OFFSETTING THE INCREASE IN SOIL EROSION DUE TO RISING R-FACTORS BY DECREASING C-FACTORS OF BARE LANDS

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ABSTRACT: In the USLE (Universal Soil Loss Equation) model, soil erosion is controlled by the rainfall erosivity factor (R_m), the soil erodibility factor (K_m), the topographic factors (L and S), the cropping factor (C), and the conservation practice factor (P). Among the six factors, it is noted that the R_m factor was found increasing due to global climate change. To offset the increase in soil erosion associated with the R_m factor, we explored a possible option of reducing the C factors of bare lands in this study. The Shihmen reservoir watershed in northern Taiwan is used as the study area to estimate how much the C factor needs to be reduced and how much bare land needs to be vegetated to effectively offset the impact of the rising R_m factor.

1. INTRODUCTION

When using the Universal Soil Loss Equation (USLE) to analyze soil erosion, there are six factors, namely R_m, K_m, L, S, C, and P (to be explained below). Among them, R_m is the rainfall erosivity factor and is influenced heavily by the increase of rainfall brought by climate change. In this study, we used the researches conducted by different scholars in different periods to obtain the R_m values in order to observe their trend over time and analyze their changes. Since the cover and management factor (C) is the easiest factor to control and the most efficient tool to reduce soil erosion, we further examined the possibility of converting bare land to vegetated land to offset the influence of climate change and rainfall increase.

2. LITERATURE REVIEW

The Universal Soil Loss Equation is currently the most widely used method for estimating soil erosion. The equation was originally proposed by Wischmeier and Smith (1965) in the USDA Agricultural Handbook No. 282, and later revised and replaced by USDA Agricultural Handbook No. 537 (Wischmeier and Smith, 1978). Wischmeier and Smith (1978) used the multiplication of the rainfall and runoff factor (R_m), the soil erodibility factor (K_m), the slope length factor (L), the slope steepness factor (S), the cover and management factor (C), and the support practice factor (P) to estimate soil erosion. The formula is used to calculate the long-term average of sheet and rill erosion. It does not calculate the amounts of gully erosion and landslides, nor does it determine the distribution of sediment movement.

To understand the water erosion tendency, Liu et al. (2019) evaluated the vulnerability of global water erosion from 1982 to 2015 using the Revised USLE (RUSLE). They found that the vulnerability of worldwide water erosion worsened over 51% of the ground area, but greening provided by vegetation could partially compensate for the stress induced by climate change. Another study focusing on the long-term land use/land cover (LULC) change in Malaysia also concluded that vegetation cover protected the soil from the direct effect of rainfall and reduced soil loss to a minimum (Abdulkareem et al., 2019).

