INTEGRATED USE OF REMOTE SENSING AND GIS FOR PREDICTING SOIL EROSION PROCESS

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ABSTRACT:

Soil erosion is one of the most important environmental problems, and it remains a major threat to the land use of mountainous environment. Runoff from eroding mountainous landscapes contains sediment and any nutrients, fertilizers that were present in the soil. Soil erosion may be reflected in reduced crop production potential, lower surface water quality and damaged drainage networks. Assessment on soil erosion hazard is essential for soil conservation plans in a mountainous region for sustainable development. RS and GIS technique has been recognized as a powerful and effective tool in detecting land-use change. The objective of this study was to predicting soil erosion process of Yizi region based on RS and GIS technique by integration of soil erosion controlling soils cape, land cover, terrain and climatic parameters as inputs. Integrated predicting approach resulted in severs classes of soil erosion hazard in the study area with numerical values of the Soil Loss Equation (SLE) ranging between low hazard to high hazard. The results indicate that RS and GIS technique is indeed valuable tools for predicting soil erosion process.

1. INTRODUCTION

Soil erosion is one form of soil degradation along with soil compaction, low organic matter, loss of soil structure, and poor internal drainage problems. These forms of soil degradation, serious in themselves, usually contribute to accelerated soil erosion. Erosion hazard is a major land degradation problem in mountainous environment. Consequently, many models have been developed for quantifying soil loss or pinpointing areas suffering from soil erosion. Although increased use of GIS led to a great many GIS-based model applications at the catchments level and larger scale during the past decades, there has been no emphasis on predicting erosion hazard for specific environment such as the peculiar and attractive mountainous region commonly distributed in Yizi region, southern-west of Sichuan province, P.R. China. This environment contains particularly fragile ecosystem because thin soil that have low fertility and readily succumb to decertification predominate. There is considerable potential for the use of GIS technique as an aid to soil erosion hazard assessment. Soil erosion hazard is most frequently assessed by using Universal soil Loss Equation (USLE). Several studies showed the potential utility of GIS technique for quantitatively assessing soil erosion hazard based on USLE predicated erosion soil loss (Saha and Pande, 1993; Mongkolsawat et al., 1994). Cruz (1992) developed a scalogram (numerical grades) modeling concept and he utilized this concept for upland agriculture suitability assessment following GIS using soils and terrain parameters. A GIS based integrated modeling approach utilizing soil, terrain and climatic parameters controlling soil erosion is the effective means of practical assessment of soil erosion hazard. How to predict the soil erosion process based on the remote sensing (RS) and GIS technique is discussed in this paper.

2. STUDY AREA

Yizi region is one part of Renhe disrtict and lies between 10l°24′to 102°02′E longitudes and 26°06′to 26°46′N latitudes approximately, Panzhihua City, located in southern-west part of Sichuan province(see figure 1), P.R. China. Yizi' topography is varied and complicated, with towering mountains, with an elevation of 2920m, different sizes, and low river valley, with an elevation of 937m. Between the Yunnan-Guizhou plateaus and Tibet plateau, mountainous landscape in Yizi region makes up more than 80 percent of the region's total area. This region belongs to subtropics weather. About 90 percent of annual rainfall concentrated between June and October. Intense rain shows of more than 100 millimeters in 24 hours are common. The study area is 1552.32hm2. Soil loss studies predict erosion rates reaching as high as 32.01 tons per hectare. The location of study area is presented in figure 1.

3. DATA

The various types of data used in this study are: (1)the vector outline of study area, (2)1:50000 scale vegetation, (3)1:50000 scale land use/land cover map, (4)1:50000 scale geological map,(5) 1:50000 scale soil map, (6) soils grid,(7)rainfall map,(8)Landsat TM 30-meter satellite imagery,(9)1:5000 scale topographic map, and (10)DEM(20m).

4. METHODOLOGY

The study method is model calculation soil erosion process based on the RS and GIS technique. Factors affecting erosion

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prccess can be summarized as follows: natural factors and human-induced factors (Larney F J, 1995). The proposed model considers soil erosion caused when soil particles are detached by the impact raindrops and transported by runoff (B0er, 2003).In this paper the factors considered included soils, land cover, terrain and climatic parameters. This model calculates soil process by incorporating parameters concerned, such as rock infiltration (RI), soil erodibility (SE), Land sensitivity (LS), morphology (M), vegetation affects (VA), and rain erodibility (RE). These parameters proposed are extracted from the various types of data used in this study based on RS and GIS technique, respectively. The parameters information extracted is classified into five classes based on Reclassification tool and model calculates soil process by incorporating parameters and relative weight concerned making use of the Model Builder in ARCGIS9.0.Because these parameters do not have an equal effect on erosion hazard, they are not given the same weight. In this study area six main parameters with a weight of 0.2, 0.2, 0.2, 0.1, 0.2 and 0.1are considered according to relative importance with respect to soil erosion of the study area, respectively.

