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Hydrology and Earth System Sciences Discussions

A comparison of the soil loss evaluation index and the RUSLE Model: a case study in the Loess Plateau of China

"soil loss evaluation index" was used in many places throughout the paper. Suggest using an acronym.

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Abstract

The development of new methods to examine the influence of land use on soil erosion is currently a popular research topic in contemporary research. The multiscale Soil Loss Evaluation Index is a new, simple soil erosion model that can be used to evaluate the relationship between land use and soil erosion; however, applications of this model have been limited, and a comparison with other soil erosion models is needed.

In this study, we used the Yanhe watershed in China's Loess Plateau as a case study to calculate the Soil Loss Evaluation Index at the small watershed scale (SL_{sw}), to identify the similarities and differences between results from the Soil Loss Evaluation Index and the Revised Universal Soil Loss Equation (RUSLE), and to determine the key location where land use patterns need to be optimized in the study area.

The procedure for calculating the SL_{sw}, namely, using the delineation of the drainage network and the sub-watersheds as starting points, includes the calculation of soil loss horizontal distance index, the soil loss vertical distance index, slope steepness factor, rainfall-runoff erosivity factor, soil erodibility factor, and cover and management practices factor. ~~During the calculation procedure,~~ several functions within geographic information system (GIS), especially the spatial analyst function, are used to calculate these factors layers, and many of the data are expressed in grid format. Moreover, The AVSWAT2000 hydrological model and upscaling methods were used to calculate some of the factors in this study.

When comparing the SL_{sw} with the RUSLE, some similarities and differences were discovered. The similarities of the two models include ~~the following~~: (1) both use GIS techniques at the watershed scale, (2) the same factors appear in both models, (3) and the resolution of the basic data is closely related to the evaluation results. The differences between the SL_{sw} and the RUSLE are ~~as follows~~: (1) they have different outcomes, namely, the former analyzes the relationship between land use and soil erosion, and the latter analyzes the amount of soil erosion; (2) different grain scales are used in the two models, namely, the former uses the sub-watershed scale, and the

This sentence appears to indicate the purpose of this study, but it was not thorough. Comparison with other model does not justify the limited application of the index model. Instead it could help verifying if the new model is sufficient (with limited applications and verifications) by comparing with the well accepted model. The objective of this study need to be clearly addressed in the abstract.

Spatial analyst is a GIS extension that includes many functions/ applications. Did you use several extensions or several functions in one extension?

No "s" after "factor".

considered?

rate?

Four "namely" were used in the abstract. Consider using "i.e.," to replace some of them.

latter uses the grid cell; and (3) the evaluation results are different, namely, the former is dimensionless but can identify the key area for land use pattern adjustment, and the latter provides the coarse soil loss rate but may have difficulty identifying the key area where the land use pattern urgently needs adjustment to control the soil loss because of the different soil erosion factors.

Wouldn't an area with higher soil loss rates indicate a problem?

On the basis of our results regarding the Soil Loss Evaluation Index in the Yanhe watershed and comparisons with the RUSLE, we conclude that the area with substantial soil erosion is primarily located in the middle and southeastern parts of the Yanhe watershed and is a composite effect from different soil erosion factors. Additionally, the sensitive area where land use patterns need to be optimized is primarily located in the middle part of the Yanhe watershed, covering 53.3 % of the watershed. In future studies of land use pattern optimization, the calculation of the Soil Loss Evaluation Index at the slope scale may play a key role in identifying where land use patterns need to be adjusted in the sub-watersheds of sensitive areas.

How come the southeastern part is not considered as part of optimization?

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; Szilassi et al., 2006; Piccarreta et al., 2006; Feng et al., 2010). To understand the ongoing erosion processes and the effects of land use on soil erosion, much effort has been devoted to the research of land use and soil erosion from the slope scale to the small watershed, watershed, regional and global scales (Smithson, 2000; Zhao et al., 2006; Leys et al., 2010; Zokaib and Naser, 2011).

sub watershed?

In the research process, soil erosion models, including empirical models and process-based models (or physics-based models) (Harmon and Doe III, 2001; Aksoy and Kavvas, 2005; Sonneveld et al., 2011), are continuously being developed to determine the various aspects of erosion and sediment generation. All of these different models have provided many new insights into the processes associated with soil erosion and sediment transport (de Vente and Poesen, 2005) and have provided a possible means to evaluate the impacts of land use on soil erosion. However, several problems frequently appear in soil erosion model applications.

associate with?

The empirical soil erosion models can be implemented in situations with limited data and parameter inputs. These models are particularly useful as a first step in identifying the sources of sediment and nutrient generation; however, empirical models are often criticized for employing unrealistic assumptions about the physics of the catchment system, ignoring the inherent nonlinearities in the catchment system and poorly predicting the spatial patterns of sediment delivery and deposition within a catchment (Picouet et al., 2001; Merritt et al., 2003).

depict?

Physical models, on the other hand, can reflect soil loss processes and simulate soil erosion changes as a function of land use change by using more parameters, and they are potentially good tools for locating soil sediment sources and guiding efficient soil and water conservation planning; however, many factors that compromise the accuracy of the soil erosion prediction results and restrict its actual applications, such as a lack of available data for all of the model parameters, the inability to adequately represent the soil erosion processes in a complex natural system, error propagation and uncertainties in the estimation of input data for complex models (Jetten et al., 1999; Boardman, 2006; Vigiak et al., 2006; Krysanova et al., 2007).

That is to say, each model type serves a particular purpose and may not categorically be considered more appropriate than others in all situations. The choice of a suitable model structure relies heavily on the function that the model needs to serve (Merritt et al., 2003).

therefore?

