World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:4, No:4, 2010

Application of GIS and Statistical Multivariate Techniques for Estimation of Soil Erosion and Sediment Yield

Masoud Nasri[1], Ali Gholami[2], Ali Najafi[3]

Abstract**—**In recent years, most of the regions in the world are exposed to degradation and erosion caused by increasing population and over use of land resources. The understanding of the most important factors on soil erosion and sediment yield are the main keys for decision making and planning. In this study, the sediment yield and soil erosion were estimated and the priority of different soil erosion factors used in the MPSIAC method of soil erosion estimation is evaluated in AliAbad watershed in southwest of Isfahan Province, Iran. Different information layers of the parameters were created using a GIS technique. Then, a multivariate procedure was applied to estimate sediment yield and to find the most important factors of soil erosion in the model. The results showed that land use, geology, land and soil cover are the most important factors describing the soil erosion estimated by MPSIAC model.

Keywords**—**land degradation, Soil erosion, Sediment yield, Aliabad, GIS technique, Land use.

I. INTRODUCTION

SOIL erosion is the most important limitation for the sustainable development, optimal land and water management and development. In recent years, most of the regions in the world are exposed to degradation and erosion caused by increasing population and over use of land resources. Logan et al., [6] expressed that the need for quantifying soil erosion processes and factors as an essential task for investigators. These factors include rainfall, runoff, soil physical properties such as structure, texture, infiltration which are used in different empirical methods for erosion estimation like MPSIAC (Modified Pacific South west Inter Agency Committee). Zachar [7] stated that natural and human factors are the most important factors affecting soil erosion by water. Johnson and Gebhardt [5] introduced a modification of the PSIAC method called" Modified MPSIAC". This method has 9 parameters: surface geology, soil, climate, runoff, relief, land cover, land use, current status of the basin erosion and river erosion. Foster et al., [2] demonstrated the advantages of the modified method which can be used in regional decision making and management planning.

Soil erosion in Iran is increasing in recent years and has reached to an alarming stage which needs urgent attention. In this study, the MPSIAC method was applied to estimate soil erosion and sediment in the ungaged Aliabad basin, near Chadegan in the western region of Isfahan Province.

(1) Faculty of , Islamic Azad University, Ardestan branch, Iran,
e-mail: ps_sepahan@yahoo.com
(2) Department of Agriculture, Islamic Azad University, Khorasgan branch, Iran
(3) Faculty of Natural Resources, Tarbiat Modarres University, Tehran, Iran

II. MATERIALS AND METHODS

2.1. Study Area

With an area of more than 66 km2, the Aliabad basin is located at 50’ 17’ to 50’27’ longitude and 32’39 to 32’46 latitude. The basin is divided into 7 hydrologic watersheds. Figure 1 shows the location of the study area.

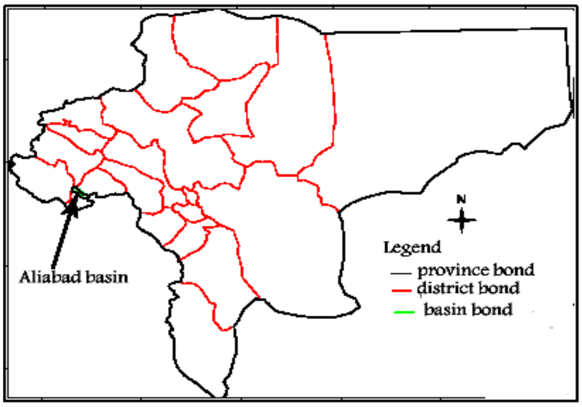

Fig. 1 The location of the Alibad basin

2.2. Physical properties of watersheds

The physical properties of the watershed used in MPSIAC are used in the GIS techniques.

2.3. Statistical analysis

In order to define most important factors of soil erosion based on the MPSIAC method, multivariate techniques were applied. These multivariate techniques are “Principal Component Analysis, PCA” which is used to find the most effective factors and “ Cluster Analysis” which is applied to classify the watersheds based on the most important factors derived from PCA . Multivariate techniques are common methods for classifying physical and statistical data . Principal components and cluster techniques are used in this study to find the most important factors on soil erosion and to classify the watersheds based on these factors.

