Available online at www.elixirpublishers.com (Elixir International Journal)

Civil Engineering

Elixir Civil Engg. 80 (2015) 31361-31365

ISSN: 2229-712X

Sediment and Erosion Estimation by Geographical Data System Using PSIAC (Case Study: Sardasht)

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ARTICLE INFO

Article history:

Received: 23 October 2014;

Received in revised form:

28 February 2015;

Accepted: 26 March 2015;

Keywords

Erosion,

Sediment,

Sardasht,

GIS,

PSIAC.

ABSTRACT

The adverse effects of erosion may be not much noticeable in short term, yet it will be important in long term. Soil loss and erosion is one major factor interfering reduced fertility, reduced products, deposition of materials in waterways, irrigation canals and rivers, a decrease in reservoir capacity of dams and their reduced life, floods, environment pollution and road closures. The current research was carried out using GIS technique and PSIAC model in order to estimate the erosion and sediment of Sardasht watershed located in Kohkiluyeh& BoyerAhmad province with an area of 5940 hectares. PSIAC studies erosion status and sediment production in a business unit based on the strength and weakness of 9 environmental factors including; geology, soil, climate, runoff, topography, land cover, land use, surface erosion and river erosion. Here, layers corresponding to model factors are prepared in GIS environment and, in the end, the amount of sediment is measured using spatial analysis and overlapping layers of information. In order to measure particular erosion, SDR index (ratio of precipitation evolution) was used and 27.88 tons per hectare per year was estimated as erosion amount for the area considered. In the evaluation of soil erosion and sediment production of Sardasht basin, among factors influencing the erosion, land cover and land use with highest ratio (15.24) are first and weather with lowest ratio (4.11) is the last in rank. Qualitative classification of basin based on PSIAC model guide shows that the basin as a whole is located in high erosion class. The approximation of results from the model considered (27.88 tons per hectare per year) with real statistical analysis (30.3 tons per hectare per year) shows that currently, this model is effective for the basin.

Introduction

Soil is a principal natural resource of a country. Today, soil erosion is considered as a danger for human wellbeing and even for its life (4). Water and wind erosion is destroying thousands of hectares of high-quality lands in many countries. The most considerable disaster in this regard is huge holes appearing in central parts of the U.S during 1929s (2).

The erosion and sediment is a major problem in country's watershed management. Erosion and its consequences have imposed negative effects on vital ecosystem by escalation of human exploitation of nature since early 20th century (11), the main reason of which is population increase and excessive land use (1). French and English word 'Erosion' (abtrag in German) derivates from Latin word 'Eroder' meaning erosion and permanent loss of soil by wind or water (7).

For many years, there has been an effort to estimate soil loss in slopes and preserve its fertility preparing a land use program. These methods, at first, were qualitative and based on an individual index but as data increased, some multiple index-based equations appeared. First, during late 19th century, Wollny carried out some studies on erosion. Miller (1917) studied runoff and erosion and Musgraye (1930s) studied erosion Pashmany (6).

Rastgoo et al estimated the amount of erosion and sediment of Tang Genesht watershed by MPSIAC and EPM models using GIS and they concluded that MPSIAC provides better results for the basin considered compared with EPM (3).

Rahmani et al applied satellite data and geographical data system to estimate erosion and sediment using MPSIAC model in Sharafkhaneh- Shabestar watershed and showed a high correlation of this model with sediment measured in hydrometric base (almost 89%) (5). Shrestha et al carried out a case study in Euta in Thialand measuring soil erosion rate by USLE model and RS, GIS systems estimating a 0-279.32 erosion rate (12). Using satellite images, Kokh- Sherstha carried out an erosion and land use zoning in Khula in Nepal and they estimated a 0.01-0.4 tons per hectare per year soil erosion for lands with agriculture and water uses and eventually they estimated 12.6 tons per hectare soil erosion rate (10).

Daniels et al prepared an erosion-risk zoning map in Pacific Washington using GIS environment (ERDAS software), to provide separation map for areas with erosion risk, and digital data of wise TM images (9).