3. MATERIAL AND METHOD

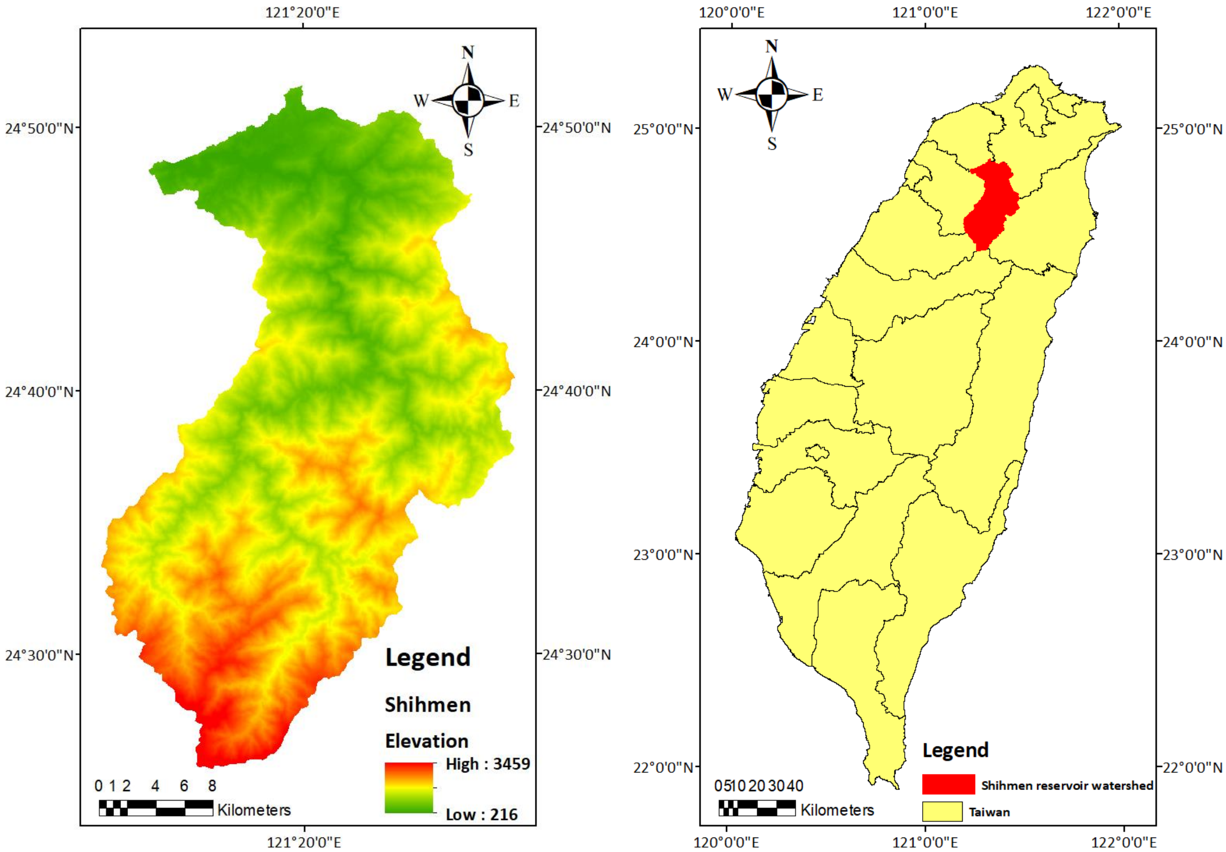
In this study, the Shihmen (Shimen) Reservoir watershed was selected as the research site (Figure 1). The watershed covers an area of 75,954 hectares with an annual rainfall of 2,500 mm. The altitude ranges from 216 meters to 3549 meters above sea level. The latitude and longitude lie between 121°10'15"-121°23'10" east longitude and 24°25'45"-24°51'30" north latitude.

The Digital Elevation Model (DEM) used in this study is the ASTER GDEM v2 released in 2011 with a resolution of 30 m. When we calculated the soil erosion by USLE, we used the ArcGIS Model Builder to compute the six erosion factors, and multiplied the six factors together to obtain the amount of soil erosion (in metric units). Among the six factors, the slope length factor (L) and the slope steepness factor (S) were calculated from the ASTER GDEM. The soil erodibility factor (K_m) was based on the study of Jhan (2014) but with a different interpolation method (Kriging). The support practice factor (P) was assumed to be 1.

The remaining two factors (R_m and C) are the focus of this study. The R_m factors were calculated using the results obtained by different scholars (Huang, 1979; Lu et al., 2005; Liu, 2019), whereas the C factors were based on a revision of the classification table originally proposed by Jhan (2014). Since this study only focused on the influence of R_m and C factors on soil erosion, the rest of the factors were kept constant when we calculated the amount of soil erosion. Figure 2 shows the distribution of K_m, L, S, and C factors in the watershed.

The change of C factor is related to vegetation cover. Although most of the Shimen reservoir watershed is forested, some areas are still lacking such a protection. According to the classification of the National Land Surveying and Mapping Center (Taiwan), there are three types of bare land in the Shihmen reservoir watershed: vacant land, collapsed area, and rock outcrop. Table 1 shows the total areas of the three types of land in the study area. We revised the C factor classification table (Jhan, 2014), and changed the C values of vacant land and collapsed land to 1 and rock outcrop to 0.01.

Following the natural succession process, bare lands tend to be colonized by pioneer species such as grasses quickly. Therefore, in our simulation we converted vacant land to grassland (C value = 0.03) first in order to reduce the C factor. After conversion, the new C factor and the amount of soil erosion were calculated to see if the reduction in C factor would be enough to offset the influence of R_m. If it was not enough, collapsed area would be converted to grassland next. The goal was to determine if there was sufficient land to be vegetated to compensate the negative influence of R_m.



