Fully Automatic Mapping for Vegetation and Soil Erosion Monitoring Using Remote Sensing, Mathematic Modelling and GIS Techniques

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Abstract

Traditional mapping for vegetation and soil erosion monitoring was usually done by visual airphoto or image interpretation or by computer-aided classification and interpretation. These methods are time-consuming and less accurate. Here a new method is presented, which only uses landsat TM images, mathematic models and GIS techniques without using of any visual interpretation and computer-aided mapping. This research also designed and experimented on a new atmospheric correction method for vegetation index calculation. This method depends upon one or few correct reference values, which were extracted from TM image itself or derived from ordinary geographic statistics. For example, by TM images classification or dynamic color composition, the average vegetation coverage value for a study area (only one value for one scene of image) can be obtained, with which the due average vegetation index value can be deduced. Continually, the due correct parameters for atmospheric correction can be obtained. Using these correction parameters, the correct vegetation index values and maps (all pixels have their values) was calculated and generated. By mathematic models, the vegetation coverage maps and vegetation coverage grades maps were calculated and generated. Thereupon the vegetation change monitoring was realized. By vegetation coverage grades maps and slope grades map from DTM, the soil erosion grades maps were calculated and produced and the dynamic soil erosion monitoring was also realized.

Key words: atmospheric correction, dynamic monitoring, automatic mapping, soil erosion

Introduction

Vegetation and soil erosion monitoring was traditionally conducted by visual airphoto interpretation, satellite image interpretation or digital image classification plus visual interpretation (computer-aided mapping).

These methods are very time-consuming and their results are not accurate enough.

A new method was designed and tested, which is composed of generating digital terrain model from topographic maps and calculating vegetation index from TM images.

But the vegetation indices computed from original TM images of different years are seriously distorted by atmospheric affects, so the results are far from the objective reality and absolutely inacceptable.

Correct vegetation index calculation needs atmospheric correction. However, more accurate atmospheric correction methods demand so-called synchronous meteological parameters, which are hardly obtainable to ordinary users. Moreover, of these correction methods, as Paul M. Mather indicated, “none is universally applicable”(P.M.Mather, 1992).

Same simple and easy methods for atmospheric correction such as using minimum values, water body values and mountain shadow values, were also tried. These methods were proved having effects to a certain extent. Nevertheless, the results of these methods are still inaccurate and also far from the actual situations. They cannot be adopted yet.

Through long time and numerous experiments we found out a new and practical method to correct atmospheric effects for vegetation index calculation. Its correction accuracy is acceptable.

This method depends upon one or few correct reference values, which were extracted from TM image itself or derived from ordinary geographic statistics. Taking these reference values as starting points and simultaneously establishing a series of mathematic models, the due and correct parameters for atmospheric correction can be deduced. And then by using the correction parameters, the original TM images can be atmospherically corrected and the more correct vegetation indices and their maps will be calculated and generated. Proceeding to the next step, using the vegetation index maps and related mathematic models, the vegetation coverage maps and the vegetation coverage grades maps can be calculated and generated. So the vegetation change monitoring was realized. Then, on the basis of the resulted vegetation coverage grades maps and the slope grades map derived from the digital terrain model, the soil erosion grades maps were calculated and generated. So the soil erosion charge monitoring was also realized.

This method completely abandoned the traditional visual interpretation of airphotos, images or image processed maps and wholly realized the automatic mapping of vegetation and soil erosion monitoring by only using remote sensing image processing, mathematic modeling and geographic information system techniques.

This article briefly presents the research results.

Methodology

One or few correct reference values are needed for deducing correct atmospheric correction parameters.

These values may derive from ordinary geographic statistics. For example, some soil erosion area values for a region smaller or larger than the study area might be used to deduce the averaged soil erosion area values for the study area.

From the latter the due correct vegetation coverage values or vegetation index values for the study area can be reckoned by using mathematic models and simulation calculations. And then the correct atmospheric correction parameters will be determined. This method proves successful and applicable. But here is no enough room to talk it more.

The reference values can also be derived from TM image itself. For example, the average vegetation coverage value $\overline{Vc}$ for a study area is just one of them.

