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Short Communication

Evaluation of soil losses and sediment yield using modified PSIAC model

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ABSTRACT- One of the big problems today human societies are faced with is the problem of soil erosion. In this study, the "MPSIAC model" was used to estimate sediment yield and provide sediment yield map in Cachoyeh watershed. The MPSIAC method incorporates nine environmental factors that contribute to sediment yield of the watershed. These factors are: surface geology, soil, climate, runoff, topography, ground cover, land use, channel and surface erosion. ArcGIS 10.2 software was used to prepare the map of each factor and analyze them to create the sediment yield map and erosion map. According to the results based on MPSIAC model, 94.2 % (476.1 km^2) of study area was classified in the slight sedimentation and 29.2 % (147.5 km^2) of it was classified in the moderate erosion classes. The total sediment yield of basin was calculated as 1236.5 (m^3 km^{-2} $year^{-1}$) and the total of erosion was calculated as 5091.6 (m^3 km^{-2} $year^{-1}$). The sensitivity analysis of parameters of MPSIAC model showed that the most sensitive parameters of the model based on their importance were: channel erosion, land cover and geology with Pearson correlation of 0.75 to 0.36. Land use factor was found to have a lower effect than the output model.

INTRODUCTION

Soils are one of the most important natural resources of every country and, in this century, soil erosion is one of the main factors that destroy the environment. Sediments resulting from soil erosion pollute water; fill dam reservoirs and lower environmental potentials. Therefore, knowledge of the erosion situation and the total annual sediment production in the watersheds require more studies and investigations and recognition of effective factors in this complex process (Zakeri et al., 2015). One of the basic problems in estimating the amount of erosion and sediment yield to plan the utilization of water and soil resources is lack of statistics (especially in small basins), which causes problems for experts and users in the management of watersheds and in the development of protective programs. Empirical relations have been developed for estimating the amount of erosion and sediment yield in basins that lack required data (Heininger and Cullmann, 2015; Nearing et al., 2015; Naqvi et al., 2015; Zakeri et al., 2015).

In recent decades, various methods have been used for estimating the amount of erosion, such as FAO model, WEPP model, USLE model, EPM model, and PSIAC model (Mahammadyan and Sururjalhladdin, 2007). The MPSIAC was created in 1982 based on PSIAC which was introduced in 1968 for planning purposes by Pacific Southwest Inter Agency Committee in the United States and specially designed for arid and semi-arid watersheds (PSIAC, 1968). The modified version of PSIAC is mostly used in Iran (Zakeri et al., 2015).

Moradi et al. (2012) used the MPSIAC and EPM models as a comparison to estimate erosion and sediment in the Poorahmadi Watershed Basin. Noori et al. (2016) used MPSIAC method to assess the efficiency of these methods for estimating the sediments yield and erosion intensity within short-term and long-term timeframes over two sub-basins of Dez watershed, west of Iran. Mahboubi and Pasban (2013) estimated sediment yield and erosion intensity using GIS technique and MPSIAC model in Sarghayeh - Sarnish watershed in south of Mashhad. Ghazanfari et al. (2014) evaluated the annual delivery sediment in these basins, using EPM and MPSIAC models, and made comparisons between them. In this relation, after field surveying, for each sub-basin, lithology, soil, vegetation cover and other maps were used and the compilation of all information was carried out. Corresponding tables were prepared for quantitative calculation of each parameter for studying erosion using MPSIAC model and classification of erosion intensity was carried out using EPM model. Therefore, this study intends to evaluate the sediment yield, soil losses and delivery ratio at each sub-basin of the Cachoyeh watershed, southwest of Iran using MPSIAC model, and prepare the maps of sediment yield after the MPSIAC model by GIS analysis which can be applied in the rehabilitation plans at the study area.

MATERIALS AND METHODS

Study Area

Study area is the Cachoyeh watershed with an area of 502.1 square kilometer that lies between latitude 29°07′ N to 29°24′ N and longitude 53°32′ E to 53° 52′E, including nine sub-basins (Fig 1. and Table 2). This watershed is mainly mountainous with a maximum and minimum elevation equal to 3160 and 1485 m above sea level in the west and northeast. The study area has a semi-arid climate based on the modified De Martonne method, with a mean annual precipitation of 313 mm to 363 mm and a mean annual temperature of 17.1°C.