(a) (b)

Figure 1 The (a) DEM and (b) geographical location of the Shihmen reservoir watershed

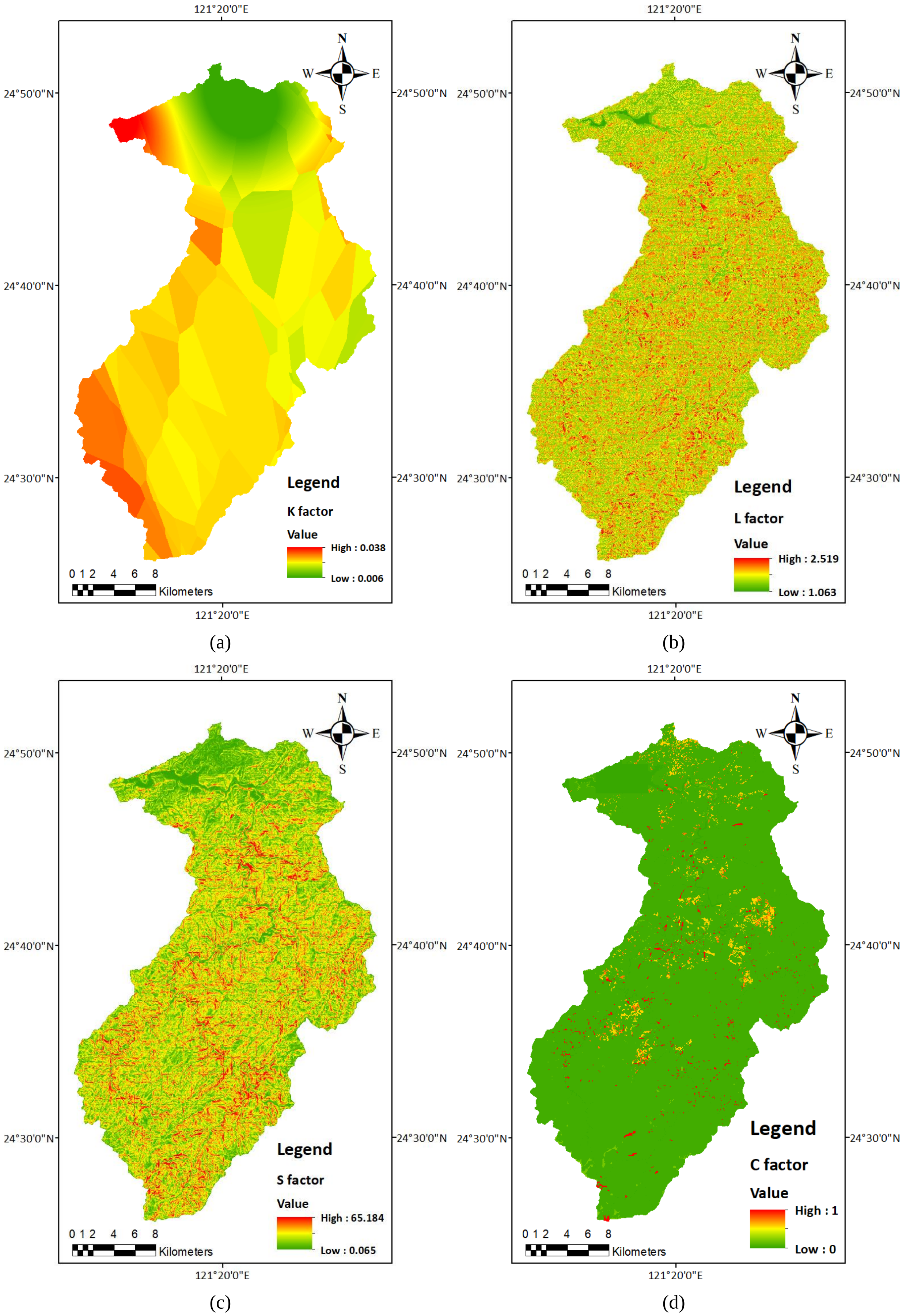


Figure 2 The maps of soil erosion factors of the Shihmen reservoir watershed: (a) K_m factor, (b) L factor, (c) S factor, and (d) C factor

