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Original Article

The regional difference in engineering-control and tillage factors of Chinese Soil Loss Equation

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Abstract: Accurate assessment of soil erosion is an important prerequisite for controlling soil erosion. The engineering-control (E) and tillage (T) factors are the keys for Chinese Soil Loss Equation (CSLE) to accurately evaluate water erosion in China. Besides, the E and T factors can reflect the water and soil conservation effects of engineering-control and tillage practices. But in the current full coverage of soil erosion surveys in China (such as soil erosion dynamic monitoring), for the same practice, the E or T factors are assigned the same value across the country. We selected 469 E and T factors data based on runoff plots from 73 publications, and they came from six soil and water conservation regions. Correlation analysis, regression analysis, and nonparametric tests were used to determine the comparability of the data, and it was proved that the runoff plots dimensions are consistent with the local topography. The results of one-way ANOVA and nonparametric tests for E and T factors in different regions showed that the engineering-control practices have good soil and water conservation effects and weaken the regional differences of other environmental factors, so there were no significant differences in E factors between different regions. However, there were significant differences in T factors between different regions, and the geodetector was applied to explore the intrinsic driving force of the spatial distribution of T factors. The results of the geodetector showed that the dominant driving forces of the spatial distribution of different types of tillage practices were not completely the same. When using CSLE to calculate water erosion, the E factor of the same practice can be used uniformly throughout the country, and the T factor needs to be considered and selected according to regional differences. At the same time, when choosing tillage practices in each water and soil conservation region, practices with better sediment reduction benefits should also be selected according to the regional environmental conditions.

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1 Introduction

Soil erosion is the result of the combined action of natural factors and human factors. It has become one of the global resources and environmental problems that threaten human survival and seriously affect the sustainable development of human society (Bai et al. 2020; Lizaga et al. 2020). Soil erosion will not only cause on-site hazards: soil degradation, decreased soil fertility, desertification, and declined infiltration and water storage capacity, etc., but also off-site hazards: eutrophication of watercourses and lakes, damaged to infrastructure by siltation of rivers and muddy floods, etc. (Helming et al. 2006; Verheijen et al. 2012; Bai et al. 2020; Kihara et al. 2020; Li et al. 2020). Regular investigation and announcement of soil erosion are the basis for objectively reflecting the effectiveness of soil and water conservation, evaluating the effectiveness of governance, and preparing governance plans (Cheng et al. 2009).

The methods of water erosion investigation vary with the scale of the study area (Wang et al. 2016a; Batista et al. 2019). In areas with small scales (slopes, small watersheds, etc.), tracer methods and physical model methods are often used for quantitative evaluation of soil erosion (Liu et al. 2004; Fu et al. 2012; Liu et al. 2017; Cao et al. 2020; Liu et al. 2020b; Srivastava et al. 2020; Zheng et al. 2020), while for large-scale research areas such as countries or provinces, the factors that affect soil erosion have great spatial differentiation, and the parameters necessary for the tracer method and physical model are difficult to obtain through direct observation or repeated experiments, so empirical models (USLE, RUSLE, etc.) are mostly used for quantitative evaluation of soil erosion (Boyle et al. 2011; Demirci and Karaburun 2011; Mallick et al. 2014; Mondal et al. 2016; Das et al. 2020).

According to the results of the latest National Monitoring of Soil and Water Loss, the problem of soil erosion in China still cannot be ignored (Lin and Li 2019). In order to more accurately assess soil erosion, combining Chinese terrain and landform, and the characteristics of soil and water conservation practices, Chinese scholars have proposed the Chinese Soil Loss Equation (CSLE) improved by USLE (Liu et al. 2002; Zhang et al. 2018a). This equation has been used in the national water conservancy census and dynamic monitoring of soil erosion to estimate regional soil erosion after accumulating rich research results (Li et al. 2012; Liu et al. 2013a; Shi et al. 2018; Duan et al. 2020; Huang et al. 2020). The expression of this equation is $A = R \times K \times L \times S \times B \times E \times T$, where A is the annual average soil erosion amount, R is the factor of rainfall erosivity, K is the factor of soil erosivity, L is the factor of slope length, S is the factor of slope steepness, B is the factor of biological-control, E is the factor of engineering-control practices, T is the factor of tillage practices. The B, E, and T factor are split from the land cover (C) and conservation practice (P) factors of USLE. When using CSLE to calculate soil erosion, the E factor and T factor are usually to assign a certain value directly, and the assignment data of E factor and T factor are generally calculated from the observation data of runoff plots, or obtained from previous research results (Fu et al. 2001; Fan et al. 2011; Ma et al. 2018; Wang et al. 2018b). In the current full coverage of soil erosion surveys in China (such as soil erosion dynamic monitoring), for the same practice, the E or T factors are assigned the same value across the country (Liu et al. 2020a). However, China has a vast territory, great topographic relief, diverse climate types, diverse soil and vegetation types, and large differences in human activities between regions, resulting in significant spatial differentiation of soil erosion environments. In fact, implementations of engineering-control and tillage practices are not affected by one or two factors, but by regional conditions. Therefore, more attention should be paid to the influence of the overall regional conditions on the values of the E and T (Jia et al. 2019).

Based on the main geomorphic units, climate, soil, vegetation, land use, soil and water loss types and areas in China, as well as the positioning of the main functions of the state, the regional layout of soil and water conservation is proposed in the National Soil and Water Conservation Plan (2015-2030) (Wang et al. 2016b; Jia et al. 2019). The country is divided into eight first-level regions: The North China mountainous region, the Northeast China black soil region, the South China red soil region, the Northwest China Loess Plateau region, the Southwest China karst region, the Southwest China purple soil region, the North China sandstorm region, and the Qinghai-Tibet Plateau region. Up to the present, there were few studies have evaluated the impact of overall regional conditions on E and T factors (Guo et al. 2013; Liu et al. 2015). At the same time, the limited understanding of the differences in E and T factors between different regions also limits the application of engineering-control and tillage practices. It also increases the difficulty of selecting appropriate E and T factor values in different regions during using CSLE to calculate water erosion, which affects the accuracy of water erosion evaluation results.

Based on the above problems, the objectives of this paper are: (1) To analyze the spatial distribution of E and T factors in various soil and water conservation regions in China and provide reference values for E and T factors when using CSLE to evaluate water erosion. At the same time, it can be used as the basis for selecting the best engineering-control and tillage practices in each region. (2) Explore the inherent driving force of the spatial distribution of E and T factors.

2 Materials and Methods

2.1 Data collection

The engineering-control practice factor means the ratio of the amount of soil loss that takes a certain engineering-control practice to the amount of soil loss of continuous fallow under the same conditions. The tillage practice factor refers to the ratio of the amount of soil loss that adopts a certain tillage practice to the amount of soil loss of continuous fallow under the same conditions (Liu et al. 2002). We collected and analyzed publications on soil and water conservation engineering-control and tillage practices from 1992 to 2019. The data were selected from these publications according to three following rules: (1) The values of E and T factor were directly calculated based on the actual measurement data of the runoff plot; (2) The values of E and T factor came from the sediment reduction effect of a certain measure; (3) The values of E and T factor derived from the first national water conservancy census results (PRC 2013). According to the above criteria, a total of 47 publications on tillage practices were selected, including 358 T factors data, and 32 publications on engineering-control practices were selected, including 111 E factors data (We have presented all data in Appendix 1).