$\overline{Vc}$ values can be acquired through supervised or unsupervised classification of the images. The classified classes have different gray level curves. By a model describing the curves' characteristics D_0=f (D_i) (i = 2, 3, 4, 5), the vegetation classes and the non-vegetation classes can be discriminated between. Herewith the average vegetation coverage values are determined.

Besides, our research also indicated that the dynamic color composition technique (Computer Department, ITC,1993) could be used too to determine the average vegetation coverage values. Because we found that the average of the gray level (color counts) values $\overline{G}$ of this kind of composed image is proportional to the average of the vegetation coverage values $\overline{Vc}$, i.e., $\overline{Vc} = k\overline{G}$. k is a constant.

By research on some measured data and by conducting simulation calculations, some relationships between the vegetation coverage Vc values and the vegetation index V values were established, for example, $Vc = f(V)$ and $\overline{V} = f(\overline{Vc})$.

Using $\overline{Vc}$ values and equation $\overline{V} = f(\overline{Vc})$, the due average vegetation index $\overline{V}$ values for the study area can be calculated. The $\overline{V}$ values might be looked upon as the due average vegetation index values after atmospheric correction.

Calculating the atmospherically uncorrected average vegetation index $\overline{V_1}$ values from the original images, Their differences with the corrected one $\overline{V}$ values, the $\Delta V = \overline{V} - \overline{V_1}$, were obtained.

Simulated calculation proved that the average atmospheric correction parameter C for TM3 and TM4 is a function of ΔV . That is $C = f(\Delta V)$.

Atmospheric influences upon TM3 and TM4 are different: TM3 is a visible band, which is influenced by atmospheric effects greater than TM4 which is a infrared band (J.D.Tarpley et al., 1984). The difference coefficients k_3 and k_4 for TM3 and TM4 were estimated by gray level variation rates of some ground features in TM3 and TM4 bands (for example, the mountain shadows in this research).

Supposing c_3 is the atmospheric correction value for TM3 and c_4 for TM4, then $c_3 = k_3C$, $c_4 = k_4C$.

Atmospherically corrected normalized vegetation index NVI (V) should have a form as below:

$$NVI = \frac{(TM4 - c_4) - (TM3 - c_3)}{(TM4 - c_4) + (TM3 - c_3)} \times A + B \tag{1}$$

In formula(1), the so-called gain factor A and offset factor B are used for converting the initially calculated NVI values (positive and negative real values) to 0～255 integer values. Here this problem could not be said more.

Formula(1) may be simplified to

$$NVI = \frac{(TM4 - TM3 + a)}{(TM4 + TM3 + b)} \times A + B \tag{2}$$

Comparing formula (1) with formula (2) may obtain:

$$a = c_3 - c_4 \tag{3}$$

$$b = -(c_3 + c_4) \tag{4}$$

Up to here the due atmospheric correction parameters c_3 and c_4 or a and b for vegetation index calculation were obtained.

The $\overline{V}c$, $\overline{V}$, $\overline{V}_1$, ΔV, or C for deducing the atmospheric correction parameters all is only one value for one scene of image. So it is easier to be acquired.

Now we already have the correction parameters a and b values. Using them the atmospherically corrected vegetation index maps (all pixels have their values) will be calculated and generated from the original TM3 and TM4 images. And then based on the vegetation index maps and using already established mathematic models, the vegetation coverage maps and, furthermore, the vegetation coverage grades maps will be calculated and generated. Proceeding to next step, on the basis of the resulted vegetation coverage grades maps and the slope grades map derived from the digital terrain model (all pixels have their values), the soil erosion grades maps will be calculated and generated.

All the above processes can be computerized. Hence, the fully automatic mapping for vegetation and soil erosion monitoring was realized.

The automatic work flowcart is shown as figure 1.

Some parameters and mathematic models needed in calculation processes are listed in table 1.

