STUDY ON SOIL EROSION USING REMOTE SENSING TECHNIQUE IN THE LOESS PLATEAU OF THE NORTH SHAANXI PROVINCE

Chen Chuqun

Assistant Professor
Institute of Remote Sensing Application
Chinese Academy of Sciences, P.R.China

Abstract

This paper introduces the study on soil erosion in the Loess Plateau of the North Shaanxi province using remote sensing data in two parts. The first part introduces the manners, process and results of surveying and mapping the types and intensity of soil erosion using landsat TM images on the scale of 1:100 000. Through surveying and mapping, 7 intensity grades and 46 types of soil erosion are devided,and their spatial distribution characteristics have been found out. The second one introduces a new model of soil erosion for predicting the amount of water erosion in small watersheds using aerial photos. The model is set up on the base of the Grey System Theory and the data of many years in six typical watersheds. According to the principle of dynamics of soil erosion and the evolution features of motive force in the erosive process, 7 factors are elected, and their data are obtained from aerial photos on the scale of 1:10000 as far as possible. The model has concise form and good accuracy with only 7.48% mean relative error and can be used to estimate the intensity of water erosion types and to provide reference basis for the plan of water and soil conservation.

Key Words: Soil Erosion, Thematic Mapping, Remote Sensing, Predicting Model, Grey System.

1.INTRODUCTION

The Loess Plateau is located in the middle reaches of the Yellow River, which is one birthplace of China's ancient culture. The distribution of loess is deep (from dozens meters to hundreds meters), wide (430000 km^2.)and continuous. It is one of the area with the most serious soil erosion in the world, the erosive module in some areas may amount to 30000 tons / km^2 per year, which not only causes the reduction of land productivity, desertification of land, wastage of land and water resouces, the deterioration of the local ecological environment and decline of civilization, but also makes the lower reaches of the Yellow River silt up and become "super–ground river", and threaten seriously the security in the plain of North China. So it is the key of developing and harnessing the Yellow River to decrease the soil erosion and to make a good job of water and soil conservation.

Chinese goverment has been paying much attention to the environmental problem in the Loess Plateau. During the seventh five–year planning period (1985– 90), it became one part of the National Key Project of Science and Technology to survey the environment and the resources and to compile serial thematic maps using remote sensing in the Loess Plateau of the North Shaanxi province. The investigation reveals the situation of soil erosion, landuse, forest, grassland, land type and land resources, and provides scientific basis for regional development and management.

2. GENERAL SITUATION OF RESEACH REGION

2.1 Geomorphology

The reseach region is one of main erosion region of the Loess Plateau, located in the North Shaanxi province, including 15 counties (or cities), with the area of 31522 km^2, linked with the Maowusu Desert in the west and limited by the Yellow River in the east. Generally speaking, the topography slopes from west to east and from northwest to southeast. According to the features of landform, two geomorphologic subregions may be devided: the north wind–sand dune subregion and the south loess hilly and gullied subregion. In the former region the topography slopes gently, the dunes rise and fall smoothly, the wind erosion takes the dominant place. In the latter region the topography is cutted seriously, the hills rise and fall abruptly, the gullies distribute densely, and the water erosion takes the dominant place.

2.2 Climate

The climate of the region is belong to the semiarid continental monsoon climate in the warm temperate and the temperate zone. The mean rainfall per year varies from 350 mm in the northwest to 590 mm in the southeast, most of the rainfall occurs in summer and in storm form, which is one of reason of serious soil erosion.

2.3 Plant and Soil

The zonal plant of the region is steppe, to the north of the Great Wall is wind–sand arid steppe, and to the south is forest steppe. To the south of Yan'an city there are some forests. According to the soil zonality, the soil is belong to chestnut soil sequence or chernozem sequence. Because of destruction of plants, decrease of humus accumulation, calcification, saltnization, desertification and soil erosion, the zonal soil were destroyed, some infancy soils appear, which include loess–soil, sandy loess and wind–sand soil.

3.SURVEYING AND MAPPING FOR SOIL EROSION TYPES AND INTENSITY

3.1 Principle

It is carried out on the basis of studying the factors of soil erosion to survey and to map the soil erosion types and intensity in the vast region using landsat TM images. According to the effective degree of the erosive factors, the types and intensity of soil erosion can be defined from the types of the factors' combination, which can be interpreted from TM images, furthermore, the map of types and intensity of soil erosion can be compiled.

