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Soil erosion and Sediment yield risk Assessment using an empirical Model of MPSIAC for upstream Watershed of Abbaspour and Masjed-soleiman dams, SW-Iran

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ABSTRACT
Watershed degradation due to soil erosion and sedimentation is one of the major environmental problems in Iran. With respect to the relatively suitable compatibility of Pacific South West Inter Agency Committee (MPSIAC) model to the arid and semiarid conditions of Iran and lack of enough hydrometric station in region, we employed the "modified PSIAC model" to estimating of sediment yield and providing sediment yield map in these sub-watersheds. At first, to enter the available raw data into the GIS framework we digitized the nine factors of maps. In the second stage, digitized maps were encoded with respect to the values of each factor and then these factors of maps were summed together, and finally sedimentation score map was provided. We applied (QS) equation on the sedimentation score map and finally related map was obtained. The results show that the most values of erosion are in Shaly, Marly, Gypsum and weathered alluvial deposits parts of sub-watersheds correlated with sensitive formations such as Gachsaran, Aghajari and Quaternary sediments. According to sediment score that estimated from the established MPSIAC model, more than 75% of the total sub-watersheds area falls within a class IV of erosion category which is considered to be high. Also, the amount of sediment yield for upstream watersheds of Abbaspour and Masjed-soleiman dams were calculated 7.7 and 6.7 ton/hec that are equal to 2 and 1.35 million ton per year by MPSIAC model, respectively. Linear regression analysis between MPSIAC model results and two of most influencing factors on erosion, the Surface and gally erodibility indicated that there was a significant correlation. The results of this paper suggested that the model is suitable for predicting yearly average sediment yield of the Iranian watersheds with similar conditions.
Keywords: *MPSIAC, GIS, Erosion, Sediment Yield, Abbaspour & Masjed-soleiman dams.*

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INTRODUCTION

Soil erosion is a widespread environmental problem threatens human being in the developing countries and it can effect dynamically balanced watershed system indirectly by increasing water runoff and degrade water quality and cause misdistribution of water in the watershed[7]. It has therefore economic, political, social and environmental consequences due to both on-site and off-site damages. The conflict between environmental protection and the economic development by different land uses within a watershed are challenges facing land use planners in many developing countries [1]. 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, dams, and land use planning in most of countries like Iran [2].

In Iran, it is estimated that the average annual erosion rate of watershed is more than 20 times as much acceptable average level in the world [6]. In Iran, the climate variation, geologic formations and topographic conditions have important role on the increasing of erosion. Also, overgrazing, dry farming and deforestation are the other major causes of watershed degradation in Iran [3]. These various factors need to modeling for better assessment.

Modeling 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]. In watershed management studies, having knowledge on the erodibility of the soil, the state and intensity of erosion, and the expected effect of conservation measures control are of paramount importance in the understanding of erosion. These are especially critical in areas without any gauging station like our study area.

In this study, the "Modified PSIAC (MPSIAC) method" which is specially design for arid and semi-arid area in the United States was assessed for its applicability to the Iranian watershed environment [6, 1]. In this study we used newest GIS software to obtain a good and accurate result at the least time. The upstream area of Masjed-Soleiman and Abbaspour Dams in Khuzestan province in SW of Iran was taken as an example of the use of GIS techniques, spatial data management and modeling for assessing erosion severity and sediment yield. This area represents the southwestern Zagros part of Iran which is supposed to be one of the most dynamic regions of Iran in terms of water and energy supply, industrial–urban development and agrarian activities. This area located between the latitude of 30° 40’ 28” to 33° 34’ 37” North and longitude of 48° 37’ 45” to 51° 06’ 57” East (Figure 1). This area is one of the sub-basins of Karoon River watershed with a total area of 4542 km^2. There are seven gauging (hydrometric) stations installed at the Karoon River, where the data of sediment and discharge were used in the present study. This region is high mountainous (more than 70%) and the climate is generally arid to semi-arid with average precipitation of 900 mm per year [7]. The maximum, minimum and average temperatures in this area are 52°C, -6.8°C and 24.8°C.

