

Regional Evaluation of Soil Erosion by Water: A Case Study in the Loess Plateau of China

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Abstract: This paper shows how recent situation of soil erosion evaluation and prediction on a regional scale based on the techniques of spatial information. The study, which was carried out in central China, identified sediment discharge, precipitation, soil composition, gully density and land use as erosion factors at the regional level. It showed that soil erosion can be assessed and predicted quantitatively at a regional scale; that quantitative evaluation can be used to study and describe the soil erosion mechanism at the macro scale; and that soil erosion at the national or provincial scale can be rapidly surveyed using remote sensing, GIS and erosion modelling.

CHINA suffers severe soil erosion (Xianmo Zhu *et al.*, 1999; Qinke Yang 1994). As the country's economy has developed, soil conservation and ecological rehabilitation have been increasingly taken into account and land-use policy has shifted its focus from small watersheds to large regions (China's Agenda 21; Posen *et al.*, 1996). As a result, policy makers and those responsible for planning soil conservation and environmental rehabilitation measures are demanding systematic data about the current situation and trend of soil erosion, the benefits of conservation, etc. This information is required urgently and will need to be continually updated.

Regional soil erosion and conservation are not just local effects, they also affect the surrounding region, including rivers downstream. Widespread events such as floods, sediment deposition in rivers and reservoirs, dust-storms, land degradation and water shortages may result from localised erosion events. Consequently, we must quantify and predict the degree and effects of soil erosion at the regional, national and even global scales.

Spatial information sciences and techniques include remote sensing, geographic information systems (GIS), global positioning systems (GPS) and related internet technology, have been widely applied to soil erosion monitoring and surveying since the 1980s. Recent techniques include. Modelling and prediction technology of soil erosion have been developing perfectly and applied at the regional scales based on the GIS and remote sensing methods (Rui Li *et al.*, 1998; Qinke Yang and Rui Li 1996; Feng Jiao *et al.*, 1998). Usually the study area is divided into several integrated spatial units, so the heterogeneous characteristics, or spatial differentiation of the units can be taken into account.

Most research into erosion evaluation and prediction has been carried out at the scale of the slope or plot (Renard *et al.*, 1997); there have been relatively few regional studies. Where studies have been carried out, they have usually been based on small areas, with scaling up and/or aggregation being used to extrapolate soil erosion data to a regional or even global scale (J. W. Posen *et al.*, 1996, Kirkby *et al.*, 1996; Qinke Yang and Rui Li 1998). China has been divided into eight soil erosion areas and the soil erosion trends in each of the areas has been predicted by relating the sediment discharge to the limited factors including annual runoff, daily maximum runoff and control area (percent) (Peihua Zhou, 1988). At the same time, soil erosion data also can be get with aggregation method with the plot data from the monitoring network in American by USDA (Rui Li, Qinke Yang *et al.*, 1998). However, the problems of evaluating and predicting soil erosion at a regional scale have not been solved entirely.

1 Methodology

1.1 Study area

The study area was the 623,700 square kilometre Loess Plateau in the centre of China. The Plateau includes the southern part of Ningxia Autonomous Region, the whole of Shanxi Province, Northern Shanxi Province, the eastern and central parts of Gansu Province, the southern part of the Inner Mongolia Autonomous Region, and the western part of Henan Province. It borders the Riyue Mountains to the west and the Taihang Mountains to the east; and it extends from Qinling Mountains in the south to the Yingshan Mountains in the north. Fig. 1 shows the general location of the area.



Fig. 1 Location of the loess plateau

The Loess Plateau is located in the second of the three grand relief landform terraces in China. The basic geomorphological types include loess hills, sand-loess hills and loess tableland; the gully density is $4\text{km}/\text{km}^2$ — $6\text{km}/\text{km}^2$ and the ratio of gullies is 40%—60%. The climate is continental monsoonal, with an mean annual temperature of 6.6°C — 14.3°C and an mean annual rainfall of 250 mm—700 mm. Rain falls mainly in summer (50%—70% of annual total) and is most intense during the period from July to October. The dominant soils are widely eroded, especially in northern Shanxi Province, central eastern Gansu Province and western Shanxi Province. Secondary vegetation is limited to only a few stony hills. For over 2000 years crop growing has been the main form of land use in the area. The population density is $40/\text{km}^2$ — $270/\text{km}^2$. The relationship between people and the eco-environment is not harmonious.