The purpose of examining the relationship between land use and soil erosion is to identify the key locations where the land use pattern needs to be adjusted to reduce soil loss. It is helpful to identify the sources of sediment generation with empirical soil erosion models, and while there are a number of factors (e.g. rainfall, terrain, and soil type) that can lead to soil erosion, the areas with the most significant soil erosion may not require an urgent adjustment to the land use pattern. It is meaningful to predict the

why?

The highlighted in blue appears to convey the similar meaning on page 2412, lines 20 to23. Consider merging those sentences or remove some.

amount of soil loss with physical soil erosion models for this type of research; however, as mentioned before, there are some problems that may appear and restrict model application. The most appropriate model for a specific study depends on the problem under consideration (de Vente and Poesen, 2005). New methods and soil erosion models should be tested for their ability to examine the relationship between land use and soil erosion.

Some studies have verified that conceptual (or semi-empirical) models offer the advantage of combining the physical interpretability of modeling results with a simple structure, which makes them less prone to over-parameterization and error propagation problems, even if the model data exposes them to the risk of aggregation or disaggregation errors. These types of models may also be appropriate for characterizing the distribution of erosion within a catchment (van Rompaey et al., 2001; Vigiak et al., 2006).

change to " models that are"

to use?

sub watershed?

The Multiscale Soil Loss Evaluation Index (expressed as SL) is one type of semi-empirical soil erosion model that is based on scale-pattern-process theory in landscape ecology and calculation methods for some of the erosive factors in the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997). The model has been proposed that uses scale transition methods and accounts for the key factors of soil erosion (Fu et al., 2006). The Multiscale Soil Loss Evaluation Index uses different equations with different factors at the slope, small watershed, and watershed scales. These values are expressed as SL_s (soil loss evaluation index at the slope scale), SL_{sw} (soil loss evaluation index at the small watershed scale), and SL_w (soil loss evaluation index at the watershed scale), and these equations are used under different scenarios ~~as follows~~: (1) when one region is used as a case study and we need to determine which watershed's land use pattern needs to be optimized to control the soil loss in the region, the SL_w will be used after the region has been divided into several watersheds; (2) if we need to determine which watershed has land use that needs further adjustment, the SL_{sw} will play a central role in identifying which sub-watersheds in the overall watershed urgently need land use pattern changes to reduce the watersheds' sediment

yield; and (3) after identifying which sub-watersheds require land use pattern optimization, the SL_s can be used to specify those slopes that require an adjustment to their land use structure.

The Multiscale Soil Loss Evaluation Index can semi-quantitatively evaluate the influence of land use on soil erosion and avoids the use of too many model parameters. It is inferred that the Multiscale Soil Loss Evaluation Index may be used to evaluate the relationship between land use and soil erosion at different scales and to help identify the key area where the land use pattern needs to be optimized.

The development of the Multiscale Soil Loss Evaluation Index yields several 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 Multiscale Soil Loss Evaluation Index and other soil erosion models?

It appears what scale to be used can't be decided?

With regard to the first question, the SL_{sw} is a middle link between slope scale and watershed scale, and serves as a connection within the Multiscale Soil Loss Evaluation Index. SL_{sw} is also a good starting point when applying this index. Regarding the second question, some factors used in the Multiscale Soil Loss Evaluation Index are from the RUSLE, and the RUSLE can predict the erosion rates of ungauged catchments by using knowledge of the catchment characteristics and local hydro-climatic conditions (Angima et al., 2003); therefore, it may be helpful to compare the results obtained using the RUSLE with those obtained using the Multiscale Soil Loss Evaluation Index for a particular watershed.

The Loess Plateau of China has one of the highest erosion rates in the world at approximately 5000–10 000 Mg km^{-2} per year in most areas, but the rate can be greater than 20 000 Mg km^{-2} per year in some areas (Chen et al., 2001). We previously applied the RUSLE to one watershed (Yanhe watershed) in the Chinese Loess Plateau and identified the soil loss rate for that area (Fu et al., 2005). In the present study, we examined the same watershed as a case study with the following objectives:

1. to attempt the calculation of the SL_{sw};

2. to compare the SL_{sw} with the RUSLE; and
3. to identify the sensitive area where the land use pattern needs to be optimized within the Yanhe watershed.

2 Materials and methods

2.1 Study area

The study area (7725 km^2) was 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. 1). 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. Land use in this watershed comprises areas such as slope farmland, terrace farmland, orchards, sparse forestland, forestland, residential land, and water bodies. The most common soil in the watershed is loess, a fine silt soil, which is weakly resistant to erosion.

2.2 Soil loss evaluation index at the small watershed scale (SL_{sw})

The equation for the SL_{sw} is extrapolated from the equation of the slope scale using upscaling methods and can be expressed as follows (Fu et al., 2006):

$$SL_{sw} = \sum (D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m) / \sum (D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m), \tag{1}$$

where SL_{sw} is the small watershed scale soil loss evaluation index, D_m is the spatial distribution map of the soil loss horizontal distance index, H_m is the spatial distribution map of the soil loss vertical distance index, S_m is the spatial distribution map of the slope steepness factor, R_m is the spatial distribution map of the rainfall-runoff erosivity factor, K_m is the spatial distribution map of the soil erodibility factor, and C_m is the spatial distribution map of the cover and management practices factor. $D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m$ 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.

what m indicates?

