基于 RS 和 GIS 技术对中国陕西省北部地区土壤水蚀风险评估

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摘 要: 运用遥感(RS)和地理信息系统(GIS)技术来进行中国陕西省北部地区的土壤水蚀风险评估。综合运用 RS 和 GIS 技术以及修订的通用土壤流失方程式(简称 RUSLE)来定量化地评估土壤侵蚀。建立了一个关于土壤侵蚀、斜坡长度/坡度、降雨侵蚀和人类活动的评估系统。评估值输入修订的世界土壤亏损方程式中,用来计算土壤退化进程的风险,土壤退化又叫土壤侵蚀。利用榆林和靖边两地区的 1987 年和 1999 年的陆地卫星TM 传感图像来制作研究区土地使用/覆盖情况的地图,然后用这些地图产生 RUSLE 方程中的人类活动因子。使用 ER mapper/Info 两个软件来管理和处理主要数据,及处理卫星图像和表格数据源。根据统计分析,3 985.9 km^2(33.12%)的土地面积有轻微到中度的土壤侵蚀,2 941.4 km^2(24.44%)的土地面积有高的土壤侵蚀,总土地面积中 3 522.1 km^2(29.27%)正面临着很高的土壤侵蚀风险,总体上来说,研究区处于高的土壤水蚀风险中。

关键词: 土壤水蚀; 修订的通用土壤流失方程式; 遥感; 地理信息系统
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Assessment of Soil Water Erosion Risk Using RS and GIS in Northern Part of Shaanxi Province, China

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Abstract: The remote sensing and GIS are applied to evaluate the soil water erosion risk in the northern part of Shaanxi Province, China. This research integrates the revised universal soil loss equation(RUSLE) with RS and GIS techniques to quantify erosion risk. A system is established for rating soil erodibility, slope length/gradient, rainfall erosivity and conservation practices. The rating values serve as inputs into a modified universal soil loss equation(USLE) to calculate the risk for soil degradation processes, namely soil water erosion. Two Landsat TM senses from 1987 and 1999 for each location in Yulin and Jinbian County were utilized to produce land use/cover maps of the study area based on the maximum likelihood classification method. These maps were then, used to generate the conservation practice factor in the RUSLE. ER mapper and Arc/Info software's were used to manage and manipulate thematic data, to process satellite images, and to tabulate data. Statistical analysis determined that 3 985.9 km^2(33.12%) of land has slight to moderate soil degradation, 1 583.5 km^2 (13.16%) has moderately high soil degradation, 2 941.4 km^2(24.44%) has high soil degradation and 3 522.1 km^2(29.27%) of the total land is at risk of a very high soil degradation. The study area, in general, is exposed to a high risk of soil water erosion.

Keywords: soil water erosion; RUSLE; RS; GIS; Shaanxi Province; China

1 Introduction

Soil degradation is one of the most important challenges facing mankind. The problem is as old as settled agriculture. Worldwide concern has been emphasized recently. Soil degradation is defined by Lal and Stewart(1990) as the decline in soil quality caused through its misuse by

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humans[1]. UNEP[2] refers to soil degradation as the diminution of soils current and/or potential capability to produce quantities or qualities goods or services as a result of one or more degradation processes. Olsen[3] stated that most ancient civilizations flourished on fertile soil and that soil degradation was responsible for their decline.

Soil water erosion also is a severe kind of land degradation. According to Agenda 21, referring to a remote sensing survey in 1990, soil erosion affects 3 670 000 square kilometers in China, covering about 38% of the total land area. Annual soil loss is said to account for 5.0×10^6 tons; 70 000 hectares of arable land are lost every year by soil erosion. According to the State Science & Technology Commission(referred to by UNDP) between 1985 and 1994, about 360 000 hectares of farmland annually have been affected by top-soil loss[4].

The professional methodology for soil degradation assessment[5] is found to be a successful mean to identify, map and monitor the potential and present status of soil degradation. This methodology is base to be applicable at universal, regional, detailed and very detailed levels. Climatic data, soil condition, topography, and human activity are the main inputs for assessment of soil degradation processes.

The geographic information system(GIS), according to Jamaguire et. al.[6], is an information technology which stores, analyses, and displays both spatial and non-spatial data. Of a number of GIS systems, ARC/INFO and ArcView are relatively comprehensive packages and allow storage, editing, data management and plotting functions.

The aim of this study is to construct a GIS containing the environmental parameters influencing regional and global changes, with focus on soil degradation problems in the northern part of Shaanxi Province.