In this study, engineering-control practices mainly involved level terrace (ELT), sloped terrace (EST), fish scale pit (EFS), field ridge (EFR), narrow terrace (ENT), level bench terrace (ELBT), contour trench (ECT), tree disk (ETD), horizontal pit (EHP), and intercepting ditch (EID). Among them, ELT refers to the field that the sloping land is manufactured into steps along the contour line direction, and the field surface is horizontal, and EST is similar to ELT, but its field surface is not horizontal. EFS are half-moon-shaped rainwater retention pits that are constructed on steep slopes and arranged such that they resemble the arrangement of scales on a fish. EFR means a ridge in the field, employed to divide and store water. ENT is the same as ELT, but the field width is less than 5m and greater than 1.5 m. ELBT refers to that the slope surface is made into steps with a width of 1.0-1.5m and a reverse slope of 3° to 5° which is also called reverse slope terrace, and ECT refers to the trench excavated along the contour line. ETD refers to the pit which is square in-plane, 1.6-2.0 m in width, and 0.3-0.5 m in depth. EHP is to dig a square (rectangular) pit with a depth of 0.2 - 0.4 m on the barren hillside. EID refers to the drainage channel designed to intercept surface runoff in the upper reaches of the drainage area (Chen et al. 2006; Bi 2007; Fu et al. 2010; Liu et al. 2013b; song et al. 2018; Guo et al. 2020). Tillage practices mainly included contour tillage (TCT), furrow and ridge tillage (TFRT), micro-basins tillage (TMBT), no-tillage (TNT), no-tillage with mulch (TNTM), subsoiling (TSS), intercropping (TIC), rotation (TRT), artificial hoeing and digging (TAHD), and collecting soil to form ridge with no-tillage (TCN). TCT means plowing across a slope and following elevation contour lines. TFRT refers to cultivating along the contour lines on sloping farmland to form a ground with furrows and ridges to keep rainwater and reduce soil erosion. TMBT refers to the construction of small soil ridges in a ditch of a certain distance to form a micro-basin. TNT refers to the method of cultivating the crops without sowing before planting, and sowing directly on the previous stubble field, without using agricultural machinery during the crop growth period. TNTM refers to a farming measure that adds ground cover based on TNT. TSS refers to a farming method that loosens the soil, breaks the bottom of the plow, and improves the structure of the plow layer. TIC refers to the planting method of planting two or more crops in the same field and the same growth period. TRT refers to the planting method of planting different crops on the same field to rotate between seasons and years. TAHD refers to hoeing along the ground surface from the bottom of the slope to the top of the slope or digging holes with a hoe along the contour line on the sloped land. TCN is a unique farming method in the Southwest China purple soil region. It is a comprehensive farming method by gathering soil to build ridges and fertilizing in furrows (Liu et al. 2013b; Liu and Huang 2013; Yang et al. 2018; Niu et al. 2019; Wang et al. 2020a; Wang et al. 2020c; Zhang et al. 2020).

The data collected were mainly distributed in six regions: North China mountainous region (R1), Northeast China black soil region (R2), South China red soil region (R3), Northwest China Loess Plateau region (R4), Southwest China karst region (R5), and Southwest China purple soil region (R6), which are shown in Fig. 1. Due to the geographical environment, the number of soil and water conservation practices implemented in the North China sandstorm region and the Qinghai-Tibet Plateau region is limited, and scientific research on water erosion is rarely reported.

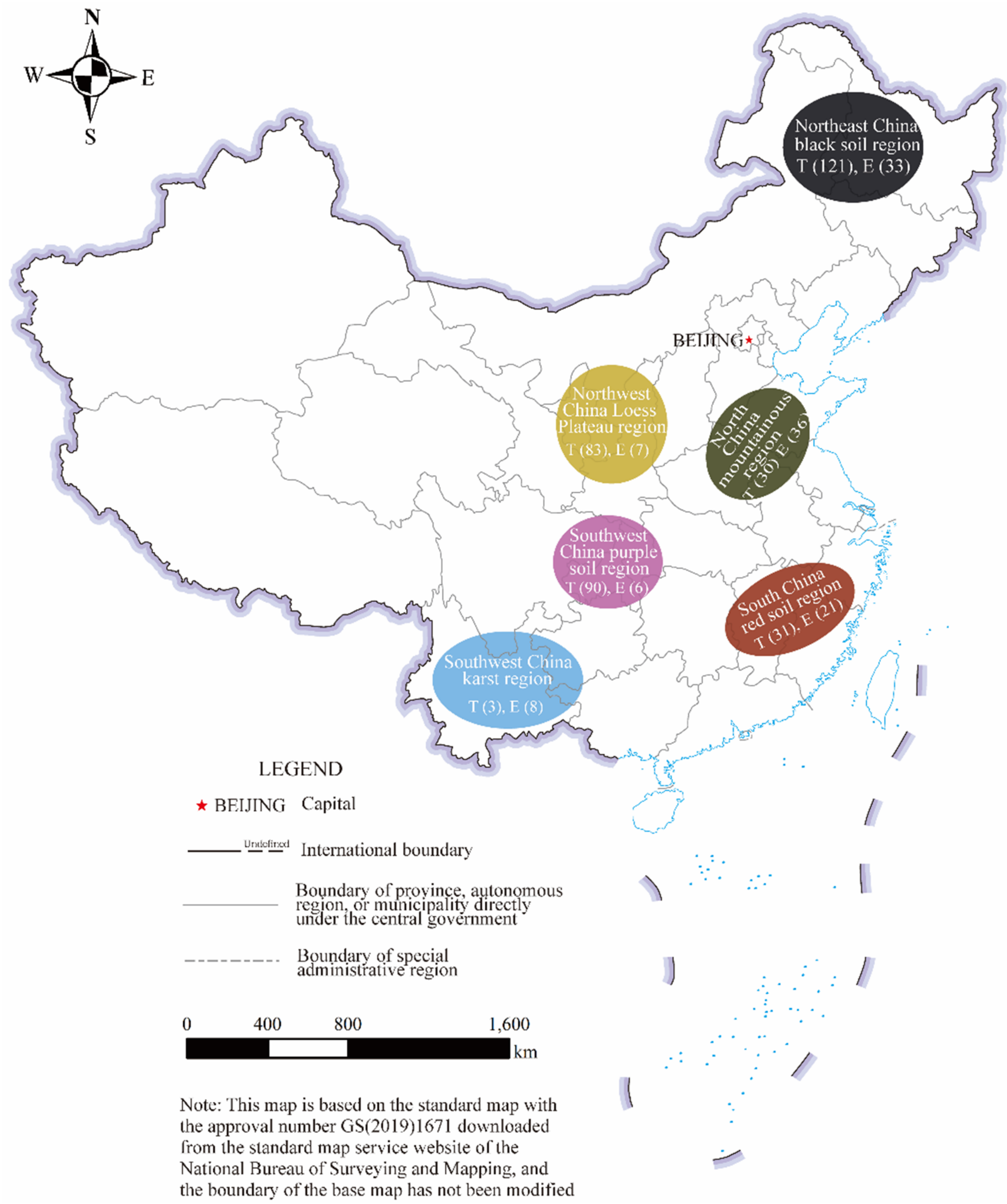

Fig. 1 Geographical distribution and quantitative distribution of the collected database in China.

2.2 Data analysis

The purpose of this study is to compare the E and T factors between different soil and water conservation region. Based on this premise, the correlation analysis and regression analysis were utilized to explore the relationship between the value of practice factor and the runoff plot dimension. The one-way ANOVA was used to compare the slope gradient and length of runoff plots between different soil and water conservation regions to explore the spatial distribution. Finally, according to the analysis results, judge whether the data are comparable.

After ensuring the comparability of the collected data, one-way ANOVA was used to test whether there were significant differences in the value of soil and water conservation practices factors between different soil and water conservation regions. When the collected data do not meet the premise assumption of one-way ANOVA, nonparametric tests were used for analysis.

