Vol. 35, No. 01, pp. 97-110/Marzo 2022

ISSN-E 1995-9516
Universidad Nacional de Ingeniería

http://revistas.uni.edu.ni/index.php/Nexo
https://doi.org/10.5377/nexo.v35i01.13920

Study of the effect of geological and geomorphological parameters on soil erosion and sediment yield of Gabrik River basin, S.E Iran

Estudio del efecto de los parámetros geológicos y geomorfológicos sobre la erosión del suelo y el rendimiento de sedimentos de la cuenca del río Gabrik, S.E Irán

Shahrooz Shojaei, Mohammad Reza Noura*, Mohammad Elyas Moslempour

Department of Geology, Faculty of Sciences, Zahedan Branch, Islamic Azad University, Zahedan, Iran.
* Corresponding author email: shahram_shiravi@yahoo.com

(recibido/received: 15-noviembre-2021; aceptado/accepted: 17-enero-2022)

ABSTRACT

The Gabrik River basin is located in the Makran zone in southeast of Iran. This basin is characterized by specific geomorphological features related to its geological characteristics and geographical location. The present study investigates the attempts to minimize the negative effects of sediment accumulation behind the Gabrik dam in this region. Therefore, the main objectives of this research are to study the geomorphological status of the basin and analyze the sensitivity of geological units to erosion. Investigation of geomorphological forms of the Gabrik basin indicates that the internal (tectonic) and external (erosion and sedimentary processes) dynamic processes have a significant role in the basin evolution. The results could be used to identify the potential areas for erosion and sediment production. To estimate the sediment erosion and yield, the Gabrik basin was divided into two hydrological units (i.e., HU1 and HU2). Then, the required information to determine nine factors of the MPSIAC model and five factors of the FSM model were provided and determined for each unit. Afterward, the soil erosion maps were extracted in ArcGIS software. As a result, the rate of sediment yield from MPSIAC and FSM models was determined 4 and 6.23 tons per hectares, respectively. The findings of this research indicate the importance of tectonics, lithological units, and climate on erosion rate, sediment production, and geomorphology of the Gabrik basin. Also, according to the results from erosion maps, it was revealed that the soil erodibility in the Gabrik area is low to medium. So, in these areas, the implementation of soil and water conservation programs is essential.

Keywords: Geomorphology; Soil erosion; Gabrik River; MPSIAC model; FSM model

RESUMEN

La cuenca del río Gabrik se encuentra en la zona de Makran en el sureste de Irán. Esta cuenca se caracteriza por características geomorfológicas específicas relacionadas con sus características geológicas y ubicación geográfica. El presente estudio investiga los intentos de minimizar los efectos negativos de la acumulación de sedimentos detrás de la presa Gabrik en esta región. Por tanto, los principales objetivos de esta investigación son estudiar el estado geomorfológico de la cuenca y analizar la sensibilidad de las unidades geológicas a la erosión. La investigación de las formas geomorfológicas de la cuenca de Gabrik indica que los procesos dinámicos internos (tectónicos) y externos (procesos de erosión y sedimentarios) tienen un papel significativo en la evolución de la cuenca. Los resultados podrían usarse para identificar las áreas potenciales de erosión y producción de sedimentos. Para estimar la erosión y el rendimiento de los sedimentos, la cuenca de Gabrik se dividió en dos unidades hidrológicas (es decir, HU1 y HU2). Luego, se proporcionó y determinó la información requerida para determinar nueve factores del modelo MPSIAC y cinco factores del modelo FSM para cada unidad. Posteriormente, los mapas de erosión del suelo se extrajeron en el software ArcGIS. Como resultado, la tasa de rendimiento de sedimentos de los modelos MPSIAC y FSM se determinó en 4 y 6.23 toneladas por hectárea, respectivamente. Los hallazgos de esta investigación indican la importancia de la tectónica, las unidades litológicas y el clima en la tasa de erosión, la producción de sedimentos y la geomorfología de la cuenca del Gabrik. Además, de acuerdo con los resultados de los mapas de erosión, se reveló que la erosionabilidad del suelo en el área de Gabrik es de baja a media. Entonces, en estas áreas, la implementación de programas de conservación de suelos y agua es fundamental.

Palabras claves: Geomorfología; La erosión del suelo; Río Gabrik; Modelo MPSIAC; Modelo FSM.

