Evaluation of soil erosion and sediment yield using semi quantitative models: FSM and MPSIAC in Eivaneki watershed and the sub basins (Southeast of Tehran/Iran)

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Abstract: Soil erosion and sediment yield are the most important environmental problems that should be considered. Erosion is not only causes of soil degradation but also fills dam reservoirs; irrigation structures and decreases their capacity. Because of no sediment reservoir (check dams) at the Eivaneki watershed outlet that can show the yearly sediment yield, both of the semi-quantitative models (FMS and MPSIAC) are used to evaluate the annual rate of sediment in five Eivaneki watershed sub basins. In modified FSM model five factors: topography, vegetation, gully erosion, lithology and watershed shape with the score range of 1 to 3 were studied and scored. The nine MPSIAC model factors consist of: lithology, soil, climate, run off, topography, vegetation cover, land use, surface erosion and channel erosion. The specific sediment yields that were evaluated by using FSM model are 0.91 ton/ha/y and 3.21ton/ha/y with MPSIAC. Also rainfall simulator was used in order to classify the erodible formation in Eivaneki watershed. After evaluating the rate of sediment in Eivaneki watershed, these quantitative values compared with each other and the result of Eivaneki gauging station (0.93 t/ha/y). Results showed that FSM evaluation was nearer to SSY than MPSIAC.
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Introduction:

Erosion is the result of weathering of rocks and soil loss (Feiz Nia, 2008). Soil erosion is one of the important environment problems that should be considered. Every year million tons of sediments, deposit in the rivers, lakes, reservoirs and dams that will be accumulated and we spend heavy cost for dredging them (Goldman &colleagues, 1986). The frequent flooding causes of destruction of farmlands, roads, and contaminates of drinking water.

Sedimentation yield potential in Eivaneki watershed is high due to natural conditions such as: formation erosion, human activities, agriculture and animal husbandry. Therefore estimating of the sediment yield and sensitive erosion areas for soil conservation in this region is necessary. Due to lack of tanks or reservoir at the end of this watershed, information and statistics of water discharge and annual precipitation amount is not available .So it was so appropriate to use empirical methods to estimate the rate of soil erosion and Sediment Yield (Refahi, 2009).Selected models is based on weather conditions in the region, being practical and usable. (Refahi, 2009). PSIAC model with nine factors: lithology, soil, climate, runoff, topography, vegetation, land use, surface and channel erosion, was presented by the American Water Management Committee in 1968 to estimate annual sediment yield in the watershed. In 1982, Johnson & Gebhardt modified this nine environmental factors into numerical equations that brought this model to the semi quantitative model (MPSIAC,Table 1). Because this model is consist of most factors that affecting soil erosion, it is suitable for evaluating of erosion and annual sediment yield in the watershed. A second semi-quantitative model is Factorial Scoring Model (FSM), one of the newest models of estimating the annual sediment yield. Verstraeten & their colleagues presented FSM in 2003 and it was used to evaluate the erodibility of watersheds in Spain. De Vente and poesen modified this model in 2005, and khoddami and his colleages used that for the first time in Iran to evaluate annual sediment yield in Latshoor watershed in 2006.