Factors of Modified PSIAC Model

For applying MPSIAC model, it is necessary to divide the studied watershed into hydrological units (sub-basins of watershed) or equal geomorphological working units according to the intended purpose. The modified PSIAC model has nine factors with nine equations including 1) surface geology factor 2) soil factor 3) climate factor 4) runoff factor 5) topography factor 6) Land cover factor 7) land use factor 8) surface erosion factor and 9) channel erosion factor. The values of the nine factors are ranked based on the corresponding tables shown in Table 1. Studies in Iran indicate that statistical data of the measured flow of water in general, and precipitation in particular are very limited. The lack of applied statistic research in the field of evaluation of soil qualitative erosion and production of sediment encourages research experts of in soil erosion and production of sediment to use other countries excremental formulas in the fields without statistical data (Refahi, 1996). Therefore, in this research, MPSIAC approach was used.

To evaluate geological sensitivity to erosion, geology map with 1:50000 scale was used (created by Iran geographic institute). In this study, based on geological condition of the study, the shale/phylite formation is a low-grade metamorphic rock derived from fine-grained sediments and contains a large amount of aligned mica, which imparts a coarse splitting plane. Land units map of the study area was used to determine soil factor. The erodibility factor of soil in USLE model (K) was used to calculate soil factor. The soil map of Cachoyeh watershed is mostly divided into mount and hill types. In this study, climate factor was based on 30 years (1984-2014) of rainfall record. *P* Parameter was obtained from the rainfall intensity duration and frequency curve. The rainfall data layer consists of five classes from 313 to 363 mm, and the isotherm data layer is classified to four classes from 16 to 18°C. In MPSIAC model, runoff factor was estimated based on specific pick discharge in cubic meter square kilometer per second (Q_P) and average of runoff height in millimeters (R) data. The runoff potential of the Cachoyeh watershed was divided into three classes including high, moderate and low. In this study, to determine the slop digital elevation maps, DEM and ArcGIS 10.2 software were used. To that end, the slope map was categorized into five levels from <5 % to above 90 %. To evaluate Land cover factor, the percentage of bare grounds at each land unit was used. The land cover system in the Cachoyeh watershed was divided into five classes including residential area, forest, irrigated farming and gardens, dry farming, rangeland.

To estimate Land use, different land uses in the Cachoyeh watershed were divided into three classes including cultivated lands, residential areas and other lands. Surface erosion factor was obtained based on the score of soil surface erosion (*SSF*) in the BLM method.

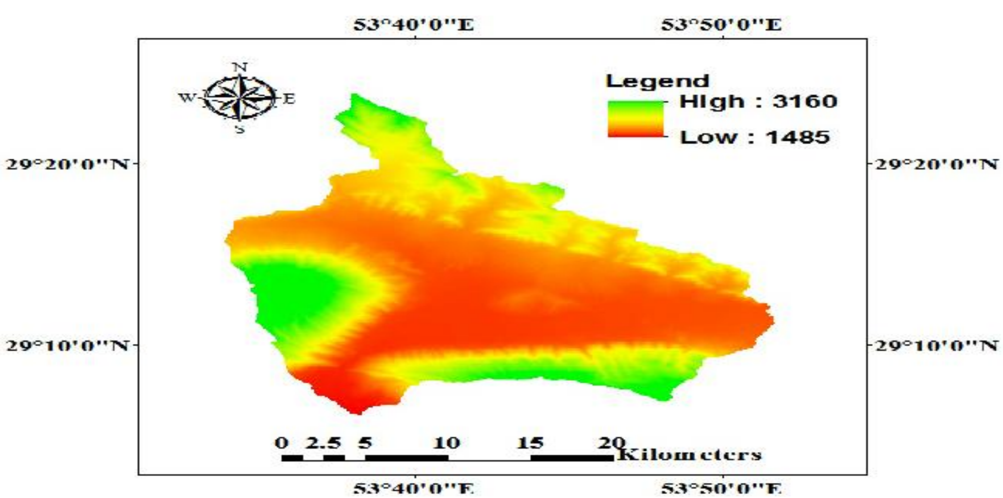

Fig.1. Location of the Cachoyeh watershed

Table 1. Nine factors of MPSIAC model and their descriptions

Factors	Symbol	Equation	Domain of Value	Description
Surface geology	Y_1	$Y_1 = X_1$	0 to10	X_1 determined on the basis of stone type hardness and fracture
Soils	Y_2	$Y_2 = 16.67K$	0 to10	K is soil erodibility factor in the USLE model
Climate	Y_3	$Y_3 = 0.2\ P_2$	0 to10	P_2 is 6-h rainfall intensity with a returning period of 2 years (*mm*)
Runoff	Y_4	$Y_4 = 0.006\ R - 10Q_p$	0 to10	R is annual runoff elevation (*mm*), and Q_p is specific peak discharge measured ($m^3\ s^{-1}\ year^{-1}$)
Topography	Y_5	$Y_5 = 0.33\ S$	0 to10	S is the average slope (%)
Land cover	Y_6	$Y_6 = 0.2\ P_b$	−10 to 10	*Pb* is the bare grounds at each land unit (%)
Land use	Y_7	$Y_7 = 20 - 0.2\ P_c$	−10 to 10	*Pc* is the canopy covering each land unit (%)
Surface erosion	Y_8	$Y_8 = 0.25\ SSF$	0 to 25	*SSF* is the score of soil surface erosion in the BLM method

