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Original Research Article

Improved USLE-*K* factor prediction: A case study on water erosion areas in China

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ABSTRACT

Soil erodibility (*K*-factor) is an essential factor in soil erosion prediction and conservation practises. The major obstacles to any accurate, large-scale soil erodibility estimation are the lack of necessary data on soil characteristics and the misuse of variable *K*-factor calculators. In this study, we assessed the performance of available erodibility estimators Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Erosion Productivity Impact Calculator (EPIC) and the Geometric Mean Diameter based (Dg) model for different geographic regions based on the Chinese soil erodibility database (CSED). Results showed that previous estimators overestimated almost all *K*-values. Furthermore, only the USLE and Dg approaches could be directly and reliably applicable to black and loess soil regions. Based on the nonlinear best fitting techniques, we improved soil erodibility prediction by combining Dg and soil organic matter (SOM). The NSE, R^2 and RE values were 0.94, 0.67 and 9.5% after calibrating the results independently; similar model performance was showed for the validation process. The results obtained via the proposed approach were more accurate that the former *K*-value predictions. Moreover, those improvements allowed us to effectively establish a regional soil erodibility map (1:250,000 scale) of water erosion areas in China. The mean *K*-value of Chinese water erosion regions was 0.0321 (t ha h)·(ha MJ mm)$^{-1}$ with a standard deviation of 0.0107 (t ha h)·(ha MJ mm)$^{-1}$; *K*-values present a decreasing trend from North to South in water erosion areas in China. The yield soil erodibility dataset also satisfactorily corresponded to former *K*-values from different scales (local, regional, and national).

1. Introduction

Soil erosion is a serious environmental, economic, and social problem (Wang, Zheng, Darboux, & Römkens, 2013a). It not only contributes to severe land degradation and economic loss at an alarming rate, but also threatens sustainable social development (Tang, 2004). To grapple with the intensifying competition for limited soil resources, an effective soil erosion prediction model has became an essential and urgent endeavor. Unfortunately, soil erosion prediction is a complex and multifaceted process that is affected by a host of factors.

Soil erodibility is, of course, the key parameter for assessing the soil's susceptibility to erosion; it is essential for predicting soil loss and evaluating its environmental effects. It is usually regarded as the amount of soil loss per unit erosive force, whether rainfall, surface flow, or seepage. The most commonly utilized soil erodibility term is the soil erodibility factor (*K*) of the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965). Since the direct measurement of the *K*-value requires the establishment and maintenance of natural runoff plots over lengthy, expensive observation periods at various locations, numerous attempts have been made to simplify the technique and to establish estimators for soil erodibility calculation from readily available soil property data and standard profile description (Wischmeier, Johnson, & Cross, 1971; Römkens et al., 1997). To date, the widely used soil

Abbreviations: CSED, Chinese soil erodibility database; SISChina, Soil Information System of China; USLE, the Universal Soil Loss Equation; RUSLE2, the Revised Universal Soil Loss Equation (version 2.0); EPIC, the Erosion Productivity Impact Calculator; Dg, the Geometric Mean Diameter (mm); SOM, soil organic matter content (%); Dg model, an estimate of soil erodibility by Geometric Mean Diameter; Dg-SOM model, the improvement of soil erodibility predication with a combination of Dg and SOM

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erodibility estimators include USLE (Wischmeier & Smith, 1965), the Revised Universal Soil Loss Equation (RUSLE) (Renard, Foster, Weesies, McCool, & Yoder, 1997), the Erosion Productivity Impact Calculator (EPIC) (Sharply & Williams, 1990) and the Geometric Mean Diameter based (Dg) model (Römkens et al., 1988). These models were developed in the United States based on American soil-erosion databases, however, which may render them entirely ineffective for soils at other geographical locations. In fact, numerous researchers have attempted to determine which model is the best-suited to soil erodibility estimation at various scales (with mixed results) (Römkens et al., 1988; Torri, Poesen, & Borselli, 1997). Several efforts have been made to compare models for specific regions or conditions (e.g., watershed/county-scale studies or rainfall simulation studies) (Hussein, Kariem, & Othman, 2007; Wang, Zheng, & Wang, 2012; Zhang, Li, Peng, & Yu, 2004; Zhang, Shu, Xu, Yang, & Yu, 2008). Unfortunately, hardly any model has yet definitively been proven superior because researchers usually only state that one model overestimates or underestimates soil erodibility compared to the others; further, the literature contains some comparisons that are not based on observed data.

There are diversiform soil types in China due to differences in climate types and landforms across the country. In this study, we attempted to confirm which soil erodibility estimation approach is suitable to each specific geographical area in China. Our ultimate goal was to provide basic data corresponding to a regional map of Chinese soil erodibility. Hence, the main objectives of this study were, accordingly, to: (1) evaluate and calibrate the available soil erodibility models (USLE, RUSLE2, EPIC and Dg models) based on a Chinese soil loss dataset; (2) quantify the differences in these exiting models' performances and establish suitable soil erodibility estimator for specific geographical areas in China; and (3) to provide a regional soil erodibility map for water erosion areas in China based on the improved *K*-factor prediction.

2. Materials and methods

2.1. Input data

2.1.1. Chinese soil erodibility database

The Chinese soil erodibility database (CSED), which covers the 32 main Chinese soils in the four main water erosion regions in China (Wang, Zheng, & Römkens, 2013), is a reference dataset often used for comparing and calibrating the available soil erodibility estimators. The CSED includes attributes such as soil types, soil texture, soil organic matter content (SOM), and the measured soil erodibility value according to the USLE-*K* factor concept. The measured *K*-values were obtained from long-term observations of natural runoff plots (Wang et al., 2013b).