Table 1 Some parameters and mathematic models for calculating vegetation index, vegetation coverage, soil erosion grades and generating various maps

A=250 B=38 K_c=0.680 k_e=0.180 K_3=1.1394 K_4=0.8606
D_o=-0.45760 D_2+1.28129 D_3-1.06774 D_4+0.195271 D_5 (D_o<-10.80:vegetation classes)
$\overline{V}$ =66.23460+0.722244 $\overline{V}c$ +0.011944 $\overline{V}_c^2$
Vc =-129.2627+1.80188 V_2-0.00340343 V_2^2
$a=c_3-c_4$ $b=-(c_3+c_4)$ V_{2w}=34.02 V_{2b}=78.51 V_{2v}=206.49

In Fig. 1, V_2 is the atmospherically uncorrected vegetation index computed from a scene of reference image by which the equation $V_c=f(V_2)$ was established. V and V_1 are respectively the atmospherically corrected and uncorrected vegetation indices computed from a scene of image used for dynamic monitoring.

Because in Fig. 1, $V_2=f(V_1)$ is dependent upon the images used for monitoring, it is needed in the software execution process to interactively input the V_{1w}, V_{1b} and V_{1v}, which are the vegetation index V_1 values respectively for clear water, barest land and densest vegetation.

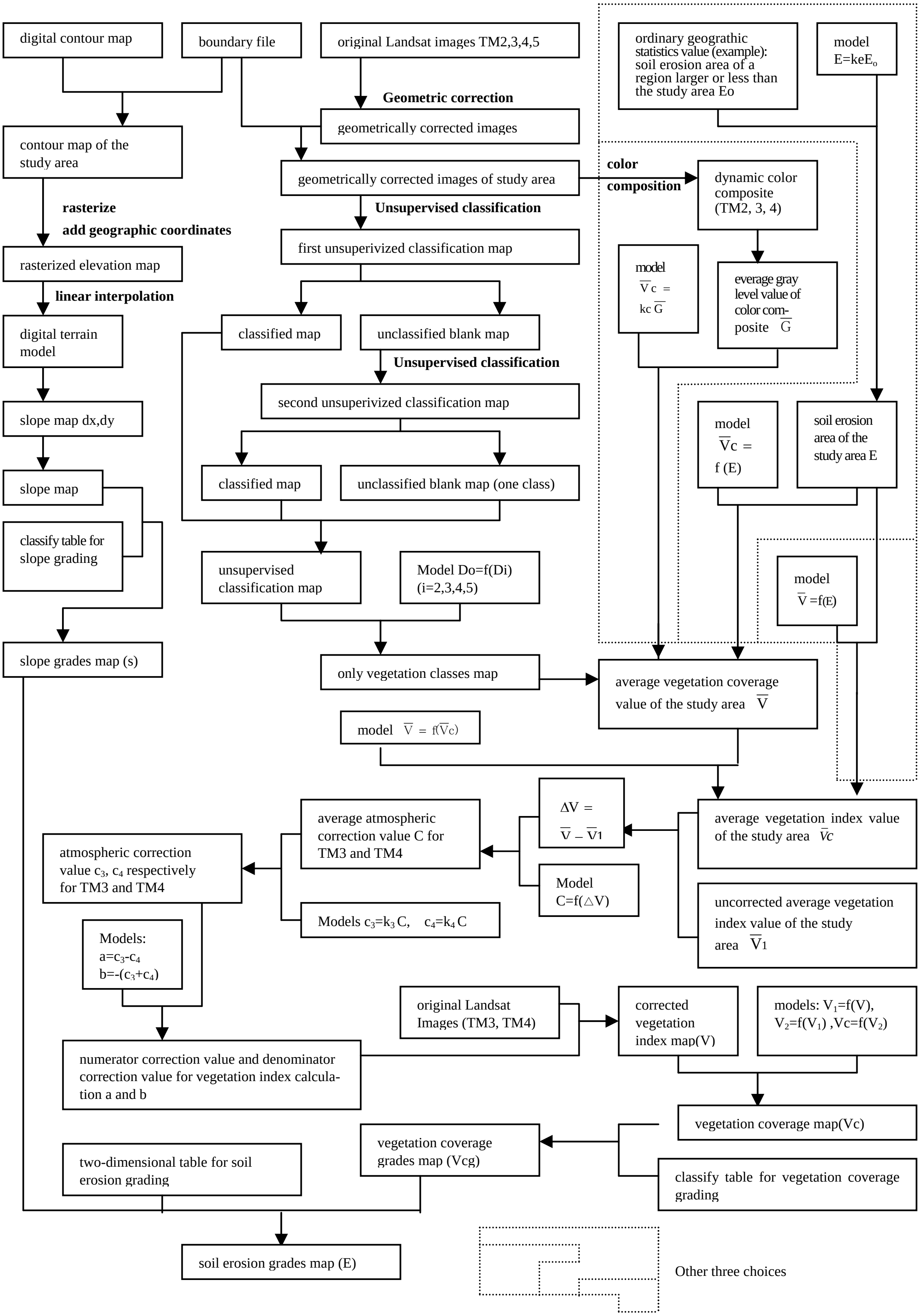

Fig. 1 Work flowcart of fully automatic mapping for vegetation and soil erosion monitoring

Correspondingly, the V_{2w}, V_{2b} and V_{2v}, which are the vegetation index V_2 values respectively for clear water, barest land and densest vegetation, were already stored in the software. Using the V_{1w}, V_{1b}, V_{1v} and V_{2w}, V_{2b}, V_{2v} values, the regression equations V_2=f(V_1) was established. This equation is a linear one.

Similarly, using the software to extract a number of V_1 and V values from predesignated positions in images for monitoring, the regression equation V_1=f(V) can also be established. This equation is also a linear equation.

The equation V_c=f(V_2) describes the relationship between some measured vegetation coverage V_c values and corresponding atmospherically uncorrected vegetation index V_2 values computed from the reference image. This equation is a second order polynomial equation and already stored in the software.

The $\overline{V}$, $\overline{V}_1$ and $\Delta V = \overline{V} - \overline{V}_1$ in Fig.1 are also calculated from images for monitoring. Executing the simulation calculations' software and simultaneously using ΔV , the $C = f(\Delta V)$ can be formulated. $C = f(\Delta V)$ is also a second order polynomial equation.