Table 2. Characteristics of the sub-basins, mean sediment yield, sediment production, sediment delivery ratio and mean soil losses in each Sub-basin of the study area

Sub-basin	Length (*km*)	Area (km^2)	Mean sediment yield ($m^3\ km^{-2}\ year^{-1}$)	Sediment production ($m^3\ year^{-1}$)	Sediment production Percent from total basin	Mean soil losses ($m^3\ km^{-2}\ year^{-1}$)	Sediment delivery ratio
Sb1	9.19	43.76	145.9	6384.6	9.3	583.6	0.25
Sb2	10.04	39.79	114.6	4559.9	6.7	440.8	0.26
Sb3	20.95	92.52	124.2	11490.9	16.7	591.4	0.21
Sb4	19.54	116.27	141.	16487.1	24.0	675.2	0.21
Sb5	12.07	40.76	136.3	5555.6	8.1	545.2	0.25
Sb6	15.85	42.34	156.3	6617.7	9.6	625.2	0.25
Sb7	8.52	56.85	137.8	7833.9	11.4	574.2	0.24
Sb8	9.72	30.76	136.5	4198.7	6.1	505.6	0.27
Sb9	13.8	39.05	143.1	5588.1	8.1	550.4	0.26

SSF was estimated by field operation and filling the BLM method tables (Bagherzadeh and Mansouri Daneshvar 2013). Channel erosion factor was estimated based on the score of gully erosion (*SSF.g*) in the BLM method and by the relationship between yearly rainfall (*mm*) and gully erosion improvement (Aker, 1971). Based on this factor, geomorphology map was encoded and a new data field in this map was created.

Estimation of Sediment Yeld, Sediment Production, Sediment Delivery Ratio and Soil Losses

The erosion severity and the annual sediment yield are estimated based on the total sum of values of all factors, signed by R as follows:

$$Q_s = 18.60\ e^{0.0360\ R} \qquad (1)$$

Where Qs is the rate of sediment yield (in cubic meters per square kilometer per year) and R is the total value of nine factors of MPSIAC model (in cubic meters per square kilometer per year).

To estimate sediment production, equation 2 was used:

$$S = Q_s.A \qquad (2)$$

Where S is the total sediment production based on sediment yield (in cubic meters per year) and Qs is the rate of sediment yield (in cubic meters per square kilometer per year).

To calculate Sediment Delivery Ratio or SDR (ratio of sediment yield to total soil losses), equations 3 and 4 were used:

$$Log(SDR) = 1.8768 - 0.14191\log(10\ A) \qquad (3)$$

$$SDR = \frac{Q_s}{T} \qquad (4)$$

Where SDR is the sediment delivery ratio and A is the sub basin surface area (in square mile), Qs is the sediment yield per unit cubic meters per square kilometer per year at the watershed outlet and T is the total soil loss (in cubic meters per square kilometer per year), defined as the total eroded soil on the areas eroding above the watershed outlet.

RESULTS AND DISCUSSION

Based on the attributions of the nine factors and the given scores by the MPSIAC model, the total ranking values for each sediment class were determined. The values of sediment yield (Qs) were estimated and analyzed in ArcGIS 10.2 (Fig 2.A).

The value of mean sediment yield varies from 114.6 at Sb2 to 156.3 at Sb6 sub-basin, with sediment production of 4559.9 and 6617.7 $m^3\ year^{-1}$, respectively. The highest value of sediment production yields from Sb4 sub-basin (16487.1 cubic meters per year) was due to its having more surface area than the other sub-basins (Table 2).

The soil loss values were estimated and categorized into five erosion classes and mapped in ArcGIS 10.2 (Fig 2.B). The calculated soil loss values varied from <215 to >1900 ($m^3\ km^{-2}\ year^{-1}$), which was categorized into "very slight" to "severe" classes, where 69.5 % of the surface area belongs to the "slight" class with mean soil losses of 215–615 ($m^3\ km^{-2}\ year^{-1}$) (Table 3).