2.1.2. Chinese topsoil data

The geographical extent of the present study includes 27 provinces (municipalities or autonomous regions), covering the main water erosion area of China (Fig. 1). Necessary attributes of topsoil were collected from the Soil Information System of China (SIS-China) database (Shi et al., 2004) and the first-ever National Water Census (2010–2012), which includes (among other information) the particle size distribution, soil texture (Chinese Soil Taxonomy), SOM, soil nutrients (N, P, K), pH and infiltration class of Chinese soils. Provincial soil type maps at 1:250,000 scales were collected and digitally processed. Physicochemical attributes data of 7896 soil samples based on the SISChina and the National Water Census were classified and assigned to the corresponding soil species or soil genus.

2.2. Soil erodibility (K) estimates

All *K*-values in this paper are expressed in SI metric units, i.e.,

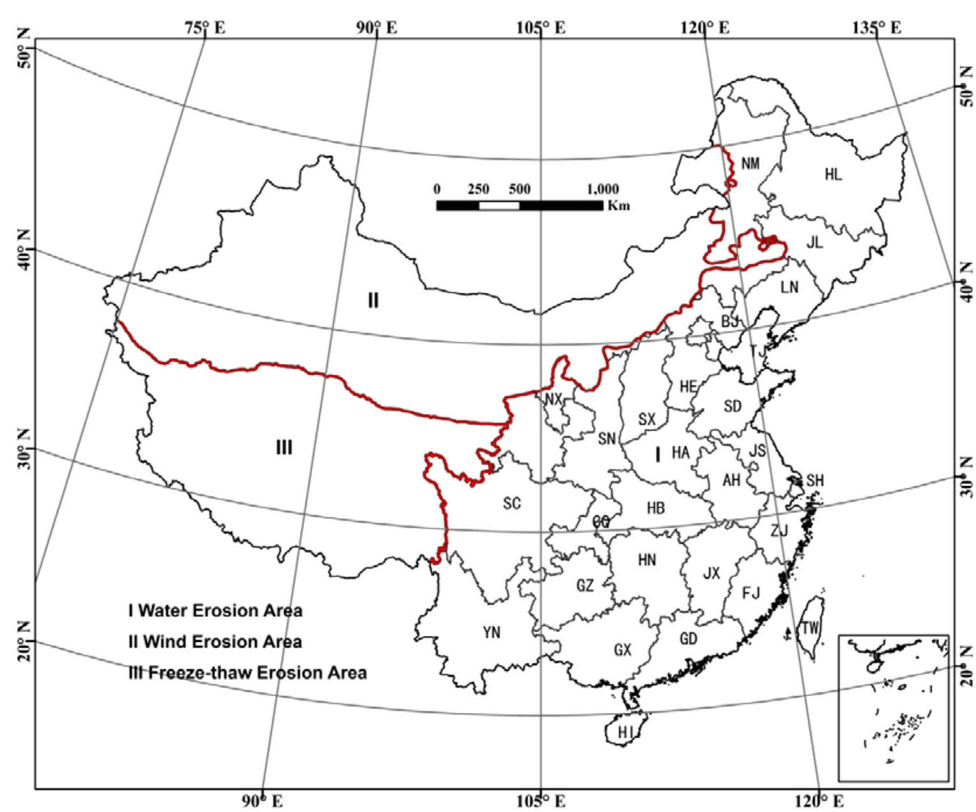

Fig. 1. Zoning of soil erosion in China (according to Liao (1999)). Note: HL, JL, NM, LN belongs to the Black soil region; HE, SX, SN, part of NX, part of HA belongs to the Loess soil region; SC, CQ, GZ, YN, part of GX belongs to the Purple soil region; HB, ZJ, FJ, JX, HN, GD, HI, part of HA, part of AH, part of JS, part of GX belongs to the Red soil region of China.

$(\text{t ha h})\cdot(\text{ha MJ mm})^{-1}$. To convert the erodibility value from the US customary unit of (ton acre hour)·(hundreds of acre foot-ton inch)$^{-1}$ to the SI metric unit, it was multiplied by 0.1317. For simplicity we omitted the unit of *K*-value throughout the remainder of this paper.

2.2.1. USLE-K factor estimate

As direct measurement of *K*-value on a standard plot is costly and unsustainable at the national scale (Wischmeier et al., 1971; Wang et al., 2013), the USLE-*K* factor estimate has become the most popular and well-accepted soil erodibility calculation method. The *K*-value based on basic soil property variables can be expressed in mathematical terms (Wischmeier et al., 1971; Wischmeier & Smith, 1978) as follows:

$$K = \left[2.\ 1\times10^{-4}(12 - \text{SOM})M^{1.14} + 3.\ 25(S_t - 2) + 2.\ 5(P' - 3)\right]/100 \quad (1)$$

where *M* represents a newly defined term, the product of the silt+very fine sand (0.002–0.1 mm) and 0.1–2 mm sand fractions (%), S_t and P' are the soil structure and permeability class, respectively, and SOM, as mentioned above, is soil organic matter content (%). The relationship can be applied for those soils in which *M* is less than 70%.