1. INTRODUCCIÓN

Soil erodibility is one of the key factors in erosion (Igwe 2003; Fu et al. 2005; Ferreira et al. 2015). This phenomenon is defined as soil sensitivity to erosion processes (Bryan et al. 1989; Bagarello et al. 2012). However, erosion is a complex concept that is influenced by many factors such as soil properties (Singh et al. 2012; Chen et al. 2013; Wang et al. 2015), terrain (Mwaniki et al. 2015; Parajuli et al. 2015), climate (Sanchis et al. 2012; Hussein et al. 2013), vegetation (Sepulveda-Lozada et al. 2009), and land use (Cerda et al. 1998; Tang et al. 2016). Meanwhile, rivers, as one of the most important drainage systems, transport the erosive material of the earth's crust as suspension or bed loads into various sedimentary basins such as reservoirs of dams, lakes, seas, playas, or different sub-environments of the river system. In addition to carrying sedimentary particles, rivers play an important role in the erosion of older deposits and the deformation of the earth's crust (Thorndycraft 2008). Nevertheless, it should be noted that the different behavior of rocks against erosion makes some lithological units sensitive to erosion and leads to sediment production (Feyznia et al. 2003). Therefore, in studies related to soil erosion and protection in a catchment area, the geological and geomorphological features of the basin are also of special importance. Geomorphologists have developed and introduced numerous concepts and theories to better understand the complex intrinsic relationships between shapes, processes, materials, and energies (Hutton 1795; Gilbert 1890; Thornbury 1969).Show more The geomorphic processes are defined by physical and chemical changes that affect the shape of the earth's surface and. In general, they can be divided into two categories including internal processes (i.e., folding, faulting, volcanism, diastrophism, landslide, and metamorphism) and external processes (i.e., weathering, sediment transportation and accumulation, erosion, and mass transport). The most important factors in the formation and development of a basin are tectonic activities (morphotectonic) that occur on a large scale and control the folding trends, as well as faults and joints systems. Simultaneous with tectonic processes, climatic processes cause erosion and land degradation of the basin. These processes depend on a variety of factors including the latitude of the region, the height of different parts of the basin, the nature and genesis of formations (morphogenesis), and the existence of weaknesses related to tectonic processes (Lee Praa et al. 2000).

Recently, the researchers have been accomplished many studies on the performance and efficiency of empirical models in the different basins of Iran. These works have mainly focused on hydrogeomorphology and flood hazard zoning by application of satellite and geographic data to estimate the erosion and sedimentation rate in the basin. (e.g., Jokar 2001; Borzoo et al. 2004; Nabipy Lashkarian et al. 2008; Mohammadiha et al. 2013). But some of these studies have considered the geomorphology and soil erosion of the Gabrik basin (Faridi et al. 2013; Sistani-Bedouei 2017). Therefore, there is no comprehensive study on the factors affecting erosion and its impact on sediment yield in the Gabrik basin. The present study is an attempt to estimate the erodibility rate of the Gabrik basin by considering factors such as climate, geology, and geomorphology of the region, semi-quantitative MPSIAC, and FSM models.

The application of these models in basins without sedimentation stations such as the Gabrik basin is essential for evaluating the erosion, construction, and management of structures such as dams in these areas.

2. STUDY AREA

Gabrik catchment with an area of 4290.35 km2¬ is located in the southeastern part of the Hormozgan province (Bandar Jask). It extends from the northern mountains of the basin in the village of Darsoharan to the outlet of the Gabrik River at the Parekouh region and covers the Bashagard and central areas. The Gabrik River, as one of the independent rivers in the Bandar Abbas-Sadich basin, originates from the Bashagard Mountains, and flows into the Oman Sea northward (Fig. 1). The length of the mainstream flows to the site of the Gabrik dam is 208.7 km. Based on the low altitude, topography (consists of numerous mountains, mostly semi-high, almost without vegetation) and air masses entering to the Gabrik region (polar continental, polar maritime, tropical continental), it is characterized by a warm and dry climate.

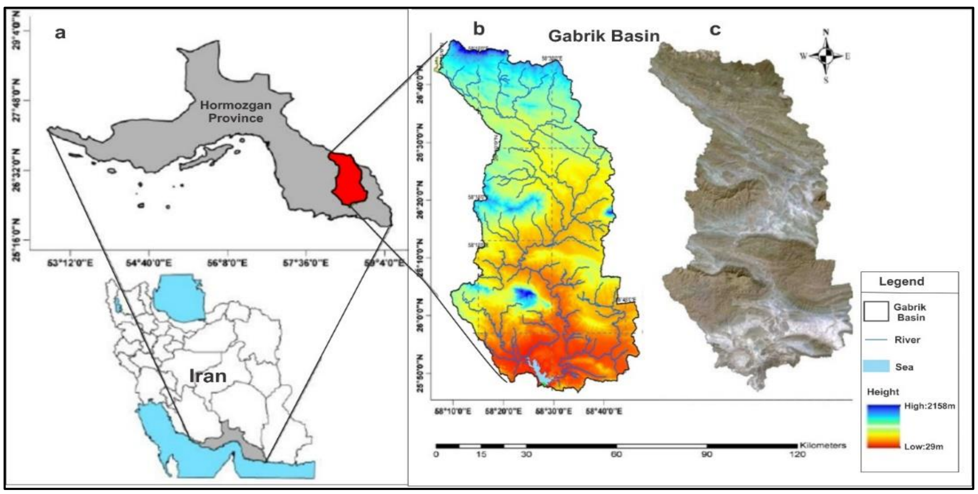

Fig. 1. (a) Geographical location of the Gabrik Basin in southeast of Iran; (b) The Gabrik Basin topography map with (c) Aerial image. They show that mainly, the studied basin composed of height.

2.1. Geology

Gabrik catchment area is located in one of the sedimentary-structural units of Iran (Aghanabati 2006), called the Makran zone. The western boundary of the Makran zone is limited by the Minab fault with a north-south trend. The southern border is the Oman Sea, and it is traceable from the east to the Pakistan border. The Gabrik basin consists of 14 rock and sedimentary units from the Cretaceous to Quaternary. Sandstone, shale, marl, and siltstone are the dominant lithology of these units in the basin. Among the most important faults in this area are Bashagard, Mal-e-Kamo (Zehab), and Gabrik (Jahlizak) faults. The characteristic feature of the fault pattern in the basin is tectonic blocks, mostly in the form of horst, developed in a compressive system. In General, the faults of Makran Mountain are more or less parallel and form a fault zone that has been of great importance during the Tertiary period.

