Soil erodibility ~~estimation by using five methods~~and its influencing factors on the Loess Plateau of ~~estimating *K* value~~China: A case study in the Ansai watershed~~ of Loess Plateau, China~~

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Abstract

The objectives of this work were to ~~select~~identify the possible best ~~texture-based~~ method to estimate soil erodibility (*K*) and understand ~~possible indirect environmental~~the influencing factors of soil erodibility. In this study, 151 soil samples were collected during soil surveys in the Ansai watershed~~. Five methods~~ of ~~estimating *K* value were used to estimate soil erodibility, including the~~the Loess Plateau of China. The *K* values were estimated by five methods: erosion-productivity impact model (EPIC), ~~the~~ nomograph equation (NOMO), ~~the~~ modified nomograph equation (M-NOMO), ~~the~~ Torri model and ~~the~~ Shirazi model. The main conclusions of this paper are (1) *K* values in the Ansai watershed ranged between 0.009 and 0.092 t·hm^2·hr/(MJ·mm·hm^2)~~. The *K* values based on Torri, NOMO, and Shirazi models were similar~~), and the maximum values were 1.872-7.333 times larger than the corresponding minimum values, and ~~were located close to each other in the Taylor diagrams. By combining~~ the ~~measured soil erodibility, we suggested~~ Shirazi and Torri ~~model as~~models were considered the optimal models for the Ansai watershed. (2) Different land use types had different levels of importance; PC accounted for 100% (native grassland), 48.88% (sea buckthorn), 62.05% (*Caragana korshinskii*) and 53.61% (pasture grassland) of the variance in soil erodibility. (3) The correlations between soil erodibility and the selected environmental variables

~~changed for~~differed among different vegetation ~~type~~types. For native grasslands, soil erodibility had significant correlations with terrain factors. For the most artificially managed vegetation types (e.g., apple orchards) and artificially restored vegetation types (e.g., sea buckthorn),~~ the~~ soil erodibility had significant correlations with the growing conditions of vegetation. ~~The dominant factors that influenced soil erodibility differed with different vegetation types.~~ Soil erodibility had indirect ~~relationship with~~relationships not only with environmental factors (e.g., elevation and slope~~),~~) but also human activities, which potentially altered soil erodibility.

Keywords: Influencing factors, Soil erodibility, Variation features, Shirazi model, Torri model

1 Introduction

Soil erodibility (*K*),~~ as~~ one of the key factors of soil erosion (Igwe, 2003; Fu et al., 2005; Ferreira et al., 2015), is defined as the susceptibility of soil to erosional processes (Bagarello et al., 2012; Bryan et al., 1989). It has been extensively used in both theoretical and practical approaches to measure soil erosion. ~~Yet~~However, it is a complex concept ~~and is~~ affected by many factors, including soil properties (~~e.g., soil texture, permeability and structural stability) (~~Chen et al., 2013; Wang et al., 2015; Manmohan et al., 2012~~);~~), terrain (Wang et al., 2012; Mwaniki et al., 2015; Parajuli et al., 2015~~);~~), climate (Hussein et al., 2013; Sanchis et al., 2010~~);~~), vegetation (Sepúlveda-Lozada et al., 2009~~);~~), and land use (Cerdà et al., 1998; Tang et al., 2016). ~~In order to~~To calculate soil erodibility, many strategies have been used to perform ~~research~~researches to understand soil erodibility, including measurements of physical and chemical soil properties, instrumental measurements, mathematical models and graphical methods (Wei et al., ~~2017~~2017a). Although ~~a~~the direct measurement of soil erosion ~~with~~in large plots under natural rainfall over long-term ~~period~~periods can provide ~~more~~ accurate estimates of soil erodibility, this method is time consuming and ~~very expensive~~costly (Bonilla et al., 2012; Vaezi et al., 2016a, b). Therefore, mathematical models are more commonly used to estimate soil erodibility.

Some of the most common estimation models are the nomogram model (NOMO) and the modified nomogram model~~,~~ (M-NOMO), which were established by Wischmeier (Wischmeier et al., 1971, 1978); the erosion-productivity impact model (EPIC), which was developed by Williams (Williams et al., 1990); the best nonlinear fitting formula using the physical and chemical properties of the soil, which was developed by Torri (Torri et al., 1997); and the estimation model developed by Shirazi that ~~is using~~uses the average size of the soil geometry (Shirazi et al., 1988). Each estimation method ~~may differ~~differs in terms of ~~their~~ applicability, even within the same area, because the different estimation methods include different physical and chemical soil properties (Lin et al., 2017; Wang et al., 2013b; Kiani et al., 2016). Consequently, the estimated results can differ significantly among methods because soil conditions vary by region (Lin et al., 2017; Wang et al., 2013b). Selecting the optimal estimation method of soil erodibility is therefore critical to estimate the amount of soil erosion.

Soil erosion ~~in~~on the Loess Plateau of China is among the highest in the world (Fu et al., 2009; Huang et al., 2016). The area affected by soil and water loss is as large as 4.5~~×~~ $\times$ 10^5 km^2 ($\sim$71% of the local land area~~)~~), and the long-term average sediment loss is up to 1.6~~×~~ $\times$ 10^9 t (Fu et al., 2017). To maintain water quality and ~~to~~ control soil erosion (Fu et al., 2011), the Chinese government has implemented a large-scale policy to convert farmlands to forests and grasslands since the 20th century (Lü et al., 2012; Feng et al., 2013b; Wu et al., 2016). Although ~~this~~the large-scale introduction of vegetation ~~should reduce~~is expected to have reduced soil erosion, the extent of the reduction remains unclear. ~~Accordingly~~Therefore, different estimation methods should be used to calculate erosion factors, including the soil erodibility factor. In this ~~article,~~study, the Ansai watershed ~~in~~of the Loess Plateau of China was chosen as a case study, and the five above~~ five~~-mentioned estimation methods of estimating *K* value were ~~used, and the~~applied. The objectives of this study ~~are~~were (1) to estimate the soil erodibility factor with different methods~~;~~, (2) to select the ~~possible best texture-based~~optional method to estimate *K*~~;~~, and (3) to understand ~~possible indirect environmental~~the influencing factors ~~on~~of soil erodibility for the local area.