Table 1 The statistics of bare lands

Type	Code	C value	Area (ha)	Total (ha)
Collapsed area	90402	1	705.10	765.79
Vacant land	90404	1	60.69	
Rock outcrop	90403	0.01	86.09	86.09

4. RESULTS

The average R_m factor of the Shihmen reservoir watershed was calculated by the Kriging interpolation method to be 14371.56 MJ-mm/ha/hr/year and 13458.35 MJ-mm/ha/hr/year according to the data from Huang (1979) and Lu et al. (2005), respectively. Liu (2019) used the data of Su et al. (2016) to calculate the average R_m factor of the watershed and obtained a value of 16678.16 MJ-mm/ha/hr/year. The results are summarized in Table 2 and Figure 3. As can be seen from Figure 3, a slight decrease followed by an increase in the average R_m factor is observed.

Table 2 The average R_m factors and amounts of soil erosion based on different data sets

	Data period	Average R_m factor (MJ-mm/ha/hr/year)	Average C factor	Average soil erosion (t/ha/year)
Interpolated by Kriging using R_m data from Huang (1979)	1935 - 1976	14371.56	0.0240	224.21
Interpolated by Kriging using R_m data from Lu et al. (2005)	1975 - 2000	13458.35	0.0240	207.86
Computed by Liu (2019) using data from Su et al. (2016)	2010 - 2018	16678.16	0.0240	255.24

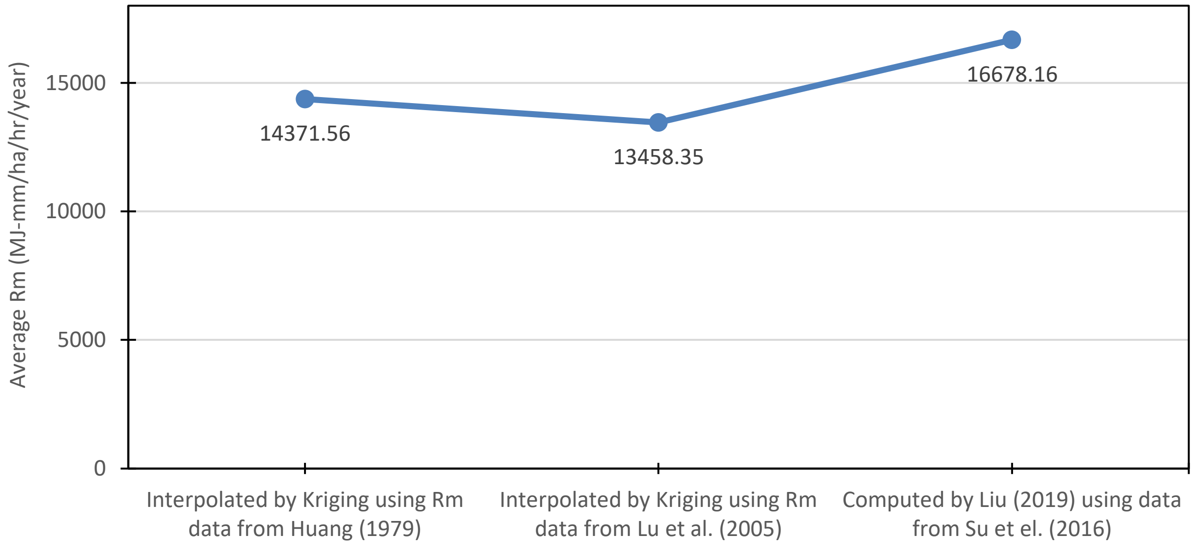
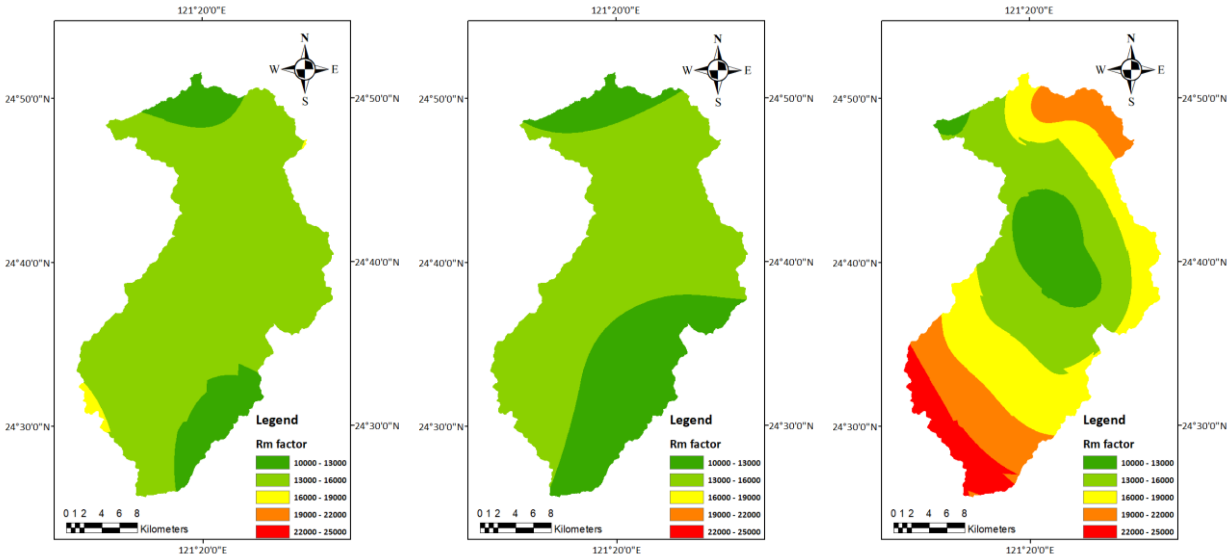