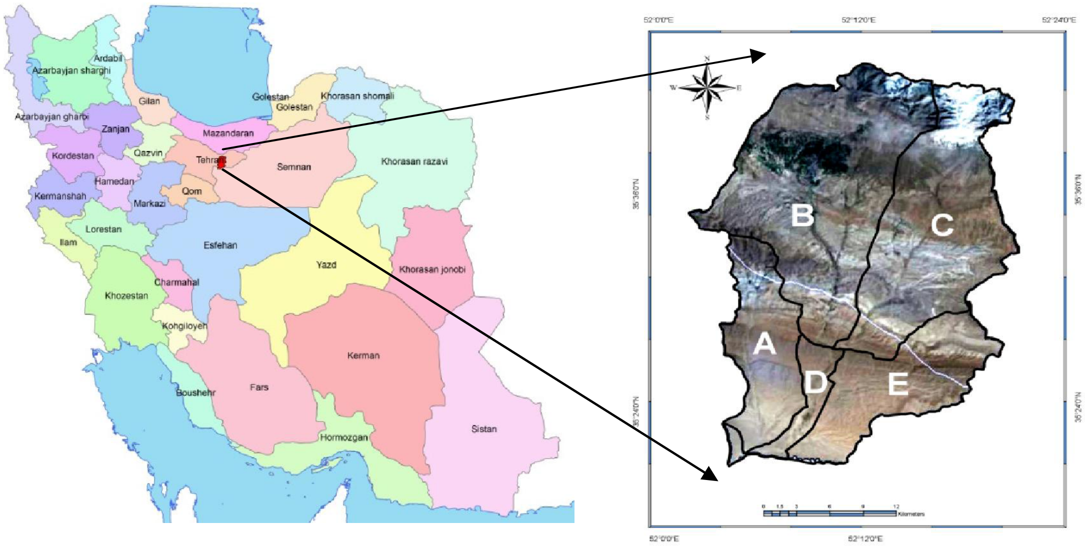

Fig 1.Location of Eivaneki watershed and its sub basins (A, B, C, D, E)

Study area

Eivaneki river watershed with an area of 800 square kilometers. is part of central desert basin in Iran and is located in south east of Tehran .The study area is located between northern latitude 52^8, 01 to 52^8, 219 and eastern longitude 35 ,209 to 35 ,439 Northern part of the central Alborz Mountains and southern part of the city that is known Eivaneki. The main river with the same name flows from north to south of watershed with the length of 50 Km. Mainly older and more rigid geological formations are located in the northern areas and erodible formations such as Neogene are in the middle to the end of area.

Considering the physiographic data and information that obtained from topographic and lithology maps, five sub basins A, B, C, D and E were assigned (Figure1).

Material and methods

In this research, in order to evaluate of erosion rate and sediment yield of Eivaneki (SSY) watershed and its sub basins using MPSIAC and FSM, we had to determine the watershed area. For this purpose first the basic topographic maps with the scale of 1:50,000 (Army Geographic Organization, 2002 and lithology maps with scale 1:100000 (Garmsar region 2004 & Damavand 2003) were studied and digitized. Also satellite images (LANDSAT 2001/ASTER 2006 /Google Earth 2009) in GIS environment were used to draw the watershed and its sub-basins border line. Collection data for the scoring gathered by study on site and incorporated with geological maps, topography, geomorphology, slope, land units, land use maps that were obtained in GIS environment (Mohamadiha, 2009).

MPSIAC Model

In this semi-quantitative model, nine erosion factors depending on levels of erodibility were scored between one to ten, then using the equation for each factor, values were modified, (Johnson and & Gebhardt 1982, Table 1.)

After scoring and adding the factors, the MPSIAC index is obtained. The relation between the specific sediment yield (t/km^2/year) and MPSIAC index is shown in equation [1]:

$$Qs=SSY=0.253e^{R0.036} \qquad [1]$$

Notice: In this research, Surface soil sampling in each land unit was taken in order to determine soil texture and scoring soil factor(X2) in MPSIAC model.

FSM Model

Factorial Scoring Model is a semi quantitative model that consists of five factors(table2,Verstraeten et al.,2003;de Vante et al.,2005) .In This model each factor is scored between 1-3, after field study and additional information that was extracted from various data sources(see materials and methods), topographic map and watershed physiographic .This model is based on drainage area(A:km2) and FSM index that obtained by multiplication of the five erosion factors(de Vante et al 2005,equation[2]):

$$SSY=4139*A^{-0.44}+7.77*FSMIndex-310.99 \qquad [2]$$

Rain fall simulator

Lithology is one of the important factors in both of semi quantitative erosion models that should be classified. Scoring was based on their erodiblity in the watershed. Therefore in addition of using Shariat Jafari et al(2006) and Feiznia (1996) methods for scoring this erosion factor , we used portable rainfall simulator on erodible formation (on site) to evaluate run off rate and the relative erodibility (Fig 2) .

Rain fall simulator with surface dimension of precipitation 25 × 25 cm with elevation of precipitation 40 cm was used. Before using the device it was calibrated with intensity 30 and 60 mm per hour. The tests were done only on accessible formations with gentle slopes (less than 30 percent) with two repeats, overall twenty seven plots were examined. Samples were transferred to the laboratory and the volume of runoff and weight of deposits were determined. At last the formations were classified with Duncan technique (Mohamadiha, 2009, Table 3).In each land unit on site, soil sampling was taken in order to determine soil texture for scoring soil factor(X2) in MPSIAC model (Table 3).

Results and discussion

After studying on prepared maps that mentioned before , field surveying ,analysis results of rain fall simulator (Table 3) ,soil texture and physiographic of Eivaneki watershed, factors in MPSIAC and FSM semi quantitative models in this area and the sub basins were scored and modified (table 4 & 5).Also annual erosion rate was classified in this watershed (table 6).

