International Soil and Water Conservation Research 4 (2016) 199–206

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr

Original Research Article

Assessment of sediment yield using RS and GIS at two sub-basins of Dez Watershed, Iran

CrossMark

Hamed Noori, Seyed Mostafa Siadatmousavi*, Barat Mojaradi

School of Civil Engineering, Iran University of Science & Technology, Narmak, Tehran 1684613114, Iran

ARTICLE INFO

Article history:
Received 29 August 2015
Received in revised form
29 May 2016
Accepted 11 June 2016
Available online 30 June 2016

Keywords:
Soil erosion
GIS
Remote sensing
Modified Pacific South-West Inter Agency Committee method (MPSIAC)
Erosion Potential Method (EPM)

ABSTRACT

Soil erosion is a serious threat to soil and water resources in semi-arid regions. Modified Pacific Southwest Inter Agency Committee (MPSIAC) and Erosion Potential Method (EPM), as two well-known models, have shown their performance in many case studies. The goal of present study is 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. The results showed that the study area can be categorized into slight, moderate, high and very high erosion zones. Almost half of the study area is highly susceptible to erosion due to the geological formations and land cover. Moreover, the long-term (i.e. 30 years) sediment yield of 387 and 615 (kton) y^{-1} estimated by MPSIAC and EPM models demonstrated the superiority of EPM. Compared to the measured value of 612 (kton) y^{-1}, the performance of EPM was astonishing. By splitting the dataset into six periods of five years, the sediment yield was predicted in short-term periods by both aforementioned methods. Such segmentation provides the opportunity to evaluate the impact of extreme flooding events on the models performances. The results showed that both models failed in estimation of sediment load during flood conditions. Nevertheless, the correlation coefficients for estimating the sediment yield were found to be R=0.93 and R=0.85 for EPM and MPSIAC models respectively, for short-term simulations.

1. Introduction

Soil erosion due to surface water is one of the most important land degradation problem and a critical environmental hazard worldwide (Jain & Das, 2010). Human development and the inappropriate land utilization have accelerated the soil erosion at many locations on the earth's surface (Ahmadi, 1995; Bennett, 1939; Refahi, 1996; Zhang et al., 2015). As a result, every year millions of tons of sediment are produced around the world, and the water erosion is responsible for more than 56% of this sediment volume (Elirehema, 2001). The detrimental impacts of soil erosion include decrease of effective root depth, nutrient and water imbalance in the root zone, and subsequent decrease in soil quality that leads to loss of fertile top soil cover and finally a reduction in agricultural production. It also delivers millions of tons of sediment into reservoirs and lakes, causes damages to the dams facilities, and results in high economic costs by affecting the water quality (Refahi, 1996; Wang, Gertner, Fang, & Anderson, 2003). Thus, soil erosion is being considered as one of the major threats to global economic and environmental sustainability. Some temporally invariable parameters such as lithology, size of watershed, and variable factors such as climate, hydrology, ground cover, and land use also affect the sediment yield (Milliman & Syvitski, 1992; Zhang, Wenhong, Qingchao, & Sihong, 2010; Zhu & Li, 2014). Note that soil erosion and sediment yield from agricultural or highly degraded forest areas is typically higher than that from uncultivated areas. In fact, cultivated areas can act as both a source and a pathway for transporting nutrients (Ouyang & Bartholic, 1997).

Many studies have shown that human activity is the major cause of recent changes in the land use (Bennett, 1939; De Koning, Veldkamp, & Fresco, 1998; Jain & Das, 2010; Le Bissonnais, Montier, Jamagne, Daroussin, & King, 2002; Martınez-Casasnovas, 2003; Pandey, Chowdary, & Mal, 2007). Also in non-residential areas biophysical conditions of the land, such as lithology, soil characteristics, hydrology, topography, and ground cover largely determine the spatial pattern of the land use and its temporal changes (Estrany, Garcia, & Walling, 2010; Veldkamp & Fresco, 1996).

Several empirical, numerical and experimental methods have been developed to estimate the sediment yield of a watershed (e.g.