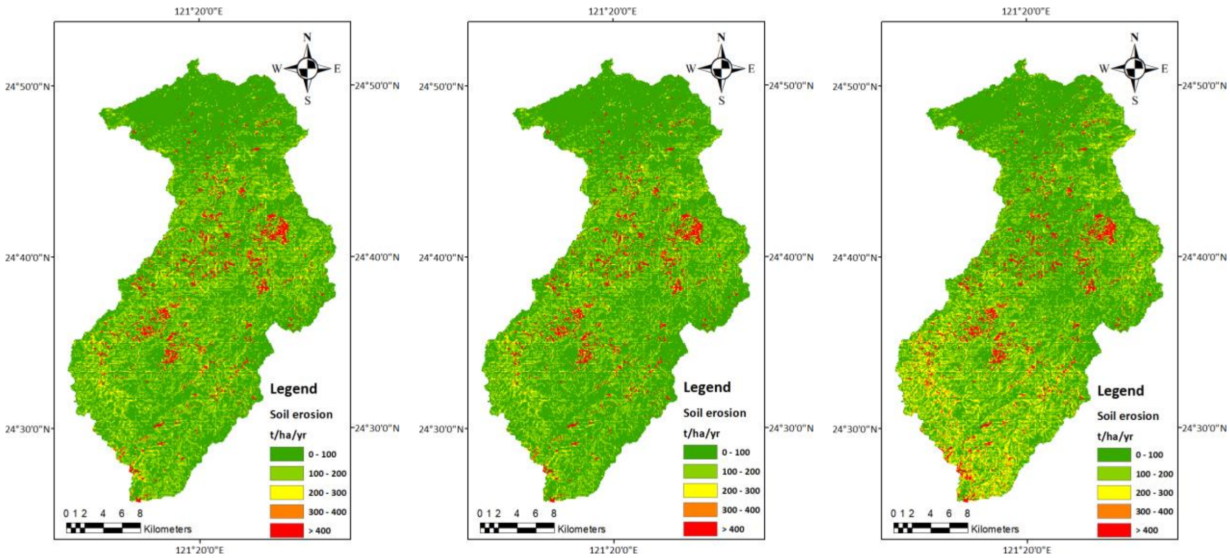
Figure 3 Changes in the average R_m values

The R_m distribution maps of the study area were also created using three references (Huang, 1979; Lu et al., 2005; Liu, 2019). They are shown in Figure 4. The resulting distribution maps of soil erosion are shown in Figure 5. It can be seen that when the average R_m factor is 14371.56 MJ-mm/ha/hr/year, the average amount of soil erosion is 224.21 t/ha/year. When the average R_m factor is 13458.35 MJ-mm/ha/hr/year, the average amount of soil erosion is 207.86 t/ha/year. Lastly, when the average R_m factor is 16678.16 MJ-mm/ha/hr/year, the average amount of soil erosion is 255.24 t/ha/year. It is worth noting that this is only a scenario simulation. Since the C factor classification table was changed to test different situations, the calculated amounts of soil erosion might not represent the true values under real conditions.