The geodetector is a set of statistical methods to detect spatial differentiation and reveal the driving force behind it (Wang and Xu 2017). The core idea of this method is that when the independent variable is crucial to the dependent variable, the spatial distribution of the independent variable and the dependent variable should be similar, so the method has outstanding advantages in the field of spatial differentiation research (Wang et al. 2010; Wang and Hu 2012; Li et al. 2017; Ruan et al. 2018; Wang et al. 2018a). The geodetector contains four modules: factor detector, risk detector, interaction detector, and ecological detector. The factor detector is used to detect the spatial differentiation of the dependent variable *Y*, and the q value is used to measure the explanatory ability of the independent variable *X* to the spatial distribution characteristics of the dependent variable *Y* (Wang et al. 2010). The *q* value is between 0-1, the closer the *q* value is 1, the stronger the ability of the independent variable to explain the spatial distribution characteristics of the dependent variable, otherwise, the weaker it is. Interaction detector is used to identify the interaction between different risk factors *Xs*, that is, to evaluate whether the factor *X1* and *X2* together will increase or decrease the explanatory power of the dependent variable *Y* (Wang and Xu 2017). In this study, when there are differences in the practice factor values between different soil and water conservation region, we analyze the intrinsic driving factors of the spatial distribution law of factor values through geodetector. According to the prior knowledge, we divide the reasons for the differences of the same practice in different regions into two categories: one is that the practice specifications may not be uniform when different experimenters conduct research, resulting in differences in the final practice factor value; the other is that there are differences in the influence factors of the practice factor value among the water and soil conservation regions. For the first reason, each practice has a corresponding standard when it is designed. Generally, the specification of a certain practice will be limited within a certain range, and the specifications will not be much different, so the impact on the value of practice factor is not considered in this study. In consideration of the influencing factors of the practice factor values, we selected 8 factors: average annual precipitation from 1980 to 2015, remote sensing monitoring data of crop rotation system (CRS), gravel content in the top layer of soil, sand content, silt content, clay content, soil bulk density, and organic carbon content from the Harmonized World Soil Database (http://www.resdc.cn/, http://bdc.casnw.net/). Among the six soil and water conservation regions, the South China red soil region has the highest average annual precipitation and gravel content. The Southwest China purple soil region has more frequent crop rotation. The Northwest China Loess Plateau region has the highest sand content, the Northeast China black soil region has the highest silt and organic carbon content, and the Southwest China karst region has the highest clay content. Although the soil bulk density of the Southwest China purple soil region is the largest, the difference between several regions is not obvious. Taking the mean of each practice factor values in each soil and water conservation region as *Y* variable and 8 factors as *X* variable, the inherent driving force of the spatial distribution law of the practice factor value was analyzed by geodetector. Among them, CRS adopts the original classification standard, and the remaining 7 factors are divided into 7 levels using equal interval classification.

3 Results

3.1 Analysis of data comparability

3.1.1 Relationship between the value of practices factors and runoff plot dimensions

Since the collected E factors and runoff plot dimensions data complied with abnormal distribution, Kendall's rank correlation coefficient was used to estimate relations between variables. The results showed that there was a positive correlation between the E factors and the slope of the runoff plots, but the correlation is weak (Kendall's tau_b = 0.199, p = 0.016), while there was no significant correlation between E factors and the length of runoff plots (Kendall's tau_b =- 0.004, p = 0.968). Considering the relationship between E factors and the overall dimensions of the runoff plots, this study took E factors as the dependent variable and the slope and length of the runoff plot as the independent variables in regression analysis. The results showed that the regression analysis does not violate the premise assumptions (heteroscedasticity, autocorrelation, and multicollinearity), and the results were meaningful (p <0.05). However, the correlation coefficient is small (R^2 = 0.155), which shows that the regression line has the poor fitting degree to the observed values (Fig. 2).

The T factors and runoff plot dimensions data also complied with abnormal distribution, according to the analysis method for E factors, we got the following results: There was no significant correlation between the T factors and the slope of the runoff plots (Kendall's tau_b =0.01, p = 0.796), similarly, there was no significant correlation between the T factors and the length of the runoff plots (Kendall's tau_b =-0.055, p = 0.152). Regression analysis was carried out with T factors as the dependent variable and runoff plot slope and length as the independent variables. The results showed that there was no significant correlation between T factors and runoff plots slope and length (R^2 = 0.005, p = 0.153) in Fig. 2.

3.1.2 Analysis of runoff plot dimensions

Due to data complied with abnormal distribution, Kruskal-Wallis one-way ANOVA (k sample) as a nonparametric test to compare the slope and length of runoff plots between different soil and water conservation regions. The result showed that there were significant differences in the slope and length of runoff plots between different soil and water conservation regions (Fig. 3).

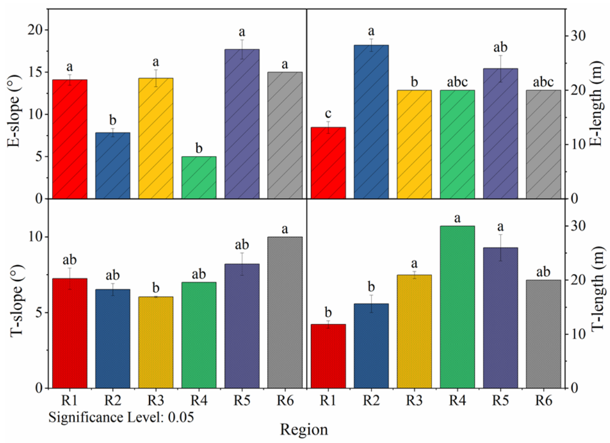

Fig. 3 Comparison of slope and length of runoff plots in six selected regions distributed in China. **Note:** North China mountainous region (R1), Northeast China black soil region (R2), South China red soil region (R3), Northwest China Loess Plateau region (R4), Southwest China karst region (R5), and Southwest China purple soil region (R6). The different letters mean significant difference among different regions.

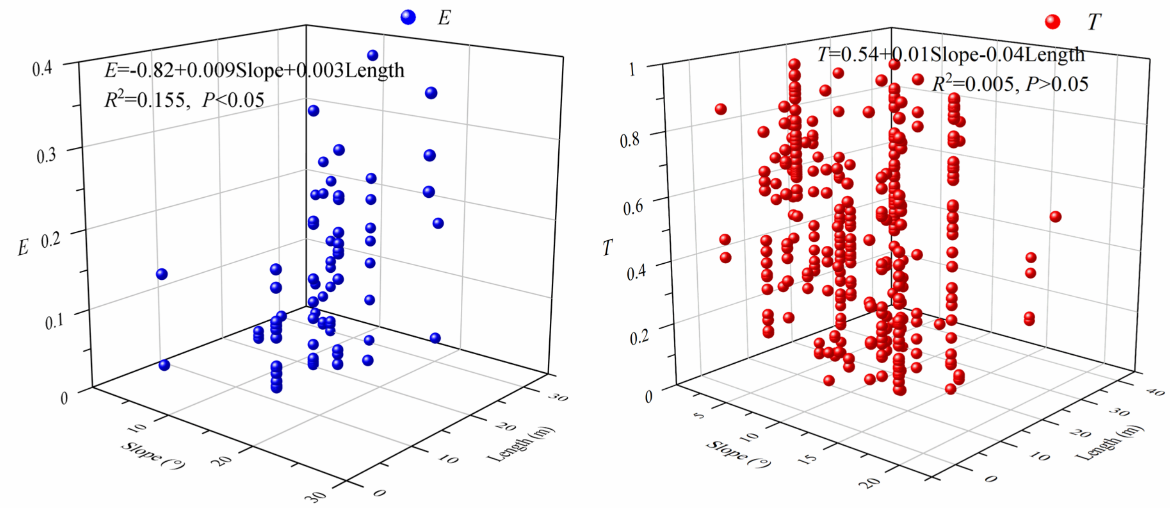

Fig. 2 The relationship between E values and runoff plot dimensions (left) and the relationship between T values and runoff plot dimensions (right).