2 Materials and Methods

2.1 Materials

The study area, located in Northern Shaanxi Province, lies within longitude 109°00′00″E to 110°00′00″E and from latitude 38°40′00″N to 37°20′00″N. The area is 158 km long(from north to south) and 87 km wide (from east to west) and has a total area of 13 746 square km. In order to study the development of soil degradation, Yulin, Jinbain, Hengshan and Mizhi County have been selected as a study area. The county are situated in the northern part of Shaanxi Province. The area is located in a typical transitional zone(continental monsoon climate zone). The images have been acquired on 1st September and 24th October, 1987 and in August and October, 1999. All the five thematic layers are generated in GIS environment on 1∶250 000 scale. The softwares used for this study are Arc/Info and ER mapper imagine.

2.2 Methods

Representative soil samples were collected from Yulin, Jinbain, Hengshan and Mizhi County during the study period from fifteen typical soils of each city. Important physical and chemical properties of the soils were listed in table 1 by the procedures of Black et al[7]. Value for average precipitation data were obtained for the investigated location according to information recorded during the period 1987—1999 from published papers and from Yulin meteorological station. The present methodology is based upon such parametric models. The universal soil loss equation (USLE) was adopted for the assessment of wind erosion, water erosion, salinization, and physical degradation. The equation results in the following:

$$A = F\ (K* \ R* \ LS* \ C* \ P)$$

Where:

A, is the soil loss in($t\cdot ha^{-1}\cdot y^{-1}$); F is the function; K is the soil erodibility factor($t\cdot ha\cdot h\cdot ha^{-1}\cdot mJ^{-1}\cdot mm^{-1}$); R is the rainfall-runoff erosivity factor in($mJ\cdot mm\cdot ha^{-1}\cdot h^{-1}\cdot y^{-1}$); L is the slope length factor; S is the slope steepness factor; C is the cover and management factor; and P is the conservation practice factor. The formula describes the processes only approximately, and the values assigned to each factors are approximate in the present state of knowledge. These values are merely giving an approximate indication of the magnitude of degradation[5].

3 RS and GIS Processing

Landsat TM image, covering the study area of Yulin, Jinbain, Hengshan and Mizhi were used in this study(TM image of 1987 & 1999). The image was digitally enhanced using High pass filter" technique.

Table 1 Some Chemical and Physical Properties of Soil Used

Counties	Physical properties					Chemical properties			
	Sand/ ($g\cdot kg^{-1}$)	Silt/ ($g\cdot kg^{-1}$)	Clay/ ($g\cdot kg^{-1}$)	Texture	Bulk D. / ($gm\cdot cm^{-3}$)	pH	EC/ ($ds\cdot m^{-1}$)	O.M/ ($g\cdot kg^{-1}$)	CaCO3/ ($g\cdot kg^{-1}$)
Yulin	810.0	109.8	90.25	Loamy Sand	1.522	7.40	1.85	1.105	116.4
Jinbain	820.5	98.7	80.80	Loamy Sand	1.430	7.20	1.92	2.709	112.4
Hengshan	200.3	469.0	330.7	Silty Loam	1.325	7.65	1.95	3.907	80.5
Mizhi	090.4	470.2	439.4	Silty Clay	1.092	7.90	2.20	4.453	75.3

This result in obtaining false color composite image in red, green and blue respectively in scale 1:250 000. In order to perform the geometric correction of the image, several ground control points coordinates had to be collected. ARC EDIT program was used to collect the location of these points from the layer of irrigation and drainage channels and roads. ER mapper software was used for geometric correction of the images. The live-link model between ARC/INFO and ER mapper was used to match the image and the thematic map layers. More information were collected or calculated and entered into the GIS system. ARC/INFO and ArcView system are capable to use different information layers for different purposes. The principle thematic layers are the soil map where, all other information is related to its soil polygons. A master tic file was created, with 50 tic points, for geometric correction. The coordinates were converted to the universal transverse marcator (UTM) system using the ARC/INFO software. ARCEDIT was used to edit each information layer and to assign attributes to each polygon. Tables program was also used to assign additional attributes to soil polygon. Other information layers were transferred from ER mapper software to the ARC/INFO system. JOINITEM function of "TABLES" program was used to have all needed attributes in one polygonal attribute table. Calculation function was used to compute the universal soil loss equation (USLE) for all degradation processes. ARC PLOT program was used to plot maps of soil degradation risk and present state of soil degradation.

