Application of a modified distributed-dynamic erosion and sediment yield model in a typical watershed of hilly and gully region, Chinese Loess Plateau

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Abstract. Soil erosion not only results in the destruction of land resources and the decline of soil fertility, but also ~~makes~~ contributes to river channel sedimentation. In order to explore the spatiotemporal evolution of erosion and sediment yield before and after returning farmland in a typical watershed of a hilly and gully region~~, ~~ (Chinese Loess Plateau), a distributed-dynamic model of sediment yield based on the Chinese Soil Loss equation (CSLE) was established and modified to assess the effects of hydrological factors and human activities on erosion and sediment yield ~~from~~ between 1995 ~~to~~ and 2013. Results ~~indicate~~ showed that: 1) the modified model has characteristics of simple algorithm, high accuracy, wide practicability and easy expansion, and can be applied to predict erosion and sediment yield in the study area,~~of the hilly and gully region, Chinese Loess Plateau.~~ 2) soil erosion gradations are closely related to the spatial ~~distributions~~ distribution of rainfall erosivity and land use patterns, the current soil and water conservation measures are not ~~very ideal~~efficient for high rainfall ~~intensity~~intensities~~.~~, 3) the average sediment yield ~~modulus~~rate before and after model modification in recent 5 years (in addition to 2013) is 4574.62 Mg/km^2 and 1696.1 Mg/km^2, respectively, ~~it has decreased~~decreasing by about 35.4% and 78.2% ~~comparing~~ when compared to~~with~~ the early governance (1995-1998). However, in July 2013 the once-in-a-century storm is the most important reason for ~~the emergence of~~ maximum sediment yield. Results may provide effective and scientific basis for soil and water conservation planning and ecological construction of the hilly and gully region, Chinese Loess Plateau.

~~**Key words:** Soil erosion; Sediment yield; Dynamic model; Returning farmland; Spatio-temporal evolution~~

1. Introduction

Soil erosion is one of the main environmental ~~disasters~~ risks that restricts the survival and development of human beings (Ongley et al., 2010), affects regular land development and has been reported as the main cause of~~it will bring disastrous~~ land degradation and ~~affect regular land development~~ (Sun et al., 2012). ~~Soil~~ According to Miao et al. (2010), soil erosion in the Chinese Loess Plateau is serious ~~(Miao et al., 2010), the~~. The annual average soil loss ~~amount~~ in this region is about 1600

Gg, and the annual erosion amount of surface soil in the most seriously affected areas reaches 20 mm or more (~~Rudi & Victor~~Hessel and Jetten, 2007). Recent studies on the Loess Plateau are mainly focused on the water erosion control in the water-wind crisscrossed erosion region, soil quality indicators in relation to land use and topography, overland flow on abandoned slopes, effects of long-term fertiliser applications on soil organic carbon and hydraulic properties, soil water content, interrill erosion on unpaved roads, and temporal variations of flow-sediment relationships (Zhao et al., 2015; Zhao et al., 2016a; Yu et al., 2016; Shi et al., 2016; Li et al., 2016a, 2016b; Cao et al., 2015; Yu et al., 2015; Gao et al., 2016). But there is little research on the distributed-dynamic simulation of erosion and sediment yield at watershed scales.

Majiagou River watershed belongs to the first grade tributary of the Yanhe River~~, it~~. It is located in the typical hilly and gully region of the Loess Plateau (Li, 2009), ~~its~~ with a particular topography and geomorphology ~~have very strong representative, it~~. It is one of the ~~is one of the serious soil and water loss~~ regions in the middle reaches of the Yellow River more seriously affected by soil loss (Fu et al., 2010; Jia et al., 2014). Before the implementation of China's returning farmland policy in 1997 (Zhao et al. 2016b), the soil erosion area in Majiagou River watershed reached 72.31 km^2, which accounts for 98% of the total watershed area~~, the soil erosion modulus~~. Soil erosion rate was up to 8740 ~~$Mg/(km^2 \cdot a)$~~ $Mg\ km^{-2}\ year^{-2}$, it belongs to the very intensive soil erosion region (Dang et al., 2013). After the implementation of returning farmland to forestland project for nearly 10 years, the soil erosion ~~modulus~~rate of the Majiagou River watershed decreased to 5700 ~~$Mg/(km^2 \cdot a)$~~ $Mg\ km^{-2}\ year^{-2}$ in 2008 (Wu et al., 2010). Therefore, it is necessary to track spatiotemporal evolutions of erosion and sediment yield in the Majiagou River watershed, and results may provide reference for scientific management of land resources and reasonable planning of soil and water conservation measures.

Under the international background of serious soil loss, ~~the researches~~research on monitoring, modelling and ~~the most~~other advanced ~~technology~~ technologies ~~have~~ has developed rapidly in the world (Chen ~~&~~and Cui 2006; Cui et al., 2013; Borrelli et al., 2015). In the field of experimental study, the earliest quantitative study of soil erosion ~~quantitative observation~~ began in 1912 (Meyer, 1984), the related scholars in the world carried out long-term experimental studies in the runoff plot under rainfall and natural status (Xia et al., 1998; Zhou et al., 2000; Yu et al., 2009; Chen et al., 2010), which provides the scientific basis for the study of soil erosion and the theoretical supporting for the development of factor analysis model. In the field of model study, soil erosion models may be divided into factor analysis ~~model~~ (empirical statistical models) and physical-mechanism process models (Zhou ~~&~~and Shangguan, 2004; Cao et al., 2015) ~~according to different modelling ideas~~. The factor analysis model is simple and intuitive~~, it~~ and can be modified according to the specific application area. The typical representative is the USLE and its ~~modified form~~revised version (RUSLE) (Wischmeier ~~&~~and Smith, 1965, 1978; Renard et al., 1997; Xie et al., 2003; Wang ~~&~~and Lu 2004; Sadeghi ~~&~~and Mizuyama, 2007), which have been widely used ~~in the world~~ (Liu et al., 2001, 2002; Fu et al., 2001; Yin ~~&~~and Chen, 1989; Wang et al., 1996; Cheng et al., 2009; Arekhi et al., 2012; Ligonja ~~&~~and Shrestha 2015). ~~In the field of~~Regarding physically-based models, ~~the soil erosion model~~they may be

Comment [AJL1]: Just a suggestion. Although "a" is correct for annum (year), according to the International System of Units, I suggest using "year" to avoid confusion.
Using parentheses in these expressions is not good. Here, and through the manuscript, please change "$Mg/(km^2 \cdot a)$" with "$Mg\ km^{-2}\ a^{-1}$" (or "$Mg\ km^{-2}\ year^{-1}$").

divided into four main processes including precipitation sputtering, migration, runoff dispersing, and sediment transport (Wang et al., 2008). Meyer (1984) established the theory of shallow gully erosion~~ in 1972 (Meyer, 1984).~~ and Foster (1980) proposed ~~the ~~a physical-based soil erosion model~~ in 1980 (Foster, 1980)~~. The United States Department of Agriculture (USDA) introduced the WEPP model in 1995. At the same time, in Europe and Australia ~~there are ~~some classic physical ~~process ~~process-based models, such as the Holland LISEM~~ model~~, the British EUROSEM ~~model ~~and the Australian GUEST, were developed~~ model~~. Since 1980, Chinese scholars have successively established ~~the ~~soil erosion prediction models with local characteristics (Mou ~~&~~and Meng, 1983; Yang et al., 2008; Tang, 1996; Cai et al., 1996; Fan, 1985; Yang et al., 2007). With the development of modern information technology, the distributed and dynamic models have been developed and applied gradually. In the field of distributed model, the typical soil erosion distributed models mainly include SHE~~ model~~, IHDM ~~model ~~and EUROSEM models (Wang et al., 2003). In particular, some of the agricultural non~~-~~point source pollution evaluation models such as SWAT and AGNPS also ~~embed ~~include soil erosion evaluation modules (Zhang et al., 2007; Li et al., 2009). Dynamic models for soil erosion of small-scale watershed systems also have a wide application value (Tang ~~&~~and Chen, 1997; ~~Gao & Lei~~Peiling and Tingwu, 2010; Liao et al., 2012)~~, the~~. The most representative dynamic model is KINEROS, ~~model ~~which simulates storm event-based sediment processes (Singh et al., 1999). In recent years, ~~the researches of~~research on soil erosion has evolved rapidly with new computer-based technologies, ~~with the advanced technology such ~~as GIS~~ and ~~/RS, BP neural networks, genetic algorithm and fruit fly algorithms ~~have developed rapidly great progress ~~(Zhao et al., 2004; Dai et al., 2008; Ochoa-Cueva et al., 2015). ~~They can realize the~~These can make real-time accurate simulations ~~with high accuracy ~~and assess~~the~~ quantitative ~~assessment of ~~spatiotemporal ~~evolutions ~~changes (Caro & Legarda, 2013). In short, with the development and popularization of information technology, GIS/RS technology and computing technology, ~~the distributed ~~research on the watershed sediment yield has become an inevitable trend, and the dynamic simulation has also become a necessary means to track temporal variations of erosion and sediment yield (Yao ~~&~~and Xiao, 2012).