As shown in Fig. 4, to a certain extent, the distribution of slope and length in runoff plots were the same. Among them, the maximum slope and length of runoff plot were from the Southwest China karst region, while the minimum slope came from the Northeast China black soil region, and the minimum length came from the Northwest China Loess Plateau region. Correlation analysis of the average slope data of each soil and water conservation region extracted from DEM (1 km) and the average slope data of runoff plots showed that the correlation coefficient was 0.853 (p <0.05), indicating that the slope of runoff plots can well represent the true slope of local place. However, in this study, roads and ditches will intercept the slope length and affect the slope length value (Liu et al. 2001), so this study will not include slope length for discussion. Therefore, the practice factors data measured by the runoff plot does not have to be normalized according to the runoff plot dimensions. The collected data are real local factors, which are already comparable.

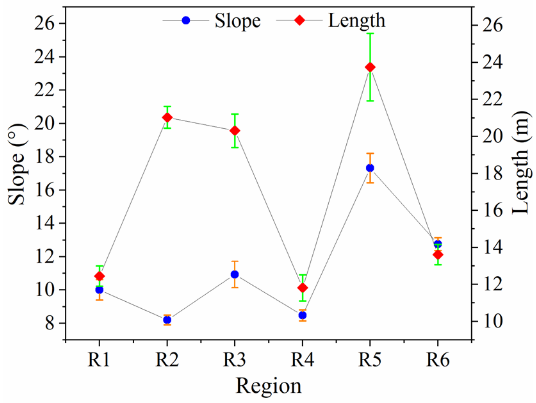

Fig. 4 Average values of slope and length of runoff plots in six selected regions distributed in China. **Notes:** For R1, R2, ···, R6, please see the note under Fig. 3.

3.2 Analysis of E factors

As can be seen from the Fig. 5, there were 7 types of E factors in the North China mountainous region, 6 types in the Northeast China black soil region, 3 types in the South China red soil region, 3 types in the Northwest China Loess Plateau region, 4 types in the Southwest China karst region, 3 types in the Southwest China purple soil region.

Comparing the mean of the same type of E factors, we found that for ELT, the maximum factor value came from the North China mountainous region (0.149), and the maximum factor values of EST, ELBT, ECT, and ETD all came from the North China mountainous region, with values of 0.621, 0.352, 0.503, and 0.185. The maximum EFS factor value came from the Northwest China Loess Plateau region (0.203). The EFR values of the Southwest China karst

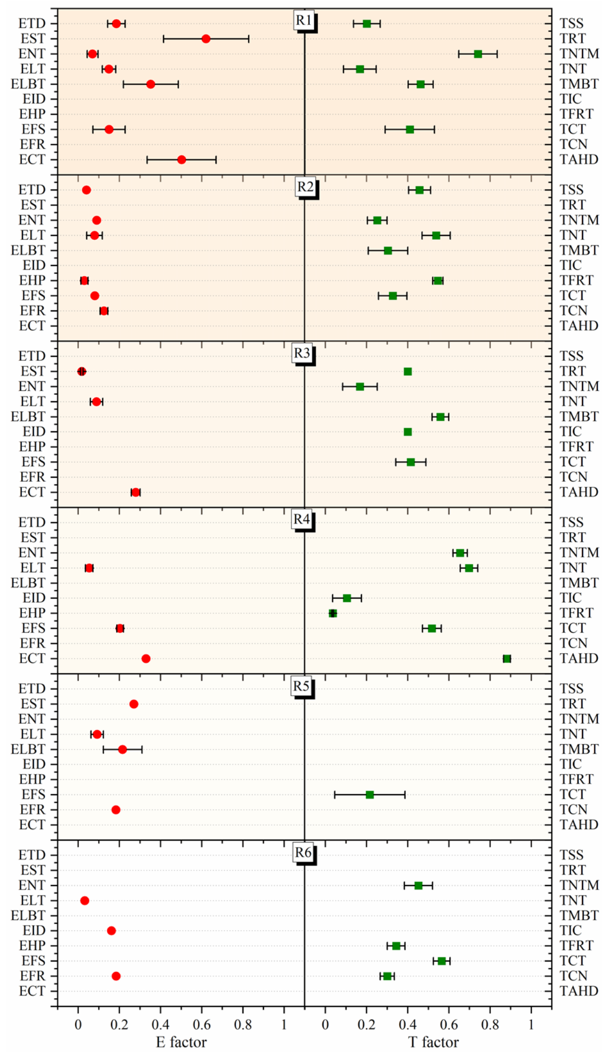

Fig. 5 The values of engineering-control and tillage practices factors in six selected regions distributed in China. **Notes:** For R1, R2, ..., R6, please see the note under Fig. 3. Abbreviations on the left side of the figure represent the engineering-control practices. ETD: tree disk; EST: sloped terrace; ENT: narrow terrace; ELT: level terrace; ELBT: level bench terrace; EID: intercepting ditch; EHP: horizontal pit; EFS: fish scale pit; EFR: field ridge; ECT: contour trench.

Abbreviations on the right side of the figure represent the tillage practices. TSS: subsoiling; TRT: rotation; TNTM: no-tillage with mulch; TNT: no-tillage; TMBT: micro-basins tillage; TIC: intercropping; TFRT: furrow and ridge tillage; TCT: contour tillage; TCN: collecting soil to form ridge with no-tillage; TAHD: artificial hoeing and digging.

region and the Southwest China purple soil region were equal and the highest, which was 0.184. The maximum ENT value came from the Northeast China black soil region, with a value of 0.090. The minimum ELT value was from the Southwest China purple soil region, with a value of 0.032., and the minimum values of EST and ECT were from the South China red soil region, with values of 0.018 and 0.279, respectively. The minimum values of EFS, EFR, and ETD were all from the Northeast China black soil region, with values of 0.080, 0.125, and 0. 040. The minimum ENT factor value was 0.069, which was derived from the North China mountainous region, and the minimum ELBT factor value came from the Southwest China karst region, with a value of 0.216. EHP and EID only existed in a single soil and water conservation regions, so there was no discussion about them.

Due to statistical data limitations, only the ELBT values met the premise of one-way ANOVA. Therefore, ELBT used one-way ANOVA and the other engineering-control practices data used nonparametric tests to evaluate whether there were significant differences among different water and soil conservation regions. From Table 1, it was apparent that there was no significant difference in each water and soil conservation regions (p>0.05).

Table 1 Significance of engineering-control and tillage practices factor values of the statistical analysis

Engineering-control practices	Significance	Tillage practices	Significance
ELT	0.134	TCT	0.036
EST	0.117	TFRT	0.000
EFS	0.677	TMBT	0.074
EFR	0.779	TNTM	0.000
ENT	0.546	TIC	0.180
ELBT	0.559	TNT	0.000
ECT	0.165	TSS	0.008
ETD	0.18	-	-

Note: For the meaning of abbreviations, please see the note under Fig. 5.

3.3 Analysis of T factors

As can be seen from Fig. 5, there were 5 types of T factors in the North China mountainous region, 6 types in the Northeast China black soil region, 5 types in the South China red soil region, 6 types in the Northwest China Loess Plateau region, 1 types in the Southwest China karst region, 4 types in the Southwest China purple soil region.