The SL_{sw} is a dimensionless index between 0 and 1. A larger SL_{sw} shows that the land use pattern is more indicative of soil loss, while a smaller SL_{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 a number of sub-watersheds to provide the basic unit for the SL_{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 the SL_{sw}, and 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 was extracted from a DEM using AVSWAT2000 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 Soil loss horizontal distance index

The farther the land use type is away 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

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

where D_i is the soil loss horizontal distance index of a certain point in the small watershed, D_{max} is the maximum soil loss horizontal distance in the small watershed, and

which point? Be specific.

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 soil loss horizontal distance index can be produced by calculating the straight-line distance in the Geographic information system (expressed as GIS).

2.2.3 Soil loss 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

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

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 in the small watershed, 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 soil loss 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 the GIS.

2.2.4 Other factors associated with the SL_{sw}

~~There are four other factors that need to be calculated to apply the SL_{sw}: the rainfall-runoff erosivity factor, the slope steepness factor, the soil erodibility factor, and the~~

add "remaining"

~~cover and management practices factor.~~ Based on the fundamental equations from the RUSLE, the four factor maps at the watershed scale were obtained with the help of GIS and upscaling methods. The detailed procedure can be found in ~~the paper, which title is "Assessment of soil erosion at large watershed scale using RUSLE and GIS: a case study in the Loess Plateau of China" (~~Fu et al. 2005~~)~~.

add "(".

Please remove those crossed-out texts since they either repeat previously discussed or are unnecessary. Using the room briefly discuss the upscaling methods.

2.2.5 Calculation of the SL_{sw}

After determining the index and factor maps needed in Eq. (1), the SL_{sw} was calculated as the basic unit of the 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 in the GIS. $\sum(D_m \cdot H_m \cdot S_m \cdot R_m \cdot K_m \cdot C_m)$ 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 the SL_{sw} with the RUSLE

2.3.1 Assessment of soil erosion with the RUSLE

By applying the SL_{sw} and RUSLE to the same watershed, we can compare the two models. The SL_{sw} was calculated using the previously described procedure. The RUSLE was already applied in the previous study by Fu et al. (2005) to assess the soil erosion in the Yanhe watershed. The detailed techniques and methods used in this study can be found in the paper (Fu et al., 2005).

2.3.2 Comparison of the two models

There are both similarities and differences between the use of SL_{sw} and RUSLE. To compare the two models, the following model aspects were considered: (1) the design purpose of each model, (2) the factors used in each model, (3) calculation of the factors, (4) the modeling scale, and (5) the outputs.

Because the evaluation results obtained using the two models do not have the same dimension, i.e. one model expresses the results as the soil loss rate (RUSLE) and the other expresses them as a dimensionless number (SL_{sw}), it was necessary to convert the results into the same dimension to allow us to compare the two models. In this study, the SL_{sw} and RUSLE evaluation results was ~~transformed~~ from its value into the range of 0 and 1 using the following equation:

normalized

$$\lambda_i = (x_i - x_{min})/(x_{max} - x_{min}), \tag{4}$$

where λ_i is the standardized value of the soil loss rate (SL_{sw}), x_i is the original value of the soil loss rate (SL_{sw}), and x_{max} and x_{min} represent the maximum and minimum values of the soil loss rate, respectively.

add "s" after rate.

3 Results and discussion

3.1 Application of the 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 express soil erosion control in the Loess Plateau. Using AVSWAT2000, the drainage network and sub-watersheds can be delineated from the DEM of the Yanhe watershed as follows: (1) load the DEM grid of the study area from the disk and edit the DEM map properties regarding the vertical and horizontal units of measure, (2) import or create a grid map that masks part of the Yanhe watershed, (3) preprocess the DEM to remove sinks, (4) set the threshold area for stream definition, (5) define the outlet and select the main watershed outlet, and (6) use AVSWAT2000 to determine the drainage network and sub-watersheds for the Yanhe watershed. During the procedure, the threshold area plays an important role in determining the detail of the stream network, and its value in the Yanhe watershed was set as 5 km^2.

Figure 2 shows the drainage network as delineated using AVSWAT2000. Accompanied by the stream delineation, the Yanhe watershed was divided into 820 sub-watersheds (Fig. 3), which were used as the basic unit with which to calculate the SL_{sw}. The mean area of the sub-watersheds was 9.42 km^2, with different areas of each sub-watershed.

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 distance from each cell in the Yanhe watershed to the closest drainage network was 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 value of the soil loss horizontal distance index was 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 catchment 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 SL_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). These map layers were created using GIS and upscaling methods, and more details can be found in the paper by Fu et al. (2005).

repeat the text in section 2.2.4

3.1.5 The SL_sw value map in the Yanhe watershed

Based on the map layers needed for Eq. (1), the soil loss evaluation index for each sub-watershed can be calculated using the raster calculator in the GIS. As seen in Fig. 7, the value of the SL_sw in the Yanhe watershed is in the range of 0.15 to 0.45, with a mean of 0.33. The sensitive area where the land use pattern needs to be optimized is primarily in the middle part of the Yanhe watershed.

what are the definitions for LS and P factors?

3.2 Comparison of the SL_sw and RUSLE

3.2.1 Results of the soil erosion assessment using RUSLE

The R-, K-, LS-, C- and P-factors need to be calculated before evaluating the soil loss by integrating the RUSLE and the GIS. The total gross and spatial distributions of the soil loss for the Yanhe watershed were obtained, and the average annual soil loss map for the Yanhe watershed was created at the grid-cell scale (more details can be found in the paper of 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 RUSLE, the sub-watershed map of the Yanhe watershed was used to unify the evaluation units, and the spatial distribution map of the average annual soil loss rate for the sub-watersheds in Yanhe watershed was produced (Fig. 8, derived from Fu et al., 2005).