However, the existing distributed-dynamic ~~model takes~~models which focus on event-based rainfall processes ~~as the research object, there is very little involved in~~are not suitable to assess inter-annual variability of erosion and sediment yields, and ~~there is still less scholar who in-depth considers~~research hardly considers the effects of upstream/downstream interactions on soil erosion and sediment yields at watershed scales. ~~relationships between upstream and downstream on dynamic changes of erosion and sediment yield in a watershed. ~~Therefore, the objectives of this study are [i] to establish and modify a yearly distributed model of watershed erosion and sediment yield, and [ii] to evaluate spatiotemporal ~~evolutions ~~changes of erosion and sediment yield before and after returning farmland projects in the Majiagou River watershed. Results may provide reliable scientific basis for the dynamic ~~simulation ~~modelling of multi-scale erosion and sediment yield, land use planning and watershed management.

Comment [AJL2]: I do not understand this. Do you mean raindrop impacts?

Comment [AJL3]: This is not in the reference list. Do you mean Caro et al. (2012)?

2. Material and ~~Methods~~methods

2.1 Study area

Majiagou River, ~~which is~~ located in the western Ansai County of Yanan city, Northern Shaanxi Province (China), is one of the first grade tributaries of the Yanhe River (Fig.1). It flows into the Yanhe River in Ansai County from the northwest to the southeast~~, t~~. The main channel is about 17.4 km in length~~,~~ and the average gully slope is about 6.5‰. The watershed~~, with a total catchment area of~~ (73.83 km^2~~,~~) is situated on the typical hilly and gully region of the Loess Plateau (northern China~~(~~; 109° 9′ 30″ ~ 109° 18′ 59″ E and 36° 49′ 42″ ~ 36° 56′ 42″ N). The watershed belongs to a warm-temperature and semi-arid continental monsoon climate~~, t~~. The evaporation capacity is ~~greater than~~above 1000 mm, the annual average temperature is 6-11°C~~, t~~. The average annual ~~average~~ precipitation is about 500 mm, ~~the precipitation in 6-10 months accounts for about 80% of the total annual precipitation~~with 80% of rainfall concentrated between May and October. Normally, precipitation occurs as intense and short storms, which favor the rapid formation of runoff, which greatly increases the risk of water erosion and flooding.~~The precipitation form is mainly heavy rainstorm with characteristics of high intensity and short duration, which will easily produce a large number of surface runoff under excess infiltration, and then leads to hyperconcentrated flood disaster under the action of water erosion.~~

2.2 Environmental database

The parameters included in this study include digital elevation model (DEM), daily precipitation data, runoff, soil properties, land use types (Figs. 2 and 3; Table 1).

2.3 Dynamic model of erosion and sediment yield

~~Soil loss is the comprehensive results of various natural and human factors~~Accelerated erosion risk is the result of different natural and anthropic factors (Fu et al., 2014; Tian et al., 2016). Climate, soil, topography and vegetation are the natural factors affecting soil loss (Zhao et al., 2013). ~~The irrational~~Inadequate land use, the destruction of forest and grass, ~~excessive~~ unsuitable reclamation and overgrazing, cultivation on steep slopes, mining, road construction and unreasonable waste soil and residue treatments are the main human factors affecting soil loss (Chen & Lv, 2012). Based on the USLE/RUSLE equations, the Chinese soil loss equation (CSLE) model put forward by Liu Baoyuan was selected and applied to quantitatively evaluate soil erosion of the Majiagou River watershed. The basic expression is as follows,

$$Q = A \times R \times K \times L \times S \times B \times E \times T \quad (1)$$

where Q is the annual average soil erosion rate, (Mg km^{-2} year^{-2}~~t/hm^2·a~~); A is the catchment area, hm^2; R is the rainfall erosivity factor, (MJ·mm/hm^2·h·a); K is the soil erodibility factor, (~~t~~Mg·hm^2·h/hm^2·MJ·mm); L is the slope length factor; S is the slope gradient factor; B is the biological measure factor (equivalent to factor C of the RUSLE equation); E is the

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engineering measure factor; T is the tillage measure factor.

Because not all eroded soil is actually delivered to the basin outlet, based on the equation (1) and the sediment delivery ratio factor, the annual average sediment yield can be estimated by the Eq. (2),

$$Q_s = A \times R \times K \times L \times S \times B \times E \times T \times \lambda \qquad (2)$$

However, the Eq. (2) is the multi-year average sediment yield amount, it is not a dynamic changing expression. Furthermore, the dynamic-continuous modeling studies on the processes of sediment yield are very critical and necessary for accurately estimating annual changing trends of sediment yields (Gessesse et al., 2015). Rainfall runoff and human activity are two important factors affecting erosion and sediment yield (Mu et al., 2012; Liu et al., 2014; Lieskovský ~~&~~and Kenderessy 2014). According to the related study results (Long et al., 2008; ~~Liu, 2009;~~ Miao et al., 2012), the rainfall erosivity factor and the sediment delivery ratio factor affected by hydrological elements ~~were~~ are defined as the dynamic hydrological factor; the biological measures, engineering measures, tillage measures and the sediment delivery ratio factor affected by human activities were designed as the dynamic land management factor, so the dynamic equation of sediment yield suitable for the hilly and gully region of Loess Plateau was put forward as follows,

$$Q_{s,i} = A \times K \times LS \times (R_i \times \lambda_{q,i}) \times (B_i \times E_i \times T_i \times \lambda_{m,i}) \qquad (3)$$

where subscript i represents the i-th year, Supposing that the factor λ_i can be divided approximately into the product of $\lambda_{q,i}$ related only to hydrological conditions and $\lambda_{m,i}$ related only to land management measures.

Impacts of hydrological elements on sediment transport are mainly manifested in ~~the moving action~~transport of sediments from erosion sources to ~~the~~ river courses by ~~rainfall runoff~~surface runoff flow (Mu et al., 2012). $\lambda_{q,i}$ can be estimated by the sediment transport capacity ~~that is widely used in hillslope and fluvial geomorphology (Prosser & ustomji~~Prosser and Rustomji 2000). According to the general situation of the study area, $\lambda_{q,i}$ can be supposed as follows,

$$\frac{\lambda_{q,i}}{\lambda_q} = \frac{TC_i}{TC} = \frac{k \times q_i^a \times s^b}{k \times q^a \times s^b} = \left(\frac{q_i}{q}\right)^{1.45} \qquad (4)$$

where TC is the average sediment transport capacity per unit width of slope (kg m^{-3}); q is the average runoff amount per unit width (m^{-3}); k, a and b are coefficients. Those coefficients and the surface gradient factor S are constants when there are no changes in underling surfaces of runoff.

