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Research Article

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Comparative analysis of rainfall erosion force R by using different algorithms for soil erosion controlling based on GIS and mathematical models

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ABSTRACT

In this paper, different mathematical models were used to quantitative assessment of temporal and spatial distribution of rainfall erosion force R based on geographic information systems, comparing the difference between the different algorithms, the results showed that rainfall erosion force by different algorithms are quite different, the calculation results of annual rainfall erosion force R sorted for Z> F>W>L model, while that of monthly results ordered as Z> W>L>F model. While carry out risk assessment of soil and water losses, should adjust measures to local conditions, it is very important to choose reasonable risk evaluation model for accurate prediction of regional soil erosion. Different algorithms has the different spatial distribution of rainfall erosion force R, high risk areas are mainly concentrated in the west and the south, however, low risk areas are mainly distributed in the north and east. These results can provide scientific basis for prevention and control of soil erosion.

Keywords: GIS, mathematical models, rainfall erosion force R, soil and water losses, comparison of algorithms

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INTRODUCTION

Soil erosion refers to a process of the soil particles and surface appendages were eclipsed handling, migration, and deposition under external force [1-3]. Rainfall erosion force R said potential ability of soil erosion caused by rainfall to reflect the impact of climatic factors on soil erosion, is one of the calculation factors of Universal Soil Loss Equation [4-6]. How to accurately evaluate risk of rainfall erosion force R of soil erosion, has very important significance for identifying regional soil erosion risk and formulating reasonable measures of prevention and control [7, 8].

Risk of rainfall erosion force R of soil erosion is closely related to rainfall, rainfall intensity and rainfall time, it is difficult to directly measured, most with rainfall intensity, rainfall and other parameters to estimate [9-11]. To this end, researcher had proposed various calculation parameters and methods of rainfall erosion force R, and combined with the geographic information system, research on spatial and temporal dynamic of rainfall erosion force R [12-16]. However, the rainfall erosion force R algorithms in different regions is difficult to be extended to other areas, therefore, how comparative analysis the differences of spatial distribution and different algorithms the based on existing algorithm is an important research direction.

This study application of daily rainfall data in three monitoring sites of Zhangjiakou, Huailai and Chengde in 1980-2000, and the four different calculation methods of rainfall erosion force R, based on the geographic information system and models in Hebei province of China, assessment of regional rainfall erosion force conditions, comparison of different calculation methods of R value to analyze spatial distribution of different algorithms in order to provide a reference for the regional soil erosion prevention.

EXPERIMENTAL SECTION

2.1 Study area

Hebei province is located in north latitude 36 ° 03 '- 42 ° 40', longitude 113 ° 27 '- 119 ° 50', a total area of 188, 000 km². Landform with plateau, mountains and plains, which accounted for 9.3%, 49.5% and 41.2% of the total area, respectively, the altitude of roughly from the northwest to the southeast gradually declined. In western is Taihang Mountain, and northern is Yanshan, surrounded by a semi-circular Hebei Plain. A temperate continental monsoon climate, the annual average temperature of -0.3℃-4 ℃, the average annual precipitation is 350-15mm (Fig. 1).

