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ORIGINAL RESEARCH

Estimate of Erosion and Sedimentation in Semi-arid Basin using Empirical Models of Erosion Potential within a Geographic Information System

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Abstract: This research is aimed at predicting erosion and sedimentation in the Ghareh Aghach Basin in the central part of Iran using Erosion Potential Model (EPM) models incorporated into Geographic Information System (GIS) software. This basin has an area of about 8955 hectares. The region has a range of vegetation, geological, soil texture and land use types. The basin was subdivided into 5 sub-basins. Data required for this study were collected in part through published reports, whilst the remaining was derived by field surveys. Necessary maps in EPM models were prepared in Autocad-2006 medium and were transported to IILWIS, after some revision. After constructing topologies for all polygons, we entered weightings for all layers within the Arc-View software. Combinations of all layers were managed thereafter. Coefficient of each factor was determined, and erosion intensity coefficient (Z) was calculated. Four layers for EPM model were combined to develop the final layer of erosion and sedimentation. The results of the EPM model for homogenous and uniform sampling units showed that 0.19% (16.7 ha) of the total watershed area were classified as class I of erosion category with very low sedimentation and 15.1% (1352 ha) were classified as class II of erosion category with low sedimentation and 41.3% (3699 ha) were classified as class III of erosion category with medium sedimentation and 13.2% (1175 ha) were classified as class IV of erosion category with high sedimentation and finally 30.2% (2711 ha) were classified at class V of erosion category with very high sedimentation, respectively. The result of comparing erosion and sediment values using an EPM model with measured values showed that no significant difference was observed between the estimated and measured values ($P < 0.05$).

Keywords: EPM model, GIS, sedimentation, erosion, watershed

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Introduction

The gradual soil salinization along with deterioration of rangeland vegetation covers has caused accelerating soil erosion and sedimentation in water reservoirs.[1,2] The United Nations in its development plan[3] has reported that at present rate of soil erosion in Iran is about 20 tones/ha, which has increased by 10 tones/ha compared to the last decade.[3] There are not enough sediment measurement stations in most watersheds in the country which makes it more difficult to provide specific models with details of local watershed characteristics. One of the most important problems with empirical models of soil erosion is their lack of accuracy in processing the huge amount of data which should be digitalized by GIS systems and analyzed by mathematical models. EPM is an empirical model for estimating the quantity and quality of sediment. In fact, quantifying and digitalizing the sediment data is an important breakthrough in developing sediment assessment models.[4] This problem could be partially solved by estimating models.[5] Since soil erosion is a product of few different interacting factors, there is no simple model that can assess all the contributing elements simultaneously.[6]

Lack of information for preparing erosion maps for quantitative and qualitative evaluation of sedimentation rates is a major need in the watershed management in Iran. Finding a suitable model for evaluation of erosion and sedimentation processes is an important area of research in soil conservation. The goal of this research was to apply an EPM model and a GIS system (to reduce the error level to the minimum) to have the most possible accurate assessment of the soil erosion and sedimentation in the study area and make the best applicable suggestions to control it.

Material and Methods

Modeled area

The area of Ghareh Aghach watershed is about 8954 hectares which is located between 51° 45′ 53″ and 51° 34′ 54″ eastern latitudes and 31° 30′ 28″ and 31° 26′ 19″ northern altitudes. The maximum and minimum heights of the area are 3810 and 2630 m from the sea level. The mean altitude of the watershed is 2936 meters from the sea level. The watershed area is divided in five major hydrologic sections according to its topographic features.[15] Long-term mean annual precipitation and temperature are 358 mm and 10.5 °C respectively, which classifies the site in semi-arid climatic conditions according to Ambergie (Q = 40.7) and Demartin (Ia = 17.4) categories. There are about 17 different vegetation types. The natural vegetation is mostly *Astragalus* spp., *Agropyron trichophoum*, *Bromus tomentalus*, forbs, and annual perennial grasses. Four major landscapes of mountainous lands, hilly lands, plateau and gravel lands consisting of nine minor land units.[7]