Impacts of human activities on sediment transport are mainly demonstrated in water and sediment reduction effects by all kinds of water conservation measures (Schilling et al., 2011; Sarma et al., 2015). Under the annual changing conditions of $\lambda_{m,i}$, B, E and T, the dynamic land management factor was introduced and defined as,

$$¦_i = \frac{B_i \times E_i \times T_i \times \lambda_{m,i}}{B \times E \times T \times \lambda_m} \qquad (5)$$

Comment [AJL5]: I do not understand this. Please, reword.

Comment [AJL6]: In the next lines, explain what is the meaning of λ.

Comment [AJL7]: Do you mean "calculates the multi-year…"?

Comment [AJL8]: Erosive processes?

Comment [AJL9]: Delete. This is obvious and is not part of methods. Delete also cited references.

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Comment [AJL12]: I do not understand.

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According to Xu et al. (2012), who studied the evolution of runoff and sediment load of Yanhe River basin between 1956 and 2009, ~~research results of 1956-2009 runoff and sediment characteristics in the Yanhe River watershed, the year of 1956-1969~~the period between 1956 and 1969 is a sporadic governance stage with little intervention of human activities, the intervention is only 0.9-3.9% and fluctuations of runoff and sediment are mainly caused by fluctuations of natural rainfall~~; after~~. After this stage, human land management activities gradually ~~become~~ became the main driving force for changes of runoff and sediment, soil and water conservation measures are the main factors leading to reduction of runoff and sediment (Gao et al., 2010; Li et al., 2011). In order to quantitatively study impacts of human land management activities on the sediment transport process, this study takes the year of 1956-1969 as the base period, and the years after the 1970s have been defined as the governance period (Wang et al., ~~2015~~2016). ~~Based on the related literatures (Wang & Fan, 2002)~~In agreement with Wang and Fan (2002), the fitting relationship expression (R^2=0.912) of runoff and sediment in Ganguyi hydrological station in 1954-1969 was taken as the denominator, and the fitting relationship expression (R^2=0.857) of runoff and sediment in 1954-1989 as the numerator. The ratio of sediment yield amount between the governance period and the base period was defined as the dynamic influencing factor which reflects effects of human land management activities on yearly changes of watershed sediment transport. The expression is,

Comment [AJL14]: Percentages of what?

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$$¦_i = \frac{y_{g,i}}{y_{b,i}} = \frac{0.449x_i - 5062.6}{0.4436x_i - 4559.9} \qquad (6)$$

where x_i ~~represents~~ is the runoff amount in the i-th year (10^4 m^3), n is the number of years, $y_{g,i}$ ~~represents~~ is the sediment amount in the i-th year during the governance period (10^4 m^3~~),~~) and $y_{b,i}$ ~~represents~~ is the sediment amount in the i-th year during the base period (10^4 m^3)

In summary, the dynamic model of erosion and sediment yield was determined as follows,

$$Q_{s,i} = ¦_i \times \left(\frac{q_i}{q}\right)^{1.45} \times R_i \times ª \times A \times K \times LS \times B \times E \times T \qquad (7)$$

where $\lambda = \lambda_q \cdot \lambda_m$ ~~represents~~ is the average sediment delivery ratio, B, E and T represent the average value of the watershed for many years.

Comment [AJL16]: This is not in the equation, please, delete.

2.4 Determination of model factors

~~1)~~2.4.1 The rainfall erosivity factor

Rainfall erosivity ~~refers to~~is the potential ~~capacity~~ erosive force of rainfall~~of soil erosion caused by rainfall~~. ~~Scholars in the world~~ Different authors have proposed simple algorithms of rainfall erosivity in different forms~~, where the half-month~~

~~rainfall erosivity model shows the seasonal distribution of rainfall erosivity by the period of half month~~. In this study, a half-month simple algorithm of rainfall erosivity ~~established by Zhang et al. (2003)~~(Zhang et al., 2003) was applied to estimate the monthly and annual rainfall erosivity~~, the~~. The half-month algorithm of rainfall erosivity estimated by daily precipitation is ~~as follows~~calculated as:

$$R_i = \sim\sum_{j=1}^{k}(P_j) \qquad (8)$$

$$= 0.8363 + \frac{18.144}{P_{d_{12}}} + \frac{24.455}{P_{y_{12}}} \qquad (9)$$

$$\sim = 21.586^{\ -7.1891} \qquad (10)$$

where R_i ~~represents~~ is the rainfall erosivity value in i-th half-month period (MJ~~.~~ mm~~.~~ hm^{-2} h^{-1}), k ~~represents~~ is the number of days within the half-month period, P_j is the rainfall in the j-th day during the half-month period (the erosive rainfall standard ≥12mm), P_{d12} ~~represents~~ is the average daily rainfall when the daily rainfall ≥12mm,~~ ~~ and P_{y12} ~~represents~~ is the average annual rainfall when the daily rainfall ≥12mm. In this algorithm, the half-month division standard is that the first 15 days of each month are used as the former half-month period, and the remaining days of this month as the other half-month period. According to the above algorithm, the annual dynamic results of R factor in the Majiagou River watershed are determined in Table 2, and spatial distributions of the average annual rainfall erosivity are spatially interpolated and shown in Figure 4. ~~Table 2 shows that most~~Most of the rainfall erosivity values in the hilly and gully region of Loess Plateau are all below 2000 MJ·mm/hm^2·h·a (Table 2). However, Yan'an suffered a once-in-a-century storm ~~attack~~ in July 2013, which is the key reason for abnormally large rainfall erosivity value of the Majiagou River watershed in 2013.

Comment [AJL17]: I think this can be deleted, but you decide.

~~2)~~2.4.2 Soil erodibility factor

Soil erodibility is used to characterize properties whether the soil is susceptible to erosion, it embodies the sensitivity of the soil to the separation and handling of erosion (Lu et al., 2011). ~~The modified method presented by Zhang et al. (2007) was applied to calculate the factor K values, the formula is~~ According to Zhang et al. (2007), the soil erodibility factor (K) is calculated as:

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$$K = 0.74488K_n - 0.03336 \qquad (11)$$

$$K_n = [2.1\times10^{-4}M^{1.14}(12 - OM) + 3.25(SSC - 2) + 2.5(PL - 3)]/100 \qquad (12)$$

where M is calculated by the formula of particle mass fraction of (0.002~0.1mm) × (particle mass fraction of (>0.002~0.05mm) + particle mass fraction of (>0.05~2mm)); OM is the soil organic matter content, g/kg; SSC is the structural coefficient; PL is the permeability level.

Based on the soil quality survey results of the study area (Table 1), the average *K* value of soil erodibility in the watershed was calculated as 0.0542 Mg. h. MJ^{-1}. mm^{-1}, which is close to the research results byresults reported by Li & Zheng (2012) in the Yanhe River basin. The soil in the study area is focused on loessial soil, the *K* values of different soil types were calculated by the above equations. Under the GIS-aided analysis conditions, different *K* values were added to the attribute table of soil map as a column attribute value, then the vector map will be converted to raster map based on *K* value field. Finally the spatial distribution map of soil erodibility factor in the Majiagou River watershed was presented in Figure 4.

3)2.4.3 Topography factor

Topography is an important factor affecting soil erosion. *LS* factor reflects the influencing degree of terrain factors to soil erosion, it can be divided into slope length factor and slope gradient factorfactors. Many scholars authors have established suggested empirical formulas used for quantitative analysis according to the standard definition of *LS* factor (Wang, 2007).

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Through comprehensive comparison analysis, the slope length factor (*L*) in this study was estimated by the below equation,

$$L = (\frac{a}{22.13})^{\sim} \qquad (13)$$

where *λ* is the horizontal slope length; *α* is the slope length index. α is calculated as:

$$\sim = \frac{}{+1} \qquad (14)$$

Where β is calculated as:

$$= (\frac{\sin ^{-}}{0.0896}) / \left[3.0(\sin ^{-})^{0.8} + 0.56 \right] \qquad (15)$$

where *λ* is the horizontal slope length; *α* is the slope length index;where *θ* is the slope gradient (°).