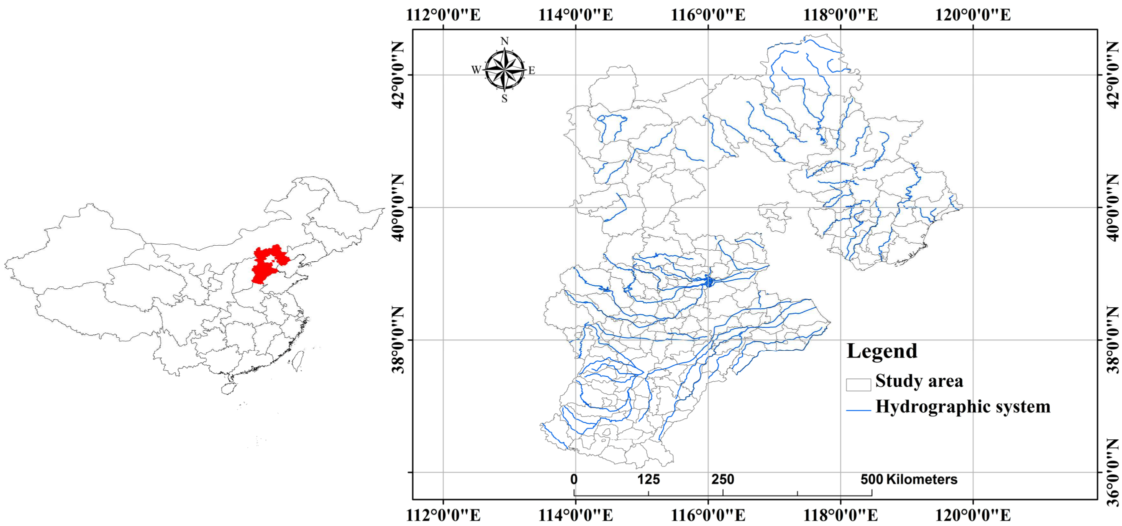


Fig. 1. The study area of Hebei province in China

2.2 Z model

Zhang *et al*. established rainfall erosion force R model by daily rainfall data, referred to as the Z model, calculated for half monthly rainfall erosion force, the summary can be obtained monthly rainfall erosion force and annual rainfall erosion force. The Z model calculated as follows [17]:

$$R_i = \lambda \sum_{j=1}^{k} (P_j)^{\delta} \tag{1}$$

$$\lambda = 21.586\delta^{-7.1891} \tag{2}$$

$$\delta = 0.8363 + \frac{18.177}{P_{d12}} + \frac{24.455}{P_{y12}} \tag{3}$$

Where, R_i for the first k months of rainfall erosion force (MJ·mm/hm² /a/h); P_j said the first j days of rainfall of half period , k said the days of half period, P_{d12} refers daily rainfall≥12mm, P_{y12} refers daily rainfall ≥12mm of annual rainfall.

2.3 L model

Its model requires only annual rainfall or average annual rainfall, we can calculate the average annual or multi-year of rainfall erosion force R-value by Roose [18], referred to as the L model, which was expressed as:

$$R = 0.5P \tag{4}$$

Where, P is the average annual or monthly rainfall, R is the rainfall erosion force.

2.4 F model

Soil and water conservation experimental station in Fujian and Fujian Agricultural University presented, referred to as the F model, calculated as follows [19]:

$$R=\sum_{i=1}^{12}(-1.15527+0.1792P_i) \quad (5)$$

Where, P_i is the first i monthly rainfall, P is the annual rainfall.

2.5 W model
Formula of rainfall erosion force empirical by Wischmemier referred to as the W model, as following [20]:

$$R=\sum_{i=1}^{12}1.735\times10^{(1.51\lg\frac{P_i^2}{P}-0.8188)} \quad (6)$$

Where, P_i is the first i monthly rainfall, P is the annual rainfall.

2.6 IDW spatial interpolation method
Inverse Distance Weighted method is a global interpolation method, that is, all samples are estimated to be involved in a point estimate of Z values based on GIS, calculated as follows:

$$v_e=\sum_{j=1}^{n}wjvj \quad (7)$$

Where, v_e ($j = 1, ... n$) is the point (x_j, y_j) of variable value, w_j is the weight corresponding coefficients.

RESULTS AND DISCUSSION

3.1 Comparison of different monitoring sites of rainfall erosion force R by using Z model
3.1.1 Analysis of changes of annual rainfall erosion force

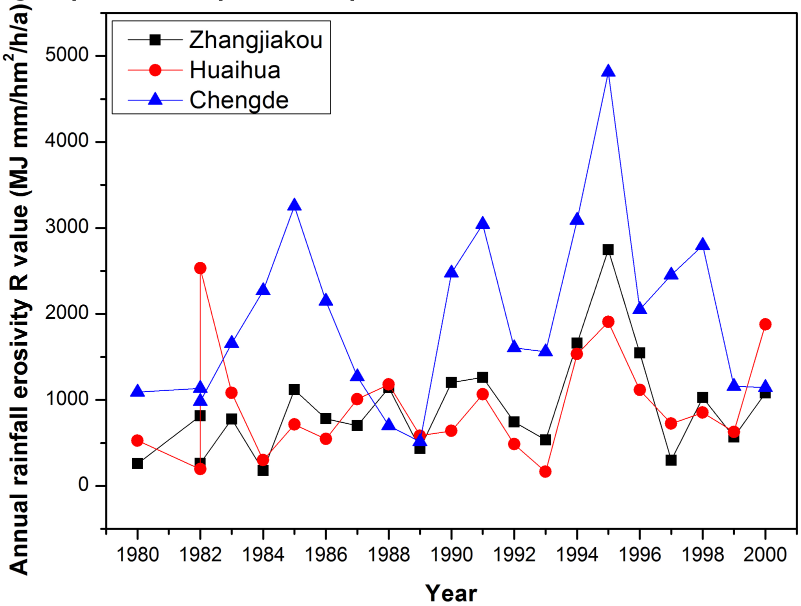


Fig. 2. Change trend of annual rainfall erosion force R in different monitoring sites