2.2.2. EPIC-K factor estimate

Only two soil properties are needed in EPIC to calculate the soil erodibility *K*-value: the soil organic carbon content and soil particle size distribution (Sharply & Williams, 1990). The equation is as follows:

$$K = \left(0.2 + 0.3e^{\left[-0.0256SAN(1-SIL/100)\right]}\right) \times \left(\frac{SIL}{CLA + SIL}\right)^{0.3} \times \left[1 - \frac{0.25C'}{C' + e^{(3.72-2.95C')}}\right] \times \left[1 - \frac{0.7SN_1}{SN_1 + e^{(22.9SN_1-5.51)}}\right] \quad (2)$$

where *SAN* is the sand content (%), *SIL* is the silt content (%), *CLA* is the clay content (%), C' is the soil organic carbon content (%), and $SN_1 = 1 - SAN/100$.

2.2.3. RUSLE2-K factor estimate

In RUSLE2, the *K*-value has been made to fluctuate during the year, rather than remaining constant. The soil erodibility calculation method was also changed in order to express the soil structure sub-factor (K_s). The equation used to modify K_s is (USDA – Agricultural Research Service, 2008):

$$K_s = 3.25(2 - S_t) \quad (3)$$

2.2.4. Dg model

For most soils, the measured soil erodibility factor or necessary information from which the *K*-value can be derived from measured soil properties are unavailable. Römkens et al. (1997) derived an alternate, yet less accurate, expression for estimating *K*-values using only soil texture information.

$$K = 0.0034 + 0.0387\exp\left[-\frac{1}{2}\left(\frac{\log_{10}(Dg) + 1.533}{0.7671}\right)^2\right] \quad (4)$$

$$Dg = \exp(0.01 \times \sum_{i=1}^{n} f_i \ln m_i) \quad (5)$$

where D_g is the Geometric Mean Diameter of the soil particles (mm), f_i is the weight percentage of the particle size fraction (%), m_i is the arithmetic mean of the particle size limits (mm), and *n* is the number of particle size fractions.

2.3. Model evaluation and statistical analyses

Performances of the four *K*-value estimators were evaluated for both the calibration and validation processes. The coefficient of determination (R^2), the relative error (RE) and the Nash-Sutcliffe efficiency (NSE) (Nash & Sutcliffe, 1970) were adopted to evaluate the model performance. NSE was derived by:

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (6)$$

where O_i is the *i*-th observation, S_i is the *i*-th predicted value, and $\bar{O}$ is the mean value of the entire observations. Although R^2 and NSE are widely accepted for model performance assessment (Schaefli & Gupta, 2007), various criteria can be applied for different case studies. Most scholars recommend $\text{NSE} > 0.5$ and $R^2 > 0.5$ for SWAT studies (Santhi, Arnold, Williams, Hauck, & Dugas, 2001), whereas $\text{NSE} > 0.4$ has been set as a criteria for erosion prediction evaluation (Ahmad et al., 2011). Considering the different accuracy requirements of soil erodibility studies, we used model performance evaluation criteria of $\text{NSE} > 0.4$ and $R^2 > 0.5$ for this study.

The Mann-Whitney *U* test was used to determine whether the estimates from the models departed significantly from the observed data (where *P* value < 0.05 indicates significant difference). Regression analyses were performed to develop a new formula for estimating soil erodibility. To make sure the evaluation and validation of the soil erodibility model was reliable, two groups of relatively independent soil data were chosen randomly from the CEDB; one group for calibration and the other for validation. All statistical analyses were accomplished in MATLAB R2015b (MathWorks Inc., Natick, MA, USA) and IBM SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA).

2.4. Soil erodibility mapping

In this study, the *K*-value of each soil species was estimated by the improved soil erodibility prediction. The link between soil erodibility and soil species contributed a visual and continuous erodibility map of China based on the 1:250,000 scale of national soil-type maps. Compared to the spatial interpolation approach, the aforementioned method reduces error accumulation and possible bias (Auerswald, Fiener, Martin, & Elhaus, 2014). The high-resolution dataset of the soil erodibility map was validated against various local and regional studies. Based on an extensive review of Chinese efforts in soil erodibility and anti-erodibility research from 1954 to 2013 (Wang et al., 2013), more than 180 assessments were synthesized on a local or regional scales. In order to ensure maximum accuracy and representativeness, we selected and aggregated data of 19 publications covering most provinces of the water erosion areas in China.

3. Results and discussion

3.1. Performance of the soil erodibility estimates

Model evaluations were performed by comparing the observed values with the predicted values estimated by the USLE, EPIC, RUSLE2 and Dg models. In general, we found that those models overestimated almost all *K*-values for CSED (Table 1). USLE and EPIC overestimated soil erodibility *K*-value by an average of 93.6% and 96.2%, respectively (Fig. 2a and b), while RUSLE2 and Dg models showed better performance than USLE and EPIC with a

Table 1
Available soil erodibility estimates (USLE, EPIC, RUSLE2 and Dg model) performance and statistics ratings versus observed K-values.

