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ORIGINAL ARTICLE

Evaluation of Soil Erosion and Sediment Yield Using Some Semi-Quantitative Models Based on GIS and RS Data (Case Study: Amameh Watershed, Iran)

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ABSTRACT
Soil, the basic foundation of most vegetable coverings, is one of the most valuable natural resources. In recent decades, because of the increasing population and inefficient water and soil management issues, soil degradation was increased over the basins. Soil erosion can be a potential treat in economic, social, cultural and even political fields. One of the main aspects in soil erosion studies is estimation of the soil erosion and sediment yield amount in basins. There are many different models The present study aimed at estimating soil erosion and sediment yield in Amameh Watershed using semi quantitative models: GAVRILOVIC, PSIAC, MPSIAC and Fournier (1960), Fournier (1962) and two qualitative models: FAO and BLM using a GI System. The accuracy of models was calculated based on relative error index comparing with the observed sediment data. The comparison among specific sediment yield (SSY) which obtained from observed sediment data and SSY from applied models were done using one sample t-test. The results show significant difference between observed and estimated values (Pvalue<0.05). However the results also show the MPSIAC model has the lowest relative error and the Fournier (1962) has the highest relative error which is 93 percent and 275 percent respectively.
Keywords; *Soil erosion, Sediment yield, Geographic Information System, Modeling*

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INTRODUCTION

Soil erosion is one of the most prominent environment problems that should be taken under consideration. Every year million tons of sediments deposit in the rivers, lakes, reservoirs and dams that will be accumulated and human spend heavy cost for dredging them [1].
Not only erosion causes the soil enrich and (not only it) makes the farms deserted, as the result of which irretrievable damage are left, but also the sedimentation of mud and material in water streams and behind dams and also the reduction at their water- taking capacity leads to unbearable damages. [2].
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 [3]. Thus, soil erosion is one of the important components of watershed management which also involves planning and managing terrestrial and aquatic ecosystems, surface and groundwater and land use planning [3]. Modelling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces [4]. Empirical mathematical methods are an inseparable part of any erosion research to estimate the amount of sedimentation [5]. Land degradation is defined as the reduction in physical, chemical or biological status of land, which may restrict its productivity capacity and can occur under wide variety of conditions and circumstances [6].
The changes in the land status are linked to geological, biological and socio-economic processes of varying magnitude, severity and effects. These conditions can occur due to global changes, intense exploitation, and inadequate land use and accelerated natural processes such as flooding gravitational mass

movements and anthropogenic influences [7]. Land degradation is portrayed as world's major environmental problem and is perceived as a key indicator of crises in the environment of developing countries [8]. Land degradation causes dramatic decrease in prime lands, and now, only 3% of the global surface is left prime or class 1. Land degradation assessment is necessary to know the degree of damage and to know whether land degradation is reversible or controlled [8]. Globally, an estimated 954.8 million hectares of land is affected by salinity and sodality, and about 1.9 billion hectares of land worldwide (an area approximately the size of Canada and the USA) is affected by land degradation [9]. Several methods of land degradation assessment are available but the use of the geoindicators is recommended because geoindicators identify a minimum set of parameters that describe short-term environmental disturbances, degree of damage and are proxies representing all the parameters on which land degradation processes depend [10]. The role of erosion and sediment production in reducing the soil fertility, reducing the volume of dewatering of dams, filling the reservoirs clogging waterways, Mud contaminated river, reducing water quality and water pollution of the downstream areas (some sediment pollutants act as a carrier) that was identified and considered by the experts of the Water and Earth Science [11, 12]. Resource map preparation for watershed management such as soil erosion map can be assisted by spatial information processing using Geographic Information System (GIS) [13]. 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 [14]. Geographic Information System (GIS) is one of the most important tools to manage resources. The present study aimed at estimating erosion and sedimentation rate in Amameh Watershed using GAVRILOVIC, PSIAC, MPSIAC, FAO, BLM, and Fournier [15]. Moreover, using GIS based on their proven performance in watersheds of Iran, the study aimed at estimating these systems' efficiency in erosion and sediment studies and ultimately at reducing the volume of sediment in watershed and behind dams.