The figure 2 shows that the rainfall is abundant in Hebei province, rainfall erosion in large extent, and annual rainfall erosion force R in 166.03-4810.12 MJ·mm/hm²/h/a. The maximum rainfall erosion force R appeared in Chengde in 1995, the R value was 4810.12 MJ·mm/hm²/h/a, the minimum of rainfall erosion force R appeared in 1994, which was 166.03 MJ·mm/hm²/h/a. R value of three monitoring sites of total are more than 1000 MJ·mm/hm²/h/a, including the year of 1991, 1994, 1995, 1996 and 2000, different monitoring sites showed annual rainfall erosion force are quite different in Hebei province.

3.1.2 Analysis of changes of monthly rainfall erosion force

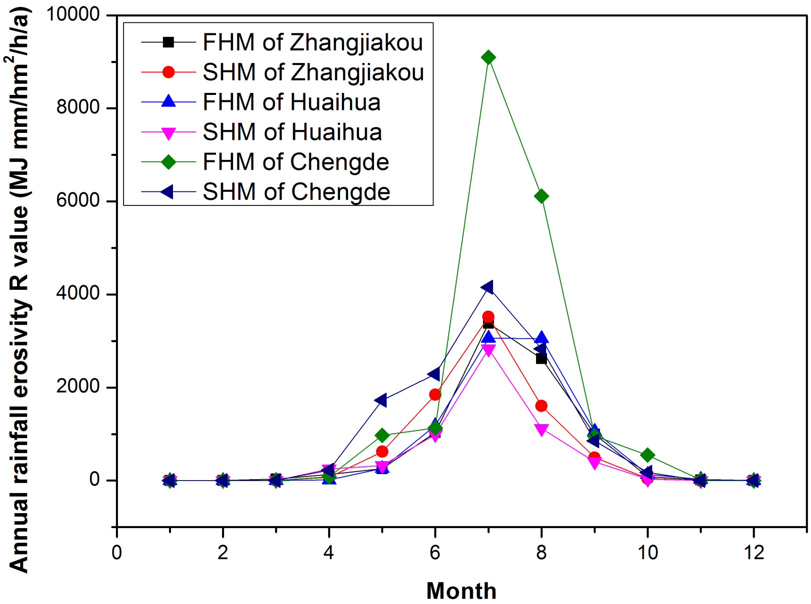


Fig. 3. Change trend of monthly rainfall erosion force R in different monitoring sites

Figure 3 indicates that maximum of the monthly rainfall erosion force R in the first half of July in Chengde was 9096.67 MJ·mm/hm²/h/a, ample rainfall period concentrated in June-August in Hebei, water shortage period focused on January-March, and December. Monthly rainfall erosion force R in Chengde is greater than the Zhangjiakou and Huaihua, showed that rainfall is larger in Chengde, monthly rainfall erosion force R is relatively higher, protection measures should be paid attention to the plentiful rainfall period to reduce the risk of soil erosion.

3.2 Comparison of different monitoring sites of rainfall erosion force R by using L model
3.2.1 Analysis of changes of annual rainfall erosion force

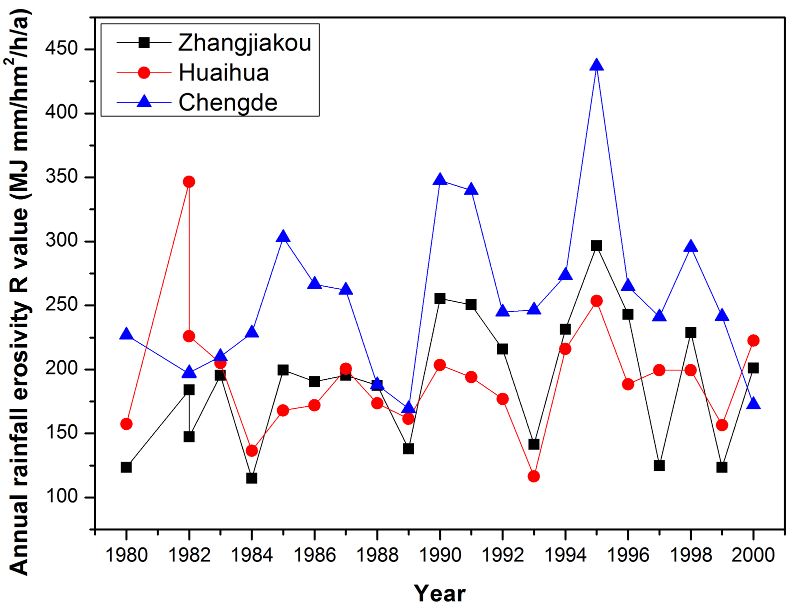


Fig. 4. Change trend of annual rainfall erosion force R in different monitoring sites