4. 1 Predicting Soil Loss Equation

In predicting approach, an arithmetic operation was combined with the corresponding numerical weights for the main criteria and sub-criteria to generate a score that includes attribute (Cruz, 1992). The approach of prediction on soil erosion in this paper considers soil erosion caused when soil particles is detached by the raindrops and transported by runoff. Soil erosion calculates by incorporating both internal and external dynamic parameters. The parameters considered in this study don not have an equal effect on soil erosion hazard, so they are not given the same weights. According to this approach, soil erosion hazard was predicting using the Soil Loss Equation (SLE). The corresponding weights for RI stated in the Eq1 were assigned using Weighted Overlay in ArcGIS 9.0 to obtain the final RI parametric raster layer. The soil loss equation, along with its component parameters, is show in Eq1, Eq2 and Eq3.

The soil equation (SLE) is given by Eq. (1).

$$SLE = 0.2RI + 0.2RE + 0.2LS + 0.1M + 0.2VA + 0.1RE \quad (1)$$

Where the SLE is soil loss, the RI is rock infiltration, SE is soil erodibility, the LS is land sensitivity, M is morphology, the VA is vegetation affects, and the RE is rainfall erosivity.

The rock infiltration (RI) is given by Eq. (2).

$$RI = 0.4LIT + 0.35LFD + 0.25DRD \quad (2)$$

Where the RI , the LIT is lithology, the LFD is lineaments frequency density, and the DRD is drainage density.

The soil erodibility (SE) is given by Eq. (3).

$$SE = 0.35ST + 0.35SOM + 0.3SD \quad (3)$$

Where the ST is soil texture, the SOM is soil organic matter, and the SD is soil depth.

The morphology (M) is given by Eq. (4).

$$M = 0.4SGA + 0.4SC + 0.2SA \quad (4)$$

Where the SGA is slope gradient affects, the SC is slope curvature, the SA is slope aspect.

4.2 Soil erosion process controlling parameters

4.2.1 Rock infiltration (RI): Infiltration is a function of a number of interactive factors, such as lithology, lineament frequency density, and drainage density, and so on, which can be manipulated using GIS. High rock infiltration indicates recharging of considerable amounts of water into subsurface strata (Tang Keli et al., 1993), which diminishes potential runoff and decreases the quantity of transported particles. In this study area three main parameters, such as lithology (LIT), lineaments frequency density (LFD), and drainage density (DRD) with a weight of 0.4, 0.35, and 0.25 are considered according to relative importance with respect to Rock Infiltration of soil erosion in this study area, respectively.

(1) Lithology (LIT)

To extract the lithological formation, a 1:50000 scale geological map covering the study area was registered using the georeferening tools in ArcGIS 9.0. All lithological formation was then delineated by head-up digitizing. Using Model Builder, the vector shapefile created through digitizing was converted to raster. Depending on the rock type, the previously obtained raster was classified into five classes based on rock infiltration capacity using the Reclassification tool and Model Builder.

(2) Lineaments frequency density (LFD)

Lineaments, i.e., topographic features that are thought to represent hidden crustal structures, generally associated with high infiltration rates. Lineaments were extracted from geological maps and through visual interpretation of georeferenced Landsat TM 30-meter satellite imagery. The lineament density map was established using the Density command in the ArcGIS Spatial Analyst extension. The raster layer obtained was reclassified into five classes on LFD using the Reclassification tool and Model Builder according to the infiltration rates. Higher values were assigned to more dense areas to define the infiltration index rates raster.

(3) Drainage density (DRD)

The drainage lines were digitized from topographic map, the resulting shapefile converted to a raster and was reclassified into five classes on DRD using the Reclassification tool, and the drainage infiltration index layer ereated. All involved factors do not have the same effect on the rock hydrologic infiltration property.

