QUANTITATIVE SOIL EROSION MAPPING AND CLASSIFICATION IN CHINA: A CASE STUDY USING GIS AND REMOTE SENSING TECHNIQUES FROM THE XICHANG AREA IN SOUTH WEST SICHUAN PROVINCE

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1.INTRODUCTION

Prior to the end of the 1970's soil erosion studies in China were conducted using ground truth and air photographs only. At the end of this period and 1980's MSS imagery had been imported into China and remote sensing techniques were developed. Maps at a scale of 1:100 000 were produced using this method for Shaanxi and Hebei provinces. In 1984 every province in China undertook soil erosion map compilation at 1:500 000 scale. In 1983 a soil erosion map in Gansu province was produced at 1:200 000 scale. All of these maps were compiled using visual interpretation techniques and the quality of the assessment depended on the skills and experience of the interpreter. As a result different erosion classes were attributed to the same variables both within and between provinces. In order to improve mapping quality more research on quantitative assessment more research has been undertaken which is described in this paper.

This research attempted to adopt a technique whereby the variables have a quantifiable attribute. In this way the final evaluation process becomes a more quantified process with the establishment of an erosion formula. The erosion assessment evaluation described in the following sections is derived from a formula utilising all the relevant variables rather than by purely visual interpretative analysis. As such it is considered a more reliable guide to the erosion condition of the area. Finally, this research makes automatic soil erosion assessment available when the remotely sensed imagery and relevant maps are loaded on Geographic Information System.

2. RESEARCH BACKGROUND

This research was conducted between 1987 and 1992 as part of the EEC financed project NA 86/26 Strengthening Soil and Water Conservation Measures in Sichuan Province. The aim is to complete a soil erosion map at a scale of 1:100 000 making use of SPOT, TM imagery and air photographs. This map should be suitable for use at the county planning level.

The research area is located in Xichang, southwest Sichuan province at longitude E 101° 46′ to 102° 31′ and latitude N 27° 32′ to 28° 11′. It covers an area of 3117.2 square kilometres lying between 1170 and 4182 meters elevation. The climate of the area is classified according to the Chinese National System as subtropical monsoon in type. Annual rainfall is about 980mm mainly concentrate in the June to September period.

The geology of the area is complex with sedimentary, igneous and metamorphic rocks often intensely folded, subject to considerable tectonic movements and metamorphism and they are highly erodible.

Within the generally permanently cultivated land the slopes are below 15 degrees. In areas of shifting cultivation slopes reach 25 degrees. Much of the area is covered by heavily overgrazed grassland. the steeply sloping landscape high rainfall and non rational land use practices mean that soil erosion occurs widely throughout the area. Sheet erosion, gully erosion, soil slides, occurs frequently. As a result this area exhibits many of the erosion features that are suitable for research purpose.

3. VARIABLE SELECTION

The aim of purpose of the current research is to provide a service for the local government. To be useful at this level of administration the scale of the map should be 1:100 000. The variable selected should be based on the requirements for the mapping at this scale, and can be directly derived from remotely sensed imagery and relevant maps or generated on GIS system.

This research has eliminated the use of the landform unit as a variable and substitute instead of the slope variable for the reason of the mapping at large scale.

The selection of the variables has been designed to meet the following criteria:

1) detail compatible with mapping at 1:100 000 scale;
2) easily used in production and practice;
3) ability to reflect the tendency of erosion.

Based on the above principles the selected variables and the reasons for their selection are given as follows:

1) Soil and Rock type-- this factor clearly shows the soil type itself and also expresses the underlying influence of the rocks. Because the same rock can give rise to different soil types in different ecological environments the rock variable by itself is not a sufficient indicator of erosion.

2) Slope-- because slope is an objective variable and a reflection of the land it can affect the dynamic condition of erosion.

3) Vegetation-- it is expressed as the degree of land that is protected by vegetation.

4) Land use type-- can strongly affect the soil erosion intensity.

5) Soil and Water Conservation Measures Types-- can reflect the future tendency of erosion.

6) Rainfall-- is a dynamic condition of erosion and should be included in the evaluation. However, rainfall index data is not available for widely distributed points in the research area and the information that is available has been placed in a zoning context as described in the following text. The rainfall factor is not included as a variable on the map polygons.

For the selected six variables 5 are put on

the map as shown in Table 1, and the variable X_5 has been included as an extra variable as a direct result of our research work.

Table 1.

Y_1	Y_2	X_1	X_2	X_3	X_4	X_5
Intensity of erosion	Rate class	Soil/Rock type	Slope degree	Vegetation cover (%)	Land use	Soil cons. measures

The information in table 1 is derived from remotely sensed imagery and other maps. This detailed information guarantees the necessary detail which the large scale of maps needed and guarantees the productive and practical use of the map.