Table 1. Nine MPSIAC factors and their modification are sh (Johnson and Gebhardt, 1982).

Erosion factors	Modified factors	parameters
lithology	Y1=X1	X1=Geological erosion index
Soil	Y2=16.67X2	X2=Soil erodibility factor
climate	Y3=0.2X3	X3=6-hour rainfall with a 2-year return period
runoff	Y4=0.006R+10Qp	Q_p= annual specific Debi (m^3/skm^2) R=annual of runoff Height (mm^3)
topograghy	Y5=0.33X5	X5=Percentage of the average basin slope
vegetation	Y6=0.2X6	X6=Percentage of land without vegetation
Land use	Y7=20-0.2X7	X7=Percentage of vegetation cover
Surface erosion	Y8=0.25X8	X8=total surface soil factor scoring in BLM*
Channel erosion	Y9=1.67X9	X9=Gully scoring in BLM*

*BLM: Breau of Land Management (Refahi 2006)

Table 2. Description of the Factorial Scoring Model (FSM) (Verstraeten et al., 2003; de Vante et al.,2005).

Factor	Score	Description
Topography	1	very gentle slopes, elevation difference <200 m within 5 km
	2	moderate slopes, elevation difference 200-500 m within 5 km
	3	steep slopes, elevation difference >500 m within 5 km
Vegetation cover	1	good contact cover of soil(>75% protected surface)
	2	moderate contact cover (25-75% protected surface)
	3	poor contact cover (<25% protected)
Gullies	1	bank and ephemeral gullies are very rare
	2	few bank and/or ephemeral gullies
	3	many bank/or ephemeral gullies
Lithology	1	limestone, sandstone, conglomerate(low weathering degree)
	2	Neo gene sedimentary deposits(gravel, silt, etc)
	3	strongly weathered(loose) material and/or marls
watershed shape	1	elongated watershed shape, one main river channel draining to the reservoir
	2	between elongated and semi-circular watershed shape
	3	semi-circular, circular watershed shape with many rivers draining to the reservoir

Fig 2.rainfall simulator that was used on site to evaluate the relative erodibility of formations.

Table 3 - Comparison of average runoff and sediment lithology units earned in Eivaneki watershed results obtained from the rain simulator classification with Duncan technique (Hassanzade nofuti et al 2008, mohamadiha, 2009)

Lithology factor scoring MPSIAC	erodibility	Sediment average amount(g)	Runoff average volume(cc)	Lithology	Lithology unit	Formation
6	Very high	32.57	410	alluvial	Q	terrace
5	Very low	3.3	283	Conglomerate, sandstone	Plc	Kahrizak
10	Very high	75.66	820	Marl, shale	M3	Upper red
8	high	53.58	650	Marl, sandstone	M2	Middle red
5	medium	27.06	603	Marl, sandstone, shale	M1	Lower red
4	medium	27.52	620	Chalk, marl, limestone	Om	Qum
9	Very high	69.61	690	Marl, chalk	Ekn_{gy}	Kond
2	low	11.04	366	tuff	Ek_{tms}	Karaj
9	Very high	70.65	855	Red shale	Ks	Cretaceous red shale

Table4.Scoring erosion factors of MPSIAC model in Eivaneki watershed and its sub basins.

Erodible factors	Sub A	Sub B	Sub C	Sub D	Sub E	Eivaneki
lithology	7.10	5.87	6.01	8.14	7.44	6.59
soil	6.32	5.68	5.69	7.24	6.36	6.16
weather	3.47	4.25	4.1	3.14	3.26	3.98
Run off	2.87	11.48	9.42	0.3	1.76	7.48
topography	5.93	6.57	7.64	3.66	7.65	6.84
vegetation	10.36	7.23	7.12	9.05	8.93	8.47
Land unit	16.48	15.31	14.69	15.20	16.06	12.92
Surface erosion	11.93	10.54	10.79	14.30	12.06	11.57
River erosion	6.91	5.30	6.20	9.07	8.27	6.78

Table 5- Scoring factors of FSM model in Eivaneki watershed and its sub basins.

tershed	FSM index	Area Km2	SSY(ton/km2/y)	SSY(ton/ha/y)
A sub-basin	22.18	108	390	3.90
B sub-basin	31.36	319	260	2.60
C sub-basin	30.17	241	294	2.94
D sub-basin	22	36	719	7.19
E sub-basin	18.9	131	320	3.20
Eivaneki	24.13	800	95	0.91