The aims sought in this research are estimation of erosion and sediment by geographical data using PSIAC model in considered watershed, conformity evaluation of estimated sediment, by PSIAC empirical model, with the sediment measured through statistical analysis, identification and prioritization of erosion factors based on their importance and also evaluation of erosion in each sub-basins and classifying them according to erosion level.

Materials and methods

Studied area statue

Sardasht watershed with an area of 59.4 square kilometers located 182 **k** far from southern Shahrekord in Lordegan in Chaharmahal & Bakhtiari province. The area locates between ¨50° 49′ 24¨ to 50° 59′ 27¨ **E** and 19′ 56¨ and 31° to 30¨ and 24′and 31° **N**. Sardasht village is in northwest of the area with Abza Sardasht and Kal Galleh located there (fig. 1).

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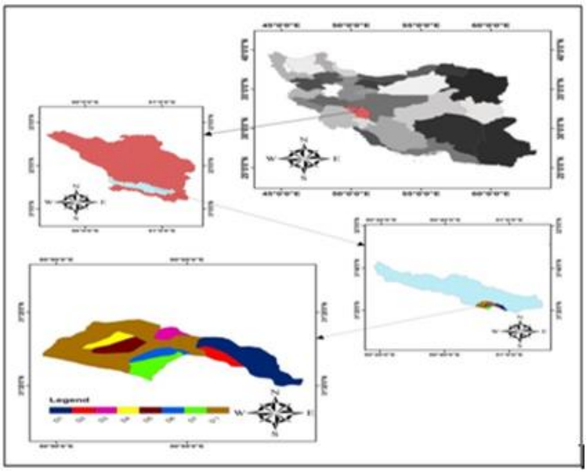

Fig 1. Mathematical location of studied area

Research method

In this research, topographic maps in 1:25000 scale, geological maps in 1: 100000 scale and land use were used. In order to evaluate erosion and sediment in this watershed, PSIAC model was used which reviews erosion status and sediment production in each business unit based on the strength and weakness of nine environmental factors including; geology, soil, climate, runoff, topography, land cover, land use, surface erosion and river erosion. In this research, layers corresponding to nine erosion factors in considered watershed are prepared in GIS environment and the effect of each factor in the basin as a whole is evaluated and prioritized. The amount of sediment reduction in each of these sub-basins is measured and the sub-basins are prioritized based on sediment reduction in a year.

Geology

In PSIAC model no coefficient is enforced for this factor i.e. Y1=X1. According to 1:100000 geological map published by geological survey and mines of Iran, the organization and formation of watershed were extracted and units were digitized in GIS environment. Then, considering formation sensibility to erosion, a score between 1- 10, low to high sensibility, was determined according to table (1). Next, through an average weight, sensibility level and following it, geology factor in each sub-basin was determined according to table (7) using following equation:

$$Y1= X1 \qquad \text{Equation 1}$$

Where

X1 is the ratio of stones sensibility to erosion.

Soil

Soil erosion amount of the area studied is estimated based on Wishember diagram of land unit Gerophil control properties including; sand, silt, fine sand and organic matter ratio according to table (2) for the whole land unit soils of the area and eventually, through an average weight, soil erosion values of each sub-basin are determined and following that, using the equation provided below, the number of soil factors in each sub-basin is acquired according to table 7.

$$Y2= 16.67\, K \qquad \text{Equation 2}$$

Where

K is soil erosion.

Climate

According to meteorological data reported, 6-hour precipitation with a return period of two years is the same for all sub- basins since, considering small size of the basin, climatic changes are little and these values are the same for all sub-basins or in some cases, they contain very little difference. Therefore, in the area studied, the number of factors is estimated the same using following equation for all basins and according to table (7):

$$Y3= 0.2X3 \qquad \text{Equation 3}$$

Where

X3 is six-hour precipitation with a two-year return period.

