



Erosion Risk Assessment using an Empirical Model of Pacific South West Inter Agency Committee Method for Zargeh Watershed, Iran

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Abstract

Watershed degradation due to soil erosion and sedimentation is one of the major environmental problems in Iran. In addressing the issue, a study on the validity of an empirical model of Pacific South West Inter Agency Committee Method (MPSIAC) to predict annual average sediment yield to Zargeh watershed was undertaken. The MPSIAC method incorporates nine environmental factors that contribute to sediment yield of the watershed namely: surface geology, soil, climate, runoff, topography, ground cover, land use, channel and upland erosion. Open-source Geographic Resources Analysis Support System (GRASS) was used to facilitate the spatial interpolation of the nine model factors and interpretation of predicted sediment yield for the entire watershed. Twenty year sediment yield records from 1980 to 1999 were used to validate the simulated model results. Simple linear regression analysis between simulated model results and actual field records indicated that there was a significant correlation ($P < 0.05$) with $r^2 = 0.6124$. The results suggested that the model is suitable for predicting yearly average sediment yield on a long term basis for the Iranian watersheds with similar conditions.

Keywords: MPSIAC, Erosion, Sediment Yield.

Introduction

Soil erosion is a worldwide environmental problem that degrades soil productivity and water quality, causes sedimentation and increases the probability of flood (Ouyang and Bartholic 2001). In Iran, it is estimated that the average annual erosion rate of watershed is more than 20 times of acceptable average level in the world (Jalalian *et al.* 1997). Soil loss in Iran for the period of 1950 to 1990 has increased tremendously from 500 million to 2200 million ton per year, an increase of more than four folds in four decades (Ahmadi 1995). Overgrazing, dry farming and deforestation are the major causes of watershed degradation in Iran (Jalalian *et al.* 1997).

The equilibrium between geological erosion and soil formation is easily disturbed by human activities (Jalalian *et al.* 1997). It is estimated that 26.4 million hectare of land in Iran are under the influence of water erosion and 35.4 million hectare are under the influence of wind erosion (Lal 1999). Iran has more than 10 million hectares of cultivated land under irrigation (Anon 1974) and more than 8 million hectares of agriculture land under dry farming (Iran daily 2000). Overgrazing, deforestation, cultivation, road construction, drought, civil and industrial development are possible causes that tend to accelerate the removal of soil material in excess of which is removed by geological erosion. This type of erosion is known as accelerated erosion.

Accelerated erosion takes place when vegetation cover which protect topsoil from erosion agents such as rain and wind is removed. The soil particles movement becomes extensive until the top soil has been completely washed away, leaving the subsoil or the parent rock behind (USDA 1995). The problem of erosion is further exacerbated by loss of organic matter in the topsoil that hold the soil particles together due to improper land use activity (Nikkami *et al.* 2002). Prolong

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overgrazing and drought will expand the patches of bare soil and worsen the erosion problem (Blaszczynski 2001).

Modelling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces (Wijesekera *et al.* 2002). Empirical mathematical methods are an inseparable part of any erosion research to estimate the amount of sedimentation (Zachar 1982, Bartsch *et al.*, 2002). In watershed management studies, knowledge on the erodibility of the soil, the state and intensity of erosion, and the expected effect of conservation measures control are of paramount importance in the understanding of erosion. These are especially critical in areas without any gauging station (Noman and Tahir 2002). Empirical methods are commonly used as a means of expressing existing (actual), expected (forecasted or predicted) and possible (potential) erosion (Ghadiri 1990). Lack of data and data precision are the main issues in the application of empirical method (Zachar 1982). In such cases, the use of equation is limited, and they may not even be useful for making approximate calculations. There are few methods that were generally used for soil erosion studies such as Food and Agriculture Organization (FAO), Water Erosion Prediction Project (WEPP), Universal Soil Loss Equation Method (USLE), Erosion Potential Method (EPM), and Pacific South West Inter Agency Committee Method (PSIAC) (Jalalian *et al.* 1997). The suitability of each method depends on climate and area, type of research and availability of data.

In this study, Modified PSIAC (MPSIAC) method which is specially design for arid and semi-arid area in the United States was assessed for its applicability to the Iranian watershed environment. The MPSIAC was created in 1982 based on PSIAC which was introduced in 1968 for planning purposes by Pacific Southwest Inter Agency Committee in the United States for watershed basins of larger than 10 square mile (PSIAC, 1968).

Both models used nine factors to describe the surface geology, soil, climate, runoff, topography, ground cover, land use, upland erosion and channel erosion. The difference is that nine equations were used in MPSIAC, whereas in PSIAC method, sediment yield is assumed to be directly proportional to the total numerical values assigned to the nine factors (PSIAC 1974).