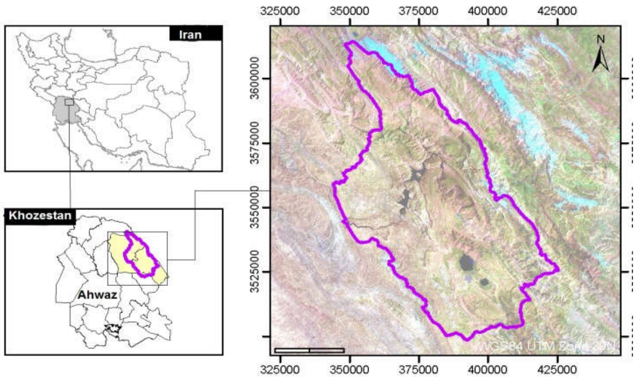

Figure 1. Geographical position of the study area

The average elevation is 858 m. Watershed physiographical Specification is shown in Table 1. The majority of the slope class in watershed is in class 3 (slope angle range of 10 to 20%) and class 4 (slope angle range of 20 to 30%) with 26% and 20% of the study area (Figure 2). The majority of the steep area is around the east, north and north east of the study area. Watershed characteristics such as morphological and drainage properties are shown in Table 1. The length of stream in order 1 (main stream) is 566.975 km, in order 2 is 204.341 and in order 3 is 149.685km (Table 1).

Surface erosion and mass movements within a catchment area produce sediment which becomes available for transport. Changes in land use due to development strategies exposing erosion-sensitive geological formations consisting largely of Shale, Marl, Gypsum (like Gachsaran and Aghajari formations) and poor vegetation cover in the Zagros Mountains are the main factors in making millions of tons of sediment available annually for erosion and transport.

Table 1. Physiographical Specifications of watershed.

Area (hectare)	*Compactness Coefficient (*1)*	*Form Factor (*2)*	*Max Height (m*	*Min Height (m)*	*Drainag e Density (*4)*	*Average of Slope (%)*	*Length of main Stream (km)*	*Time of Concentra tion (hr) (*3)*
454189	2.14	0.081	3724	223	0.243	26	135	11.8

Note ((number); (*1) Gravelius Equation [Kc=28P/A^0.5) A: area (km^2), P: perimeter (km)] (*2) Form Factor in Horton Equation (F=A/L^2) A: area (km^2), L: Length (km) (*3) Kiripich Equation [Tc(hr)=o.ooo3L^0.77*S^-0.385)L: Length of stream(main), S: Average of watershed slope (m/m)] (*4) Drainage Density Equation [Dd=L/A: L: Length streams (km), A: area (km^2)]*

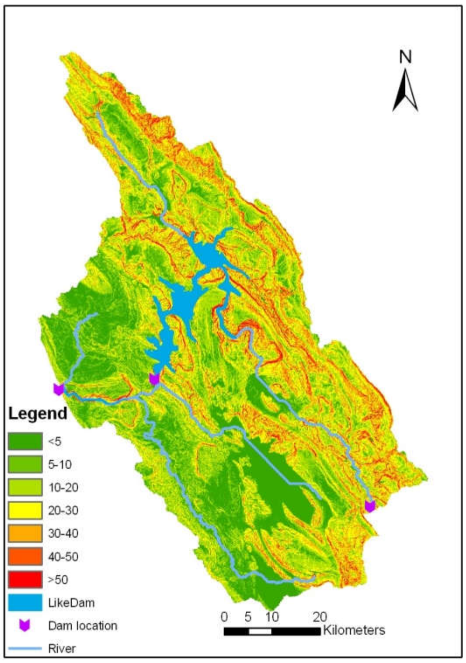

Figure2. Slope angle distribution of the watershed.

MATERIAL AND METHODS

The methodology includes nine sections for model derivation. By reason of the great number of data, activity and changeability of these data in the natural resources, Geographic Information System (GIS), as a useful tool, is carried to solving many problems. MPSIAC model incorporated nine factors from nine equations are: surface geology, soil, climate, runoff, topography, land use, ground cover, and erosion condition and channel erosion (Table2). According to the table, the erosion factors maps were encoded and with overlaying these maps in GIS framework, the sediment yield map in accordance with sediment yield (Qs) equation was obtained. For ease of interpretation, each of the factors is discussed in Table 2. Fieldwork was undertaken for 20 days from 5 to 25 December 2013.

To calculate Surface geology (y_1), in the first step, geology map was digitized and then based on the stones and sediments sensitivity to erosion, this map was encoded and a new data field in the geology map database (based on Y_1 factor) was created(Figure 3)..

With due attention to the soil (y_2) studies and soil experiments, the effective factors on the K (k is erodibility factor in the USLE method), namely, silt + very fine sand percent, sand percent, organic matter percent, soil structure and permeability were determined and then by using Wischmeir monograph, K value and at last Y_2 value was estimated (figure4).

