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A comparison between soil loss evaluation index and the C-factor of RUSLE: a case study in the Loess Plateau of China

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Abstract. Land use and land cover are most important in quantifying soil erosion. Based on the C-factor of the popular soil erosion model, Revised Universal Soil Loss Equation (RUSLE) and a scale-pattern-process theory in landscape ecology, we proposed a multi-scale soil loss evaluation index (SL) to evaluate the effects of land use patterns on soil erosion. We examined the advantages and shortcomings of SL for small watershed (SL_{sw}) by comparing to the C-factor used in RUSLE. We used the Yanhe watershed located on China's Loess Plateau as a case study to demonstrate the utilities of SL_{sw}. The SL_{sw} calculation involves the delineations of the drainage network and sub-watershed boundaries, the calculations of soil loss horizontal distance index, the soil loss vertical distance index, slope steepness, rainfall-runoff erosivity, soil erodibility, and cover and management practice. We used several extensions within the geographic information system (GIS), and AVSWAT2000 hydrological model to derive all the required GIS layers. We compared the SL_{sw} with the C-factor to identify spatial patterns to understand the causes for the differences. The SL_{sw} values for the Yanhe watershed are in the range of 0.15 to 0.45, and there are 593 sub-watersheds with SL_{sw} values that are lower than the C-factor values (LOW) and 227 sub-watersheds with SL_{sw} values higher than the C-factor values (HIGH). The HIGH area have greater rainfall-runoff erosivity than LOW area for all land use types. The cultivated land is located on the steeper slope or is closer to the drainage network in the horizontal direction in HIGH area in comparison to LOW area. The results imply that SL_{sw} can be used to identify the effect of land use distribution on soil loss, whereas the C-factor has less power to do it. Both HIGH and LOW areas have similar soil erodibility values for all land use types. The average vertical distances of forest land and sparse forest land to the drainage network are shorter in LOW area than that in HIGH area. Other land use types have shorter average vertical distances in HIGH area than that LOW area. SL_{sw} has advantages over C-factor in its ability to specify the subwatersheds that require the land use patterns optimization by adjusting the locations of land uses to minimize soil loss.

1 Introduction

Soil erosion is a common cause of soil deterioration around the world and has been accelerated by improper land use practices over the last several decades (Stanley and Pierre, 2000; Vannière et al., 2003; Piccarreta et al., 2006; Szilassi et al., 2006; Feng et al., 2010). To understand the effects of land use on soil erosion, much effort has been devoted to understanding the relationship between land use and soil erosion at the slope, small watershed, basin, and regional scales (Smithson, 2000; Zhao et al., 2006; Leys et al., 2010; Zokaib and Naser, 2011). The land cover and management factor (C) used by the Revised Universal Soil Loss Equation (RUSLE) reflects the effects of cropping and management practices on soil loss rates (Renard et al., 1997; Millward and Mersey, 1999; Navas, 2009). For comparing the relative impacts of management options of conservation plans, the C-factor indicates how land uses affect the average annual soil loss. However, it is not only the land use type that can have effects on

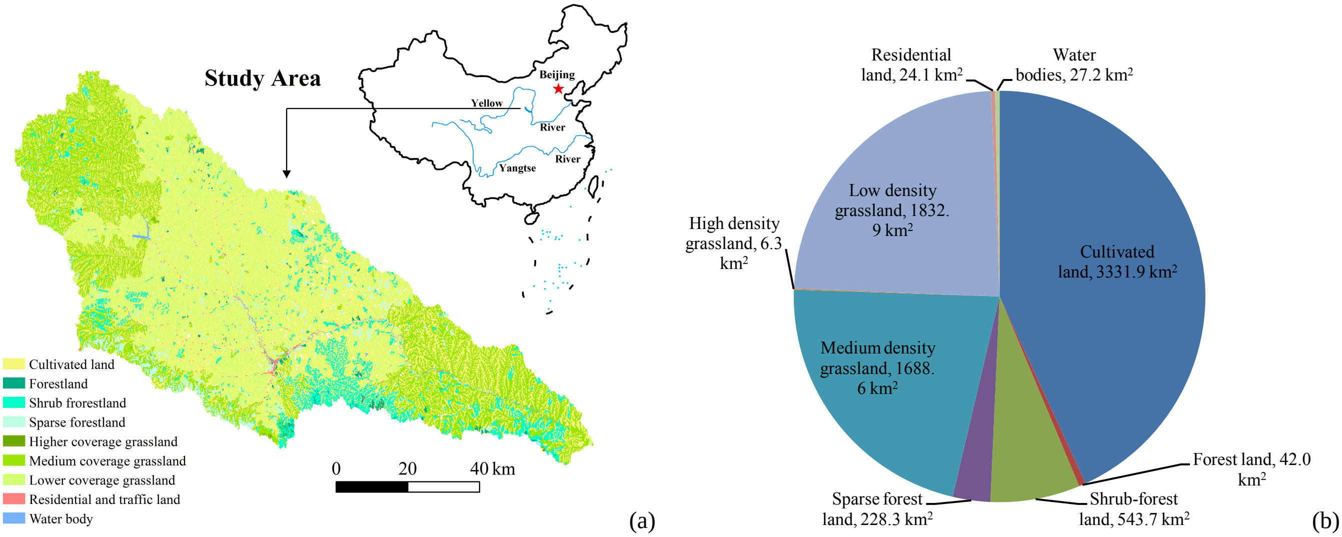

Fig. 1. **(a)** The location and land use of the study area. **(b)** Land use compositions of Yanhe watershed.