Besides all the above stated, it is necessary to get some works prepared before starting the software: (1) digitizing contours of the topographic maps for the study area; (2) digitizing the boundary line of the study area; (3) choosing ground control points and recording their geographic coordinates and finding and recording the corresponding image line and sample coordinates for geometric correction.

Results

The study area is situated in Lianshui basin, which belongs to Ganjiang River, a tributary of Yangtze River in China. Its area equals to 579.26 km^2. The region is in the conditions of humid mesosubtropic zone and of low-mountain and undulating hills. 90% of the agricultural land is composed of paddy fields. And the sloping upland is very few. Natural vegetation has been seriously destroyed and the secondary vegetation includes forest of masson pine, shrubs and grasses.

The basin is precisely the study area. The basin boundary and contour lines on the topographic maps were digitized. The required digital terrain model, slope map and slope grades map were calculated and generated.

The used landsat images consist of TM2, TM3, TM4 and TM5 bands of 1987, 1995 and 1996 years. For avoiding season differences' disturbance, all the images were chosen in the month of December.

Among these images the TM2, 3, 4 and 5 were used for supervised or unsupervised classification; the TM2, 3 and 4 were used for dynamic color composition; and the TM3 and TM4 for vegetation index calculation.

The pixel size in all the image processing is stipulated to be 25m×25m. So the pixel number for the whole study area amounts to 926815.

A supervised classification was carried out for the images of 1995. And unsupervised classifications for the images of 1987 and 1996. All these classifications aimed to discriminate vegetation classes from non-vegetation classes. Using the model $D_0=F(D_i)$ to calculate D_0 values for each class (not for all pixels) and using the threshold value $D_o<-10.80$, the vegetation classes were picked out; and the average vegetation coverage $\overline{V}c$ values of the study area were determined for each year. It is 36.83%, 54.87% and 60.71% respectively for 1987, 1995 and 1996 (only one value for one scene of image).