Figure 4 shows that, annual rainfall erosion force R was 115-437 MJ·mm/hm²/h/a in 1980-2000 in Hebei province. The minimum and maximum R was respectively in 1984 of Zhangjiakou and in 1995 of Chengde. The rainfall erosion force R greater than 200 MJ·mm/hm²/h/a in 1994 and 1995, the rainfall erosion R of Chengde was significantly higher than that of Zhangjiakou and Huaihua, showed that annual rainfall erosion of different monitoring sites are quite different in Hebei province.

3.2.2 Analysis of changes of monthly rainfall erosion force

The Figure 5 indicates that R value of monthly rainfall erosion force in 1980-2000 in Hebei province in the range of 16.00-1128.50 MJ·mm/hm² /h/a, minimum value in the Huaihua site in December, while the maximum site in Huaihua in July. High value period of rainfall erosion force R over 800 MJ·mm/hm² /h/a, and middle and low value were 100-800, and ≤ 100 MJ· mm/hm²/h/a, respectively. It should adopt the measures of prevention and control, so as not to cause soil erosion in plentiful rainfall period.

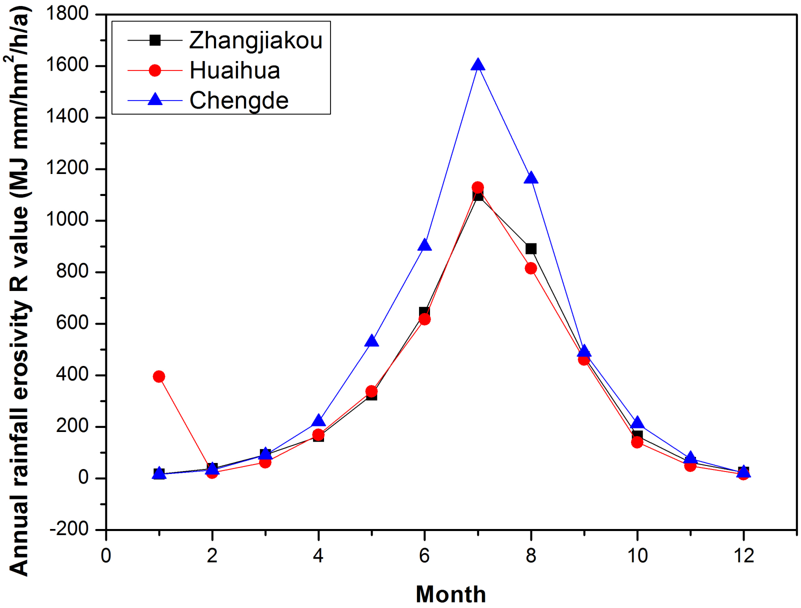


Fig. 5. Change trend of monthly rainfall erosion force R in different monitoring sites

3.3 Comparison of different monitoring sites of rainfall erosion force R by using F model

3.3.1 Analysis of changes of annual rainfall erosion force

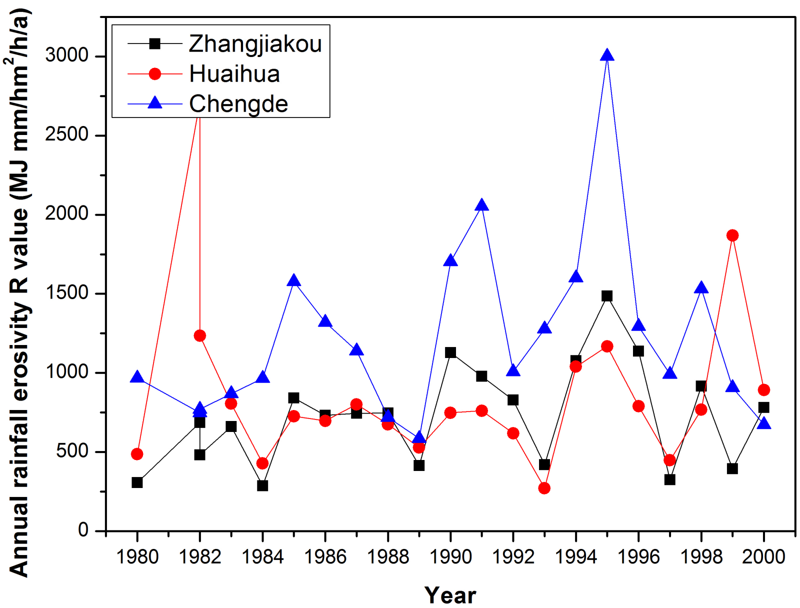


Fig. 6. Change trend of annual rainfall erosion force R in different monitoring sites