soil loss but also the location of the land use type (Bakker et al., 2008; Chen et al., 2008; Ouyang et al., 2010). At the slope scale, for a given type of land use, the steeper the corresponding slope and the nearer it is from the slope base, the greater the contributions that piece of land will make to soil erosion and the sediments that flow off of the slope. At the watershed scale, when a certain type of land use has a steeper slope and is closer to the drainage network, that piece of land will make greater contributions to the sediment output of the watershed (Fu et al., 2006). The spatial distribution pattern of land use can exert an important influence on soil loss processes at different scales. It is important to quantify the effects of land use patterns on soil erosion to develop effective soil erosion control through orientated spatial planning of land use.

Fu et al. (2006) proposed a multi-scale soil loss evaluation index (expressed as SL), which reflects the effects of spatial land use patterns on soil erosion. This index is based on the C-factor of RUSLE and a scale-pattern-process theory in landscape ecology. To reflect the spatial distribution of land use type, other relative factors are also considered (Fu et al., 2006). SL can evaluate the influence of land use patterns on soil erosion and help identify the key areas where the land use pattern needs to be optimized.

SL uses different equations with different factors at the slope, small watershed, and watershed scales. These values are expressed as SL_s (slope scale), SL_{sw} (small watershed scale), and SL_w (the large watershed scale). Among the different scales, SL_{sw} is a middle link between the slope scale and the watershed scale and serves as a connection within the SL. The SL development yields questions about the use of the index for further study: (1) how does one calculate the factors for the index and use it at different scales and (2) what is the difference between using the SL and the C-factor of RUSLE?

The Loess Plateau of China has one of the highest erosion rates in the world, approximately 5000–10 000 Mg km^{-2} per year in most areas (Chen et al., 2001). There are several reasons for these very high erosion rates. Improper land use by humans is a key factor. Through altering the natural vegetation cover, soil properties, and surface hydrologic processes, land use affects the occurrence and development of soil erosion. To understand the complex relationship between land use and soil erosion, we previously applied the RUSLE to the Yanhe watershed on the Loess Plateau in China (Fu et al., 2005). In the present study, we used the same watershed as a case study to further examine the use of SL_{sw} in quantifying the effects of spatial patterns of land use on soil erosion to provide guidance to land use planning. The specific objectives are (1) to examine the spatial distribution of SL_{sw} and its controlling factors, and (2) to compare the SL_{sw} with the C-factor of the RUSLE.

2 Materials and methods

2.1 Study area

The study area (7725 km^2) is the Yanhe watershed (108°38′–110°29′ E, 36°21′–37°19′ N), which lies in the middle part of the Loess Plateau in northern Shaanxi Province, China (Fig. 1a). The elevation of this area varies from 495 to 1795 m. The region has a semi-arid continental climate, with an annual average precipitation of 520 mm. The rainfall in July, August, and September accounts for 60–70 % of the total annual precipitation and markedly affects runoff and soil erosion. The most common soil in the watershed is loess, a fine silt soil, which is prone to soil erosion. Land use in this watershed comprises of cultivated land, forest land, sparse forest land, shrub-forest land, high density grassland, medium density grassland, low density grassland, residential land, and water bodies. Cultivated land, low density grassland, and medium density grassland are the main land use types for the study area (Fig. 1b).

2.2 Soil loss evaluation index at the small watershed scale ($\mathrm{SL}_{\mathrm{sw}}$)

The equation for the $\mathrm{SL}_{\mathrm{sw}}$ is expressed (Fu et al., 2006):

$$\mathrm{SL}_{\mathrm{sw}} = \sum (D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m) / \sum (D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m), \quad (1)$$

where $\mathrm{SL}_{\mathrm{sw}}$ is called soil loss evaluation index for small watershed, D_m is the soil loss horizontal distance index, H_m is the soil loss vertical distance index, S_m is the slope steepness factor, R_m is the rainfall-runoff erosivity factor, K_m is the soil erodibility factor, and C_m is the cover and management practices factor used in RUSEL. $D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m$ and $D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m$ refer to the products of these map layers, and $\sum (D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m)$ and $\sum (D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m)$ are the spatial sums of the map layers after the multiplication.

The $\mathrm{SL}_{\mathrm{sw}}$ is a dimensionless index with values ranging between 0 and 1. A larger $\mathrm{SL}_{\mathrm{sw}}$ shows that the land use pattern is more indicative of soil loss, while a smaller $\mathrm{SL}_{\mathrm{sw}}$ indicates that the land use pattern is more capable of controlling soil loss. Before we could calculate the factors used in the equation for the study area, the Yanhe watershed was divided into 820 sub-watersheds to provide the basic unit for the $\mathrm{SL}_{\mathrm{sw}}$ calculation.

2.2.1 Sub-watersheds and the drainage network

The procedure for delineating the sub-watersheds is to divide the entire watershed into many small watersheds to provide the basic unit for calculating $\mathrm{SL}_{\mathrm{sw}}$. Delineating the drainage network is the starting point for conducting the soil loss distance analysis.