Table 3. Erosion classes, soil losses and the surface area per each class in the study area

Erosion class	Soil losses ($m^3\ km^{-2}\ year^{-1}$)	Surface area	
		km²	%
Very slight	<215	0	0
Slight	215-615	351.2	69.5
Moderate	615-1000	147.5	29.2
Heavy	1000-1900	7.1	1.4
Severe	>1900	0	0

The values of mean soil loss at the study area varied from 440.8 at Sb2 to 675.2 at Sb4 sub basin. The calculated values of SDR ranged from 0.21 at the Sb3 and Sb4 to 0.27 at the Sb7 sub-basin (Table 2). The observed heavy sedimentation and erosion classes in the central parts of the watershed might be related to the higher soil erodibility of hills, gradient topography, and land cover changes to pastures, while the main areas of watershed with slight sedimentation and erosion class in the northern, southern, and eastern parts were affected mainly by ultrabasic and crystallized limestone formations, rocky mounts, and planted lands (Figs 2.A and 2.B). In the sensitivity analysis, it was found that the most sensitive parameters of the model based on importance were channel erosion, land cover and geology (Pearson correlation 0.75 – 0.36) while topography (slope), land use, runoff, climate (rainfall), soil and surface erosion factors were found to have lower effects on the model output (Table 4).

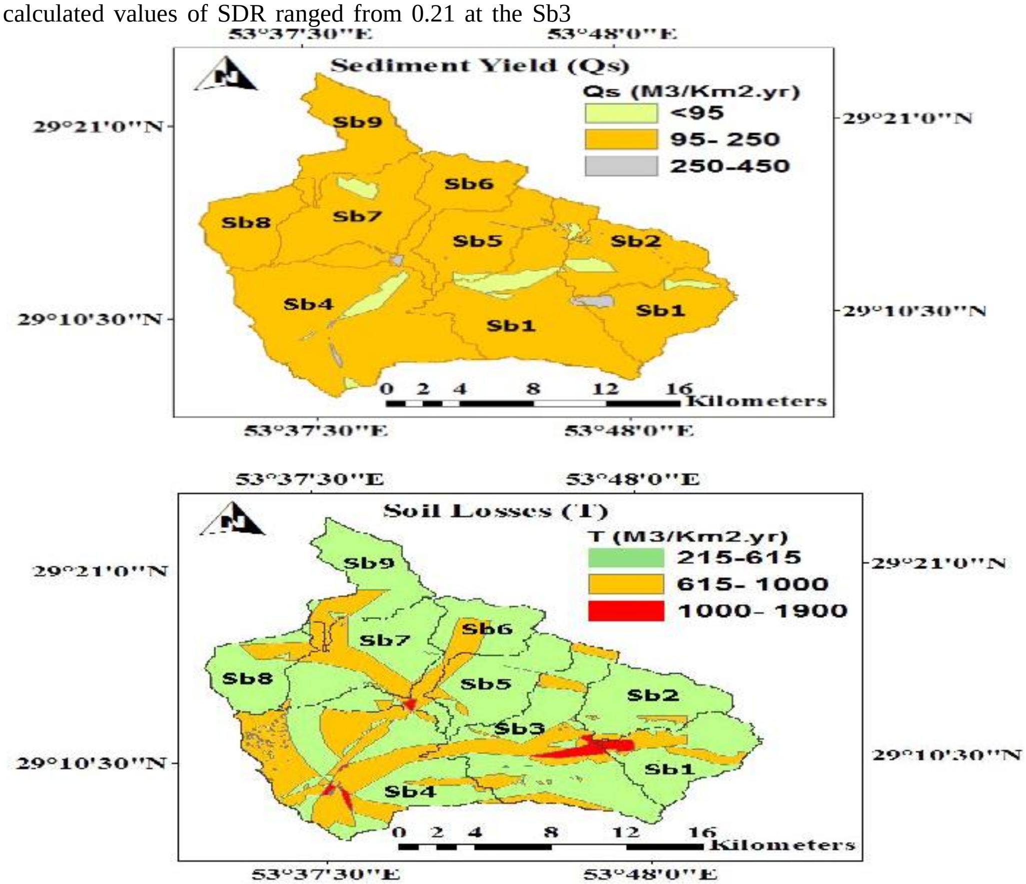

Fig. 2. A. Sediment yield **B**. Soil loss map of the Cachoyeh watershed based on the MPSIAC model

