Estimating and Mapping Sediment Production at Kardeh Watershed by Using GIS

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Abstract

The study of geological factors in sub-basins to evaluate the sensitivity of formations to erosion is considered as one of the most important factors in calculating soil erosion and sediment rates. The present study aims to evaluate sediment yield at each sub-basin of the Kardeh watershed and prepare the maps of sediment production after EPM and PSIAC models by GIS analysis which can be applied in the rehabilitation plans at the study area. According to our results the study area can be categorized into three erosive zones: heavy, moderate and slight. The middle and south part of the watershed near the dam is highly eroded due to its geology and soil erodibility while the northern parts are moderately eroded because of the intensity of land cover. Comparing the output maps from EPM and PSIAC models showed that the results of sediment production in most areas correspond well with each other and with field observations. The results indicated high correlation coefficient ($R^2=0.945$) between total sediment production derived from the EPM model, and the corresponding values of PSIAC model at each sub-basin of the study area

Key words: *Erosion, EPM model, PSIAC model, GIS, Sediment production*

Introduction

Methods for estimating sediment yield were first developed for the analysis of the effects of agricultural practices. The first model used was the Universal Soil Loss Equation or USLE. The commonest models now being used are MUSLE (Modified Universal Soil Loss Equation), WEEP (Water Erosion Prediction Project), RUSLE (Revised Universal Soil Loss Equation), PSIAC (Pacific Southwest Interagency Committee); and EPM (Erosion Potential Method). Gavrilovic (1988) originally developed the EPM model for Yugoslavia. The model has tested in some basin areas in Iran and it is concerned that output results are compatible with field observation. Both the EPM and the PSIAC models are factor-based, which means that a series of factors, each quantifying one or more processes and their interactions, are combined to yield an overall estimation of soil loss. Applications of Geographic Information Systems (GIS) and remote sensing techniques in erosion and sediment yield assessment have been developed recently. The aim of the present study was to compare the output results of the EPM and PSIAC models for estimating erosion processes and sediment yield at Kardeh watershed Khorasan-e-Razavi Province, Northeast of Iran. This study applied GIS analysis as a priority technique in watershed management to identify and quantitative classification of sediment yield at sub-basins of the study area.

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Methodology

General characteristics of the study area

The Kardeh basin is located about 40 Km northward Mashhad, Khorasan-e-Razavi province, Iran (Fig.1). The study site lies between latitude 36° 37' N to 36° 58' N and longitude 59° 26' E to 59° 44' E consist of eight sub-basins with total area of about 555 Km^2 and total main stream length of 45 Km (Table1). The study area is covered mainly by limestone formation and lime members (>75%), such as dolomite and lime-shale, aged to Jurassic period. The oldest rock units at the study area are Jurassic limestones of the Kashafrud Formation and the youngest are neogene red-bed conglomerates. The topographical elevation values of the study area vary between 1200 m a.s.l at the southward and 2977 m a.s.l at the northward, while the dominant topographical elevation range over 1800 m a.s.l. The study area has a semi-arid climate with mean annual precipitation of 322 mm and mean annual temperature of 11.8°C. The basin consists of thirteen settlements with population of about 6410 people, scattered along main streams of the basin. The main land use practice in the study area is pasture land. More than 68% of the basin is dominated by slopes over 15%, while mild slopes of <15% occupy small portion of the area. One of the most important characteristics of the basin is Kardeh dam lake with 200 ha area at 1200 m a.s.l, southward of the basin which collects the sediments of the rivers.

EPM model

The Erosion Potential Method (EPM) is a model for qualifying the erosion severity and estimating the total annual sediment yield of a sub-basin area. This model considers four factors which are surface geology (rock and soil), topographic features (elevation and slope), climatic factors (mean annual rainfall and mean annual temperature), and land use. Three naturally occurring factors control erosion development (geology, topography, and climate), while land use is entirely man-dependent. According to the model, annual specific production of sediment (W_{SP}) per km^2 in m^3/yr is calculated using the following equation:

$$W_{SP} = T \times H \times \pi \times Z^{\frac{3}{2}} \qquad (1)$$

where:

T, is temperature coefficient

t, is the mean annual air temperature (°C),

H, is the mean annual precipitation (mm/yr), $\qquad$ Z, is the coefficient of erosion,

This equation gives an estimate of the total production of erosion deposits in a watershed.