4. TECHNICAL PROBLEMS

The evaluation process is complex since as many as 6 variables are used and the erosion is also graded into 6 classed. It is apparent that a great deal of field data is needed to establish a proper classification system and evaluation system. Nevertheless accessibility in this area is difficult, field data is therefore difficult and expensive to obtain in order to establish a proper classification system for adequate ranking and evaluation. It is hard to impossible to obtain 100's sample sites what we have obtained are only 70 sample points of which only 50 sample points can be accurately used for the soil erosion evaluation. It is extremely difficult to set up a proper and accurate evaluation system using only 50 sets of data. In addition because the data intensity is low any mathematical or statistical analysis involved is mot accurate and there is insufficient data for modelling.

The application of this research is how to use this low intensity data to establish an evaluation system. In many ways it is advantageous to develop a system on small number of sample sites. The high cost of collecting field data and the time involved requires the development of low cost system of evaluation which is suitable for conditions in China and can be used by other workers in the similar field. The second difficult is to establish quantitative relationship for the assessment of the results and the variable so that the assessment can be presented in a quantified form.

Table 1 can be used as a note of the classed occurring on the map polygons. It is also a list of the variables and their assessment results.

5. CLASSIFICATION SYSTEM

First let us outline a few of the basic assumptions.

Rainfall information in the research area has been divided in 4 regions (shown in figure 1).

1) Anning River valley this region to be set as standard rainfall amount (980 mm) and the rainfall coefficient is 1.0.

2) Xiaoliang Mountain, rainfall corresponds to 1350 mm and the rainfall coefficient is 1.4.

3) Maoniu mountain, rainfall is 1200mm and the rainfall coefficient is 1.1.

4) Yalong hot and dry valley, 880mm rainfall, coefficient 0.9.

Soil erosion intensities are graded in Table 2 according to the standards set by the Yangste River Authority in its upper reaches.

Table 2

GRADE	DESCRIIPTION	EROSION RATE Ton/sq.km/yr	DEPTH OF SOIL LOSS (mm/sq.km/yr)
1	None	<500	---
2	Slight	500 - 2500	< 1.9
3	Moderate	2500 - 5000	1.9 - 2.7
4	Strong	5000 - 8000	2.7 - 5.9
5	Very Strong	8000 - 13500	5.9 - 10
6	Severe	> 13500	> 10

Source: Yangste River Authority

Soil erosion rate classes are graded into 5 shown in Table 3.

Table 3.

GRADE	DESCRIPTION	PERIOD BEFORE SOIL LOST YEARS
1	No danger	> 1000
2	Relative danger	100 - 1000
3	Dangerous	20 - 100
4	Very dangerous	< 20
5	Mined	All gone

Source: Yangste River Authority

The details of classification for soil and parent materials are shown in Table 4.

Table 4

Map Unit	Description of Soils	Geology
1	paddy soils, brown soils, sub alpine meadow soils, mountain brush and meadow soils	Quaternary Metamorphic rocks
2	Yellow brown soils	Igneous and metamorphic rocks
3	Red forest soils	Granites and limestones
4	Red forest soils	Quaternary
5	Red forest soils	Triassic
6	Red forest soils	New Tertiary
7	Purple soils	Purple shale and sandstones
8	Entisols	Colluvial tills mud rock flows, slides

Table 5 shows the slope classes.

Table 5

Map Unit	Slope Class	description
1	< 5	Gentle
2	6 - 12	12 limit for gully erosion
3	13 - 25	Steep
4	26 - 35	Very steep
5	> 35	Extreme steep

Vegetation classes are made in considering for both vegetation type and vegetation coverage degree as:

Table 6

Map Unit	Type of Vegetation	Percent Cover
1	Forest, brushland and meadow grassland	> 90
2	Forest, brushland and meadow	60 - 90
2	Sparse forest and grassland	70 - 90
3	Sparse forest, brushland and meadowland	40 - 60
3	Sparse forest brushland and grassland	50 - 70
4	Sparse brushland and meadow	15 - 40
4	Sparse grassland	25 - 50
5	Grassland and brushland	< 15
5	Various grassland and bare soil	< 25

Land use type classes is shown in Table 7.