3. DATA AND STUDY METHOD

In this research, to investigate the geomorphology and calculate the sedimentation rate and soil erosion of the Gabrik Basin, the required information was first prepared as follows:

Several data including DEM, topography, geology, and soil maps, as well as climatic, hydrologic, and satellite data were required. DEM data were supplied by National Mapping Agency, meteorological and hydrological data were supplied by Regional Water Authority, and other required maps including geology, soil, geomorphology, land cover, etc. were drawn from prior investigations. Also, several field assessments were carried out to identify natural features and geomorphology of the basin, adjust the available maps in the study area, identify current soil erosion, and evaluate the status of vegetation and ground control points using GPS. Moreover, ETM+ data were acquired from land-use and vegetation density map downloaded from http://earthexplorer.usgs.gov/. In this research, the ArcGIS software was applied to assess and analyze the gathered data.

3.1. Determination of erosion rate and sediment yield by factors of Modified PSIAC (MPSIAC)

The MPSIAC model (PSAIC, 1986) was developed primarily for application in arid and semi-arid areas in the southwestern USA, and is believed to appropriate for the same environmental conditions in Iran (Eisazadeh et al 2012). The MPSIAC model are factor-based, which means that a serious of factors, each quantifying one or more processes and their interactions, are combined to yield and overall estimation of soil loss. Regarding the prior investigations showing higher accuracy for the MPSIAC model (Daneshfaraz et al. 2017) and its wide applications for erosion assessments in Iran, this model was selected for our research. Quantification of the sediment rate and considering the highest numbers of effective factors on soil erosion are the most important advantages of the model. The MPSIAC model predicts soil erosion according to nine factors with nine equations including 1) surface geology, 2) soil, 3) climate, 4) runoff, 5) topography, 6) land cover, 7) land-use, 8) surface erosion, and 9) channel erosion. In Table 1 the scores of nine factors in MPSIAC model for each HU¬s of the Gabrik Basin have been shows.

Table 1. The scores for factors in the MPSIAC model in the Gabrik Basin

Factors	HU1	HU2	Gabrik Basin
Surface geology	2.2	2.7	1.9
Soil	14.7	11.98	12.12
Climate	10.7	6.1	6.4
Runoff	4	5.2	3.9
Topography	9.8	6.1	6.3
Land cover	5.4	3.8	5.1
Land use	14.7	13.5	14.7
Current status of erosion	20.3	13.1	10.9
Channel erosion	10.8	6.9	7.3
Sum(R)	92.6	69.4	68.6

In this research, for determination the role of surface erosion factor in sediment production was used the BLM model. Also, soil erodibility zoning map was prepared by calculating the score of the soil erodibility factor and determining its numerical value in each of the land units based on the Wischmeier (1978) relationship. The soil erosion map has been prepared and digitized based on the map of the Ministry of Agriculture Jihad. To assess the climate factor of the study area, a map of annual rainfall was prepared in the Gabrik catchment area. In this region the climate factor was determined dry according to the De Martonne method. Also, the score of runoff factor for the basin was determined by examining the specific discharge, intensity, continuity and repetition of floods, and soil hydrological group. Meanwhile, specific discharge in time and surface units was a suitable criterion for evaluating the runoff factor.

Due to the key role of geological units on soil permeability and erodibility in the Gabrik Basin, the soil permeability map and drainage network density map were also prepared and compared with the annual average rainfall map.

Finally, to map the erosion by the MPSIAC model, first, data evaluation was carried out using ArcGIS software and then a layer was prepared for each effective factor of the model. So, an erosion map of the study area was created through ArcGIS.

It is of note that applying the MPSIAC model, it is necessary to divide the studied basin into hydrological units (sub-basins) or equal geomorphological working units according to the intended purpose. So, in this research, the Gabrik Basin based on topography map, satellite images and geographic information system is divided into two hydrological units , namely HU1 and HU2 (Fig. 2).

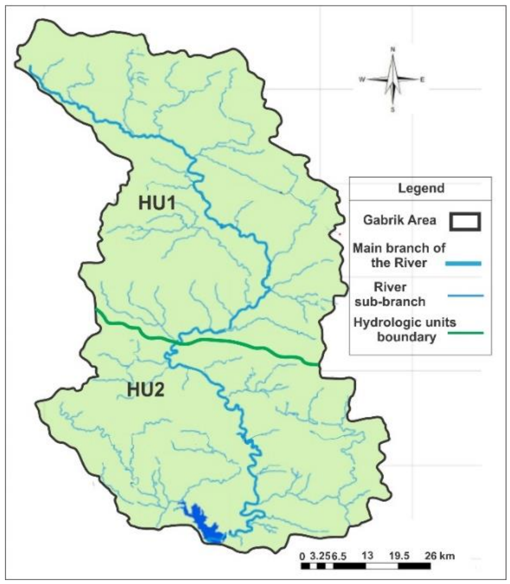

Fig. 2. Map of the hydrological units of the Gabrik Basin

3.2. Estimation of Sediment Yield, Specific Sediment, Sediment Delivery Ration

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

$$Qs = 38.77 \times e^{0.035R} \quad (1)$$

$$Qs = 0.253 \times e^{0.036R} \quad (2)$$

In Eq. (1), Qs is the rate of sediment yield (in cubic meters per square kilometer per year). Also, in Eq. (2), Qs is the rate of sediment yield (in ton per hectare per year). In both equations, e is the Napier number (~2.718) and R is the sum of nine factors of MPSIAC.