Model	Water erosion area of China					Black soil region					Loess soil region					Red soil region					Purple soil region				
	n	P[a]	R^2[b]	NSE[c]	RE[d] (%)	n	P	R^2	NSE	RE (%)	n	P	R^2	NSE	RE (%)	n	P	R^2	NSE	RE (%)	n	P	R^2	NSE	RE (%)
USLE	32	< 0.05	0.07	−2.90	93.6	7	**0.95**	**0.55**	**0.53**	**0.1**	8	< 0.05	0.60	−30.99	187.4	12	< 0.05	0.37	−7.18	124.2	5	0.07	0.11	−1.38	63.2
EPIC		< 0.05	0.38	−1.50	96.2		0.31	0.05	−3.81	18.5		< 0.05	0.70	−8.44	155.8		< 0.05	0.58	−9.14	139.3		0.11	0.59	−0.55	51.1
RUSLE2		< 0.05	0.06	−1.35	54.4		< 0.05	0.19	−5.43	−30.7		< 0.05	0.27	−20.49	157.0		0.08	0.35	0.13	68.4		0.47	0.14	−0.29	40.8
Dg		0.64	0.24	0.24	36.3		< 0.05	0.01	−4.58	−10.8		**0.95**	**0.65**	**0.61**	**14.1**		0.22	0.16	−2.16	87.7		0.38	0.52	0.19	6.9

[a] P value by Mann-Whitney *U* test comparison.
[b] Adapted from Santhi et al. (2001) and Boone et al. (2004): satisfactory ($R^2 > 0.5$).
[c] Nash-Sutcliff efficiency. Adapted from Ahmad et al. (2011): good (NSE > 0.7), satisfactory (0.4 < NSE ≤ 0.7) and unsatisfactory (NSE ≤ 0.4).
[d] Mean value of the relative error. The relative error is (K-predicated − K-observed)/K-observed as percent.

slight trend overestimating *K*-values. RUSLE2 overestimated *K*-values by an average of 54.4%, but when the observed *K*-value was larger than 0.32, it underestimated the *K*-values (Fig. 2c). The Dg model showed the best performance among the four existing models with an average overestimation rate of 36.3% (Fig. 2d). The Dg model was not sensitive, however, estimated values did not vary with the observed values and the predicted *K*-values ranged widely from 0.025 to 0.031.

We gained additional insight into each model's performance by comparing their *K*-values performance through the four exiting estimators in different soil regions of China. The R^2, NSE, and RE were 0.55, 0.53, and 0.1%, respectively, for the USLE application in the black soil region indicating a satisfactory relationship between the observed and predicted datasets (Table 2). A satisfactory relationship was also found for the Dg model's application to the loess soil region, with R^2, NSE, and RE of 0.65, 0.61, and 14.1%, respectively (Table 1). The *P* value (Mann-Whitney *U* test) was 0.95 for USLE and Dg estimators, indicating that there were no significant differences between estimated *K*-values and the observations. These results altogether suggested that the USLE model can be applied directly to the black soil region, while the Dg model can be applied to the loess soil region without calibration.

The performance of USLE, RUSLE2, EPIC, and Dg models applied to the red soil and purple soil regions were shown in Table 2. The results indicated that estimated *K*-values did not reach a "satisfactory" level without calibration. Zhang et al. (2008) and Wang et al. (2012) reported similar results and proposed a set of linear relationships between the observed and predicted *K*-values to improve prediction accuracy. Unfortunately, no effective linear relationships were found between the observed and predicted values. Therefore, a more accurate and suitable soil erodibility estimator for Chinese *K*-value calculation is yet necessary.

3.2. Improvement of the erodibility prediction

Numerous studies on soil erosion prediction around the world have indicated that erodibility is mainly related to soil texture parameters, SOM, soil structure and permeability (Wischmeier et al., 1971; Römkens, 1985; Renard et al., 1997; Zhang et al., 2008). Unfortunately, soil texture is not organized into any universal classification system, but several ones (e.g., the International Soil Science Society (ISSS) system, U.S. Department of Agriculture (USDA) – Soil Taxonomy, or Chinese Soil Taxonomy), and information on soil structure and permeability is often unavailable. For these reasons, we attempted to link *K*-values to SOM and *Dg* which is an easily accessible and uniform textural parameter (Shirazi & Boersma, 1984; Römkens, Poesen, & Wang, 1988). Only a regression obtained by the nonlinear best fitting techniques yielded a significant relationship (R^2=0.67, n=32) to explain *K*-values with a combination of *Dg* and SOM. This relationship, named 'Dg-SOM', was as follows:

$$K = 0.0667 - 0.0013\left[\ln(SOM/Dg) - 5.6706\right]^2 - 0.015\,\exp\left[-28.9589\left(\log(Dg) + 1.827\right)^2\right] \quad (7)$$

3.2.1. Calibration of improved estimator

The optimal Gaussian distribution of residuals (Fig. 3) showed that Eq. (7) was a highly effective interpolator of the *K* dataset. The improved estimator showed a fairly complex relationship between *Dg* and SOM and suggested a certain level of interaction between particle distribution information and SOM. This relationship apparently has physical significance, as evidenced by the similar bell-shapes indicating that the erodibility factor decreased as *Dg*