* Corresponding author.
E-mail address: siadatmousavi@iust.ac.ir (S.M. Siadatmousavi).

Peer review under responsibility of the International Research and Training Center on Erosion and Sedimentation and China Water and Power Press.

http://dx.doi.org/10.1016/j.iswcr.2016.06.001
2095-6339/

see De Vente and Poesen (2005), Heininger and Cullmann (2015), Onstad and Foster (1975) and Stone (2000)). The empirical methods were first developed for the analysis of the effects of agricultural practices. The earliest model was the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). The method of USLE assessed the long-term average of annual erosion rate over a sloped area based on the rainfall pattern (R_i), soil characteristics (K), topography (LS), ground cover (C), and management practices (P) (Ahmadi, 1995). The USLE model was used in conjunction with Geographic Information Systems (GIS), Remote Sensing (RS), and satellite data to estimate sheet and rill erosion from watersheds (Ghosh, De, Bandyopadhyay, & Saha, 2013; Jain & Das, 2010; Kothyari, Jain, & Ranga Raju, 2002; Nearing, Unkrich, Goodrich, Nichols, & Keefer, 2015; Onyando, Kisoyan, & Chemelil, 2005; Pandey et al., 2007). Various modifications were suggested to enhance the performance of USLE under different conditions. The outcomes of these modifications were summarized in new methods such as RUSLE (Revised Universal Soil Loss Equation), and MUSLE (Modified Universal Soil Loss Equation). Other well-known empirical methods used in different parts of the world are FAO (Food and Agriculture Organization), Fournier, PSIAC (Pacific South-west Inter Agency Committee), Modified PSIAC (MPSIAC), EPM (Erosion Potential Method).

These methods have been used successfully in many watersheds (Bagherzadeh & Daneshvar, 2011; Daneshvar & Bagherzadeh, 2012; Kothyari et al., 2002; Naqvi, Athick, Ganaie, & Siddiqui, 2015; Solaimani, Modallaldoust, & Lotfi, 2009). In times of flood, large volumes of sediment were carried by water. It is important to evaluate the model performance in such sever conditions to check whether these models perform similar to calm weather conditions or not. The main purpose of this study is to assess the efficiency of MPSIAC and EPM models at two sub-basins of large Dez watershed located in west of Iran, where three severe floods occurred during study period. Both EPM and MPSIAC models used in this study are based on assigning a score to each factor depending on its intensity. Some of these factors are estimated using RS and GIS in this study. In fact, application of RS and GIS in land erosion increases day by day, and assessment of soil erosion using these techniques was more cost effective, and in some cases resulted in a better accuracy, when compared to traditional methods (Bagherzadeh & Daneshvar, 2011; Clark, 1980; Gebreslassie, 2014; Heydarian, 1996; Le Bissonnais et al., 2002; Martınez-Casasnovas, 2003; Rafaelli, Montgomery, & Greenberg, 2001; Refahi & Nematti, 1995; Renard, Foster, Weesies, & Porter, 1991; Şahin & Kurum, 2002; Tangestani, 2006; Yuliang & Yun, 2002). After creating score maps for main factors, the sedimentation of a watershed using each model is calculated, and compared to in situ measurements.

1.1. Study area

Dez watershed is one of the largest watersheds in Iran and is a part of the Persian Gulf basin. Geographic extension of this watershed involves six provinces of Iran shown in Fig. 1: Lorestan, Hamedan, Chaharmahal bakhtiari, Esfahan, Markazi and Khuzestan. Most part of this watershed is located in Lorestan province. Total surface of the Dez watershed is approximately 17,320 km^2 and its perimeter is roughly 875 km. Dez River is the main stream in this watershed and is a tributary of the Karun River. Dez watershed erosion rate is roughly 25.77 ton ha^{-1} year^{-1} which is almost two-fold of the threshold for erosion (12.5 ton ha^{-1} y^{-1} according to Bennett (1939)). There are several dams downstream of the study area which emphasizes the importance of having a proper estimation of the erosion in this region.

