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Soil Degradation Risk Prediction Integrating RUSLE with Geo-information Techniques, the Case of Northern Shaanxi Province in China

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Abstract: This research integrated the Revised Universal Soil Loss Equation (RUSLE) with RS, GIS and GPS techniques to quantify soil erosion risk and the northern part of Shaanxi province in China was taken as a case. A system was established for rating soil erodibility, slope length/gradient, rainfall erosivity and conservation practices. The rating values served as inputs into a modified Revised Universal Soil Loss Equation (RUSLE) to calculate the risk for soil degradation processes, namely, soil water erosion. Two Landsat TM senses in 1987 and 1999, respectively, were used 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. ERmapper and Arc/Info software were used to manage and manipulate thematic data, to process satellite images and tabular data source. In term of statistic analysis 3985.9 km^2 (33.12%) of land area had slight to moderate soil erosion risk, 1583.5 km^2 (13.16%) had moderately high soil erosion risk, 2941.4 km^2 (24.44%) had high soil erosion risk and 3522.1 km^2 (29.27%) of the total land area was in a very high soil erosion risk. The study area, in general, is exposed to high risk of soil water erosion.

Key words: Geoinformation Techniques, Soil Erosion, RUSLE, Shaanxi, China

INTRODUCTION

Geoinformation Techniques or 3S Techniques (RS, GIS and GPS) are technologies for collecting and dealing with geographic information. They have percolated into common man's life since the utility of these technologies have a variety of uses right from agriculture, desertification study, forestry, archeology, disaster management, environment, geology, health, land information system, transportation, urban and rural development, telecommunication, to name a few. Geoinformation Technique plays a vital role in mapping inaccessible area on the earth [1].

Soil degradation is one of the most important challenges facing mankind. The problem is as old as the settled agriculture. Worldwide concern has been emphasized recently. Soil degradation was defined as the decline of soil quality caused through its misuse by humans [2, 3] refered to soil degradation as the diminution of soils current and/or potential capability to produce quantities or qualities of goods or serviced as a result of one or more degradation processes. Olsen [4] stated that most ancient civilizations flourished on fertile soil and that soil degradation was responsible for their decline.

Soil water erosion is also a severe kind of land degradation. According to Agenda 21, referring to a remote sensing survey in 1990, China's soil erosion area was corresponding to 3,670,000 square kilometers, covering about 38% of the total land area. Annual soil loss was said to account for 5×10^6 tons; 70,000 ha of arable land were lost every year by soil erosion. According to the State Science and Technology Commission (referred to by UNDP) between 1985 and 1994, about 360,000 ha of farmland were annually affected by top-soil loss [5]. In the northern Wei River Valley of Shaanxi Province in China, soil erosion has been extremely serious, affects 130,000 km^2 (67% of Shaanxi Province). Soil loss was estimated at 850 million t year^{-1} and average erosion rate was about 6500 t km^{-2} year^{-1} in the Loess Plateau of Shaanxi and sediment concentrations in the middle reaches of the Yellow River in China (the loess plateau) approached 700 kg m^{-3} (about 50% by weight) [6].

The professional methodology for soil degradation assessment [3, 7] was found to be a successful mean to identify, map and monitor the potential and present status of soil degradation. This methodology is a 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) is an information technology that stores, analyses and displays both spatial and non spatial data [8]. Among a lot of GIS systems, ARC/INFO and ArcView are rather comprehensive packages that allow using their storage, editing, data management and plotting functions.

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

MATERIALS AND METHODS

The study area, located in the northern part of Shaanxi province, lies within longitude 109° 00′ to 110° 00′ E and from latitude 38° 40′ to 37° 20′ 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 13746 km^2. In order to study the development of soil degradation, Yulin, Jinbain, Hengshan and Mizhi cities have been selected as a study area. The cities 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 at a scale of 1:250,000. The softwares used for this study are Arc/Info and ERmapper imagine.