4.2.2 Soil erodibility (SE): Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Tillage and cropping practices which lower soil organic matter levels, cause poor soil structure, and result of compacted contribute to increases in soil erodibility. Decreased infiltration and increased runoff can be a result of compacted subsurface soil layers. A decrease in infiltration can also be caused by a formation of a soil crust.

The soil maps at 1:50000 scale registered, and the soil units were digitized. In the attribute table for soil shapefile, three new fields for texture, soil organic matter, and soil depth were created. For each soil unit polygon, related values were added in the corresponding field. Three physical properties of soil erodibility were used to determine susceptibility to erosion: soil texture (ST), soil organic matter (SOM), and soil depth (SD) (Wischmeier, 1971). In this study area three main parameters with a weight of 0.35, 0.35, and 0.30 are considered according to relative importance with respect to soil erosion in this study area, respectively.

4.2.3 Land sensitivity (LS): The land use/cover change （LUCC） is the importance components in the world environment changes and the important reason causing environment changes all over the world, and also is a significant dynamic parameter affecting the erosion process (Bunn J A,1997; Chappell A,1998). Water erosion reaches its maximum when the soil is bare and kept without protection against rainfall. A digital vector 1:50000 scale land use/land cover map of the study area was provided for reference in data extraction from the TM. After the RS image process and interpretation, the supervised is performed by making use of ERDAS IMAGINE 8.5 software; the result of classification is leaded to data shape document, and then is converted into coverage with the Topy relationship. From the above, the figure of land use/land cover in study area is acquired.

In order to promote the integration of remote sensing and geographic data, geographic information system (GIS) should be established in which both the image and graphic data are stored in a digital form, retrieved conditionally, overlaid on each other and evaluated with the use of a model. In addition, the classification of remote sensing imagery will become more accurate if the auxiliary data contained in maps are combined with the image data. Interpretation document is converted translation applying the GIS software and is edited based on ARC/INFO. After the country checked, and verified proceeding for the error diagram spot, and make it get to the accuracy request; the statistics of land use vector model based on the geographical statistic is analyzed. Making use of the GPS technique, after the open country adoptions, verification and contrast with the data collected, the land use/cover change diagram is obtained. The shapefile was converted to a raster, five influence rate classes were assigned using the reclassification option in Model Builder, and the final land sensitivity parametric raster layer was obtained.

4.2.4 Morphology (M): There are three morphological parameters in this study, such as slope gradient affects, slope aspect, and slope curvature is proposed. In this paper, 1:50000 topographic maps as basic maps were scanned into computer. After the topographic maps had been rectified, vectors maps were attained through GIS software. Three primary terrain attributes, such as slope gradient, slope curvature, slope aspect were calculated from a digital elevation model (DEM) provided by the ArcGIS 3D Analyst extension. The tree derived raster were reclassified based on the effective rate of erosion and combined by assigning weights using Weighted Overlay and producing the Morphology (M) parametric raster layer. In this study area three main morphological parameters, such as slope gradient affects (SGA), slope curvature (SC), and slope aspect (SA) with a weight of 0.40, 0.40, and 0.20 are considered according to relative importance with respect to soil erosion in this study area, respectively.

(1) Slope gradient affects (SGA)

The velocity of the surface flow subsequently increases, and the depth of the surface flow and ponding decreases (Mutchler and Young 1975). Slope affects soil erosion rates in several different ways. As slope gradient increases, the impact angle of raindrops becomes more acute. The amount of soil loss from erosion by waters with the steeper the slope. As a result of gravity, a greater proportion of the mass and the momentum of the soil, water, and sediment particles act in the down slope direction (Ekern 1950; Giancoli 1988; Wan et al. 1996). The slope is obtained based on the DEM covering the study, and then reclassified according the slope degree to five classes using the Reclassification option tools in Model Builder.

(2) Slope aspect (SA)

Slope aspect has an effect on the microtopography (i.e. small-scale pattern of irregularities) of the soil's surface, which tends to cause this overland flow to concentrate in closed depressions. Both the flowing water, and the water in detention storage, protects the soil from raindrop impact, so that rain splash redistribution usually decreases over time within a storm, as the depth of surface water increases. There are, however, complex interactions between rain splash and overland flow. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. A slope aspect can be expressed from DEM, which is one of the most important items for topographical analysis. In this study, the slope aspect means a direction along the maximum slope inclination at one target pixel; the slope aspect is obtained based on the DEM covering the study, and then reclassified according the slope aspect degree to five classes using the reclassification option tools in Model Builder.