Conservative method to estimate sediment yield in a watershed is to analyse long term field records of at least 15 years hydrometric (gauging) data which includes discharge, associated flow duration curve, sediment and associated sediment/discharge curve at outlet of a watershed. The flow duration curve expresses the relationship between magnitudes of daily flow that is likely to be equalled or exceeded. The curves are part of flow analysis of hydrologic system (Riggs 1968) needed for the study.

Soil erosion can effect dynamically balanced watershed system indirectly by increasing water runoff and degrade water quality and cause maldistribution of water in the watershed (Black 1982). Thus, soil erosion is one of the important component of watershed management which also involves planning and managing terrestrial and aquatic ecosystems, surface and groundwater, and land use planning (Black 1982, Chess and Gibson 2001).

Resource map preparation for watershed management such as soil erosion map can be assisted by spatial information processing using Geographic Information System (GIS) (McHugh 2002, Millward *et al.* 2001). Geographic Information System can also provide linkages between maps and other information related to geographic location for environmental modelling purposes especially in the watershed management (Green and Rix 1995, Shrestha 2002).

Geographic Resources Analysis Support System (GRASS) is a GIS software used for data management, image processing, graphics production, spatial modeling and visualisation of many types of data. It is an open source software released under General Public License (GPL). It is originally written by the United States Army Construction Engineering Research Laboratories (USA-CERL, 1982-1995), as a tool of land management and environmental planning. GRASS has evolved into a powerful utility with a wide range of application in many different areas of scientific research. GRASS allows users to analyse, store, update, model, and display data quickly and easily (Neteler and Mitasova 2002). GRASS had been widely used in soil erosion studies (Renard *et al.* 1997). In developing countries, where the commercial GIS softwares are expensive and not affordable by the universities, governments and other organizations, GRASS is a good alternative. The capability of GRASS is similar or sometimes better than the commercial GIS softwares (Paudits 2002, Raghunath 2002).

The objectives of the study are to derive and validate the MPSIAC model for sediment prediction in Zargeh watershed, Iran.

THE STUDY AREA

The study area is Zargeh watershed with an area of 8.8 km². It is located between the latitude of 30 ° 58' 8" to 30 ° 59' 52" North and longitude 50 ° 26' 9" to 50 ° 28' 22" East in Southern Iran (Figure 1). Zargeh is one of the sub-basins of Maroon River watershed with a total area of 2802 km². There is only one gauging (hydrometric) station installed at the Maroon river, where the data of sediment and discharge were used in the present study. The climate of the area is generally semi-arid (Alizadeh 1990) with average precipitation of 667 mm per year. The maximum, minimum and average temperature are 30.7°C, 14.7°C and 22.7°C respectively.

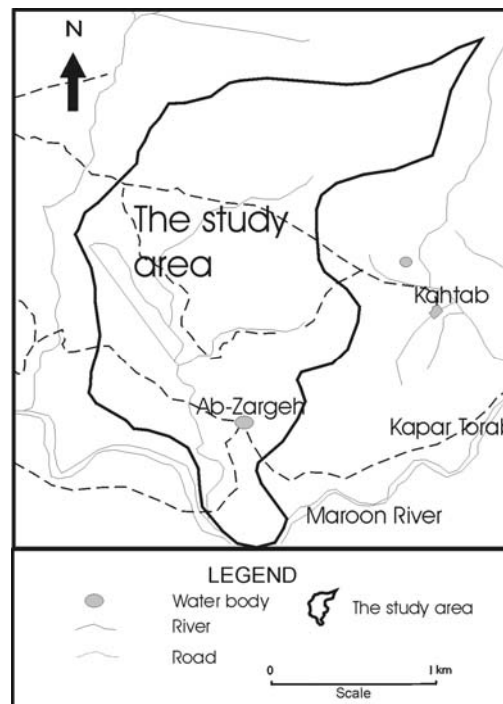


Figure 1: The study area

Watershed characteristics such as morphological and drainage properties are shown in Table 1. The minimum and maximum elevation of the study area is about 620 m and 1540 m respectively, located in the north and south respectively of the study area (Table 1). The average elevation is 858 m. The majority of the slope class is in class 5 (slope angle range of 12 to 30%) and class 6 (slope angle range of 30 to 60%) with 29% and 25% of the study area respectively (Figure 2). The majority of the steep area (more than 30% in slope angle) is around the north east and south west of the study area (Figure 3).