2 Materials and methods

2.1 Study area

The Ansai watershed (108°5′44″-109°26′18″E, 36°30′45″-37°19′3″N) is located ~~in~~around the upper reaches of the Yanhe River~~.~~, in the inland hinterland of the northwestern Loess Plateau. This watershed lies in the northern part of Shanxi ~~province~~Province and ~~the inland hinterland of the northwestern Loess Plateau and at the edge of~~borders the Ordos basin. It belongs to the typical loess hilly-gully region and covers an area of approximately 1334 km^2. The soil type in the study area is loess soil, with low fertility and high vulnerability to erosion (Zhao et al., 2012; Yu et al., 2015).~~topography is complex and varied, and the ground surface is fragmented. The elevations within the watershed are high in the northwest and low in the southeast, and these elevations range from 997 to 1731 m above sea level.~~ The topography is complex and varied, and the land surface is fragmented into different land uses, dominated by~~The watershed belongs to the mid-temperate continental semi-arid monsoon climate region. The average annual precipitation is 505.3 mm, and 74 percent of the rainfall occurs from June to September. The predominant land use types in the Ansai watershed are~~ rain-fed farmland, apple orchard, native grassland, pasture grassland, shrubland, and forest (Feng et al., 2013a). The elevations within the watershed are high in the northwest and low in the southeast, ranging between 997 and 1731 m above sea level. The watershed belongs to the mid-temperate continental semi-arid monsoon climate region. ~~The soil type in this study area is loess soil~~The average annual precipitation is 505.3 mm, and 74% of the rainfall occurs from June to September. ~~with low fertility and high vulnerability to erosion (Zhao et al., 2012; Yu et al., 2015).~~

2.2 Sample point setting

The soil data used in this study came from 151 typical sample data sets that were obtained during soil surveys conducted from July to September ~~in~~ 2014. The soil ~~types~~type of all 151 sample points ~~are~~is loess soil. Representative vegetation types were selected~~, which included~~: (1) natural vegetation~~, including~~: native ~~grassland~~grasslands (NG); (2) artificially managed vegetation types~~, including~~: apple orchards (AO) and farmland

(FL); and (3) artificially restored vegetation types~~, including~~: pasture ~~grassland~~grasslands (PG), sea buckthorn (SB), *Caragana korshinskii* (CK), David's peach (DP~~),~~) and black locust (BL). The distance between each vegetation ~~sampling~~ site sampled was at least 2 km, and the area of each vegetation type was greater than 30 m by 30 m~~, and the~~. The selected sample plots were distributed evenly within the study area. The sample plots within the farmland and grassland had a size of 2 ~~m by~~× 2 m, whereas the corresponding dimensions for the sample plots within the shrubland and forest areas were 5 ~~m by~~× 5 m and 10 ~~m by~~× 10 m, respectively. Each sample plot was ~~repeated~~replicated three times. The locations of the sampling points were determined using a GPS unit (Garmin eTrex 309X~~).~~, Garmin Ltd. subsidiary in Shanghai, China). The collected soil samples were taken ~~back~~ to the laboratory, dried naturally, ground and ~~filtered~~sieved with a 2-mm sieve. The ~~grain~~soil particle size distributions of the soil samples were evaluated using the hydrometer method. The size classes of ~~the~~soil particles in this study were based on USDA classes and were as follows: sand (0.005-2.0 mm), silt (0.002-0.05 mm) and clay (< 0.002 mm) (Wang, et al., 2012).

To fully explore the primary factors influencing soil erodibility in the Ansai watershed, we chose four types of environmental factors~~, including~~: physicochemical soil properties, topographic factors, climate factors and vegetation factors. ~~While~~Although soil ~~erodiblity~~erodibility does not directly depend on environmental factors, soil properties such as soil particle size distribution and soil organic matter can be affected by environmental factors~~. Soil erodibility~~ ; thus~~ has indirect relationship with the~~, environmental factors~~.~~ have indirect relationships with soil erodibility. These environmental factors covered 20 independent variables~~, specifically~~: elevation (Ele), slope position (SP), slope aspect (SA), slope gradient (SG), slope shape (SS), clay ~~(Cla)~~ content~~,~~(Cla), silt ~~(Sil)~~ content~~,~~(Sil), sand ~~(San)~~ content~~,~~(San), organic matter (OM) content, soil bulk density (SBD), porosity (Por), average annual rainfall (AAR), vegetation coverage (VC), aboveground biomass (AB), vegetation height (VH), litter biomass (LB), plant density (PD), crown width (Cro), basal diameter (BD), and branch number (BN). All of the data on environmental factors were derived from the field surveys. The main characteristics and sampling numbers for the study area are shown in Table 1, and the sampling points are shown in Fig. 1. Based on the results of the Spearman correlation analysis, we ~~then~~ retained some environmental variables that displayed significant correlations ($P < 0.05$) with soil erodibility to perform a principal component analysis (PCA) and ~~to~~ obtain the minimum data set (MDS) (Xu et al., 2008). Only those principal components (PCs) with eigenvalues $N > 1.0$ and only those variables with highly weighted factor loadings (i.e., those with absolute values within 10% of the highest value) were retained for the MDS (Mandal et al., 2008).

2.3 Research methods

Soil erodibility indicates the degree of difficulty ~~that~~with which soil becomes separated, eroded and transported by rainfall ~~erosion~~erosivity (Wang et al., 2013a; Cerdà et al., 2017). ~~Soil~~The soil erodibility factor, which is commonly known as the *K*-factor in ~~the model~~models, is defined as the average rate of soil loss per unit of rainfall erosivity index from a cultivated continuous fallow plot on a 22.1-m-long, 9% slope in the universal soil loss equation (Zhang et al., 2008). To minimize bias from ~~using only one~~any single estimation method, we estimated the *K* values using five estimation models (i.e., EPIC, NOMO, M-NOMO, Torri and Shirazi), ~~that~~which have been widely applied in ~~the~~ research on soil erodibility (Wischmeier et al., 1971, 1978; Williams et al., 1990; Torri et al., 1997; Shirazi et al., 1988).