MATERIALS AND METHODS

Study area

Amameh Watershed is one of the famous watersheds of Iran, which is located in the Jajrood River basin and at the upstream of Latyan Dam. It is located between the longitude 32° 51' to 51° 38' east and latitude 35° 51' to 35° 58' north with an area of 37 Km2. The maximum and minimum elevations of the study area are 3868 and 800 meters above the mean sea level, respectively. The north and south parts consists of high steep slopes and the middle part consists of low slopes with an area of about 200 hectares. Amameh River flowing from northeast to southwest is the main river. This river is located in the east side of Lashgarak-Shemshad Road and 48 kilometers northeast of Tehran, where Amameh- Bala and Amameh-Pa'in villages are located. This area is limited to the north by southern elevations of Lar valley; to the west by Oshan Kooh and eastern highlands of Jajrood River basin; to the east by Rahat Abad and Koosa highlands; and to the south by the Jajrood River and Golukan Village. Topographically, this area is mountainous and consists of two parallel mountain ranges located along the northeast-southwest. In the middle part, it is relatively flat triangular shaped comprising Amameh- Bala and Amameh- Pa'in villages [16]. This watershed has two hydrometric stations: Bagh Tangeh and Kamarkhani and two weather stations: Amameh and Golukan which are located at the centre and outlet of watershed respectively.

Methods

In order to evaluate soil erosion and sediment yield, GAVRILOVIC, PSIAC, MPSIAC, FAO, BLM, and Fournier [15] Models were used. These empirical models are widely used in many watersheds in Iran. Some of these models are qualitative such as and FAO, BLM and some models are semi-quantitative such as GAVRILOVIC, PSIAC, MPSIAC, and Fournier [15]. Most of these models focus on some main processes that affect soil erosion and sediment transport in watersheds.

Some models focus on specific type of erosion and sediment process such as rill and inter-rill or gully etc., and some models evaluate different types of erosion and sediment processes such as rill and inter-rill, gully and bank erosion. Selected models in this study focus on different types of erosion and sediment processes at the basin.

Factors used to describe erosion and sediment transport process in selected models are land use, slope, precipitation amount and intensity, runoff and peak runoff rates, current erosion condition, soil condition, and surface roughness.

PSIAC AND MPSIAC

One of the most famous semi-quantitative models in Iran is PSIAC (PSIAC, 1968) and modified PSIAC [17] which the original model was developed by the Pacific Southwest Inter-Agency Committee (PSIAC) for application in arid and semi-arid areas in the south-western USA. The model widely used in many of the watersheds of Iran. This model consists of a rating technique that characterises a drainage basin in terms of sensitivity to erosion, possibilities for sediment transport and floodplain storage, the protective role of vegetation, and the influence of human land use practices. Nine factors characterise a drainage basin by providing a score to each factor. The sum of the nine scores of a drainage basin gives an index that is related to an area-specific sediment yield (SSY). The modified PSIAC was presented by Johnson and Gebhart [17] who introduced empirical relations to assess the score of each factor and to reduce the subjectivity of the assessment. Scoring system of nine factors of PSIAC is shown as table 3.