Comparing the mean of the same type of T factors, the results showed that the maximum TCT practice factor value was from the Southwest China purple soil region, with a value of 0.565, while the maximum values of TFRT and TSS were from the Northeast China black soil region, with values of 0.546 and 0.457, respectively. The maximum TMBT and TIC factor values were from the South China red soil region, with values of 0.558 and 0.400, respectively. The maximum TNT factor value was from the Northwest China Loess Plateau region, with a value of 0.698, and the maximum TNTM value was 0.741, from the North China mountainous region. The minimum TCT practice factor value was from the Southwest China karst region, with a value of 0.216. The minimum factor values of TFRT and TIC were from the Northwest China Loess Plateau region, with values of 0.035 and 0.105, respectively. The minimum TMBT factor value came from the Northeast China black soil region, with a value of 0.304. The minimum factor values of TNT and TSS came from the North China mountainous region, with values of 0.167 and 0.201, respectively. The minimum TNTM factor value came from the South China red soil region, with a value of 0.168. TRT, TAHD, and TCN only existed in a single soil and water conservation regions, so there was no discussion about them.

The results of the variance analysis hypothesis test showed that only the data of TNT and TSS met the requirements. Therefore, in this study, the factor values of TNT and TSS were analyzed by one-way ANOVA, and the data of other tillage practices factors were analyzed by nonparametric tests to determine whether there were significant differences in different regions. The results were set out in Table 1.

From the Table 1 we can see that except for TIC, there were significant differences in other tillage practices between different soil and water conservation regions (among them, TFRT, TNTM, TNT, and TSS were highly significant (p<0.01), TCT was significant (0.01<p<0.05), and TMBT was generally significant (p<0.1)).

3.4 Analysis of internal driving factors of T factors

In this study, the larger the q value in the result of the factor detector, the greater the controlling power of the influencing factor on the spatial distribution of the T factors. The results of the geodetector showed that the 8 influencing factors of

TCT had small q values, and the maximum q value came from the silt content, which was 0.081. The q value of the influencing factors of TFRT was different, the interpretive ability of gravel content to the spatial distribution of TFRT values reached 19.1%, while the interpretive ability of CRS was only 4.2%. Overall, each factor had a relatively strong ability to interpret TMBT values in spatial distribution. Among them, precipitation had the highest q value of 0.690, while the average q value can reach 0.225. Among the influencing factors of TNT, CRS had the strongest explanation ability for the spatial distribution of factor values, at 18.2%, and the second strongest influencing factor was precipitation, with an explanation ability of 13.7%, besides, the other factors had less explanatory power, no more than 7.5%. Among the influencing factors of TNTM, precipitation had an explanatory power of 35.1% on the spatial distribution of factor values. The dominant factor for the spatial distribution law of the TSS factor value was CRS, and the q value is 0.269 (Fig. 6).

However, in general, the single factor had limited ability to explain the spatial distribution of T factors, and the results of the interaction detector can analyze the influence of the interaction of two factors on the spatial distribution of T factors. Table 2 was the interactive form of the top three interpretation ability.

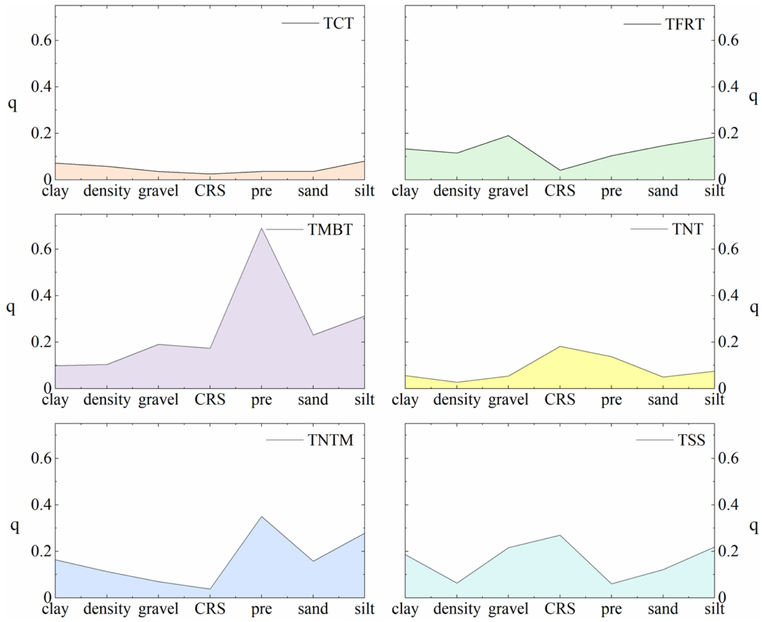

Fig. 6 Results of factor detector (In all results, organic carbon (p > 0.05) is not included in the discussion). **Note:** For the meaning of abbreviations, please see the note under Fig. 5, and the meaning of each parameter of the abscissa is clay content, soil bulk density, gravel content, crop rotation system, average annual precipitation from 1980 to 2015, sand content, and silt content.

4 Discussion

4.1 Comparability of data

The correlation and regression analysis results showed that the correlation between the practice factors values and the runoff plot dimensions was very weak or even that there was no significant correlation. According to the definitions of E and T, their values come from the ratio of soil loss in two runoff plots with the same dimensions, so the influence from runoff plot dimensions had been eliminated in the calculation (Liu et al. 2002). At the same time, one of the E and T factors sources is directly given in the publication, and the second source is the results of the first national water conservancy survey. These two parts of E and T factors have been recognized by the public. The third E and T factors source is calculated based on the sediment reduction effect of soil and water conservation practices, and the prerequisite for calculating the effect of sediment reduction is to ensure that the dimensions of runoff plots with implemented measures and those of runoff

Table 2 The interactive form of the top three interpretation ability

Tillage practices	TCT	TFRT	TMBT	TNT	TNTM	TSS
Interaction1	precipitation ∩ silt	clay ∩ gravel	CRS ∩ precipitation	CRS ∩ precipitation	gravel ∩ precipitation	CRS ∩ silt
q	0.224	0.445	0.764	0.268	0.514	0.419
Interaction2	gravel ∩ silt	gravel ∩ silt	precipitation ∩ silt	CRS ∩ silt	CRS ∩ precipitation	gravel ∩ silt
q	0.206	0.438	0.763	0.240	0.472	0.412
Interaction3	gravel ∩ clay	gravel ∩ sand	gravel ∩ precipitation	CRS ∩ sand	precipitation ∩ silt	sand ∩ silt
q	0.194	0.402	0.751	0.222	0.447	0.412

Note: For the meaning of abbreviations, please see the note under Fig. 5.

plots without measures are unified. Therefore, there is no need to unify the dimensions of runoff plots, which is consistent with previous studies (Guo et al. 2013).

Analysis of the dimensions of runoff plots showed that there were significant differences between different region, and the slope of the runoff plots are highly correlated with the local slope. What stands out in Fig. 4 is that the slope of the runoff plots in the Southwest China karst region was larger than that of other regions. The reason is that as a typical representative of the surrounding area, runoff plots are generally built based on local terrain, while because of the high population density, the cultivated lands in this region are characterized by steep slopes and thin topsoil, of which more than 80% of the farmland is located on slopes above 6 ° (Zhang et al. 2018b). The reason why the slope of the Northeast China black soil region was smaller than other regions is that the terrain in this area is gently undulating, the slope is generally below 7°, and mostly less than 4° (Shi et al. 2019). To sum up, the dimensions of runoff plots in each water and soil conservation zone are consistent with the local topography, and the E and T factors calculated for the corresponding runoff plots are local real values, and the data are comparable.