3.2.2 Normalization of the SL_sw and RUSLE results

Using Eq. (4) and the raster calculator in the GIS, the values obtained from the SL_sw and RUSLE were normalized into the range of 0–1. The normalization maps of the average annual soil loss value and the SL_sw value were derived from Figs. 7 and 8, and the result maps are shown in Figs. 9 and 10. After converting the evaluation results from the SL_sw and RUSLE into dimensionless results, the differences in the two maps became more obvious.

Incorrect. SLsw does not need a conversion.

add "according to the RUSLE model results " after watershed

The comparative analysis between Figs. 9 and 10 shows that most of the evaluation results in the watershed were not similar, although there were some similar values in the northwest part of the study area. The significant soil erosion areas were primarily located in the middle and southeast parts of the Yanhe watershed, while the higher SL_sw values were located in the middle parts of the watershed. ~~As illustrated, the results from the SL_sw and RUSLE are different.~~

3.2.3 The differences and similarities between the SL_{sw} and RUSLE

Considering the aforementioned analysis, the similarities and differences between SL_{sw} and RUSLE can be described as follows (Table 1).

1. Model design purpose. The RUSLE is an empirical model that is designed to estimate the average annual soil loss and sediment yield resulting from interrill and rill erosion. It is derived from the theory of erosion processes, as well as from more than 10 000 plot-years of data from natural rainfall plots and numerous rainfall-simulation plots. The SL_{sw} is a semi-empirical model that is part of the multiscale soil loss index that is designed to analyze the relationship between land use and soil erosion. It is derived from the theory of erosion processes and landscape ecology, and it uses some of the same model factors as those used in the RUSLE. Both of the models are tools used in conservation planning; however, RUSLE evaluates the soil erosion rate, and SL_{sw} identifies the sub-watersheds that need adjustments to their land use patterns to control soil loss.

2. Model factors. The SL_{sw} is derived partly from the RULSE, and the two models use some of the same factors when applying the model, including the steepness factor, the rainfall-runoff erosivity factor, the soil erodibility factor, and the cover and management practices factor. There are also different factors used in the two models. To describe the effects of the spatial land use patterns on the soil loss, the soil loss distance index is used in the SL_{sw}, which can reflect the soil loss process to a certain extent. Because the support practice factor is difficult to map at the watershed or small watershed scale, the SL_{sw} does not currently consider the spatial distribution pattern of the support practice for soil loss.

supporting.

so the land use wasn't really taken into account?

3. Application scale. Scale is an essential concept in both the natural and social sciences and refers primarily to the grain (or resolution) and extent of an object in space and/or time (Wu and Qi, 2000). When applying the RUSLE and SL_{sw}, each model has a specific scale to declare. For the time scale, because the RUSLE is designed to estimate the average annual soil loss and because some factors in the SL_{sw} come from the RUSLE, both of the models are applied at the same time scale. Regarding the spatial scale, when the two models are used at the small watershed or watershed scale, they have the same extent; however, the grain scale is different. The RUSLE takes the grid cell as the grain scale, and every cell has its own value, which can be seen in Fig. 8 in the paper by Fu et al. (2005). The SL_{sw} uses the small watershed (or sub-watershed) as an evaluation unit, and one small watershed (or sub-watershed) has a value of SL_{sw}, which can be seen in Fig. 6 of the current paper.

Figure 7?

4. Calculation procedure. The calculation procedures of both models have a very close relationship with GIS functions. The techniques used for the two models are based mostly on the spatial analyst function of GIS. To calculate the *R*- and *C*-factor maps, upscaling methods are also used when applying both models. However, the two models also have different calculation procedures for their different constituent elements. The SL_{sw} requires the hydrologic analysis module or a hydrological model to extract the sub-watersheds for the SL_{sw} calculation, and the distance function is needed to derive the soil loss horizontal distance index and the soil loss vertical distance index. The RUSLE must estimate the P-factor map at the watershed scale.

GIS-based?

5. Output results. The output from the two models is presented in grid-map form (Figs. 7–10). These figures show that the results of the two models are significantly different from each other. The locations with higher SL_{sw} values in Figs. 7 and 9 do not necessarily correspond to the higher values for the average annual soil loss in Figs. 8 and 10. By examining this comparison more closely, even

though the SL_{sw} is dimensionless and does not provide a soil loss rate for the study area, it can identify those sub-watersheds that urgently need to have their land use patterns adjusted and can provide the basis for calculating the soil loss evaluation index at the slope scale. The results from the RUSLE provide the coarse soil loss rate; however, because there are so many factors that influence soil erosion, such as soil, topography, and land use, it may have difficulty identifying the key areas that need land use pattern adjustment to control soil loss. With regard to the accuracies of the model results, the accuracies of both of the models are strongly dependent on the resolution and the source of the input map data, such as the DEM, soil type map, and land use map.

3.3 Identifying the sensitive areas that need land use pattern optimization in the Yanhe watershed

On the basis of a comprehensive analysis of Figs. 7 and 8 and the results from Fu et al. (2005), we conclude that the significant soil erosion area is primarily located in the middle and southeastern parts of the Yanhe watershed. The causes of this soil loss are associated with improper land use, erodible soils, steep slopes and high-intensity summer storms. Among these factors, land use may be the most easy to change to provide soil loss control.

easiest

Figures 6 and 9 show the identified sensitive area where the land use pattern needs to be optimized to control soil loss, and these sub-watersheds are primarily located in the middle part of the Yanhe watershed. To identify these sub-watersheds more directly, a histogram was used to graphically summarize and display the distribution of the SL_{sw} values, which can be used to classify the Yanhe watershed into two categories: the non-sensitive area and sensitive area where land use patterns need to change.