(a) (b) (c)

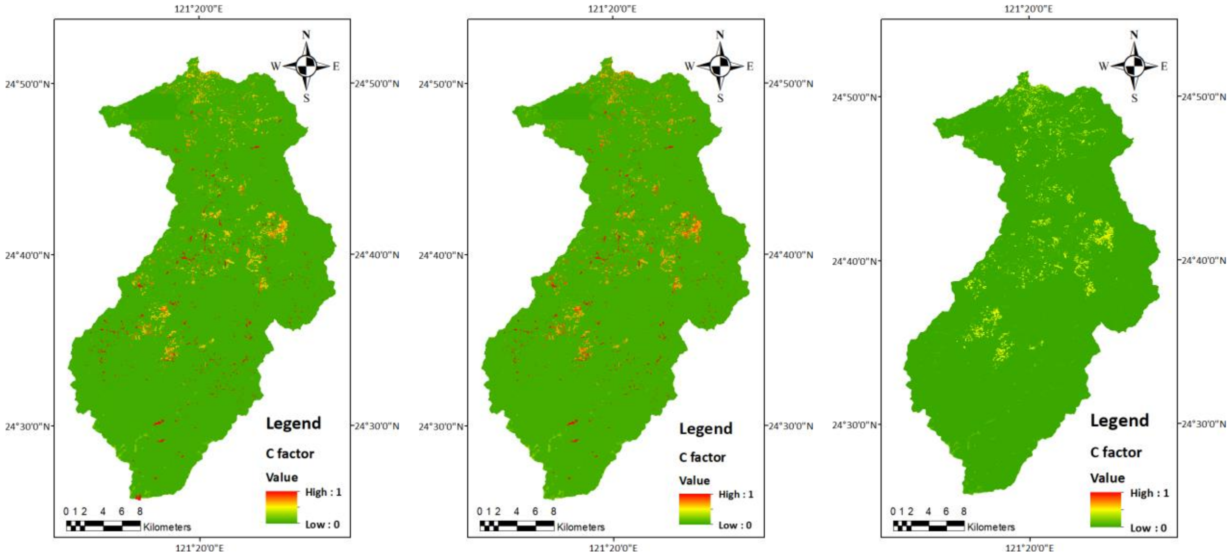
Figure 4 The distribution of R_m factors based on different data sets: (a) interpolated by Kriging using R_m data from Huang (1979), (b) interpolated by Kriging using R_m data from Lu et al. (2005), and (c) computed by Liu (2019) using data from Su et al. (2016)



(a) (b) (c)

