, accounting for 26.06% of the area. It can be seen that the soil loss in the Xiangxi River basin is slightly intensified in most areas, and a few areas are more serious.

Table 5 Soil loss severity in the Xiangxi River basin. Source: own elaboration

Soil loss (tons ha^{-1} year^{-1})	Severity class	Area (km^2)	Total area coverage (%)
0-5	Low	1628.39	50.79
5-25	Moderate	742.30	23.15
25-50	High	464.96	14.51
50-80	Very high	246.31	7.68
80-150	severe	104.74	3.27
above 150	Very severe	19.23	0.60
	Total	3205.93	100



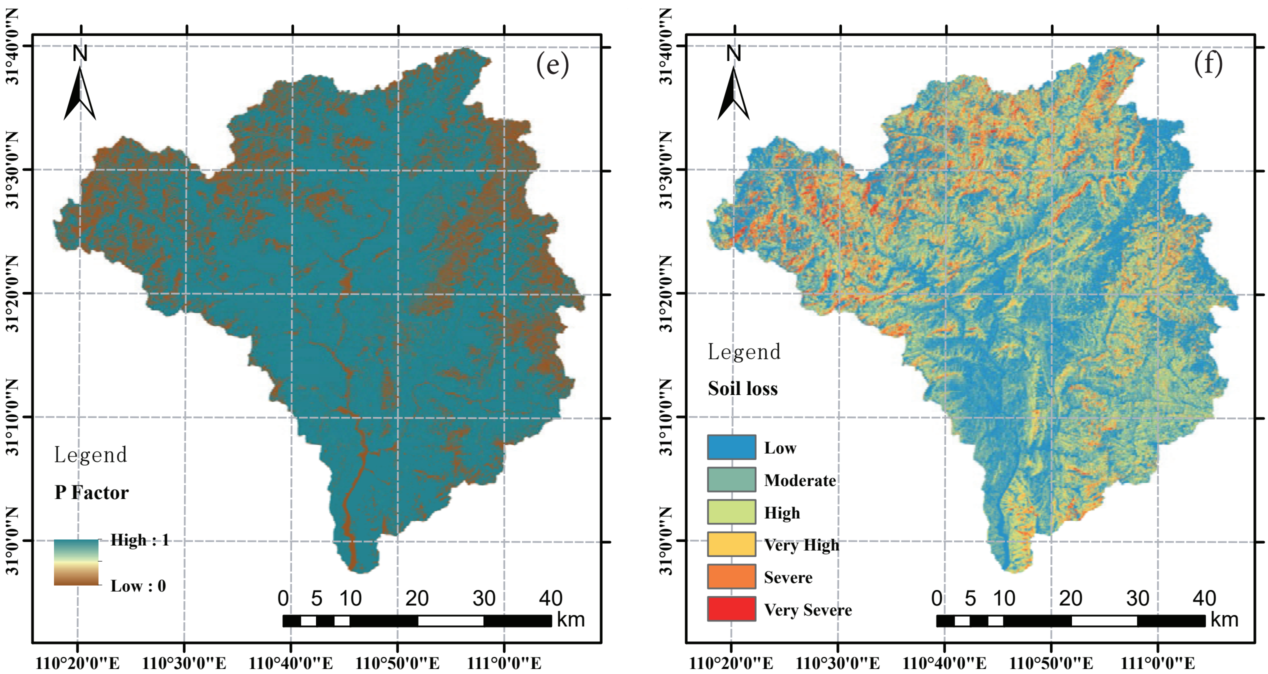


Fig. 3 R-factor map (a), K-factor map (b), LS-factor map (c), C-factor map (d), P-factor map (e) and soil loss map (f) of the Xiangxi River basin. Source: own elaboration

The study area is divided into eight zones from zero to 80 degrees. As can be seen from *Table 7*, some of the main characteristics of soil erosion occur in [10, 50) and the highest soil loss is 35.27% which is in [30, 40) covered 25.69% of the soil erosion area. The proportion of soil loss in [20, 30) is nearly equal to that of [40, 50) at 23.48% and 24.52% respectively. While soil erosion area of [20, 30) at 29.40% is more than twice as much as that of [40, 50) at 12.30%. The situation of [20, 30) and [50, 60) are similar. Meanwhile, the low slope zone mainly suffers from low grade erosion and they are opposite of the high slope zone.