Table 2. *Effective factors on the erosion and calculation method in the MPSIAC model*

Description	Equation	Effective factors	No
X1 =Stones sensivity to erosion(0-10)	Y1=X1	Surface geology	1
K=soil erodibility	Y2=16.67K	Soil	2
P2 =6-hour rainfall with 2-year return period	Y3=0.2P2	Climate	3
R=runoff height Qp =1-year specific pick discharge	Y4=0.006R+10Q P	Runoff	4
S=slope (%)	Y5=0.33S	Topography	5
Pb=bare ground percent	Y6=0.2Pb	Land cover	6
Pc =crop canopy percent	Y7=20-0.2Pc	Land use	7
SSF=the score of soil surface erosion in the BLM method	Y8=0.25SSF	Surface erosion	8
SSFg=the score of gully erosion in the BLM method	Y9=1.67SSFg	Gully erosion	9
R=sediment yield score R= X1+16.67K+0.2P2+0.006R+10QP+0.33S+0.2Pb+20-0.2Pc+ 0.25SSF+ 1.67SSFg (QS= sediment yield (ton/hectare/y) = 0.253e0.036R)			

In this model, Rainfall was estimated based on 6-hours precipitation amount with 2-year return period. In this study, climate factor was based on 30 years (1982-2012) of rainfall record (figure5). From the record, the rainfall intensity duration and frequency curve were derived. The climate factor (y_3) was estimated according to table1. And the rain station whose data were used in the calculation rain fall depicted in figure5.

Runoff factor (y_4) was obtained based on analysis of discharge data. In the study areas, runoff largely depends on atmospheric conditions and the surface lithology of the formation permeability. According to the runoff equation (Table 2), by calculating the average of runoff height (R) and specific pick discharge (Q_P).

Topography factor (y_5) was determined based on average percentage of slope steepness. To providing this layer at first by using DEM layer (Digital Elevation Map) (Figure 5), slope map was obtained and then this map was multiplied by 0.33, and at last the topographic factor map was obtained.