4.2 E factors

The sediment reduction mechanism of engineering-control practices are as follows: The practices implemented changes the continuity of the original slope, making it flat or reverse slope (such as ELT, EST, ENT, and ELBT), which greatly shortened the slope length, at the same time cut off the slope runoff, undermined the runoff formation conditions, prolonged the infiltration time and increased soil infiltration, to avoid the collection of runoff on the slope at the downhill position, thereby preventing the soil from being washed away by water (such as EFS, EFR, ECT, ETD, EHP, and EID), and finally achieving water and soil conservation (Fu et al. 2010a; Li et al. 2014; Liu et al. 2014; Tarolli et al. 2014). Based on the above-mentioned mechanism, we speculate that the reason why there was no significant difference in E factors among different soil and water conservation regions is that: (1) Although there were differences in the natural environment of different regions, the engineering-control practices have good soil and water conservation effect, and the engineering-control practices implemented weakened other influence factors. (2) There are many restrictions on the construction of runoff plots for engineering-control practices, and not all engineering-control practices are suitable for research on runoff plots, so there was little data about it. Comparing different practices in the same region, there was no significant difference between them; therefore, when implementing engineering-control practices, it can be selected according to the actual situation (location, project budget, etc.).

4.3 T factors

The analysis of the T factor shows that in this study, except for TIC, which did not have significant differences between the regions, other tillage practices were significantly different among the regions. Therefore, when calculating soil erosion on a national or larger scale, the same practices should not be assigned the same value across the country, but should be appropriately selected based on regional differences (the value can be obtained by referring to the results of this study). At the same time, when choosing tillage practices in each water and soil conservation region, practices with better sediment reduction benefits should also be selected according to the regional environmental conditions. There are two reasons why there are no significant differences in TIC values in various regions: first, the amount of statistical data is small and may not be highly representative; second, TIC has various forms and specifications are not as uniform as other practices, so it is difficult to clarify the differences between soil and water conservation regions (Group 1977).

The results of the factor detector were shown that the leading factors for the spatial differentiation of different T factors were not the same, but the explanatory power of the leading factor is relatively weak. Combining the results of the interaction detector, we found that the interaction of rainfall, soil texture-related factors (gravel, silt, sand, and clay), and CRS has a strong ability to explain the difference in the spatial distribution of T factors. Among them, the erosion of erosive rainfall and the displacement of soil particles caused by surface runoff is the most fundamental sources of power for water erosion on slopes (Wang et al. 2013; Rutebuka et al. 2020; Talchabhadel et al. 2020). Soil texture is an important consideration affecting soil permeability (Sajjadi et al. 2016; Marquart et al. 2020). CRS reflects the frequency of planting and harvesting of crops within a year (Xu and Liu 2014). The three interaction methods with the strong ability to explain the spatial distribution of TCT factors show that the interaction between precipitation and soil texture (mainly composed of silt, gravel, and clay) has a great impact on it. TCT achieves the objective of soil and water conservation by effectively blocking surface runoff and increasing penetration (Liu and Huang 2013; Ricci et al. 2020). In general, the amount of precipitation determines whether TCT has the ability to intercept, and the soil texture affects the permeability. Compared with TCT, the main influencing factors of TFRT do not include precipitation, but are all related to soil texture. The reason is that the existence of furrows in TFRT (Xu et al. 2018; Wang et al. 2020b) can better intercept surface runoff formed by precipitation, so that precipitation is no longer the dominant factor affecting TFRT values, and whether the intercepted runoff can be effectively infiltrated is still greatly affected by soil texture. Based on traditional furrow and ridge cultivation, TMBT refers to the construction of small soil ridges in a ditch of a certain distance to form a micro-basins (Liu et al. 2013b). Due to the construction of tiny soil ridge in the ditch, once the precipitation is too large, it is easy to form lateral runoff and cause more serious soil erosion. Besides, TMBT needs an intense tillage operation to change the microtopography, which is easy to cause additional soil erosion during the implementation of this practice, that is, during the sowing and harvesting cultivation, and the benefit of the practice is affected (Zhang et al. 2010; Jia et al. 2019). The soil texture is also a key factor that determines whether the blocked precipitation can effectively infiltrate, so the interaction between precipitation, CRS, and soil texture had greater control over the spatial differentiation of TMBT values. TNT refers to the method of cultivating the crops without sowing before planting, and sowing directly on the previous stubble field, without using agricultural machinery during the crop growth period (Liu et al. 2013b; Wang et al. 2020a). The damage to soil particles during sowing and harvesting is the most important human factor affecting soil erosion, and long-term TNT may increase bulk density and decrease macroporosity, thereby decreasing sorptivity and hydraulic conductivity (Mohammadshirazi et al. 2017; Jia et al. 2019). Also, precipitation as the erosion power and soil texture as the infiltration power have a dominant role in the spatial distribution of TNT values. Therefore, the dominant interaction methods for the spatial distribution of TNT values were the interactions of CRS and precipitation and soil texture. Compared with TNT, TNTM can reduce the chance of raindrops directly hitting the surface to a certain extent (Sun et al. 2010). Therefore, the dominant interaction methods of influencing factors of TNTM values were the interaction of precipitation and soil texture and CRS. TSS can loosen the soil, break the bottom of the plow, improve the permeability of the soil, and promote root growth to achieve the purpose of soil and water conservation (Zhang et al. 2015; Wang et al. 2020a). The most influential factors are soil texture and when to implement practices. Therefore, among the influencing factors of its T factor, the dominant interaction methods were the interaction between soil particle contents and CRS.

5 Conclusions

There were significant differences in the dimensions of runoff plots between different soil and water conservation regions. The reason is that when selecting a site to build a runoff plot, it is mostly based on local topography. Therefore, the statistical data can truly reflect the local factor values, and the data are comparable. Due to the good water and soil conservation effect of the engineering-control practices, the regional differences of other factors have been weakened, and due to the limitations of the implementation practices, the data of the E factors are limited. Based on the above reasons, there was no significant difference in E factors between different soil and water conservation regions. Owing to differences in environmental conditions, T factors were significantly different between different regions. The principle of soil and water conservation of different tillage practices is unique, so the internal driving force of spatial distribution of their T factors is also different. The results of this paper can provide a reference for the determination of E and T factor when CSLE is used in the national soil erosion survey. For the same kind of engineering-control practices, the same E factor can be adopted nationwide, but for tillage practices, the T factor should be determined by distinct regions. At the same time, we also found that the data of runoff plots available in various places is limited, so more research based on runoff plots should be carried out in the future, and relevant departments should also strengthen the construction and management of runoff plots.

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References

Bai L, Wang N, Jiao J, et al. (2020) Soil erosion and sediment interception by check dams in a watershed for an extreme rainstorm on the Loess Plateau, China. Int J Sediment Res 35: 408-416. https://doi.org/10.1016/j.ijsrc.2020.03.005

Batista PVG, Davies J, Silva MLN, et al. (2019) On the evaluation of soil erosion models: Are we doing enough? Earth-Sci Rev 197: 102898. https://doi.org/10.1016/j.earscirev.2019.102898

Bi X (2007) Studies on the Soil Loss Equation of the slope in the mountainous area of Beijing. PhD thesis, Beijing Forestry University, Beijing, China.

Boyle JF, Plater AJ, Mayers C, et al. (2011) Land use, soil erosion, and sediment yield at Pinto Lake, California: Comparison of a simplified USLE model with the lake sediment record. J Paleolimn 45: 199-212. https://doi.org/10.1007/s10933-010-9491-8

Cao Z, Zhang Z, Zhang K, et al. (2020) Identifying and estimating soil erosion and sedimentation in small Karst watersheds using a composite fingerprint technique. Agric Ecosyst Environ 294: 106881. https://doi.org/10.1016/j.agee.2020.106881

Chen G, Fan H, Chen H, et al. (2006) Benefits of sediment reduction of soil conservation practices in the Black Region of Northeast China. Sci Soil Water Conserv 4(6): 13-17. (in Chinese).

Cheng L, Yang Q, Xie H, et al. (2009) GIS and CSLE based quantitative assessment of soil erosion in Shaanxi ,China. J Soil Water Conserv 23(5): 61-66. (In Chinese).