Figure 6 shows that, the annual rainfall erosion R ranged from 287.67 to 3000.43 MJ·mm/hm² /h/a in 1980-2000, minimum and maximum values respectively in 1984 of Zhangjiakou and in 1995 of Chengde. Among them, rainfall erosion R value were all more than 1000 MJ·mm/hm²/h/a in 1994 and 1995 of three monitoring sites, and the ordered as: Chengde > Huaihua > Zhangjiakou, it indicates that the character of rainfall erosion force R in different monitoring sites of Hebei Province has the large degree of difference.

3.3.2 Analysis of changes of monthly rainfall erosion force

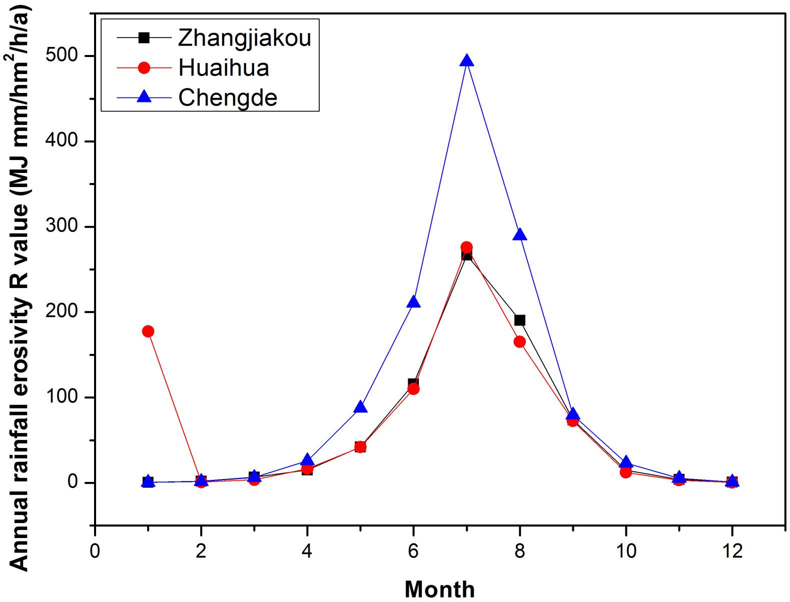


Fig. 7. Change trend of monthly rainfall erosion force R in different monitoring sites

Figure 7 indicated that, the monthly rainfall erosion R for 0.48-493.27 MJ·mm/hm² /h/a, the minimum value in January in Zhangjiakou, while that the maximum in Chengde in July. Monthly rainfall erosion R in Chengde was greater than Zhangjiakou and Huaihua. Showed that greater rainfall in Chengde, and rainfall erosion R is relatively higher, it should strengthen management and reduce soil erosion risk under the sufficient precipitation period.

3.4 Comparison of different monitoring sites of rainfall erosion force R by using W model

3.4.1 Analysis of changes of annual rainfall erosion force

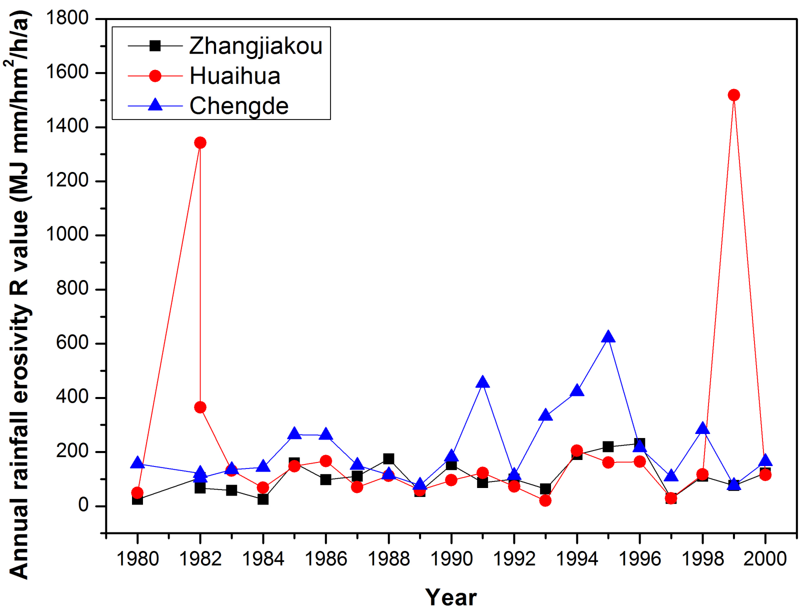


Fig. 8. Change trend of annual rainfall erosion force R in different monitoring sites