Runoff

First, according to table (3), particular annual peak discharge values and annual runoff in each sub-basin is extracted from hydrologic report of the area studied and after corresponding coefficients are enforced using the equation provided, runoff values for each sub-basin are acquired according to table (7).

$$Y4= 0.2X4 \qquad \text{Equation 4}$$

Where

X4= (50* particular annual peak discharge + annual runoff * 3%)

Topography

Using GIS software, first, slope map is prepared for the whole basin and after weighted average values are acquired, mean gradient is obtained according to table (4) in each sub-basin and after it is replaced in corresponding equation, topographic values in each sub-basin is determined according to table (7).

$$Y5 = 0.33X_5 \qquad \text{Equation 5}$$

Where

X_5 is mean slope.

Land cover

Using land cover map, soil cover data and land uses, the values of bare soil for all land uses are determined and following that, by weighted average method, bare soil value in each basin is obtained (table 5) which once replaced in following equation, vegetation values in each sub-basin are acquired according to table (7).

$$Y_6 = 0/2X_6 \qquad \text{Equation 6}$$

Where

X_6 is bare soil value.

Land use

Based on soil cover data for all land use types and vegetation map, first, canopy values of all land use types and then through weighted average method, canopy values in each sub-basin is identified. In the end, using the equation and values provided, land use factor in each sub-basin is acquired according to table (7).

$$Y_7 = 20 - 0/2\, X_7 \qquad \text{Equation 7}$$

Where

X_7 is canopy value.

Surface erosion

After field visits are carried out on area surface lands and erosion feature map is prepared for all erosion units identifying values for seven factors i.e. dirt, surface litter, paving, prominences resulted from rill erosion, waterways and gales, soil factor values are obtained. After weighted average is carried out, soil factor of each sub-area and following that, once replaced in the equation above, erosion status in each sub-area are identified according to table (7).

$$Y_8= 0/25\, SSF \qquad \text{Equation 8}$$

Where

SSF is soil factor.

River erosion

Values for this factor are determined when erosion units are visited and once weighted average is obtained, the number of this factor in each sub-area and following that, replacing in above equation, waterway erosion and sediment move values for each sub-area are obtained according to table (7).

$$Y_9 = 1/67 X_9 \qquad \text{Equation 9}$$

Where

Y_9 is gale erosion value.

Determining particular sediment and erosion class

Once values of nine factors considered in PSIAC model are determined and their sum in each sub-area is obtained according to table (7) and following equation, erosion class and particular sediment in each sub-area are acquired according to table (8).

$$QS = 38.77\ e^{0/0353\ R} \qquad \text{Equation 10}$$

where QS is annual sediment amount on the basis of cubic meter in square kilometer and R is deposition degree. Considering inaccessibility of particular weight of sediments, average particular weight is 1.3 tons per cubic meter and by multiplying particular sediments amount, particular sediments weight is obtained.

Discussion and conclusion

The efficiency and reliability of a model is determined by comparing estimation level of the method considered through values recorded by measurement devices. In this research, results from sediment studies and discharge statistics are analyzed and they are compared with results from PSIAC model. According to real statistic analysis, total amount of sediment produced in basin is 30.3 tons per hectare per year and in PSIAC model, this amount is 27.88 tons per hectare per year. Figures show little difference so in current situation, this model is efficient for the studied basin. Results of this research can be helpful in reviewing other models an methods in the region identifying strength and weak points of PSIAC there. Considering data information layers prepared in GIS software, sediment statistics for each unit and sediment map produced according to model properties ranking in each unit and review of parameters necessary for each unit, the basin was zoned regarding sediment level and through erosion class identification, PSIAC model, according to erosion class and sediment level of basin, is classified as a High class. Among factors influencing the erosion, according to soil erosion and sediment production of Sardasht basin, land cover and land use with 15.24 scores are first and weather with 4.11 scores is the last in rank and other factors (runoff, surface geology, river erosion, soil, ruggedness, surface erosion) with the scores 4.97, 6.38, 6.98, 9.42, 10.33 and 11.53 in order, are considered as third to eighth in basin erosion. Regarding total score of nine factors mentioned for sub-basins, D7 (100.1) is first and D1 (81.33) is the last in rank and other sub-basins D6, D2, D4, D5, D3, D1 with their scores 96.53, 95, 94.85, 9026, 85.76 and 83.06 are second to seventh in rank. Regarding particular erosion in sub-basins, D7 with 34 tons per hectare per year contains highest erosion and sub-basins D3 and D4 with 15 tons per hectares per year contain lowest erosion level and other sub-basins i.e. D6, D2 and D1, D5 and D1 with 28, 26 and 24 tons per hectares per year are placed in remaining ranks.