Model description

EMP model is the other package which has been used to estimate soil erosion in Iran. However, since fewer environmental factors are considered in this model, its accuracy in sediment estimation is less than in other models.[8,9] This model was created based on erosion measurements during 40 years in previous Yugoslavia and for the first time was introduced in River Stream International Conference.[10] In the use of this model, the first step was to develop a topographic map in 1:25000 scale of the study area. This was done by digitizing the data using the GIS ILWIS program[11] to provide a contour map. Using the contour map, the slope and aspect maps as well as the digital evaluation model (DEM) of the site were prepared. An Erosion feature map was obtained using aerial photos of 1:40000 scale. In the second step a land use map was obtained from supervised classification of the satellite images (ETM^+ bands 1-7) and data obtained from the field visits that were used to provide information on the local topography, climatic factors, geology, pedology and land use data of the study area. Precipitation and temperature maps were obtained from the climatic data measured by gages placed in the watershed. By integration of geology map, erosion faces map and slope maps, 21 homogenous uniform sampling units were identified to apply EPM model (Fig. 1).

Model information layers comprised four effective factors in erosion and sedimentation in the watershed site. These were obtained by digitalizing and classifying the basic information data in the GIS program. In frequent field visits all the necessary

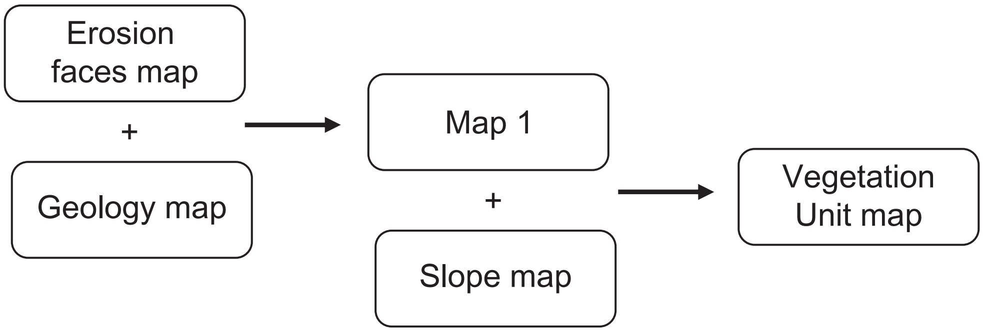

Figure 1. Scheme for developing homogeneous unit map.

data for EPM model were collected, checked and improved in 21 homogenous and uniform sampling units. Following of finalizing the information layers, all of them were integrated to create the final erosion map (Fig. 2).

Therefore, sediment estimation in this model is based on four factors consisting: Ψ: Erosion coefficient of watershed, X: Land use Coefficient, Y: susceptibility of rock and soil to erosion, I: mean watershed slope each one of these factors will receive a proper value according to its contribution to erosion process (Table 1).

Explination of Point Procedure by Quadruplet Factors

Erosion coefficient

The accurate way for determinding of erosion coefficient is providing geomorphologic map of watershed up to facieses or sampling units, there for the amount