The vector map of the sub-watersheds and the drainage network in the Yanhe watershed were extracted from a DEM using the AVSWAT2000 tool (Di Luzio et al., 2002) and the Spatial Analyst (version 1.1 or later) extension in ArcView. The DEM dataset for the Yanhe watershed was derived from a 1:50 000-scale contour map with a 25-m cell size.

2.2.2 Horizontal distance index (D)

The farther the land use type is located from the drainage network, the smaller the contribution of its soil loss to the river sediment yield. The soil loss horizontal distance index is used to reflect the effects of the horizontal distance (from the stream to a point within the watershed), and its equation is

$$D_i = (D_{\max} - d_i) \big/ D_{\max}, \quad (2)$$

where D_i is the soil loss horizontal distance index of the i point in the small watershed, $D_{\max}$ is the maximum soil loss horizontal distance for the study area, and d_i is the soil loss horizontal distance of a certain point in the small watershed. D_i is between 0 and 1. The larger the D_i is, the closer the drainage network will be to the said land use type in the level direction and the more it will contribute to the yielded soil loss in the stream. Using Eq. (2), the spatial distribution map of the horizontal distance index can be produced by calculating the straight-line distance in geographic information system (GIS).

2.2.3 Vertical distance index

Corresponding to the soil loss horizontal distance index, the soil loss vertical distance index is designed to reflect the effects of the vertical direction distance, and its equation is

$$H_i = (H_{\max} - h_i) \big/ H_{\max}, \quad (3)$$

where H_i is the soil loss vertical distance index of a certain point in the small watershed, $H_{\max}$ is the maximum soil loss vertical distance for the study area, and h_i is the soil loss vertical distance of a certain point in the small watershed. H_i is between 0 and 1. The larger the H_i is, the closer that the drainage network will be to the land use type in the vertical direction and the more that it will contribute to the yielded soil loss in the stream.

Using Eq. (3), the spatial distribution map of the vertical distance index was calculated using the DEM data and the elevation of the drainage network. Because the elevation of the drainage network changes from upstream to downstream in the Yanhe River, the elevation of the drainage network was produced using the raster calculator in GIS, and the river elevation was expanded to encompass the full extent of the study area by using the expanding function in GIS.

2.2.4 The C-factor for the Yanhe watershed

There are nine land use types in the Yanhe watershed. The C-factor values of different land use types can be obtained by the following methods. For cultivated land, an upscaling method was used to calculate the C-factor values. For the other land use types, the C-factor values were adopted based on the literature (Wang and Jiao, 1996).

The C-factor values for cultivated land are calculated by the following equation:

$$C = \sum_{i=1}^{n} \mathrm{RSLR}_i \cdot \mathrm{SDRE}_i \Big/ \sum_{i=1}^{n} \mathrm{SDRE}_i \quad (4)$$

where RSLR_i is the regional soil loss rate in different months and SDRE_i is the spatial distribution of rainfall-runoff erosivity in different months. Further details can be found in the paper by Fu et al. (2005).

2.2.5 Other factors associated with the $\mathrm{SL_{sw}}$

Based on the fundamental equations derived from the RUSLE, the remaining three factors at the watershed scale were measured using GIS (Fu et al., 2005).

The R-factor map layer of the Yanhe watershed was created using a Kriging interpolation in GIS, and the R-factor values for rain gauges were calculated with the following equation:

$$R = 8.35 \cdot \mathrm{rain}_9^{1.26}, \tag{5}$$

where R is the rainfall-runoff erosivity factor, and rain_9 is the total monthly rainfall for days with ≥ 9.0 mm.

The K-factor is the rate of soil loss per rainfall erosion index unit as measured on a unit plot, and the value of the K-factor was calculated using the following equation (Renard et al., 1997; Liu et al., 2001):

$$K = 7.594 \left\{ 0.0034 + 0.405 \exp\left[-\frac{1}{2} \left[\frac{\log(\mathrm{Dg}) + 1.659}{0.7101} \right]^2 \right] \right\}, \tag{6}$$

where $\mathrm{Dg} = \exp(0.01 \sum f_i \ln m_i)$, and Dg = geometric mean particle diameter. In this equation, f_i is the primary particle size fraction, expressed as a percentage, and m_i is the arithmetic mean of the particle size limits of that size.

The hillslope steepness of the Yanhe watershed is estimated using the ARC Macro Language (AML) program, which is developed by Van Remortel et al. (2001). After deriving slope steepness, the S-factor layer is calculated using the following equations:

$$\begin{cases} S = 10.8 \cdot \sin\left(\mathrm{slope_{angle}}\right) + 0.03 \cdot \mathrm{slope_{angle}} < 9\% \\ S = 16.8 \cdot \sin\left(\mathrm{slope_{angle}}\right) - 0.50 \cdot \mathrm{slope_{angle}} \geq 9\% \end{cases} \tag{7}$$

where S is the slope steepness factor and $\mathrm{slope_{angle}}$ is the slope steepness.

2.2.6 Calculation of the $\mathrm{SL_{sw}}$

After the index and factor maps are derived, the $\mathrm{SL_{sw}}$ was calculated for each sub-watersheds in the Yanhe watershed. In Eq. (1), $D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m$ and $D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m$ were calculated using the raster calculator function in the GIS. The two values of $\sum(D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m)$ and $\sum(D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m)$ were accounted for in each sub-watershed using the zonal function in the GIS.