An unsupervised classification was also conducted for the images of 1995. The average vegetation coverage value which was determined by these classified classes approaches very closely to that determined by the supervised classification. The difference between them is only 1.45 percentage points.

Dynamic color composites were also made using the images of 1987, 1995 and 1996 respectively. The average gray level (color count) values $\overline{G}$ of the composites for 1987, 1995 and 1996 are 54.24, 80.56 and 89.99 respectively.

By the model $\overline{V}_c = k_c\overline{G}$ (k_c=0.680), the average vegetation coverage $\overline{V}c$ values were obtained. They are 36.88%, 54.78% and 61.19% for the years of 1987, 1995 and 1996 respectively. The results are very near to those of the classification. In this research the classification results were used.

Using equation $\overline{V} = f(\overline{V}c)$, the due average vegetation index $\overline{V}$ values were obtained for the years of 1987, 1995 and 1996. They are 109.0363, 141.8241 and 154.1041 respectively (only one value for one scene of image).

Herewith the ΔV for the years were also obtained. They are 6.3563, 52.8441 and 49.4941.

By means of simulation calculations, the established equations of $C=f(\triangle V)$ are as follows:

$$C_{87}=-0.003132+0.276590(\triangle V_{87})-0.002746(\triangle V_{87})^2 \quad (r^2=0.9974) \tag{5}$$

$$C_{95}=0.667798+0.291114(\triangle V_{95})-0.001665(\triangle V_{95})^2 \quad (r^2=0.9704) \tag{6}$$

$$C_{96}=1.358823+0.231549(\triangle V_{96})-0.000800(\triangle V_{96})^2 \quad (r^2=0.9969) \tag{7}$$

As a result, $C_{87}=1.6440$, $C_{95}=11.4019$, $C_{96}=10.8594$.

According to the models $c_3=1.1394\,C$, $c_4=0.8606C$, the c_3 and c_4 for the years were figured out:

1987: $c_3=1.8732$ $c_4=1.4748$

1995: $c_3=12.9913$ $c_4=9.8215$

1996: $c_3=12.3732$ $c_4=9.3456$

According to $a=c_3-c_4$, $b=-(c_3+c_4)$, the a and b for the years are:

1987: a=0.4584 b=-3.2880

1995: a=3.1788 b=-22.8038

1996: a=3.0276 b=-21.7188

Using the a and b values for the different years and using the formula (2), the atmospherically corrected vegetation index V values were calculated from the original TM3 and TM4 images, and the corrected vegetation index maps were generated for these years. This time, all the pixels for the study area (926815) do have their values.

The average vegetation index $\overline{V}$ values were testingly calculated from all pixels and for each year, The resulted values are 109.10, 142.21 and 154.28 for 1987, 1995 and 1996 respectively. Now you can see that these values are exactly close to those estimated before by the average vegetation coverage values from the original images (Table 2).

Table 2 Average vegetation index $\overline{V}$ and average vegetation coverage $\overline{V}c$'s comparison between the all pixels averaged from the corrected images and the classification estimated form the original images

	Average vegetation index $\overline{V}$			Average vegetation coverage $\overline{V}c$		
	1987	1995	1996	1987	1995	1996
From the corrected images (all pixels averaged)	109.10	142.21	154.28	36.65%	55.18%	61.00%
from the original images (only one value)	109.04	141.82	154.10	36.83%	54.87%	60.71%
coincidence rate %	99.95	99.73	99.88	99.51	99.44	99.52

Choosing the corrected and the corresponding uncorrected vegetation index V and V_1 values from the 1995's image, the regression equation $V_1=f(V)$ was established below:

$$V_1=40.05551+0.581904V \quad (r=0.8229) \tag{8}$$

From the V_1 values' map the V_{1w}, V_{1b} and V_{1v} were extracted. Using them and the V_{2w}, V_{2b} and V_{2v} in Table 1, the regression equation $V_2=f(V_1)$ was obtaind as fallows:

$$V_2=-5.63117+1.210107V_1 \quad (r=0.9959) \tag{9}$$

Using equations (8), (9) and the $V_c=f(V_2)$ (Table 1), the vegetation coverage V_c values were calculated and the vegetation coverage maps for different years were generated. Similarly, all the pixels for the study area do have their values.