3.2 Election of the Erosive Factors

The serious soil erosion in the Loess Plateau is the results of interaction of varied natural factors with human factors, however the factors is intricate and as many as dozens, including mainly: rain, geomorphology, plant, contents of ground material, human activities and so on. It is very difficult to interpret directly the rain and human factors from TM images. Thinking the interpretability of TM images, we take the following four factors: the geomorphology, devided into hills, loess tableland, loess ridge–shoulder, terrace, valley, dune; the ground slope, devided into plain (<3°), gentle–plain (3°–5°), gentler (5°–8°), gentle (8°–15°), abrupt (15°–25°), abrupter (25°–35°), extremely abrupt (>35°); the rate of plant cover, devided into extremely high (>90%), high (90–70%), mid–high (70–50%), middle (50–30%), low (30–10%), extremely low (<10%); and the contents of ground material, devided into rock, soil–rock, soil (including loess), sand, as the basis of deviding soil erosion types and intensity, and set up classification system of soil erosion.

3.3 Classification System of Soil Erosion

Three–grade classification is used in the classification system. The first grades classification are devided, according to the erosive pattern and forces, into three: water erosion, gravitation–water erosion and wind erosion, on their base the second grades are devided into nine according to intensity of erosion, on the base of second grades the third grades are devided into 46 types according to the combinational characteristics of the factors' grades.

The Classification System for Investigation of Soil Erosion Types and Intensity Using Remote Sensing in the Loess Plateau of North Shaanxi Province

I.water erosion

1.feeble erosion (M < 1000t / km^2.a)

11.wide valley farming land type
12.terrace type
13.tableland type
14.extremely high cover type
15.extremely high cover type in soil–rock area
16.extremely high cover type in rock area
17.extremely high cover type in rock and soil–rock area

2.light erosion (M:1000–2500t / km^2.a)

21.loess ridge–shoulder farming land type with gentle–plain slope
22.loess ridge–shoulder type with high cover and gentle slope
23.middle cover type with gentle slope in soil–rock area
24.high cover type with abrupt slope in rock area
25.high cover type with abrupter slope in rock area
26.middle cover type with abrupter slope in rock area

3.middle erosion (M:2500–5000t / km^2.a)

31.loess ridge–shoulder farming land type with gentler slope
32.sandy loess ridge–shoulder farming land type with gentle–plain slope
33.middle cover type with gentle slope or high cover type with abrupt slope
34.low cover type with gentle slope in soil–rock area
35.low cover type with gentle slope in rock area
36.mid–high cover type with abrupter slope in rock area

4.intensive erosion (M:5000–8000t / km^2.a)

41.loess ridge–shoulder farming land type with gentle slope
42.sandy loess ridge–shoulder farming land type with gentler slope
43.middle cover type with abrupt slope
44.mid–high cover type with abrupter slope
45.middle cover type with abrupt slope in soil– rock area
46.middle cover type with abrupt slope in rock area

5.super intensive erosion (M:8000–15000t / km^2.a)

51.loess ridge–shoulder farming land type with abrupt slope
52.sandy loess ridge–shoulder farming land type with gentle slope
53.middle cover type with abrupter slope
54.low cover type with abrupt slope in rock area
55.middle cover type with abrupter slope in soil–rock area

6.strong erosion (M:15000–25000t / km^2.a)

61.loess ridge–shoulder farming land type with abrupter slope
62.low cover type with abrupter slope in loess area
63.low cover type with abrupter slope in rock area
64.middle cover type with extremely abrupt slope in loess area

7.extremely strong erosion (M > 25000t / km^2.a)

71.low cover type with abrupter slope in sandy loess area
72.low cover type with extremely abrupt slope in loess area
73.extremely low cover type with extremely abrupt slope in soil–rock or rock area

II.gravitation–water erosion

8.landslip erosion

81.middle erosion type with gentle slope
82.intensive erosion type with abrupt slope

