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A GIS-based Modeling Approach for Fast Assessment of Soil Erosion by Water at Regional Scale, Loess Plateau of China

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Abstract: The objective of this study is to develop a unique modeling approach for fast assessment of massive soil erosion by water at a regional scale in the Loess Plateau, China. This approach relies on an understanding of both regional patterns of soil loss and its impact factors in the plateau area. Based on the regional characteristics of precipitation, vegetation and land form, and with the use of Landsat TM and ground investigation data, the entire Loess Plateau was first divided into 3 380 Fundamental Assessment Units (FAUs) to adapt to this regional modeling and fast assessment. A set of easily available parameters reflecting relevant water erosion factors at a regional scale was then developed, in which dynamic and static factors were discriminated. ArcInfo GIS was used to integrate all essential data into a central database. A resulting mathematical model was established to link the sediment yields and the selected variables on the basis of FAUs through overlay in GIS and multiple regression analyses. The sensitivity analyses and validation results show that this approach works effectively in assessing large area soil erosion, and also helps to understand the regional associations of erosion and its impact factors, and thus might significantly contribute to planning and policymaking for a large area erosion control in the Loess Plateau.

Keywords: soil erosion by water; GIS-based modeling; soil erosion assessment; regional scale; Loess Plateau

1 Introduction

Soil erosion occurs at varied spatio-temporal scales—from plot and watershed in which individual measurements are made via the field scale that concerns the individual farmer, to regional, national and global scales that may influence major planning decisions (Kirkby *et al*., 1996; Cohen *et al*., 2006; Descroix *et al*., 2008). Therefore, it is necessary either to recognize the dominant patterns and processes of soil erosion at each scale, or to build a dynamic system containing a network of spatio-temporal interactions to create forecasting models directly at various scales. However, available modeling studies mainly addressed erosion issues at fine scales (De Vente and Poesen, 2005; Hoyos, 2005; Boardman, 2006; Boix-Fayos *et al*., 2006; Lundekvam, 2007), with only few on broader scales. In particular, the regional soil erosion processes and patterns, which may own some scale-dependent features, are poorly understood. On the other hand in contrast, there is a growing demand to simulate and predict environmental processes at a regional scale for policymakers and planners to be able to implement proper land management measures (De Jong *et al*., 1999; Vrieling, 2006). A quantitative evaluation on the extent and magnitude of soil erosion problems and possible management strategies on a regional basis is often needed (De Roo *et al*., 1996; Van Rompaey and Govers, 2002).

So far, broader scale soil erosion issues have been increasingly addressed by four approaches in a general sense (Bou Kheir *et al*., 2006; Verstraeten, 2006; De Vente *et al*., 2008): 1) Scaling-up from field plot to watershed and then to regional scale (Kirkby *et al*., 1996; Fu *et al*., 2006). 2) Integrated macro-scopic method. For instance, Zhou *et al*. (1988) estimated the national soil loss trend in China in 2000 by dividing the country into seven erosion zones, each with own submodels on the basis of hydrological observation and calculation. Fargas *et al*. (1997) developed a qualitative methodology for erosion processes assessment using easily available

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terrain information at a regional scale. 3) Grid field monitoring-based information aggregation approach through the Universal Soil Loss Equation and its revised form (USLE/RUSLE) or Water Erosion Prediction Project (WEPP) suchlike (Fernandez *et al.*, 2003; Lufafa *et al.*, 2003). Renschler and Harbor (2002) documented the use of WEPP model in combination with GIS to assess whether the scale and direction of variation in model results could affect management and policy decision-making. Recently, modeling erosion on the continental level has also been addressed in the Pan-European Soil Erosion Risk Assessment Project—PESERA (Irvine and Kosmas, 2003) and sediment yield flux on a global scale (Dearing and Jones, 2003). 4) Distributed models. This approach has often been used to tackle the regional issues in more recent days (Verstraeten, 2006; De Vente *et al.*, 2008). Earlier, De Jong *et al.* (1999) also reported the use of a distributed model—the Mediterranean Soil Erosion Model (SEMMED) to produce simulated regional soil loss maps for two Mediterranean sites. Although these efforts have supplied useful clues for modeling regional soil erosion, critical limitations, particularly in data acquisition and extensive application—data availability and quality, still exist. The causes rely on the fact that the used models or their components were mainly developed on a physical basis and thus required too many inputs from field variables (Van Rompaey and Govers, 2002; Boardman, 2006), which will then hinder the efficiency and quality in assessing soil erosion over a large area. In this sense, Kirkby *et al*. (1996) noted that modeling at a regional scale is inevitably a compromise between detailed process understanding and reasonable computing times.