Table 1: Morphological and drainage characteristics of Zargeh Watershed

Area (Km ²)	Compactness Coefficient (*1)	Form Factor (*2)	Max Height (m)	Min Height (m)	Average Height (m)
8.8	1.43	0.23	1540	620	857.8
Drainage Density (*4)	Horton Stream order (km) (*5)				Average of Slope (%)
	1	2	3	4	
1.8	15.8	27	6.1	0	27
Length of main Stream (km)	Average slope main Stream (%)		Time of Concentration (hr)(*3)		Length Streams (km)
6.1	7.9		0.61		25
<p>Note (*(number);</p> <p>(*1) Gravelius Equation [$Kc=28P/A^{0.5}$ A: area (km²), P: perimeter (km)]</p> <p>(*2) Form Factor in Horton Equation ($F=A/L^2$) A: area (km²), L: Length (km)</p> <p>(*3) Kirpich Equation [$Tc(hr)=0.0003L^{0.77}*S^{-0.385}$]L: Length of stream(main), S: Average of watershed slope (m/m)]</p> <p>(*4) Drainage Density Equation [$Dd=L/A$: L: Length streams (km), A: area (km²)]</p> <p>(*5) Horton Stream Numbers</p>					

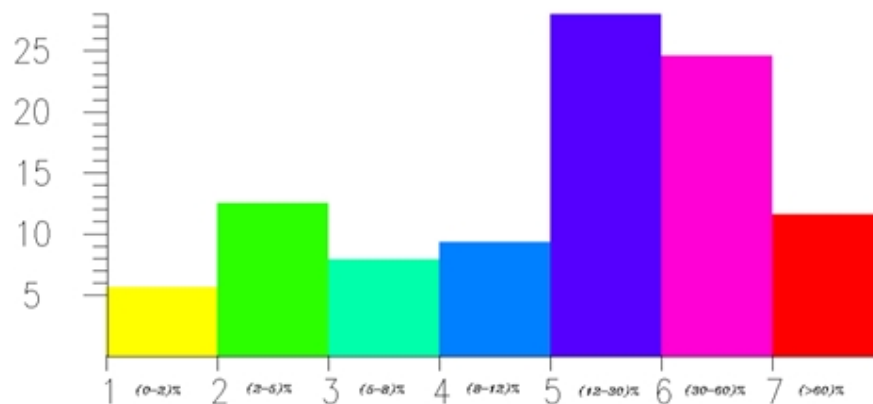


Figure 2: Slope angle distribution of the Zargeh Watershed

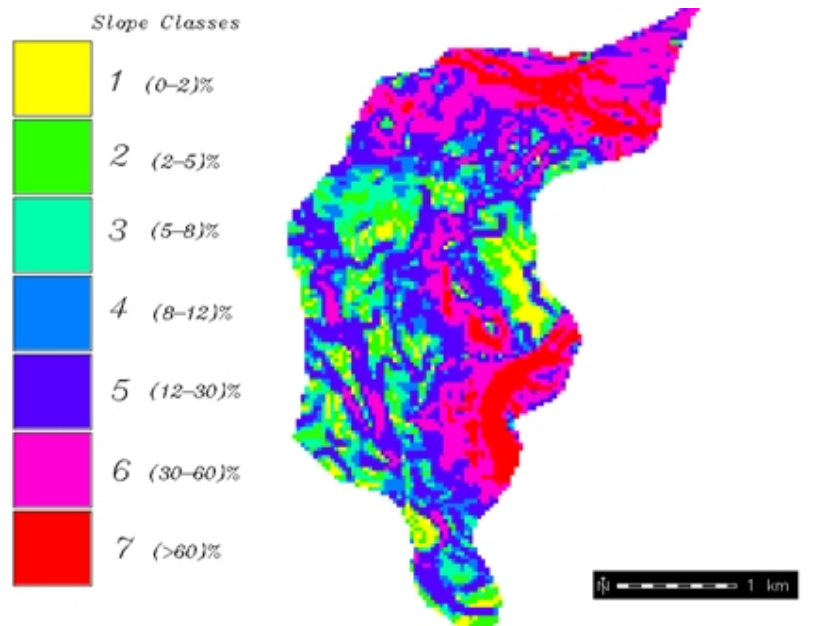


Figure 3: Histogram of the slope angle in Zargeh Watershed

The length of stream in order 1 is 15.8 km, in order 2 is 3.1 and in order 3 (main stream) is 6.1 km. The total length of stream in the study area is about 25 km (Table 1). Based on Iran soil map (Abrokh, 2002) and field surveying, a current representation of soil map for watershed in the form of land component map was prepared (Figure 4 and Table 2). There are six major soil types identified (Figure 4).