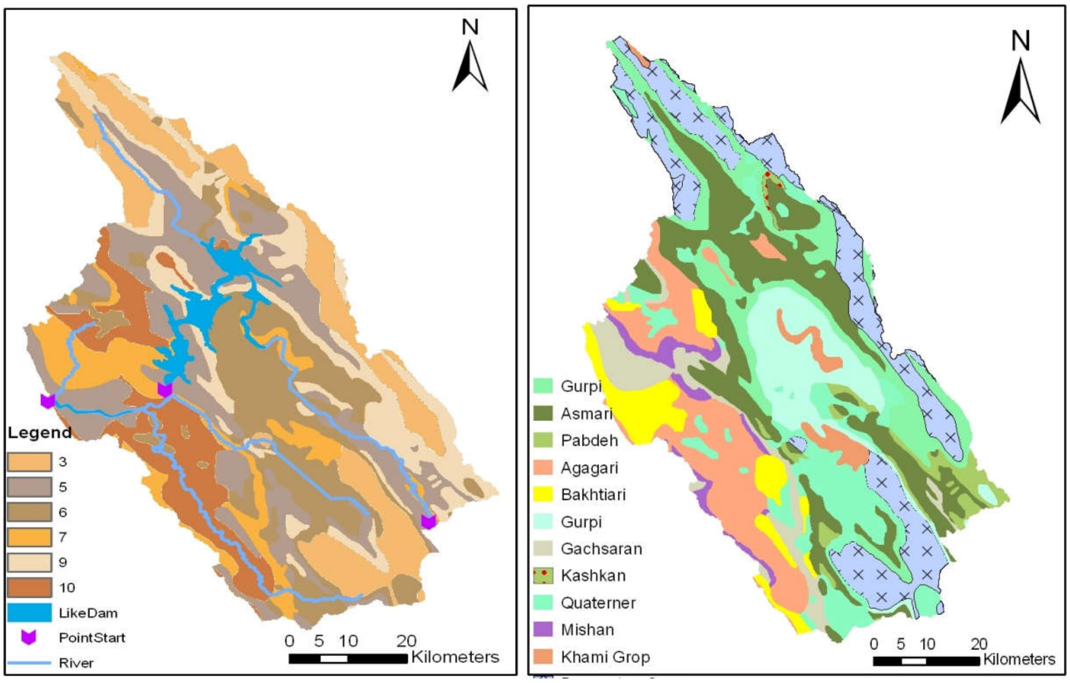

Figure3. *Geology map (Right) and geology factor score map of watershed (Left).*

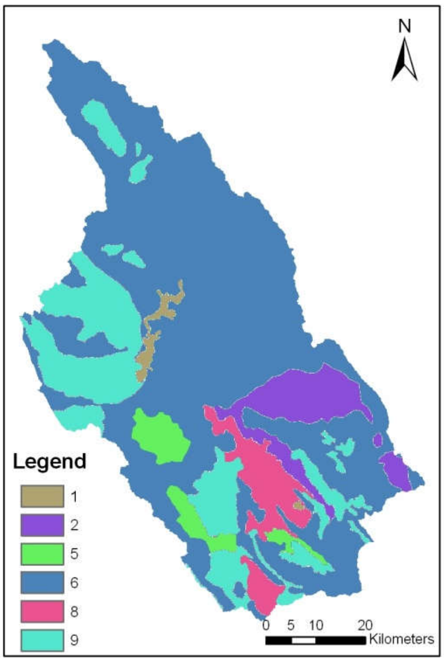

Figure 4. *Soil factor map of study area.*

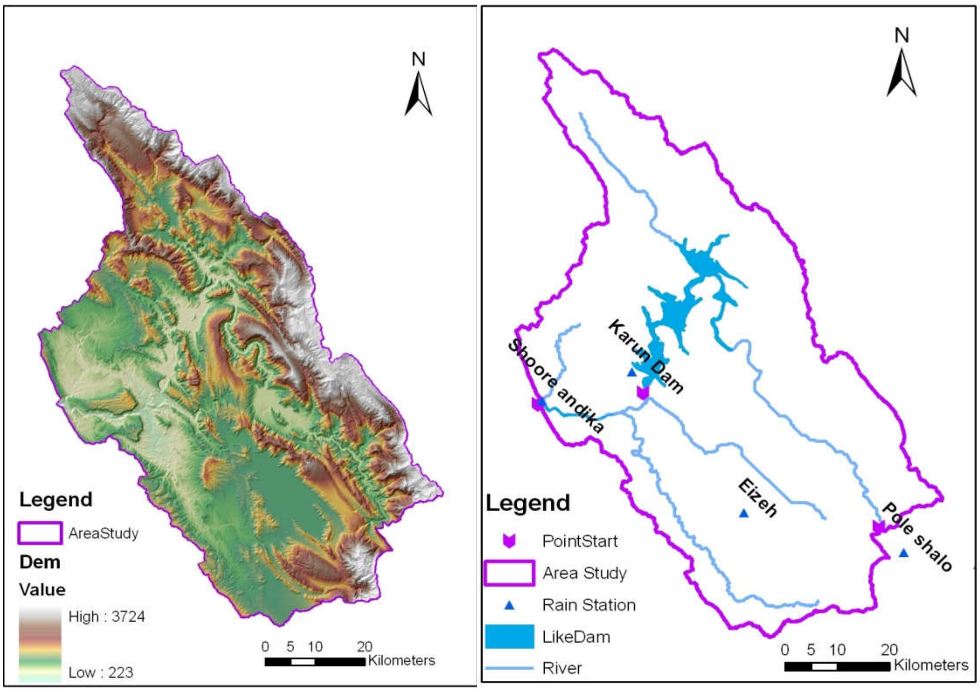

Figure 5. *Rain Station map (Right) and DEM layer (left) of watershed*.

The main characteristics considered as ground cover are vegetation, litter and rocks. To providing Ground cover (y_6) factor, at first we digitized plant cover map and then in this map based on the bare grounds percent, a new data field was created and classified (figure 6).
Land use factor (y_7) was estimated based on canopy cover. With due attention to the crop canopy percent in each cover type and by using Land sat ETM imagery, topographic maps and field visits, plant cover map based on Y_7 value was encoded and classified (figure 7).
Upland erosion factor(y_8) was obtained based on Bureau of Land Management (BLM) method [8]. This method is used from 7 factors: surface erosion, land cover, rill erosion, surface litter, demolition traces on the ground surface, surface flows traces and gully erosion. By field surveying, IRS and Landsat ETM imagery, the score of these factors was determined and then with digitizing geomorphology map, this map was encoded based on Y_8 factor value and a new data field (based on Y_8 factor) was created in this map (figure 8).
Channel erosion factor (y_9) was obtained based on gully erosion factor from the BLM method and by the relationship between yearly rainfall (mm) and gully erosion improvement. Based on this factor, geomorphology map was encoded and a new data field in this map was created.