Table 1-The factors of the PSIAC model

score	Factor and Description
	Surface geology
0	(a) massive hard formations
5	(a) rocks of medium hardness, (b) moderately weathered, (c) moderately fractured
10	(a) marine shales and related mudstones and siltstone
	Soils
0	(a) high percentage rock fragments, (b) aggregated clays, (c) high in organic matter
5	(a) medium texture, (b) occasional rock fragments, (c) caliche layers
10	(a) fine texture, easily dispersed, saline–alkaline, high shrink–swell characteristics, (b) single grain silts and fine sands
	Climate
0	(a) humid climate with rainfall of low intensity, (b) precipitation in form of snow, (c) arid climate with low-intensity storms, (d) arid climate with rare convective storms
5	(a) storms of moderate duration and intensity, (b) infrequent convective storms
10	(a) storms of several days duration with short periods of intense rainfall, (b) frequent intense convective storms, (c) freeze–thaw occurrence
	Runoff
0	(a) low peak flows, (b) low volume of runoff per unit area, (c) rare runoff events
5	(a) moderate peak flows, (b) moderate volume of flow per unit area
10	(a) high peak flows, (b) large volume of flow per unit area
	Topography
0	(a) gentle upland slopes (<5%), (b) extensive alluvial planes
10	(a) moderate upland slopes (<20%) (b) moderate floodplain development
20	(a) steep upland slopes (>30%), high relief, little or no floodplain development
	Ground cover
-10	(a) completely protected by vegetation, rock fragments, litter; little opportunity for rainfall to reach erodible material
0	(a) cover <40%; noticeable litter, (b) if trees present understory not well developed
10	(a) ground cover <20%, vegetation sparse, little or no litter, (b) no rock in surface soil Land use
	Land use
-10	(a) no cultivation, (b) no recent logging, (c) low-intensity grazing
0	(a) <25% cultivated, (b) 50% or less recently logged, (c) <50% intensively grazed, (d) ordinary road and other construction
10	(a) >50% cultivated, (b) almost all of the area intensively grazed, (c) all of area recently burned
	Upland erosion
0	(a) no apparent signs of erosion
10	(a) about 25% of the area characterised by rill and gully or landslide erosion, (b) wind erosion with deposition in stream channels
25	(a) >50% of the area characterised by rill and gully or landslide erosion Channel erosion and sediment transport
	Channel erosion and sediment transport
0	(a) wide shallow channels with flat gradients, short flow duration (b) channels in massive rock, large boulders or well vegetated, (c) artificially controlled channels
10	(a) moderate flow depths medium flow duration with occasionally eroding banks or bed
25	(a) eroding banks continuously or at frequent intervals with large depths and long flow duration, (b) active headcuts and degradation in tributary channels

Based on the range of the summation of nine factors scores, the PSIAC Index can be categorized to five classes and determined and translated into an estimated sediment yield and a descriptive Index class (For the Pacific Southwest USA) (table 4). According to the table 4, soil erosion and sediment yield can be interpret and determine qualitatively and quantitatively and it can be shown as a classified map.

By quantitative interpretation in the studied area, the obtained map would be specific destruction map or specific sediment or erosion map of that sub area. Specific destruction is defined as total eroded materials per year per tons divided by the study area in hectares.

Table 2-The sum of factors classes and SSY factors of the PSIAC model

Descriptive classes	Range of sum of scores (PSIAC Index)	SSY range (t/km2/year)
Very high	>100	>1830
High	75–100	610–1830
Moderate	50–75	300–610
Low	25–50	120–300
Very low	0–25	<120

For the Pacific Southwest, the relation between area-specific sediment yield (t/km2/year) and the PSIAC Index is:

$SSY= 48.594e^{0.0364 \text{PSIAC Index}}$

In order to calculate area-specific erosion rate, the SDR (sediment delivery ratio) can be used according to the simple monograph for the Pacific Southwest.

The Gavrilovic model

Gavrilovic model is well known as Erosion Potential Model (EPM) in Iran. This model is a semi-quantitative method for erosion and sediment yield and it was originally developed for application in torrential basins of south and south-eastern Yugoslavia, but it was widely used in watersheds of Iran. Erosion in the Gavrilovic method is calculated from 4 main factors: soil protection factor, soil erodibility factor, the type and severity of erosion, and the average slope of basin. Furthermore, the annual precipitation, temperature, mean elevation, perimeter and surface area of the watershed, length of the principal waterway, and cumulated length of secondary waterways considered.

The erosion rate, as calculated for each watershed, is summed to provide the erosion rate for the whole basin. The Gavrilovic model uses a scoring approach for only three descriptive variables (soil cover, soil resistance, type and extent of erosion), whereas the other variables are quantitative descriptors of the catchments conditions. The relations used for erosion and sediment yield description are shown as below. The values used for the factors are presented in Table 5.

GSP= Ru *WSP

WSP = T*H*π*Z1.5*A

Z = Xa*Y*(ψ + I0.5)

T= [(t/10) + 0.1]0.5

Ru= [(P*D) 0.5*(lp+la)]/[(lp+10)*A]

in which, GSP: Watershed sediment yield (m3/year), Ru: sediment retention coefficient (–), WSP: average annual gross erosion (m3/year), T: temperature coefficient (–), H: average annual height of precipitation (mm/year), Z: erosion coefficient, A: area of the watershed (km2), Xa: coefficient of soil cover or land use, Y: coefficient of soil resistance, and ψ: coefficient of type and extent of erosion, I: average slope steepness of the watershed (%), t: annual average temperature (oC), P: perimeter of the watershed (km), D: average elevation of the watershed (km), lp: length of the principal waterway (km), la: cumulated length of secondary waterways (km).