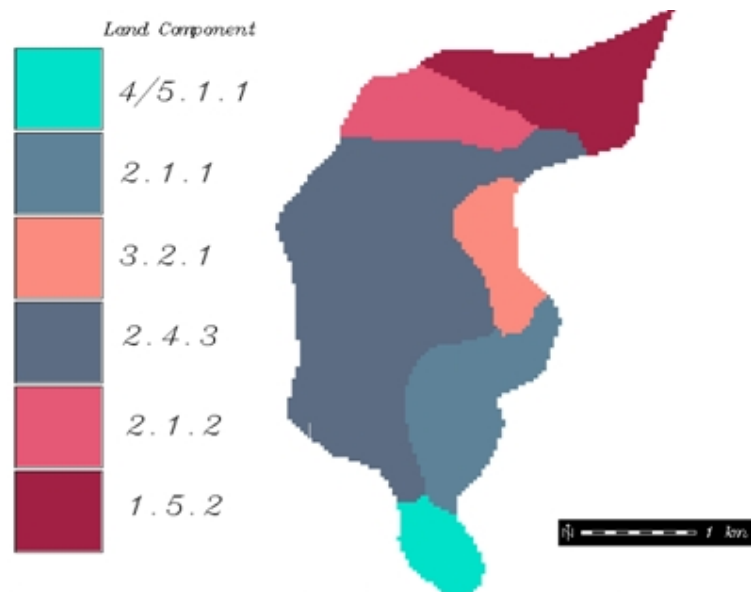


Figure 4: Land component map incorporates soil properties in Zargeh Watershed.

Table 2: Landform characteristic of the study area

Landform code	Landform	Geology	Rock face slope angle (%)	Average slope angle (%)	Soil depth	Landuse	Soil structure	Soil texture
1.5.2	Mountain	Karst	70-80	40-70	Very low	Forest	Massive	Loam
2.4.3	Hill	Red shale and gypsum	40-50	12-25	Very low	Range and dry farming	Massive	Silt clay loam
2.1.1	Hill	Compact silt stone	20-30	12-25	Very low	Range land	Massive	Clay loam
2.1.2	Hill	Karst	20-30	12-25	Low	Range land	Massive	Clay loam
3.2.1	Plateau	Red shale and gypsum	-	2-5	Deep	Dry farming	Massive	Silt loam
4/5.1.1	Alluvial plain of piedmont and river	Alluvium	-	2-5	Deep	Irrigation farming	Massive	Clay loam

METHODOLOGY

The methodology is divided into three sections namely; the model derivation, gauging station data analysis and data interpretation and validation.

MPSIAC model derivation

MPSIAC model incorporated nine factors from nine equations: namely surface geology (Y1), soil (Y2), climate (Y3), runoff (Y4), topography (Y5), ground cover(Y6), land use(Y7), surface erosion(Y8) and channel erosion(Y9) (Table 3). Fieldwork was undertaken for 10 days from 5 to 12 December 2002 (Table 3). For ease of interpretation, each of the factors is discussed below.

Table 3: Effective factors on the erosion for the MPSIAC model

No	Effective factors	Description	Equation	
1	Surface geology	X1=Stones sensitivity to erosion (0-10)	Y1=X1	Equation 1
2	Soil	K=soil erodibility	Y2=16.67K	Equation 2
3	Climate	I6,2=6-hour rainfall with 2-year return period	Y3=0.2X3 X3=I6,2	Equation 3 Equation 4
4	Runoff	Ro=runoff height , PSF=yearly peak stream flow	Y4=0.2 X4 X4=A + B A=R.O X 0.006 where	Equation 5 Equation 6 Equation 7
			R.O:=yearly runoff volume (mm) B=PSF X 10: PSF: yearly peak stream flow (m3/sec.km2)	
			To obtain equation equation7, Runoff coefficient was estimated based on: C = Q/P Where C = Runoff coefficient Q = Average Annual discharge for 20 years P = Average Annual precipitation for 20 years	Equation 8
			Then yearly runoff volume (R.O) (mm) was based on: R.O = C X P	Equation 9
			where R.O=yearly runoff volume (mm) C=Runoff coefficient Pi=Yearly precipitation (mm)	
5	Topography	S=slope (%)	Y5=0.33S	Equation 10
6	Land cover	Pb=percentage of bare ground	Y6=0.2Pb	Equation 11
7	Land use	Pc= percentage crop canopy cover	Y7=20-0.2Pc	Equation 12
8	Final land cover		Landcover (100%) = canopy cover (%) + bare ground (%) + stone or rock (%) + surface litter (%)	Equation 13
9	Surface erosion	SSF=the score of soil surface factors from the BLM method	Y8=0.25SSF	Equation 14
10	Gully erosion	SSFg=the score of gully erosion from the BLM method	Y9=1.67SSFg	Equation 15

Surface geology (Y1)

A 1:50 000 scale geological map by Iran Geographic Institute (1970) was used as the base map to interpret the geological sensitivity to erosion. Factors on surface geology (Y1) were evaluated based on stone sensitivity to erosion (X1). The score of each unit of surface geology was determined from the scale between 1 for the most resistant face, to 10 for the most sensitive face

to erosion. These scaling factors are based on the local condition of Iran (Feiznia,1995). The scaling factor is then used as attributes to the geological map.