III.wind erosion

9.wind–sand erosion

91.light erosion type in valley sand land
92.light erosion type in fixed dunes
93.middle erosion type in semifixed dunes
94.intensive erosion type in bare plain sand land
95.intensive erosion type in loess hills covered by sand
96.super–intensive erosion type in fluid dunes
97.strong erosion type in bare fluid dunes

3.4 The Manners and Process of Investigation

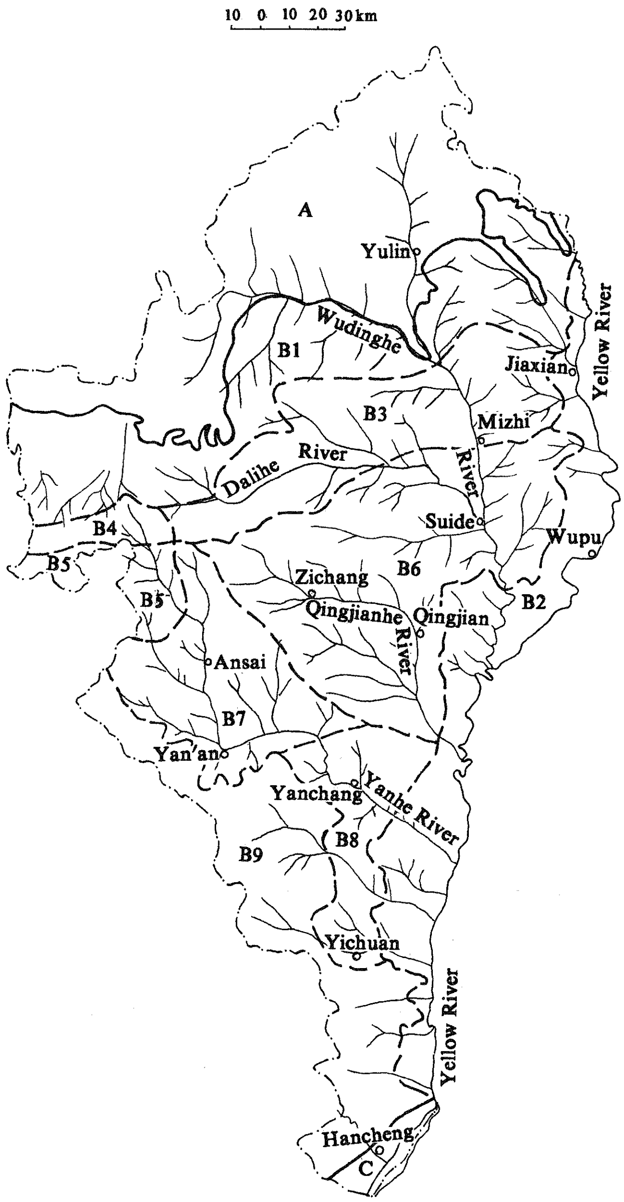
3.4.1 Information Resources and Interpretation Keys: The landsat TM rectificated false colour composite images on the scale of 1:100 000 are used as basic information resource, and the images such as "Jianbing–1" satellite black–white images (1:100 000), false colour infrared aerial photos (in 1988), and black–white aerial photos (in 1950s and 1970s) are used as assistant information resources. Through field survey, the interpretation keys and the grade criterions of erosive factors are set up.

3.4.2 Mapping Unit and Classification System: According to the requirement of surveying and mapping, and the interpretability of TM images, the minimal map spot is 2mm * 2mm. The classification system showed above is set up on the base of features of erosive factors and TM images.

3.4.3 Geographic Base Map: In order to compile directly the soil erosion map on the TM images and to coordinate it with other thematic maps, the geographic base map is compiled according to the topographic map on the scale of 1:100 000 using polyester cellophane paper.

3.4.4 Interpretation and Compilation: The geographic base map is put on TM images for interpreing directly the images and

Fig.1. Map of Regionalization of Soil Erosion Types and Intensity



A. wind–sand dune area with middle erosion.

B. loess hilly and gullied area.

B1 sand–covered loess ridge area with super intensive erosion

B2 soil–rock hills area in Yellow River gorge with strong erosion

B3 snady loess ridge–shoulder area with strong erosion

B4 sandy loess ridge and low mountain area with strong erosion

B5 loess ridge and low mountain area with extremely strong erosion

B6 loess ridge–hills area with strong erosion

B7 loess ridge–shoulder area with super intensive erosion

B8 remained tableland and ridge area with intensive erosion

B9 soil–rock ridge–shoulder hills area covered by forest with light erosion

C. tableland terrace area with middle erosion

compiling soil erosion map according to classification system.