The slope gradient factor (*S*) in this study was calculated using piecewise method. Considering this mountainous terrain of the watershed, the gentle slope used the formula proposed by McCooL et al. (1987), and the steep slope adopted the formula proposed by Liu et al. (2010), the specific expressions are as follows,

Comment [AJL20]: Please, reword.

$$\begin{aligned} S &= 10.8\sin ^{-} + 0.03 \quad && ^{-} < 5° \\ S &= 16.8\sin ^{-} - 0.05 \quad && 5° \le ^{-} \le 10° \\ S &= 21.9\sin ^{-} - 0.96 \quad && ^{-} > 10° \end{aligned} \qquad (16)$$

where *θ* is the slope gradient (°).

In this study, the multi-year average *LS* value from the Majiagou River watershed is determined as 12.9 based on the existingprevious research results (Wang 2007). In addition, according to the above GIS-based extraction algorithm of slope gradient and slope length, the grid layers of slope gradient and slope length in the study area were extracted from the 30m resolution DEM, and then the topography factor was spatially calculated by the optimal calculation formula of the slope

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gradient factor and the slope length factor. The spatial distribution layer of *LS* factor in the study area is shown in Figure 4.

~~4)~~2.4.4 *BET* factor

Biological ~~measure~~ factor (*B* factor) refers to the ratio of soil erosion amount between the standard plot for growing crops and for continuous abandonment within a certain time under the same conditions (Wischmeier & Smith, 1965)~~, its value changes~~ and varies between 0 and 1. Soil and water conservation engineering ~~measure~~ factor (*E* factor) is defined as the ratio of the soil erosion amount between engineering ~~measures~~ and non engineering measures ~~(Qin, 2013)~~. Tillage ~~measure~~ factor (*T* factor) is the ratio of the soil erosion amount between ~~the certain tillage~~tillaged farmland and the continuous relaxation bare land under the same conditions~~, its value is also~~and varies between 0 and 1 (Guo et al., 2013).

Considering the synchronization of human activities on underlying surface conditions between the Majiagou River watershed and the Yanhe River basin, based on the related research results of *B*, *E* and *T* factors in the Loess hilly area (~~Xie, 2008;~~ Zhang et al., 2012~~; Qin, 2013~~), 0.1562, 0.497 and 0.712 values were assigned respectively.~~the average *B*, *E* and *T* values of the Majiagou River watershed for many years were in turn assigned to 0.1562, 0.497 and 0.712. Besides, the~~The spatial distribution of the average *BET* factor for many years ~~is~~ were spatially calculated ~~and shown in Figure 4~~(Figure 4).

~~5)~~2.4.5 The sediment delivery ratio (*SDR*)

~~Reference to systematic research results of erosion and sediment yield in the Loess Plateau (Jing et al., 2005)~~According to Jing et al. (2005), there are different fluctuations for ~~the~~ annual *SDR* values of the Majiagou River watershed, ~~the~~ with average value ~~is~~ around 0.9. ~~Furthermore, considering the research results of the Yanhe River basin by Zhu et al. (2007), a~~A *SDR* value of 0.92 for many years was determined as the average *SDR* value of the Majiagou River watershed (Zhu et al., 2007).

3. Results and ~~Discussion~~discussion

3.1 Validation of erosion and sediment yield

Considering the very similar climate and underlying surface conditions, the soil erosion ~~modulus~~rate in the study area has a certain comparability with the Yanhe River watershed, the previous research results of Yanhe River waterhshed can be used to verify ~~this~~ our results. According to the dynamic simulation results of soil erosion in the Yanhe River watershed from 2001 to 2010 reported by Li ~~&~~and Zheng (2012)~~ dynamic simulation results of soil erosion in the Yanhe River watershed from 2001 to 2010~~, the annual average erosion ~~modulus~~rate of Yanhe River watershed is 5812.28 Mg km^{-2} year^{-1}~~t/(km^{2}.a), it~~ has little difference with the average simulated value of 6307.86 Mg km^{-2} year^{-1}~~t/ (km^{2}.a)~~ in the Majiagou River watershed from 1995 to 2012~~, the relative error is comparatively small; the~~. The annual erosion ~~modulus~~rate of the Majiagou River watershed in 2008 ~~alone~~ is 2485.46 ~~t/(km^{2}.a)~~Mg km^{-2} year^{-1}~~,~~ and the corresponding simulated value is 2278.2 Mg km^{-2}

Comment [AJL22]: I suggest the extended form, not the abbreviated one. May be "Biological factor"?

Comment [AJL23]: I suggest: "the cropped plot".

Comment [AJL24]: I suggest: "the abandoned plot".

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Comment [AJL26]: "Not cultivated soil"?

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Comment [AJL28]: How many?

year^{-2}t/(km^2.a), the relative error iswith relative error 8.34%; the aboveThese results demonstrate that the dynamic erosion and sediment yield model has scientific rationality and good reliability, this. This study results can be used for adsorbed NPS pollution load estimation.

In addition, the previous research results of sediment variations in Ganguyi hydrological station from between 1961 to and 2012 (Ren et al., 2012) and the simulation results of sediment yield in this study were also comparatively confirmed that the sediment yield both showed a decreasing trend although there were fluctuations of different degrees in individual years (Fig. 5), it indicates that the overall changing trends of sediment yield in the study area are consistent with the background of returning farmland policy (Zhao et al., 2013), the current simulation accuracy basically meets the requirements of changing tendency evaluation. However, it can also be seen from Fig. 5 that the model largely fails for the individual events especially after 2006 when the simulated values are distinctly different from the observed values (Fig. 5). The main reason can roughly be summed upfor this may be that the sediment transport processes in the established model may not clearly reflect spatiotemporal variations of the watershed underlying surface, especially for the physically-based complex sediment yield relationship between the upper and lower reaches areas of the watershed after returning farmland.

Therefore, it is necessary to modify the above established model, the. The influencing factor considering relationships the upper and lower reaches of the watershed was introduced to further improve the accuracy of the established sediment yield model. According to the existing research results (Xie 2012; Xie &and Li 2012), Eq. (7) can be changed into the following formula,

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$$Q_{s,i} = \frac{Q_{w,i}}{Q_i - Q_{b,i}} \times \text{¦}_i \times \left(\frac{q_i}{q}\right)^{1.45} \times R_i \times \text{ª} \times A \times K \times LS \times B \times E \times T \qquad (17)$$

where $Q_{w,i}$ is the annual saturated water when the saturated sediment transport amount is the observed sediment transport amount in a hydrological station, $Q_{b,i}$ is the annual base flow, Q_i is the observed annual runoff amount.

For the Ganguyi hydrological station, the simulated value of the annual average sediment yield modulusrate after model modification from 1995 to 2012 has changed from 5803.23 t/ (km^2.a) to 4510.66 t/ (km^2.a) during between 1995 and 2012 period, t. The observed value in the Ganguyi hydrological station of the Yanhe River watershed is 3411.53 t/(km^2.a), the relative error of the modified model decreases by 30-40% (Fig. 6). For Ansai and Zaoyuan hydrological station, the simulation results after modification also improved a lot.

3.2 Spatiotemporal evolutions of soil erosion gradations

Figure 7 shows spatial distribution of soil erosion gradations of the Majiagou River watershed in 1995 and 2010. The annual average soil erosion modulusrate of the Majiagou River watershed is 6307.86 Mg km^{-2} year^{-2}. t/ (km^2.a), the soil erosion belongs to intensive erosion based on standards for classification and gradation of soil erosion (SL 190-2007), it confirms that theThe current situation of soil and water loss in the study area is serious and erosion control measures and adequate management plans for soil and water resources are necessary in this hilly and gully region, it also indicates that it is vigorously necessary for the protection and management of soil and water resources in the hilly and gully region. Although there are not large variations in the overall spatial distribution of soil erosion between 1995 and 2010, small differences in the intensity of soil erosion rates are observed (Table 3). The area with very low to moderately low erosion rates decreased from 55.41 to 46.93 Mg km^{-2} year^{-}2 between1995 and 2010 in the Maiagou River watershed (approximately 8.48% of the total area). In contrast, the area under moderate to extreme soil erosion rates increased from 44.59 to 53.07 Mg km^{-2} year^{-2} during the same period.Although the overall spatial distribution patterns of soil erosion in two typical years of 1995 and 2010 are generally the same, there is a little difference for the gradation distribution of soil erosion (Table 3). Compared with 1995, there was a slight decline in the micro and mild erosion occurrence area of the Majiagou River watershed in 2010, the reduction area accounts for 8.48% of the watershed area. However, the area of moderate and above moderate erosion in 2010 increased by 8.48% than that in 1995, among them the area of intensive erosion increased more obvious and the corresponding increasing range was 4.22%. The above results indicate that spatiotemporal evolutions of soil erosion intensity in the watershed are closely related to temporal and spatial distributions of rainfall intensity, rainfall duration, rainfall amount and land use patterns. The long-duration concentrated rainfall in 2010 results in a little higher erosion intensity than 1995 in and easily-eroded sloping farmland, it. It also shows that the current soil and water conservation measures are not very idealsuitable for high rainfall intensity, and the results. Results potentially emphasize the necessity of further efforts on land resources management.