Figure 8 shows that the rainfall erosion force R value ranged from 25.47 to 1518.32 MJ·mm/hm² /h/a in three monitoring sites in 1980-2000, minimum and maximum values in 1980 and 1999, respectively in Zhangjiakou and Huaihua. Rainfall erosion force R in Chengde is greater than the Zhangjiakou and Huaihua, however in 1981 and 1999 that of the Huaihua is much larger than the Chengde and Zhangjiakou. It showed that annual rainfall erosion force in different monitoring sites was quite different.

3.4.2 Analysis of changes of monthly rainfall erosion force

The Figure 9 indicated that the monthly rainfall erosion force in the range of 0.03-2791.17 MJ·mm/hm² /h/a, the minimum value is Zhangjiakou in January and Chengde in January, while that of the maximum in Huaihua in July. Monitoring sites of the monthly rainfall erosion force R in Chengde was greater than the other two monitoring sites, indicating that the rainfall erosion force at different monitoring sites was quite different; the plentiful rainfall period should take effective measures to protect water and land resources, so as not to cause serious soil and water losses.

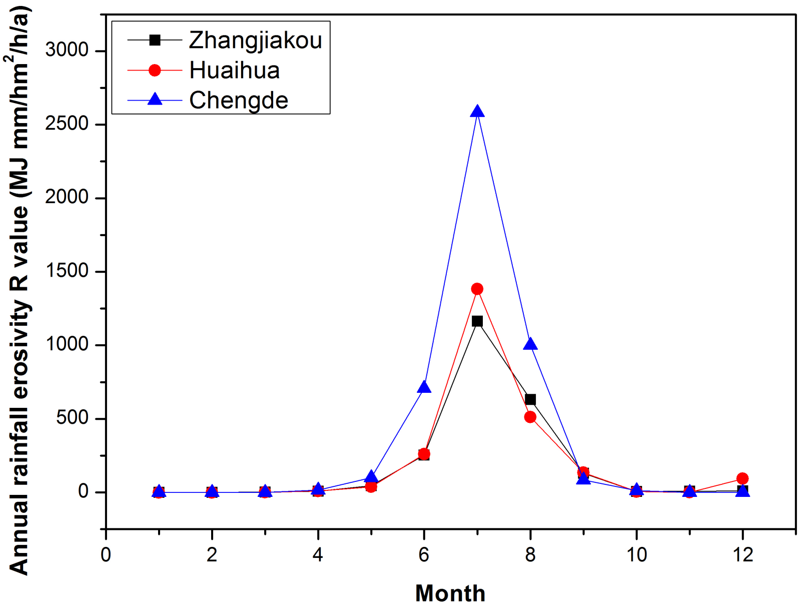


Fig. 9. Change trend of monthly rainfall erosion force R in different monitoring sites