3.3. Determination of Specific Sediment

To calculate the specific sediment in the catchment, first, the sediment input is measured at the river's hydrometric station based on the suspended load concentration. Then, by determining the relationship between sediment input and simultaneous river discharge, the specific sediment in the station is estimated and generalized to the desired areas. For this purpose, FAO and USBR methods are used to calculate the sediment load at the site of hydrometric stations. Using this method in rivers with measured sediment statistics is the most practical approach for estimating sediment load. The reason is that in hydrometric stations, according to known methods, only suspended sediment sampling is done. Thus, to obtain the total sediment load (total suspended load and bedload), after determining the concentration of suspended load, bedload is considered as a percentage of suspended load and the total sediment load of the river is obtained from the sum of them. Eventually, the amount of specific sediment load at the site of the studied hydrometric stations is estimated.

3.4. Calculation of sediment delivery ratio (SDR) and specific erosion

The sediment delivery ratio (SDR) indicates the ratio of the amount of sediment transported from the catchment area to the total erosion in the basin. This parameter is obtained from (3) and (4), where Qs is the amount of produced sediment (ton/km2/yr), Ws is the amount of gross (specific) erosion (ton/km2/yr), and A is in square mile. Specific erosion refers to the total erosion of surface, rill, gully, and waterway in the study area.

$$Log\ (SDR) = 1.8768 - 0.14191\ \log(10A) \tag{3}$$

$$SDR = Qs/Ws \tag{4}$$

Finally, to prepare the specific erosion map of the basin and sub-basins, the layer of specific produced sediment was divided into the SDR layer. Then, the erosion layer and the sub-basins layer were combined, and the amount of specific erosion for each sub-basin was calculated. Also, to determine the total sediment and erosion of the sub-basins, their area was multiplied by the specific produced sediment and erosion (Ahmadi 2010).

3.5. Estimation of erosion and sediment with Factoring Scoring Model (FSM)

The FSM model (Verstraten et al., 2003) predicts the annual specific sediment yield of a basin (>100 km2) based on a nonlinear equation involving the basin area and five weighted additional factors: topography, vegetation cover, gullies, lithology and slope. Verstraten et al (2003) identified the general geomorphic setting of the basin, the presence or absence of gullies in the immediate vicinity (5 km) of the reservoir or main river channels, the presence of highly erodible substrates such as like marls, and vegetation cover in the surroundings of the reservoir. This method consists scoring of each five factors with a score of 1, 2, and 3 for low, moderate and high sediment yields, respectively.

The steps to estimate the erodibility rate using the FSM model in the Gabrik catchment area are as follows:

1. Preparing the layers of the slope, vegetation, gully erosion status, geology, hydrological units, climate, and status of soil conservation structures using DEM digital maps, satellite images, aerial photos, and field observations;
2. Determining the weight of the five factors of the FSM model such as topography, vegetation, gullies, lithology, and slope based on the standard table, and making their layers, and assigning the scores to the layers;
3. Overlaying the added layers in the ArcGIS environment, multiplying the five factors of the FSM model, and obtaining the erodibility index (FSM Index); and
4. Estimating the annual erodibility rate of the study basin and its sub-basins using (5).

$$\mathrm{SSY} = 4193\mathrm{A}^{-0.44} + 7.77(\mathrm{FSM\ Index}) - 310.99 \tag{5}$$

where SSY is specific sediment yield (ton/km2), A is the area (km2), and FSM Index is the product of the above five factors in the FSM model. The FSM index is calculated by multiplying the score given to each factor. The index can vary between 1 and 243 (when all factors are assigned 3).

4. RESULTS AND DISCUSSION

The study of the Gabrik catchment is important because a part of its upstream catchment is the Gabrik dam. In this regard, studying erosion and sedimentation rate is important in terms of preservation of surface cortex and soil fertility, wall stabilization of canals, and prediction, and evaluation of sediment accumulation and volume behind the dam. Therefore, identifying the areas of the basin with significant erosion and calculating the amount of sediment that enters the Gabrik dam using two empirical MPSIAC and FSM models are the most important contributions of this study. But, before examining the results of the models, it is necessary to discuss the role and importance of geological and geomorphological characteristics on erosion and sediment production rate of the Gabrik basin.