2.3 Comparison of $\mathrm{SL_{sw}}$ with the C-factor of RUSLE

After calculating the C-factor and $\mathrm{SL_{sw}}$ for the Yanhe watershed, the spatial differences were compared. Because the C-factor and $\mathrm{SL_{sw}}$ use a grid cell format and we used the sub-watershed as the evaluation unit, C-factor map in grid format was scaled to the sub-watershed scale.

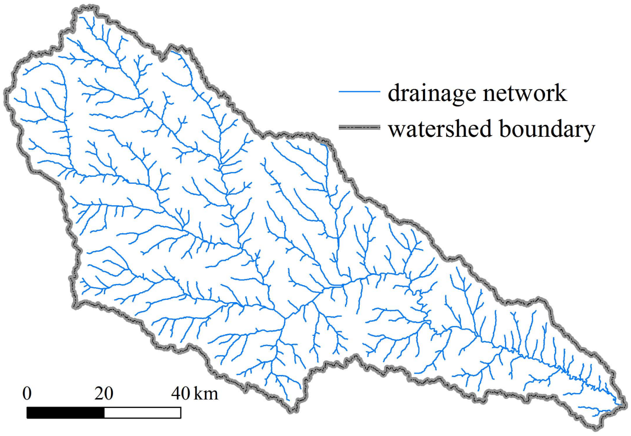

Fig. 2. Spatial distribution of the drainage network in the Yanhe watershed.

3 Results and discussion

3.1 Application of the $\mathrm{SL_{sw}}$ to the Yanhe watershed

3.1.1 Drainage network and sub-watershed map layer

The sub-watershed is the basic unit used to examine soil erosion patterns in the Loess Plateau. Using AVSWAT2000, the drainage network (Fig. 2) and sub-watersheds (Fig. 3) can be delineated from the DEM by these steps: (1) load the DEM grid of the study area and edit the DEM map properties regarding the vertical and horizontal units; (2) import or create a grid map that masks part of the Yanhe watershed; (3) remove sinks in the DEM; (4) set the threshold area for stream definition; (5) define the outlet and select the main watershed outlets; and (6) determine the drainage network and sub-watersheds. During the procedure, the threshold area plays an important role in determining the detail of the stream network, and its value was set as 5 $\mathrm{km^2}$ for the study watershed.

The entire Yanhe watershed was divided into 820 sub-watersheds (Fig. 3), which were used as the basic unit with which to calculate the $\mathrm{SL_{sw}}$. The watershed size ranges from 0.1 $\mathrm{km^2}$ to 58.4 $\mathrm{km^2}$, with a mean of the sub-watersheds was 9.42 $\mathrm{km^2}$.

3.1.2 Soil loss horizontal distance index map layer (D_m)

The soil loss horizontal distance index is designed to reflect the effects of the level distance to the drainage network. Using the drainage network map of the Yanhe watershed and the straight-line distance function in GIS, the distances from each cell in the Yanhe watershed to the closest drainage network were identified. Based on Eq. (2) and the raster calculator in GIS, the spatial distribution map of the soil loss horizontal distance index was produced by performing the mathematical calculation using arithmetic operators (Fig. 4). As seen in Fig. 4, the values of the soil loss horizontal distance

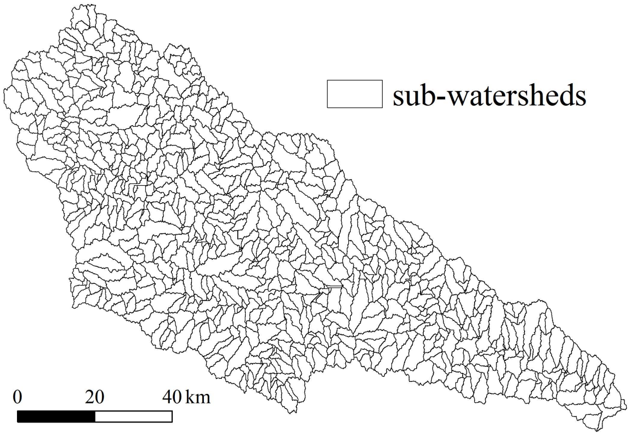

Fig. 3. Spatial distribution of the sub-watersheds in the Yanhe watershed.

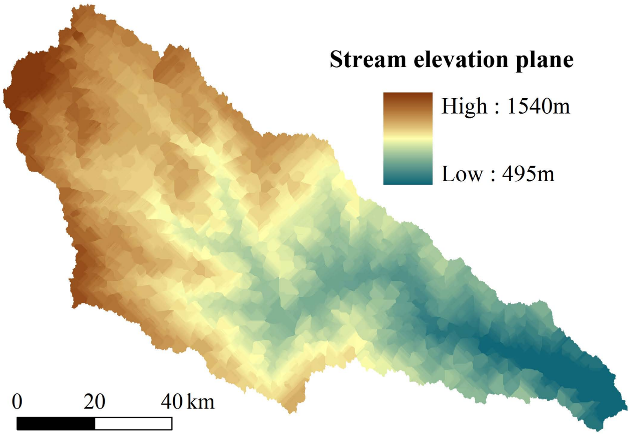

Fig. 5. Spatial distribution of the stream elevation plane in the Yanhe watershed.