3.4.5 Coordination and Verification: As one of the serial thematic maps, the compilational original of soil erosion must be coordinated with other thematic maps on contents and boundary of map spots, tested and verifyed in the field, and modifyed.

3.4.6 Other Works: including map fair drawing, colouring and area measurement.

3.5 The Regional Features of Soil Erosion

After surveying and mapping the types and intensity of soil erosion, the regional features of soil erosion were showed up. The wind erosion distributes to the northwest of the Great Wall, which erosive intensity is middle. The water erosion distributes in the rest area of the region, which can further be devided into 9 areas by the types and intensity of soil erosion (Fig.1). The gravitation–water erosion distributes disjointedly along some rivers in the water erosion area. The most intensive erosion is in the middle of the region, where there are lower plant cover rate, abrupter slope, more farming slope–land and higher population density than in the south and north area of the region.

4.THE MODEL OF SOIL EROSION FOR SMALL WATERSHEDS

The surveying and mapping for soil erosion have showed up the regional distribution of soil erosion types and intensity, and can provide reference basis for regionlization of water and soil conservation, however, the soil erosion intensity indicated by mapping is not accurate enough to be the basis of planning water and soil conservation for small watersheds, because rain factor, the extremely key factor, is not considered in mapping. In order to indicate the intensity of soil erosion more accurately and to serve the planning water and soil conservation, the model of soil erosion has been set up according to the data of six typical small watersheds in loess hilly and gullied area.

4.1 Election of Erosive Factors for Modelling

The erosive factors are elected on the base of the dynamics principles, including the motive force factors and the factors which effect the evolution and action way of the motive force. The runoff– producing rainfall (R) is elected as the motive force factor, the factors effecting motive force include follows: the contents of ground material showed by the coefficient of sand (diameter >0.05mm) to silt (diameter <0.005mm) in the loess (S), the topography factor of surface erosion showed by the ratio of surface area of watershed to its level projection area (F), the topography factor of gully erosion showed by gully density (L), the topography factor of gravitation erosion showed by cliff density (C), the human erossion factor showed by population density (P), the human anti–erosion factor showed by the ratio of harnessed area to the whole area of watershed (H). The data of all the factors are obtained from aerial photos on the scale of 1:10 000, except the runoff–producing rainfall, the coefficient of sand to silt and the population density, which are obtained from field investigation (table 1.).

The gully erosion, gravitation erosion and surface erosion are separately the results of the runoff–producing rainfall interacting with gully, cliff and loess surface under the effection of ground material. So we take the products of that gully density, cliff density and ratio of surface area to whole area of watershed time separately the

Table 1. The Basic Data of Erosive Factors in Typical Watersheds

erosive factors	Shangbian gou gully (1)	Shangbian gou gully (2)	Dabian gou gully	Xiaobian gou gully	Jiuyuan gou gully	Wangmao gou gully	Peijiamao gully (1)	Peijiamao gully (2)
erosive modulus (Ms) (t/km^2.)	8051.4	14009.1	6294.5	7884.9	16906.0	16957.0	14921.0	3867.0
runoff-producing rainfall (R) (mm)	326.8	494.8	249.4	257.2	223.0	205.0	223.1	61.1
gully density (L) (km/km^2)	34.32	34.32	27.44	33.31	33.83	30.33	32.15	32.15
cliff density (C) (km/km^2)	10.0	10.0	10.27	13.47	12.58	15.02	13.53	13.53
ratio of surface area to level projection area of watershed (F)	1.2195	1.2195	1.1445	1.2450	1.2725	1.313	1.268	1.268
population density (P) (person / km^2)	37.0	29.3	120.9	62.7	124.2	106.0	114.6	130.7
ratio of harnessed area to whole area (H) (%)	27.19	8.5	23.6	0.05	32.4	25.0	5.0	16.79
ratio of sand to silt in loess (S)	1.008	1.008	1.008	1.008	2.6455	2.6455	2.6455	2.6455
period of data	1982–86	1981	1959–66	1961–67	1954–1986	1961–63	1960–69	1986

runoff–producing rainfall and ratio of sand to silt in loess, i.e. RSL, RSC, RSF, as the factors of gully erosion, gravitation erosion and surface erosion.