Table 3- Descriptive factors used in the Gavrilovic model

Coefficient of soil cover	Score
Mixed and dense forest	0.05–0.20
Thin forest with grove	0.05–0.20
Coniferous forest with little grove, scarce bushes, bushy prairie	0.20–0.40
Damaged forest and bushes, pasture	0.40–0.60
Damaged pasture and cultivated land	0.60–0.80
Areas without vegetal cover	0.80–1.00
Coefficient of soil resistance	
Hard rock, erosion resistant	0.2–0.6
Rock with moderate erosion resistance	0.6–1.0
Weak rock, schistose, stabilized	1.0–1.3
Sediments, moraines, clay and other rock with little resistance	1.3–1.8
Fine sediments and soils without erosion resistance	1.8–2.0
Coefficient of type and extent of erosion	
Little erosion on watershed	0.1–0.2
Erosion in waterways on 20–50%of the catchment area	0.3–0.5
Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6–0.7
50–80% of catchment area affected by surface erosion and landslides	0.8–0.9
Whole watershed affected by erosion	1.0

The Gavrilovic model for prediction of sediment in some watersheds in Europe. In table 4 according to the range of Z factor values, a descriptive classification were suggested [18].

Table 4- Descriptive classes and range of Z factor in the Gavrilovic model [18]

Descriptive classes	Range of Z values	Mean values of Z
Very high	1 < Z	1.25
High	0.71 < Z < 1	0.85
Moderate	0.41 < Z < 0.7	0.55
Low	0.2 < Z < 0.4	0.30
Very low	Z < 0.19	0.10

FAO Method

The FAO model consists of a relation between soil erosion intensity and six descriptive factors. The six factors used are Soil conservation (A), Bedrock material (B), topography and slope (C), Structure and soil aggregation (D), Agricultural operations (E) and Current state of erosion (F). The summation of these factors represents an index for soil erosion intensity as followed equation:

$$S = A+B+C+D+E+F$$

Each factor is classified using a scoring system. After a subdivision of each basin in some homogeneous terrain units, a score for each of the six factors is determined based on visual interpretation of aerial photos, Landsat Thematic Mapper satellite images, thematic maps, topographic map and field visits. The score per basin is obtained by the area-weighted average of all homogeneous terrain units.

The scores are classified in six descriptive orders with some recommendation for each class of soil erosion (table 5). Factors that considered in the FAO method are very similar to factors in PSIAC Model, However in this method there is no quantitative estimation of soil erosion or sediment yield. The scoring range of each factor is presented in the table 6.

Table 5- Factors used in the FAO method

Factor	Range of score
Surface Geology	1-18
Soil (Structure and Texture)	1-16
Topography and slope	1-16
Soil cover	1-20
Land Use	0-15
Current state of erosion	0-15
Sum of scores	4-100

Table 6- Descriptive factors used in the FAO method

Estimated score	Erosion class	Recommendation
0-8	I	Actions that are operated at the present time are acceptable.
9-20	II	Revision on land management with some modifying operations
40-21	III	Revision on land management added to modifying operations
41-65	IV	Broad and comprehensive changes in land management, application of modifying operations, and constructions
66-85	V	Comprehensive actions in land restriction, property assessment, extensive structural measures
+86	VI	Restrictions on land ownership and maximum modifying operations

Bureau of Land Management (BLM)

The American Bureau of Land Management proposed a method for evaluating soil surface condition in a qualitative procedure. In this method seven factors is considered: Soil movement by water, wind, gravity, etc. (0-14), Litter on the soil surface (0-14), State of rocks (mainly from distribution level point of view) (0-14), Consolidated rock fragments (bumps) (0-14), Rill erosion (0-14), Channels' form (0-15), Gully erosion (0-15). Each factor is categorized in five classes and the sum of scores of the seven factors called soil surface factor (S.S.F index). The erosion condition is qualitatively expressed based on the soil surface factor (S.S.F index) in five descriptive classes (table 7).