2.3.1. Principal Component Analysis

“Principal Component Analysis” was first applied to reduce a large data matrix into some important factors (Principal Components). The first principal component is the linear combination of the original variables that captures as much of the variation in the original data as possible. The second component captures the maximum variation that is uncorrelated with the first component, and so on.

2.3.2. Cluster Analysis

The use of cluster analysis involves the grouping of various observation or variables into clusters, such that each cluster is composed of observations or variables having similar characteristics such as geographical, physical, statistical or stochastic behaviour. We apply the main hierarchical type of cluster technique in this study. There are several methods in hierarchical cluster and the Ward method is used with the best results (Gabson, 1992).

III. RESULTS AND DISCUSSION

3.1. Physical characteristics

For applying the GIS techniques, the physical properties of the watersheds are used such as area, perimeter, slope, land use and other essential parameters are used in the MPSIAC method. Table 1 shows these properties of the watersheds in Aliabad basin.

TABLE I
PHYSICAL PROPERTIES OF THE STUDY AREA (GHOLAMI, [4])

Basin name	Area circumference (km)	Area (km2)	% from total	basin type
D	7.79	1.37	2.05	Non-hydrologic
S11	16.27	10.02	14.99	hydrologic
S12	10.29	3.84	5.75	hydrologic
S2	24.99	13.20	19.75	hydrologic
S21	14.06	8.20	12.27	hydrologic
S211	16.79	12.89	19.29	hydrologic
S2112	10.20	6.00	8.98	hydrologic
S2111	14.82	11.31	16.92	hydrologic
Total		66.83	100.00	-

Based on the information, the parameters of the MPSIAC method were calculated. The score of the 9 parameters used in the MPSIAC method are presented in Table 2 for each watershed.

TABLE II
MPSIAC PARAMETER SCORE FOR EACH WATERSHED (GHOLAMI, [4])

Sub basin	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	sum
S11	6.5	5.8	6	9.1	4.6	4.5	12.4	7.8	6.7	63.4
S12	9.8	5.7	6	4.1	2.8	4	11.7	6.5	8.4	59
S2	7.2	5.3	6	32.7	6.8	4.5	11.9	5.8	6.7	86.9
S21	4.6	5.4	6	16.9	7.3	4.2	11.8	9	8.4	73.6
S211	4.4	5.4	6	12.3	7.8	4.2	12	9.5	10	71.6
S2111	4.3	6.1	6	7.8	9.4	4.8	13.5	11	11.7	74.6
S2112	4.5	6.6	6	8.4	9.3	8.9	9	10.5	11.7	74.9
total	5.9	5.7	6	9.6	4.9	4.4	11.7	7.7	4.3	60.2

Based on these scores, the erosion severity classes of the basin were estimated and the area of these classes were calculated using GIS techniques. The erosion classes are shown in table 3 with their corresponding area.

Using the sediment equation of MPSIAC method, the sediment yield of each watershed was estimated and the watersheds were ranked according to sediment yield. The results of sediment yield estimation and watershed ranking are presented in table 4 and 5, respectively. Fig. 2 shows the spatial groups of the erosion classes.

TABLE III
EROSION CLASSES OF ALIABAD BASIN (GHOLAMI, [4])