Fig. 2a shows how water erosion can be subdivided according to erosive intensity. According to this classification, the Loess Plateau has three erosion regions: the water erosion region, the wind—water erosion region and the wind erosion region.

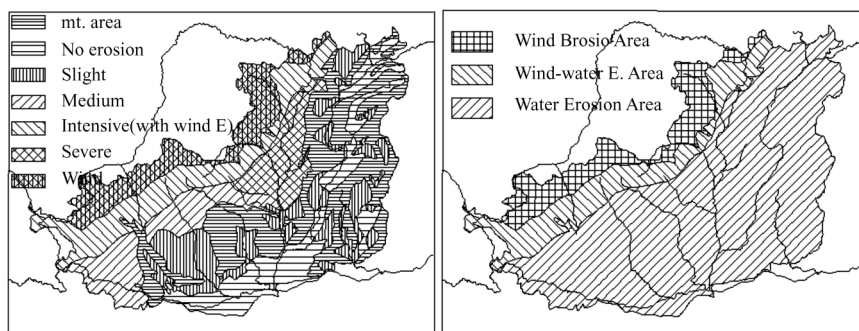


Fig. 2 Soil erosion map; a types, b regions

1.2 Data and materials

Field surveys and cartographic research by Xianmo Zhu (1981a, 1981b, 1982a, 1982b) show that regional soil erosion is a very complicated process that affected by many factors, including geomorphology, soil conditions, meteorology and hydrology, land use, vegetation coverage and soil conservation measures. By analysing these environmental factors and how they affect erosion, we can

describe the processes of erosion at the regional scale and quantitatively evaluate their intensity. In this study, we have used the following data.

- **Sediment discharge data** were obtained from the records of 250 hydrological stations covering the period from 1959 to 1986.
- **Precipitation** was measured from 1955 to 1986 at 178 meteorology stations. We used the rainfall data to calculate the mean rainfall in the rain season (July to October) for each station in the Loess Plateau; we then ascertained the latitude and longitude of each gauge using a map of hydrology stations located in the Yellow River watershed.
- **Soil classification data** were obtained from the 1 : 2,000,000 Loess Plateau soil map produced by the Institute of Soil and Water Conservation (ISWC), Chinese Academy of Sciences and the Ministry of Water Resources in 1991. Soil organic matter content data were extracted from monographs that reported the results of 2nd national soil surveys.
- **Gully density data** and the latitude and longitude were determined from a gully density annotation points in 1 : 500,000 soil erosion map of the Loess Plateau that was produced in 1991.
- **Land-use data.** We estimated the ratio of cropland to forest/grassland from a 1:250,000 land-use map in ARC/INFO format, produced by ISWC in 1993 based on the interpretation of TM.

Precipitation, sediment and gully density data were in coordinate format (x,y,z) and were processed using ARC/INFO software to generate a contour map. All data were transformed into common projection, with Albers projection.

2 Parameterisation and parameters database

2.1 Parameterisation

A number of parameters were selected for the evaluation. Their choice was dictated by what was needed for prediction, and also by what already is available.

Table 1 Parameters in the evaluation

Erosion factor	Soil erosion	Climate	soil	plant	Land using	relief
Para-meters	Sediment intensity	Rainfall in raining season	>0.25mm soil round particle quantity	Plant covering	Slope area ration	Gully density

2.2 Data basis

The characteristics of regional soil erosion vary over space and time. Consequently, multilevel areas and classes of erosion can be identified. The study of erosion on a regional scale is based on experimentation and observation at plot and watershed scales, but from a slope surface or other small area to a larger area is not simply extrapolating. according to the theory and method of Spatio-temporal modelling of the eco-environment (P. A. Burough, 1998).