The Loess Plateau of China is well-known for its severe soil and water loss conditions. Much work has been done on soil erosion evaluation at plot or catchment scale in the plateau (Kang *et al.*, 2001; Zhang, 2001; Fu *et al.*, 2004; 2005), and some at a regional scale (Qiao and Qiao, 2002). However, the current knowledge on soil erosion, e.g., understanding the associations between erosion and its impact factors at a regional scale, is also far from perfect in the plateau, and thus more work should be done on the topic (Fu *et al.*, 2005). An efficient modeling approach for better understanding and more precise and fast assessment of soil erosion by water at the regional level, using easily available variables, is needed.

This study reports the use of GIS and remotely sensed data in modeling and fast assessing soil erosion by water at a regional scale based on Fundamental Assessment Units (FAUs) and easily available variables in the Loess Plateau. The objectives of this study are: 1) to develop a unique modeling approach for fast assessment of soil erosion by water at a regional scale; 2) to provide a fresh understanding of regional scale soil erosion processes as determined by the relationships between erosion and its contributing factors in the plateau.

2 Theory to Model Erosion at Regional Scale

2.1 Discriminating soil erosion impact factors

Soil erosion by water is a result of multiple factors, such as precipitation, soil, landform, vegetation and management (Meyer, 1984). Kirkby *et al.* (1996) suggested that the spatio-temporal scale of observation determines the measured rates of soil erosion and the processes responsible for the sediment transport. In a single plot up to the slope catena, the timing and volume of overland flow hydrographs are critical. On the other hand, catchment topography, soil and vegetation patterns as well as periods of storm events have also become important considerations. At both national and global scales, climate and lithology have become critical variables, with related time spans from a few years to hundreds or thousands of years. By understanding the relationships between patterns and processes at various scales, variables at a given scale can be determined for each specific process.

To save computing time for facilitating a fast assessment of large area soil erosion, the erosion factors can be categorized as dynamic ones and static ones. The dynamic factors, varying spatio-temporally, usually cover precipitation or runoff, vegetation cover, and management scenarios. In contrast, the static factors, with little or no variations in a short term over a large area, normally refer to landform and soil (Xin and Jiang, 1982). For the dynamic factors, the acquisition of ground information is relatively easy through remote sensing monitoring and data renewal. And precipitation data also can be easily obtained via local meteorological service network. As to the static factors, used data can be re-applied at a later period. As a result, it will facilitate large amounts of data renewal by only updating the dynamic factors' information during assessing erosion in a large area.

2.2 Parameterizing requirement

Proper variables, as model parameters depicting soil erosion impact factors, must be selected carefully for modeling soil erosion at various scales. In this study, the erosion factors ought to be defined at a regional scale. Since the use of too many field-based variables that require many inputs will preclude the assessing efficiency, therefore, many field variables, e.g., slope length, slope gradient and rainfall intensity, which are often used to describe the physical processes of soil erosion at fine scales, are not applied for a FAU-based regional scale modeling (Hu, 1998). Thus, variables with macro-scopic features, e.g., gully density instead of slope steepness, are welcome. Particularly, selected variables must be readily available for the sake of associated data availability in fast application and convenience for GIS treatment and spatial analysis.

2.3 FAU-based modeling approach

On the basis of the FAU concept and GIS application by using readily available variables, this study attempts to present a modeling approach as a management tool for fast assessment of soil erosion by water in the Loess Plateau. This approach initially adheres to a hypothesis that areas with similar erosion traits are prone to erosion in similar ways.

But what does the FAU mean? Given as a basis for regional modeling and assessment like the Hydrologic Response Unit (HRU) (Gowda *et al.*, 1999), a FAU is a geographic area seen as a map unit created by multiple themes′ spatial analyses and thus with similar climatic and groundcover attributes. Between neighboring FAUs, erosion features differ significantly. But within a FAU, basic map units, for example, polygons and lines of a theme, are still included.