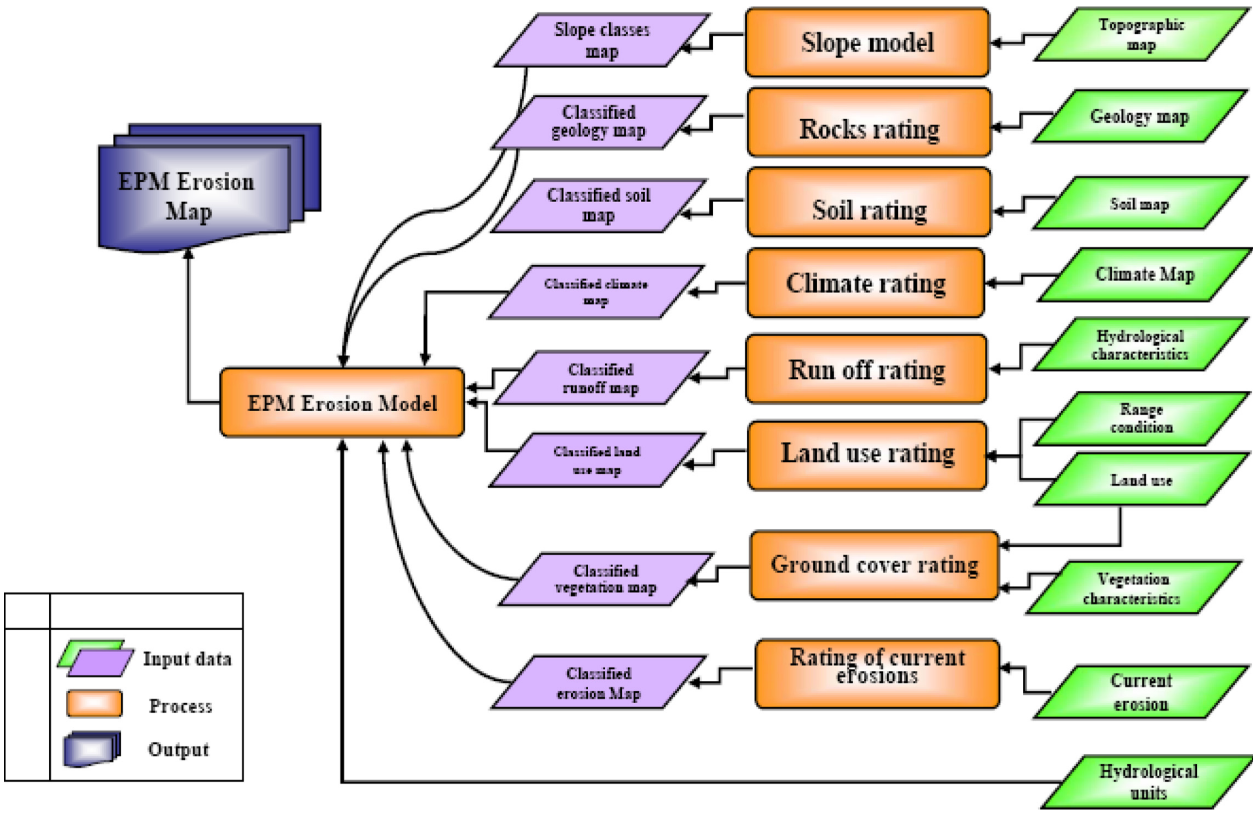

Figure 2. EPM model for soil erosion.

Table 1. The contributing factors in EMP model to estimate the soil erosion.

Factor	Necessary information	Results
1	Slope map	I: mean watershed slope
2	aspect map	Ψ: value for different erosions
3	land use	Xa: value for different land uses
4	rock and soil susceptibility to erosion	Y: value for rock and soil susceptibility

of erosion coefficient can be obtained base on Table 2, for each sampling units.

Mean watershed slope

By using topography map of watershed slope map was provide, then the average weight slope for each sampling units were calculate.

Coefficient susceptibility erosion of rock and soil

The soil erosion sensitivity coefficient map was obtained based on point to geomorphologic and pedological map for each sampling units according to Table 3.

Table 2. Erossion coefficient point in facieses or sampling units.

No.	Explanation erosion properties in facieses or sampling units	
1	The area that immensely covered by head cat or Gully erosion	1
2	The area that covered 80% by Gully erosion or Rill erosion	0.9
3	50% of the area covered by Gully erosion or Rill erosion	0.8
4	The Immensely of the area covered by Surface erosion, Mass movement and with less Karst, Gully erosion and Rill erosion	0.7
5	The vest area has Surface erosion without severe erosion	0.6
6	50% of quarter covered by Surface erosion which merge by white point	0.5
7	Surface erosion observed in 20% of the area	0.4
8	The area without erosion	0.3
9	Agriculture land with less erosion	0.2
10	Range and Forest land with less erosion	0.1

Table 3. The soil erosion sensitivity coefficient.

No.	The properties of facieses or sampling units	Sensitivity coefficient
1	Sand, Gravel, Schist, Salty, Loess, Dissolved Limestone and Salt	1
2	Loess, Tof, Alkali and Salty soil, Step soil	0.9
3	Limestone weathering, Clay, Loess without dissolved	0.8
4	Red sand and Flaishi sediment	0.7
5	Tiny schist, Mica schist, Gneiss, Schist and Arailite	0.6
6	Limestone, Humus soil	0.5
7	Brown Forest soil and Rocky soil	0.4
8	Black or gray Hyrmopher soil	0.3
9	Chernosom soil and alluvial sediment with suitable texture	0.2
10	Igneous, Metamorphic and Crystalline Rock	0.1

Land use coefficient

The amount of land use coefficient was determined according to Table 4.

The Relationship between Erosion and Sedimentation in EMP Model

This model is able to measure erosion, sediment carrying capacity as well as a primary as estimation of sediments behind the reservoirs.

The coefficient of erosion intensity (Z) is calculated by the following equation in this model:

$$Z = Y.Xa\ (\Psi + I^{0.5}) \qquad (1)$$

Where:

Y: rock and soil susceptibility coefficient, Xa: land use coefficient, Ψ: Erosion coefficient of watershed, I: average slope (percent). Tabular values are

Table 4. The land use coefficient.