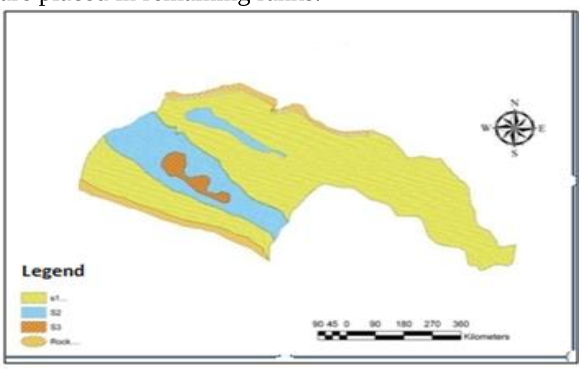

Fig 3. Soil map of Sardasht basin

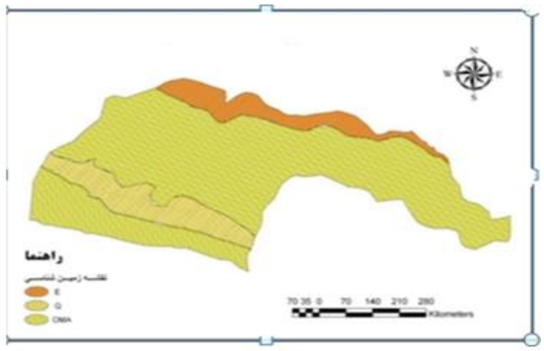

Fig 4. Geological map of the studied area

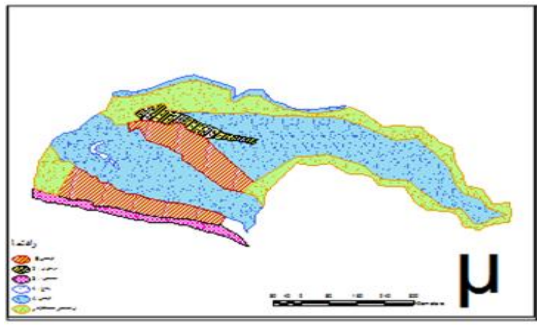

Fig 5. Vegetation map of studied area

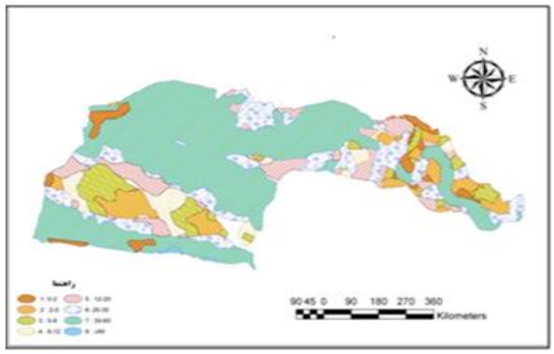

Fig 6. Slope map of Sardasht basin

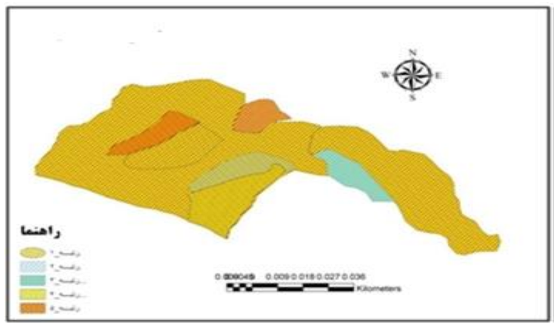

Fig 7. Erosion ranking map of the area

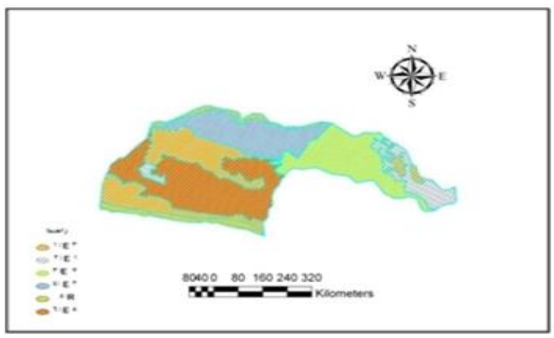

Fig 8. Erosion distribution map

Table 1. Sensibility ratio of geological formations

no	Dominant rock	Sensibility ratio
1	Q	10
2	OMA	6
3	E	5

Table 2. Soil erosion values

Land unit	Silt +vf. sand%	% o.m	Soil erosion (k)
S1	50	1.53	0.55
S2	50	0.99	0.64
S3	47	1.45	0.50

Table 3. Particular annual peak discharge

Particular peak discharge of flood (m^3/s. km^2)	Runoff height (mm)	Sub-basin
0/48	127/8	D1
0/89	124/3	D2
1/6	124/65	D3
1/21	102/76	D4
1/22	101/27	D5
1/06	111/71	D6
1/25	104/52	D7
0/43	112/31	D‘1
0/43	112/31	basin as a whole

Table 4. Mean slope

Sub-basin	Mean slope (%)
D1	25/4
D2	23/2
D3	35/1
D4	30/1
D5	28/7
D6	32/6
D7	31/3
D1‘	31/3
The whole basin	31/3

Table 5. Grassland type soil cover data of studied area

Type code	Type name	Canopy (%)	Bare soil(%)	Stone & gravel (%)	Brushwood (%)
1	AS.ad – Da.mu	43	41	9	7
2	As. Sp – Da. mu	39	48/5	7/5	5

Table 6. Determining annual sediment production and soil erosion class by PSIAC method

	Values showing deposition level (R)	Annual sediment production	Erosion level	Deposition & erosion class