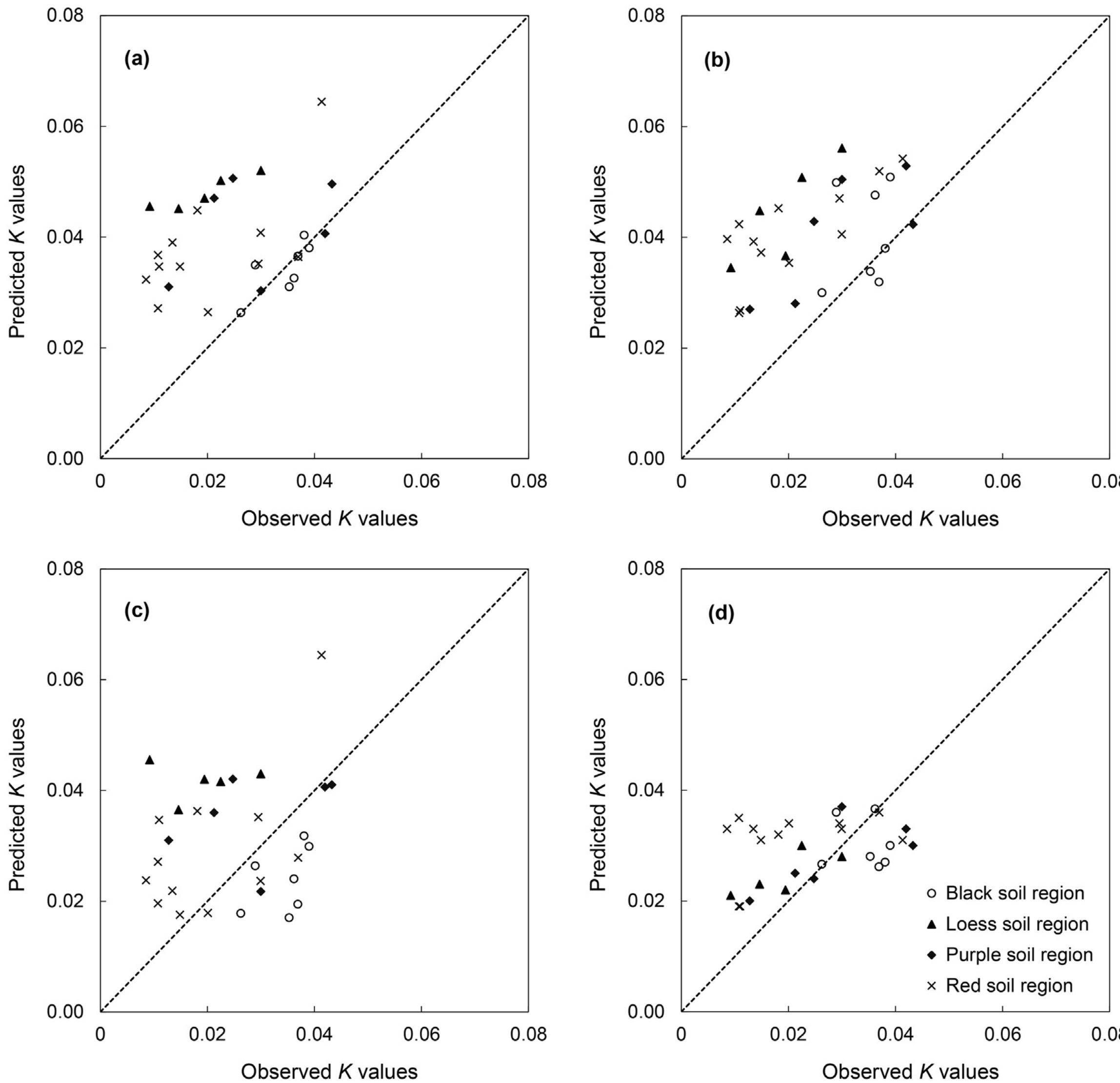

Fig. 2. Comparisons of the observed and predicted K-values (by USLE (a), EPIC (b), RUSLE2 (c), and Dg model (d)) based on the Chinese soil erodibility database (CSED).

increased due to the dominance of coarser particles reflecting higher infiltration rates (sandy soils). This was also evident as *Dg* decreased, reflecting the structural stability of soils due to a high clay content and clay-associated organic and inorganic binding agents as well as high infiltration rates. Two peaks in *K*-value were observed for the medium-textured particle size material, implying a greater degree of detachability and transportability. We also found a relatively small valley point at *Dg* value around 0.013 corresponding to silt-clay and clay texture. It probably caused by the colloidal properties of clay mineral compositions and sesquioxides materials (Römkens et al., 1997; Li, Cai, Shi, & Wang, 2005).

The observed and predicted *K*-values by the Dg-SOM model for the calibration dataset are shown in Fig. 4. The R^2 of 0.67 and NSE of 0.94 indicated that the model performed well. The predicted data were mostly distributed along the 1:1 line of the observed data and were concentrated in the range of 0.015–0.035, similarly to the results obtained from the observed *K*-values. The relative error mainly varied from −23.7% to 24.4%, was averaging at 9.5%. This result demonstrates that the Dg-SOM model is sufficiently accurate for estimating Chinese soil erodibility.

3.2.2. Validation of the improved estimator

The observed and predicted *K*-values are plotted in Fig. 5 for the cross validation dataset. The predicted data were distributed along the 1:1 line with the observed *K*-values. The relative error of the Dg-SOM model for the validation process was concentrated in the range of −30.4% to 34.9%, was averaging at 6.5%, which was much better than the pre-existing four erodibility estimating models' in China. Although there were deviations between the observed and predicted values, the R^2 of 0.66 indicates that the correlation between predicted and observed soil erodibility values was acceptable; the NSE of 0.93 also indicates a satisfactory model validation.

3.3. Soil erodibility map of the water erosion area in China

The mean value of soil erodibility USLE-*K* factor in the water erosion area was calculated as 0.0321 with a standard deviation of 0.0107 via the improved estimator (Fig. 6). *K*-values in water erosion areas of China varied from 0.0001 to 0.0667, and were mainly concentrated in the range of 0.0229–0.0457, exclusive of rivers, lakes, glaciers, and urban areas.