No.	Land use condition	Coefficient
1	Very poor rangeland condition	1
2	poor rangeland condition	0.9
3	moderate rangeland condition	0.8
4	good rangeland condition	0.7
5	Continuous farm land and alfalfa farms	0.6
6	Rocky land	0.5
7	Arbor	0.4

available for each coefficient. Table 5 shows classification of Z values. According to Z values the erosion intensity map can be prepared. Table 5. Classification of Z coefficient values

Specific erosion, sediment yield coefficient, specific sediment yield, and total erosion and sediment yield can be computed using following equation. The volume of soil erosion is calculated by the following equation in this method.

$$WSP = T.H.\pi.Z^{1.5} \quad (2)$$

Where:

H: mean annual rainfall (mm), π: 3.14, WSP: the volume of soil erosion ($m^3/km^2/yr$), T: coefficient of temperature which is calculated by equation No. 3.

$$T = (t/10 + 0.1)^{0.5} \quad (3)$$

Where: t = mean annual temperature

The sediment production rate in this model is calculated based on the ratio of eroded materials in each section of the stream to the total erosion in the whole watershed area (Equation No. 4).

$$Ru = 4\ (P.D)^{0.5}/L + 10 \quad (4)$$

Where:

P = circumference of the watershed, L = watershed length (km), D = height difference in watershed area (km), After calculation of the Ru value the special sediment rate is estimated by equations No. 5 and 6 (9).

$$GSP = WSP.\ Ru \quad (5)$$

$$GS = GSP.\ F \quad (6)$$

Where:

GSP: special sediment rate, WSP: volume of special erosion, Ru: coefficient of sedimentation, GS: total sediment rate (m^3/yr), F: total watershed area (Km^2).[8,12]

Table 5. Classification of Z coefficient values.

Z value	Erosion intensity
<0.20	Very low
0.20–0.40	Low
0.40–0.70	Moderate
0.70–1.00	High
>1.00	Very high

Study of the Validity of the Model

The model was checked against the ground data to study its validity. For this purpose, during the visits from the region at the data, the validity of the model was determined and with regard to the data from 5 control points in each subunits. T-Test was employed to compare the estimated erosion and sediment values by EPM model with measured values using SPSS statistical package.

Results

When the proper maps are prepared in EPM model, different contributing factors in erosion and sedimentation will receive their values in GIS system.

EPM model

The calculated values of four contributing factors for Ghareh Aghach watershed in EPM model is presented in Table 6. The maps of susceptibility values for each contributing factor created by ILWIS system are presented in figures 3 to 10. After the information layers were valuated to produce the erosion map, the map of erosion intensity (Z) was prepared and the susceptible sites to erosion were identified (Fig. 8). The volume of erosion (WSP) was then calculated by equation No. 2 (Table 7) Figure No. 9 shows the erosion in the watershed area. The sedimentation yield in the Ghareh Aghach watershed was classified in four erosion categories eroded (low, medium, high and very high) using EPM model.

Discussion

The efficiency of EPM model to estimate erosion and sedimentation in Ghareh Aghach watershed

In order to determine the accuracy of EPM model, five sample points were randomly assigned to each

Table 6. Coefficients of four contributing factors in erosion by EPM model.

Subunits of watershed	C1	C2	C3	C4	C5
Y	0.59	0.53	0.46	0.47	0.50
Ψ	0.34	0.32	0.30	0.33	0.33
Xa	0.35	0.34	0.33	0.36	0.37
I	6.87	6.22	3.03	3.78	3.35

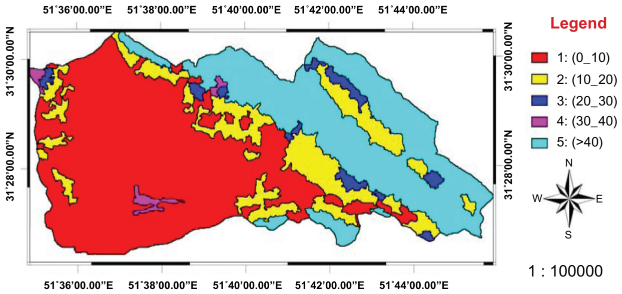

Figure 3. The Slope map of Ghareh Aghach watershed.