The FAUs form a basis for a regional scale modeling and assessment by overlay spatial analyses between FAUs and thematic maps in GIS. As a result, the thematic values of selected variables will be determined by their areal weights within FAUs through spatial analyses. Therefore, this FAU-based regional scale erosion modeling approach consists of four steps in a general sense: 1) dividing the target area into FAUs by use of GIS, remotely sensed data, and ground investigations; 2) selecting proper variables that reflect water erosion factors at the regional scale; 3) spatial analysis to form thematic data arrays by extracting information from FAUs in GIS environment; and 4) building the mathematical model to link soil erosion and selected variables at the regional scale. Based on the model, an erosion assessment for a specific period or storm event can be achieved easily by only updating information of the dynamic factors.

2.4 Model selection

To fulfill above modeling perspective into a real model, we still need to develop a mathematical formula to link the selected erosion variables. However, taking too many field-based physical processes into account for modeling soil erosion at the regional scale is still a challenge. In reference to USLE that has provided useful clues in dealing with such puzzles by means of empirical statistics (Wischmeier, 1976), we assume a formula to link soil erosion by water with its essential factors at a regional scale as follows:

$$\begin{aligned} L &= f(R, S, T, C, M) \\ &= \xi \cdot R \cdot S \cdot T \cdot C \cdot M \end{aligned} \quad (1)$$

where L is the regional soil erosion; R, the precipitation factor; S, the soil factor; T, the landform factor; C, the vegetation factor; M, the land management factor at a regional scale; f, a function name; and ξ, a coefficient.

3 Modeling Procedures

3.1 Study area

The Loess Plateau, which lies in the geographic center of China, has an area of about 623.8×10^3 km^2 outlined by Taihang Mountains in the east, Riyue Mountain in the west, Yinshan Mountain in the north, and Qinling Mountains in the south. About 70% of the plateau belongs to mountainous area and more than 65% is covered by loess deriving from dust storms since the Quaternary. A temperate continental monsoon climate exists in the plateau, descending in humidity and temperature from southeast to northwest. Annual precipitation is about 250–650 mm, which concentrates in July–September mainly in a form of erosive storms. Annual evaporation potential (EP) is about 620–1 260 mm, usually exceeding 1 000 mm. Drought Index (DI) values, defined as ratio of EP to annual precipitation, over the plateau range from 1.5 to 4.0. Local vegetation belongs to the warm temperate steppe flora and is distinguished into silva-steppes and typical steppes. Nowadays, local primary vegetation has almost been replaced by crops and sparse secondary vegetation. Fragile ecological environment and long managed history as well as distinctive natural features, such as terrain, climate, soil and vegetation, have caused a complicated and unique environment of soil erosion. In the meantime, soil erosion and ecological environment degradation are intensified by population growth and resources exploitation (Qiao and Qiao, 2002). In the 1980s, transported amount of sediment yield along the Huanghe (Yellow) River was about 900×10^6 –1.6×10^9 t/yr. With extensive effort to combat erosion in recent decades, the amount has decreased to a present level of about 300×10^6–700×10^6 t/yr. Therefore, improving ecological environment and strengthening soil and water conservation have become unquestionable issues in the plateau region.

In this study, an area of about 500×10^3 km^2 in the Loess Plateau is selected to conduct this large area erosion modeling and assessment without some marginal areas that lack adequate ground survey support. As a result, our study area covers the whole of Ningxia, Shaanxi, Gansu and Shanxi, and parts of Henan, Qinghai and Inner Mongolia (Fig. 1).

3.2 Proper model variables selection

With respect to the parameterizing requirement, six readily available variables are finally selected with each reflecting a specific factor that influences soil erosion by water: 1) Annual rain-season rainfall. Rainfall from June to September makes up about 70%–85% of local annual precipitation (Wang and Jiao, 1997). Many erosive storms occur during this period in a year, which usually cause erosion when exceeding the tolerance of soil resistance. Thus, we define this period to be a rain-season in the plateau and the annual rain-season rainfall is considered as a proper climatic component to influence erosion at a regional scale (Ma, 1990). 2) Gully density. The Loess Plateau is a highly fragmented gully-hilly area, which often causes a data acquisition obstacle to delineate the region′s landform of the plateau by using fine scale variables such as slope gradient and length. Thus, the gully density variable, which refers to the total gully lengths of an area and has been proven effective to measure the regional landform features closely related to erosion in the plateau region, is selected (Ma, 1990; Fu, 1992). 3) Content of soil water-stable aggregates exceeding 0.25 mm in diameter. Gao (1991) suggested that the content of soil water-stable aggregates with particle size exceeding 0.25 mm in diameter is a perfect variable to measure loess′s stability in the plateau. By the mean time, this information is also available in the plateau for a long field survey support. 4) Vegetation cover ratio against FAU. Vegetation is always considered as an essential element to prevent erosion (Gyssels *et al.*, 2005). Wang (1991) stipulated that the vegetation cover ratio is an applied variable to link with erosion in the plateau. Therefore we select the variable of vegetation cover ratio against FAU in this study. 5) Slope farmland ratio against FAU. Boardman *et al.* (2003) indicated that land use regi-