3.3 Temporal evolutions of sediment yield

Figure 8 shows that the sedimentSediment transport amount in the study area has an overall decreasing trend from 1995 to 2012 (Figure 8), the. The average sediment transport modulus before and after model modification in recent 5 years (in addition to 2013) is 4574.62 Mg/km^{2}Mg km^{-2} and 1696.1 Mg km^{-2}Mg/km^{2} respectively, it. It has decreased by about 35.4% and 78.2% compared with theof sediment transport from the early governance period (1995-1998). Results show that the modified model is more accordance with practical circumstances, the main reasons for the decreasing sediment yield mainly result from water and soil conservation measures for regular rainfall events. Since the late 1990s, China has gradually carried out construction projects of returning farmland to forestland land use changes, beautiful mountains and rivers, warp-land dam engineering and terracing of Yanhe River, funded by the by World Bank loan in Northern Shaanxi. A lot of targeted soilSoil and water conservation measures were implemented for coping with serious soil and water loss situation ofin the Yanhe River basin, this project improveshave contributed to improve underlying surface conditions and reduces to reduce

Formatted: Not Superscript/ Subscript soil erosion disasters. Especially after 2003, ~~the~~ sediment transport in the study area not only had an overall decrease trend, but also ~~the tendency of~~ inter-annual fluctuations ~~was~~ were small and the whole sediment transport level was low. It also fully indicates that the effective implementation of soil and water conservation measures and the continuous improvement of underlying surface conditions have significant benefits of water and sediment reduction (Ran et al., 2006).

Soil and nutrient loss in the Loess Plateau mainly results from few transient rainstorms (Zhang et al., 2004; Austin et al., 2004). But only serious soil erosion hazards in the study area due to the once-in-a-century storm ~~encountered~~ observed in 2013 can not reflect the general sediment yield evolutions. Figure 9 shows the monthly sediment yield dynamics in 2013~~, it~~. It can be seen that the monthly distribution of sediment transport in the watershed is very uneven, and the maximum values of rainfall erosivity and sediment both occurred in July, the sediment transport capacity in July alone accounted for 96.18%. The reason for this is that ~~the rainfall erosivity~~rainfall-induced erosion ~~value~~ in July accounted for 80.49% of the whole year, and it is 3.11 times more than the corresponding average value for many years~~, thus~~. Thus a powerful hydraulic erosion force was formed due to the once-in-a-century storm. ~~By~~ According to the statistics the corresponding monthly runoff in the watershed also accounted for 56.22% of the total annual runoff, and it accounted for 76.79% of the multi-year average runoff amount in the Majiagou River watershed. ~~Since this the~~The corresponding monthly sediment yield ~~modulus~~ reached 44.5 times more than the average annual sediment yield ~~modulus~~. Therefore, the once-in-a-century storm in July 2013 is the main reason for the maximum sediment yield level~~, it also~~ and shows that ~~non~~ non-conventional storm plays a very critical role on the evolution process of erosion and sediment yield.

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The above analysis of ~~the~~ sediment transport dynamics indicates that rainfall and human activity are two main factors affecting dynamic changes of soil erosion (Yao et al., 2011). Rainfall is the promotion factor for erosion evolution, it can affect the formation and development of soil erosion process by splash effects of raindrops and erosion moving of rainfall runoff. The positive human activities are the restraining factors for erosion evolution, ~~they can increase~~increasing vegetation cover, ~~consolidate~~ consolidating soil, weaken soil erosivity, and strengthening effects of interception ~~and hindrance~~.

3.4 Spatial evolutions of sediment yield

~~Figure 10 shows spatial distributions of the sediment yield modulus in the Majiagou River watershed in 1995 and 2010~~. Due to widely distributed sloping farmland along river banks, bank erosion dominated sediment sources of the Majiagou River watershed, and peak values of the sediment yield ~~modulus~~ also mainly appears on ~~the main river banks of the whole Majiagou watershed from northwest to southeast~~these areas (Figure 10). According to statistical analysis, the change of farmland area between 1995 and 2010 is small, while the area of forestland in 2010 increased by about 2.2% than in 1995. The spatial distribution map of soil erosion in these two years also suggests that soil erosion significantly reduced due to changes of vegetation cover and flow path, and the increase of vegetation cover (forestland) in the steep sloping land is stronger than the gently sloping farmland, which results in changes of watershed sediment distribution pattern. Through the comparative analysis, the spatial results of this study are basically consistent with the results of Zhu et al. (2016). In general, spatial and temporal variations of sediment transport in the watershed are generally related to spatial distribution of land use types, the large spatial variations of sediment transport are also closely associated with spatial changes of topography and soil (Gao et al., 2016).

4. Conclusions

~~1) ~~A distributed-dynamic sediment yield model based on the CSLE equation was modified and verified to investigate impacts of returning farmland on erosion and sediment yield in the Majiagou River watershed from 1995 to 2013. Results ~~indicate ~~showed that the overall status of the watershed ~~belongs to intensive erosion~~is under intense erosion risk~~, the~~. After changes carried out in the watershed, multi-year average soil erosion ~~value after modification in the watershed ~~decreased by about 8%~~ compared to the level before modification~~. Spatiotemporal evolution~~s~~ of soil erosion ~~gradation ~~in the watershed ~~are~~ is closely related to ~~distributions of ~~rainfall intensity, rainfall amount, and land use pattern~~s~~.

~~2) The multi~~Multi-year average sediment yield decreased from 5803.23 (before modifications in the Majiagou River watershed) to 4510.66 Mg km^{-2} (after modifications).~~ modulus before and after modification in the Majiagou River watershed was 5803.23 Mg/km^2 and 4510.66 Mg/km^2 respectively, the annual~~ Annual sediment yield ~~tracked to an overall decreasing trend from 1995 to 2012~~generally decreased between 1995 and 2012. After 2003, the annual sediment transport in the study area ~~was especially diminishing~~decreased sharply~~, the~~. The fluctuation trend is weak and the overall sediment yield level is relatively low~~, ~~ and the average sediment yield ~~modulus~~ before and after model modification in recent 5 years (in addition to 2013) is 4574.62 ~~Mg/km^2 ~~and 1696.1 Mg km^{-2}~~Mg/km^2, it~~. It has respectively decreased by about 35.4% and 78.2% compared with the early governance (1995-1998).

~~3) ~~The implementation of large-scale soil and water conservation projects in the late 90's of last century has continuously improved sediment situation of the watershed, but the changing trend of event-based rainfall ~~is still grim and it ~~urgently needs to continuously increase the level of integrated watershed management. In particular, ~~the ~~extreme storms will lead to large fluctuations of sediment yield~~, for~~. For example, the once-in-a-century storm of Yan'an city in July 2013 is the most important factor for the appearance of maximum sediment yield (1983.36×10^4 Mg km^{-2}~~Mg/km^2~~) in the watershed. Therefore, the current soil and water conservation measures are not ~~very ideal~~suitable for high rainfall intensity observed in July 2013, and the results potentially emphasize the necessity of making further efforts on soil and water resources management in ~~the easily eroded ~~sloping farmland of hilly and gully regions of the~~,~~ Chinese Loess Plateau.