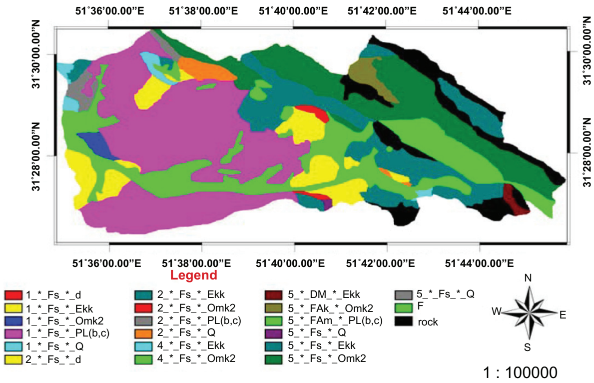

Figure 4. Uniform Sampling Units map of Ghareh Aghach watershed.

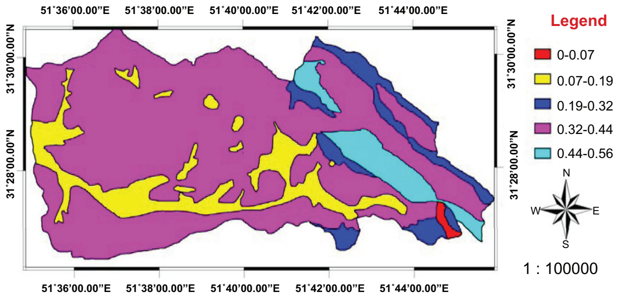

Figure 5. The Geomorphology Facieses map of Ghareh Aghach watershed.

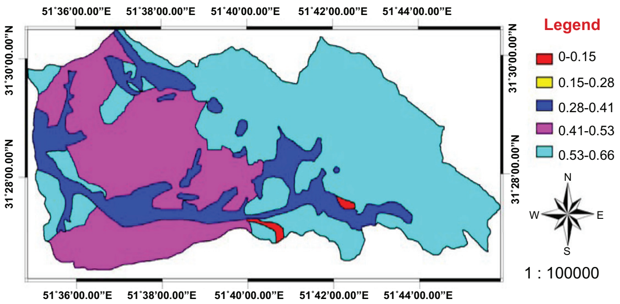

Figure 6. The Geology erosion map of Ghareh Aghach watershed Based on erosion sensitivity.

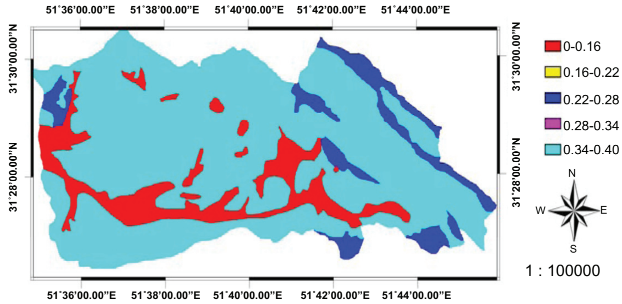

Figure 7. The Land use map of Ghareh Aghach watershed Based on erosion sensitivity.

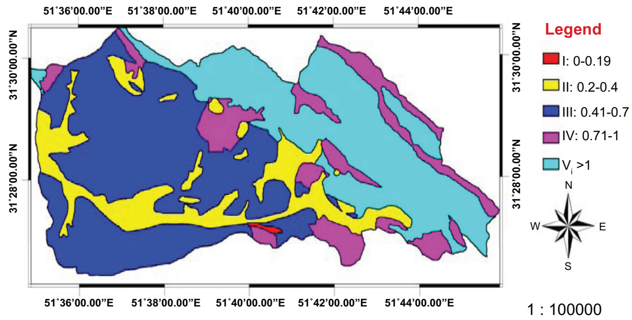

Figure 8. The Erosion classes map (Z) of Ghareh Aghach watershed.

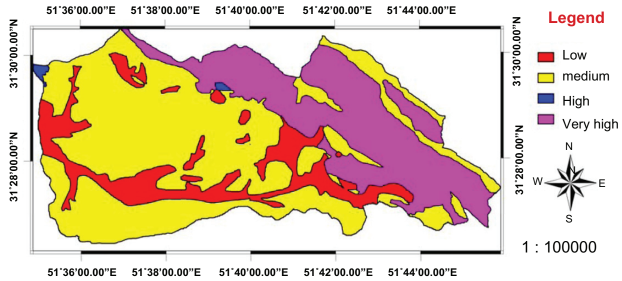

Figure 9. The Intensity Erosion map (WSP) of Ghareh Aghach watershed.