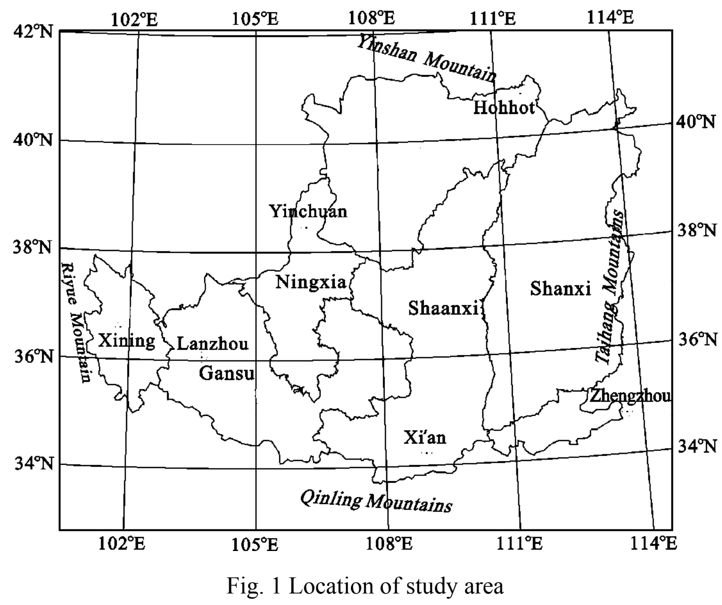


Fig. 1 Location of study area

me in agriculture plays a critical role in erosion processes and conservation measures affected by so-cio-eco-nomic factors determining land management. In the Loess Plateau, slope farmland is a major land use type, in which soil erosion often occurs due to irrational farming activities. Ma (1990) and Fu (1992) both presented that slope farmland area is a proper variable to delineate the man-made impact on soil erosion by water in the plateau. So we select the variable of slope farmland ratio against FAU in this study. 6) Sediment yield intensity. To link erosion with its contributing factors, a variable that depicts the soil erosion result is needed. In this study, the variable of sediment yield intensity over a target area like FAU, which can be easily obtained through available gauging networks, is selected.

3.3 Data sources and preparation

3.3.1 Base maps

1) The plateau boundary map. The boundary map is crucial in this study, which is used to define the interest range of selected maps during spatial analysis in GIS. This map was digitized from a 1∶500 000 boundary map of the Loess Plateau originally completed by the Natural Resources Survey Commission, Chinese Academy of Sciences in 1991. 2) Topography maps. The 1∶250 000 digital topography maps covering the interest area were provided by the China State Services for Survey and Mapping. These maps are used to calibrate the Landsat TM data for mapping the FAUs, landuse/landcover, and landform types.

3.3.2 Landsat TM data

The TM imageries of the interest area were first obtained in digital form by the China State Center for Satellite Data Reception in August, 1992. These data are used for mapping FAUs, landuse/landcover, and landform types in the plateau. By this way, the information of vegetation covers, farmland areas, and landform types needed for the modeling can be collected. We completed the mapping in ERDAS 8.0 and ArcInfo. Related interpreting accuracy is about 87.8% under rigorous quality control. As a result, 43 pieces of 1∶250 000 digital maps with compound information on landuse/landcover and topography of the interest area were built as GIS coverages. Meanwhile, a precise map projection plus coordinates transformation was also implemented for these maps with an error rate of lower than 5%.

3.3.3 Sediment yields dataset

The sediment yields dataset with geographical coordinates and observation values in 1956–1988 were provided in original form by the Yellow-river Water Conservancy Services, China. These sediment yields data were obtained from the hydrologic observation network with 178 sites that monitor runoff and sediment yields across the basins plateau. The sites were located at all representative watershed outlets, with the same standard applied for monitoring sediment transport as well as data collection, along the hierarchical waterways within the basins instead of plot-based observation. Since sediment delivery ratio is near 1∶1 in the Loess Plateau, the sediment transport observations from critical waterways can be used as the sediment yields inside the basins.