Table 4. Correlation between MPSIAC factors and sediment yield

Statistical analyses		MPSIAC fac s								
		Land cover	Land use	Topography	Runoff	Surface erosion	Channel erosion	Climate	Geology	Soil
Sediment yield	Pearson correlation (R)	0.42**	-0.009	-0.05**	-0.09**	0.08**	0.75**	0.06**	0.36**	0.17**

Table 5. Sedimentation classes, sediment yield and the surface area per each class in the study area

Sedimentation class	Sediment yield ($m^3\ km^{-2}\ year^{-1}$)	Surface area	
		km^2	%
Very slight	<95	25.89	5.1
Slight	95–250	476.15	94.2
Moderate	250–450	3.29	0.7
Heavy	450–1450	0	0
Severe	>1450	0	0

CONCLUSION

Often the terms soil erosion and sediment yield are used as synonyms. However, sediment yield reflects the result of soil erosion, sediment transport and sediment deposition. Soil erosion is one of the most prominent environmental problems that should be taken to consideration. Every year, million tons of sediments are deposited in the rivers, lakes, reservoirs and dams that will be accumulated and heavy costs are spent by humans for dredging them. In this study, the MPSIAC model was used at Cachoyeh watershed using GIS to facilitate the spatial interpolation of the nine model parameters and the interpretation of predicted sediment yield and erosion for the entire watershed, which could be used in the management of natural resources. Based on this model, the study area can be categorized into five sedimentation classes (Table 5).

According to the results based on MPSIAC model, 94.2 % (476.1km^2) of area in study area was classified in the slight sedimentation and 29.2 % (147.5 km^2) of it was classified in the moderate erosion class. The total sediment yield of basin was calculated as 1236.5 ($m^3\ km^{-2}\ year^{-1}$) and the total erosion was calculated as 5091.6 ($m^3\ km^{-2}\ year^{-1}$).

By evaluation of MPSIAC factors, it was clarified that channel erosion, land cover and geology factors were the most sensitive factors. Channel erosion was the most sensitive factor with Pearson correlation of 0.75. Therefore, it could be concluded that most investment should be done on this issue to prevent the soil erosion and sediment yield which are concerns of managers responsible for maintaining and conservation of land resources. Land use factor was not sensitive in MPSIAC model. Therefore, it is suggested that the use of remote sensing and satellite image processing could reduce the error due to special and temporal varieties.

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مقاله کوتاه

ارزیابی تخریب خاک و تولید رسوب با استفاده از مدلPSIAC اصلاح شده

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واژه های کلیدی:
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چکیده- یکی از مسائل بزرگی که امروزه جوامع بشری را تحت تاثیر قرار داده است بحث فرسایش خاک می باشد. دراین مطالعه با استفاده از مدل PSIAC اصلاح شده (MPSIAC) اقدام به بررسی و تخمین میزان رسوب زایی و همچنین تهیه نقشه رسوب زایی در حوضه آبخیز کچویه گردید. مدل MPSIAC شامل ۹ فاکتور زیست محیطی است که به کمک آنها اقدام به تخمین میزان تولید رسوب در حوضه های آبخیز می گردد این فاکتور ها عبارتند از : زمین شناسی، خاک، اقلیم ، روان آب، توپوگرافی، پوشش سطح زمین، کاربری اراضی، فرسایش شیاری و فرسایش سطحی. در این مطالعه به منظور ارزیابی فاکتور ها و تهیه نقشه های فرسایش و رسوب زایی از نرم افزار ArcGIS 10.2 استفاده شد. نتایج بدست آمده برمبنای مدل MPSIAC نشان داد که ۹۴/۲ درصد از مساحت منطقه مورد بررسی (۴۷۶/۱ کیلو متر مربع) در کلاس رسوب زایی کم قرار دارند و ۲۹/۲ درصد از مساحت منطقه مورد بررسی (۱۴۷/۵ کیلو متر مربع) در کلاس فرسایش متوسط قرار دارند. بر این اساس کل رسوب زایی و فرسایش برآورد شده در حوضه به ترتیب معادل ۱۲۳۶/۵ و ۵۰۹۱/۶ مترمکعب در کیلو متر مربع در سال محاسبه گردید. آنالیز حساسیت پارامتر های مدل MPSIAC نشان داد که شاخص های فرسایش کانالی، پوشش سطح زمین و زمین شناسی با ضریب همبستگی ۰/۷۵ تا ۰/۳۶ (روش پیرسون) با میزان فرسایش به ترتیب حساس ترین پارامتر ها و شاخص کاربری اراضی با کمترین همبستگی کم حساسیت ترین پارامتر در مدل مورد استفاده هستند.