The average vegetation coverage $\overline{V}c$ values of the study area were also testingly calculated from all pixels and for each year. The resulted values are 36.65%, 55.18% and 61.00% for 1987, 1995 and 1996 respectively. They are also exactly close to those estimated before by classifications of the original images (Table 2).

Based on the vegetation coverage maps and a so-called "classify table" for vegetation coverage grading the vegetation coverage grades maps for the years were calculated and generated. Thereupon, the dynamic vegetation monitoring was realized (Table 3).

As shown in Table 3, the area of vegetation coverage ≤70% has greatly decreased from 1987 to 1996, reaching to 23～58%; and correspondingly the area of vegetation coverage > 70%

has greatly increased, reaching to 534.06%. This indicates that vegetation cover situations in the study area have improved.

Table 3 Areas of vegetation coverage grades in the study area and their variations for different years

Vegetation coverage grades	Coverage values %	Pixel numbers			Area, km²			Area, %			Area variation (96 to 87) ±%
		1987	1995	1996	1987	1995	1996	1987	1995	1996	
1	<10	159990	100537	91790	99.99	62.84	57.37	17.26	10.85	9.90	-42.63
2	10～30	227880	127339	95992	142.43	79.59	60.00	24.59	13.74	10.36	-57.88
3	31～50	237509	139408	123507	148.44	87.13	77.19	25.63	15.04	13.33	-48.00
4	51～70	232528	185923	178606	145.33	116.20	111.63	25.09	20.06	19.27	-23.19
5	71～90	68908	293510	248489	43.07	183.44	155.30	7.43	31.67	26.81	+260.61
6	> 90	0	80098	188431	0.00	50.06	117.77	0.00	8.64	20.31	+534.06*
Total		926815	926815	926815	579.26	579.26	579.26	100.00	100.00	100.00	

* add-up computation for grade 5 and grade 6

Based on the vegetation coverage grades maps, the surface slope grades map and a so-called “two-dimensional table” for soil erosion grading (decided by both vegetation coverage grades and slope grades), the soil erosion grades maps for different yeas were calculated and generated. Thereupon, the dynamic monitoring of soil erosion was also realized (Table 4).

Table 4 Areas of soil erosion grades in the study area and their variations for different years

Soil erosion grades	Erosion intensity	Pixel numbers			Area, km²			Area, %			Avea variation (96 to 87) ± %
		1987	1995	1996	1987	1995	1996	1987	1995	1996	
1	nil*	175087	175087	175087	109.43	109.43	109.43	18.89	18.89	18.89	0.00
2	slight	87497	167462	260394	54.69	104.66	162.75	9.44	10.07	28.10	+197.60
3	light	347496	435739	368010	217.19	272.34	230.01	37.49	47.07	39.71	+5.90
4	medium	248144	121677	100637	155.09	76.05	62.90	26.77	13.13	10.86	-59.44
5	intensive	45897	18713	16117	28.69	11.70	10.07	4.95	2.02	1.74	-64.88
6	very intensive	16964	6311	4874	10.60	3.94	3.05	1.83	0.68	0.53	-71.27
7	serious	5370	1826	1696	3.58	1.14	1.06	0.62	0.20	0.18	-70.40
Total		926815	926815	926815	579.27	579.26	579.27	99.99	100.00	100.01	

* The nil erosion was thought to exist in the area with surface slope equaling to zero.

As shown in Table 4, the area of the more intensive erosion (medium and more serious) has greatly decreased from 1987 to 1996, reaching to 60～70%; and the area of the slight erosion has greatly increased, nearly reaching to 200%. This clearly states that the soil erosion in the study area was prominently controlled and the environment was improved to an extent.

These results are, more and less, near to other researchers’ results which were obtained by traditional visual interpretation method （李德成等, 1998）. It proves that the methods in this research, including vegetation coverage determination, atmospheric correction, relationship formulation between vegetation index and vegetation coverage, dynamic monitoring, etc., are correct, reliable and more precise

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