Table 7- Descriptive classes and range of scores in the BLM method

State of erosion	sum of the seven scores
Very low	0-21
Low	21-40
Average	41-60
High	61-80
Very high	81-100

Fournier methods
Fournier equations are quantitative models for estimating sediment yield in watersheds. These two equations are used in some watersheds of Iran and are consisted of four quantitative factors to calculate area-specific sediment yield (SSY). The first model [15] for estimating SSY in the watershed is:
Log SSY= [2.65*log (P2W/Pa)] + [0.46*log H*(tan S)] – 1.56
The second model (Fournier, 1962) for estimating area-specific sediment yield in a watershed is:
Log SSY= [2.65*log (PW/Pa)] + [0.46*log (H2/ A)] – 1.56
In which:
SSY: area-specific sediment yield (t/km2/year)
PW: the rainfall amount in the wettest month
Pa: the annual precipitation (mm)
H: Mean elevation (m)
S: Mean slope of the area in degrees
A: watershed area (Km2)
Using these models, the area-specific sediment yield, specific erosion, annual sediment, and annual erosion values were calculated. It should be noted that since the calculated erosion and sediment values in each model have different units, the results of annual erosion and sediment in all models turned into tons per year. Finally, the output of each model were entered GIS to produce soil erosion map.
Using a sediment rating curve based on method the Johnson method [17], the observed sediment where calculated for the sediment data from the main river of the Amameh watershed by the equation:
$Qs=aQ_w^b$
In which: Qs: Sediment yield, Qw: Water discharge, a and b: regional coefficients.
Finally the observed and estimated amount of sediment yield where comprised based on the index of relative error using the equation:

$$Error_i = \frac{Obs_i - For_i}{Obs_i} \times 100$$

In which: Obs: the observed amount of sediment yield, For: the estimated amount of sediment yield

RESULTS
The results of estimating soil erosion and sediment yield of watershed with empirical methods in the study are shown in Tables 8 to 14. In these tables, the required parameters for each model and special sediment, special erosion, annual sediment, and annual erosion values are given.
In order to estimate soil erosion and sediment produced in Amameh watershed based on the calculated values of the erosion rates coefficient for each unit, the mean value for the entire watershed was calculated. Using physical data on watershed and the relationships of specific erosion, sediment coefficient, area-specific sediment yield, and total sediment of the area were calculated for each model. For mapping soil erosion rates or hazard, the erosion features map was first prepared using aerial photographs and satellite images. Then, by over laying them and rocks sensitivity to erosion maps and slope in GIS environment, the homogeneous unit map was prepared. The empirical models were applied in homogeneous units.

The results of the applying GAVRILOVIC Model in watershed
The result of this model is presented in table 8. Erosion intensity factor (Z) was calculated as 0.46 using four factors of rock and soil, land use, erosion state, and average slope (Table 8). Erosion intensity of Amameh Watershed was mapped based on the classification of erosion intensity factor values. Then specific erosion was calculated as 667.93T/Km2/y, and total sediment of the watershed was calculated as 23894.46 T/year (Table 8).

Table 8- Steps of calculating erosion and sediment rate in GAVRILOVIC model

Erosion intensity and specific erosion		Sediment factor, area-specific sediment yield, sum	
Soil and rock Y	0.83	Average height	2687.00
Land Use Xa	0.46	Minimum height	1750.00
Erosion ψ	0.60	Height difference	0.94
Average slope (%)	49.64	Perimeter (km)	29.51
Erosion intensity Z	0.46	Area (km2)	38.01
Average rainfall	864.99	Length	12.35
Average temperature	5.32	Sediment factor	0.94
Factor T	0.80	Area-specific sediment yield	628.63
Specific erosion WSP	667.93	Total sediment (T/year)	23894.46

According to the tables, erosion intensity factor (Z) was calculated using the relevant factors and erosion intensity of Amameh Watershed was mapped based on erosion intensity factor values classified into five categories of very low (negligible), low, medium, high, and very high (Table 9).