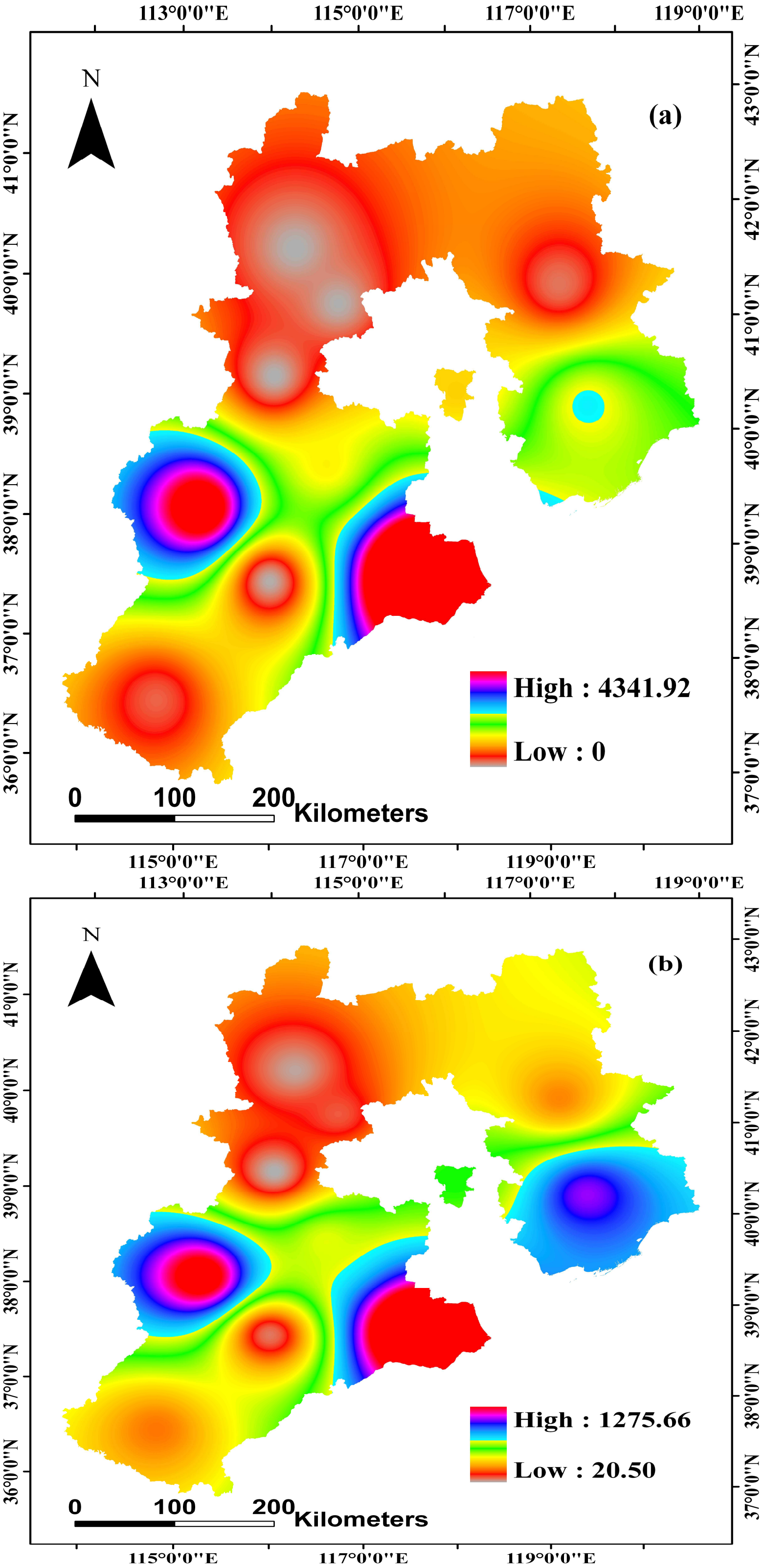
3.5 Comparison of rainfall erosion force R by different mathematical models

The calculation results of rainfall erosion force R by different models were quite different. Among them, calculation results of the annual rainfall erosion force R sorted as: Z>F>W>L model. Comparatively speaking, results of L model are smaller, while that of the Z model is larger. Calculation results of the monthly rainfall erosion force R ranking: Z>W>L>F model. In contrast, Results of Z model is larger, while that of the F model is larger. It showed that rainfall erosion force R was greatly influenced by different models. Assessment of soil and water losses should be adapted to local conditions, a reasonable choice for evaluation model is extremely important for accurately predict the regional soil erosion risk.

3.6 Spatial analysis of rainfall erosion force R based on inverse distance weighted interpolation method of GIS

Spatial distribution of rainfall erosion force R was quite different by different models, but the overall trend was basically identical (Fig. 10).

The rainfall erosion force R is 0-4341.92 MJ·mm/hm² /h/a by Z model, larger rainfall erosion in eastern, relatively speaking, that of the smaller in the north, northwest and southwest. In contrast, rainfall erosion force R is 20.50-1275.66 MJ·mm/hm² /h/a by L model, larger rainfall erosion in northwest and southwest, while the northern and eastern was smaller. However, rainfall erosion force R is 0.83-345.31 MJ·mm/hm² /h/a by F model, larger rainfall erosion in the western, nevertheless, southwest, northern and eastern was smaller. In contrast, rainfall erosion force R is 0.13-1710.35 MJ·mm/hm² /h/a by W model, the larger rainfall erosion in southern, while that of the western, northern was smaller.