Remote Sensed Image Preprocessing: Two windows of 6967×5968 pixels from each scene, covering the study area, were used in this study (Landsat TM). In order to perform the geometric correction of the images, the Geodetic Datum WGS84 and map projection NUTM49 coordinate system were built into the vector using Linear method and the resampling method chosen was nearest-neighbour that preserved original reflectance value, Several Control Point (SCP) coordinates had to be collected. ERmapper system was used for geometric correction and some image processing. The images were digitally enhanced using "high pass filter" technique. ERmapper software was used to classify, compute the NDVI. Iso-clustering classification technique was used to classify the NDVI image into six vegetation density classes to produce 14 polygons. The classified image file was converted to ARC/INFO vector format.

Field Sampling and Model Parameter Extraction: Representative soil samples from northern part of Shaanxi province were collected during the study period from three typical soils of each polygon. Important physical and chemical properties of the soils were listed in Table 1 by the procedures of Black [9]. Values for average wind velocity (m/s), rainfall (mm), temperature (°C) and evaporation (mm) data were obtained for the investigated location according to information recorded during the period 1987-1999 from four meteorological stations. The universal soil loss equation (RUSLE) was adopted for the assessment of Soil water erosion. The equation result is as follows:

$$A = F(K{*}R{*}LS{*}C{*}P) \qquad (1)$$

Where:
A is the soil loss in t $ha^{-1}\,y^{-1}$
F is the function;
K is the soil erodibility factor (t ha h $ha^{-1} mJ^{-1}\, mm^{-1}$);
R is the rainfall-runoff erosive factor in mJ mm $ha^{-1} h^{-1}\, y^{-1}$
L is the slope length factor; S is the slope steepness factor;
C is the cover and management factor;
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 [3, 7].
More data were collected or calculated and entered into the GIS system. ArcView system is capable to use different information layers for different purposes (Table 2). The principle thematic layers are the soil map and 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 mercator (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 ERmapper 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 (RUSLE) for all degradation processes. ARC PLOT program was used to plot maps of soil degradation risk and present state of soil degradation.

Determining RUSLE Factors Values: Numerical values were assigned to each soil polygon in the polygon attribute table of the soil coverage layer. The values were chosen according to the following parameters:

Soil Erodibility Factor (K): The K values were usually estimated using the soil erodibility nomograph method [10]. This method uses % silt plus very fine sand (0.002-0.1 mm), % sand (0.1-2 mm), % organic matter and soil structure and permeability class to calculate K. However, there is lack of structure and permeability class data in the soil survey data source. Therefore, we adapted following equation, which was recommended by RUSLE when lack observation data. The soil erodibility factor was estimated using the equation of Renard *et al.* [11] as follows:

$$K = 7.594\,\{(0.0034+0.0405\exp(-1/2\,(\log(D_g)+1.659/0.7101)^2))\} \qquad (2)$$

$D_g = \exp 0.01 \text{ sum } (\text{fi} - \ln \text{mi})$ (3)

Where:
K, soil erodibility factor (t ha h ha^{-1} mJ^{-1} mm^{-1});
D_g, mean geometric particle diameter (mm);
fi, primary particle size fraction (%);
mi, arithmetic mean of the particle size limits of that size (mm);

Rainfall Erosivity Factor (R): The rainfall-runoff erosivity factor (R) refers to climate (rainfall) factor. The agents for the erosion are raindrops and flowing water. Raindrop, rain splash or splash erosion is the process of erosion on barren soil surfaces. Rainfall data were collected from four meteorological stations in Northern part of Shaanxi for the years 1987 and 1999. The estimation of annual rainfall erosivity was done using the regional (statistical) regression indices (modified Fournier equation). The rainfall database obtained from the Yulin meteorological office includes the rainfall data for the years 1987 and 1999. Rainfall erosivity was determined by using Rrain formula [12].

$$R_{ann} = [4.17 \times \sum_{i=1}^{12} (P_i^2 / P)] - 152 \quad (4)$$

Where,
P_i is the month i average rainfall (mm)
P is the annual average rainfall (mm) and
R_{ann} is the approximate annual average R rainfall erosivity factor value. Table 3 shows the annual average rainfall and rainfall ersosivity factor.