4.1. Geomorphology and the erodibility rate of the Gabrik basin

Depending on the type and erodibility of rocks and sedimentary units and their role in the development of geomorphological forms of the Gabrik basin, the carbonate, marl-limestone, conglomerate-sandstone, and Quaternary sediments determined as dominant lithological units. The carbonate unit consists of limestone and dolomite. The density of this unit increases its resistance to erosion. However, mechanical and weathering agents along with structural factors in some parts of the basin have led to the breaking and crushing of the rock, and eventually the development of slump structures related to this rock unit. The marl-limestone unit consists of alternating layers of marl and limestone. The marl parts of this unit with a thickness of about 15-20 m are highly impermeable and also prone to erosion. The conglomerate-sandstone unit consists of conglomerate, sandstone, and siltstone. Although the permeability of this unit is high, due to the presence of joints and cracks resulting from tectonic movements, its resistance to erosion is moderate. Physical erosion is more common in this unit, which results in the accumulation of large and fine debris at the foot of the slopes. In general, this unit is relatively resistant to erosion. The Quaternary sediments are generally the result of erosion of rock units and are unstable on high slopes, which cause them to move toward low slopes. These sediments have a very low resistance to erosion, due to the detachment, loose nature, and lack of cement between the components. Fig. 3 illustrates the map of the erosion sensitivity coefficient of rock and soil in the Gabrik basin.

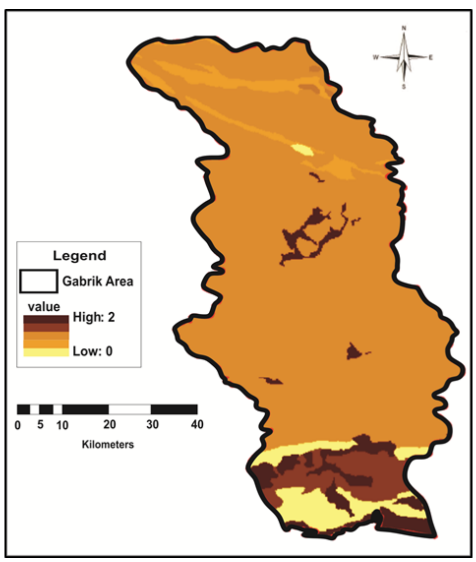

Fig. 3. Map showing the erosion sensitivity coefficient of rock and soil in the Gabrik Basin

On the other hand, the presence of geomorphological forms such as anticlines, synclines, cliff, deep valleys, high fault walls, and folds indicate tectonic activities (Fig. 4). Also the erosion forms (i.e., rockfall, debris, forms of channel wall erosion, rill erosion, honeycomb erosion (Taffoni), and gully erosion) (Fig. 5) and sedimentary forms (i.e., alluvial fans, river channel, fluvial terraces, and flood plain) (Fig. 6) are dominant geomorphologic forms in the Gabrik basin. So, it can be resulted that, in the Gabrik basin the both internal and external dynamics factors of the basin have played a role in the formation of geomorphological forms.

Fig. 4. Some photos of geomorphological forms derived from the effects of internal dynamics (tectonic activity) in the Gabrik basin; (a)-(b) A view of high scrap and folding in Cenozoic units; (c) A view of faulting and displacement of sedimentary layers, indicating the performance of a tectonic activity in the region

Fig. 5. Some photos of geomorphological forms derived from the effects of external dynamics (erosion) in the Gabrik basin. (a) Large pieces of rockfall from heights to the foothills and floodplains of the river; (b) A view of debris in the Gabrik basin. (c) Erosion of the channel wall at the twisting point of the river; (d) Rill erosion caused by rainfall on the Quaternary alluvial terraces of the Gabrik River; (e) Rill erosion resulting from the operation of waterways on loose lithology (marl). (f) Erosive honeycomb structures; and (g) and (h) Gully erosion in the Gabrik region.

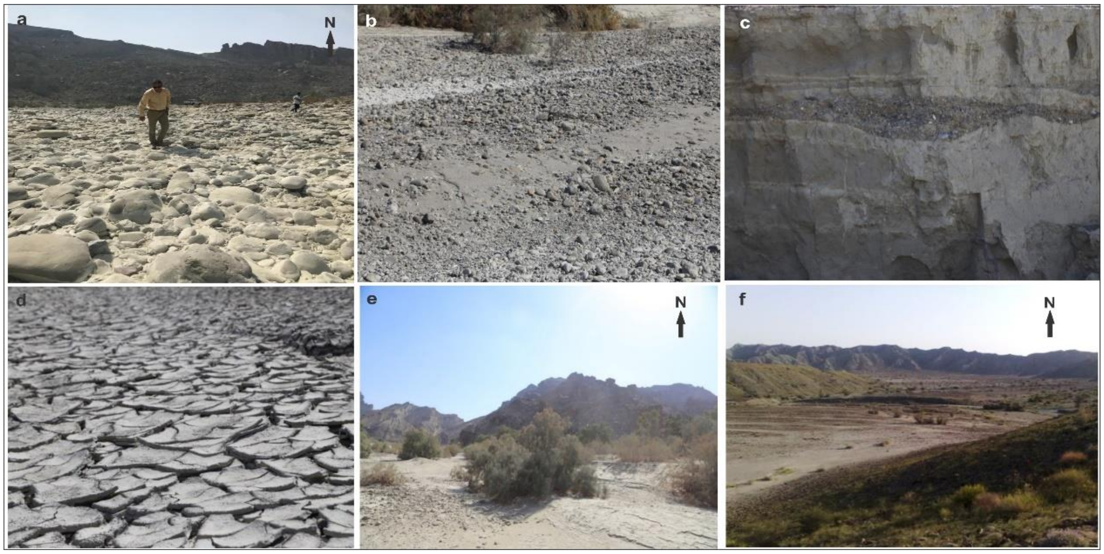

Fig. 6. Some photos of geomorphological forms derived from the effects of external dynamics (sedimentary processes) in the Gabrik basin (a) A view of the alluvial fan; (b) The main channel of the Gabrik River; (c) Crevasse splay or sub-channel of the river; (d) and (e) Flood plain of the river; and (f) One of the huge alluvial terraces of the Gabrik River