These observed sites were then treated as contour lines by the Kriging method in Surfer. The Kriging method was applied because the observations were all from well-assigned monitoring sites across the target area. Finally, these contour lines were organized as a thematic coverage with spatial attributes in GIS (Fig. 2).

3.3.4 Precipitation dataset

The precipitation dataset with geographic coordinates and daily observational values from 1955 to 1989 was provided by the local meteorological service network. These dots data were then transformed into contour maps of mean annual rain-season rainfall by Kriging. The contour lines were then organized as ArcInfo coverages with needed attributes (Fig. 3).

3.3.5 Soil data

Soil organic matter (SOM) data of different soil types and soil distribution map of the plateau are used here. The used 1∶4 000 000 digital soil map of China was created by the China Atlas Press, 1982. The SOM contents data of used soils were obtained from *China Soils* (Xiong and Li, 1987) and *Shaanxi Soils* (Guo, 1992).

In accordance to the data requirements, these soil data need to be treated as a GIS map with soil aggregate attributes. However, there exist difficulties to obtain adequate soil aggregate measurements via field survey over a vast plateau. In particular, Guo and Wang (1992) reported that there is a perfect fitness between SOM contents and our selected soil variable in the plateau as follows:

$$y = 14.6x + 0.42 \quad (2)$$

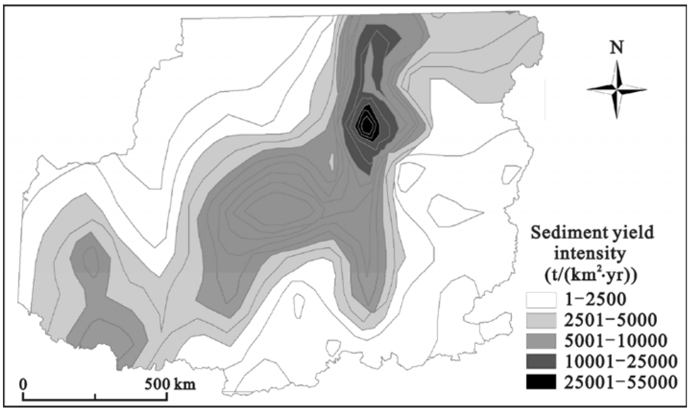


Fig. 2 Sediment yield intensity distribution

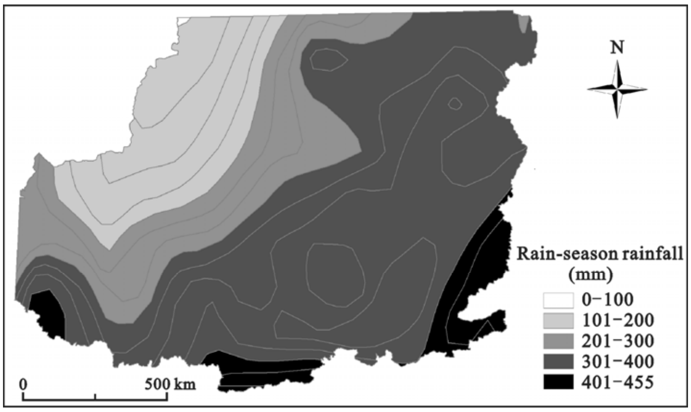


Fig. 3 Rain-season rainfall distribution

where y is the content of soil water-stable aggregates exceeding 0.25 mm in diameter (g/kg), and x is the SOM content (g/kg). $R = 0.94$, $F = 451.3$ ($> F_{0.05} = 4.01$).

By using this formula, the involved soils were given the variable values (Table 1), which were then added to the soil map as needed attributes in ArcInfo GIS (Fig. 4).

3.3.6 Gully density data

The gully density data were collected from a 1∶500 000 *Soil Erosion Map of the Loess Plateau* completed by the Institute of Soil and Water Conservation, Chinese Academy of Sciences, 1992, which originally came from routine socio-economic survey & statistics conducted by local services.

We extracted the gully density messages from available locations on the map and then added required coordinates to build a dataset appearing in a form of (X, Y, Z) dots set. By using the Kriging in Surfer and transforming into GIS, we created a gully density contours map in ArcInfo with needed attributes (Fig. 5).

