ROUGH AREA SOIL EROSION MAPPING VIA GIS MODELING

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1. INTRODUCTION

Soil conservation is an important aspect of environmental protection, especially in China which has over one billion people who rely on limited land resources to develop agriculture. Since the 1980's, due to a fast growing population and excessive land utilization, soil erosion has become a serious issue in China. In the middle 1980's, a national soil erosion survey (1:500,000) was undertaken using MSS imagery through visual interpretation. However, as environmental pressure increased, soil erosion mapping with a larger scale and higher quality was more desirable than before. In 1987, The European Commission provided 1.5 million European Currency Unit (ECU) to support the soil conservation research in the Upper Yangtze River. In this program, a significant part of funds were for soil erosion mapping using remote sensing and GIS technologies.

1.1 Soil Erosion Mapping Status in China

Soil erosion mapping is a challenging topic which not only requires both remotely and ground-based data, but also requires the knowledge of soil erosion mechanisms. Soil erosion mechanisms, which are complicated, were generalized into six factors in the Universal Soil Loss Equation (USLE) developed in the 1940's in the United States. Since then, the USLE was widely used in the world. However, despite the popularity of USLE, it was found hard to apply in China because 1)The rainfall index needs many experimentation to set; and 2) A slope factor is hard to establish when the slope is greater than 15 degrees. The new Revised Universal Soil Loss Equation (RUSLE) which is starting to be implemented in the United States is uncited to address the concerns identified in this research.

The experiments required to set factor values are expensive and time consuming, so the China national soil erosion survey did not adopt USLE in the 1980's. Instead, the approach of visual interpretation and assessment was used. However, visual interpretation and assessment is strongly dependent on the personal knowledge and skills, which led to quality differences from map to map.

1.2 Overview of the Research

The research was aimed at providing a dependable approach to soil erosion mapping, at scale 1:100,000, which should be applicable in high relief mountains and in areas with a complicated geological background. The mapping technique should be simple and inexpensive to implement, with a mapping quality should satisfy the requirements at the county level government. Therefore, remote sensing and GIS was adopted to achieve this goal.

A model of soil erosion assessment was developed, named as **RASEAM** which stands for **R**ough **A**rea **S**oil **E**rosion **A**ssessment **M**odel. RASEAM adopts six factors to conduct assessment for soil erosion intensity, which are rainfall, vegetation, slope, soil and parent material, land use and soil sonservation measures. All of these six factors were quantitized into ranks. Land use type was assumed to be the key factor influencing soil erosion, so RASEAM conducts assessment in two ways for both agricultural and non-agricultural land. The quantitative assessment was based on a discovered rule of the research which indicates that soil erosion follows an inverse relationship with vegetation and slope.

1.3 Results

The research was conducted in the very rough southwest China mountain area which has developed many kinds of soil erosion. Thematic Mapper (TM) and SPOT images, helped by color airphoto interpretation, were used to generate land use and vegetation maps. Other maps were used in analysis, such as soils, topography map etc.. RASEAM was used manually for soil erosion mapping of 3120 square kilometers.

RASEAM was used in two computer formats: PC ERDAS 7.3 which produced a soil erosion map in raster format and PC ARC/INFO which produced a soil erosion map in vector format. Both maps presented correct mapping results. Due to data and hardware limits, the maps produced by computer covered a 200 km^2 subarea, in a very rough part of the study area.

For the purpose of providing easier service, RASEAM was programmed into independent X-window software which can be loaded on any UNIX or LINUX platform, reading ERDAS .lan file and produce raster format maps.

2. GOALS AND STRATEGY

2.1 Background

The research area is located in the southwest mountains, N 27°32'~28°10', E 101°46'~102°31', where the altitude ranges from 1170 meters to 4182 meters. This big relief, 3012 meters, creates five vertical climate zones. Average annual rainfall is 1013.1 mm with annual average temperature 17.0°C. This sufficiency of rainfall and solar energy enables various vegetation types to grow in the five vertical climate zones. The vegetation development in the low altitude V-shaped valleys are relatively poor due their hot and dry climate. Crops are developed according to the climates with rice, wheat, potato being the main products.