(3) Slope curvature (SC)

Soil surfaces that are not rough or ridged offer little resistance to the water. However, over time, ridges can be filled in and the roughness broken down by abrasion to produce a smoother surface susceptible to the water. Excess tillage can contribute to soil structure breakdown and increased erosion. A Slope curvature can be expressed from DEM, which is one of the most important items for topographical analysis. In this paper, the slope gradient is obtained based on the DEM covering the study, the slope curvature is obtained based on slope gradient, and then reclassified according the slope curvature degree to five classes using the reclassification option tools in Model Builder.

4.2.5 Vegetation affects (VA): Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate.

The role of vegetation in the control of soil erosion needs some consideration. Vegetation plays a vital role in landscapes by maintaining biodiversity, providing shade and shelter, recycling nutrients, utilizing carbon dioxide and using moisture that may leak into groundwater and contribute to salinity problems (Mangan J M, 2004). They also provide stability to stream banks and prevent landslip on susceptible steep slopes. In vegetation, the leaf litter, shrubs, grasses and a variety of other forms of vegetation covering the soil surface, provide protection from erosion. The 1:50000 scale vegetation is digitized for reference in vegetation data extraction from the TM, the resulting shapefile converted to a raster and was reclassified into five classes using the Reclassification tool in ARCGIS9.0.

4.2.6 Rain erodibility (RE): Both rainfall and runoff factors may be considered in assessing a rainfall erosion problem. Rain may move soil directly, which is known as rain splash erosion. Splash is only effective if the rain falls with sufficient intensity. If it does, then as the raindrops hit bare soil, their kinetic energy is able to break down soil aggregates, disperse the aggregate material, and move soil particles a short distance. So, soil movement by rain splash is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Although the erosion caused by long-lasting and less-intense storms is not as spectacular or noticeable as that produced during thunderstorms, the amount of soil loss can be significant, especially when compounded over time. High rainfall quantities are indicative of important soil loss quantities (Lancaster N, Helm P, 2000). To obtain the RE layer, the digital rainfall map was converted to raster, and then reclassified according the erosion process to five classes using all the above mentioned tools in Model Builder.

5. MODEL VALIDATIONS

A validation run of 120 sites was conducted for a period from the beginning of June to October 2006. This period coincided with the critical erosion period for the area. For each site, the tributaries of each linear system were counted and the dimension measured. For each linear channel, reading of depth and width were taken within an interval of 10 percent of the total curved length of the channel. Erode volume in cubic meters per year for each linear channel was calculated by multiplying the average cross-section area (depth x width) by the total length. The total volume for each site is equal to the mean eroded volume multiplied by the number of detected gullies in the field. Where there was no erosion, zero values were recorded. A statistical validation of the model was performed by arranging the obtained linear channel volumes into five classes and comparing them with modeled erosion classes.

6. RESULTS

All six parameters raster layers were combined using Weighted Overlay tool in ARCGIS9.0. The model created soil erosion processes layer for the study area is presented in figure 2. Soil erosion area in every grade of the study area is given by table1. From the table 1, soil erosion process in this study area can be divided into low, slightly low, moderate, slightly high, and high according to erosion degree, soil erosion area is 1.8hm^2, 2.6hm^2, 588.92hm^2, 390.72hm^2, and 568.28hm^2, makes up for proportion of 0.116%, 0.167%, 37.938%, 25.170%, and 36.608% covering total study region, respectively. The high soil erosion degree makes up more than one third in area or proportion in this region. The amount of high and slightly high soil erosion degree in area or proportion is over 60 percent covering the study region, respectively. The result shows that soil erosion degree in this region is in the process of development trend.

7. CONCLUSIONS

Soil erosion may be a slow process that continues relatively unnoticed, and it may occur at an alarming rate causing serious loss of top soil. Soil erosion, and its associated impacts is one of the most important (yet probably the least well-known) of today's environmental problems. The model can define, for a representative region of Yizi, a map showing erosion risk with five classes. This map is the result of modeling available knowledge and data and can serve the needs of a variety of researchers and decision makers. It has advantage over physical and event based models, which require too much data to be applied at a region scale. If the functional capabilities of ArcGIS 9.0 are used, this model can be easily extrapolated to the entire county. Using ArcGIS 9.0 Model Builder, a new spatial data can be added and codes modified to automatically analyze basic and factorial data. There is more data derived RS imagery applying for soil erosion. This study demonstrates that RS and GIS technique is very valuable tools in predicting soil erosion process.