In order that the study area be adequately described, the study area has to be discretized in space and time. Conventionally geonentities in space are described by vector data such as points, lines, and polygons homogeneous factors. We divided our study area into 3,380 spatial units, uniformed map area (UMA), according to Landsat Thematic Mapping (TM) imagery.

The parameters were processed into map format and integrated into each of the UMA, based on the theory and method of the georelationship model. During the process of integration, the data for location and topology were based on the UMA map or base map. The number of data entities on the base map remained the same for all the integrating operation.

3 Results and analysis

3.1 Modeling regional erosion

The general format of the model for the processes of regional erosion can be expressed as follows:

$$A = f(Q, S, g, v, c) \quad (1)$$

where A is the erosion intensity, Q is a hydrological/climate factor, S is a soil factor, g is a landform factor, v is a vegetation factor, and c is a conservation measures factor.

There is an exponential correlation among the amount of erosion, the amount of rainfall in the rain season, the gully density, the area ratio of slopecropland, coverage of vegetation and the content of aggregate ($>=0.25$ mm) (JunJieMa *et al.*, 1990, JiYangLiang *et al.*, 1992, QiuShengWang *et al.*, 1991.) The relationship can be expressed as:

$$L = 0.4735P^{0.9282} S^{-0.08855} G^{2.2666} M^{0.07254} e^{-0.00047C} \quad (2)$$

where L is the erosive intensity (tonnes/km².annual) , P is the precipitation in the wet season (mm), S aggregate content (g/kg), G is the gully density (km/km²), M is the ratio of slopecropland(%), and C is vegetation cover (%).

The highly significant regression result (multi-correlative modulus $R=0.9369$, $F=2,984.64 \gg F_{0.05} = 0.21$) indicates that the erosive intensity is positively correlated with rainfall quantity in the wet season, gully density, and ratio of slopecropland. It is negatively correlated with the content of aggregate and vegetation cover. In other words, the higher the rainfall in the wet season, the greater the erosion intensity; the higher the aggregate content and vegetation covering, the lower the erosion intensity. This accords with general principles of soil erosion, and with other research.

3.2 Evaluating the erosion factors

We have identified five variables as erosion factors at the regional scale. These factors can be converted into specific units and extracted from existing survey or remote sensing information. For a macro study to evaluate trends, these parameters can meet the demand of our study. Because land-use data have been taken into account, the parameters can also indicate, to some degree, the extent to which soil and water conservation is practised in the region.

For the purpose of analysing erosion potential, the landscape can be categorised into plains, terraces, hills, and mountains. There are obvious differences between the categories in patterns of erosion, measures and patterns of soil conservation and types of reasonable land use. The use of topographic maps and TM imagery in the mapping process has made it possible to determine locations with a high degree of accuracy. As the UMA map has 2,230 polygons and the 1 : 500,000 Loess Plateau erosion map has only 1,100 polygons, each of these units can contain parameter values derived from different parameter thematic layers. Thus erosion levels can differ between units of the same landscape zone.

We applied several algorithms for attribute values from the parameter map (in digital format) to the parameter database. We used a flexible method to calculate the relationship between the location and descriptive data. Consequently, all parameters in the model required can be integrated into the UMA map and a database with multi-items can be built to satisfy the demand of multifactor evaluation (Qinke Yang 2001).

Fig. 3 is a GIS map showing soil erosion calculated using equation 2; it shows the relationships among the different factors affecting soil erosion and accords with the spatial differentiation pattern of soil erosion observed on the Loess Plateau. The result is useful in macro policy making.