Due to the strong tectonic movements, the geological background is very complicated with the existence of many rock types generated from Paleogene to Quaternary. The tectonic movements heavily squeezed and cracked the rock layers, so the bedrocks are normally instable. Consequently, many soil types were developed in this changing environment.

In this rough environment, which has sufficient rainfall and steep slopes with cracked bedrocks, soil erosion developed in many forms, including mud-and-rock-flows and mud-forest, with varying intensities.

2.2 Soil Erosion Map

2.2.1 Soil Erosion Intensity: The intensity was classified into six grades which was defined by Chinese National Hydro-Power Ministry (CNHDM), and illustrated in Table 1.

Table 1. Erosion Intensity Definitions

Rank	Intensity	Definition (T/km^2.Yr)	Soil Layer Dep. Loss (mm)
1	None	< 500	None
2	Slight	500 -- 2,500	<1.9
3	Medium	2,500--5,000	1.9 -- 2.7

4	Strong	5,000--8,000	2.7 -- 5.9
5	V. Strong	8000--13500	6.0 -- 10.00
6	Severe	> 13,500	> 10.0

2.2.2 Soil Erosion Rate: It was ranked in five grades which was defined by CNHDM as well, and shown in the Table 2.

Table 2. Erosion Rate

Rank	Description	Soil Layer Loss Time (Yr.)
1	None	>1000
2	Relative Danger	100 -- 1000
3	Danger	20 -- 100
4	V. Danger	< 20
5	Destroyed	All gone

2.3 Research Strategy

In order to output a soil erosion map at a large scale via remote sensing and GIS technologies, the following strategies were adopted:

1) Considering map usage, several factors appear on a map:

- Must be match with 1:100,000 scale;
- Must can be obtained from remotely sensed data or from the other supportive data;
- Can enhance applications at county level;
- Can suggest future change.

2) Factors were ranked not on theory, but based on practical experience. In the other words, the research was application oriented, so even if a known theory of soil erosion existed it was not adopted if it could not be implemented smoothly in practical mapping. Hence the ranking system for each factor:

- Must be identifiable on remotely sensed data; or identifiable on the other supportive data;
- Must be identifiable in the field sampling sites;
- Be as simple as possible for easy modeling; but
- Establish sufficient ranks for the other application modification.

3. FACTOR SELECTION AND GENERATION

Factor selection is very important to soil erosion mapping on a large scale. In China National Soil Erosion Survey in the 1980's, landform was used as a very important factor. The authors, however, think the landform factor has little influence on large scale mapping, so this research did not adopt this factor.

3.1 Rainfall Factor

In the USLE, the rainfall factor was termed as the Rainfall Index which was calculated based on the maximum rainfall period. But as the rainfall type varies, the index is hard to determine. The authors had no sufficient experimental data and time to work out which time span, 15 minutes, 30 minutes or 60 minutes, is optimal for the index calculation, and which index, I_{30}, I_{60} or I_{15}, could satisfy the mapping needs in an area of high local relief.

The rainfall factor was simplified, in this research, in terms of rain coefficient which were defined in relative values. The research area was delineated into five subzones according to their annual precipitation. Any subzone can be taken as a standard, so the rainfall coefficient in this standard subzone was set as 1.0. Then the coefficients in the other subzones were set according to annual precipitation increment against the standard precipitation.

3.2 Soil and Parent Material Factor

The soils, though complicated in types, were ranked into eight grades according to their resistability to erosion, rather than the erodability which was adopted by USLE. This inverse setting was purely for easier manipulation in modeling. The ranking table is illustrated in Table 3.

Table 3. Soil and Parent Material

Rank	Soil	P. Material
1	mountain meadow soil, mountain brown soil	metamorphic rocks, granites
2	mountain yellow brown soil, yellow soil	metamorphic rocks, granites
3	red soil, limestonic soil	granite, limestone etc.
4	red soil	Quaternary red soil
5	red soil	Triassic carbonic shale
6	red soil	New Ternary clay
7	purple soil	shale & sandstone
8	recent mixure	mass movement

In Table 3, the red soil, which is the zonal soil, was ranked into three grades according to the parent material. Because red soils developed from different parent materials, they have different textures which lead to different resistabilities.