Table 7

Map Unit	Land Use Type	Characteristics
1	Rice fields, plains and dryland	Extensive cultivation
2	Upland dryland, fallow land, orchards	Cultivated land
3	Forest, Mountain brushland, grassland	Natural vegetation
4	Grassland, dry & hot valley grassland, bare soil	Natural vegetation

Conservation measures are classed as:

Table 8

Map unit	Type	Description
1	Protected	> 90% vegetation cover, terraced fields, controlled land use, protected areas.
2	Innovation	Biological and engineering control measures limited
3	natural	Balanced or harmonised land use practices
4	Susceptible	Forest removal on steep slopes for cultivation, overgrazing of pastures and excess logging
5	Badly eroded	Landscape destruction, "soil forest" badlands

Based on the above classification systems each polygon on the map can initially be noted by five digits to express the land information. These 5 variables are then used to produce the erosion rate and grade. Finally the full 7 digits are used to note the characteristics of each polygon.

On the basis of the analysis of the field data we have established relationships between these variables and soil erosion in the research area:

When rainfall condition is the same the variable of slope and vegetation present a relationship of growth and decline. Vegetation is the first variable, slope is second. Therefore vegetation is the most important factor. Relationship is as follows:

> When vegetation is very high no matter how steep the slope is or what type of soil or rock no obvious soil erosion occurs.
>
> When vegetation coverage is reduced the effect of slope increases.
>
> when vegetation coverage is low the slope variable becomes of primary importance.

The relationship of growth and decline for the two variables has been used as a guideline for the design of the assessment system.

The system consists of two sub systems:

a) a system for non cultivated land; and
b) a system for cultivated lands.

1) Non Cultivated Lands

This type of land usually has natural vegetation cover. It also includes artificial forest and grassland. But in the initial stage of artificial vegetation development (i.e. trees at seedling stage or sparse, newly sown grass cover) such soil and water conservation measures do not affect soil erosion status. It is therefore keeps its original intensity without any changes. That is why for such vegetation types we do not let soil and conservation measures come into the assessment. However, as soon as the seedlings or grass develops it should begin to have a soil and water conservation influence. Therefore they should be noted on the map units or polygons, to indicate their possible future influence on soil erosion. Such a measure will present a conservation effect in the future years.

We have assumed that there is a fair constant relationship between vegetation cover and soil erosion which occurs irrespective of other variables, in particular of slopes. However, there is no such a constant relationship for land use as a comprehensive variable it affects all the other variables and so has been assigned a land use coefficient c_4. This is defined in formula (2).

The variables involved in this assessment are:

R: rainfall coefficient;
C_4: land use coefficient;
X_1: soil and rock type class;
X_2: slope class;
X_3: vegetation class.

The formula is:

$$Y_1=R\cdot C_4\cdot (W_1\ X_1 + W_2\ X_2 + W_3\ X_3)\ ....(1)$$

Where:

$$C_4 = 1/[1 + 1/(X_4-2)]\ ....(2)$$

X_4 is land use type.

$$\begin{cases} W_1 = 0.10 \\ W_2 + W_3 = 0.90 \end{cases} ....(3)$$

Before the formula (1) and (3) are applied, a comparison between X_2 and X_3 should be made first. Whichever has the lower points is regarded as most important and the first controlling variable. For example when vegetation coverage is high i.e. $X_3<X_2$ then weights are determined by:

$$\begin{cases} W_3 = 1 - 0.04\ X_3\ X_4 \\ W_2 = 0.9 - W_3 \end{cases} ....(4)$$

If vegetation index is low when $X_3>X_2$ then:

$$\begin{cases} W_2 = 0.04\ X_2\ X_4 \\ W_3 = 0.9 - W_2 \end{cases} ....(5)$$

Formula (4) and (5) really simulate the relationship of growth and decline of vegetation and slope. For c_4, it is possible to construct a table for convenience, but in computer this analytical expression for C_4 is more useful.

For instance in polygon A illustrated in Figure 1 where:

R = 1.0
X_1 = 2 (yellow brown soil)
X_2 = 5 (slope 40 degree)
X_3 = 2 (vegetation is 75 percentage)
X_4 = 4 (sparse forest land)
X_5 = 3 (natural conservation type)

Where soil layer depth is 400mm.

The amount of erosion is calculated as follows:

Since $X_3<X_2$, then follow formula (4)

$W_3 = 1 - 0.04\ X_2\ X_4 = 0.68$
$W_2 = 0.9 - 0.68 = 0.22$

The characteristics of the polygon according to formula (1) are:

$Y_1=1.0 \times 0.89 \times (0.1X_1 + 0.22X_2 + 0.68X_3) = 2.94$

Y_1 whose grade can be classed by table 9.

Table 9

Grade of erosion	Y_1 values Non Cultivated	Cultivated
1	< 0.84	< 0.82
2	0.84 - 1.63	0.82 - 1.36
3	1.64 - 3.05	1.37 - 2.40
4	3.06 - 3.45	2.41 - 3.10
5	3.46 - 4.14	3.11 - 3.60
6	> 4.14	> 3.60

then placed in the erosion rate class 2 relatively dangerous from Table 3. Because the existing soil and water conservation measures are a natural type we can foresee that this lands soil erosion will be kept as current status in future years.