113°0'0"E
115°0'0"E
117°0'0"E
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N
(a)
High : 4341.92
Low : 0
0 100 200 Kilometers
41°0'0"N
40°0'0"N
39°0'0"N
38°0'0"N
37°0'0"N
36°0'0"N
43°0'0"N
42°0'0"N
41°0'0"N
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39°0'0"N
38°0'0"N
37°0'0"N
(b)
High : 1275.66
Low : 20.50

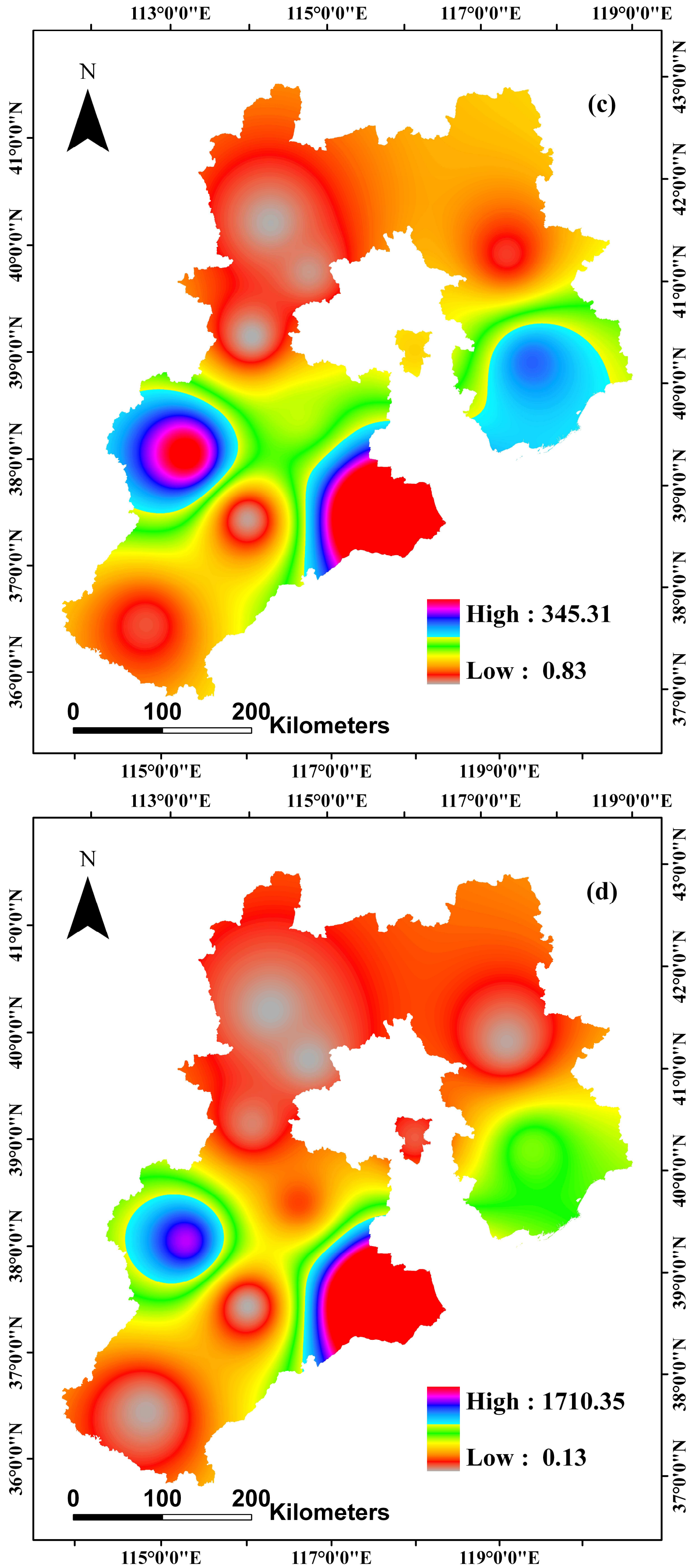

Fig. 10. Spatial distribution of monthly rainfall erosion force R based on inverse distance weighted interpolation method of GIS. (a):Z model; (b):L model; (c):F model; (d):W model

CONCLUSION

In this study, a comparative analysis of different algorithms for rainfall erosion force R based on GIS and the mathematical models, results indicated that different algorithms has important influence on the calculation results of rainfall erosion force R, the annual change in the maximum by Z model for 4810.12 $MJ \cdot mm/hm^2/h/a$, while the L model is the smallest, is 437 $MJ \cdot mm/hm^2/h/a$. In contrast, the monthly change of largest by Z models for 9096.67 $MJ \cdot mm/hm^2/h/a$, but the F model is the smallest of 493.27 $MJ \cdot mm/hm^2/h/a$.

Interpolation analysis of inverse distance weighted results show, spatial distribution of rainfall erosion force R was different by different algorithms. Rainfall erosion force R was 0.83-345.31 $MJ \cdot mm/hm^2/h/a$ by F model, rainfall erosion force R of western was bigger, while that of the northern and eastern southwest were smaller. Comparatively speaking, rainfall erosion force R for the 0-4341.92 $MJ \cdot mm/hm^2/h/a$ by Z model, which eastern was larger, while the north, northwest and southwest were smaller.

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