Table 9-Comparison of area erosion classes in GAVRILOVIC model

Soil erosion intensity category	Very low	Low	Average	High	Very high	Sum
Area (hectare)	580.54	287.66	302.21	1953.17	675.28	**3798.86**
Percent	**15.28**	**7.57**	**7.96**	**51.41**	**18.78**	**100**

The results of applying PSAIC model in the watershed

In order to investigate state of erosion and sediment of watershed and estimating its value, nine factors influencing erosion and sediment were studied and scored based on the tables related to each factor (Table 10). Erosion and sediment of the watershed were estimated considering the sum score of various factors (Table 10). The state of erosion of Amameh watershed was mapped based on total score of different factors. After reviewing the situation and characteristics of the studied watershed, the scores of nine factors were determined and the sediment rate was obtained by summing the scores. The results of scoring and estimating the sediment using the empirical approach are reflected in table3.

Table 10- Steps of calculating erosion and sediment rate in PSAIC model

Erosion rate	1356.58
SDR	0.38
Sediment yield	515.50
Total scores	73.30
River bank erosion	15.00
Erosion state	11.80
Land use	1.20
Surfaces cover	1.30
Ups and downs	18.30
Runoff	7.20
Climate	7.00
Soil	7.30
Lithology	**4.10**

The results of applying MPSIAC Model in the watershed
In this model, nine factors of PSIAC have entered into equations in order to reduce error rates of expertise in scoring. After calculating the total scores of various factors, sedimentation and erosion rates were estimated (Table 10). Moreover, the erosion intensity of Amameh watershed was mapped based on classification of erosion intensity values. After reviewing the situation and characteristics of the studied watershed, the scores of nine factors were determined and the sediment rate was obtained by summing the scores. The results of scoring and estimating the sediment using the empirical approach are reflected in Table 11.

Table 11- Steps of calculating erosion and sediment rate in MPSIAC Model

Lithology	Soil	Climate	Runoff	Ups and downs	Surfaces cover	Land use	Erosion state	River bank erosion	Total scores	Sediment yield	SDR	Erosion rate
4.10	9.32	4.16	2.90	16.38	4.70	12.90	12.00	5.84	72.34	498.24	0.38	1311.15

The results of applying Fournier Model in the watershed
Using the first and second methods Fournier, the sediment yield values in the watershed were calculated. In these two methods, area-specific sediment yield values are calculated using the ratio of the rainiest month rainfall to the mean annual rainfall, mean slope, and height the area (Table 12).

Table 12- Steps of calculating area-specific sediment yield values in the first and second methods of Fournier Model

Average height	Average slope	Average rainfall	Average rainfall of the rainiest month	Pw	Pw2	Area-specific sediment yield in the first method	Area-specific sediment yield in the second method
2687	49.64	864.99	137.37	0.16	21.82	590.02	967.84

The results of applying FAO Model
In this model, soil erosion status in the watershed is studied using six factors and soil erosion intensity is qualitatively determined after calculating the sum of scores. Table 13 shows the mean weight values of each watershed. After reviewing the situation and characteristics of the studied watershed, the scores of six factors of the model were determined and the sediment rate was obtained by summing the scores of factors. The results of scoring and estimating the sediment using the empirical approach are reflected in Table 6. According to the results of BLM Model, the study area has an average rate of erosion.

Table 13- Steps of determining erosion intensity in FAO Model

Lithology	Soil	Topography	Surfaces cover	Land use	Erosion state	Total score	Erosion class	Erosion intensity
8.70	10.20	16.00	8.60	10.10	6.20	59.80	4	average

The results of applying BLM Model in the watershed
This method evaluates quantitatively soil erosion status based on reviewing and scoring seven factors. Total scores given to each factor express qualitatively soil erosion status. Table 14 presents the scores of each factor and their sum in the watershed.

Table 14- Steps of calculating erosion and sediment in BLM method

Soil movement	Litter	State of rocks	Rock fragment	Rill erosion	Channel form	Gully erosion	Total score	Erosion status
8.10	9.00	8.10	7.00	7.20	5.20	3.50	48.00	average

The results of estimating sediment yield value of the watershed using the observed sediment statics. In order to estimate the amount of sediment yield of the watershed, intermediate data method was used.