Table 7 The proportion of soil erosion in different slope distribution in the Xiangxi River basin (unit: %). Source: own elaboration

Soil loss class		Slope (degree)							
		[0,10)	[10,20)	[20,30)	[30,40)	[40,50)	[50,60)	[60,70)	[70,80)
Low	area	8.58	14.32	13.72	8.98	3.38	0.59	0.06	0
	soil loss	0.55	1.87	1.54	0.84	0.28	0.05	0.01	0
Moderate	area	0.10	5.94	9.33	5.77	2.05	0.38	0.04	0
	soil loss	0.06	4.82	8.63	5.55	1.99	0.37	0.04	0
High	area	0	0.66	4.96	5.92	2.75	0.55	0.05	0
	soil loss	0	1.12	9.10	11.19	5.28	1.06	0.10	0
Very high	area	0	0.01	1.31	3.75	2.25	0.50	0.05	0
	soil loss	0	0.04	3.88	11.71	7.12	1.58	0.17	0
Severe	area	0	0	0.08	1.23	1.59	0.43	0.04	0
	soil loss	0	0	0.33	5.70	7.77	2.14	0.20	0.01
Very severe	area	0	0	0	0.04	0.28	0.24	0.05	0
	soil loss	0	0	0	0.28	2.08	1.98	0.52	0.02
Total	area	8.68	20.93	29.40	25.69	12.30	2.69	0.29	0
	soil loss	0.61	7.85	23.48	35.27	24.52	7.18	1.04	0.03

The study area is made up of six types of soil, meanwhile, yellow-brown soil and limestone soil are the dominant soil types covering 39.42% and 38.89% of the study area, respectively (*Table 3*). From *Table 8*, these two types of soil also occupy a high proportion of soil loss which are 39.29% and 40.92%, respectively, and similar to the proportion of their erosion area (39.39%, 38.97%). Yellow soil and purple soil cover 3.76% and 4.72% of the study area; in the same way, they occupy less proportion of soil loss with 2.41% and 1.24%, respectively. The soil erosion is mainly observed at a very high grade and the soil erosion areas are relatively large in the low grade like 19.33% in yellow soil. On the whole, most areas suffer from low erosion in every type of soil, and the higher the grade, the smaller the proportion of soil erosion area.

The main types of land use in the Xiangxi River basin include waters, woodland, garden soil, road construction, and mountain. As shown in *Table 9*, the mountains suffered from the major soil loss at 61.13%. This is followed by woodland with 38.31% which has the highest soil erosion area (47.28%). Moreover, mountains mainly suffer from high erosion compared with woodland. The remaining four types of land use are subjected to low erosion slightly, with nearly 0 in waters, 0.37% in nudation, 0.79% in the garden plot, and 0.03% in road construction, respectively.

Table 8 Different types of soil distribution of soil erosion in the Xiangxi River basin (unit: %). Source: own elaboration

Soil loss class		Soil					
		yellow soil	yellow-brown soil	brown soil	limestone soil	purple soil	paddy soil
Low	area	2.19	19.33	3.03	17.44	3.87	0.25
	soil loss	0.29	1.84	0.14	2.18	0.49	0.04
Moderate	area	1.08	9.30	0.68	10.66	0.75	0.24
	soil loss	0.93	8.52	0.67	9.66	0.58	0.22
High	area	0.35	6.08	0.91	6.37	0.07	0.12
	soil loss	0.62	11.39	1.75	11.86	0.13	0.21
Very high	area	0.10	3.24	0.72	3.07	0.01	0.05
	soil loss	0.30	10.05	2.25	9.51	0.04	0.15
Severe	area	0.04	1.26	0.45	1.19	0	0.03
	soil loss	0.17	6.04	2.19	5.70	0	0.13
Very severe	area	0.01	0.18	0.08	0.24	0	0.01
	soil loss	0.10	1.45	0.61	2.01	0	0.04
Total	area	3.77	39.39	5.87	38.97	4.70	0.70
	soil loss	2.41	39.29	7.61	40.92	1.24	0.79