2.3.1 K value estimation using the EPIC model

The erosion-productivity impact model (EPIC) developed by Williams (Williams et al. 1990) is as follows:

$$K = [0.2 + 0.3e^{-0.0256SAN(1-\frac{SIL}{100})}]\left(\frac{SIL}{CLA+SIL}\right)^{0.3}\left(1.0 - \frac{0.25C}{C+e^{3.72-2.95C}}\right)\left(1.0 - \frac{0.7SN_1}{SN_1+e^{-5.51+22.9SN_1}}\right)$$

$$K = [0.2 + 0.3e^{-0.0256SAN(1-\frac{SIL}{100})}]\left(\frac{SIL}{CLA+SIL}\right)^{0.3}\left(1.0 - \frac{0.25C}{C+e^{3.72-2.95C}}\right)\left(1.0 - \frac{0.7SN_1}{SN_1+e^{-5.51+22.9SN_1}}\right) \quad (1)$$

where *SAN* is ~~the~~ percent sand content, *SIL* is ~~the~~ percent silt content, *CLA* is ~~the~~ percent clay content, *C* is ~~the~~

percent organic carbon content, and $SN_1 = 1$~~-~~ $-$ SAN~~/~~ / 100. The resulting K value is reported in United States customary units of [short ton·ac·h / (100 ft·short ton·ac·in)].

2.3.2 K value estimation using the NOMO model

Wischmeier (Wischmeier et al., 1971) proposed this model after analyzing the ~~relationship~~relationships between soil erosion and five soil characteristic indicators~~, including the~~,: percent silt~~+~~ + very fine sand fraction (0.05-0.1 mm), ~~the~~ percent sand fraction,~~ the~~ soil organic matter content, a code for soil structure, and a code for soil permeability:

~~$K = [2.1 \times 10^{-4} M^{1.14}(12 - OM) + 3.25(S - 2) + 2.5(P - 3)] / 100$~~

$$K = [2.1 \times 10^{-4} M^{1.14}(12 - OM) + 3.25(S - 2) + 2.5(P - 3)] / 100 \qquad (2)$$

where M is the product of the percent of silt~~+~~ + very fine sand and the percent of all soil fractions other than clay, OM is ~~the~~ soil organic matter content (%), S is ~~the~~ soil structure code, and P is ~~the~~ soil permeability code. The resulting K value is reported in United States customary units of [short ton·ac·h~~/(~~ / (100 ft·short ton·ac·in)].

2.3.3 K value estimation using the M-NOMO model

On the basis of the universal soil loss equation (USLE) model, the RUSLE model was modified for calculating soil erodibility; ~~that is, a~~the revised nomograph equation was ~~devised~~modified from the previous nomograph equation (Wischmeier et al., 1978~~) based on the nomograph equation.~~). The revised nomograph equation is as follows:

~~$K = [2.1 \times 10^{-4} M^{1.14}(12 - OM) + 3.25(2 - S) + 2.5(P - 3)] / 100$~~

$$K = [2.1 \times 10^{-4} M^{1.14}(12 - OM) + 3.25(2 - S) + 2.5(P - 3)] / 100 \qquad (3)$$

where M is the product of the percent of silt~~+~~ + very fine sand and the percent of all soil fractions other than clay, OM is ~~the~~ soil organic matter content (%), S is ~~the~~ soil structure code, and P is~~ the~~ soil permeability code. The resulting K value is reported in United States customary units of [short ton·ac·h~~/(~~ / (100 ft·short ton·ac·in)].

2.3.4 K value estimation using the Torri model

Torri (Torri et al., 1997) established this model in 1997 using data describing soil particle size and soil organic matter content. The model has few parameters~~,~~ and simple data acquisition~~ of the relevant data is simple.~~. The formula used ~~in evaluating~~for this model is as follows:

$$\cancel{K = 0.0293(0.65 - D_g + 0.24D_g^{\,2}) \times \exp\left\{-0.0021\frac{OM}{c} - 0.00037\left(\frac{OM}{c}\right)^2 - 4.02c + 1.72c^2\right\}}$$

$$K = 0.0293(0.65 - D_g + 0.24D_g^{\,2}) \times \exp\left\{-0.0021\frac{OM}{c} - 0.00037\left(\frac{OM}{c}\right)^2 - 4.02c + 1.72c^2\right\} \quad (4)$$

where *OM* ~~is the~~and *c* are percent ~~content of~~ soil organic matter~~,~~ and~~ c is the percent content of~~ clay~~. In addition, the~~ content, respectively. D_g can be calculated by using the following formula:

$$\cancel{D_g = \sum f_i \lg\sqrt{d_i d_{i-1}}}\; D_g = \sum f_i \lg\sqrt{d_i d_{i-1}} \quad (5)$$

where D_g is the Napierian logarithm of the geometric mean of the particle size distribution, d_i (mm) is the maximum diameter of the i-th class, d_{i-1} (mm) is the minimum diameter and f_i is the mass fraction of the corresponding particle size class. We ~~calculate the~~calculated D_g based on three particle-~~-~~size classes~~, namely~~: sand, silt, and clay. The resulting *K* values are reported in the international units of [(t·hm^2·h~~)/(~~) / (MJ·mm·hm^2)].

2.3.5 K value estimation using the Shirazi model

Shirazi (Shirazi et al., 1988) put forward a model that is appropriate for situations involving ~~fewer~~few physical and chemical properties of the soil materials. ~~He~~The authors suggested that *K* values can be calculated ~~through considering~~by using only the geometric mean diameter (D_g) of ~~the~~ soil grains~~. The relevant formula is~~:

$$\cancel{K = 7.594\left\{0.0034 + 0.0405e^{-\frac{1}{2}\left[\frac{\log(D_g)+1.659}{0.7101}\right]^2}\right\}}\; K = 7.594\left\{0.0034 + 0.0405e^{-\frac{1}{2}\left[\frac{\log(D_g)+1.659}{0.7101}\right]^2}\right\} \quad (6)$$

$$\cancel{D_g(mm) = e^{0.01\sum f_i \ln m_i}}$$

Meanwhile, D_g in this model can be calculated by using the following formula: (7)

$$D_g(mm) = e^{0.01\sum f_i \ln m_i}$$

~~where D_g is the geometric mean diameter of the soil particles,~~where f_i is the weight percentage of the i-th particle size fraction (%), m_i is the arithmetic mean of the particle size limits for the i-th fraction (mm), and n is the number of particle size fractions. The resulting K value is reported in United States customary units of [short ton·ac·h~~/(~~ / (100 ft·short ton·ac·in)].