PSIAC Model

The PSIAC Model was developed to allow the estimation of sediment yield for a large variety of factors within a watershed. In the PSIAC Model, the range of total ranking values was set down as -20 to +130 but in the revised PSIAC it's 0 to 150 and the ranking produced the following five classes of sediment yield. The model assists nine factors were recommended for erodibility and annual sediment as follows: (1) geology; (2) soils; (3) climate; (4) runoff; (5) topography; (6) land cover; (7) land use; (8) upland erosion; and (9) channel erosion (Fig.2)

Each factor is subdivided into different categorical classes and based on the degree of impact for each factor class a ranking value assigned to each class by using the model tables. The erosion severity and the annual sediment yield are estimated, based on the total sum of values

which signed by *R*. In order to control the accuracy of interpolations and extrapolations of erosion-factor values, Eq. (2) is applied:

$$Q_s = 38.77\, e^{0.0353R} \qquad (2)$$

where:

Q_s, is the rate of sediment yield at each sub-basin in $m^3/km^2 yr$,

R, is erosion rate total values of nine factors

Results and discussion

EPM and PSIAC models for the study area were run within Arc-GIS. The annual specific production of sediments (Wsp) after EPM model was predicted for eight sub-basins and divided into three classes based on the model tables (Table 2). Likewise, the rate of sediment yield (Q_s) at each sub-basin after PSIAC model was generated through combining the values of factor classes based on the model tables (Table 3). The values of W_{SP} and Q_s derived from both models revealed that the heavy erosion and sediment potential corresponds well to Shurijeh and $Mozduran_1$ formations witch composed mainly of gypsum, brown marl, siltstone and alternation of limestone and shale, respectively. Areas with slight and moderate erosion potential correspond to $Mozduran_2$ formation which composed mainly of thick bedded limestone and dolomite. Comparison of tables 2 and 3, shows that the areas which fall within the same erosion potential category are similar in total sediment production with negligible variations due to effect of land use and –cover factor. In order to produce total sediment production, the values of W_{SP} derived from the EPM model and Q_s derived from PSIAC model were multiplied in the area of each sub-basin (Fig.3). The results indicated high correlation coefficient ($R^2=0.945$) between total sediment production derived from the EPM model, and the corresponding values derived from PSIAC model at each sub-basin of the study area. In consistent with our results, Tangestani (2006) found similar sediment production/ yield comparing the EPM and PSIAC models, however it is suggested that the PSIAC model is more reliable for assessing erosion potential values in semi-arid climate conditions. Verification of the EPM and PSIAC output data was performed using a field observation method. The field verification of EPM and PSIAC output maps revealed that locations of moderate to heavy annual sediment production/ yield were well corresponded to middle sub-basins of the watershed.

Conclusion

The EPM and PSIAC models are normally applied in order to estimate soil erosion and sediment production/ yield in master plans. The results from both models revealed high correlation coefficient ($R^2=0.945$) between total sediment production at each sub-basin of the watershed. According to our results the middle and south part of the watershed near the dam is highly eroded due to its geology and soil erodibility while the northern parts are moderately eroded because of the intensity of land cover. Field observations suggested that the common approach to limiting erosion is grazing control. It can also be concluded that gabion dams along the branch streams is the most effective factor in decreasing sediment production, specially in south parts of the study area.

Table 1: The symbols, length, surface area and the physiographic units of sub-basins at the study area

sub-basin	symbol	length (Km)	area (Km^2)	physiographic unit
Balghur	Bl	22.21	93.09	Mounts
Kharkat	Kh	22.68	97.39	Mounts
Karimabad	Kr	19.01	69.16	Mounts
Kushkabad	Ku	22.07	91.30	Mounts
Sijoal	Sj	27.31	146.47	Mounts
Mareshk	Ma	12.01	44.49	Mounts
Firuzabad	Fr	6.76	7.08	Hills
Dam Surrounding	Su	3.97	6.92	Hills

Table 2: Contribution of sub-basins in average annual specific production of sediment, the area and the percentage of each erosion class from total basin area, resulted from EPM model

Erosion class	Wsp (m^3/km^{2}yr)	Sub basins	Area (Km^2)	Percentage from total basin area
Heavy	x>275	Kh-Kr- Ku-Ma	302.33	54.39
Moderate	225<x≤275	Sj- Fr-Su	160.47	28.87
Slight	x≤225	Bl	93.09	16.75

Table 3: Contribution of sub-basins in rate of sediment yield, the area and the percentage of each erosion class from total basin area, resulted from PSIAC model