Soil (Y2)

Soil factor (Y2) was determined based on soil erodibility factor (K). Soil sampling from six soil components in the study area were undertaken. Financial constraints limit the sampling to three samples from each soil components. The particle distribution of the soil, soil structure and permeability parameters were analysed to obtain the soil erodibility factor. K factor was determined by using Wischmeir nomograph (Renard *et al.* 1997). Soil factor (Y2) was calculated based on K in each type of soil (equation 2 in Table 3). The Y2 value was then used as attributes in the 1:50,000 scaled digitised soil map published by Iran Soil Institute.

Climate (Y3)

In this model, rainfall is considered to be the major contributor to soil erosion and sediment movement. Rainfall was estimated based on 6-hours precipitation amount with 2-year return period. In this study, climate factor (Y3) was based on 20 years (1980-1999) of rainfall record. From the record, the rainfall intensity duration and frequency curve were derived. The climate factor was estimated by equation 3 (Table 3).

Runoff (Y4)

Runoff factor (Y4) was obtained based on analysis of discharge data. Total average runoff (mm) and peak discharge ($\text{m}^3/\text{sec.km}^2$) for 20 years period (1980-1999) were calculated as in equation 5 (Table 3).

Topography (Y5)

Topography factor (Y5) was determined based on average percentage of slope steepness. The average slope steepness was generated from digital elevation model derived from topographic map published by Iran Geographic Institute in 1970 using GIS. The topography factor was obtained by using equation 10 (Table 3).

Ground cover (Y6)

The main characteristics considered as ground cover are vegetation, litter and rocks. Ground cover factor (Y6) for the watershed from 1980-1999 were evaluated based on four sub-periods as followed;

1. 1980-1984 based on aerial photo interpretation of 1984
2. 1985-1991 based on landuse map of 1987
3. 1992-1997 based on on landuse map of 1997
4. 1998-1999 based on land use map of 1999.

The groundcover (Y6) factor was then obtained by using equation 11(Table 3).

Land use (Y7)

Land use factor (Y7) was estimated based on canopy cover using the equation 12 (Table 3) The land use factor is divided into four sub period as in Y6 because there is no other landuse being practised on the watershed. The equation 13 is used for the study area to describe the landuse in the study area.

Upland erosion (Y8)

Upland erosion (Y8) factor was obtained based on Bureau of Land Management method (Aker, 1971). Two sub-periods were evaluated. For the first ten years (1980-1989), six factors in the soil surface factors (SSF1 to SSF6) were obtained from aerial photo interpretation of 1984. It was assumed that there are no significant changes in soil surface factors in this period. The seventh factor, SSF7 was estimated from the relation between precipitation and gully formation. The total score for SSF was derived, and then, based on weighted average areas for every kind of landuse, and the upland erosion factor (Y8) was estimated by using equation 14 (Table 3). For the second ten years (1990-1999), SSF1 to SSF6 was obtained from the Statistical Centre of Iran and SSF7 was calculated by relationship between precipitation and gullies formation and land use map of 1999.

Channel erosion (Y9)

Channel erosion factor (X9) was obtained based on gully erosion factor from the BLM method and by the relationship between yearly rainfall (mm) (1980-1999) and gully erosion improvement (Najafinejad 2003). Each factor for every type of landuse was estimated using equation 15 (Table 3).

Predicted sediment yield

The nine factors were employed to estimate sediment yield (Q_s) according to:

$$Q_s = 38.77e^{0.0353R} \quad \text{Equation 16}$$

where:

Q_s : sediment yield ($m^3/km^2/y$)

$$R, \text{ sediment score} = \sum_{i=1}^9 Y_i$$

The sediment yield unit is $ton/km^2/y$ if the sediment density is assumed to be equal to $1.2 g/cm^3$.

Gauging station data

Zargheh's gauging station data for suspended sediment and discharge records from 1980 to 1999 were used to derive the flow duration and sediment discharge curves. Estimation of total sediment yield for the whole watershed was based on Iranian data collection experience (Arabkhdri *et al.* 1996, Jalalian *et al.* 1997) as follows;

$$\text{Bed load} = 0.2 \times \text{suspended load} \quad \text{Equation 17}$$

$$\text{Total sediment yield} = \text{Suspended load} + \text{Bed load} \quad \text{Equation 18}$$

The total sediment yield was used in the validation process.