Table 1 Soil types and required properties

Soil type	Sub-type	Content of soil water-stable aggregates > 0.25 mm in diameter (g/kg)
Chestnut soil	Standard	51.5
	Light	4.8
Chernozem		63.2
Black Lu soil	Standard	15.0
	Clayed	18.2
Sierozem	Standard	7.6
	Light	6.5
Sandy soil	Mobile	1.5
	Immobilised	2.9
Huangmian soil		8.5
Brown soil		15.0
Lou soil		19.4

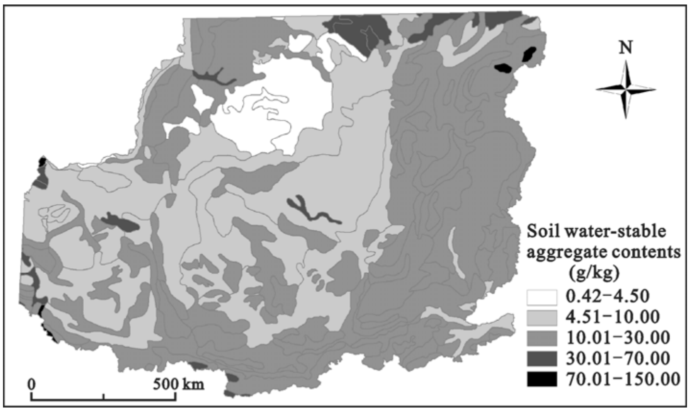


Fig. 4 Soil water-stable aggregate contents distribution

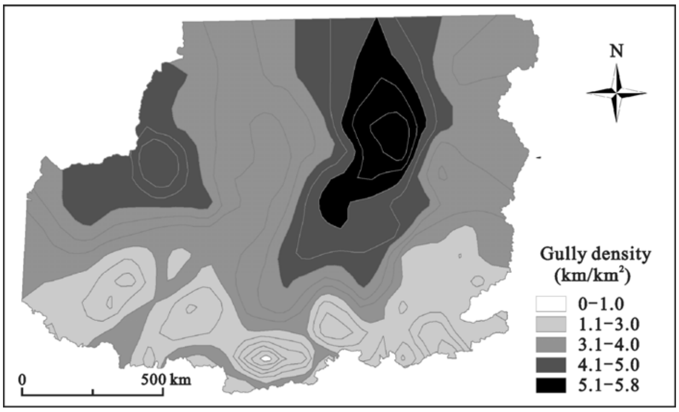


Fig. 5 Gully density distribution

3.4 Defining FAUs

An overlay between the TM-imagery-interpreted maps and the above-produced mean annual rain-season rainfall map was run in GIS to produce the FAUs. As a result, the study area was defined into 3 380 FAUs through attribute analysis, with regard to the regional characteristics of precipitation, vegetation cover, and landform (Table 2). These FAUs were saved as 43 pieces of 1∶250 000 digital maps in ArcInfo coverage form. Each FAU is about 80–150 km^2 in area size.

3.5 Extracting variables information against FAUs

In GIS environment, an overlay treatment was implemented for all the thematic maps of selected variables and the FAU maps. By applying an area-weight computing algorithm for attribute analysis, all the selected variables can be figured out to extract needed information within the FAUs.

For the vegetation cover and slope farmland variables, the algorithm is as follows:

$$T_i = \sum X_{ij} / M_i \tag{3}$$

where T_i is the extracted variable value of the ith FAU; X_{ij}, the area of the jth polygon indicating existence of vegetation cover or slope farmland in the ith FAU; and M_i, the total area of the ith FAU.

For the variables of soil water-stable aggregates, rain-season rainfall, sediment yield intensity and gully density, the extracting algorithm is:

Table 2 Criteria to define FAUs

Factor	Index	Criteria
Climate	Mean annual precipitation	< 400 mm, 400–600 mm, > 600 mm
Vegetation	Cover type	Dense forest, light forest, shrubland, grassland, farmland, bare land
Landform	Areal physiognomy	Mountain, plain, gully-hilly area

$$V_i = \sum a_{ij} A_{ij} \quad (4)$$

where V_i is the extracted variable value of the ith FAU; a_{ij}, the area weight of the jth polygon in the ith FAU; and A_{ij}, the target variable value of the jth polygon in the ith FAU.

As a consequence, the extracted values formed a complete data array ready for the modeling.