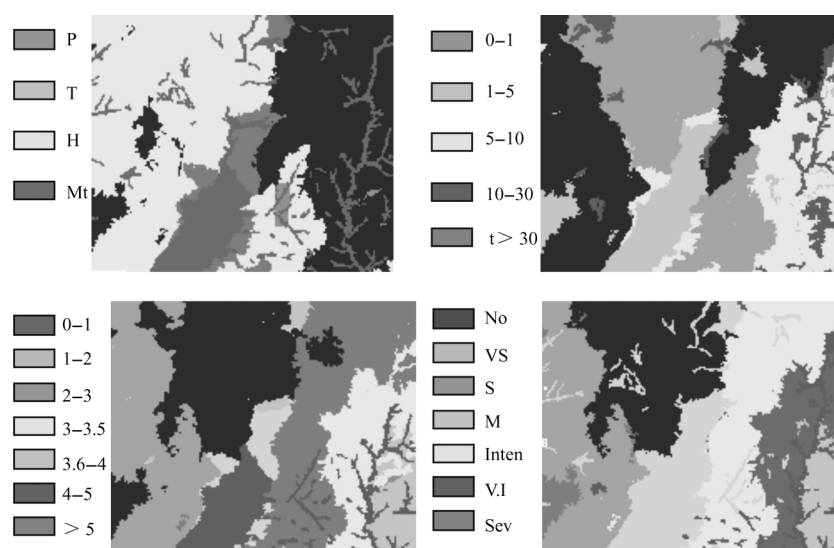


Fig. 3 Soil erosion map of loess plateau

3.3 The general form of the models for regional erosion

The primary analysis of regional soil erosion processes leads us to suggest that the following equation would provide a more scientific and reasonable model of regional erosion than the one currently used:

$$A = f(Q, S, g, v, c) \quad (3)$$

where A is erosion intensity Q = a hydrology factor, S = a soil factor, g = a geomorphology factor, v = a vegetation factor and c = a soil conservation measure factor. This equation takes soil erosion energy into account. The model can therefore dynamically reflect the current status of soil erosion and the effects of various factors on soil conversion. We are continuing to work on this concept.

3.4 The key factor in the regional soil erosion modelling

Equation 3 allows runoff modulus ($\text{kl}/(\text{km}^2 \cdot \text{a})$) to be used as a measure of relevant hydrology factors and soil anti-scourability (kg/kl) as a measure of soil factors. The relief reliefness — the maximum elevation difference in a specified area — can be used as a measure of landform factors (Xinhua Liu, Qinke Yang and Rui Li, 2001). Vegetation index and soil conservation index are studying based on the AVHRR image and soil conservation statistics data.

4 Conclusions

This study has shown that soil erosion can be assessed and predicted quantitatively at a regional scale; and that soil erosion at the national or provincial scale can be rapidly surveyed using remote sensing, GIS and erosion modelling. The information so provided will assist macro policy making at the national and provincial level..

4.1 Soil erosion can be assessed and predicted quantitatively at a regional scale

It is possible and practical to quantitatively assess and predict macro trends in soil erosion at the regional scale, using the theory and methodologies of regional soil conservation and GIS. The methodology involves:

- discretizing the study area into units in space and time with homogeneous factors and erosion types based on the analysis of processes and the spatial differentiation of soil erosion and related environmental factors at the regional scale;
- using research on the factors affecting regional erosion and the results of erosion evaluation studies, coordinated with the characters of GIS modelling methods, to identify the relevant parameters of the model;
- extracting the parameters one by one from many kinds of approaches, including field test, thematic maps, descriptions of observed materials and remote sensing imagery/DEM analysis, and integrating all the parameters into the basic unit map to build up a parameter database; and
- establishing a statistics model for the sediment discharge and each relevant factor using geostatistical and correlative analysis methods.

4.2 Soil erosion can be rapidly surveyed in China based on the GIS-based model

Our study supports the national soil erosion survey that suggests that remote sensing, GIS and erosion modelling can be used to efficiently survey soil erosion at the national or provincial scale. In the 1980s, it took about 10 years to map soil erosion in China at the national scale using mainly manual methods; in 1998—2000, it took only two years to do the same using a combination of manual and computer methods. When we have all the basic information at the national scale, we will be able to survey erosion quantitatively and annually.

4.3 Study of regional erosion processes

The accurate evaluation and prediction of regional soil erosion should be based on systematic research on the genesis and evolution of erosion at the macro scale, and on the factors that cause erosion. The current situation is far from perfect; we are doing further more work on this topic.

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