This ranking system, consisting of eight grades, is fixed in RASEAM. The authors think that a ranking system of eight grades can support the complicated soils ranking required GIS in modeling. The thematic map of this factor was made by manually editing a soil map a the geological map, then a part of it was digitized into ARC/INFO format and converted into ERDAS format as illustrated in Figure 1.

3.3 Slope Factor

Slope ranking is crucial to RASEAM. The ranking, in five grades, was established based on the soil erosion characteristics and topographic map. If the grade difference were too small, it would be hard to detect small difference in the fields and even on maps in a rough area. Since the mapping output is soil erosion intensity, rather than soil erosion quantity, it is unnecessary to set up slope length factor. The Table 4 illustrated the ranking system.

Table 4. Slope Grades

Rank	Slope (degree)	Descrip.	Erosion Feature
1	<= 5	gentle	sheet erosion only
2	6 -- 12	medium	major in sheet erosion
3	13 -- 25	steep	gully erosion in major, sheet erosion minor
4	26 -- 35	v. steep	gully erosion major
5	> 35	dangerous	gully erosion major

The thematic map of this factor was produced by manually editing a topographic map, and then part of it was digitized into ARC/INFO format because commercial Digitized Elevation Models (DEM) are not available in China. The ERDAS formatted data are shown in Figure 2.

3.4 Vegetation Factor

There are two sub-factors, vegetation types and vegetation coverage which determines the ranking of the vegetation factor. This research, used a concept of "the equivalent resistibility to soil erosion", to make the ranking for vegetation. In Table 5, the coverage stands for the total vegetation coverage of arbor, bush and grass.

Table 5. Vegetation Cover

Rank	Vege. Type	Coverage(%)
1	forest, bush, meadow, tall grass	>= 90
2	forest, bush, meadow	60 -- 90
2	sparse forest, bush & grass tall grass	70 -- 90
3	forest, bush, meadow	40 -- 60
3	sparse forest, bush & grass short grass	50 -- 70
4	sparse forest, bush & grass meadow	15 -- 40
4	short grass	25 -- 50
5	sparse forest, bush & grass	< 15
5	short grass, bare soil	< 25

Just like slope factor ranking, the grade difference was set relatively high for the purpose of easy use in the fields and on satellite imagery; and the grades could be modified according to application needs. This layer was generated by the conventional way using the normalized green vegetation index NDVI [1], on ERDAS, which is shown in Figure 3.

3.5 Land Use Factor

The authors suggest that the land use factor is the key which determines the soil erosion mechanism. Non-agricultural land use refers to that where human interfering with the soil erosion mechanism is minor. Agricultural land use is where soil erosion mechanisms were greatly changed by human effort. The ranking of land use was based on hybrid criteria that agricultural land use was ranked by slope change, but the non-agricultural land use ranking was based on vegetation coverage. The land use ranking is shown in Table 6.

Table 6. Land Use

Rank	Land Use	Land Type
1	paddy land, plain crop land	agriculture
2	upland, fallow land, orchard	agriculture
3	forest, meadow, dense bush & grass	none-agriculture
4	sparse forest, bush & grass, grass	none-agriculture
5	sparse grass, bare soil	none-agriculture

This thematic map was produced by the means of visual interpretation using color airphoto interpretation, illustrated in Figure 4. TM and SPOT imagery available during the dry season were too poor to generate reliable land use maps.

3.6 Conservation Measure Factor

Conservation can present the rationality of human's using land, therefore this factor can describe the manner of human impact on land. This factor can give hints of future change of soil erosion. The ranking is illustrated in Table 7.