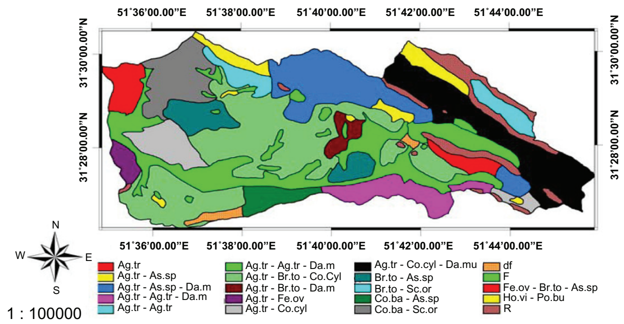

Figure 10. The Vegetation map of Ghareh Aghach watershed.

Table 7. The calculated erosion and sediment for Gharehach watershed by the EPM model.

Subunits of watershed	C1	C2	C3	C4	C5
Coefficient of erosion intensity	2.1	1.7	0.427	0.42	0.42
Erosion class	V	V	III	III	III
Erosion intensity	Very high	Very high	Medium	Medium	Medium
WSP ($m^3/km^2/yr$)	1534.1	1285.6	638.7	844.1	895.4
Area (km^2)	18.39	16.71	29.08	13.57	11.79
Special erosion ($ton/km^2/yr$)	1903.9	1595.4	792.7	1047.5	1111.2
Annual erosion (ton)	14069.4	12145.7	10111.1	5565.4	11923.2
Observed erosion (ton)	31992.5	17016.9	124.97	19584.7	15901.9
Coefficient of sedimentation (Ru)	0.1139	0.1083	0.1084	0.1332	0.1309
Special sediment ($ton/km^2/yr$)	281.3	233.8	114.8	151.7	162.8
Annual sedimentation (ton)	2073.4	1783.1	1465.4	809.1	1738.3
Observed sedimentation	12828.9	7147.1	5498.7	7794.7	6599.3

subunits. Amounts of sediment yield can be estimated from available sediment concentration data collected at sedimentary gauge in the sub-watershed outlet. The t-student test was employed to compare the estimated erosion and sediment values by EPM model with measured values using SPSS statistical package.[7] The results in Table 8 showed that there were no significant differences ($P < 0.05$) between the estimated and measured values. These results support the pervious achievements by the other researchers.[10,13,14]

Soil erosion is a major environmental threat to the sustainability and productivity of agriculture in Iran. The average soil loss in Iran is estimated to be 20 to 30 ton/ha per year, which totals to about 5 billion tons per year, and is mainly due to inadequate agricultural land use. The agent of erosion is water and wind, but the main causes are improper land use and inadequate cultural practices.

Quantification of the actual rate and pattern of soil erosion and sedimentation is necessary for designing degradation control strategies.

The EPM model estimates potential amount of erosion in a specific region and it is possible that the results of this model concerns with several factors in each homogeneous unit that could determine the potential erosion more reliably. But the model has some limitation such as getting the effect of slope in resistant rocks and formations that have very low erosion. Furthermore, the scores given for different factors were developed for Yugoslavia condition. These need to be calibrated for other countries and circumstances.

The GIS system minimizes the personal effects in integrating the different information layers to identify the working units and detects and classifies the different erosion sites in the watershed.

Disclosure

This manuscript has been read and approved by the author. This paper is unique and is not under consideration by any other publication and has not been published elsewhere. The author and peer reviewers

Table 8. The statistical analysis and mean comparisons in EPM model.

Statistical characters	Erosion statistical analysis					Sedimentation statistical analysis				
	C5	C4	C3	C2	C1	C5	C4	C3	C2	C1
d_i	10574.8	–4427.3	108628	124.4	10234.2	4027.1	–1788.2	–461.5	4716.7	4114.9
$\bar{d}$			27484.736					14803.207		
S_{n-1}			45861.896					33429.46		
$\mathbf{S}\bar{d}$			20510.0637					14950.1		
Calculated **t**			1.34*					0.991*		

t: from table of $P < 0.05$ for df = 5 equal to 2.776.
d_i: The difference between erosion and sediment (measured and estimated) (ton/ha/yr).
*: no significant difference between calculated t and t from table ($P < 0.05$).

of this paper report no conflicts of interest. The author confirms they have permission to reproduce any copyrighted material.

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