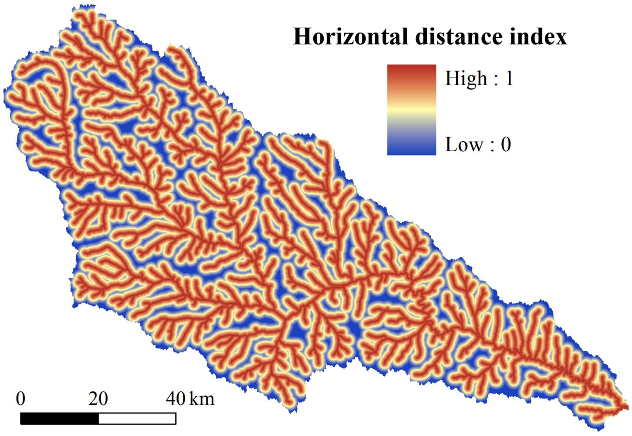

Fig. 4. Spatial distribution of the soil loss horizontal distance index values in the Yanhe watershed.

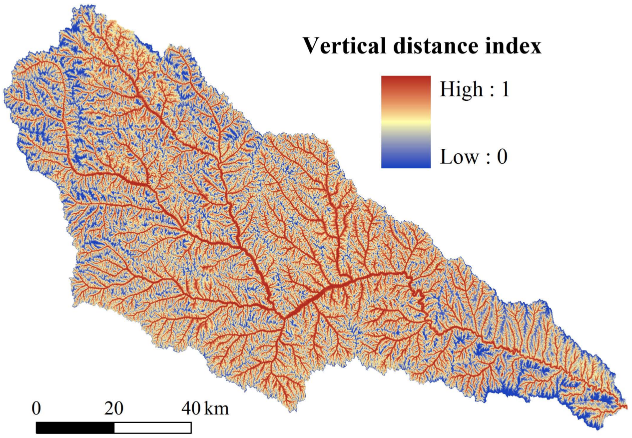

Fig. 6. Spatial distribution of the soil loss vertical distance index values in the Yanhe watershed.

index were higher along the water systems and lower at locations that were far from the stream.

3.1.3 Soil loss vertical distance index map layer (H_m)

The soil loss vertical distance index is designed to reflect the effects of the vertical distance to the drainage network on soil loss. Because the drainage network elevation changes from upstream to downstream, it is necessary to identify the elevation and elevation plane of the stream throughout the entire watershed. This information will provide the foundation for calculating the soil loss vertical distance index.

The elevation map of the drainage network in the Yanhe watershed was obtained by overlaying the stream grid and the DEM data. The elevation plane map of the stream in the Yanhe watershed was produced by using the expanding function in GIS (Fig. 5). Before expanding the stream elevation, the elevation map of the stream should be converted into an integer grid, and the maximum value of the expanding zone is set to encompass the full extent of the Yanhe watershed. As shown in Fig. 5, the stream elevation plane changes from one place to another, with a maximum of 1540 m and a minimum of 495 m.

The value of the soil loss vertical distance equals the DEM in the Yanhe watershed minus the elevation plane of the stream. Using Eq. (3), the soil loss vertical distance index can be calculated by arithmetic operators in the raster calculator function (Fig. 6). The higher values of the soil loss vertical distance index occurred primarily near the stream, and the lower values occurred in the high altitude areas.

3.1.4 Map layers for other factors (R_m, S_m, K_m, C_m)

To calculate the $\mathrm{SL}_{\mathrm{sw}}$, there are four additional map layers that need to be created: the rainfall-runoff erosivity factor map layer (R_m), the slope steepness factor map layer (S_m), the soil erodibility factor map layer (K_m), and the cover and management practices map layer (C_m). Based on the Eq. (4)

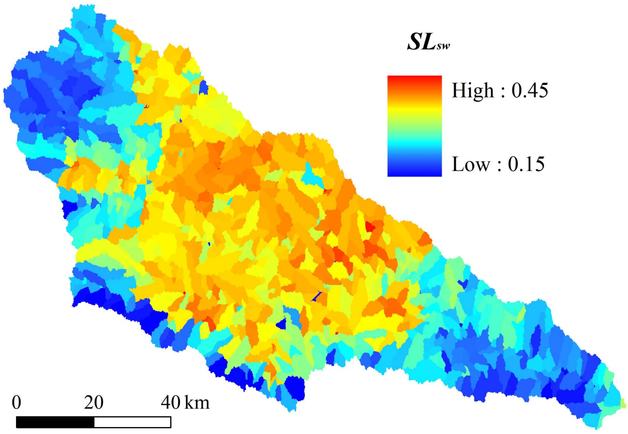

Fig. 7. Spatial distribution of the SL_{sw} values in the Yanhe watershed.