Figure 12?

The SL_{sw} histogram for the sub-watersheds in Yanhe watershed was created in SPSS (Fig. 11). The sub-watersheds of the Yanhe watershed were divided into two types of areas, based on Fig. 11, to assess the relative needs for land use pattern adjustment (Fig. 12): the sensitive area, with SL_{sw} values greater than 0.325; and the

non-sensitive area, with SL_{sw} values less than 0.325. There were 427 sub-watersheds in the sensitive area, occupying 53.3 % of the Yanhe watershed, and there were 393 sub-watersheds in the non-sensitive area, occupying 46.7 % of the watershed.

In future studies of land use pattern optimization, altering the land use structure should take into consideration not only soil erosion but also food security and economic and social development in the sensitive area. Consequently, the soil loss evaluation index at the slope scale may play a key role in the identification of which parts of the sub-watersheds in these sensitive areas need land use pattern adjustment.

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 area management. This paper developed methods to calculate the SL_{sw}, compare the similarities and differences between the RUSLE and SL_{sw}, and highlight the key location where land use pattern optimization is needed in the Yanhe watershed of the Loess Plateau in China.

The process of calculating the SL_{sw} is helpful for SL application in other areas. The results in this paper differ from those of a previous study (Fu et al., 2005), in which the RUSLE was used for soil erosion assessment. By comparing the RUSLE with the SL_{sw}, we can infer that the SL_{sw} has some similarities with the RULSE, such as the use of similar factors in the models and of a GIS and upscaling methods. The differences between the two models include different model design purposes, different grain scales, and different evaluation results. The RUSLE can provide the amount of soil erosion for a watershed, while the SL_{sw} can identify the location in which land use patterns need to be optimized to reduce soil loss. Future studies of land use pattern optimization in the Yanhe watershed need to consider economic and social effects addition to soil erosion, and the soil loss evaluation index at the slope scale may play a key role in determining the land use pattern change at small scales.

add an " in"
before addition.

This paper verifies that it is necessary to develop different models for different tasks, and simple models may be perfectly adequate for certain investigations (Boardman, 2006). Further studies of the soil loss evaluation index should include the development of built-in GIS models that can provide more convenience for SL applications.

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Table 1. The differences and similarities between the SL_{sw} and RUSLE.

		Differences	Similarities
Model design purpose	RUSLE	Empirical model, designed for soil erosion assessment	Both of the models are tools for conservation planning
	SL_{sw}	Semi-empirical model, designed to analyze the relationship between land use and soil erosion	
Model factors	RUSLE	Has the support practice factor	Both of the models have the slope steepness factor, the rainfall-runoff erosivity factor, the soil erodibility factor, and the cover and management practices factor
	SL_{sw}	Has soil loss horizontal distance index and soil loss vertical distance index	
Applying scale	RUSLE	Grain scale: take grid cell as an evaluation unit, and every cell has one value	Extent scale: can be used for small watershed scales; Time scale: annual
	SL_{sw}	Grain scale: take small watershed as an evaluation unit, and one small watershed has a SL_{sw} value	
Calculation procedure	RUSLE	Need to calculate support practice factor at the watershed scale	GIS techniques and upscaling methods are important for their calculations
	SL_{sw}	Sub-watershed extraction techniques and distance functions are needed	
Output results	RUSLE	Can provide the coarse soil loss rate but may have difficulty identifying the key area where land use pattern adjustments are urgently needed	The output accuracies of the SL_{sw} and the RUSLE strongly depend on the resolution and the source of the input map data
	SL_{sw}	Dimensionless value, can identify the sub-watersheds where land use pattern needs to be adjusted to control soil loss, but it cannot provide the soil loss rate	

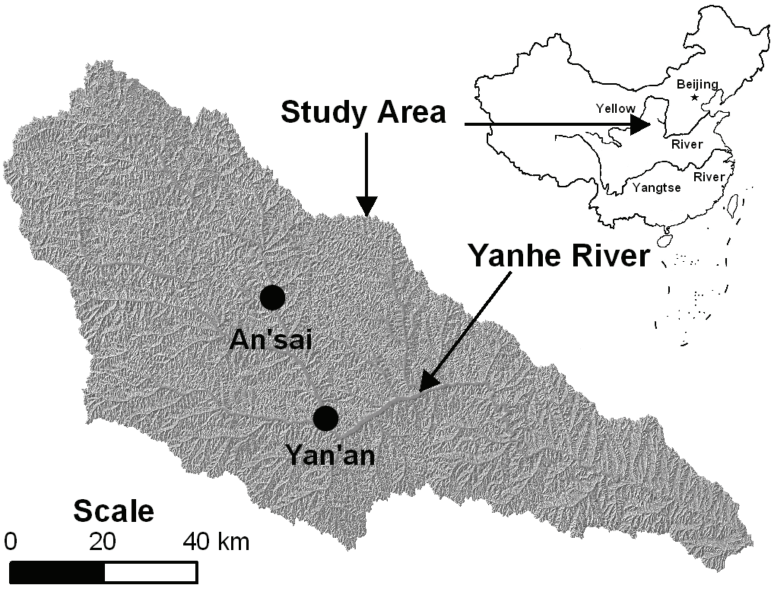

Fig. 1. The location of the study area.