Acknowledgements

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Comment [AJL47]: I have re-written the species name in italics.

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Table 1: Descriptions and sources of the environmental database for the Majiagou River watershed.

Data layer	Format	Description	Source
DEM	Raster	30 m spatial resolution DEM data of the Majiagou watershed	Computer Network Information Center, Chinese Academy of Sciences http://datamirror.csdb.cn/index.jsp
Land use	Raster	30 m spatial resolution Farmland, grassland, forest land, residential area, water area, sand	Data Center for Cold and Arid Region Sciences http://westdc.westgis.ac.cn/
precipitation	DBF	Daily values in Ansai, Yanan, Yanchang, and other rain gauges (1957-2013)	China Meteorological Data Sharing Service Network http://www.cdc.sciencedata.cn
Soil	DBF	Physical and chemical properties (organic matter, soil texture, sand fraction, clay fraction, structural coefficient, permeability level)	① (1) Soil Survey Office in Shaanxi Province. Dataset of the Second Soil Survey in Shaanxi Province (1979-1990). ② (2) Soil quality background in Loess Hilly Region (2000-2008). Data Sharing Infrastructure of Earth System Science_Data Sharing Infrastructure of Loess Plateau
Runoff and sediment	Excel	Time series of annual observed values in Ganguyi hydrological station (1954-2012), Ansai and Zaoyuan hydrological stations (2006-2012)	National Science & Technology Infrastructure of China, Data Sharing Infrastructure of Earth System Science (http://loess.geodata.cn/)

Comment [AJL48]: I have aligned all text in the table up and left.

Table 2: ~~The annual~~Annual dynamic values of *R* factor (MJ·mm/hm^2·h·a) in the Majiagou River watershed from 1995 to 2013.

Year	*R* value	Year	*R* value	Year	*R* value	Year	*R* value

Comment [AJL49]: I think this table may be summarized in the main text and deleted.

1995	1240.416	2000	759.223	2005	1573.623	2010	1235.926
1996	1046.692	2001	2004.196	2006	1957.735	2011	1904.582
1997	1253.405	2002	1856.162	2007	1515.931	2012	1470.239
1998	1804.647	2003	1890.972	2008	937.696	2013	5644.205
1999	849.033	2004	1166.029	2009	1797.271		

Table 3 Classification and gradation of soil erosion, percentage in the Majiagou River watershed in 1995 and 2010.

Erosion gradation	Erosion ~~modulus~~rate ~~(t/hm^2·a)~~ (Mg km^{-2} year^{-2})	1995		2010	
		Ratio (%)	Area (hm^2)	Ratio (%)	Area (hm^2)
~~micro~~Very low	<5	11.60	856.17	9.55	704.85
~~mild~~Low	5~10	8.85	653.08	8.01	591.36
~~mild~~Moderately low	10~25	34.96	2581.46	29.37	2168.31
~~moderate~~Moderate	25~50	37.35	2757.67	40.63	2999.59
~~intensive~~Intense	50~80	6.12	451.98	10.34	763.59
~~very intensive~~Very intense	80~150	1.12	82.63	2.06	152.32
~~severe~~Extreme	>150	/	/	0.04	2.99
~~sum~~Total		100	7383	100	7383

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Comment [AJL50]: If not determined, substitute with "ND" and add "ND: not determined" to the caption.

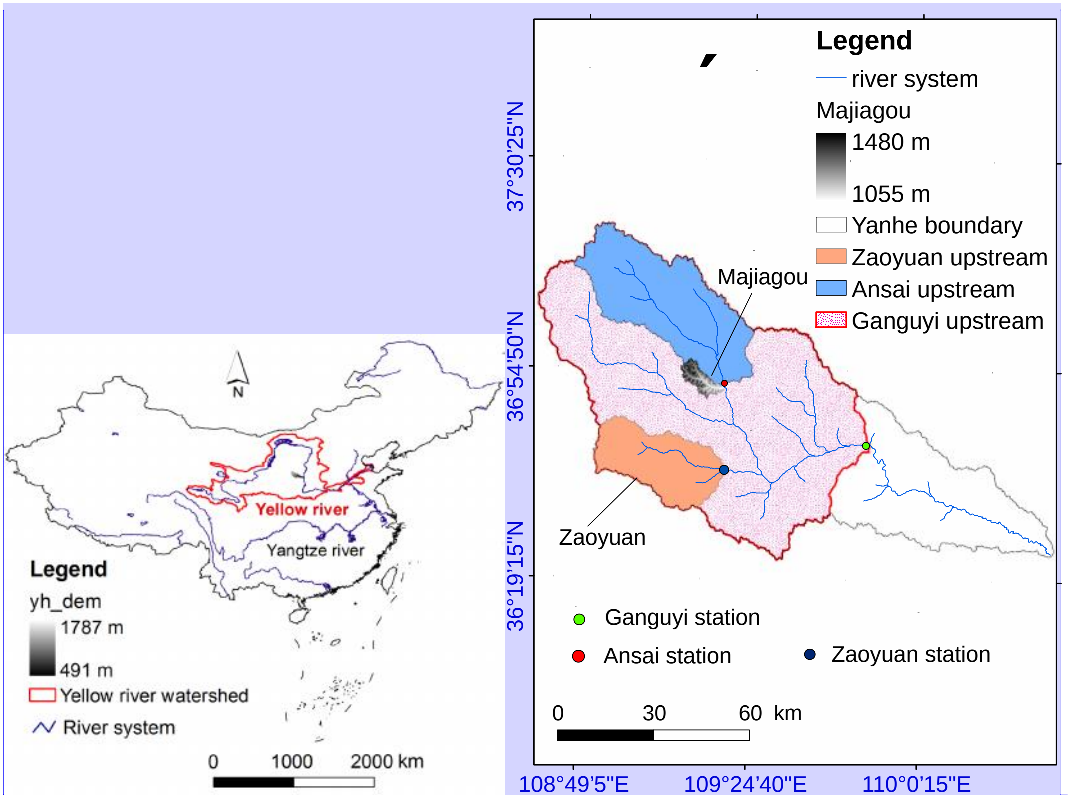

Figure 1: The relative location between the Yanhe River watershed and the Yellow River/Yellow River Basin, the geographical location sketch of the Majiagou River watershed, Zaoyuan upstream, Ansai upstream, Ganguyi upstream in the river system of Yanhe River watershed.

Comment [AJL51]: General map on the left:
- Delete everything except north arrow, scale and country borders. The objective of this map is only to provide information for the location of the study area.
- Delete the elevation scale (elevation of the very small area showed is not necessary).
- Add the study area.

Detailed map on the right:
- Delete the elevation scale and greyshade for elevation in the map. Provide information in the main text if necessary.
- Substitute “Yanhe boundary” with “Yanhe cachtment”. Also for Zaoyuan, Ansai and Ganguyi.
- Change blue coordinates into black.