3.6 Modeling

Factors in Equation (1) need to be further defined with exact variables to fulfill the modeling. In reference to research results by Ma (1990), Wang (1991) and Fu (1992), we assumed to describe the model as:

$$L = aP^p S^s G^g M^m e^{cC} \quad (5)$$

where L is the sediment yield intensity (t/km^2· yr); P, the annual rain-season precipitation (mm); S, the content of soil water-stable aggregates exceeding 0.25 mm in diameter (g/kg); G, the gully density (km/km^2); C, the vegetation cover ratio (%); M, the slope farmland area ratio (%) within FAUs; and a, p, s, g, c and m are coefficients to be determined.

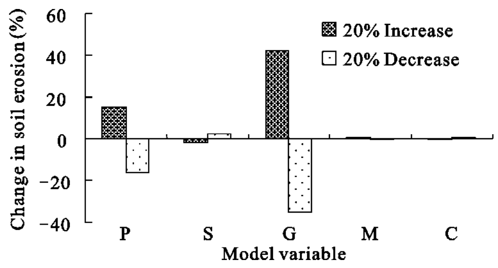
Based on the extraction, more than 3 000 rows of data records, which referred to the selected variables for the modeling, were built. In SPSS 13.0, a multiple regression analysis was applied by using the data. As a result, a mathematical model was created to link soil erosion and selected impact variables at a FAU-based regional scale as follows:

$$L = 3.521P^{0.7887}S^{-0.0962}G^{1.9945}M^{0.0190}e^{-0.0014C} \quad (6)$$

$$R = 0.8968, F = 1708\ (> F_{0.01} = 2.21)$$

4 Sensitivity Analyses

A sensitivity analysis of the model was performed by both increasing and decreasing each input variable by 20% and examining the model output (De Roo *et al.*, 1996). It shows that gully density is the most sensitive variable in the model with respect to sediment yield intensity (Fig. 6). The annual rain-season rainfall is also an important variable. However, the soil water-stable aggregates content seems to be insignificant in affecting a regional erosion outputs in the plateau. Particularly both vegetation cover ratio and slope farmland area ratio take less effect in decreasing regional erosion.



P, annual rain-season precipitation; S, content of soil water-stable aggregates exceeding 0.25 mm in diameter; G, gully density; M, slope farmland area ratio; C, vegetation cover ratio

Fig. 6 Influence of 20% changes of model variables on soil loss

5 Validation

To validate the model, 61 FAUs were randomly selected with agreeable spatial patterns across the plateau. Measurements and historical data of the 61 FAUs were collected as required in the model. They were measurements of sediment load from 13 waterway outlet-gauging stations and 15 sub-catchment sites and measurements of precipitation at 5 local rainfall gauging stations in daily form, as well as TM data of the interest area in 1996. The fitness between simulated and observed sediment yields were then validated using observations of the 61 FAUs in 1996 (Fig. 7), and it shows that there exists a good fitness between the observed and simulated sediment yields in the Loess Plateau (R = 0.96, $RMSE$ = 72.43).

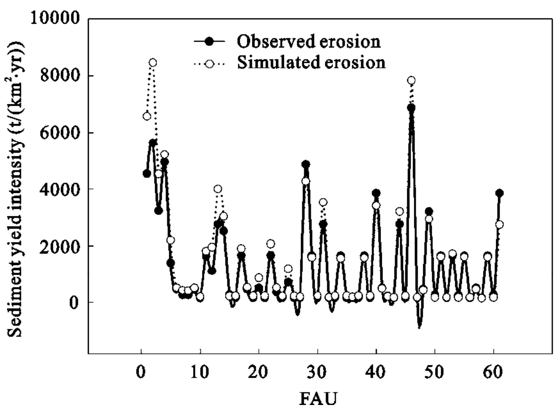


Fig. 7 Simulated and observed erosion outputs

Although the model can correctly simulate most of the cases, there exists a maximum deviation rate of about 21% (Table 3). But the deviation mainly exists between slightly and highly fragmented areas, as well as between humid and arid areas that can be easily tested from the sensitivity analysis. From the sensitivity analysis and Table 3, the difference between observed and simulated soil loss can be explained fully by variations in regional landform and rainfall.

6 Conclusions and Discussion

This study presents a unique FAU-based modeling approach for fast assessing soil erosion by water at a regional scale with the use of GIS in the Loess Plateau. The GIS provides a systematic way to spatially link sediment yields and related erosion impact factors, and the creation of FAUs also provides a basis to facilitate this fast approach. In addition, variables used in the model are all readily available. The distinction of dynamic and static factors, which is of great significance for this approach, implies a possible wider range of application. In the meantime, the use of remotely sensed data is preferred to satisfy this fast approach, combined with the aid of GIS.