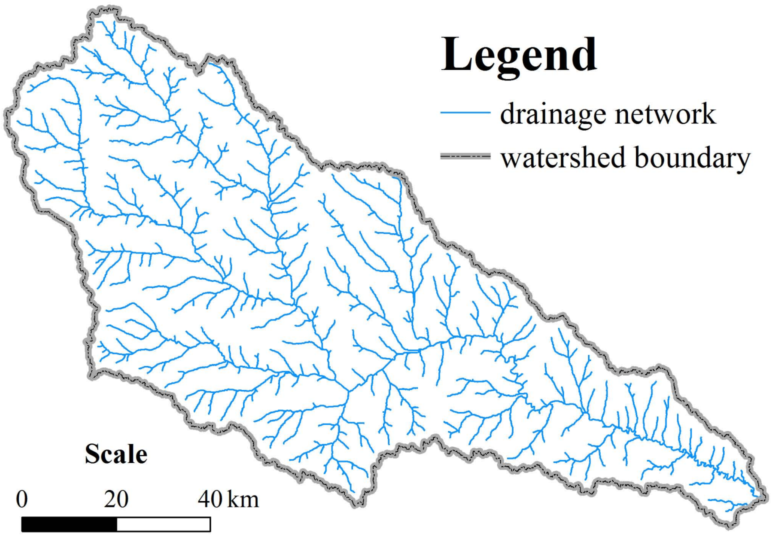

Fig. 2. Spatial distribution of the drainage network in the Yanhe watershed.

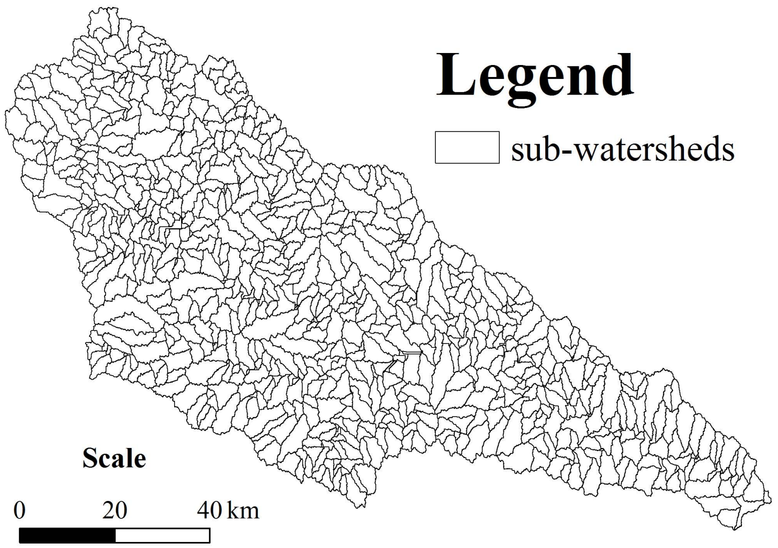

Fig. 3. Spatial distribution of the sub-watersheds in the Yanhe watershed.

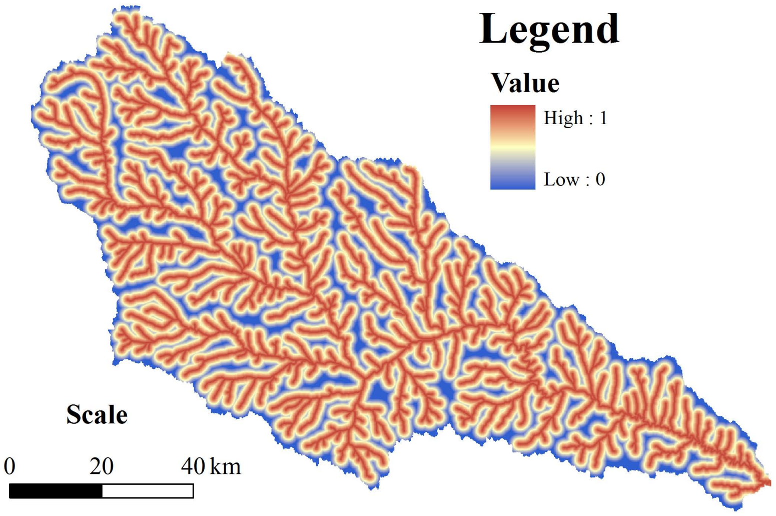

Fig. 4. Spatial distribution of the soil loss horizontal distance index values in the Yanhe watershed.

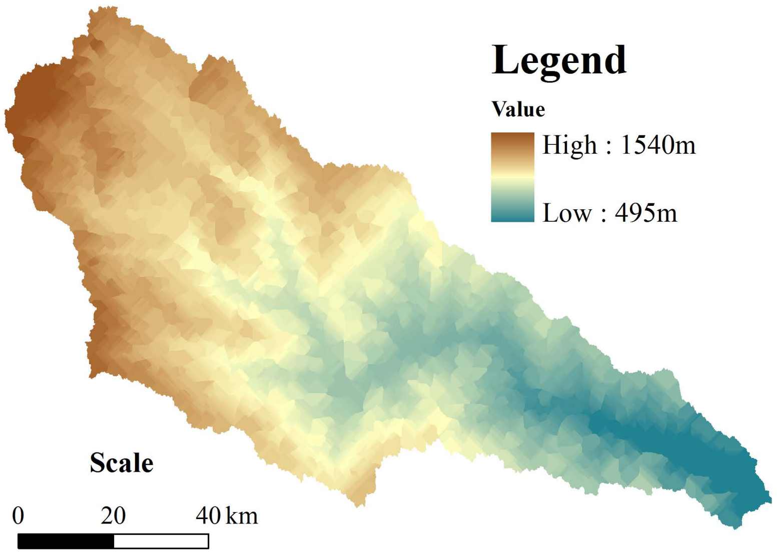

Fig. 5. Spatial distribution of the stream elevation plane in the Yanhe watershed.