The study area is part of Dez watershed. This area composed of two sub-basins denoted by Absorkh and Keshvar. Geographic limits of Absorkh sub-basin are 48°31′ to 48°39′ E and 33°06′ to 33°13′ N, with the area of approximately 8420 ha, while the limits of Keshvar sub-basin are 48°38′ to 48°46′ E and 33°06′ to 33°13′ N, with the area of roughly 11,500 ha. Similar to Bagherzadeh and Daneshvar (2011), in order to enhance the accuracy in estimation of the sediment load at the study area, the sub-basins were subdivided into smaller hydrological units based on the slope, stream lines, and flow direction . These smaller units were denoted by A1–A4, and K1–K5 for Absorkh and Keshvar sub-basins respectively (Fig. 1). The maximum and minimum slopes occurred in units A4 and K5 respectively.

The northern parts of both sub-basins are covered with dense to moderate forests. The study area is covered mainly by sandstone, shale, conglomerate, marl and limestone formations. Texture of the soils ranges between loam, sandy loam, sandy clay loam and loamy coarse sand, while mountains and hills are dominant geomorphological features over the area. The topographical elevation with respect to sea level varies between 728 m at the south and 2543 m at the north-east of the study area, with an average elevation of roughly 1300 m, and average slope of 51%. Extreme Floods of different intensities occurred in the watershed in 1987, 2001 and 2003 and produced large volumes of sediment in the study area. The mean volume of annual rainfall over Absorkh and Keshvar sub-basins are 56.8 and 81.2 million cubic meters respectively, which corresponded to the mean annual

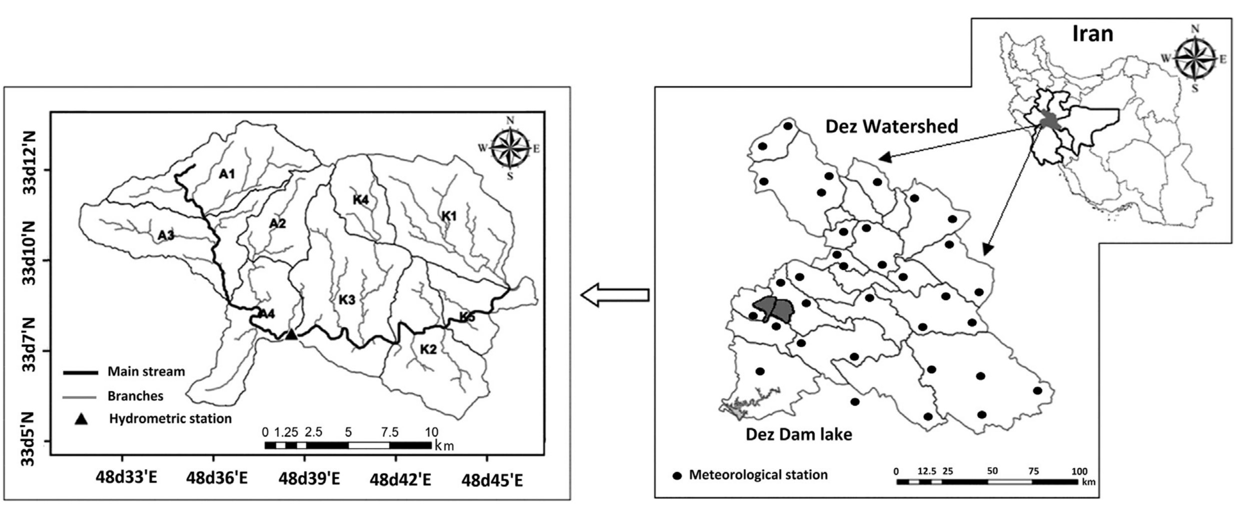

Fig. 1. Location of the study area with respect to Iran and its six provinces (inset in right panel) as well as Dez watershed (right panel). The meteorological stations are shown on the map. The hydrological units within the study area, and the hydrometric station are shown in the left panel.

precipitations of 920 and 910 mm. Approximately, 80% of total annual rainfall occurs between Decembers to March, and the mean annual temperature is roughly 22 °C. There are not many villages in the area and few nomads are living in the study area.