Table 7. Conservation Measures

Rank	Measure	Definition
1	protective	well developed biological or engineering measures
2	improving	with certain measures, but not good, or need time, or further development
3	natural	no human effort to protect, nor significant soil erosion
4	excessive	unreasonable land use damaging soil, such as overgraze, steep slope cultivation etc
5	destroyed	soil layers gone, badlands

This thematic map was made by a comprehensive way. Satellite remotely sensed data does not provide this sort of information, but airphotos do provide some, such as terraced fields. The researchers collected annual reports from the authorities, then were able to find out where and what conservation measures were applied, thus the conservation measure map was produced, shown in Figure 6.

4. MODELING RATIONALE

4.1 Non-agriculture Land

The essence for modeling none-agricultural land use, is the inverse relationship between vegetation and slope. This suggests:

1) When vegetation coverage, whatever any type, is high, no soil erosion occurs at any soil on any slope, except for mass movement;

2) As vegetation coverage declines, slope influence increases;

3) When vegetation coverage is low, slope becomes the dominant factor which effects soil erosion.

This rationale is presented in the following expressions:

$$Y = R\, C_4 (W_1 X_1 + W_2 X_2 + W_3 X_3) \qquad ......(1)$$

Where

Y is score for soil erosion intensity;
R is rainfall coefficient;
C_4 is land use coefficient;
X_1 is soil and parent material;
X_2 is slope;
X_3 is vegetation;

and

W_1, W_2, W_3 are weights for X_1, X_2, X_3 respectively, and

$$W_1+W_2+W_3=1.0$$

W_1 and is a constant as $W_1=0.1$, but W_2, W_3 change inversely against each other. This inverse changing priority is determined by the land use factor, as

a) When vegetation is high, X_3 will be small. If $X_3 <= X_2$, the weights will be

$$\begin{cases} W_3 = 1 - 0.04\, X_3 X_4 \\ W_2 = 0.9 - W_3 \end{cases} \qquad ......(2)$$

b) When vegetation coverage is low, and slope is gentle. If $X_3 > X_2$, the weights will be

$$\begin{cases} W_2 = 0.04\, X_3 X_4 \\ W_3 = 0.9 - W_2 \end{cases} \qquad ......(3)$$

In (1), C_4 is a land use coefficient defined by

$$C_4 = 1/[1 + 1/(X_4 - 2)^3] ......(4)$$

The dynamic inverse change of weights in (4) and (5), truly simulate the dominant factor shift in the soil erosion process. In this way, the complicated soil erosion mechanism was greatly simplified. The Y score in (1) was graded into soil erosion intensity by Table 7.

Table 7. Erosion Intensity

Intensity	Non-Agri. Y Value	Agri. Y Value
None	< 0.84	< 0.82
Slight	0.84 -- 1.63	0.83 -- 1.36
Medium	1.64 -- 3.05	1.37 -- 2.40
Strong	3.06 -- 3.45	2.41 -- 3.10
Very Strong	3.46 - 4.14	3.11 -- 3.60
Severe	> 4.14	> 3.60

4.2 Agriculture Land Use

Cultivated land is the land use which has been impact by human activity, so it was regarded by the authors as the original soil erosion mechanism has been changed. We did not succeed at observing any evidence of an inverse relationship existing in cultivated land soil erosion, therefore a new formula is needed for cultivated land soil erosion assessment.

High intensity soil erosion normally occurs in uplands which have steep slopes. Cultivated land usually possesses certain conservation measures, such as terraces, drain ditches, contour planting, but these conservation measures vary from one land type to another. Permanent cultivated upland, with a better draining system and higher crop density, has stronger resistibility to soil erosion; whereas fallow land, with poorer conservation measures, is less resisting to soil erosion. Nevertheless, conservation measures, except terraced fields, greatly lose efficiency as the slope increases. For permanent cultivated land the threshold is 25 degrees, and for fallow land is 15 degrees. Obviously, conservation measures are not only important but they also can effect soil erosion quickly after the measures implemented in agriculture land use, so the conservation factor was considered in assessment formula:

$$Y = R\, C_5 (0.1\, X_1 + 0.6\, X_2 + 0.3\, X_3) \qquad ......(5)$$

where

Y is score for erosion intensity;
R is rainfall factor;
C_5 is conservation coefficient;
X_1 is soil and parent material;
X_2 is slope factor;
X_3 is vegetation coverage.