2.3.6 K value comparisons

To increase the comparability of the results from the different estimation models, our research adopted the international units for the K values, [t·hm^2·hr~~/(~~ / (MJ·mm·hm^2)]. The international K value is equal to the K value reported in the United States customary units multiplied by 0.1317. To clarify the form of the distribution, we collected the frequency distribution figures of soil erodibility for each model (Wei et al., 2017a, b). The K values obtained using the five methods were normally distributed ($P > 0.05$). Therefore, the soil erodibility K values measured within the study area were statistically analyzed directly, without the need for data conversion (Fang et al., 2016). ~~, multiplied by 0.1317.~~To discuss the possible best texture-based method to estimate K, related research on K estimation, especially that involving measured values of K on the Loess Plateau of China, was consulted. A Taylor diagram was also used to compare the models.

~~To clarify the form of the distribution, we adopted the Kolmogorov-Smirnov test (Table 2) and made the frequency distribution figures of soil erodibility for each model (Fig. 2). The P >0.05 showed that the K values obtained using the five methods were normally distributed. Therefore, the soil erodibility K values measured within the study area can be analyzed directly using statistical methods without data conversion (Fang et al. 2016).~~

~~*2.3.6 K value comparisons*~~

~~In order to discuss the possible best texture-based method to estimate K, related researches on K estimation, especially the measured value of K in Loess Plateau of China, have been collected. Taylor Diagram was also used~~

~~to compare the difference between models.~~

3 Results

3.1 Soil erodibility in the Ansai watershed based on five different models ~~in Ansai watershed~~

We ~~found that the~~ obtained different values when calculating descriptive statistics of the K ~~values~~value in the Ansai watershed ~~differed when~~ among the different models ~~were used~~ (Table 2). The range of K values based on the five methods were between 0.032 and 0.060, 0.046 and 0.092, 0.047 and 0.088, 0.009 and 0.066, and 0.018 and 0.044 [t·hm^2·hr~~/(~~ / (MJ·mm·hm^2)] for K_{EPIC}, K_{NOMO}, $K_{M\text{-}NOMO}$, K_{Torri}, and $K_{Shirazi}$, respectively. The~~ range of the~~ maximum values were 1.875, 2.000, 1.872, 7.333 and 2.444 times larger than the corresponding minimum values (Table 2). The differences between the mean and median values were 0.001, -0.001, 0.000, 0.000, and 0.000 [t·hm^2·hr~~/(~~ / (MJ·mm·hm^2~~)],~~)] for K_{EPIC}, K_{NOMO}, $K_{M\text{-}NOMO}$, K_{Torri}, and $K_{Shirazi}$, respectively. The standard deviations (SDs) of the K values were 0.408, -0.447, -1.079, -2.639, and 0.059 for K_{EPIC}, K_{NOMO}, $K_{M\text{-}NOMO}$, K_{Torri}, and $K_{Shirazi}$, respectively~~, and the skewnesses~~. The skewness values of the K values were 0.946, 0.956, 4.353, 16.872, and 0.009 for K_{EPIC}, K_{NOMO}, $K_{M\text{-}NOMO}$, K_{Torri}, and $K_{Shirazi}$, respectively. The Cv value of $K_{M\text{-}NOMO}$ was 0.067 < 10~~%; in addition,~~%, and the Cv values of K_{EPIC}, K_{NOMO}, K_{Torri}, and $K_{Shirazi}$ were 0.109, 0.110, 0.113, and 0.182, respectively, all of which ~~were~~corresponded to between 10% and 100%.

In the Taylor diagrams (Taylor, 2001) (Fig. ~~3~~2), the K values based on the EPIC model ~~is~~were used as the reference ~~object~~objects. The K values based on the Torri, NOMO, and Shirazi models were similar and ~~were~~ located close to each other. In contrast, ~~there was inconsistency in~~ the K values estimated by the M-NOMO and EPIC models were inconsistent with the other K values.

3.2 Spearman correlation coefficients ~~between~~of soil erodibility and environmental variables in the Ansai watershed

The correlations between soil erodibility and the environmental variables varied ~~with~~among the different vegetation types (Table S1-S4). In general, soil erodibility in artificially managed vegetation types (apple orchards and David's peach) and artificially restored vegetation types (e.g., sea buckthorn and black locust) had significant ~~correlation~~correlations with vegetation properties. For example, soil erodibility in areas planted with apple orchards had a significant positive correlation with plant density ($P < 0.05$, Table S1). ~~The soil~~Soil erodibility ~~of~~in areas with sea buckthorn had significant negative correlations with ~~the~~ slope gradient and plant density~~, whereas it had~~ and significant positive correlations with ~~the~~ average annual rainfall and aboveground biomass ($P < 0.05$, Table S3). ~~The soil~~Soil erodibility of areas with David's peach had ~~a~~ significant positive correlation with ~~the~~ aboveground biomass~~, whereas it had~~ and significant negative correlations with ~~the~~ slope gradient, vegetation coverage, vegetation height, crown width and basal diameter ($P < 0.05$, Table S4). ~~The soil~~Soil erodibility ~~of~~in areas with black locust had ~~a~~ significant negative correlation with ~~the~~ elevation~~, whereas it had~~ and significant positive correlations with ~~the~~ slope position, slope gradient, soil bulk density, vegetation coverage, litter biomass and branch number ($P < 0.05$, Table S4). ~~Meanwhile, soil~~Soil erodibility in areas under ~~different~~other vegetation types, such as ~~grasslands~~grassland or ~~farmlands were~~farmland, was more strongly correlated with soil or landscape properties~~.~~ than other impact factors. The results of the ~~correlation analysis~~analyses of correlations between estimated K values and the selected environmental variables showed that soil erodibility in farmlands had significant positive correlations with ~~the slope position,~~ slope shape and ~~average annual rainfall and displayed~~ a significant negative correlation with ~~the~~ slope gradient ($P < 0.05$, Table S1). ~~Soil~~The soil erodibility of areas with native grasslands had ~~a~~ significant a negative correlation with ~~the~~ elevation~~, whereas it had~~ and significant positive correlations with ~~the~~ average annual rainfall and slope gradient ($P < 0.05$, Table S2). ~~Soil~~The soil erodibility of areas with pasture grasslands did not have significant correlations with ~~the~~ environmental variables other than soil organic matter content and ~~the~~ soil particle size ($P < 0.05$, Table S2). ~~The soil~~Soil erodibility ~~of~~in areas with *Caragana korshinskii* had a significant positive correlation with ~~the~~ elevation~~, whereas it had~~ and a significant negative correlation with ~~the~~ average annual rainfall ($P < 0.05$, Table S3).