This study may also provide a new understanding of soil erosion processes and the links between soil loss and its essential contributing factors at the regional scale. Physical processes and parameters of soil erosion are mainly identified at fine scales, for example, plot, slope, or small watershed, with rare at a regional scale (Laflen *et al*., 1991; Schob *et al*., 2006; Sadeghi *et al*., 2008). Therefore, the knowledge to correctly understand the processes and patterns of soil erosion at a broader scale needs a fresh strengthening. At the regional scale, landform, which is defined by gully density, is the most critical factor to influence soil loss in the plateau. And rain-season rainfall, indicating local main climatic features, is another key variable to determine the regional soil loss. These are proven by the facts that the plateau is with a highly fragmented landform and local storm events are mostly erosive to cause soil loss (Wang and Jiao, 1997). However, soil water-stable aggregates content, vegetation cover ratio and slope farmland ratio, differing from our conventional knowledge on erosion at fine scales, are insignificant to soil loss at a larger scale. The weak impact of vegetation cover ratio upon regional soil loss in the Loess Plateau can partly be explained by a geological inducing perspective (Hong, 1988) that is supported by a fact that the sediment transports in the Huanghe River remain at a stable high level (about 700×10^6–900×10^6 t/yr), though many conserving efforts have been taken at upper catchments in recent decades. Therefore, vegetation measures along slope profiles just create limited effect to prevent severe erosion. In addition, the used vegetation cover variable only accounts for the surface cover situation instead of gullies where erosion mainly occurs in the plateau (Tang, 2004). The weakness of soil stability for regional soil loss may rely on the even traits of loess particles that result in a low soil diversity across the plateau (Liang, 1992), and the soil data with lower variations in the modeling. As to the management sce-

Table 3 Simulated and observed soil loss of part of tested FAUs

FAU	Rain-season rainfall (mm)	Vegetation cover ratio (%)	Soil water-stable aggregates content (g/kg)	Slope farmland area ratio (%)	Gully density (km/km^2)	Simulated soil loss (t/(km^2·yr))	Observed soil loss (t/(km^2·yr))	Error (%)
1	375.0	36.9	16.5	8.5	4.8	5209	4950	5.23
2	375.0	97.0	18.7	3.0	2.8	1580	1650	–4.24
3	375.0	99.3	16.5	0.7	2.8	1549	1650	–6.12
4	375.0	98.3	18.7	1.7	2.8	1560	1650	–5.45
5	375.0	0.0	17.8	2.6	1.4	483	444	8.78
6	375.0	16.2	18.7	4.2	0.8	162	150	8.00
7	375.0	11.4	18.7	4.4	0.8	163	150	8.70
8	375.0	81.1	9.4	0.9	0.8	153	150	2.00
9	366.2	3.3	18.3	30.9	3.6	3034	2510	20.87
10	362.5	1.9	18.7	5.8	1.4	474	500	–5.20
11	360.0	0.0	18.71	6.41	1.4	448	500	–10.40
12	360.0	0.0	18.7	3.9	0.9	192	210	–8.57

Note: FAUs tested with similar performance are not listed narios, it is concluded that conserving activities mainly take place in slope lands but major soil loss comes from gullies in the plateau (Tang, 2004). These unique results indicate that scale-dependent features of soil erosion at a regional scale may do exist in the plateau.

This approach implies a critical significance for conservation planners and policymakers by fast providing large area computing, mapping, and dynamic varying information of massive soil erosion on the basis of FAUs. It might also be useful to evaluate conservation measures in the Loess Plateau through examining the modeling outputs of tested variables.

However, this study was based on many secondary data, which may cause some limitations in precisely describing regional erosion processes. In particular, selected variables in the model came up with certain measuring errors during given data treatments, which may result in some computing errors via specific propagations. Environmental and climatic monitoring is needed to obtain more accurate data to consolidate the association between sediment yields and its impact factors. In addition, other known field variables, such as rainfall intensity, soil texture and slope gradients were not taken into account in this study for the sake of readily data availability, which may lead to some geo-ecological confoundings. There is a need for further studies by using potentially preferable variables and long-term data upon this broader scale erosion modeling.

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