Model Validation

Validation involves the process of comparing simulated results obtained from the MPSIAC model to the real measured data for a 20 years period (1980 -1999). Regression analysis, coefficient of determination (R^2), standard error (SE) were used to explain variability or consistency (Salas, *et al.* 1989). Standard error (SE) of residuals is in equation 19.

$$SE = \left[\frac{1}{n} \sum_{i=1}^n (M_i - P_i)^2 \right]^{0.5} \quad \text{Equation 19}$$

Where: M = Measured value
P = Predicted value
n = Number of years
i = index of year (number)

Sensitivity analysis was undertaken on each factor in MPSIAC model based on simple linear regression of sediment yield.

RESULTS AND DISCUSSION

Utilising GRASS GIS, spatial data related to surface geology, soil types, climate, runoff, topography, ground cover, land use, surface erosion and channel erosion were incorporated into MPSIAC model to facilitate the prediction and assessment of sediment yield of Zargeh watershed. Summation of scores in this nine environmental factors (R) affecting soil erosion in MPSIAC model showed that the minimum and maximum values for the entire period (1980 to 1999) is 49.6 occurred in 1993, and 75.0 occurred in 1992, respectively (Figure 5). For ease of interpretation, the values of R were divided into five classes (Table 4). Majority of the classes are in classes II and III.

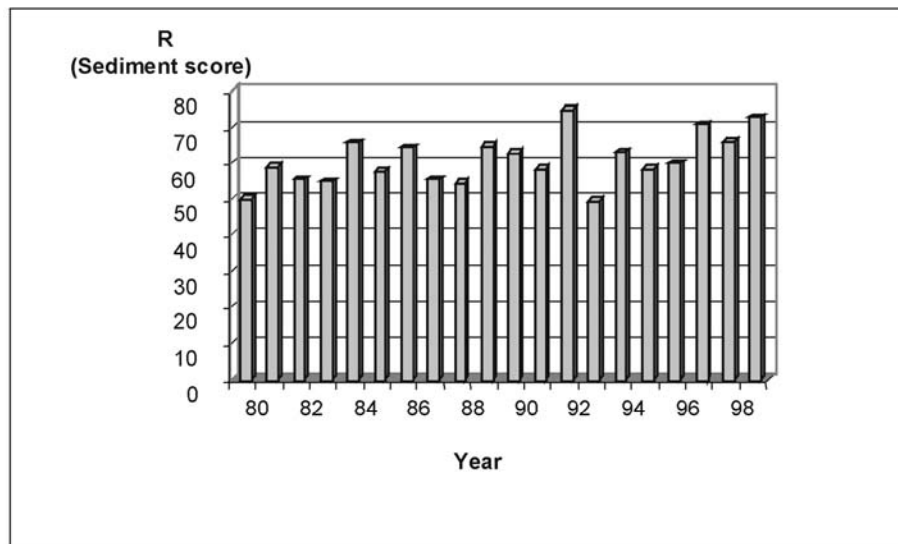


Figure 5: Sediment score histogram if MPSIAC model from 1980 to 1999

Table 4 :Derivation of the ordinal categories of average sediment yield score map

Erosion Class	R	Class
I	< 25	Very Low
II	25 – 50	Low
III	50 – 75	Moderate
IV	75 – 100	High
V	>100	Very high

The maximum predicted sediment yield is 5778 ton/year for the whole period of 1980 to 1999 occurred in 1992 and the minimum is 2356 ton/year in 1993 (Figure 6).