3.3 Principal component analysis of soil erodibility under different vegetation types

~~Our results showed the~~The PCA identified one PC each for apple orchards, native grasslands, sea buckthorn, *Caragana korshinskii* and pasture grasslands, which accounted for 100%, 48.88%, 62.05% and 53.61 of the variances, respectively (Table S5). ~~The PCA identified two PCs each for farmland and David's peach; the corresponding cumulative variances were 73.93 % and 81.07 %, respectively.~~ For ~~black locust, the PCA identified three PCs that accounted for 70.25 % of the variance (Table S5). In farmland, PC1 included two variables that had highly weighted factor loadings, the slope shape and slope position, and PC2 included only the slope gradient, which had a highly weighted factor loading. In~~ apple orchards, ~~the highly weighted factor loading was the~~ plant density~~. In~~ was the primary contributor to the high factor loading. For native grasslands, PC1 included two variables that had highly weighted factor loadings, ~~including~~ the slope gradient and elevation. ~~The pasture~~Pasture grasslands had no variables with ~~highly weighted~~high factor loadings because it had no significant environmental variables except ~~the~~ soil particle size and soil organic matter. The highly weighted factor loadings in areas with sea buckthorn were ~~the~~ slope gradient, aboveground biomass and plant density. In areas planted with *Caragana korshinskii*, two variables had ~~highly weighted factor loadings, including the average annual rainfall and elevation. In areas planted with black locust, the highly weighted factor loadings of PC1 were the slope position, elevation and litter biomass; for PC2, the slope gradient and soil bulk density had high factor loadings, whereas only vegetation coverage had a high weighted factor loading for PC3. In areas planted with David's peach, PC1 included three variables that had highly weighted factor loadings, specifically the crown width, vegetation height and vegetation coverage, whereas only the basal diameter had a high factor loading for PC2~~high factor loadings: average annual rainfall and elevation (Table S5).

The PCA identified two PCs each for farmland and David's peach; the corresponding cumulative variances were 73.93% and 81.07%, respectively. The PC1 for farmland included two variables that had high factor loadings, slope shape and slope position, whereas PC2 only included slope gradient. In areas planted with David's peach, crown width, vegetation height and vegetation coverage contributed to the high factor loading of PC1, whereas basal diameter alone had a high factor loading for PC2. In areas planted with black locust, the PCA identified three PCs that accounted for 70.25% of the variance (Table S5). PC1 had slope position, elevation and litter biomass as parameters with high factor loadings. The parameters with high factor loadings for PC2 were slope gradient and soil bulk density, and vegetation coverage had a high factor loading for PC3 (Table S5).

The MDS of ~~the~~ soil erodibility included six environmental variables for black locust, four for David's peach, three each for farmland and sea buckthorn, two each for native grasslands and *Caragana korshinskii*, one for apple orchards and none for pasture grasslands (Table ~~3).~~S1, Table S2, Table S3). In addition to ~~the~~ soil organic matter and soil particle size, which ~~are~~were included in the *K* value estimation equations, the dominant factors affecting ~~the~~ soil erodibility for farmland were slope shape, slope gradient and slope position. For apple orchards, the only dominant factor affecting soil erodibility (~~except the~~other than soil organic matter and soil particle size) was plant density. For areas with native grasslands, the dominant factors affecting soil erodibility were soil organic matter, soil particle size, slope gradient and elevation. For areas with sea buckthorn, the dominant factors affecting soil erodibility were aboveground biomass, slope gradient and plant density in addition to the two soil properties. The dominant factors affecting soil erodibility in areas with *Caragana korshinskii* were soil particle size, soil organic matter, average annual rainfall and elevation. For areas with black locust, the dominant factors were ~~the~~ slope gradient, slope position, elevation, litter biomass, soil bulk density and vegetation coverage in addition to the soil organic matter and soil particle size. The dominant factors affecting soil erodibility in areas with David's peach included ~~the~~ soil organic matter, soil particle size, crown width, vegetation height and vegetation coverage.

4 Discussion

4.1 The optimal methods for estimating *K* values in the Ansai watershed

In this study, we found that different models resulted in different ~~estimations~~estimates of soil erodibility (Table 2). Since the different estimation methods use different soil attributes as input parameters~~; even if the input parameters are the same~~, the decision coefficients of the same input parameters ~~are different.~~will differ. For example, the EPIC model focuses on the features of the soil ~~particle~~particles and soil nutrients, ~~while~~whereas the NOMO model focuses on not only ~~the~~ soil particle size and soil nutrient characteristics~~,~~ but also the soil ~~structure~~structural characteristics, such as soil structure code and soil permeability code. The existing soil erodibility estimation equations are used to calculate soil erodibility based on data on ~~the~~ physicochemical soil properties, such as soil texture, soil structure, soil permeability and soil organic matter content (Wischmeier et al., 1971, 1978; Williams et al., 1990; Torri et al., 1997; Shirazi et al., 1988). Among these factors, the main physical soil property is ~~the~~ soil particle composition, such as the contents of sand, silt and clay, and the main chemical soil property is ~~the~~ soil organic matter content (Wei et al., 2017).