Table 8 Different land use land type distribution of soil erosion in the Xiangxi River basin (unit: %). Source: own elaboration

Soil loss class		Land use					
		waters	woodland	nudation	garden plot	road construction	mountain
Low	area	0.60	19.35	19.93	6.05	2.96	0.75
	soil loss	0	3.77	0.37	0.77	0.03	0.20
Moderate	area	0	19.48	0	0.03	0	4.10
	soil loss	0	17.24	0	0.02	0	4.21
High	area	0	7.22	0	0	0	7.67
	soil loss	0	12.99	0	0	0	14.87
Very high	area	0	1.18	0	0	0	6.70
	soil loss	0	3.45	0	0	0	21.05
Severe	area	0	0.05	0	0	0	3.31
	soil loss	0	0.24	0	0	0	15.91
Very severe	area	0	0	0	0	0	0
	soil loss	0	0.62	0	0	0	4.89
Total	area	0.60	47.28	19.93	6.08	2.96	22.53
	soil loss	0	38.31	0.37	0.79	0.03	61.13

4. Discussion

In this study, RS and GIS technologies were used to analyze the spatial differentiation of soil erosion in the Xiangxi River basin of Hubei Province, China in 2019 with the soil erosion model RUSLE. According to *Table 5*, 1628.39 km^2 suffered from low erosion which is nearly 40 times as large as the figure calculated in 2011 (*Wang* et al. 2012: 60). Also, the moderate erosion is 742.3 km^2 which is about three times as large as that of 2011. The areas of the two grades account for 73.94% in the Xiangxi River basin. On the contrary, all figures above moderate grade are lower compared with the result in 2011. Overall, the proportion of the lower erosions sees a dramatic growth, and others face a relative decline in the last several years. Land use is the main factor resulting in the difference in the two studies because the Xiangxi River basin is located in the upper reaches of the Yangtze River and it had been listed as a national key soil and water conservation prevention area. Thus, many engineering measures have been taken over the years such as slope engineering (like terrace, catchwater, impounding reservoir), plant measures (like forestation), cultivation measures (like contour plowing, densely plowing, terraced plowing) and others. In 2011, the Xiangxi River basin was covered by 12.43% of farmland, while it was also replaced by garden soil (6.10%) under the government policy in 2019. On the contrary, the proportion of habitation increased to 22.96% from 0.56%. The total proportion of the forest was 72.66% in 2011 which included mountain and woodland without specific figures. Despite the vegetation coverage area hardly changing in 2019, the proportion of the woodland rose to 47.18%, and the mountain declined to 23.16% according to the official public information and the RS image. These measures taken by humans reduced high erosion to moderate erosion because the mountains were more prone to high erosion.

The soil types in the Xiangxi River basin are mainly yellow soil, yellow-brown soil, brown soil, limestone soil, purple soil, and paddy soil (*Table 3*). The yellow-brown soil and limestone soil accounted for 39.42% and 38.89% respectively, which belong to alfisol and primitive soil correspondingly. According to the previous study, the Xiangxi River basin can be roughly divided into three geomorphic types: the low-relief terrain (elevation under 800 meters distributed in the central section), the karst denudation moderate-mountain region (elevation between 800 and 1200 meters distributed in the southeast, central section and southwest), the alpine zone (elevation over 1200 meters distributed in the northeast and northwest) (*Sun* 2008). The distribution of limestone soil in our study agrees well with that previous conclusion. According to *Table 8*, the soil erosion of the limestone soil area is mainly under high erosion and the low erosion is most widely distributed. It is similar to the erosion of the yellow-brown soil, because the greater the rainfall intensity, the greater the amount of sediment loss in the limestone soil area (*Qin* et al. 2016: 2). At the same time, it was dominated by trees in the limestone soil zone according to Yichang statistical yearbook, such as palm, tung tree, tallow tree, pine tree, bamboo, and others. Most of these kinds of trees are suitable for growing on limestone soil (*Lal* 2017). Thus, the degree of soil erosion in the limestone soil is determined by rainfall. Although the precipitation in the limestone soil area of the Xiangxi River basin was mainly above moderate grade, the plant measures alleviated soil erosion. Similarly, it was dominated by garden and nudation in the yellow-brown soil and the crops were citrus and oranges which grew well on yellow-brown soil. Thus, the plant measures of the Xiangxi River basin have reference significance for other regions that are composed of limestone soils or yellow-brown soils and suffered from severe soil erosion.