The polygon can be noted by 7 digits as follows:

3 2 2 5 2 4 3

The polygon can directly used to identify the measures required in the planning exercise.

The logical process mentioned can be undertaken in GIS system, which can lead to a possibility of automatic evaluating and mapping for soil erosion.

b) For Cultivated Land

In the cultivated land there is almost continuous human activity so there is no growth and decline relationship between slope and vegetation so weights for assessment can be set. Soil and water conservation measures in cultivated land are usually engineering in type such as terrace fields, ditches, soil collection in silt ponds etc. Such measures can present soil conservation effects soon therefore conservation measures must participate in this assessment as the X_5 variable.

For permanent cultivated land because it has a relative complete terrace formation with bank and ditch and side ditch and the farmers do some work to increase the depth of the soil, maintain fertility and organic matter therefore its resistance to erodibilty is stronger than on the fallow land.

In Xichang the local agricultural authority and the authors regard permanent cultivated land on slope greater than 25 degree to show a decreasing influence of various conservation measures except only for terraced fields. In such areas simple soil conservation measures alone will be insufficient protection. For fallow land whose resistance is lower, then 15 degree slopes and above will be highly susceptible to erosion where there are no conservation measures.The investigations have shown that for the cultivated land the average cover in the rainy season is 80 percent while for the fallow land it is only 40 percent (owing to the weeds growth etc.).

the assessment formula:

$Y_1=R \cdot C_5 \cdot (0.1X_1 + 0.6X_2 + 0.3X_3)$ ....(6)

Where:

$C_5 = \mathrm{Log}_{10}\ (X_5 + 1)$ ....(7)

7. APPLICATION OF RESULTS

We have tested the sample points at 58 sites to check the assessment system. 57 points agree with the ground truth data. This proves that the system is coincident with actual observed erosion features occurring in the research areas. This quantified principle of the approach concerning the growth and decline factor have a much wider future of applications, especially in GIS system.

8. REFERENCES

N.W. Soil and Cons. Inst. of Nat. Acad. of Sc. 1986 Collection of Water Comprehensive investigation of Soil and Water Cons. in Yangste river reaches. Shaanxi Press.

Soil and Water Cons. Off. of Sichuan Hyd. Power Bureau 1988 Comprehensive report for soil loss survey using remote sensing in Sichuan Province.

Tang Ke Li, Jiang D. S., Shi D. M. 1983 Current research and future trends in research for soil erosion in "Rational utilisation & Fertilisation" Vol. 1. Nat. Soc. of Pedology

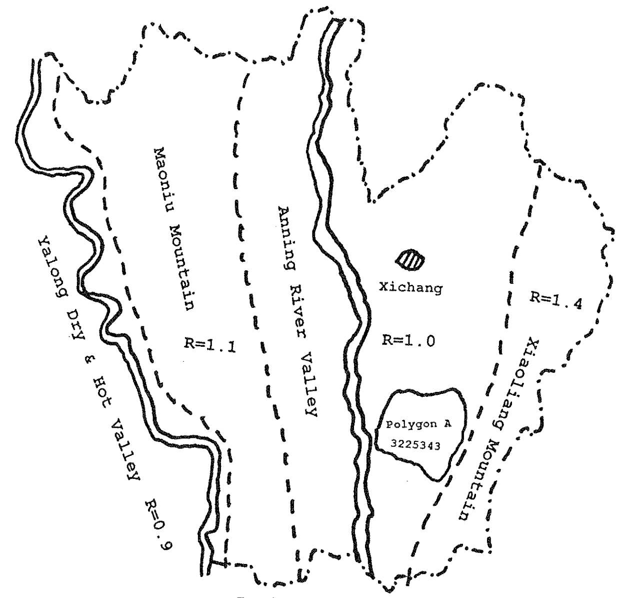
Song De Quan 1953 Booklet for soil investigation. Science Press

Nanjing Coll. Agric. & N.E. Coll. of Agric. 1981 Soil Survey and Mapping. Jiangsu Press of Science and Tech.

Shanxi Comm. of Agric. Zoning et al 1981 Landsat Image Visual Interpretation and its Mapping in Shanxi Province. Science Press.

Qi G. G. 1985 Methodology for soil erosion mapping in Gansu Province via satellite imagery. Soil Journ. 3.

Gao Q. J. Gao W. Y. 1984 Soil erosion mapping using MSS imagery. Soil and Water Cons. Journ. 5.



Zoning for Rainfall

Figure 1.