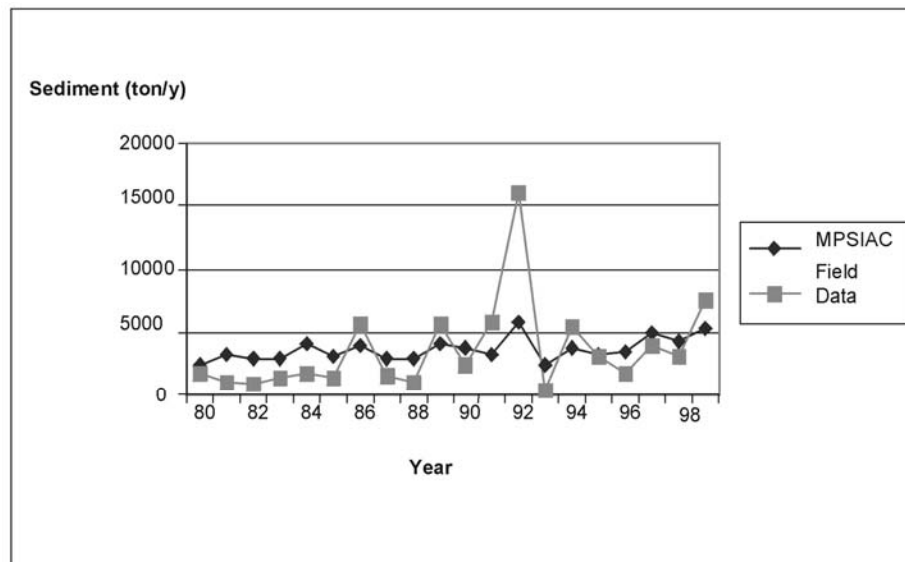


Figure 6: A plot of simulation MPSIAC and actual field data

The maximum sediment yield based on field data interpretations for the period between 1992 is about 16118 ton/year and the minimum yield for the period 1993 is about 2356 ton/year (Figure 3). This is corresponding with the highest and lowest annual precipitation in 20 years period (Figure 7). Thus it is possibly due to the amount of annual precipitation in the study area that trigger or affect the maximum and minimum sediment yield of the watershed.

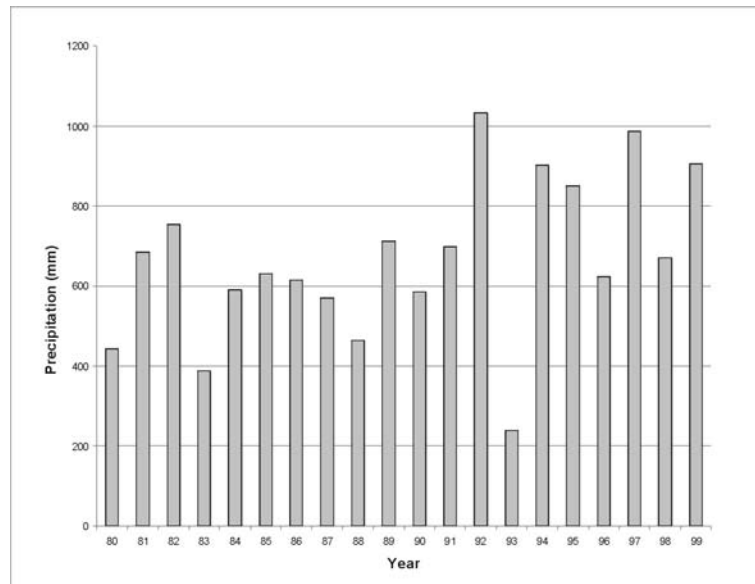


Figure 7: Annual precipitation in the study area between 1980 to 1999

It was shown also that during the first six years (1980 to 1985), the simulated MPSIAC exceeded the actual field data by a standard error of 2868.2 ton/year (Figure 8). However after 1986, the model trends to provide a better fitted with the field data with the exception of 1994. The reduction in standard error to 2704.1 ton/year for the last 14 years records (1986-1999) (Figure 9) indicates a better fit of the model. The difference in trends of the predicted results for this two period of records is probably related to changes in the rainfall regimes (Figure 7) or in climate conditions. However the overall result of regression on the entire period of records were found to be significantly correlated with a coefficient of determination (R^2) equal to 0.6124 ($P < 0.05$).

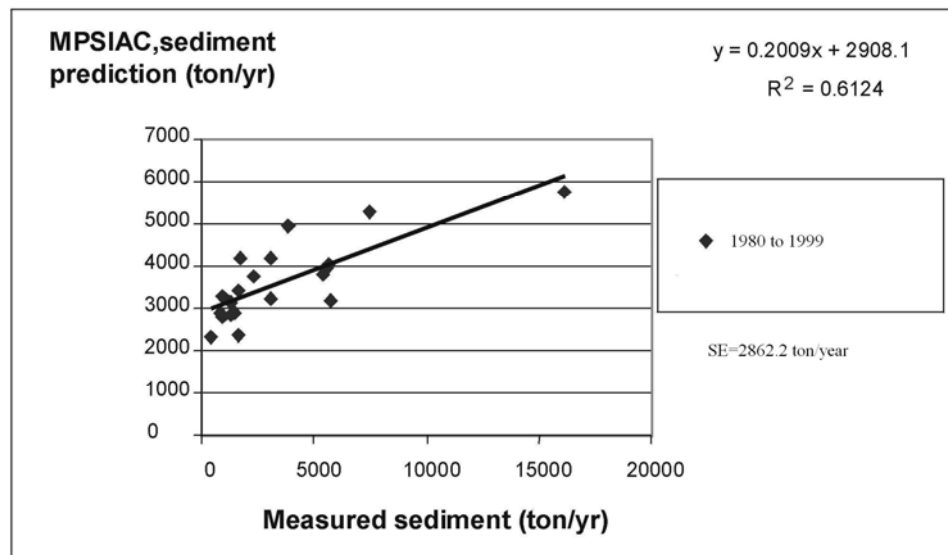


Figure 8. Correlation of simulated MPSIAC and measured field data (1980-1999)