4.2. Estimation of erosion and sedimentation rate of Gabrik basin using MPSIAC model

The results showed that for the surface geology factor, according to the scores allocated to each of the geological units of the basin, the average rank No. 6 including sandstone, shale, marl, and siltstone units with an area of 1601 km2 has the most in the region (Fig. 7a). The role of surface erosion factor in sediment production was analyzed and found that the Gabrik Basin has a high surface erosion, which is mainly observed as surface and rill erosion (Fig. 7b). Based on the soil erodibility zoning map, it was found that HU1 has more soil erodibility compared to unit2 (Fig. 7c). Furthermore, in order to evaluate the climate factor for the study area, using the annual rainfall map, it was found the value of annual rainfall in unit1 is more than the unit2, so the average annual rainfall in the whole region was determined 176 mm (Fig. 7d).

Due to the key role of geological units on soil permeability and erodibility in the Gabrik basin, the soil permeability map and drainage network density map (Figs. 7e and 7f) were compared with the annual average rainfall map (Fig. 7d). Accordingly, it was determined that most of the area is composed of low-permeable sediments. Also, concerning the annual rainfall in the region, it was found that the rainfall in the northern and upstream parts of the Gabrik River has the highest levels of rainfall. This factor along with the basin slope (from north to south of the study area) and low permeability of the sediments resulted in the transfer of runoff to the downstream parts (southern part of the basin), where the drainage network density and the amount of sediment transportation are high. Moreover, the score of the topographic agent, after examining the physiographic characteristics of the basin and the slope map, was calculated as weight. Based on this score, it was determined that the main surface of the Gabrik basin consists of hills and high mountains (Fig. 7g). Subsequently, the evaluation of land use and land cover factors in the Gabrik catchment showed that the pastures and tree lands have the highest land use in the region, in the order of their appearance (Fig. 7h).

By summing the scores of the nine factors in the MPSIAC model, the sediment production rate (R) was determined to be 68.6 (Table 2). Then, by determining this parameter (R), the amount of specific sediment in the basin was 4 ton/ha/y (Table 3).

Table 2. Characteristics of the sub-basins, area, sediment delivery ratio, and R in each sub-basin of the study area and Gabrik watershed

Basin	Area (km^2)	R	Sediment yield (ton/ hec /year)	SDR
HU1	2300.7	92.6	7.09	0.82
HU2	1995.3	69.4	3.07	0.29
Gabrik Basin	4296	68.6	3.1	0.32

Table 3. The values of suspension, bed loads, and total sediment based on the distribution of geological units in the catchment area of Gabrik Dam

Suspension load sediment (ton/ha/year)	Bed load sediment (ton/ha/year)	Total sediment (ton/ha/year)	Total sediment in concentration point (ton/year)
3.1	0.9	4	11378

Also, the amount of sediment delivery ratio (SDR) was estimated to be 0.32, of which about 3.1 ton/ha/y is suspension load. Accordingly, about 11378 ton/y of suspension sediments reach the catchment area (Table 4). According to the sediment delivery ratio (0.32) of the basin, the estimated erosion rate will be 4.0 ton/ha/y.

Fig. 8a shows the erodibility map of the Gabrik basin using the MPSIAC method. Based on this model, a large part of the studied basin has low to medium (II and III) erosion rates (Fig. 8a), which needed implementing soil and water conservation programs. Also, in areas with moderate erosion, land use has much more limitations.

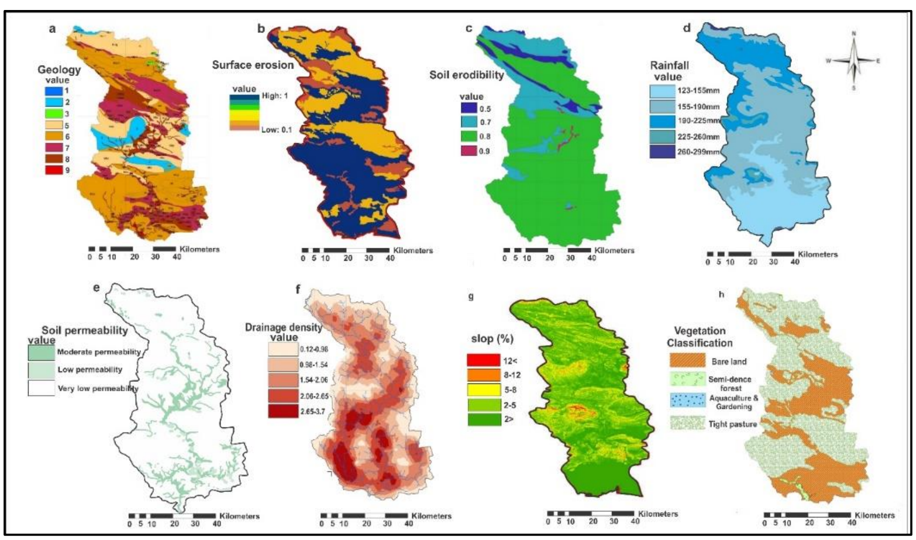

Fig. 7. Maps derived the MPSIAC model I evaluating the role of various factors on erosion and sedimentation rate of the Gabrik basin (a) Geology factor map; (b) Surface erosion factor map; (c) Soil erodibility factor map; (d) The average annual rainfall map; (e) Soil permeability map; and (f) Drainage density map (g) Slop factor map based on Wentworth method and (h) Land cover factor map derived from MPSIAC model in Gabrik basin