Utilizing GIS, spatial data related to surface geology, soil types, climate, runoff, topography, ground cover, land use, surface erosion and channel erosion were incorporated into MPSIC model to facilitate the prediction and assessment of sediment yield of the sub-watersheds. Summation of scores in this nine environmental factors is called sediment yield score (R) (Figure 9). To calculate R in the ArcGIS framework, at first all nine factors rasterized by using raster calculator menu and then combined with each other. In other words, the coordinates of the cells are combined and integrated; for this case, the data should be in raster structure to allow for their integration in ArcGIS framework. Sediment score (R) was employed to estimate sediment yield (QS) according to Johnson & Gebhardt formula [8], (Table1) and (figure 10):

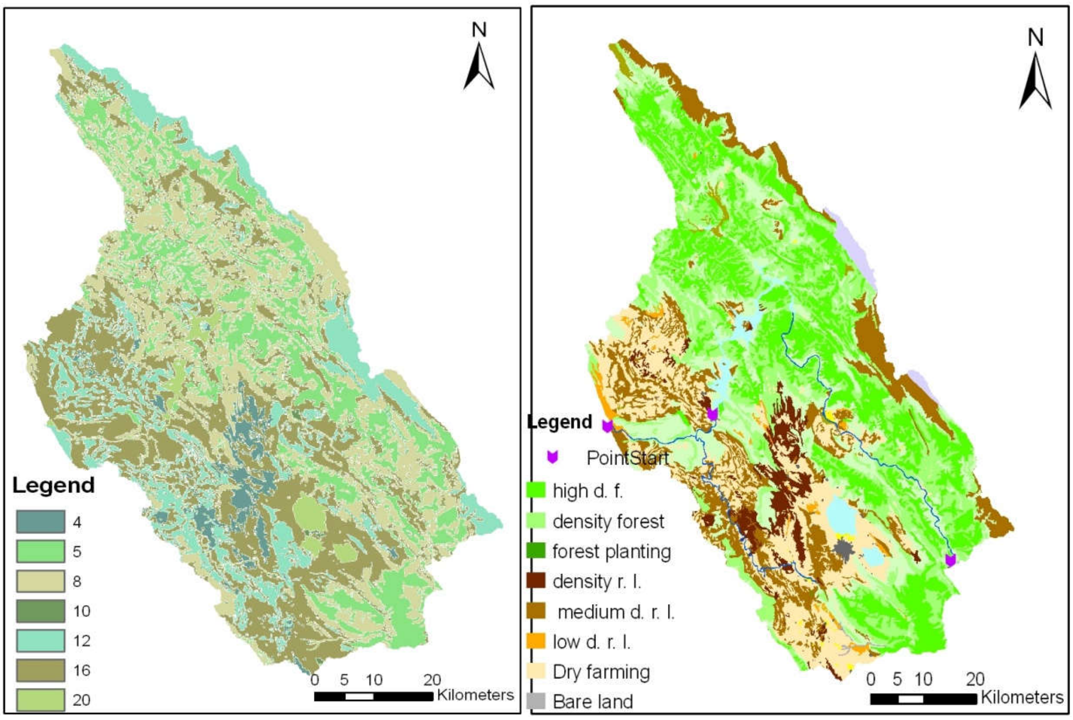

Figure 6. *Ground cover factor (Right) and classification map (Left) of watershed*.