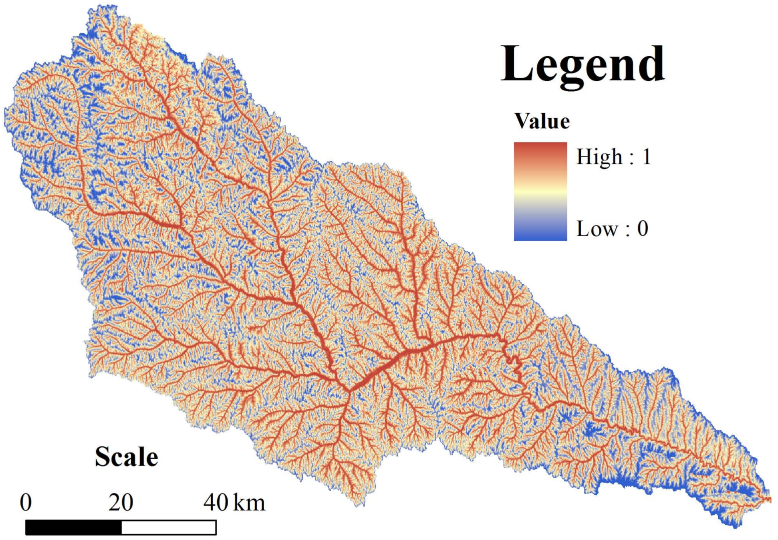

Fig. 6. Spatial distribution of the soil loss vertical distance index values in the Yanhe watershed.

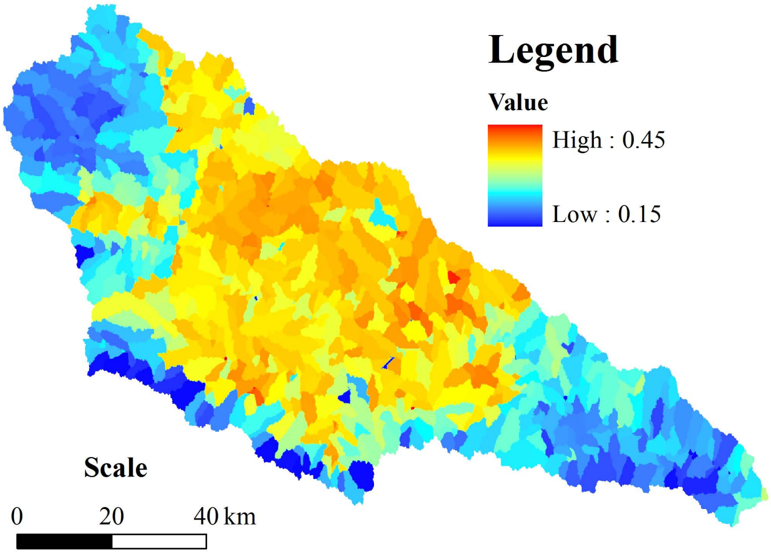

Fig. 7. Spatial distribution of the SL_{sw} values in the Yanhe watershed.

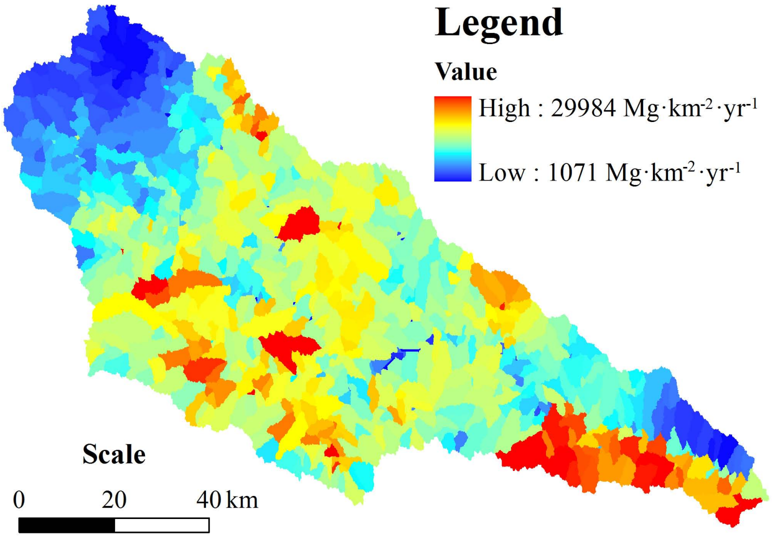

Fig. 8. Spatial distribution of the average annual soil loss rate for the sub-watersheds inYanhe watershed.

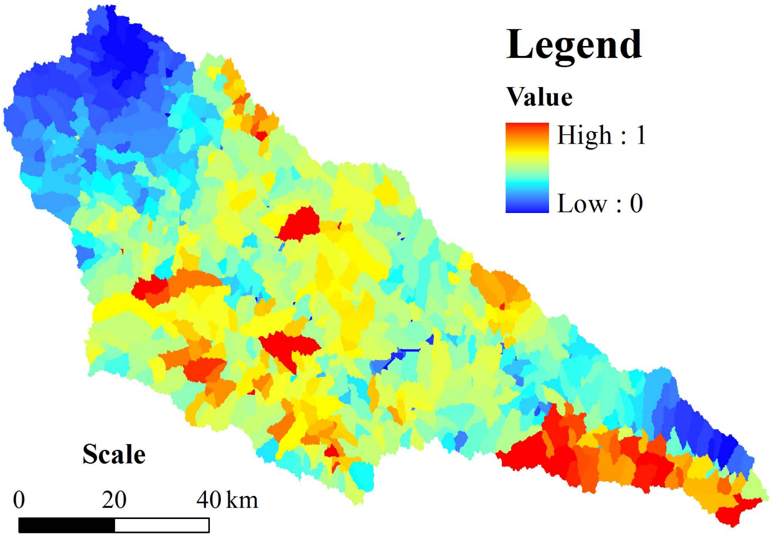

Fig. 9. Normalization of the average annual soil loss rate for the sub-watersheds in Yanhe watershed.