4 Assigning Environmental Factors

Numerical values were assigned to soil polygon (for each county) in the polygon attribute table of the soil coverage layer. The values were chosen according to the following parameters:

(1) Soil erodibility factor (K) ($t.\ ha.\ h.\ ha^{-1}.\ mJ^{-1}.\ mm^{-1}$) [8]

$$100K = 2.1\times 10^{-4}(12 - O_M)\,M^{1.14} + 3.25(S-2) + 2.2(P-3)$$

Where:

O_M = the percentage of organic matter in soil;

S = soil structure code;

P = permeability class cm/min [9];

M = silt% + very fine sand particle%;

M = (0.002 mm − 0.10 mm) size grade% + (0.02 mm − 2.0 mm) size grade%

Soil structure and permeability class assessment according to analysis soil samples in Hubei Academy of Agriculture and Huazhong Agriculture University.

(2) Rainfall erosivity (R) factor ($mJ.\ mm.\ ha^{-1}.\ h^{-1}.\ y^{-1}$) depends on shower distribution, intensity and the rainfall amount according to its relative location. It can be estimated by the following formula[8].

$$R = \sum_{i=1}^{12} 1.735\times 10^{\left(1.5\lg\frac{P_i^2}{P} - 0.8188\right)}$$

Where: P_i is the monthly average of rainfall (mm); P is the annually average of rainfall (mm).

(3) Topographic factor (LS). Percent slope data are derived from topographic maps. The GIS procedures used to extract the percent slope data entails the use of both ARC/INFO and ER mapper software's. LS values were computed from equation[8].

$$LS = [0.065 + 0.0456S + 0.006541S^2] \times (L \div C)^{NN}$$

Where: S = slope steepness (%);

L = length of slope (m); C = 22.1;

NN = see table 2.

Table 2 NN Values

S	< 1	$1\leqslant S<3$	$3\leqslant S<5$	$\geqslant 5$
NN	0.2	0.3	0.4	0.5

(4) Crop management and Land use (C) factor. For cropland and ground conditions vary considerably over

time, as a crop grows, increasing amounts of soil surface are protected from rainfall by canopy, while surface residue cover may decrease because of residue decomposition and tillage operations. It is important to predict soil loss ratio (SLR) frequently for the rapidly changing soil and cropping conditions common to most cropland. Incorporating the impact of time into the model requires defining some time step over which the other effects can be assumed to remain relatively constant. *C* factor map was prepared from Land use/cover map, which was prepared from supervised classification[11-12] (table 3).

Table 3 *C* Factor(Land Use) Value for the Universal Soil Loss Equation

Land use	*C* factor
row crop	0.240
pasture/hay	0.050
water/wet area	0.000
urban, low density	0.030
deciduous forest	0.009
evergreen/coniferous forest	0.004
mixed forest	0.007
forest/woody wetland	0.003

(5) Determining conservation practice (*P*) factor. Conservation practice factor included in this term are contouring, strip cropping(alternate crops on a given slope established on the contour), and terracing. Values are obtained from tables of the ratio of soil loss where contouring and contour strip-cropping are practiced to that where there are not conservation measures, the value of *P* factor is 1.0, so *P* factor map was prepared from Land use/cover map, which was prepared from supervised classification of images, using the values given in Table 4[11].

Table 4 P Values for Different Conservation Practices

Slope/%	Contour	Strip	Terrace
0—1	0.80	—	—
1—2	0.60	0.30	—
2—7	0.50	0.25	0.10
7—12	0.60	0.30	0.12
12—18	0.80	0.40	0.16
18—24	0.90	0.45	0.16

The *P* factor values were chosen based on the research findings of Central Soil and Water Conservation Research, Beijing.

5 Results and Discussion

Table 5 shows the value of risk and the present status of water erosion and the input parameters for their calculation. The whole study area is characterized by a high erosivity of present status while the risk is also high. However, in order to reveal the effect of different conditions, recategorization was elaborated. The highest values obtained for the present status and risk are found in the Mizhi(Slity clay). All types are subjected to a higher risk of water erosion compared with the present status. The soil is clay flats characterized by their clay texture and poor drainage conditions. Thus, impermeability surface sealing and runoff may occur. These conditions are favorable for both gully erosion and mass movement. Accordingly, values of soil erodibility and soil texture factors are high. The miscellaneous rock land has the characteristics which favor gully formation due to their surface sealing impermeability. Also rugged topographic steep slopes and dissected landscape concentrate runoff.

Table 5 Value of Risk and Present Status of Water Erosion and Input Parameters for Their Computation

Location	K_F	R_F	*Top*	H_F	*R*	P_S
Yulin	0.20	162.5	0.92	0.43	13.276	5.7088
Jinbain	0.29	210.9	1.65	0.30	30.274	9.0824
Hengshan	0.40	235.8	3.92	0.45	166.38	4.8712
Mizhi	0.40	242.9	4.80	0.45	209.86	4.4395

Not: K_F = soil erodibility factor(metric t. h. h/h. mJ. mm); R_F = erosivity factor(mJ. mm/h. h; Top= LS-factor; H_F = human activity factor (*C* and *P* factors); *R* = risk of soil degradation; P_S = present status of soil degradation.