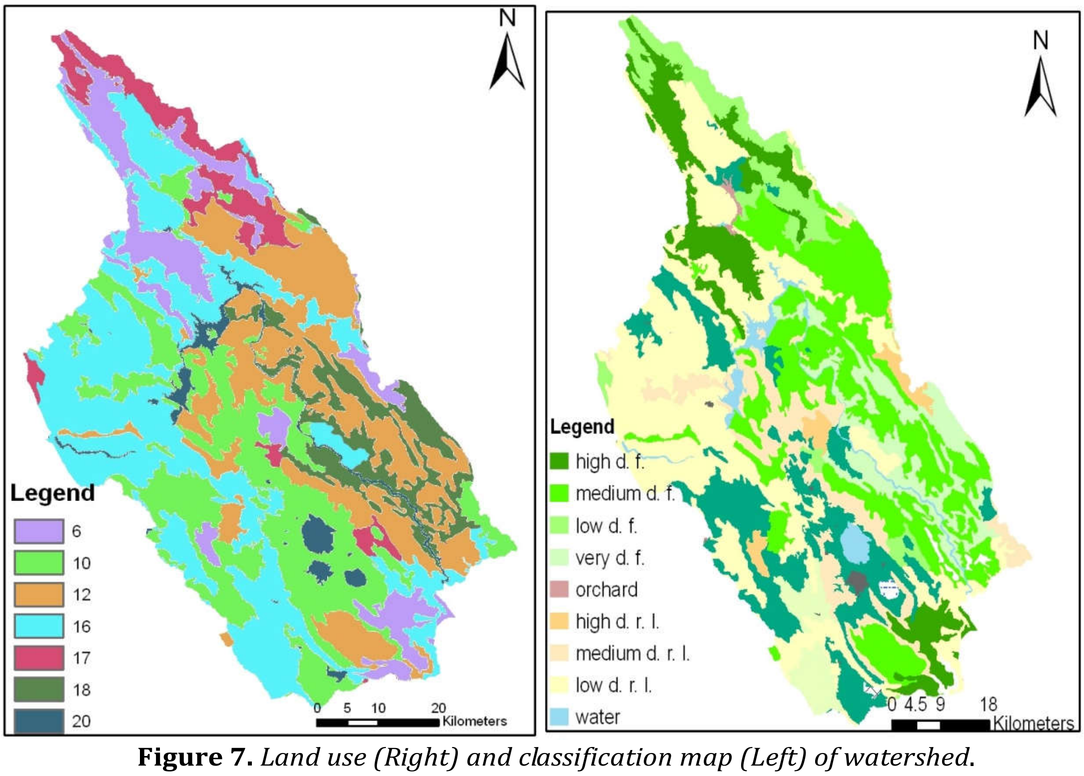

Figure 7. *Land use (Right) and classification map (Left) of watershed*.