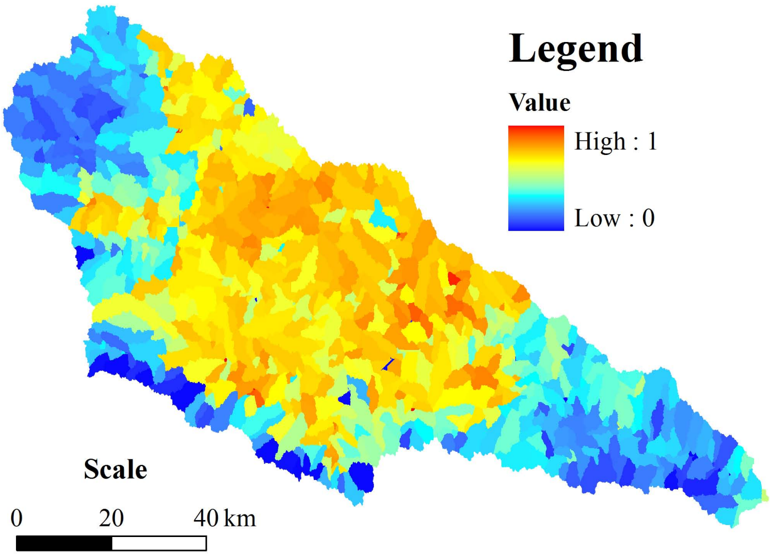

Fig. 10. The normalized SL_{sw} value in the Yanhe watershed.

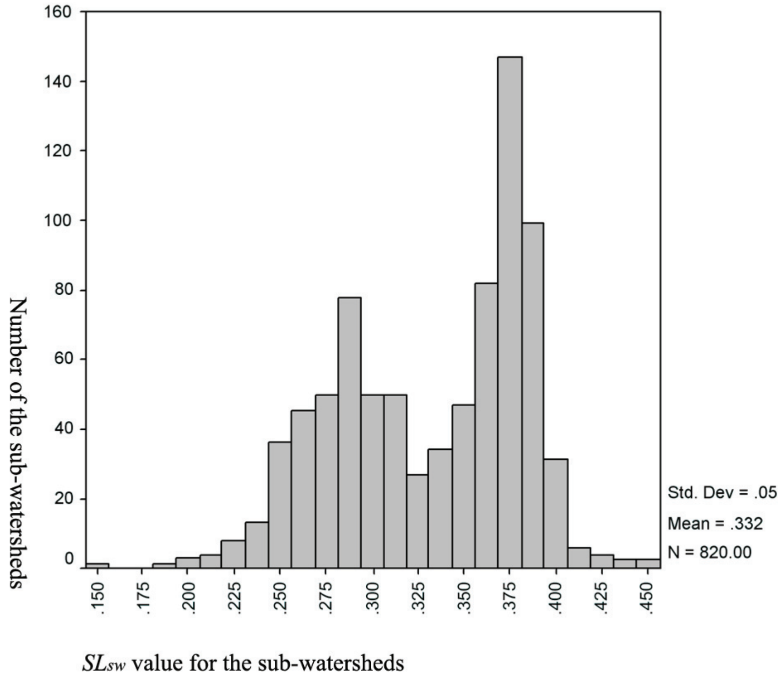

Fig. 11. SL_{sw} value histogram for the sub-watersheds in Yanhe watershed.

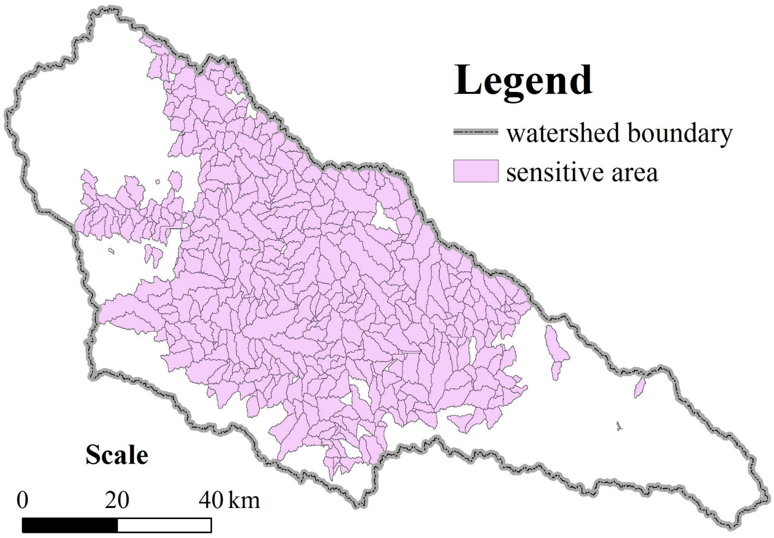

Fig. 12. The sensitive area for land use pattern optimization in the Yanhe watershed.