4.3. Estimation of erosion and sedimentation rate of Gabrik Basin using FSM model

Factors effective in estimating erosion and sediment production rate using the FSM model are topography, vegetation cover, gullies, lithology and slope. Based on these results, the erosion rate, sediment delivery ratio (SDR), and the amount of produced sediment were calculated to be 168.9, 0.32, and 6.23 ton/ha/y, respectively (Table 5). Fig. 8b shows the erodibility map of the basin using the FSM model. Based on the results of this model, a large part of the basin has low to medium erosion rates which is consistent with the results of the MPSIAC model. Finally, it can be concluded that the erosion, which is controlled by geographical conditions and geological properties, is one of the most important natural hazards in the Gabrik region. The results of this study would be more accurate by comparing them with other empirical models and evaluating them using flood risk maps. The contributions of this research can be considered in the implementation of watershed management projects and sedimentation rate control to increase the capacity of Gabrik Dam to make optimal use of this potential and also to prevent any damage to it.

Table 5. The effective factors of the FSM Model for estimation of erosion rate and the annual sedimentation volume of the Gabrik Basin

Area (km^2)	SDR	Erosion rate in FSM model	Produced sediment (ton/ha)
4296	0.32	168.9	6.23

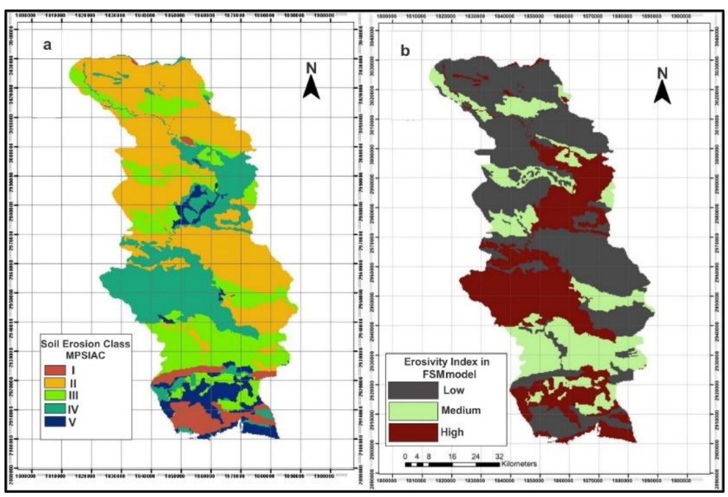

Fig. 8. Maps showing the variations in erodibility rate of the Gabrik basin using MPSIAC (a) and FSM (b) models

5. CONCLUSION

The occurrence of soil erosion in an area is influenced by geology, geomorphology, and the geographical location of that area. Therefore, the study of these factors is important in determining the factors that intensify the erosion and the amount of sediment production in the area. The study of the geomorphology of the Gabrik basin showed that the internal (such as tectonics) and external (erosion and sedimentary processes) dynamic processes have played a significant role in the formation of geomorphological forms of the region. Meanwhile, the presence of erodible sediments such as silt, sand, shale, and marl in the Gabrik basin has facilitated the formation of these features.

In this research, the MPSIC and FSM models were used to evaluate and estimate the amount of erosion and sediment yield for the entire basin. This results could be used in the management of natural resources. In this regard, the amount of produced sediment based on MPSIAC and FSM models was determined to be 4 and 6.23 ton/ha/y, respectively. Based on the erosion maps obtained from these models, it was found that in a large part of the study area, the low to medium erosion rates have a wide distribution. Therefore, it is necessary to implement soil and water conservation programs in these parts. Also, land use is severely restricted in areas with moderate erosion. So, any program for the Gabrik dam stability and environmental goals should be considered the effects of these factors in this area. Also, this study indicates that both MPSIAC and FSM models have good efficiency and accuracy in estimating the sedimentation of the Gabrik Basin. Although, the estimation made by the FSM model is more compatible to the real sediment production of the catchment, but as the MPSIAC model uses more parameters, and incorporates more characteristics of the basin in estimating the sediment, it is considered as a suitable model to estimate the sediment at the Gabrik Basin, and its similar catchments utilization of the same is recommended.

ACKNOWLEDGEMENTS

The authors would like to thank the Islamic Azad University of Zahedan Branch and Hormozgan Regional Water Authority for financial support.

REFERENCES

Aghanabati. A. (2004) Geology of Iran Geological Survey of Iran Report:583p

Ahmadi. H, Mohammadi. A. (2010) Evaluation of sediment estimation of EPM and PSIAC models using geomorphology method (case study: Dehnamak Watershed). Iranian Journal of Range and Desert Research 17.

Bagarello V, Di Stefano C, Ferro V, Giordano G, Iovino M, Pampalone V. (2012). Estimating the USLE soil erodibility factor in Sicily, south Italy Applied Engineering in Agriculture 28:199-206.