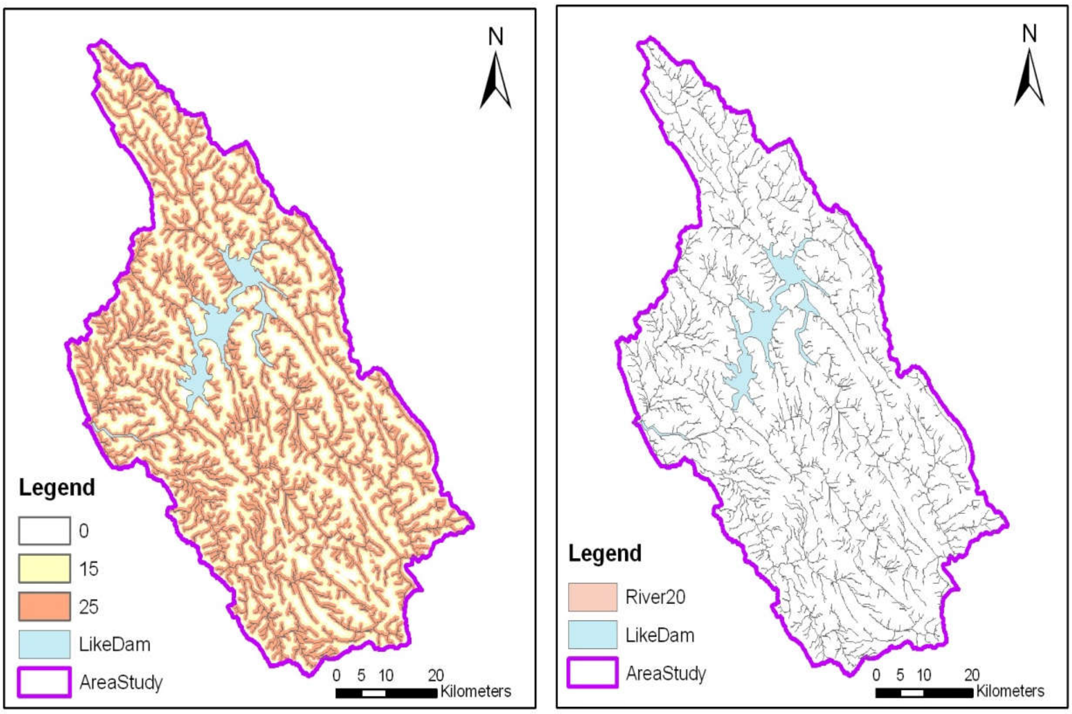

Figure 8. *River and channel factor (Right) and erosion factor map (Left).*

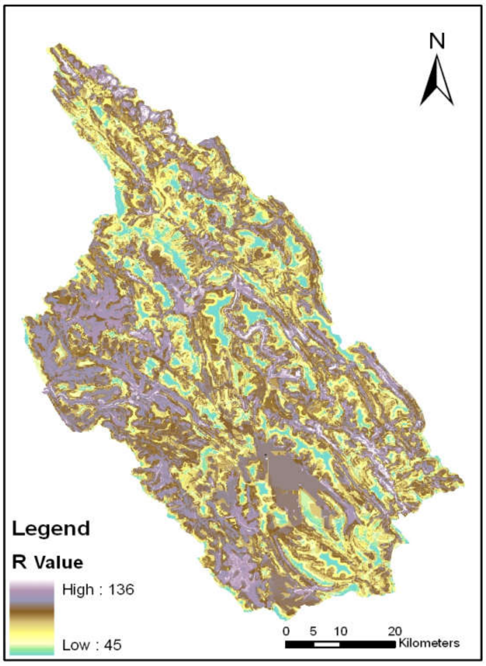

Figure 9. *Sediment yield score (R) map of study watershed.*

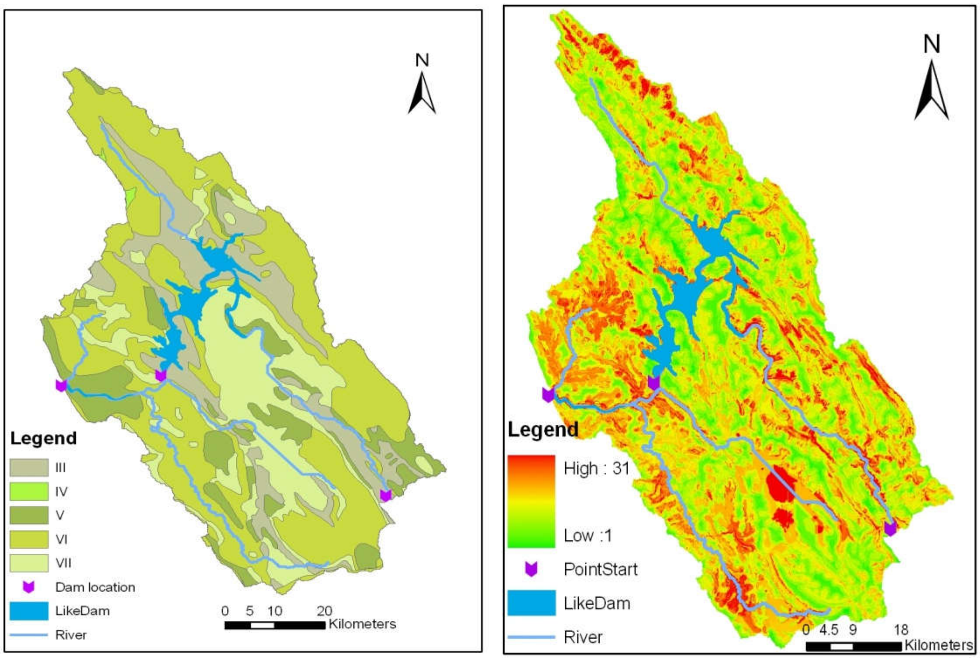

Figure 10. *Sediment yield (Right) and erosion classification map (Left) of study watershed*

DISCUSSION

The MPSIAC model was developed primarily for application in arid and semi-arid areas and is believed to be appropriate for the same environmental conditions in Iran [9]. Utilizing GIS, spatial data related to surface geology, soil types, climate, runoff, topography, ground cover, land use, surface erosion and channel erosion were incorporated into MPSIC model to facilitate the prediction and assessment of sediment yield of upstream watershed of Masjed-Soleiman and Abbaspour dams. Accordingly, the sediment yield score map of this sub-basin was prepared (Figure 10). Then based on the table 3, the sediment yield map was classified and the result is shown in figure 10.

Table 3. Sediment yield score and classification in MPSIAC model.

Sediment yield scores	The amount of sediment yield ($m^3/km^2/y$)	Sediment yield intensity	Sediment yield class
>100	>1429	Very high	V
75-100	476-1429	High	IV
50-75	238-476	Medium	III
25-50	95-238	Low	II

For ease of interpretation and evaluation, the values of R were divided into five classes (Table 3). Majority of the classes are in classes IV and III. The average, minimum and maximum values for R for this study area were calculated 92, 36 and 132, respectively. Also, the amount of sediment yield for upstream watersheds of Abbaspour and Masjed-soleiman dams were calculated 7.7 and 6.7 ton/hec that are equal to 2 and 1.35 million ton per year, respectively. The faults and joints are very frequent in this area but MPSIAC model don't consider and input them. Among all parameters, the maximum of changes and fluctuations are related to slope layer. According to average values in calculated layers, maximum to minimum amounts are related to erosion, topography, land use, groundcover, climate, geology, slope and runoff, respectively.