3.3.1. Distribution and uncertainty of soil erodibility mapping

The spatial patterns of soil erodibility generally follow the soil erosion map of China (1:12,000,000) according to Li, Zhao, and

Table 2
Average USLE-*K* values in the water erosion area of China by the improved soil erodibility estimate.

Province		SOM	*K*-factor	
Abbr.[a]	Name	Mean value (%)	Mean value (t ha h)·(ha MJ mm)$^{-1}$	Standard deviation (t ha h)·(ha MJ mm)$^{-1}$
HL	Heilongjiang	5.24	0.0298	0.0087
JL	Jilin	3.78	0.0352	0.0156
LN	Liaoning	3.84	0.0347	0.0148
NM[b]	Inner Mongolia	1.94	0.0298	0.0086
BJ	Beijing	2.58	0.0473	0.0193
TJ	Tianjin	1.61	0.0440	0.0094
HE	Hebei	2.20	0.0321	0.0149
SD	Shandong	1.99	0.0370	0.0100
HA	Henan	3.29	0.0370	0.0121
SX	Shanxi	2.02	0.0384	0.0135
SN	Shaanxi	1.82	0.0421	0.0132
NX[b]	Ningxia	1.83	0.0427	0.0196
SC	Sichuan	2.12	0.0325	0.0102
CQ	Chongqing	2.32	0.0203	0.0087
HB	Hubei	2.37	0.0350	0.0152
AH	Anhui	2.47	0.0352	0.0139
JS	Jiangsu	1.67	0.0362	0.0120
SH	Shanghai	2.60	0.0419	0.0157
ZJ	Zhejiang	2.64	0.0313	0.0065
FJ	Fujian	3.22	0.0251	0.0132
JX	Jiangxi	2.12	0.0464	0.0116
HN	Hunan	3.42	0.0264	0.0150
GZ	Guizhou	4.01	0.0278	0.0122
YN	Yunnan	2.57	0.0280	0.0078
GX	Guangxi	2.84	0.0287	0.0107
GD	Guangdong	2.58	0.0310	0.0111
HI	Hainan	2.58	0.0310	0.0102

[a] The abbreviation of province is according to the National Committee for Standardization of Geographical Names, China.
[b] Just considered the water erosion area of the province.

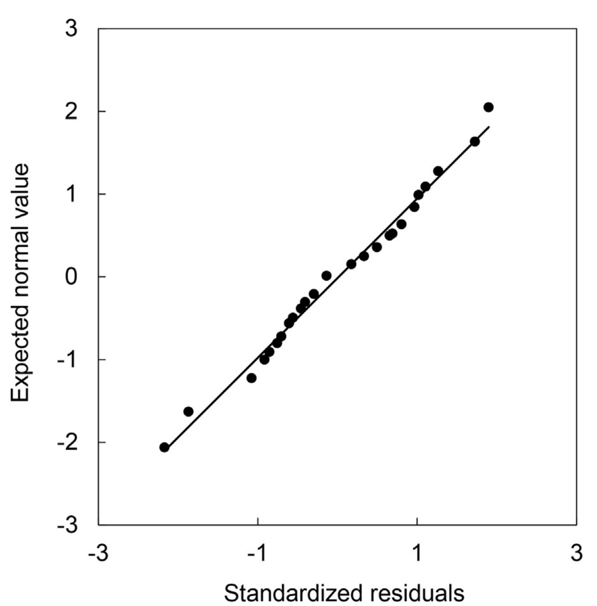

Fig. 3. Normal probability plot of residuals. Residuals are calculated as K-observed minus K-predicted with improved method. The expected normal values are relative to the curve of Gaussian distribution with the mean of 0 and the standard deviation of 1.

Yang (2014). *K*-values present a decreasing trend from North to South in water erosion areas in close accordance with SISChina's soil physical characteristics. Soil texture, in fact, is a crucial factor in terms of soil erodibility (Auerswald et al., 2014; Bryan, 2000; El-Swaify and Dangler, 1977; Römkens et al., 1997; Shi, Yu & Xing., 1997; Wischmeier and Mannering, 1969; Zhang et al., 2008). Among the main soil regions of China, soil erodibility was generally in the order of: loess soil region > black soil region (NE China) > purple soil region (SE China) > red soil region (South China).

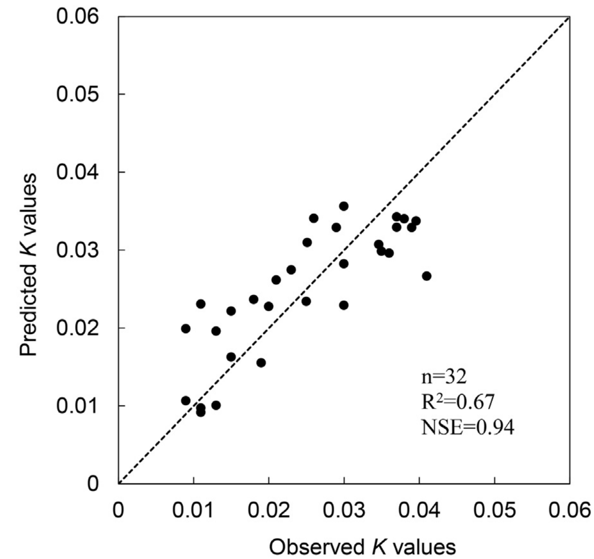

Fig. 4. Observed and predicted *K*-values with improved method for calibration.