4.2 Model of Soil Erosion for Small Watersheds

The Grey System Theory is used in modelling. Grey System is a middle system between the white one, in which all information are known, and the black one, in which any information is not known. Through analysis on the Grey Connected Degree of the erosive factors to the erosive modulus, it is showed out that RSF, RSL and RSC are main factors of soil erosion, P and H are secondary factors, then the Grey Connected Degree Model of soil erosion is set up, and on the principle of the least square method, the GM(0,5) Model is set up. On the base of the two models the integrated model of water erosion is set up as follows:

$$\overline{Ms} = RS((0.29623L+0.40337C+10.1478F)-0.283H)-151$$

where $\overline{Ms}$——the estimated erosive modulus ($t/km^2.a$)

4.3 Verification and Application of Model

Comparing the estimated erosive modulus with the actual erosive modulus of watersheds, the relative errors are calculated (table 2). The maximum of relative error is 12.38%, the mean relative error is only 7.48%. The estimated erosive modulus is accurate enough to make plan of water and soil conservation for watersheds.

The model is concise in form. It can be used to forecast the erosive amount of watershed and to estimate the quantity of three types (surface erosion, gully erosion and gravitation erosion) in the region, moreover, to provide a reference basis for defining the manners of controlling soil erosion. In the plot watersheds, the amount of surface erosion is the strongest (46.8%), the gully erosion has middle quantity (35.1%), and the gravitation erosion has the least one (18.1%).

5. CONCLUSION AND DISCUSSION

It is a rapid and economical way to survey and map the types and intensity of soil erosion using remote sensing technique in the Loess Plateau where there are varied topography and difficult traffic. It reveals the distribution characteristics of soil erosion and provides a basic data for regionalization of water and soil conservation and environment management.

According to the model the surface erosion takes the first place, taking up nearly one half of total erosion. It is important to control the surface erosion through increasing the plant cover rate.

From surveying, mapping and modelling, it is found that the main erosive factors are natural factors, such as rain factor, geomorphic or topographic factors and the contents of ground material, which can't be changed greatly in short period, so it is not possible to decrease greatly the soil erosion in the Loess Plateau in today's situations. We have long way to go in water and soil conservation and environment management.

Table 2. Verification of the Estimated Erosive Modulus

plot	Shang biangou gully (1)	Shang biangou gully (2)	Yangjia gou gully	Dabian gou gully	Xiao biangou gully	Jiuyuan gou gully	Wang maogou gully	Peijia mao gully (1)	Peijia mao gully (2)	average
the observed modulus of soil erosion ($t/km^2.a$)	8051.4	14009.1	6766.7	6294.5	7884.9	16906.0	16957.0	14921.0	3867.0	
the estimated modulus of soil erosion ($t/km^2.a$)	8595.6	13101.4	6431.2	6038.4	7091.4	16363.7	15226.3	16284.2	4345.8	
relative error (%)	6.76	6.48	4.96	4.07	10.06	3.21	10.21	9.14	12.38	7.48

references

Lin Hengzhang et al. Remote sensing investigation of soil erosion types and intensity in the Loess Plateau of the North Shaanxi province. Science Press, China, 1991.

Jiang Yongqing et al. Analysis of TM images and soil erosion character in southeast area of the North Shaanxi province in the Loess Plateau. Science Press, China, 1991.

Chen Zhengyi. Study of remote sensing investigation and series mapping in the Loess Plateau of the North Shaanxi province. Science Press, China, 1991.

Chen Chuqun. Grey model of multiple factors of soil erosion and its application —taking the typical watersheds in the North Shaanxi as an example. Journal of Water and Soil Conservation, China, vol.5.No.1,1991.

Chen Chuqun. Analysis of effective factors of soil erosion in the Loess Hilly and Gullied Region using remote sensing. special issue of Remote Sensing Technology and Its Application, 1991.