The study area is mostly characterized by moderate (10—30 t·ha^{-1}·y^{-1}) to severe (30—80 t·ha^{-1}·y^{-1}) risk and present status values of soil degradation by soil water erosion(figure 1). Human activity in the Yulin, Jinbain, Hengshan and Mizhi soils reduce the present state hazard of water erosion. However, water erosion is more pronounced in the Hengshan and Mizhi areas. As a result of this study, land was divided into four classes according to its vulnerability to erosion and to its vegetation cover.

(1) Slight to moderate soil water erosion: erosion is occasional, the ratio of the vegetation cover is medium and

land is flat or sloppy.

(2) Moderately high soil water erosion: erosion is continuous, the ratio of vegetation cover is high and the slop is medium.

(3) High soil water erosion: erosion is visible of continuous, the ratio of vegetation cover is medium and the slope is high.

(4) Very high soil water erosion: various types of erosion are visible, low vegetation cover and the slope is very high.

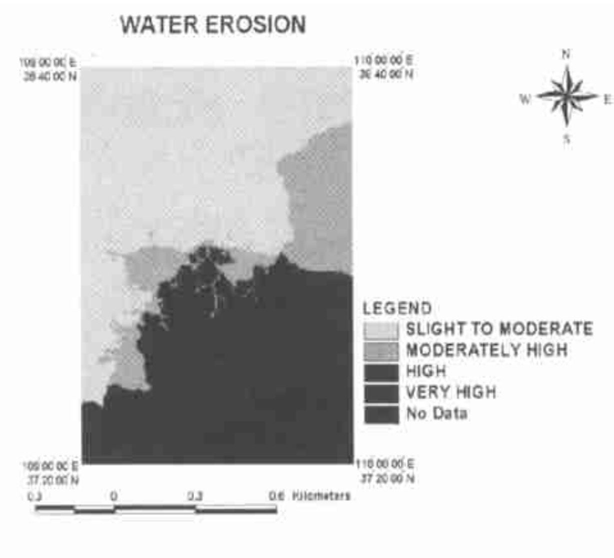

Figure 1　Risk of Soil Degradation by Water Erosion in the North Shaanxi Province.

In the table 6, we have the general estimation of soil water erosion in north Shaanxi Province. So we conclude that 33.12% of land area in north Shaanxi Province is very slightly to moderate erosion risk, 13.16% is moderately high erosion risk, 24.44% is high erosion risk, and 29.27% is very high erosion risk. No doubt these results show the gravity of soil water erosion problem in the north Shaanxi Province.

Table 6　The Ordinal Categories Soil Erosion and the Area and Proportion of Each Category

Erosion risk class	Numeric range/ $(t.ha^{-1}.y^{-1})$	Area/ km^2	Proportion/ %
slight to moderate	0—5	3985.9	33.12
moderately high	5—10	1583.5	13.16
high	10—30	2941.4	24.44
very high	30—80	3522.1	29.27
extreme	> 80	—	—

6　Conclusion

It is clear from the results of this study that the northern part of Shaanxi Province has been suffering seriously from soil degradation by water erosion resulting from climate variations but mainly from human activities and modified USEL is a powerful model for the qualitative as well as quantitative assessment of soil erosion intensity for the conservation management. Multi-temporal and multi-spectral remote sensing data have provided valuable and very important factors like C and P for this study. Since, the crop cover is a powerful weapon to reduce the direct impact of rainfall on soil particles, it can be recommended that all barren lands in local area be converted to agricultural land or forest plantations through proper land reclamation measures. GIS has given a very useful environment to undertake the task of data compilation and analysis within a short period at very high resolution. GPS data can be used for updating the age-old survey of local area topographic map, which is the prime source of data for the Digital Elevation Model and Geo-coding of image.

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《水土保持通报》2005 年征稿简则

《水土保持通报》全方位报道水土保持领域最新科技研究成果。主要报道内容包括如下:

(1) 阶段性的水土流失规律研究; (2) 水土保持措施及其效益研究; (3) 区域水土流失、生态环境监测研究及综合治理成果; (4) 高新技术在水保领域的应用研究; (5) 滑坡、泥石流、风蚀沙化、盐碱等水土流失灾害现状及其的预防、监督、治理措施; (6) 依法防治水土流失的典型经验、成果评价、问题讨论等; (7) 与水土保持有关的国家及全球性重大决策问题、热点问题研究与讨论。设有综合研究、试验研究、研究简报、水保监测、应用技术、综合治理、专家介绍、专家论坛等栏目。

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