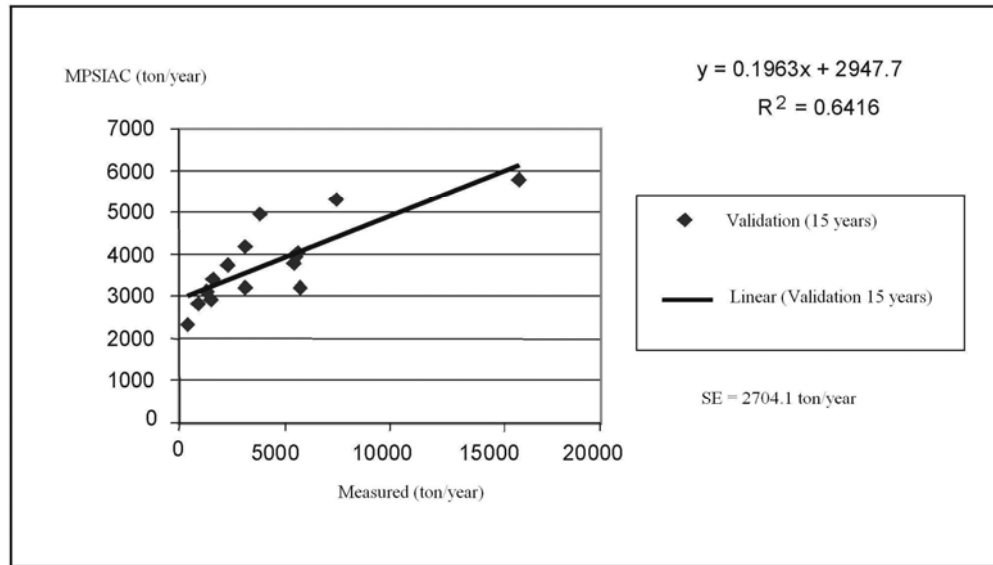


Figure 9: Correlation of simulated MPSIAC and measured field data (1985-1999)

During the study period, it was assumed that the factors of surface geology, soil and topography are constant and not sensitive to sediment yield predicted by the model. This is shown by the zero correlation between these factors and sediment yields (Table 5).

Table 5: Result of coefficient of determination (R^2) and standard error (SE) for correlation between sediment and the nine MPSIAC factors

	R^2	SE
Qs/Y1	0	3725.9
Qs/Y2	0	3722.4
Qs/Y3	0.766	3722.4
Qs/Y4	0.564	3728.3
Qs/Y5	0	3722.5
Qs/Y6	0.346	3724.9
Qs/Y7	0.120	3715.6
Qs/Y8	0.366	3725.5
Qs/Y9	0.597	3725.5

The most sensitive factors to the model are the climate (Y3), gully erosion (Y9) and runoff factors (Y4) as reflected in the R^2 value of 0.766, 0.597 and 0.564 respectively. The good correlations between Y3, Y9 and Y4 with sediment yield indicated that changes in natural agents will affect soil erosion and sedimentation. For instance, increase in annual and intensity of rainfall, and increase in runoff could result in an increase in the erosion rate. It is expected that surface erosion (Y8), ground cover (Y6) and land use (Y7) were found to be more sensitive to the model results, however in this analysis the results show otherwise. This is probably because of these three factors were established based on four sub-periods, and within these periods it was

assumed that there is no change in model outputs due to insufficient information, and while in actual condition there must be some changes occurred within the watershed. Watershed management goals such as recognition of sensitivity area to erosion, determination of critical area to erosion hazard and ranking of parcels or catchments would be one of the important objectives in watershed study. The nine factors in MPSIAC model almost represent all agents that affected soil erosion and sedimentation either directly or indirectly.

CONCLUSIONS

The MPSIAC model established for the Zargeh watershed were found to be significantly correlated with field data condition where coefficient of determination (R^2) equal to 0.6124 ($P < 0.05$). Based on the sediment score estimated from the established MPSIAC model, the erosion risk for the study area fall within a class III which is considered to be moderate. GRASS GIS was used to facilitate and interpret the model factor on spatial scale. The results of the study clearly suggested that the model can be used to predict average annual sediment yield on a long term basis. In the analysis it was showed that the most sensitive factors to the model output is the climatic factor followed by channel erosion and runoff factor. Three other factors namely surface geology, soil and slope are found not sensitive to the cause of soil erosion in the study area. A shallow soil depth on most of the mountains and hills, and low slope (2 to 5%) of the alluvium and plateau area may partly explain to the unsensitivity of the soil and slope to erosion.

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