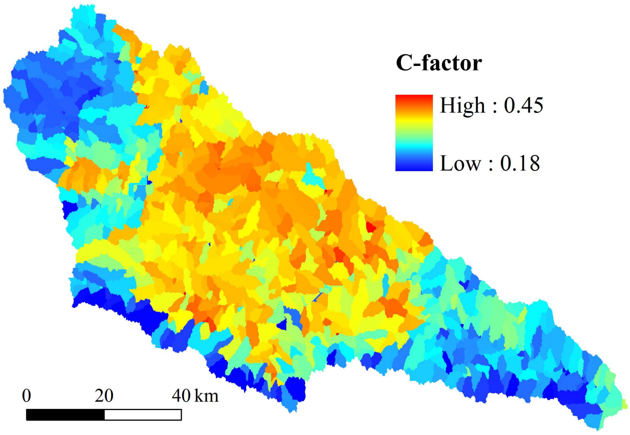

Fig. 8. Spatial distribution of the C-factor values for the sub-watersheds in the Yanhe watershed.

and the relative equations from the RUSLE, the four map layers were created using GIS. As for the detailed procedure, it can be found in the paper by Fu et al. (2005).

3.1.5 The SL_{sw} value map in the Yanhe watershed

Based on the map layers needed for Eq. (1), SL_{sw} value for each sub-watershed can be calculated using the raster calculator in the GIS. As seen in Fig. 7, the values of the SL_{sw} in the Yanhe watershed are in the range of 0.15 to 0.45, with a mean of 0.33. The area which has a high SL_{sw} value is primarily in the middle part of the Yanhe watershed.

3.2 Comparison of SL_{sw} and the C-factor

3.2.1 The C-factor for the Yanhe watershed

After calculating the R-factor and the regional soil loss rate of cultivated land in different months, the spatial distribution map of the C-factor values in the Yanhe watershed can be created at the grid-cell scale based on Eq. (4) (Fu et al., 2005). The evaluation unit for the SL_{sw} was the small watershed (the sub-watershed derived from the DEM; see Fig. 3). To compare the results of the SL_{sw} and the C-factor, the sub-watershed map of the Yanhe watershed was used to unify the evaluation units, and a spatial distribution map of the C-factor value for the sub-watersheds in the Yanhe watershed was produced with help of ArcGIS Spatial Analyst tools (Fig. 8, derived from Fu et al., 2005). The value of the C-factor value in the Yanhe watershed is within the range of 0.18 to 0.45, with a mean of 0.34.

3.2.2 Comparison between SL_{sw} and the C-factor

It appears that the SL_{sw} and C-factor values have a close relationship in general (Figs. 7 and 8). The area with a high SL_{sw} value may have a high C-factor value for many sub-watersheds. The differences between the SL_{sw} and C-factor values can be seen in Fig. 9. There are 593 sub-watersheds with SL_{sw} values that are less than the C-factor values (denoted as LOW), which are primarily located in the southeastern and northwestern parts of the Yanhe watershed, with the area of 5748.2 km^2. Most of the differences are between 0 and −0.02, and the minimum difference is −0.097. In terms of sub-watersheds with SL_{sw} values higher than the C-factor values (denoted as HIGH), there are 227 sub-watersheds, which are primarily located in the middle parts of the Yanhe watershed, with the area of 1976.8 km^2. Most of the differences are less than 0.02, and the maximum difference is 0.092.

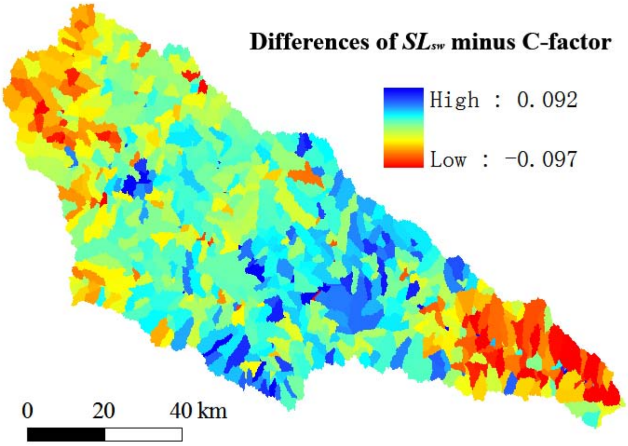

Fig. 9. Spatial distribution of the differences (SL_{sw} minus C-factor) for the sub-watersheds in the Yanhe watershed.

3.2.3 The spatial distribution differences of land use for HIGH and LOW areas

The HIGH and LOW areas are clustered in the study watershed (Fig. 9). The range difference as expressed as the SL_{sw} values minus the C-factor values for the two areas are 0.00,

Table 1. The spatial distribution data of different land use types for the Yanhe watershed.

	Areas*	Cultivated land	Forest land	Sparse forest land	Shrub-forest land	High density grassland	Medium density grassland	Low density grassland	Residential land
The area percentage of different land use types (%)	HIGH	44.5	0.9	5.6	8.4	0.1	10.4	28.8	0.4
	LOW	42.6	0.4	2.1	6.6	0.1	25.6	22.1	0.3
Mean rainfall-runoff erosivity (10^2 MJ km^{-2} h^{-1} a^{-1})	HIGH	10 176	10 351	10 747	10 323	10 994	10 335	10 256	10 766
	LOW	9557	9948	10 295	10 012	10 211	9001	9786	10 403
Mean soil erodibility (10^{-1} Mg h MJ^{-1} mm^{-1})	HIGH	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	LOW	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
Mean slope steepness (%)	HIGH	22.6	24.4	23.8	24.0	22.3	23.6	23.7	9.6
	LOW	21.9	25.6	24.2	25.3	23.3	25.1	24.6	13.6
Mean horizontal distance to drainage network (m)	HIGH	969	1680	1359	1228	1895	1086	984	349
	LOW	998	1043	957	1137	1195	904	984	317
Mean vertical distance to drainage network (m)	HIGH	114.3	137.9	104.9	91.9	105.1	92.8	82.7	20.1
	LOW	132.8	115.2	100.9	113.2	140.6	100.8	97.1	28.9

* HIGH area is the area where the SL_{sw} values are higher than the C-factor values; LOW area is the area where the SL_{sw} values are less than the C-factor values.