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REFERENCES

B(o)er J, Sch(a)r W, Conrad O et al., "The WEELS model: methods, results and limitations," Catena,52 (3),289-308(2003).

Bunn J A, "The implications of alternative beliefs about soil-erosion-productivity relationships and conservation treatments for the economic dynamics of soil erosion on the southern Texas High Plains," Journal of Soil and Water Conservation, 52(5),368-375(1997).

Chappell A,Warren A, Taylor N et al., "Soil flux in southwest Niger and its agricultural impact," Land Degradation and Development,9(4),295-310(1998).

Cruz, R.A.D. "The determination of suitable upland agricultural areas using GIS technology," Asian pacific Remote Sensing J., 5,123-132(1992).

Lancaster N,Helm P, "A test of a climatic index of dune mobility using measurements from the southwestern United States," Earth Surface Processes and Landforms,25(2),197-207(2000).

Larney F J,Izaurralde R C,Janzen H H et al., "Soil erosion-crop productivity relationships for six Alberta soils," Journal of Soil and Water Conservation,50(1),87-91(1995).

Mangan J M,Overpeck J T,Webb R S et al., "Response of Nebraska Sand Hills natural vegetation to drought, fire, grazing, and plant functional type shifts as simulated by the century model," Climatic Change,63(2),49-90(2004).

Mongkolsawat, C., Thirangoon, P. and sriwongsa, S., "Soil erosion mapping with Universal soil loss Equation and GIS proc," 15th Asian conf.Rem. Sens., Bangalore,C-1-1 to C-1-6 (1994).

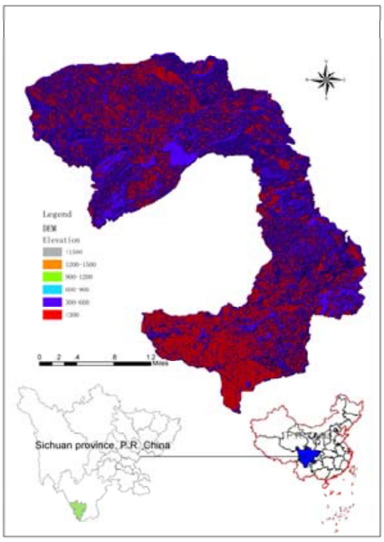
Saha, S.K. and Pande, L.M. "Integrated approach to wards soil erosion inventory for environmental conservation, using satellite and agro- meteorological data," Asian Pacific RS., 5 (2), 21-28 (1993).

Tang Keli, Zheng Fengli, Zhang Keli et al., "Research subjects and methods of relationship between soil erosion and eco-environment in the Ziwuling forest area," In:Memoir of Northwestern Institute of Soil and Water Conservation, Academia Sinica and Ministry of Water Resources, 17,3-11(1993) (in Chinese).

Wischmeier, w,h, Johnson, C.B. and Cross , B.V, "A soil erodibility monograph for farmland and construction sites ," Soil and Water Conservation, 26,189-193(1971).

Soil erosion process	Grid number	Erosion area(hm^2)	Proportion (%)
Low	45	1.8	0.116
Slightly low	65	2.6	0.167
Moderate	14723	588.92	37.938
Slightly high	9768	390.72	25.170
High	14207	568.28	36.608
Total	38808	1552.32	100

Table1. Soil erosion area in every grade of the study area



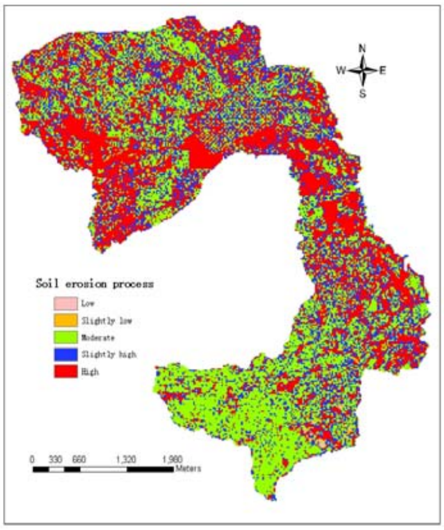


Figure1. The location and DEM of study area Figure 2.The model created soil erosion processes layer for the study area