	ton/ square kilometer	Cubic meter/ square kilometer		
>100	>2143/5	>1429	Very much	V
-100 75	714-2143/5	476-1429	much	IV
50-75	357-714	238-476	average	III
25-50	142/5-357	95-238	little	II
0-25	<142/5	<95	Very little	I

Table 7. The effect of nine factors in studied sub-basins

Deposition level	Class erosion	Area (KM^2)	total	Y9	Y8	Y7	Y6	Y5	Y4	Y3	Y2	Y1	Sub-basin
high	IV	/47 13	81/33	6	14/25	14	14	8/38	5/57	4/11	6/17	5/85	D1
high	IV	2/6	95	9	13/75	14	14	7/66	9/65	4/11	9/17	6	D2
high	IV	2	85/76	2	8/75	14	14	11/58	16/75	4/11	9/17	5/40	D3
high	IV	2/4	94/85	7	11/75	16/8	16/8	9/93	12/72	4/11	9/5	6/24	D4
high	IV	3/9	90/26	4	9/75	16/96	16/96	9/47	12/81	4/11	9/67	6/63	D5
high	IV	2/8	96/53	12/5	13	14/65	14/65	10/76	11/27	4/11	9/34	6/25	D6
high	IV	5	100/1	11	11/75	16/37	16/37	10/33	13/13	4/11	9/84	7/19	D7
high	IV	/2 27	83/06	6/20	10/25	15/55	15/55	10/33	4/97	4/11	9/5	6/6	D'1
high	IV	/4 59	84/2	6/98	11/53	15/24	15/24	10/33	4/97	4/11	9/42	6/38	Basin as a whole

Table 8. Particular sediment and erosion class

Particular erosion (Ton/Ha.Y)	Particular sediment (Ton/ha.y)	Sediment production ratio SDR(%)	Surface (KM^2)	Sub-basin
21/51	8/82	41	13/47	D1
26/92	14/27	53	2/6	D2
18/41	10/31	56	2	D3
15/26	14/19	55	2/4	D4
24/73	12/12	49	3/9	D5
28/96	15/06	52	2/8	D6
34/15	17/07	50	5	D7
24/03	9/37	39	27/2	D'1
27/88	9/76	35	59/4	Basin as a whole

Acknowledgment

It's a pleasure to thank Shahrekord Agricultural Organization for providing us required information and statistics.

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