The high slopes (>50°) were mainly distributed in the north of the Xiangxi River basin and these areas suffered from high grade erosion, but the amount of the soil erosion decreased with increasing slope due to fewer areas with high slope. This was because the north of the study area was mainly covered by nudation and mountains, meanwhile, this region suffered from heavy rainfall although it was covered by a few trees. The moderate slopes (20~50°) were mainly distributed in the central area and the total proportion of soil erosion in these areas was 83.27% of the total soil erosion. The proportion of the soil erosion area was also quite high (67.39%). Half of the area was subject to high erosion, and the amount of soil erosion was comparably high peaking at [30, 40). This was because the total area of [20, 50) was considerable and accounted for about 68% of the Xiangxi River basin. Meanwhile, the zone was mainly covered by woodland and mountains. In [20, 30), the erosion was mainly caused by woodland with moderate rainfall according to the soil land use image. However, the erosion of [30, 40) was caused by woodland and mountains, especially the latter with strong rainfall. The low slopes (<20°) were mainly distributed in the center of the study area and these areas mainly suffered from low grade soil erosion, because this zone was covered by the garden plot and experienced less than moderate rainfall. Thus, the government should pay more attention to the class [30, 40) and could plant *Neyraudia reynaudiana* in the mountain areas to increase vegetation coverage. *Neyraudia reynaudiana* has the characteristics of drought resistance, barren, fast growth, a large amount of growth and it could grow enormously in desertified mountains (*Wu* 2016: 209).

5. Conclusions and future prospects

The results obtained after using the empirical RUSLE model integrating with remote sensing (RS) and geographic information system (GIS) indicated that in this study of the Xiangxi River basin, soil erosion was significantly different from the 2011 study. Also, the results of the RUSLE model had been compared with the public data in Hubei Province Soil and Water Conservation Bulletin in 2019 to verify the precision of the model. The final results of verification showed that the calculation results of the model had high precision. In both cases, the center of the study area suffered from the lower soil erosion, and the north, the northwest, and the south of the study area suffered from the higher soil erosion. In a word, the two cases had a similar distribution of soil erosion. Firstly, the results of the model showed that the proportion of the lower erosion saw a dramatic growth and higher erosion faced with a relative decline compared with the previous study in 2011. Secondly, soil erosion in the Xiangxi River basin varied observably across different grades of the slope, land use, soil. High erosion occurred in the slope range [30, 40) due to mountains highly affected by heavy rainfall. It is suggested that relevant departments (like the Department of Water Administration and the Engineering Management Department) could take measures to reduce soil erosion. Growing grass especially *Neyraudia reynaudiana* on the mountains is a good measure. Thirdly, high soil erosion also occurred in the yellow-brown soil and the limestone soil because of the heavy rainfall. Although suitable crops have grown correspondingly in different types of soil, the department still should pay more attention to surface runoff. The results of the study can be used to guide the follow-up work of relevant departments.

The Shennongjia woodland area in the northwest of the study area was dominated by primeval woodland, with dense vegetation cover and little human activity. Future studies should be taken to consider the impact of crop cover and management (C) factors on the assessment results and further revise crop cover and management (C) factors, which has important guiding significance for the estimation of soil erosion in similar low mountain valleys landform areas, areas with dense vegetation coverage and less human activities. Furthermore, due to the important location of the Xiangxi River basin, the upper reaches of the Yangtze River, the nutrient loss in the Xiangxi River basin will receive more attention in the future.

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