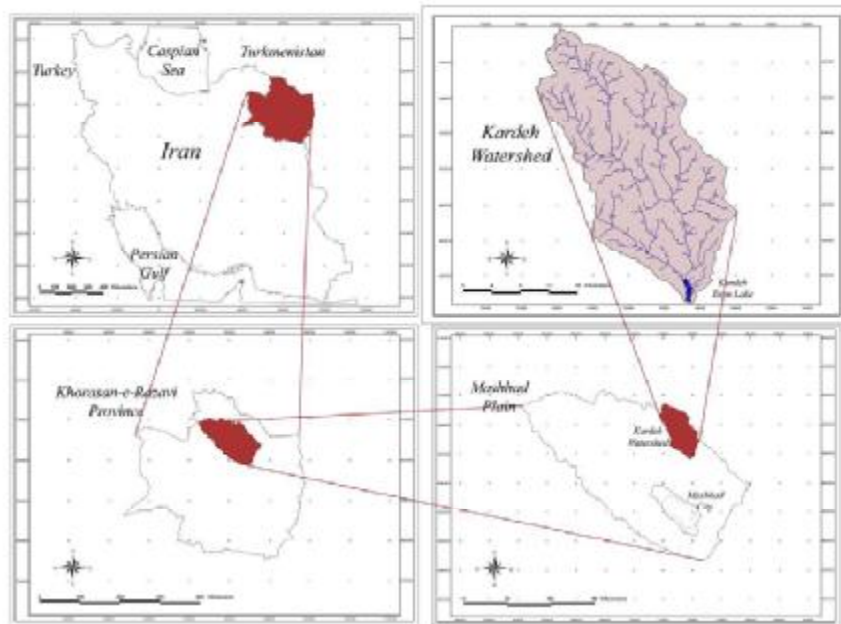| Erosion class	Q_s (m^3/km^{2}yr)	Sub basins	Area (Km^2)	Percentage from total basin area
Heavy	x>275	Ku-Sj-Ma	282.26	50.78
Moderate	225<x≤275	Bl- Kh-Kr	259.63	46.71
Slight	x≤225	Fr-Su	14.00	2.52

Figure 1: Location and geographical position of the study area
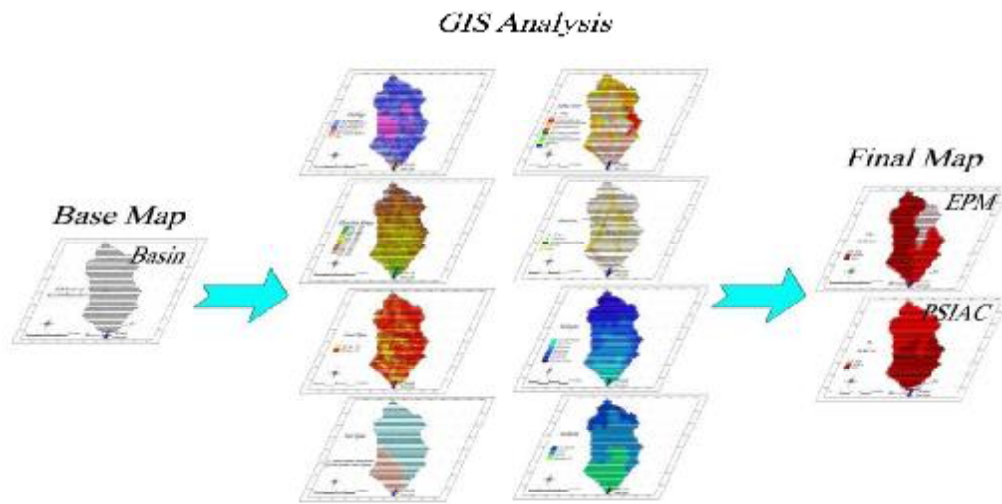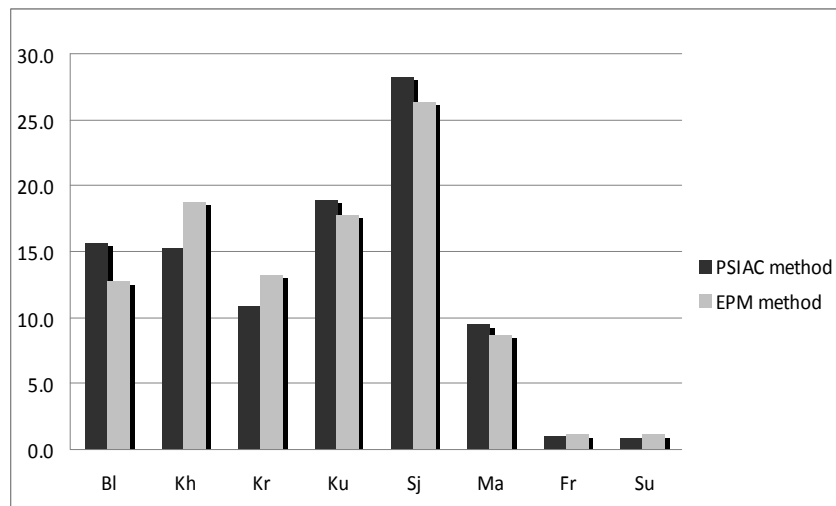

Figure 2: Parameters and factors analysis from EPM and PSIAC models with GIS at the study area

Figure 3: Percentage of total sediment production in EPM and PSIAC models at Kardeh sub-basins

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