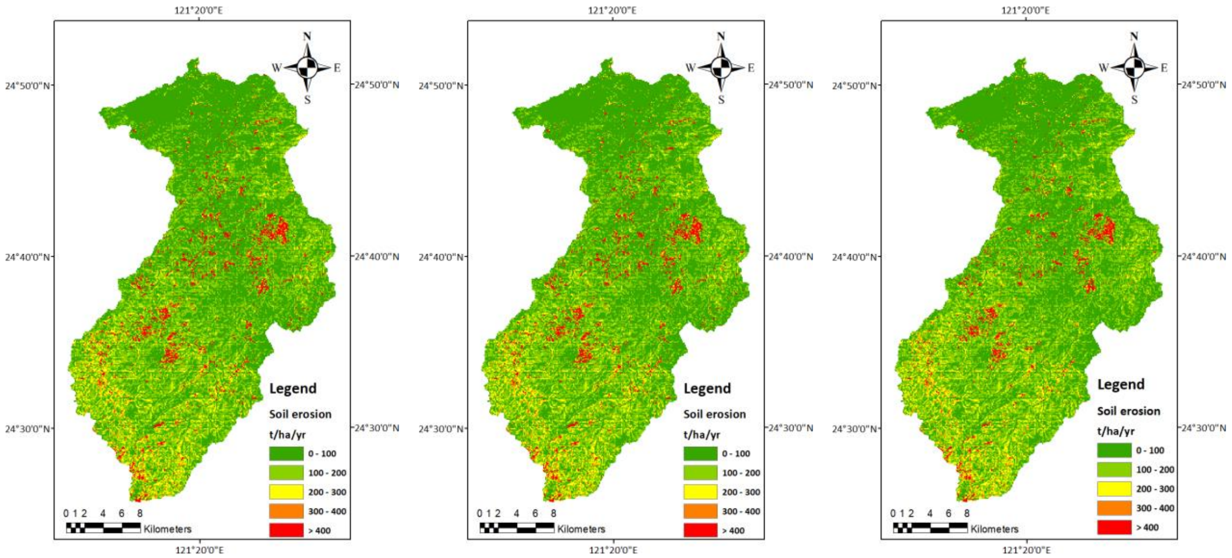
Figure 5 The soil erosion maps based on different R_m data sets: (a) interpolated by Kriging using R_m data from Huang (1979), (b) interpolated by Kriging using R_m data from Lu et al. (2005), and (c) computed by Liu (2019) using data from Su et al. (2016)

Assuming that a trend exists and it will bring the average R_m factor from 14371.56 MJ-mm/ha/hr/year to 16678.16 MJ-mm/ha/hr/year, our goal is to find out if there is enough bare land to be vegetated to offset the negative impact of the rising R_m factor. Because it takes a considerably long time to forest a bare land, it is more realistic to convert the bare land to grassland in our simulation. First, we only converted the vacant land, and the average C factor dropped to 0.0232. The average soil erosion also decreased from 255.24 t/ha/year to 247.40 t/ha/year, but it was not enough. Then, we also converted all the collapsed area to grassland. The average C factor fell to 0.0145, and the average soil erosion decreased by 48.66% to 124.19 t/ha/year, which was more than needed to offset the rising R_m factor. Finally, through trial and error, it was found that when 100% of the vacant land and 21.7% of the collapsed area were vegetated, the result was just the needed amount to bring soil erosion back to the same level. The distribution of C factors of these three scenarios are shown in Figure 6, and the corresponding soil erosion maps are shown in Figure 7. Table 3 gives more details of the numbers computed.



(a) (b) (c)

Figure 6 The distribution of C factors under different scenarios: (a) 100% of vacant land vegetated, (b) 100% of vacant land and 21.7% of collapsed area vegetated, and (c) 100% of vacant land and collapsed area vegetated



(a) (b) (c)

Figure 7 The soil erosion maps under different scenarios: (a) 100% of vacant land vegetated, (b) 100% of vacant land and 21.7% of collapsed area vegetated, and (c) 100% of vacant land and collapsed area vegetated

Table 3 The average amounts of soil erosion under different scenarios

	Average R_m factor (MJ-mm/ha/hr/year)	Average C factor	Average soil erosion (t/ha/year)
Interpolated by Kriging using R_m data from Huang (1979)	14371.56	0.0240	224.21
Computed by Liu (2019) using data from Su et al. (2016)	16678.16	0.0240	255.24
100% of vacant land vegetated	16678.16	0.0232	247.40
100% of vacant land and 21.7% of collapsed area vegetated	16678.16	0.0215	224.21
100% of vacant land and collapsed area vegetated	16678.16	0.0145	124.19

5. DISCUSSION AND CONCLUSIONS

This study calculated the R_m factor of the Shihmen reservoir watershed using data from different studies. The results show that there is a possible trend of increasing R_m after a temporary decrease. In order to reduce the impact of R_m rise, we reduced the C factor by converting bare land to grassland in our simulation. The results show that it is possible to completely offset the negative influence of rising R_m. To achieve this goal, approximately 213.79 hectares of bare land (including 60.69 hectares of vacant land and 153.10 of collapsed area) need to be vegetated.

Acknowledgements

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