Borzou A, Momayezi M, Nickandish A. (2008). Comparison of Estimating soil erosion and sediment by EPM, PSIAC and MPSIAC methods in Chehl Cheshmeh Basin Fars Province Dynamic Agriculture. 5:19-29

Bryan R, Govers G, Poesen J. (1989). The concept of soil erodibility and some problems of assessment and application Catena. 16:393-412

Cerdà A. (1998). Soil aggregate stability under different Mediterranean vegetation types Catena. 32:73-86

Chen X, Zhou J. (2013). Volume-based soil particle fractal relation with soil erodibility in a small watershed of purple soil Environmental earth sciences. 70:1735-1746

Daneshfaraz R, Rahmati M, Akbari Moghanjiq P. (2017). Soil erosion and sediment mapping in Aidoghmoush watershed appling MPSIAC model and GIS and RS technologies. Environmental Resources Research 5: 35-49. 10.22069/ijerr.2017.9991.1119

Eisazadeh L, Sokouti R, Homaee M, Pazira, E. (2012). Comparison of empirical models to estimate soil erosion and sediment yield in micro catchments Eurasian Journal of Soil Science. 1:28-33

Faridi P, Rezaei. P., Ghorbani M, Kazemi M. (2013) Application of GIS in Modeling Rainfall Erosivity Factor (Case Study: Gabric Watershed- Hormozgan Province East South) Quarterly Journal of Environmental Erosion Research 3:39-51 doi:doi:10.22067/geo.v6i2.59833

Ferreira V, Panagopoulos T, Andrade R, Guerrero C, Loures L. (2015). Spatial variability of soil properties and soil erodibility in the Alqueva reservoir watershed Solid Earth Sciences. 6:383-392

Feyznia S, Zare Khosh Eghbal M (2004) Sensitivity of Rocks and Formations to Erosion and Sediment Yield in Latian Drainage Basin Area

Gilbert G. (1890). Lake Bonneville, US Geologic Survey Monograph 1 Washington, DC, US Government Printing Office

Hussein MH. (2013). A sheet erodibility parameter for water erosion modeling in regions with low intensity rain Hydrology Research. 44:1013-1021

Hutton J. (1795). Theory of the earth: With proofs and illustrations vol 1. Library of Alexandria

Igwe C. (2003). Erodibility of soils of the upper rainforest zone, southeastern Nigeria Land Degradation & Development. 14:323-334

Mohammadiha SH, Peyravan H, Mousavi-Harami S. R, Feyznia S, Bayat R. (2013). Evaluation of erosion and sediment production rate of Ivanki watershed using FSM, MPSIAC and sedimentation station models. Journal of Stratigraphy and Sedimentology Research. 4:31-48.Show moreShow less

Mwaniki MW, Agutu NO, Mbaka JG, Ngigi TG, Waithaka EH. (2015). Landslide scar/soil erodibility mapping using Landsat TM/ETM+ bands 7 and 3 normalised difference index: A case study of central region of Kenya Applied Geography. 64:108-120

Nabipay-Lashkarian S, Hashemi SAA, Shadfar S. (2013). FSM model efficiency for sediment yield estimation in Semnan province Journal of Watershed Engineering and Management. 5:51-58

Parajuli SP, Yang ZL, Kocurek G (2014) Mapping erodibility in dust source regions based on geomorphology, meteorology, and remote sensing Journal of Geophysical Research: Earth Surface. 119:1977-1994

Pera EL, Sorriso-Valvo M. (2000). Weathering, erosion and sediment composition in a high-gradient river, Calabria, Italy Earth Surface Processes and Landforms. 25:277-292

Sanchis MS, Torri D, Borselli L, Poesen J. (2008). Climate effects on soil erodibility Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group. 33:1082-1097

Sepulveda-Lozada A, Geissen V, Ochoa-Gaona S, Jarquin-Sanchez A, Capetillo E, Zamora-Cornelio L. (2009). Influence of three types of riparian vegetation on fluvial erosion control in Pantanos de Centla, Mexico Revista de biologia tropical. 57:1153-1163

Singh MJ, Khera KL, Santra P. (2012). Selection of soil physical quality indicators in relation to soil erodibility Archives of Agronomy and Soil Science. 58:657-672

Sistani-Bedoui M, Negaresh H, Fotouhi S. (2017). Flood risk zoning in the Gabrik catchment Geography and Environmental Hazards. 6:163-182

Tang F, Cui M, Lu Q, Liu Y, Guo H, Zhou J. (2016). Effects of vegetation restoration on the aggregate stability and distribution of aggregate-associated organic carbon in a typical karst gorge region Solid Earth. 7:141-151

Thornbury WD. (1969). Principles of geomorphology

Thorndycraft V, Benito G, Gregory K. (2008). Fluvial geomorphology: A perspective on current status and methods Geomorphology. 98:2-12

Wang G, Fang Q, Wu B, Yang H, Xu Z. (2015). Relationship between soil erodibility and modeled infiltration rate in different soils Journal of Hydrology 528:408-418

Wischmeier WH, Smith DD. (1978). Predicting rainfall erosion losses: a guide to conservation planning. vol 537. Department of Agriculture, Science and Education Administration.