2. Materials and methods

For the present study, topographic data from Aster DEM of January 2008 (Digital Elevation Model, Aster stereo bands 3-1, 3-2) with accuracy of 15 m were used for determining the topographic factors. Other imagery data used for land use and land cover factors included LISS III (IRS-P6) of November 2005 with accuracy of 24 m and TM (LANDSAT5) of October 1996 with accuracy of 30 m. Rainfall data of Absorkh and Keshvar sub-basins for a 30 years period (1976–2005) were obtained from different meteorological stations located ten to twenty kilometers from sub-basins (see Fig. 1). The soil characteristics and lithology data were collected by the Karkheh Company of soil survey. Their corresponding 1:100,000 and 1:250,000 maps were used for determining the base maps and erosion factors in this study. A summary of the soil characteristics in each hydrological unit is presented elsewhere (Karkheh Company of Soil Survey, 2005). The measured sedimentation data from the hydrometric station shown in Fig. 1 (called Keshvar station) have been used to determine the amount of soil erosion and sediment yield in this area. These data were also used for skill-assessment of models. The average weight of a cubic meter of sediment in this area is equal to 1.4 ton m^{-3} (Karkheh Company of Soil Survey, 2005).

Application of traditional methods of soil loss estimation is time-consuming and costly, especially in the mountainous and impassable terrain of the study area. Therefore, according to the features of area, the modified form of Pacific South-west Inter Agency Committee (MPSIAC) and Erosion Potential Method (EPM) were adapted for estimating the sediment yield in two conditions in Absorkh and Keshvar sub-basins: (1) a long-term prediction for a period of 30 years from 1976 to 2005, (2) six short-term periods, each consisted of 5 years.

2.1. MPSIAC model

The PSIAC Model (Pacific South-west Inter Agency Committee, 1968) was devised to estimate the sediment yield based on a variety of factors within a watershed. This model was first applied over the watershed of Walnut Gulch in the south-east Arizona, United States. Later, considering the modification applied by Johnson and Gebhardt (1982), it was called modified PSIAC (MPSIAC hereafter). The successful applications of this model for estimating the sediment yield of watersheds in semi-arid areas of Iran were reported in several previous studies (Khaledian, Kiani, & Ebrahimi, 2012; Refahi & Nematti, 1995; Tangestani, 2006). Compared to other experimental methods, MPSIAC includes more effective erosion factors. The model includes the effect of geology, soils, climate, runoff, topography, land cover, land use, upland erosion, and channel erosion. Each of above-mentioned factors are presented by non-dimensional numbers in the model. Brief explanations of these nine factors are presented below.