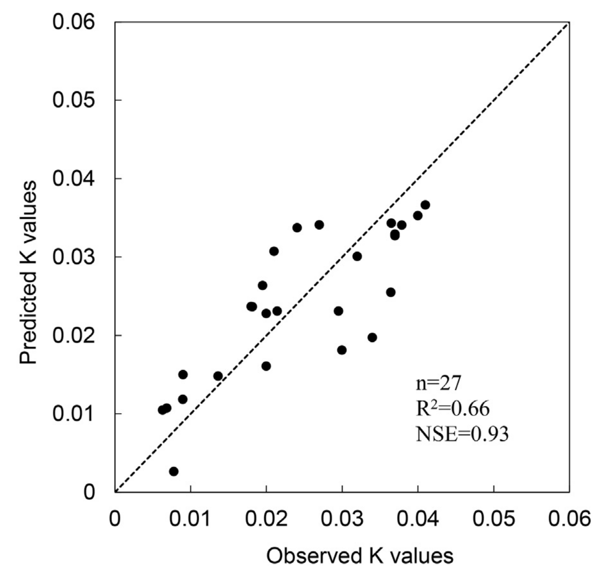

Fig. 5. Observed and predicted *K*-values with improved method for validation.

The statistics at the province level indicated the overview of soil erodibility values in water erosion areas of China (Table 2). In line with most scholars (Wang, Guo, & Gao., 1994; Rodríguez et al., 2006), SOM had an important impact on soil erodibility; the province (or region) with the highest amount of SOM was roughly provided with the lowest *K*-value. In Heilongjiang (HL), Chongqing (CQ), Fujian (FJ), Hunan (HN), Guizhou (GZ), Yunnan (YN) and Guangxi (GX), high mean SOM indicated relatively low soil erodibility values (less than 0.0300). Conversely, the greatest mean *K*-values (larger than 0.0380) were observed in Beijing (BJ), Tianjin (TJ), Shanxi (SX), Shaanxi (SN) and Ningxia (NX). This can be partially attributed to the characteristics of the loess soil region, where the soil has poor structure and relatively lower SOM (Jiang, Fan, Li, & Zhao, 1995; Zhang & Liu, 2005).

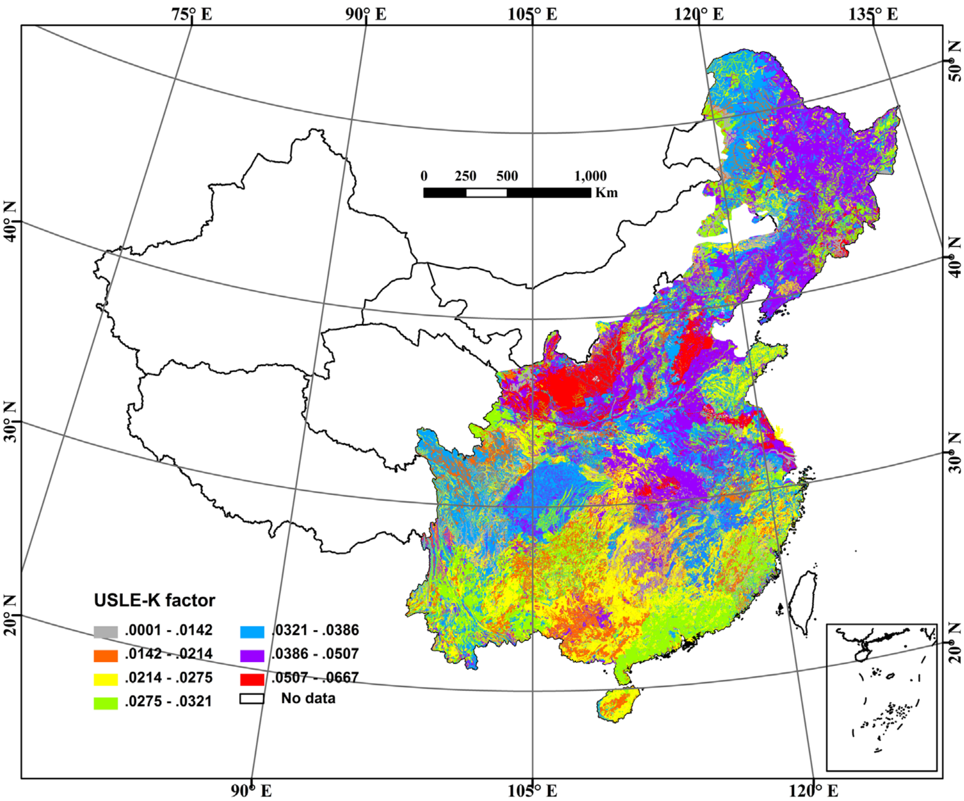

Fig. 6. Regional soil erodibility (USLE-*K* factor) map (1:250,000 scale).

Table 3
Comparisons of the soil erodibility mapping to local and regional reference.