In (5), C_5 is defined by

$$C_5 = \text{Log}_{10} (X_5 + 1) \quad .....(6)$$

where X_5 is conservation measure factor.

5. MODEL IMPLEMENTATION

The implementation has two functions: 1) to produce a soil erosion map covering 3120 km^2 for the local government; and 2) to finish the research of computerized soil erosion mapping. The model implementation on a computer was undertaken on a 200 km^2 subarea, since the hardware platform used was a PC-386 which was unable to support large quantity data manipulation.

5.1 Manual Application

After the six factors were made into thematic maps, they were then converted to semi-transparent hard copies. We were able to evaluate the soil erosion intensity on these maps polygon by polygon. Finally, a total area with 3120 km^2 was mapped which was highly approved by the local governments.

5.2 Application in Raster Format

A total of 200 km^2 of the thematic maps were input into PC ERDAS 7.3. An accurate map of soil erosion was produced. However, the resulting map needed smoothing because the raster format modeling was based on pixel by pixel, which gave the map a "noisy" appearance.

5.3 Application in Vector Format

This application was carried out on PC ARC/INFO using vector format data. The researchers noticed that the evaluation must be based on the land use layer, because this model theoretically assumed that soil erosion mechanisms differ from land use. The output in this research was satisfactory, and the result is illustrated in Figure 6.

5.4 X-Window Package

For easier mapping, this model was incorporated into a small software which reads ERDAS .lan file and produces raster format data. This package was programmed at UNIX X-Window Toolkit Intrinsic level, so it can be loaded on any UNIX and LINUX system. Likewise, the resulting map needs to be "cleaned" since it is in raster format.

6. DISCUSSIONS AND CONCLUSIONS

RASEAM was proven to be a practical approach to soil erosion mapping suitable for use in rough terrain area. The designation of a ranking system for the six factors is simple and easy to operate, without requiring expensive time consuming experiments. It requires minimal field work to establish the factor ranking scheme and to implement the model, which is particularly suitable for remote sensing and GIS mapping activities.

RASEAM can be used in any rough area by modifying ranking tables for each factor. It will be not necessary to modify the modeling rationale, but only modify the ranking tables to address different problems. It will be easy and inexpensive to apply this approach in the other places.

RASEAM is a runoff focused soil erosion model, so it does not work well for wind erosion and gravity erosion issues. For runoff erosion types, it did not specify the terms of sheet erosion, rill erosion and gully erosion, but handled this problem through a slope grading design because the researchers assumed that soil erosion characteristics are relevant to slopes.

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8. REFERENCES

1. The Northwest Institute of China Academy of Science: "Comprehensive Report for Water and Soil Conservation in Yangtze River Reaches", Shaanxi Press of Science, Xi'an,1986.

2. Sichuan Hydro-Power Bureau Office for Soil and Water Conservation: "Comprehensive Report for Soil Erosion Survey via Remote Sensing in Sichuan Province", Sichuan Hydro-Power Bureau, Chengdu, 1988.

3. Tang Keli : "Soil Erosion Researches and Prospective", China Soil Utilization and Fertilization, China Soil Association, Beijing,1983.

4. China Hydro-Power Ministry Remote Sensing Center: "National Soil Erosion Mapping Operational Rules Using Satellite Remote Sensing Technology", China Hydro-Power Ministry Press, Beijing, 1984.

5. M. J. Kerkby and P. C. Morgan: "Soil Erosion", China Hydro-Power Ministry Press, Beijing, 1987.

6. Liangshan State Zoning Committee for Agriculture: "Liangshan State Water and Soil Loss", Liangshan State Government, Xichang,1987.

7. Song Daquan: "Manual of Soil Survey", Science Press, Beijing,1953.

8. Tian Xinyuan: "Sichuan Soil and Water Conservation", Achives of Sichuan Association for Soil and Water Conservation, Chengdu,1990.