Topographic Factors (L and S): The slop factors (LS) refer to topographic and/or relief factor. In the computation of the LS factors, the topographic factors, L and S factor are usually considered together. The slope length factor L, computes the effect of slope length on erosion and the slope steepness factor S and computes the effect of slope steepness on erosion.
To describe the influence of slope steepness, Liu *et al.* [13] researched steep slopes data from China. Based on synthesizing the results presented by Liu *et al.* [13] and Nearing [14] produced a single continuous function for S:

$$s = -1.5 + \frac{17}{\left(1 + e^{2.3 - 6.1 \sin\theta}\right)} \quad (5)$$

where θ is the slope angle (degrees).
Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases to a point where deposition begins, or runoff becomes focused into a defined channel [10, 11].
To model upslope drainage area, the steepest descent algorithm (single flow), multiple flow algorithm [15] and the flux decomposition method was proposed in the literature to calculate the contributing area of each grid cell in a grid-based DEM. Desmet and Govers [16, 17] tested the three algorithms in the program USLE2D.EXE, which is designed to calculate the LS-factor in the USLE or RUSLE from a grid-based DEM and provides the user with a number of options with respect to selecting both a hydrological flow routing algorithm and a slope length and steepness algorithm [18].
The unit contributing area for the slope length value was then substituted as the slope length within the equation provided by Foster and Wischmeier [19], with each of the grid cells within the DEM considered as a slope segment having uniform slope. Substituting the values for cell outlet and cell inlet into the Foster and Wischmeier [19] equation solves the slope length L component:

$$L_{i,j} = \frac{A_{i,j-out}^{m+1} + A_{i,j-in}^{m+1}}{(A_{i,j-out} - A_{i,j-in})(22.13)^m} \quad (6)$$

Where, $L_{(i,j)}$ is the slope length factor for the cell with coordinates (i, j) , $A_{(i,j\text{-}out)}$ is the contributing area at the outlet of the grid cell with coordinates (i, j), $A_{(i,j\text{-}in)}$ is the contributing area at the inlet of the grid cell with coordinates (i, j) and m is the slope length exponent of the USLE S-factor [16]. The LS-factor was consequently determined by multiplying the S and L-factors in IDRISI to obtain the map of topographic factors.
In order to estimate the impact of slope length and slope steepness on the assessment of soil erosion risk in Yulin at the study area in particular, the following procedure were adopted: Digital Elevation Model DEM map (resolution 30 m) of the study area was created by digitizing the topographic map of Yulin (scale 1:250,000). RUSLE-LS factor values were extracted from the DEM files of the study areas by using USLE2D Ver. 4.1 software, Gover 1991 algorithm was used to estimate LS values for the study areas.

Human Factor (Land Use/Cover Factor (C) and Conservation Practice Factor (P)): 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 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 (Table 4) [10, 20]. While the RUSLE P-factor reflects the impact

Table 1: Some Chemical and Physical Properties of Soil Used

ID No.	Physical properties					Chemical properties			
	Sand ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	Texture	Bulk ($D\ g\ cm^{-3}$)	pH	EC ($dS\ m^{-1}$)	O.M ($g\ kg^{-1}$)	$CaCO_3$ ($g\ kg^{-1}$)
1	920.2	40.85	38.95	Sandy	1.689	7.25	2.52	0.502	19.0
2	900.4	50.82	48.72	Sandy	1.672	7.42	1.85	0.625	16.5
3	880.5	59.28	60.14	Sandy	1.685	7.45	1.92	0.743	16.5
4	910.0	49.86	40.12	Sandy	1.669	7.29	1.95	0.855	16.5
5	810.0	109.8	90.25	Loamy Sand	1.522	7.40	2.21	1.105	12.2
6	800.9	108.8	90.25	Loamy Sand	1.532	7.20	2.20	0.994	10.5
7	240.9	418.6	340.5	Silty Loam	1.311	7.40	2.65	1.855	10.3
8	240.2	429.7	330.1	Silty Loam	1.295	7.70	1.60	1.892	10.1
9	200.3	469.0	330.7	Silty Loam	1.325	7.65	1.70	1.758	16.5
10	90.20	600.2	309.6	Loamy Clay	1.191	7.90	2.50	2.709	6.2
11	820.5	98.70	80.80	Loamy Sand	1.430	7.20	1.20	0.929	4.5
12	240.0	489.6	270.4	Silty Loam	1.212	7.80	1.40	3.706	1.9
13	120.5	470.4	409.1	Clay Loam	1.092	7.80	2.25	3.907	1.8
14	090.4	470.2	439.4	Silty Clay	0.938	7.90	2.45	4.453	1.8