Location	Type	Period[b]	*K*-factor of reference[c] Mean value (t ha h)·(ha MJ mm)$^{-1}$	*K*-factor of Fig. 6	Absolute deviation (%)	Source
China	National	–	0.0330	0.0321	−2.80	Liang et al. (2013)
China	National	–	0.0144	0.0321	55.14	Zhang et al. (2008)
China	National	–	0.007/0.020	0.0321	78.19/37.69	Zhang, Peng, and Yang (2007)
Southern Yangtze River	Regional	–	0.0300	0.0267	−12.36	Liang and Shi (1999)
TGRA[a]	Regional	–	0.0170	0.0205	17.07	Wu et al. (2010)
Fujian (FJ)	Regional	–	0.0329	0.0251	−31.08	Fang, Ruan, Wu, and Guo (1997)
Chongqing (CQ)	Local	–	0.0250	0.0307	18.57	Zhang, Jiang, Chen, and Shi (2010)
Keshan (HL)	Local (plots)	1985–1990	0.0390	0.0350	−11.43	Zhang, Xu, Lu, Deng, and Gao (1992)
Mudanjiang (HL)	Local (plots)	1985–1990	0.035	0.0426	17.84	Zhang, Xu, Lu, Deng, and Gao (1992)
Qiqihar (HL)	Local (plots)	2008	0.0360	0.0347	−3.75	Li (2009)
Baiquan (HL)	Local (plots)	1985–2008	0.0370	0.0350	−5.71	Zhai (2008)
Gannan (HL)	Local (plots)	1995–2008	0.0380	0.0408	6.86	Zhai (2008)
Binxian (HL)	Local (plots)	2008–2010	0.0290	0.0329	11.85	Station data[d]
Hailun (HL)	Local (plots)	2009–2010	0.0100	0.0139	28.06	Station data[d]
Zhangjiakou (HE)	Local (plots)	1991–1994	0.0120	0.0182	34.07	Cai, Zhao, and Wang (1995)
Zizhou (SN)	Local (plots)	1961–1969	0.0270	0.0236	−14.41	Zhang et al. (2004)
Ansai (SN)	Local (plots)	1984–1986	0.0090	0.0157	42.68	Jin, Shi, Hou, and Zhao (1992)
Lishi (SX)	Local (plots)	1957–1964	0.0130	0.0208	37.50	Zhang et al. (2004)
Huangfuchuan (SX)	Local (plots)	1983–1989	0.0420	0.0497	15.49	Jin et al. (1992)
Fuxian (SN)	Local (plots)	1995–2006	0.0230	0.0251	8.37	Station data[d]
Yingtan (JX)	Local (plots)	1992–1994	0.0320	0.0347	7.78	Shi et al. (1997)
Dongchuan (YN)	Local (plots)	1995–1997	0.0350	0.0375	6.67	Yang (1999)
Zhaotong (YN)	Local (plots)	1995–1997	0.0290	0.0320	9.38	Yang (1999)
Hengyang, HN	Local (plots)	2003–2004	0.0430	0.0490	12.24	Zhao, Hao, Qi, Wang, and Luo (2006)

[a] Three Gorges Reservoir Area.
[b] The observation period of the standard runoff plots.
[c] The mean K-value of each reference was calculated following the USLE-defined procedure.
[d] Data obtained from our field stations.

3.3.2. Comparison of soil erodibility values at different scales

Previous studies on Chinese soil erodibility are heterogeneous in scale (from runoff plots to a regional/provincial scale, and even on a national scale). Even so, all available records were taken into account for the cross-verification of the local and regional soil erodibility references. Deviations in *K*-value were used to compare soil erodibility maps with *K*-values from the literature. The soil erodibility map in water erosion areas presented an absolute deviation of around 10.78% against past attempts, on average (Table 3). The soil erodibility map mostly overestimated *K*-values at different scales, excluding studies on the hilly-field in the Southern Yangtze River, Fujian (FJ), Qiqihar (HL), Baiquan (HL), and Zizhou (SN). Altogether, the satisfactory match between soil erodibility values with former studies indicated that the improved soil erodibility estimator is readily applicable to water erosion areas of China in terms of reasonable rough estimates. Additional validation is necessary, however, due to limited data at regional and national scales.

4. Conclusions

Soil erodibility is a key parameter and an essential requirement for erosion prediction, conservation practices, and evaluation of the related environmental impacts of erosion. Recently, empirical soil erosion predictions have been used in fairly large scales (i.e., national or regional) studies. Few scholars have attempted calibration and validation for variable *K*-factor estimations beforehand, however, due to the considerable expense of establishing a truly comprehensive database This will most certainly lead to the misuse of *K*-value calculation and uncertain results, especially for large areas with complex topographies (Wang et al., 2013).

In this study, we assessed the limitations of the available erodibility estimators (USLE, RUSLE, EPIC and Dg models) for different geographic regions based on the CSED. Improved soil erodibility prediction method which combines with Dg and SOM was established, through the nonlinear best fitting techniques. The proposed method, as discussed above, indeed showed satisfactory performances and better accuracy than several other pre-existing models. We also developed a regional soil erodibility map (1:250,000 scale) of Chinese water erosion areas. The mean *K*-value of water erosion areas in China was 0.0321 and was concentrated in the range of 0.0229–0.0457. A general trend of erodibility among the main soil regions of China was detected and found to vary in the order of: loess soil region > black soil region (NE China) > purple soil region (SE China) > red soil region (South China). This study not only evaluated the performance of the available *K*-value estimators, but also provided an alternative improved erodibility estimator and useful database for soil erosion prediction, especially for those areas with insufficient data. In the future, the proposed approach can be further improved by cross validating the soil erodibility maps.

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