Erosion type	sign of erosion type	Definition of Erosion types	Area (Km^2)	% from total
1	E0	Initial surface erosion	5.00	7.48
2	E1	Surface erosion and low rill erosion	4.32	6.46
3	S1R1G1/Scrfch	surface erosion and rill erosion and low gully erosion+ soil creeping + rock debris + river erosion	5.70	8.53
4	S1R2G1/Scrfch	Low surface erosion and moderate rill erosion and low gully + soil creeping + rock debris + river erosion	5.48	8.20
5	S1R2G2/Scch	Low surface erosion and moderate rill gully erosion + soil creeping + river erosion	2.44	3.65
6	S2R2G2/Scch	Moderate surface and rill and gully erosion + soil creeping + river erosion	23.42	35.04
7	S2R2G1/Scch	Moderate surface and rill erosion and low gully + soil creeping + river erosion	12.74	19.06
8	S2R2G2	Moderate surface and rill and gully erosion	1.67	2.51
9	S3R3G2/Scch	High surface rill erosion and moderate gully + soil creeping + river erosion	5.87	8.79
Urban (U)	-	0.19	0.29	

TABLE IV
SEDIMENT YIELDED IN ALIABAD BASIN

Subbasin name	Area (km²)	Special water Yield (m³/sec-km²)	Annual Sediment yield (1000 ton)	Turbidity (mgr/lit)	Sediment Delivery Ratio (SDR, %)
S11	10.02	0.91	0.36	1.26	45
S12	3.84	0.41	0.31	6.27	52
S2	13.2	3.27	0.83	0.61	43
S21	8.2	1.69	0.52	1.19	46
S211	12.81	1.23	0.49	0.98	44
S2111	11.39	0.78	0.54	1.93	44
S2112	6	0.84	0.55	3.43	49
total	65.5	0.95	0.32	0.17	31

TABLE V
RANKING OF WATERSHEDS BASED ON SEDIMENT YIELD

subbasin	Sediment Yield	turbidity	Sediment Delivery
S11	6	4	4
S12	7	1	1
S2	1	7	6
S21	4	5	3
S211	5	6	5
S2111	3	3	5
S2112	2	2	2

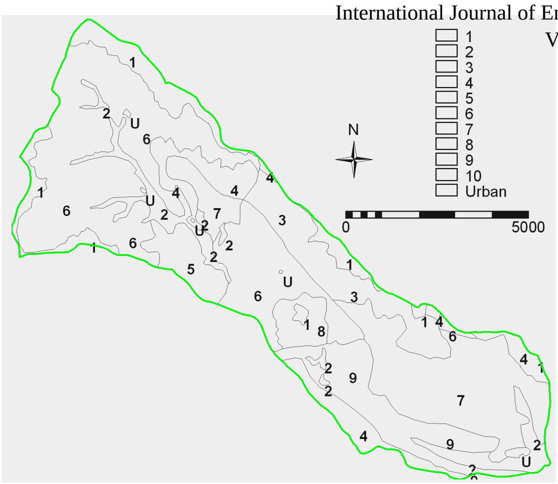

Fig. 2 Spatial map of erosion classes in the watershed

3.2. Statistical Analysis

We use PCA on the parameters of MPSIAC. The results of the PCA are presented in table 6 showing the variance explained by each factor. For example, the first component described 53 variance between the parameters used in MPSIAC method. It is obvious that 3 components explain more than 90% of the variance between different parameters. Using the VARIMAX rotated method, the loadings of each parameter in each factor are estimated. Table 7 shows the loading of each parameter in each factor.

TABLE VI
VARIANCE EXPLAINED BY EACH COMPONENT

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.309	53.861	53.861	4.309	53.861	53.861	2.483	31.042	31.042
2	2.093	26.166	80.027	2.093	26.166	80.027	1.991	24.890	55.932
3	.834	10.431	90.458	.834	10.431	90.458	1.954	24.431	80.362
4	.630	7.879	98.337	.630	7.879	98.337	1.438	17.974	98.337
5	.112	1.396	99.733						
6	1.569E-02	.196	99.929						
7	5.674E-03	7.092E-02	100.000						
8	-1.05E-16	-1.32E-15	100.000						

Extraction Method: Principal Component Analysis.