According to situation of study area and during the study period, it was assumed that the factors of climate, soil and topography are constant and sensitive to sediment yield predicted by the model. But the most sensitive factors to the model are the surface geology, gully erosion and runoff factors. The good correlations between them with sediment yield indicated that changes in natural agents will affect soil erosion and sedimentation. For instance, increase in annual and intensity of rainfall, and increase in runoff could result in an increase in the erosion rate. It is expected that surface erosion, ground cover and land use were found to be more sensitive to the model results, however in this analysis the results show otherwise. Watershed management goals such as recognition of sensitivity area to erosion, determination of critical area to erosion hazard and ranking of parcels or catchments would be one of the important objectives in watershed study. The nine factors in MPSIAC model almost represent all agents that affected soil erosion and sedimentation either directly or indirectly. Surface erosion and sediment yield are important factors that should be taken into account in planning renewable natural resource projects. Generation of erosion and sediment-yield maps for areas under soil conservation and vegetation improvement is controlled mainly by considering the extensive effects of soil-wasting. Proper environmental planning at different levels has been called for by watershed managers during last years to integrate natural resources limitations and human needs continually and effectively. The watershed optimization for each land use, especially agriculture as one of the significant contributors to the environmental degradation, is therefore necessary to achieve sustainable development [10].

Over the past few decades, the vital resources of almost entire watersheds in Iran have been subject to rapid deterioration resulting from expanding anthropogenic activities such as dams' construction. The Iran Forest and Rangeland Nationalization, Act of 56 (fixing and controlling of governmental national land) was effective in reducing land use conversion and restoring many of resources. Despite its progress, over-exploitation and mismanagement of watershed resources still remain as major threats to the watersheds in Iran. This is a major challenge because of their complex nature and the existence of diverse and diffuse contributing land uses within the watersheds [9]. The equilibrium between geological erosion and soil formation is easily disturbed by human activities [6]. It is estimated that 26.4 million hectare of land in Iran are under the influence of water erosion and 35.4 million hectare are under the influence of wind erosion. Iran has more than 10 million hectares of cultivated land under irrigation and more than 8 million hectares of agriculture land under dry farming. Overgrazing, deforestation, cultivation, road construction, drought, civil and industrial development are possible causes that tend to accelerate the removal of soil material in excess of which is removed by geological erosion. This type of erosion is known as accelerated erosion. Accelerated erosion takes place when vegetation covers which protect top soil from erosion agents such as rain and wind is removed. The soil particles movement becomes extensive until the top soil has been completely washed away, leaving the subsoil or the parent rock behind [6]. The problem of erosion is further exacerbated by loss of organic matter in the topsoil that hold the soil particles together due to improper land use activity.

CONCLUSIONS

With due attention to the studies and surveying of these sub-watersheds, types of erosion that have the largest land areas in the region are rill, stream and gully erosions. Also most values of erosion are in Shaly, Marly, Gypsum and alluvial deposits parts; which are sensitive and basically covered this region. Thus with applying the reformatory programs and considering these sub-watersheds formations, are often sensitive to erosion, we can decrease erosion. According to sediment score that estimated from the established MPSIAC model, more than 75% of the total sub-watersheds area falls within a class IV of erosion category which is considered to be high. Also, the amount of sediment yield for upstream watersheds of Abbaspour and Masjed-soleiman dams were calculated 7.7 and 6.7 ton/hec that are equal to 2 and 1.35 million ton per year by MPSIAC model, respectively.

The most sensitive factors to the model output are topography, surface geology and gully erosion. Also, increase in height and slope can cause increase in runoff which in turn leads to increase in the erosion rate in the region. By the statistical evaluation of data and information, we reached the conclusion that MPSIAC model results, shows high conformity with reality. With due attention to the obtained results and studied sub-basins conditions, obtained sediment has good accuracy. The nine factors in MPSIAC model almost represent all agents that affected soil erosion and sedimentation either directly or indirectly. The results of the study clearly suggested that the model can be used to predict average annual sediment yield on a long term basis. In the analysis it was showed that the most sensitive factors to the model output is the surface erosion factor followed by slope and runoff factor. Three other factors namely climatic, geology surface and channel erosion are found less sensitive to the cause of soil erosion in the study area.

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