0.10 and −0.10, 0.00, respectively. The spatial distribution characteristics of land use types for the two areas are summarized in Table 1 and Fig. 10.

Figure 10 and Table 1 display the land use structure of HIGH and LOW areas; cultivated land, medium density grassland and low density grassland are the main land use types for the two areas, with area percentages of 44.5 %, 10.4 %, 28.8 % in HIGH area and 42.6 %, 25.6 %, 22.1 % in LOW area.

By comparing the average value of rainfall-runoff erosivity in HIGH area and LOW area (Fig. 10a, Table 1), it can be seen that the locations of all of the land use types, especially cultivated land, high density grassland, and medium density grassland, have higher rainfall-runoff erosivity in HIGH area than in LOW area. Because the SL_{sw} values are higher than the C-factor value in HIGH area, it can be inferred that if the land use location has higher rainfall-runoff erosivity, the SL_{sw} values will be higher, and vice versa. In another words, SL_{sw} values can reflect whether locations of different land use types have high or low rainfall-runoff erosivity, but C-factor values cannot.

Figure 10b and Table 1 show that the locations of cultivated land have steeper slopes in HIGH area (22.6 %) in comparison to LOW area (21.9 %), whereas all of the other land use types have more gentle slopes in HIGH area than in LOW area. This result indicates that if the cultivated land (which has high C-factor values) is located on a steeper slope and the other land use types (which have low C-factor values) are located on gentle slopes, the land use pattern will lead to higher SL_{sw} values. Otherwise, the land use pattern will lead to low SL_{sw} values. It can be concluded from this observation that the SL_{sw} value can reflect the land use spatial distribution based on along the slope degree, whereas this is not the case for the C-factor value.

Figure 10b shows that almost all of the corresponding soil erodibility values for the different land use types are 0.02 Mg h MJ^{-1} mm^{-1}, with little difference between HIGH and LOW areas. This result arises because the main soil type in the Yanhe watershed is loess soil and the soil properties do not have much spatial variation within the study area. In other words, due to the small differences in soil types, it is difficult to use the SL_{sw} value to reflect land use spatial variations in different soil types in the loess plateau region.

The horizontal and vertical distances to the drainage network for the land use types obviously differ between HIGH and LOW areas (Fig. 10c, Table 1). The average horizontal distance from cultivated land to the drainage network is 969 m in HIGH area and 998 m in LOW area. The cultivated land in HIGH area is closer to the drainage network than that in LOW area, whereas the other land use types in HIGH area are farther from the drainage network than in LOW area. Because the SL_{sw} values are higher than the C-factor values in HIGH area and lower than that in LOW area, it can be concluded that if land use types such as cultivated land (which has high C-factor values) are close to the drainage network in the horizontal direction, whereas the other land use types (which have low C-factor values) are far away from the drainage network in the horizontal direction, the SL_{sw} value will be larger. In the opposite situation, the SL_{sw} value will be smaller. Thus, it can be inferred that the SL_{sw} value can reflect the horizontal distance to the drainage network while the C-factor value cannot.

The average vertical distance from cultivated land to the drainage network is 114.3 m in HIGH area and 132.8 m in LOW area, and the cultivated land in HIGH area is closer to