Our results showed that the *K* values based on the Torri, NOMO, and Shirazi models were ~~are~~ located close to each other in the Taylor diagrams (Fig.~~3~~ 2) and ~~those~~that these three models could therefore represent ~~the~~ soil erodibility in the Ansai watershed. Based on previous studies, these models have ~~also~~ been recommended as the optimal models ~~in Chinese~~for China's subtropical zone, China's purple hilly region, Northeast China, and ~~Chinese Loss~~China's Loess Plateau (Table 4). ~~We, however, suggested~~ However, we suggest that the Torri and Shirazi models ~~as better representatives of~~are the best models~~,~~ based on ~~their~~ estimated *K* values ~~and the~~derived from these models and actual (measured) soil erodibility data ~~in~~from the Ansai watershed (Zhang et al., 2001; Table S6). The estimated *K* ~~value~~values based on the Torri and Shirazi models were closer to the measured soil erodibility data among those of the three possible appropriate models (Table 2 and Table S6). Our ~~suggestions were also~~findings are supported by a study by Lin et al. (2017) ~~who showed~~showing that the estimated *K* ~~value~~values based on the

Torri and Shirazi models ~~was~~were closer to the measured value~~.~~ than NOMO model and M-NOMO model.

4.2 Environmental factors that influenced ~~the~~ soil erodibility

Based on the definition of *K* factor by Wischmeier et al. (1971), soil ~~erodiblity~~erodibility is estimated ~~by~~from texture data, organic matter content, soil structure index, and the soil permeability index. While soil ~~erodiblity~~erodibility does not directly depend on environmental factors, soil properties such as soil particle size distribution and soil organic matter can be affected by environmental factors. Soil erodibility thus has indirect ~~relationship~~relationships with ~~the~~ environmental factors, particularly vegetation type~~ that~~, which influences the generation of soil organic matter and the composition of soil ~~particle~~particles. Soil erodibility had ~~different correlation~~various correlations with the selected environmental variables, which ~~resulted in changes in~~affected the dominant factors ~~that influenced the~~influencing soil erodibility (Tables S1-S5, Table 3). In native grasslands, soil erodibility had significant correlations with terrain factors (e.g., elevation, slope degree) (Table S1, Table S4), and the dominant factors influencing ~~the~~ soil erodibility were soil properties and topography. Terrain factors have close relationships with soil properties. With ~~the increase~~changes of elevation and slope, the physical and chemical ~~soil~~ properties of soil (e.g., soil permeability, soil bulk density, and soil ~~nutrient~~nutrients) and soil surface conditions ~~are changed, further lead~~(e.g., roughness, litter layer) change, leading to ~~the~~ changes ~~of~~in soil particle size composition and soil erodibility (Zhao et al., 2015). For example, Li et al. (2011) found that the silt content was higher than the sand content in low ~~than~~but not high elevations, and Liu et al. (2005) found that slope gradient ~~is~~was negatively correlated with soil nutrients (e.g., soil organic matter, available nitrogen).

For most artificially managed vegetation types (apple orchards and David's peach) and artificially restored vegetation types (e.g., sea buckthorn and black locust), soil erodibility had significant correlations with ~~the~~ vegetation properties (Table S1, Table S3-S4). By ~~changing the~~affecting physicochemical soil properties and soil structure stability, vegetation properties ~~could~~ affect soil erodibility. For example, the dominant ~~factor(s)~~factors influencing ~~the ~~soil erodibility ~~associated with~~were plant density for apple orchards~~ was plant density, sea buckthorn was~~, aboveground biomass~~, black locust were ~~ for sea buckthorn litter biomass and vegetation coverage for black locust, and~~ David's peach were~~ crown width, vegetation height, basal diameter and vegetation coverage for David's peach (Table S1). ~~Because all these vegetation types are more or less affected by human~~Human activities~~, soil erodibility can also indirectly be affected by~~ (e.g., pruning) affect vegetation recovery and land cover change. These changes may then influence vegetation properties and thereby impact soil erodibility.

5 Conclusions

We evaluated soil erodibility in the Ansai watershed using five estimation models~~ in Ansai watershed; the ~~. The estimated *K* values ~~based on ~~differed among the different models ~~were different from one another ~~and ~~the resulting *K* values ~~ranged between 0.009 and 0.092 t·hm^2·hr~~/(~~ / (MJ·mm·hm^2). Based on Taylor diagrams and previous studies, we considered the Shirazi and Torri ~~model~~models the optimal models for the Ansai watershed. Since soil erodibility is estimated by soil properties, ~~soil erodibility~~it has indirect ~~relationship~~relationships with ~~environment~~environmental factors, including elevation and slope degree~~,~~ and, to a lesser extent, human activities. By changing vegetation density, biomass, and cover, ~~human~~humans can indirectly affect soil erodibility.

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Table 1 Landscape and soil characteristics in the study area

Vegetation	Natural vegetation	Artificially managed vegetation		Artificially restored vegetation				
~~type~~type	NG	FL	AO	PG	SB	CK	BL	DP
~~Sampling~~Sample number	25	22	10	11	15	18	38	12
Ele (m)	1392.60	1380.14	1370.10	1401.00	1435.67	1350.61	1326.54	1377.58
SG (°)	16.72	6.27	19.90	11.91	16.40	17.56	27.24	24.17
Cla (%)	7.44	7.93	7.05	7.88	6.70	7.21	8.30	8.34
Sil (%)	45.08	52.63	48.57	42.73	45.05	48.08	51.75	49.69
San (%)	47.48	39.44	44.38	49.39	48.25	44.71	39.95	41.97
OM (g/kg)	7.04	5.31	5.75	6.30	8.91	13.30	8.10	5.99
SBD (g/cm^3)	1.26	1.29	1.25	1.28	1.23	1.26	1.23	1.26
Por (%)	0.48	0.46	0.48	0.47	0.48	0.49	0.49	0.49
AAR (mm)	473.99	479.01	479.85	471.75	476.44	474.66	474.43	472.58
VC (%)	57.36	53.14	39.70	67.82	66.07	46.28	59.58	33.75
AB (g/m^2)	28.96	95.61	12.24	73.56	28.59	45.63	23.92	16.20
VH (m)	0.59	1.83	3.58	0.67	2.16	1.81	11.49	3.02
LB (g/m^2)	15.70	—	8.64	12.06	25.10	34.05	72.50	14.44
PD (/m^2)	—	—	30.50	—	262.40	131.89	58.66	36.17
Cro (cm)	—	—	398.39	—	184.85	205.20	448.72	293.40
BD (cm)	—	—	6.32	—	3.76	1.59	10.16	4.98
BN	—	—	10.17	—	—	27.88	12.86	8.13