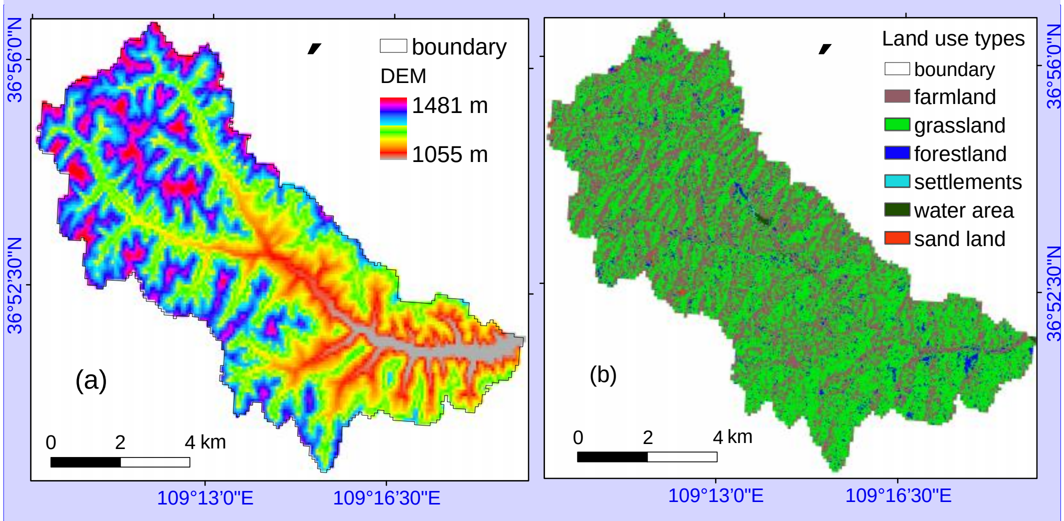

Figure 2: Figure 2: (a) Elevation map of the study area; (b) landuse types of the Majiagon River cachtment.Longitude and latitude coordinates of the study area, digital elevation model (DEM) data, reclassified land use types of the Majiagou River watershed

Comment [AJL52]: In both legends, delete "boundary".
Use only one north-arrow and one scale in the left. Delete those in the right.
Use black color for urban settlements.
Use cyan color for water areas.
Coordinates in black color.

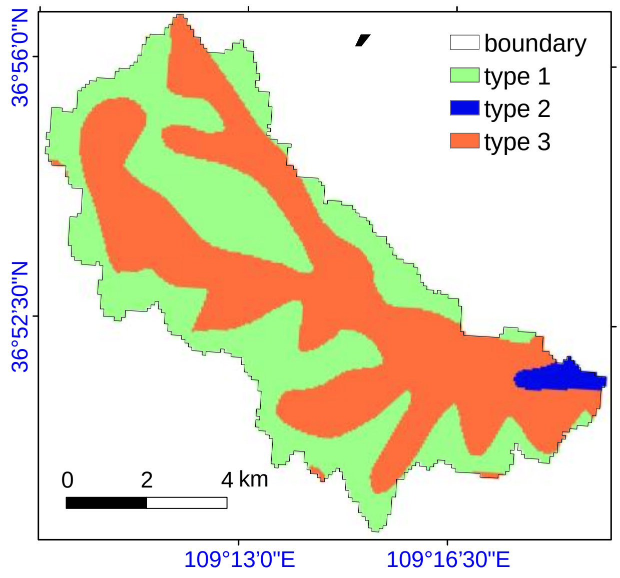

Figure 3: Soil types of the Majiagou River watershed (Legend notes:. Type 1: Tillage tillage erosive loessal soil (80%) + Erosive erosive loessal soil (20%); Type 2: Tillage tillage erosive loessal soil (80%) + Calcareous calcareous alluvial soil (20%); Type 3: Erosive erosive loessal soil (80%) + Tillage tillage erosive loessal soil (20%)).

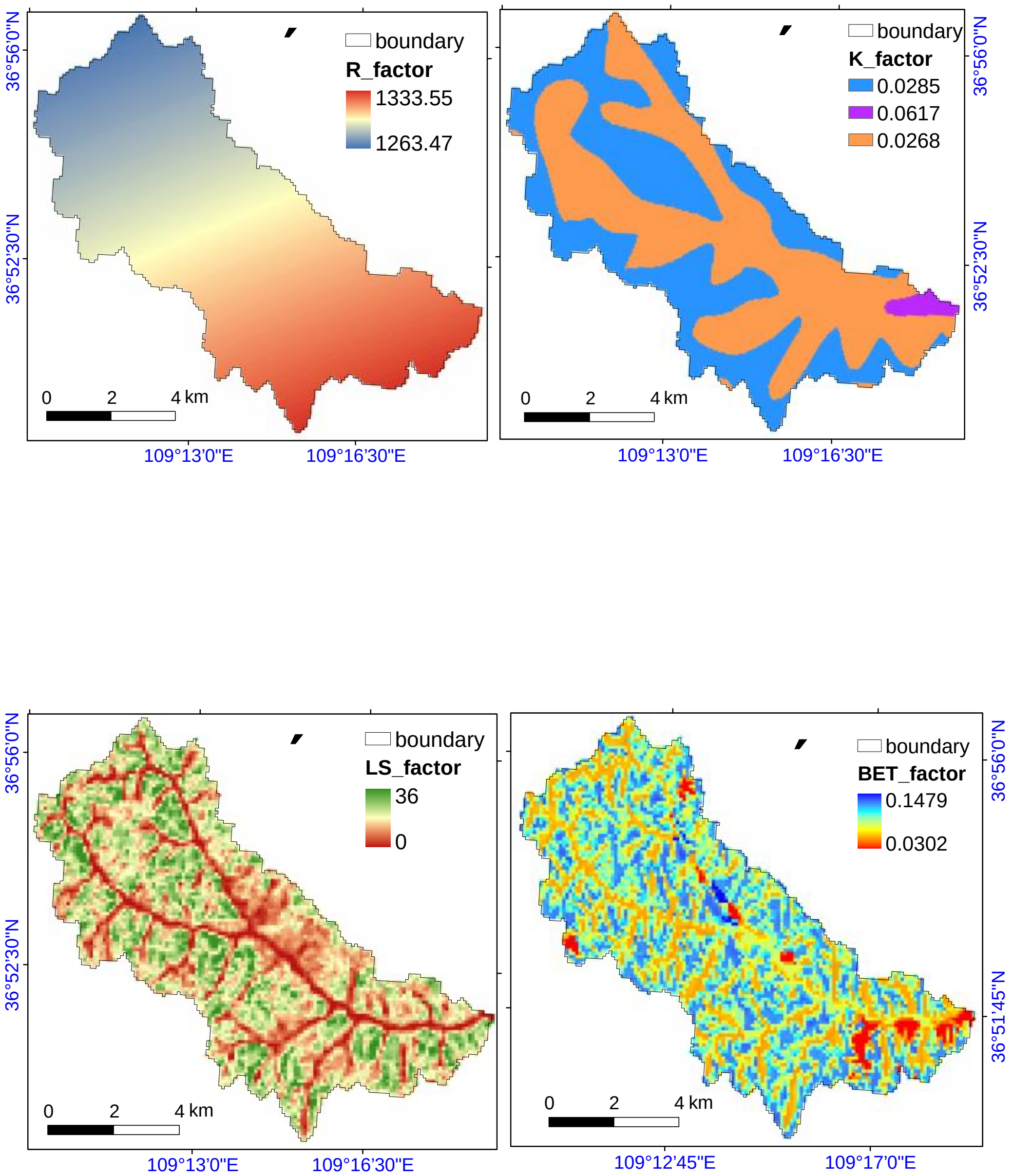

Figure 4: From left to right and up to down, Spatial spatial distributions of annual average R factor, K factor, LS factor and BET factor in the Majiagou River watershed.

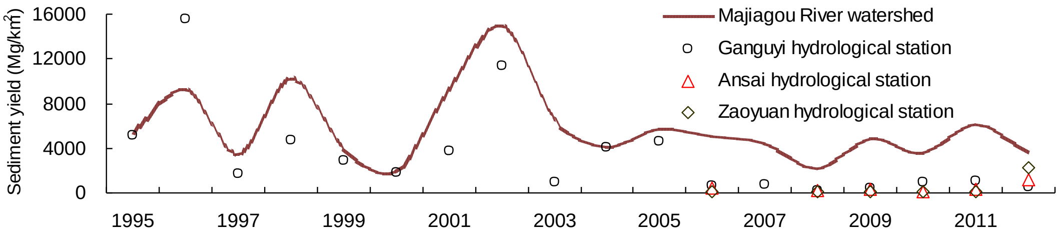

Figure 5: Validation of sediment yield modulus between Ganguyi, Ansai, Zaoyuan hydrological stations and Majiagou River watershed based on the established model