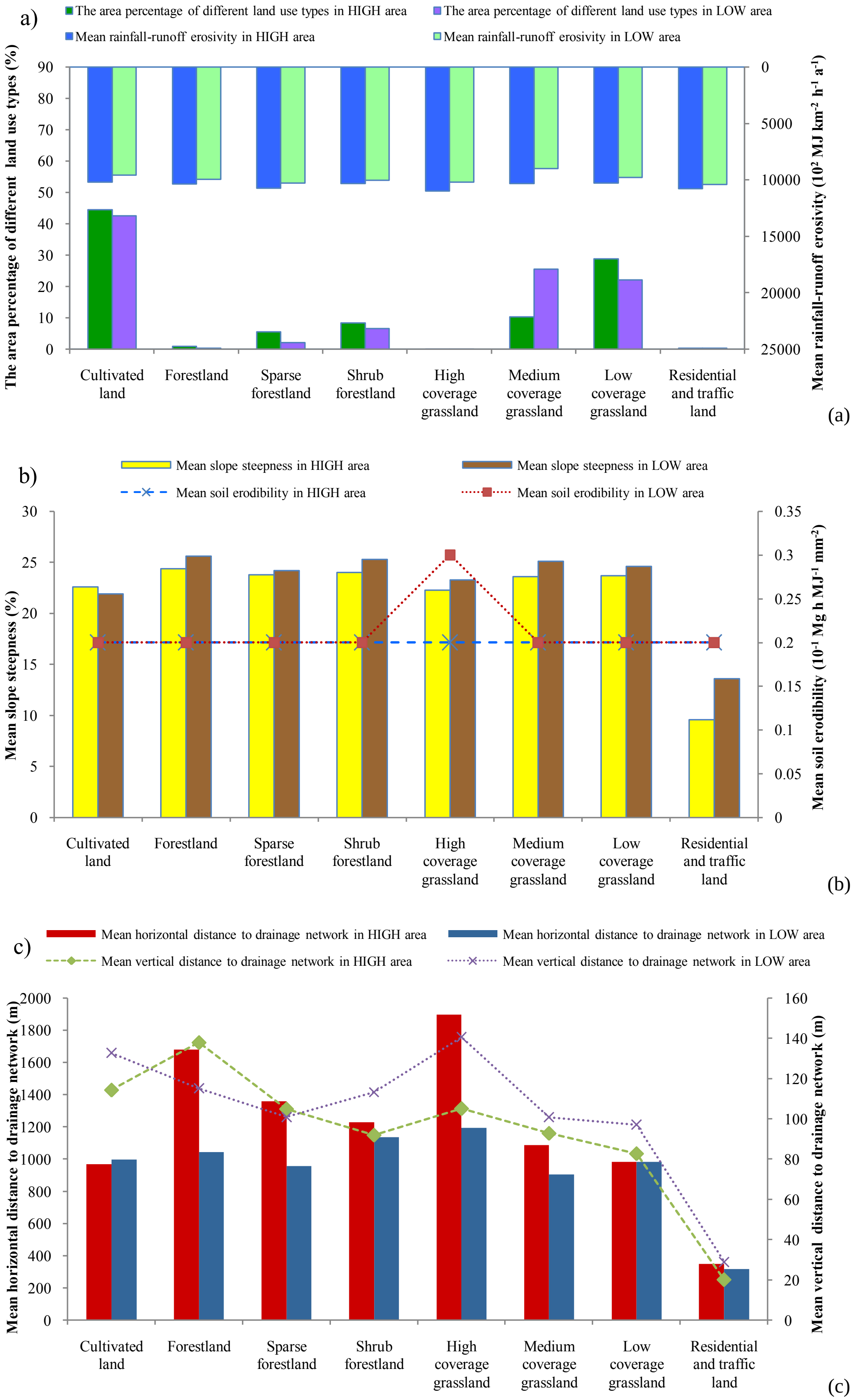

Fig. 10. The spatial distribution of land use types for the Yanhe watershed.

the drainage network than that in LOW area in the vertical direction (Fig. 10c and Table 1). It can be inferred that if the cultivated land is closer to the drainage network in the vertical direction, the SL_{sw} value will be larger and can thus reflect the vertical distance to the drainage network. However, forest land and sparse forest land are closer to the drainage network in LOW area, and shrub-forest land, high density grassland, medium density grassland, low density grassland, and residential land are closer to the drainage network in HIGH area in the vertical direction. Hence, it can be inferred that the SL_{sw} values cannot effectively reflect the vertical distance to the drainage network for the other land use types. The vertical distance index should be altered in future studies to improve SL_{sw}.

3.2.4 The advantages and disadvantages of SL_{sw}

Based on the above analysis, it can be concluded that SL_{sw} can reflect whether the locations of different land use types have high or low rainfall-runoff erosivity. If the location of given land use type have steep or gentle slopes, SL_{sw} will be different. In addition, SL_{sw} can characterize the distance to the drainage network in the horizontal directions. However, it is impossible for the C-factor to describe these spatial distribution patterns of land use.

While, we found that the SL_{sw} value cannot reflect the spatial distributions of land use in different soil types in the study watershed that have a low spatial variation in soil properties. Furthermore, the SL_{sw} value can effectively reflect the vertical distance to the drainage network for cultivated land, but not for the other land use types. A possible reason may be that if the vertical distances from some land use types to the drainage network become greater, the slope degree may increase simultaneously.

4 Conclusions

Improper land use is one of the main causes of significant soil erosion, and the development of new methods to identify the effects of land use change on soil erosion is necessary for ensuring sustainable land use and comprehensive watershed management. This paper developed a new soil erosion index proposed (SL_{sw}) that better represents the role of land use pattern in soil erosion potential at the landscape scale.

SL_{sw} was used to identify the effects of the land use spatial distribution on soil loss. The C-factor describes the effects of different land use types on soil erosion, but it cannot reflect the effect of the land use spatial pattern on soil erosion. The advantages of SL_{sw} over C-factor is that the former can be applied to evaluate the current land use pattern and to identify those subwatersheds that require land-use pattern optimization. In addition, SL_{sw} can be used for soil conservation planning. During the planning process, possible land use pattern scenarios can be modeled: thus, SL_{sw} is helpful in determining the best possible land use pattern to minimize soil loss.

However, there are potential shortcomings of SL_{sw}. First, it is difficult for SL_{sw} to distinguish among the spatial distributions of land uses in different loess soils. It may be useful to apply SL_{sw} in different regions in future studies to determine whether this problem is present in other areas. Second, the vertical distance index applied with SL_{sw} may not accurately reflect the effects of the spatial distribution of land uses on soil loss, and a number of improvements in this index are needed. It may be possible for the vertical distance and horizontal distance indices to be combined to form a more effective index in future studies. Future studies of SL_{sw} should also include the development of built-in GIS models that can make SL_{sw} applications more user-friendly.

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