The rating curve of sediment and the fitted line equation are shown in table 15. Moreover, area-specific sediment yield values and watershed sediment are presented in Table 15.

Table 15- calculating specific sediment yield of Amameh Watershed using observational sediment data

Hydrometric Station	Elevation above Sea level (m)	Upstream area (km2)	Qw (m3/s)	specific sediment yield (t/km2/year)			
				a	b	R2	Qs
Kamarkhani	1890	37	15.63	45.38	1.133	0.73	296.60

DISCUSSION

Estimating the amount of erosion and sediment yield in watersheds has always been difficult and tricky due to the complex nature of erosion and sediment processes in a way that the estimated amounts of sediment in an area with different methods sometimes considerably different from each other, and they might be impossible to be determined exactly. In the study watershed, erosion and sediment yield were estimated by two main approaches, i.e. using statistics recorded on suspended sediment and using empirical models. Regarding the data recorded on suspended sediment, the data of Kamarkhani station in watershed was studied and analyzed by various methods. The results indicate that there are significant differences between the estimated values in different methods. Moreover, since the length of sediment data recording period of different stations varies and is sometimes short, the values obtained are not reliable except in Bagh Tangeh Station. According to 25-year statistics on monthly sediment data, the amounts of suspended sediment in Kamarkhani Station and Baghtangeh have been calculated to be 296.60 tons per square kilometer per year. The results of using the empirical models in the watershed give different values for sediment yield of the area, which are somehow close. However, the difference between them is significant. Table 16 presents the comparison of the estimated special sediment for the watershed using the five semi-quantitative models. Table 16 shows annual sediment of the watershed.

Table 16- Comparison of specific annual sediment estimated using different experimental models

Model Name	GAVRILOVIC Model	Fournier (1962)	Fournier (1960)	PSAIC Model	MPSAIC Model
specific sediment yield (T/Km^2/Year)	628.63	967.84	590.02	515.50	**498.24**
annual sediment yield (T/Year)	12261.18	109678.78	66863.44	68577.80	**66281.07**

In order to compare the estimated values of sediment calculated by each of the methods, the results of five semi-quantitative models was compared with the observed sediment yield through the sediment rating curve. In table 17 the relative error criterion that is calculated from the observed and estimated sediment difference ratio is presented. In order to compare the estimates, other criteria such as mean differences, mean absolute difference, and root mean square errors are also provided. Since the criterion of relative error is simple and understandable and has been used in most studies, it was used in this study (Table 17).

Table 17- Comparison of annual estimated sediment using various methods and sediment observed in Bagh Tangeh Station

		Estimated sediment(empirical models)				
	Observed sediment yield	GAVRILOVIC Method	Fournier (1960)	Fournier (1962)	MPSAIC Method	PSAIC Method
Estimated sediment yield (tons per year)	296.60	628.63	590.02	967.64	498.24	515.5
Percent relative error	**0**	143.74	128.77	275.26	93.18	99.88

According to the table 17, among the methods based on drawing the sediment rating curve (Johnson, 1996) Empirical models, the lowest percent relative error is related to MPSIAC (93.18%) and the highest is related to Fournier (1962) (275.26%). Therefore, the results of MPSIAC model, as the closest estimation to sediment yield in Bagh Tangeh Station, were used to calculate the sediment value of Amameh watershed. Other models used in this study, Including GAVRILOVIC, FAO, BLM, Fournier [15], presented unreasonable and unrealistic results, indicating inability of these models to estimate erosion and sedimentation in Amameh Watershed. In fact, these models have been developed in areas with physical and climatic conditions different from Amameh Watershed.

RECOMMENDATIONS

According to the studies conducted by different researchers around the world, many experimental models to estimate erosion and sedimentation were evaluated and assessed. Among them, MPSIAC erosion and sedimentation prediction model was introduced as good model. In the present study, the MPSIAC Model (93.18%) showed the lowest relative error and the Fournier (1962)showed the highest relative error. According to topography of the region (being mountainous), filter strip (planting as a long strip along the river) is recommended among other protection options in order to reduce erosion in the watershed (due to the volume of executive operations, fitting with the area conditions, and reduction of erosion and phosphorus). This leads to trapping sediment and phosphorus particles and prevent them from entering the river.

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