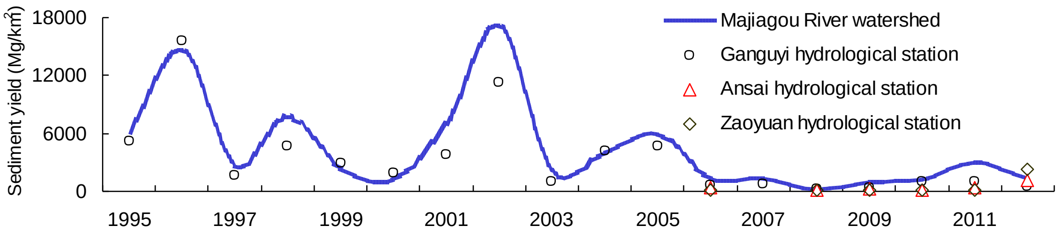

Figure 6: Validation of sediment yield modulus between Ganguyi, Ansai, Zaoyuan hydrological stations and Majiagou River watershed based on the modified model

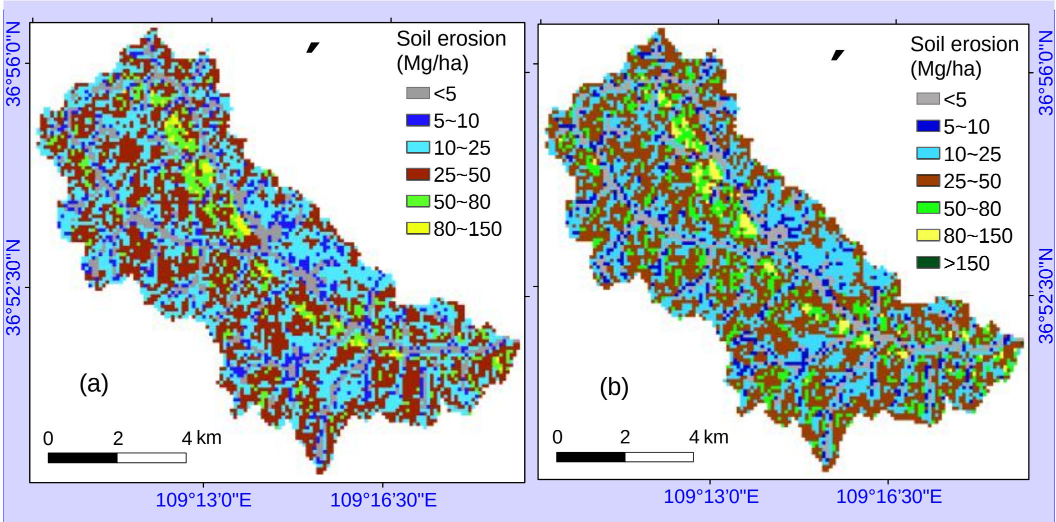

Figure 7: Spatial distribution of soil erosion gradations of the Majiagou River watershed: (a) 1995; (b) 2010.

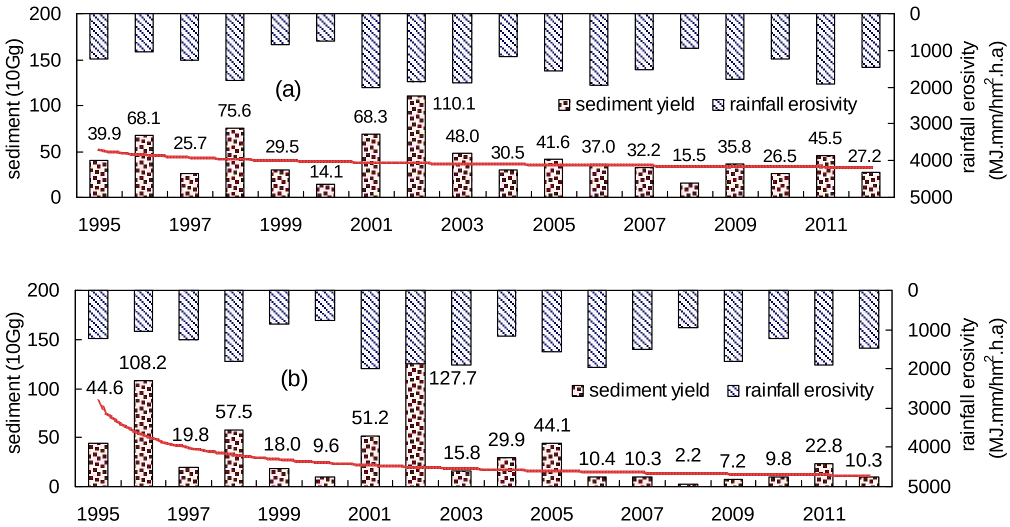

Figure 8: Comparative variations of sediment yield and rainfall erosivity in the Majiagou River watershed from 1995 to 2012: (a) the established dynamic model, (b) the modified dynamic model

Comment [AJL53]: Coordinates in black.
Do not repeat legends. Delete the legend on the left and keep the legend on the right.
As previously, use only one north arrow and one scale.

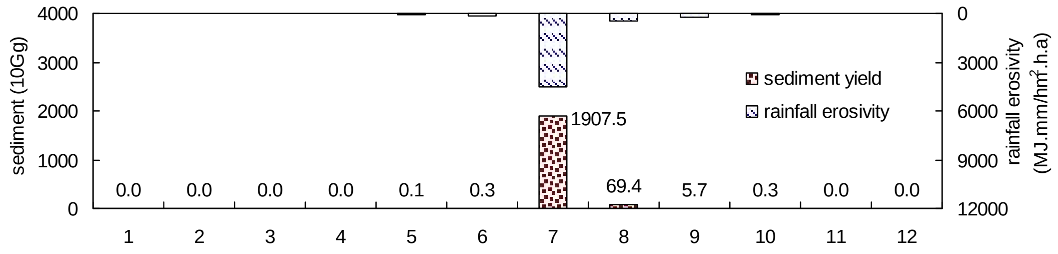

Figure 9: Comparison of monthly sediment yield and rainfall erosivity in the Majiagou River watershed in 2013

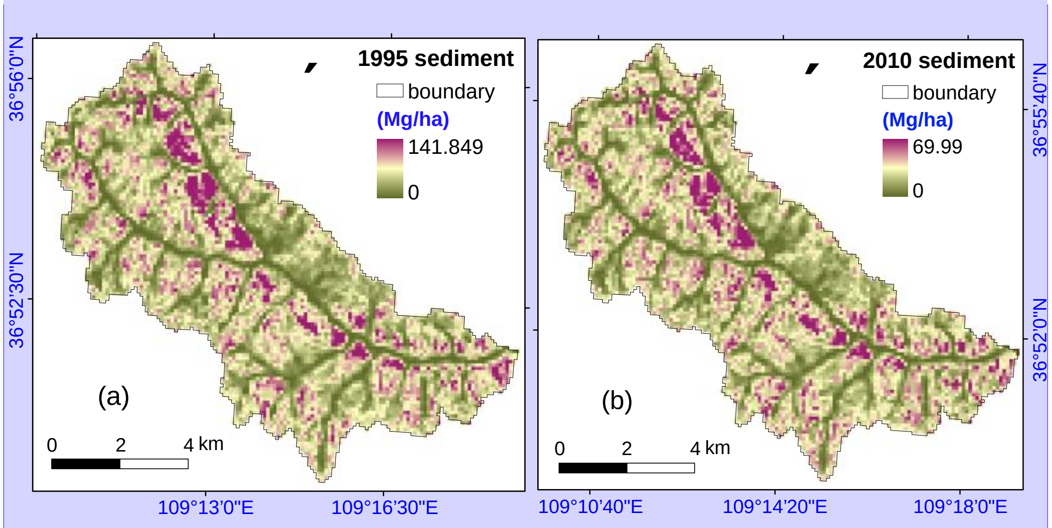

Figure 10: Spatial distribution of sediment yield modulus of the Majiagou River watershed: (a) 1995; (b) 2010

Comment [AJL54]: Coordinates in black.
Delete "1995 sediment" and "2010 sediment" (this information is in the caption).
Delete "boundary" in the legends.
Delete units (move this information to the caption).
As previously, use only one north arrow and one scale.