Table 2: GIS Thematic Data Layers

Information layers	Source	Purpose
Classified TM image	TM	Map, updating soil
(NDVI)	TM	Rating human activity
Irrigation, drainage and river	Topographic maps	Geometric correction
Contour map	Topographic maps	Calculating slop percent
Climatic data	Meteorological station	Computing climatic factor

Table 3: RUSLE-R Factor Values in the Study Areas

Meteorological station	Years	Annual rainfall (mm)	Rainfall erosivity factors R_{ann}
Yulin	1987	345.3	146.3157
	1999	361.9	156.2695
Jingbian	1987	375.4	161.1332
	1999	441.0	173.9762
Hengshan	1987	537.8	210.7652
	1999	459.2	221.9651
Mizhi	1987	550.2	273.2873
	1999	487.9	259.8956

Table 4: C-factor Value for Different Classes

Land use class	Average C factor value
Forest	0.003
Bush and grasslands	0.01
Weak vegetation	0.60
Sparse vegetation	0.90
Barren soil	1.0
Urban areas	0.0001
Croplands	0.40
Sand dunes	1.0
Sand lands	1.0
Water bodies	0.0001

Table 5: 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	-	-

of support practices dealing with the average annual erosion rate. It is the ratio of soil loss with contouring and/or strip cropping to that with straight row farming up-and-down slope. As with the other factors, the P-factor differentiates between cropland and rangeland or permanent pasture. As the study of this research work to estimate soil erosion using RUSLE modeling was applied in the area of non-agriculture or on natural (geological) erosion, it was considered that there was no conservation practice (P) in non-agricultural areas. Therefore as the conservation practice factor (P) value ranges from 0.0-1.0 and the highest value is assigned to areas with no conservation practice, the maximum value for P, that is 1.0, is assigned to this research work area.

RESULTS AND DISCUSSION

Maps of K, R, LS, C and P factors were integrated within ArcView to generate a composite map of erosion intensity [21]. Figure 1-4 shows Soil erodibility factor average values map (RUSLE_K factor), Rainfall erosivity factor (RUSLE_R factor), Slope Length and Slope Steepness Factors (RUSLE_LS factor) map, (RUSLE_C&P) factors average values map based on landsat-5 TM images and GPS data, respectively. The layers of RUSLE model were created and integrated within ArcView by an overlay procedure for the study area for the year 1987-1999. Morgan [20, 22] argued that 10 t ha^{-1} yr^{-1} was an appropriate boundary measure of soil loss over which agriculturists should be concerned.