Das B, Bordoloi R, Thungon LT, et al. (2020) An integrated approach of GIS, RUSLE and AHP to model soil erosion in West Kameng watershed, Arunachal Pradesh. J Earth Syst Sci 129. https://doi.org/10.1007/s12040-020-1356-6

Demirci A, Karaburun A (2011) Estimation of soil erosion using RUSLE in a GIS framework: a case study in the Buyukcekmece Lake watershed, Northwest Turkey. Environ Earth Sci 66: 903-913. https://doi.org/10.1007/s12665-011-1300-9

Duan X, Bai Z, Rong L, et al. (2020) Investigation method for regional soil erosion based on the Chinese Soil Loss Equation and high-resolution spatial data: Case study on the mountainous Yunnan Province, China. Catena 184: 104237. https://doi.org/10.1016/j.catena.2019.104237

Fan J, Wang N, Chen G, et al. (2011) Practice factor of soil and water conservation in Northeastern China. Sci Soil Water Conserv 9(3): 75-78+92. (In Chinese).

Fu B, Wang YK, Xu P, et al. (2012) Assessment of the performance of WEPP in purple soil area with simulated rainfall experiments. J Mt Sci 9: 570-579. https://doi.org/10.1007/s11629-012-2194-z

Fu S, Liu B, Zhang G, et al. (2010) Fish-scale pits reduce runoff and sediment. Trans ASABE 53: p.157-162. https://doi.org/10.13031/2013.29508

Fu S, Wu J, Duan S, et al. (2001) Effect of soil and water conservation practice on soil erosion at Shixia watershed. J Soil Water Conserv 15(2): 21-24. (in Chinese).

Group XUARCRSSRC (1977) Introduce several intercropping methods. Xinjiang Agric Sci (3): 16-17. (In Chinese).

Guo Q, Liu B, Zhu S, et al. (2013) Factors of main soil and water conservation farming measures in China. Soil Water Conserv China (10): 22-26. (in Chinese).

Guo W, Kang H, Wang W, et al. (2020) Erosion - reducing effects of revegetation and fish - scale pits on steep spoil heaps under concentrated runoff on the Chinese Loess Plateau. Land Degrad Dev 31:2846-2857. https://doi.org/10.1002/ldr.3643

Helming K, Rubio JL, Boardman J (2006) Soil erosion across Europe: Research approaches and perspectives. Catena 68: 71-72. https://doi.org/10.1016/j.catena.2006.03.008

Huang CL, Yang QK, Cao XY, et al. (2020) Assessment of the soil erosion response to land use and slope in the Loess Plateau-A case study of Jiuyuangou. Water 12: 14. https://doi.org/10.3390/w12020529

Jia L, Zhao W, Zhai R, et al. (2019) Regional differences in the soil and water conservation efficiency of conservation tillage in China. Catena 175: 18-26. https://doi.org/10.1016/j.catena.2018.12.012

Kihara J, Bolo P, Kinyua M, et al. (2020) Soil health and ecosystem services: Lessons from sub-Sahara Africa (SSA). Geoderma 370: 114342. https://doi.org/10.1016/j.geoderma.2020.114342

Li J, Lu D, Xu C, et al. (2017) Spatial heterogeneity and its changes of population on the two sides of Hu Line. Acta Geogr Sin 72: 148-160. (in Chinese).

Li XH, Yang J, Zhao CY, et al. (2014) Runoff and sediment from orchard terraces in Southeastern China. Land Degrad Dev 25: 184-192. https://doi.org/10.1002/ldr.1160

Li Z, Fu S, Liu B (2012) Sampling program of water erosion inventory in the first national water resource survey. Sci Soil Water Conserv 10(1): 77-81. (In Chinese).

Li Z, Ning K, Chen J, et al. (2020) Soil and water conservation effects driven by the implementation of ecological restoration projects: Evidence from the red soil hilly region of China in the last three decades. J Clean Prod 260: 121109. https://doi.org/10.1016/j.jclepro.2020.121109

Lin Z, Li Z (2019) 2018 National soil and water loss dynamic monitoring results and its enlightenment. Soil Water Conserv China (12): 1-4. (In Chinese).

Liu B, Guo S, Li Z, et al. (2013a) Sampling survey of water erosion in China. Soil Water Conserv China (10): 26-34. (In Chinese).

Liu B, Liu Y, Zhang K, et al. (2013b) Classification for soil conservation practices in China. J Soil Water Conserv 27(2): 80-84. (In Chinese).

Liu B, Song C, Shi Z, et al. (2015) Soil and water conservation measures for horizontal terraces in rocky mountain area of Southwest China. Soil Water Conserv China (4): 36-39. (In Chinese).

Liu B, Xie Y, Li Z, et al. (2020a) The assessment of soil loss by water erosion in China. Int Soil Water Conse 8: 430-439. https://doi.org/10.1016/j.iswcr.2020.07.002

Liu B, Xie Y, Zhang K (2001) Soil erosion prediction model. China Science and Technology Press, Beijing, China.

Liu B, Zhang K, Yun X (2002) An empirical soil Loss equation. 12th ISCO Conference.

Liu B, Zhang XJ, Storm DE, et al. (2017) Evaluating the WEPP rangeland hillslope model using cesium-137 estimated spatial erosion data. Vadose Zone J 16: 1-11. https://doi.org/10.2136/vzj2017.03.0067

Liu H, Huang Q (2013) Adoption and continued use of contour cultivation in the highlands of southwest China. Ecol Econ 91: 28-37. https://doi.org/10.1016/j.ecolecon.2013.03.015

Liu L, Liu H, Fu S, et al. (2020b) Feasibility of magnetite powder as an erosion tracer for main soils across China. J Soils Sediments 20: 2207-2216. https://doi.org/10.1007/s11368-020-02574-7

Liu P-L, Tian J-L, Zhou P-H, et al. (2004) Stable rare earth element tracers to evaluate soil erosion. Soil Tillage Res 76: 147-155. https://doi.org/10.1016/j.still.2003.09.005

Liu X, Wang F, Yang S, et al. (2014) Sediment reduction effect of level terrace in the hilly-gully region in the Loess Plateau. J Hydraul Eng 45: 793-800. (In Chinese)

Lizaga I, Latorre B, Gaspar L, et al. (2020) Consensus ranking as a method to identify non-conservative and dissenting tracers in fingerprinting studies. Sci Total Environ 720:

137537. https://doi.org/10.1016/j.scitotenv.2020.137537
Ma Y, Wang J, Zhang C, et al. (2018) Evaluation of soil erosion based on CSLE model in Zhifanggou watershed of Northern Shaanxi province. Bull Soil Water Conserv 38: 95-102. (In Chinese).
Mallick J, Alashker Y, Mohammad SA-D, et al. (2014) Risk assessment of soil erosion in semi-arid mountainous watershed in Saudi Arabia by RUSLE model coupled with remote sensing and GIS. Geocarto Int 29: 915-940. https://doi.org/10.1080/10106049.2013.868044
Marquart A, Eldridge DJ, Geissler K, et al. (2020) Interconnected effects of shrubs, invertebrate - derived macropores and soil texture on water infiltration in a semi - arid savanna rangeland. Land Degrad Dev 31: 2307-2318. https://doi.org/10.1002/ldr.3598
Mohammadshirazi F, Mclaughlin RA, Heitman JL, et al. (2017) A multi-year study of tillage and amendment effects on compacted soils. J Environ Manage 203: 533-541. https://doi.org/10.1016/j.jenvman.2017.07.031
Mondal A, Khare D, Kundu S (2016) A comparative study of soil erosion modelling by MMF, USLE and RUSLE. Geocarto Int 33: 89-103. https://doi.org/10.1080/10106049.2016.1232313
Niu X, Qin F, Yang Z, et al.(2019) Efficacy of several tillages in conserving soil and water in slopping areas at the Black Soil in Northwest China. J Irrig Drain 38: 67-72. (In Chinese).
PRC MoWRot (2013) Water and soil conservation bulletin of the first national water conservancy survey. Soil Water Conserv China (10): 2-3+11. (In Chinese).
Ricci GF, Jeong J, De Girolamo AM, et al. (2020) Effectiveness and feasibility of different management practices to reduce soil erosion in an agricultural watershed. Land Use Pol 90: 104306. https://doi.org/10.1016/j.landusepol.2019.104306
Ruan W, Zheng X, Li Y, et al. (2018) Spatial distribution characteristics and driving mechanism of "Hu Line" in Inbound Tourism in China. Econ Geogr 38: 181-189+199. (In Chinese).
Rutebuka J, De Taeye S, Kagabo D, et al. (2020) Calibration and validation of rainfall erosivity estimators for application in Rwanda. Catena 190: 104538. https://doi.org/10.1016/j.catena.2020.104538
Sajjadi S-A-H, Mirzaei M, Nasab AF, et al. (2016) Effect of soil physical properties on infiltration rate. Geomech Eng 10: 727-736. https://doi.org/10.12989/gae.2016.10.6.727
Shi W, Huang M, Barbour SL (2018) Storm-based CSLE that incorporates the estimated runoff for soil loss prediction on the Chinese Loess Plateau. Soil Tillage Res 180: 137-147. https://doi.org/10.1016/j.still.2018.03.001
Shi Y, Chen S, Liu J, et al. (2019) Study on effect of different cultivation measures of soil and water conservation in Northeast China Black Soil Region. Soil Water Conserv China (1): 47-49. (In Chinese).
Song C, Qu Y, Zhang X, et al. (2018) Retrospect of contour bund for soil and water conservation. Soil Crop Sci 7: 1-12. (in Chinese).
Srivastava A, Brooks ES, Dobre M, et al. (2020) Modeling forest management effects on water and sediment yield from nested, paired watersheds in the interior Pacific Northwest, USA using WEPP. Sci Total Environ 701: 134877. https://doi.org/10.1016/j.scitotenv.2019.134877
Sun J, Liu M, Li L, et al. (2010) Effects of tillage mode on soil erosion of rain-fed crop land in Inner Mongolia. Chinese J Ecol 29: 485-490. (In Chinese).
Talchabhadel R, Prajapati R, Aryal A, et al. (2020) Assessment of rainfall erosivity (R-factor) during 1986-2015 across Nepal: a step towards soil loss estimation. Environ Monit Assess 192: 293. https://doi.org/10.1007/s10661-020-8239-9
Tarolli P, Preti F, Romano N (2014) Terraced landscapes: From an old best practice to a potential hazard for soil degradation due to land abandonment. Anthropocene 6: 10-25. https://doi.org/10.1016/j.ancene.2014.03.002
Verheijen FGA, Jones RJA, Rickson RJ, et al. (2012) Concise overview of European soil erosion research and evaluation. Acta Agric Scand Sect B-Soil Plant Sci 62: 185-190. https://doi.org/10.1080/09064710.2012.697573
Wang B, Fang S, Song Y, et al. (2013) Research for standard of erosive rainfall on Quaternary Red Soil area in north of Jiangxi province in China. Trans Chin Soc Agric Eng 29: 100-106. (In Chinese).
Wang F, Liu Y, Kong X, et al. (2018a) Spatial and temporal variation of grain production and its influencing factors at the county level in China. Econ Geogr 38: 142-151. (In Chinese).
Wang JF, Hu Y (2012) Environmental health risk detection with GeogDetector. Environ Modell Softw 33: 114-115. https://doi.org/10.1016/j.envsoft.2012.01.015
Wang J, Pan Z, Pan F, et al. (2020a) The regional water-conserving and yield-increasing characteristics and suitability of soil tillage practices in Northern China. Agric Water Manage 228: 105883. https://doi.org/10.1016/j.agwat.2019.105883
Wang J, Xu C (2017) Geodetector: Principle and prospective. Acta Geogr Sin 72: 116-134. (In Chinese). https://doi.org/10.11821/dlxb201701010
Wang JF, Li XH, Christakos G, et al. (2010) Geographical detectors - Based health risk assessment and its application in the Neural Tube defects study of the Heshun region, China. Int J Geogr Inf Sci 24: 107-127. https://doi.org/10.1080/13658810802443457
Wang L, Qu C, Zhao G (2018b) Quantitative assessment of regional soil erosion based on Chinese Soil Loss Equation model. Bull Soil Water Conserv 38: 122-125+130. (In Chinese).
Wang L, Zheng F, Zhang XJ, et al. (2020b) Discrimination of soil losses between ridge and furrow in longitudinal ridge-tillage under simulated upslope inflow and rainfall. Soil Tillage Res 198: 104541. https://doi.org/10.1016/j.still.2019.104541
Wang S, Wang H, Hafeez MB, et al. (2020c) No-tillage and subsoiling increased maize yields and soil water storage under varied rainfall distribution: A 9-year site-specific study in a semi-arid environment. Field Crop Res 255: 107867. https://doi.org/10.1016/j.fcr.2020.107867
Wang X, Zhao X, Zhang Z, et al. (2016a) Assessment of soil erosion change and its relationships with land use/cover change in China from the end of the 1980s to 2010. Catena 137: 256-268. https://doi.org/10.1016/j.catena.2015.10.004
Wang Z, Zhang C, Ji Q, et al. (2016b) Soil and water conservation regionalization and its application in China. Sci Soil Water Conserv 14: 101-106. (In Chinese).
Xu X, Liu L (2014) Cropping rotation system data of China. Acta Geogr Sin 69: 49-53. (In Chinese).
Xu X, Zheng F, Wilson GV, et al. (2018) Comparison of runoff and soil loss in different tillage systems in the Mollisol region of Northeast China. Soil Tillage Res 177: 1-11. https://doi.org/10.1016/j.still.2017.10.005
Yang M, Zhao Y, Yang H, et al. (2018) Suppression of weeds and weed seeds in the soil by stubbles and no-tillage in an arid maize-winter wheat-common vetch rotation on the Loess Plateau of China. J Arid Land 10: 809-820. https://doi.org/10.1007/s40333-018-0063-5
Zhang GH, Tang MK, Zhang XC (2010) Temporal variation in soil detachment under different land uses in the Loess Plateau of China. Earth Surf Process Landf 34: 1302-1309. https://doi.org/10.1002/esp.1827
Zhang H, Zhang R, Qi F, et al. (2018a) The CSLE model based soil erosion prediction: Comparisons of sampling density and extrapolation method at the county level. Catena 165: 465-472. https://doi.org/10.1016/j.catena.2018.02.007
Zhang R, Yang H, Gao J, et al. (2015) Effect of subsoiling on root morphological and physiological characteristics of spring maize. Trans Chin Soc Agric Eng 31: 78-84. (In Chinese).
Zhang X-y, Wu K-x, Fullen MA, et al. (2020) Synergistic effects of vegetation layers of maize and potato intercropping on soil erosion on sloping land in Yunnan Province, China. J Mt Sci 17: 423-434. https://doi.org/10.1007/s11629-019-5392-0
Zhang X, Hu M, Guo X, et al. (2018b) Effects of topographic factors on runoff and soil loss in Southwest China. Catena 160: 394-402. https://doi.org/10.1016/j.catena.2017.10.013
Zheng F, Zhang XC, Wang J, et al. (2020) Assessing applicability of the WEPP hillslope model to steep landscapes in the northern Loess Plateau of China. Soil Tillage Res 197: 104492. https://doi.org/10.1016/j.still.2019.104492