Table 6.Erosin class and annual sediment yield in Eivaneki watershed and the sub-basins according to MPSIAC semi quantitative model.

watershed	Perimeter (km^3)	Total score	SSY($m^3 3km^3$)	SSY(ton3ha)	Erosion class	Erosion rate
A sub-basin	108	71.26	261.83	3.56	III	medium
B sub-basin	319	72.24	251.75	3.42	III	medium
C sub-basin	241	71.68	247.39	3.36	III	medium
D sub-basin	36	70.10	250.72	3.41	III	medium
E sub-basin	131	71.79	268.22	3.64	III	medium
Eivaneki	800	71.59	262.83	3.57	III	medium

Table 7. Evaluation of annual SSY in Eivaneki watershed by using gauging station data. (Mohamadiha 2009).

Suspension load(ton/ha/y)	Bed load (ton/ha/y)	SSY(ton/ha/y)
0.78	0.156	0.93

Due to lack of reservoir or dam in the outlet of the watershed in order to compare SSY with results of MPSIAC and FSM semi quantitative models, we compared these results with the Annual sediment yield evaluation by using gauging station data in this watershed (mohamadiha 2009). Annual sediment yield in Eivaneki watershed equal to 0.93 ha. Per year was estimated (table 7). The amount of suspension load was evaluated in direct measurement (Walling, 1994). With using recently 22 years data gauging station at the outlet of watershed (WRO, 1983-2005)due to mean of Eivaneki guaging station that should be added with the bed load .There was several problems due to lack of information to estimate the real bed load rate(Webb, Walling 1987). The average ratio of bed load to suspended load in rivers plain 7 percent and 23 percent in mountainous rivers were determined (Walling and Webb, 1987). In Iran with considering of geographic and climate conditions, bed load was determined between 15 to 30 percent (Hakimkhani & Faiznia, 2003, Arabkhedri 1998). According to the conditions of Eivaneki watershed the bed load in this area was considered as 20 percent. Also the FSM results should be lower than actual rates because in large watersheds depends on their physiographic(especially in large and long watershed), the sediments would be trapped and remain in the back of point bar in areas where the slope is too low. Therefore, the amount of sediment at the end of watershed could be less than real rate.

Table 8. Estimated annual sediment (SSY) in Eivaneki watershed used following methods.

The methods have been used in estimating SSY	SSY(ton/ha/y)
Gauging station	0.93
FSM model	0.91
MPSIAC model	3.21

Conclusion

Analyzing the results of this study indicated that:

-Evaluation of SSY using semi quantitative MPSIAC, classified Eivaneki watershed and the sub basins in medium erosion rate (class III). Also showed that the maximum erosion rates were belonged to A and E sub basin (table 6).

-Results of FSM model showed that maximum erosion in Eivaneki watershed respectively is in D, E and A sub basins. The cause of large amount of erosion in sub D is that the channel in this sub basin is the major channel in Eivaneki watershed and brings lots of sediment from upper area .Also the exaggeration of this amount is because of small area and physiographic characteristic of D sub basin that is considered in FSM semi quantitative model.many researches are showed that the marl basins like sub A, D and E have more erosion and sediment yield than the basin with limestone, sandstone and schist (Feiznia, 1995, Lahloh,1988 ,Woodward, 1995).

-The results of rain fall simulator test on the lithology formations is consistent with Shariat Jafari et al (2006) and Feiznia (1996) methods for scoring the erosion factor and also with sediment yield and is recommended to use as a method in the same research. Also was found that erosion rate in the middle and lower sub basins (sub A, E) in Eivaneki watershed is more than upper sub basin in according to the lithology, areas and physiographic (Table 6).

- Compare of evaluating the annual sediment yield (SSY) by using gauging station, semi quantitative FSM and MPSIAC model results showed that FSM has more near amount with gauging station result than FSM model (Table 8).

-The large amount of SSY in MPSIAC model and the difference between FSM and MPSIAC is according to area and physiographic of watershed that mentioned in FSM.

-MPSIAC model showed the maximum of erosion and needs more modification. It has been suggested that soil and lithology factors in MPSIAC model, be combined and also channel erosion factor be replaced with sediment and hydraulic characteristic of the channel (Strand & Pemberton 1987).

-It seems In FSM model , in long and large watershed(Eivaneki) a big amount of sediments has trapped in point bar and low land dip of Eivaneki braided river.

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