Annotation: NG ~~refers to~~denotes native grassland, AO ~~refers to~~denotes apple orchard, FL ~~refers to~~denotes farmland, PG ~~refers to~~denotes pasture grassland, SB ~~refers to~~denotes sea buckthorn, CK ~~refers to~~denotes *Caragana korshinskii*, DP ~~refers to~~denotes David's peach, BL ~~refers to~~denotes black locust, Ele ~~refers to~~denotes elevation, SP ~~refers to~~denotes slope position, SA ~~refers to~~denotes slope aspect, SG ~~refers to~~denotes slope gradient, SS ~~refers to~~denotes slope shape, Cla ~~refers to~~denotes clay, Sil ~~refers~~denotes silt, San ~~refers to~~denotes sand, OM ~~refers to~~denotes organic matter, SBD ~~refers to~~denotes soil bulk density, Por ~~refers to~~denotes porosity, AAR ~~refers to~~denotes average annual rainfall, VC ~~refers to~~denotes vegetation coverage, AB ~~refers to~~denotes aboveground biomass, VH ~~refers to~~denotes vegetation height, LB ~~refers to~~denotes litter biomass, PD ~~refers to~~denotes plant density, Cro ~~refers to~~denotes crown, BD ~~refers to~~denotes basal diameter, and BN ~~refers to~~denotes branch number.

Table 2 Statistics of soil erodibility in the Ansai watershed

~~Methods~~Method	Mean	Max	Min	Median	SD	Skewness~~Skew~~	~~Kurt~~Kurtosis	*Cv*
EPIC	0.046	0.060	0.032	0.045	0.005	0.408	0.946	0.109
NOMO	0.073	0.092	0.046	0.074	0.008	-0.447	0.956	0.110
M-NOMO	0.075	0.088	0.047	0.075	0.005	-1.079	4.353	0.067
Torri	0.053	0.066	0.009	0.053	0.006	-2.639	16.872	0.113
Shirazi	0.033	0.044	0.018	0.033	0.006	0.059	0.009	0.182

Annotation: EPIC ~~refers to~~denotes the erosion-productivity impact model, NOMO ~~refers to~~denotes the nomograph equation, M-NOMO ~~refers to~~denotes the modified nomograph equation, Torri ~~refers to~~denotes the *K* value estimation model established by Torri, Shirazi ~~refers to~~denotes the *K* value estimation model established by Shirazi, SD ~~refers to~~denotes the standard deviation, ~~Skew refers to the~~ and ~~Skewness, Kurt refers to the kurtosis,~~ *Cv* ~~refers to~~denotes the coefficient of variation~~, and P referes to p-value of Kolmogorov-Smirnov test.~~ .

Table 3 Principal component analysis (PCA) of environmental attributes

Vegetation ~~types~~type	Main influencing factors
Farmland	SS, SP, SG
Apple orchard	PD
Native ~~grasses~~grasslands	SG, Ele
Pasture ~~grasses~~grasslands	—
Sea buckthorn	AB, SG, PD
Caragana korshinskii	AAR, Ele
Black locust	SG, SP, Ele, LB, SBD, VC
David's peach	Cro, VH, BD, VC

Annotation: SS ~~refers to~~denotes slope shape, SP ~~refers to~~denotes slope position, SG ~~refers to~~denotes slope gradient, PD ~~refers to~~denotes plant density, Ele ~~refers to~~denotes elevation, AB ~~refers to~~denotes aboveground biomass, AAR ~~refers to~~denotes average annual rainfall, LB ~~refers to~~denotes litter biomass, SBD ~~refers to~~denotes soil bulk density, VC ~~refers to~~denotes vegetation coverage, Cro ~~refers to~~denotes crown width, VH ~~refers to~~denotes vegetation height, and BD ~~refers to~~denotes basal diameter.

Table 4 Suggested soil erodibility estimation models in China

Study area	~~optimal models~~Optimal model(s)	References
Hilly area of ~~Chinese~~ China's subtropical zone	Torri	Zhang et al., 2009
Purple hilly region ~~in~~of Sichuan Basin	EPIC and NOMO~~,~~	Shi et al., 2012
~~typical~~Typical black soil region in Northeast China	EPIC and NOMO~~,~~	Wang et al., 2012
Hilly and gully area of ~~Chinese Loss~~China's Loess Plateau	Torri and Shirazi	Lin et al., 2017
Hilly and gully area of ~~Chinese Loss~~China's Loess Plateau	Shirazi	Wei et al., 2017

Fig. 1 ~~Location~~Locations of the study area and the sampling points

Fig. ~~2 Frequency distributions of soil erodibility~~

~~**Fig. 3**~~**2** Taylor diagram ~~were~~ used to compare ~~the estimating~~estimated *K* values among models