TABLE VII
WEIGHTS OF EACH PARAMETER FOR EACH COMPONENT

Rotated Component Matrix [a]

	Component			
	1	2	3	4
Y1	-.891	-.203	-.357	7.702E-02
Y4	.153	-.158	-9.99E-02	.970
Y5	.634	.351	.648	.214
Y6	.113	.951	.262	3.505E-04
Y7	.951	-6.54E-02	-7.21E-02	.230
Y8	.582	.310	.624	-.416
Y9	6.106E-02	.294	.932	-.167
Y2	7.554E-02	.842	.254	-.439

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 5 iterations.

Table 7 shows that the most important factor is land use (Y7=0.95) but the effect of land use is in contrast with the geology effect (Y1=-0.89). This means that if the land use is suitable for a region, the effect of water on geologic formation could not result in high a sediment yield. On the other hand, the improper land use will result in increasing erosion. The highest score of the second component is with ground cover (Y=0.95) which is significantly related to land use and has the same effect on sediment yield. The most important factor in the third component is channel erosion which has a whigh results in proportion of sediment yield in the watersheds.

The results of the use of the hierarchical cluster analysis on the parameter values of each factor in each watershed are shown in the form of a dendrogram (Fig. 3).

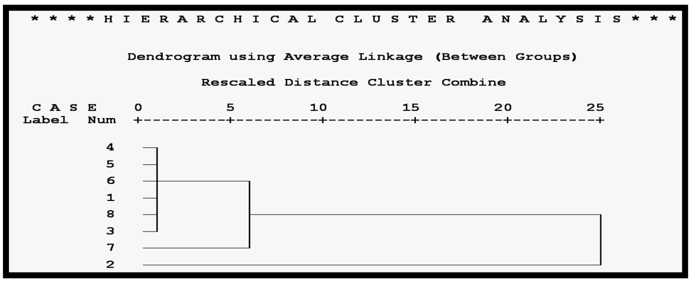

Fig. 3. Dendrogram of the watersheds of Aliabad basin based on the Ward method

The dendrogram shows that most of the watersheds have similar conditions of soil erosion and sediment yield. In the sense, the management of erosion could be uniformly applied in the watershed and there is no significant spatial difference between erosion factors in the basin.

IV. CONCLUSIONS

The results of this study show that the application of GIS techniques in the study of erosion has high potential for decreasing computer time used and increasing accuracy of the sediment and erosion estimation. However, it would be useful to find a spatial relationship between the erosion factors using statistical methods. The principal component analysis shows that land use, geologic formation and land cover are the most important erosion actors. This means that the human management of land use and land cover plays a key role in erosion control and decreasing sediment yield.

REFERENCES

[1] Feiznia, S., Mokhtari, A. and Ahmadi, H., (2002) Application of remote sensing in providing land use and ground cover information layers in MPSIAC erosion model, Pajuhesh –va- Sazandegi journal(Iranian).
[2] Foster R. H., Maureen V., Warren P., Barten, K. (1995) Comparative evaluation of land cover data sources for erosion prediction. Water Resources Bulletin, Vol 31,no. 6,991-999.
[3] Gabson, Gd. , (1992), Applied multivariate data analysis, Volume 2 : categorical and multivariate methods, Springer – Verlag, 731p.
[4] Gholami, A., (2005), Application of remote information layers in MPSIAC erosion model (AliAbad watershed in the southwest of Isfahan Province, Iran), Msc thesis, Islamic Azad University, Science and Research Campus, Tehran, Iran.
[5] Johnson. C.W. Gebhardt. K.A. (1992) Predicting sediment yields from saga brush rangeland for proceedings of the workshop on estimating erosion and sediment yield on rangelands. Tucson Aritong, March 1982.V.5.Department of agriculture ARM-W-26.p:145-156.
[6] Logan T.J., Urban D.R., Adams J.R., and Yaksichs, (1982) Erosion control potential with conservation tillage in the Lake Erie basin: estimates using the universal soil loss equation and the land resource information system (LRIS). Reprinted with permission of Journal of Soil and Water Conservation, 37: 50-55.
[7] Zachar, D., (1982). Soil erosion, development in soil science, Elsevier scientific publishing company. C. Zechelarakia. Pp: 547.