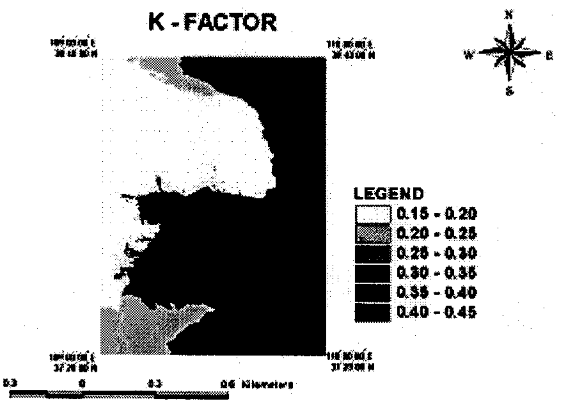

Fig. 1: Soil Erodibility Factor Values (RUSLE_K factor) Map for Study Area

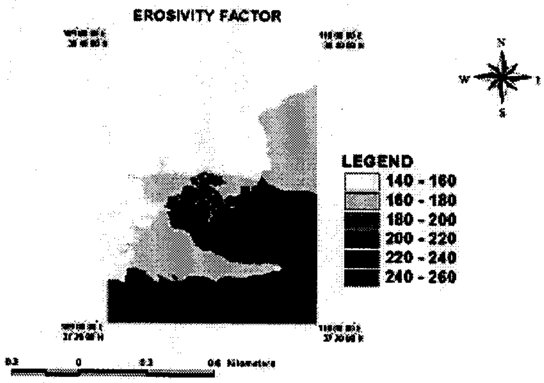

Fig. 2: Rainfall Erosivity Factor Values (RUSLE_R Factor) Map for Study Area

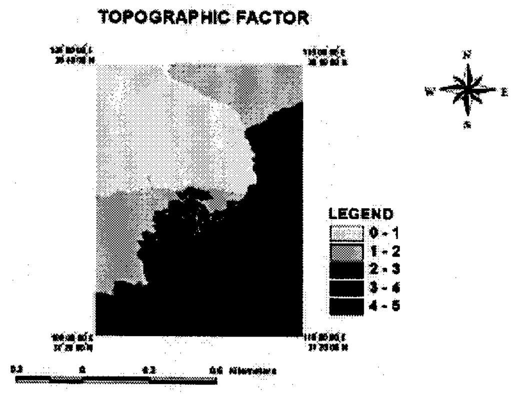

Fig. 3: Topographic (LS) Factor (RUSLE_LS factor) Map for Study Area

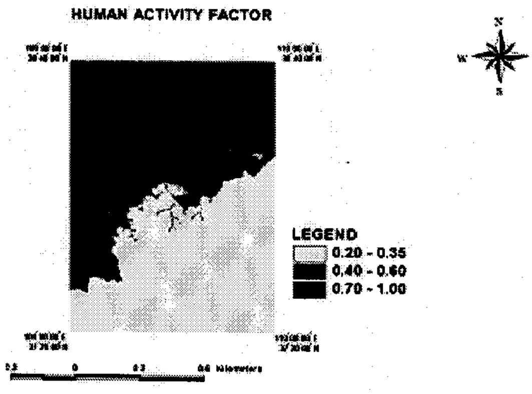

Fig. 4: Human Activity Factor (RUSLE_C&P) Map for Study Area

Figure 5 shows the assessment 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 Mizhi (Slity clay soil). 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 that favor gully formation due to their surface sealing impermeability [23]. Also rugged topographic steep slopes and dissected landscape concentrate runoff.

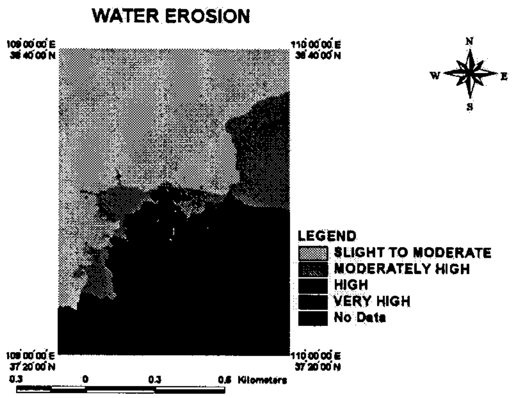

Fig. 5: Risk of Soil Degradation by Water Erosion in the North Shaanxi Province

The study area was 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 (Fig. 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 areas of Hengshan and Mizhi. As a result of this study, land was divided into four classes according to its vulnerability to erosion and to its vegetation cover.

* Slight to moderate soil water erosion: erosion is occasional, the ratio of the vegetation cover is medium and land is flat or sloppy
* Moderately high soil water erosion: erosion is continuous, the ratio of vegetation cover is high and the slop is medium
* High soil water erosion: erosion is visible continuous, the ratio of vegetation cover is medium and the slope is high
* Very high soil water erosion: various types of erosion are visible, low vegetation cover and the slope gradient is very high

In Table 5, 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 had very slightly to moderate erosion risk, 13.16% had moderately high erosion risk, 24.44% had high erosion risk and 29.27% had very high erosion risk. Without doubt these results show the gravity of soil water erosion problem in the north Shaanxi province.

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. The 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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