9. Xia Fuchuan: "Soil and Water Loss Survey in the Upper Yongding River Reaches via MSS Date", Archives of National Conference for Remote Sensing III, Beijing,1983.

10. Xin Wen: "Sichuan County Economics for Fourty Years", Sichuan Press of Science, Chengdu,1989.

11. Pu Zhaohong: Experiments for Soil and Water Loss Mapping Using Satellite Imagery", Bulletin of Pedology, Nanjing, 1984.

12. Xiong Yi and Li Qinkui: "China Soil" (Second Edition), Science Press, Beijing,1990.

13. Lin Shan: "Experiment of Universal Soil Loss Equation in Mentogou Valley", Beijing University of Agriculture, 1985.

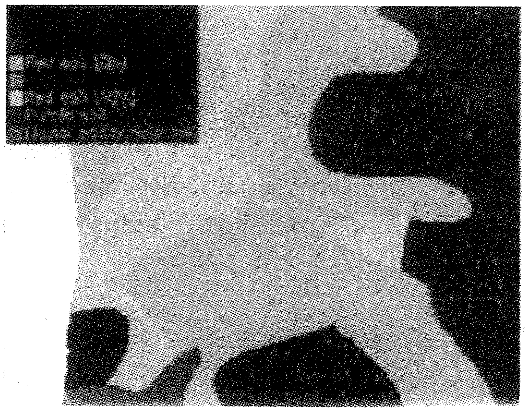

Figure 1.
Soil and Parenet Material

Figure 2.
Slope

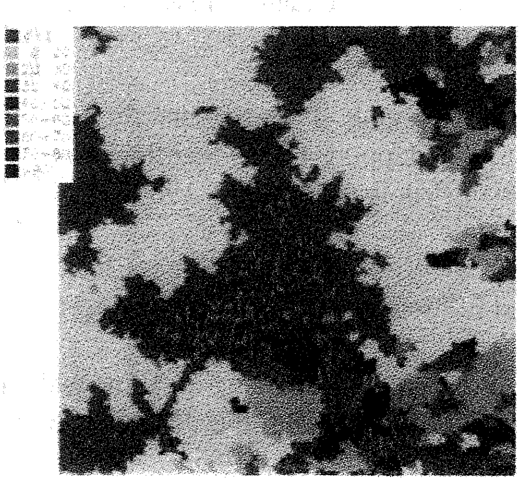

Figure 3.
Vegetation

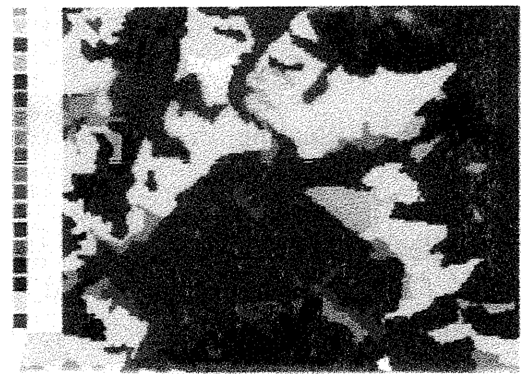

Figure 4.
Land Use

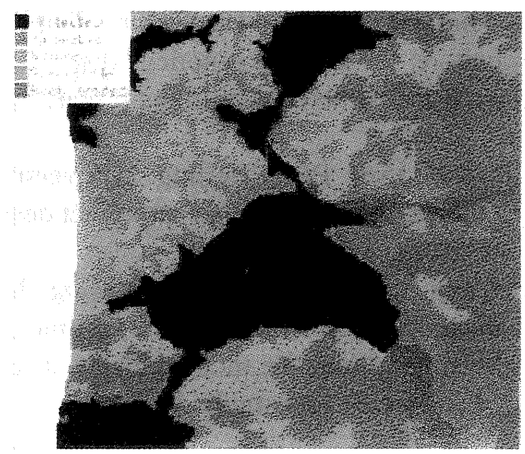

Figure 5.
Conservation Measure

Figure 6.
Map of Soil Erosion