Figure 1

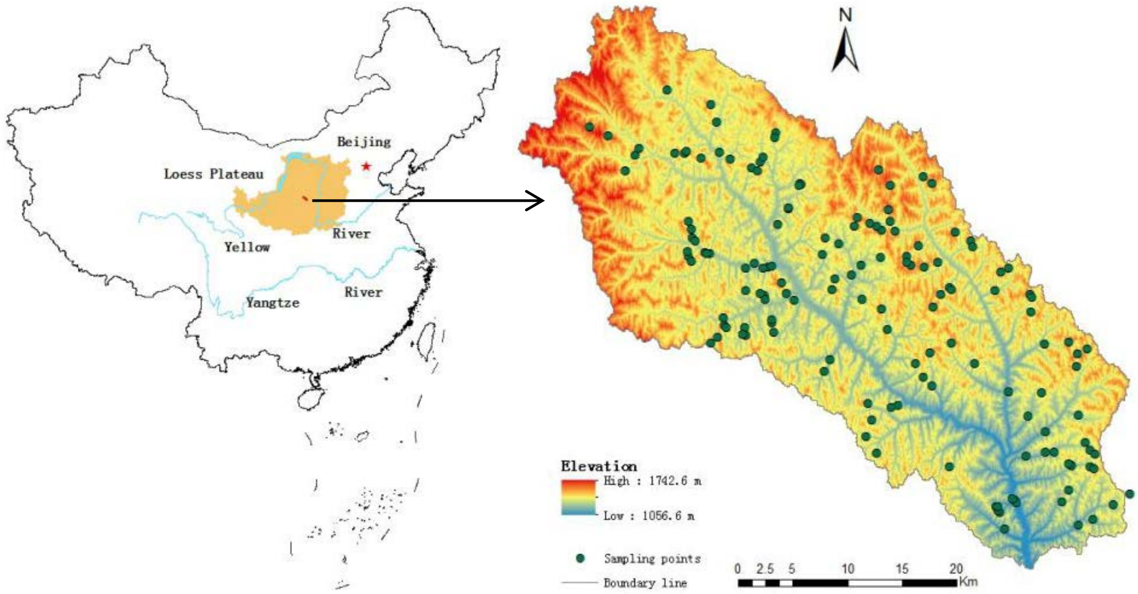
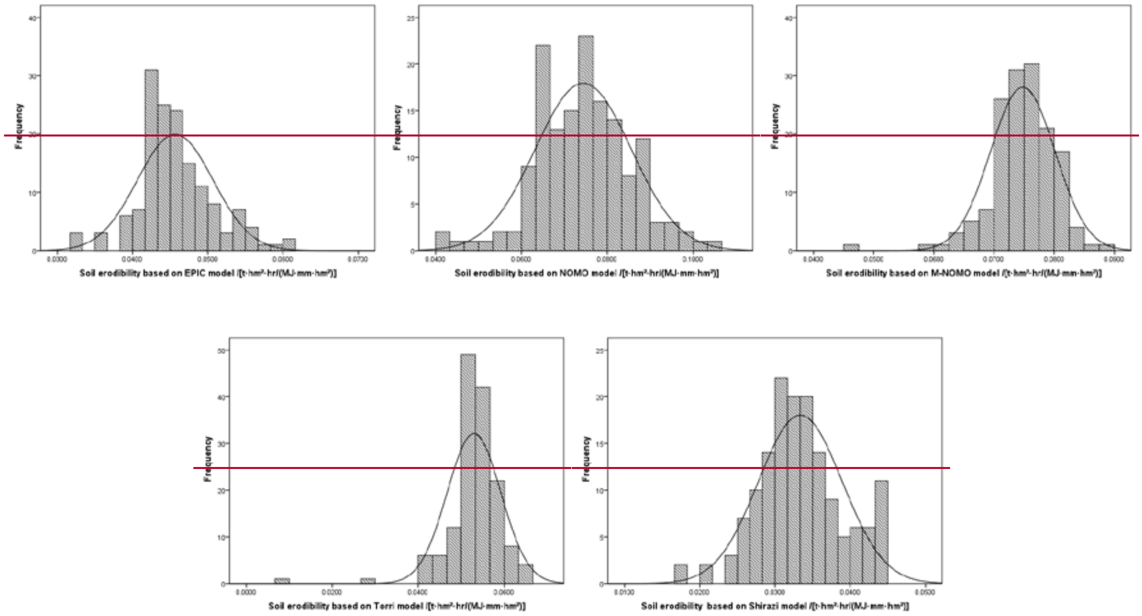
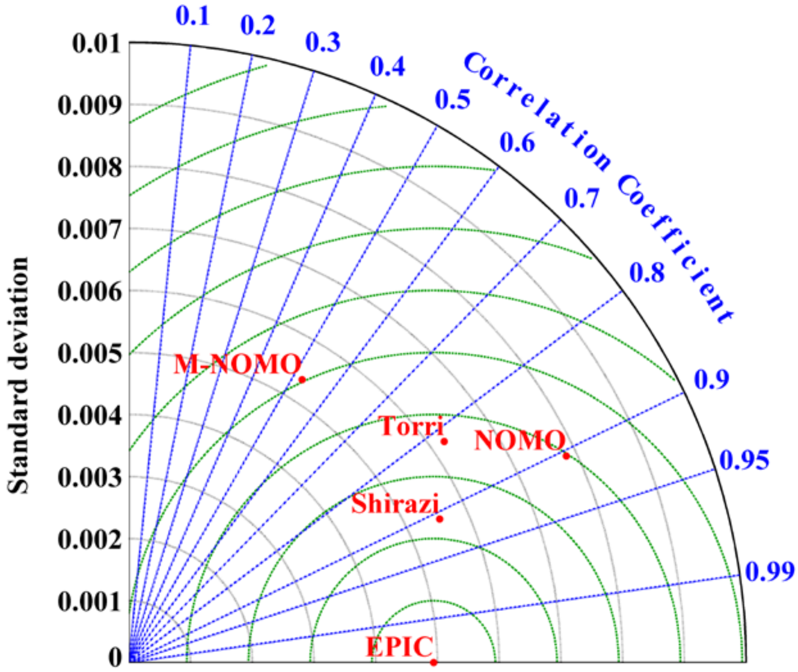

Beijing
Loess Plateau
Yellow
River
Yangtze
River
N
Elevation
High : 1742.6 m
Low : 1056.6 m
Sampling points
Boundary line
0 2.5 5 10 15 20
Km

Figure 2


Frequency
Soil erodibility based on EPIC model /[t·hm²·h/(MJ·mm·hm²)]
Frequency
Soil erodibility based on NOMO model /[t·hm²·h/(MJ·mm·hm²)]
Frequency
Soil erodibility based on M-NOMO model /[t·hm²·h/(MJ·mm·hm²)]
Frequency
Soil erodibility based on Torri model /[t·hm²·h/(MJ·mm·hm²)]
Frequency
Soil erodibility based on Shirazi model /[t·hm²·h/(MJ·mm·hm²)]

~~Figure 3~~


Standard deviation
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Correlation Coefficient
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
M-NOMO
Torri
NOMO
Shirazi
EPIC