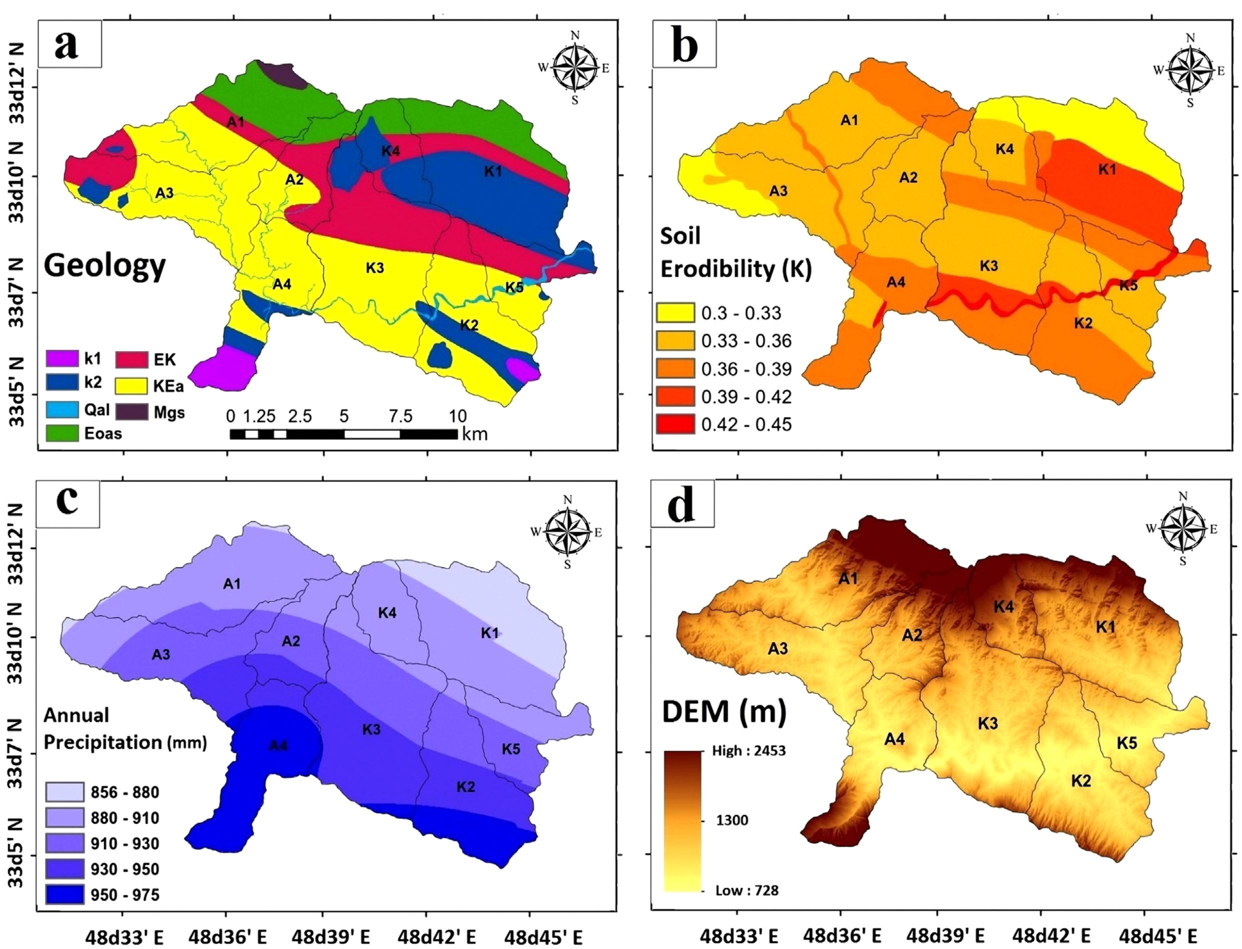

Fig. 2. (a) Geology map. The acronyms are explained in Table 3; (b) soil erodibility; (c) annual precipitation and (d) Digital Elevation Model (DEM) for hydrological units of study area.

2.1.1. Surface geology factor (X_1)

It was related to a geologic erosion index (Y_1) determined from rock types and its characteristics such as their hardness, fracturing, and weathering conditions. The value of this factor ranges from 0 to 10 (Refahi, 1996; Tangestani, 2006). The spatial distribution of the results was depicted in Fig. 2a.

2.1.2. Soil factor (X_2)

Soil factor (X_2) was equal to $16.67 \times K$, in which K was soil erodibility factor in Universal Soil Loss Equation (USLE) and depended on the texture of soil and amount of lime, gravel, silt and organic matter (Johnson & Gebhardt, 1982). The final results were shown in Fig. 2b.

2.1.3. Climate factor (X_3)

Climate factor (X_3) was estimated using 6 h precipitation amount with 2-year return period (P_2) in mm. In this study, climate factor was based on 30 years of rainfall record from 1976 to 2005. The climate factor was estimated using $0.2 \times P_2$, and the final result was illustrated in Fig. 2c.

2.1.4. Runoff factor (X_4)

Runoff factor (X_4) was obtained based on the following equation:

$$X_4 = 0.006R_0 + 10Q_p \tag{1}$$

in which total average runoff (R_0) in mm was interpolated from measurements at the meteorological stations shown in Fig. 1. The peak special discharge (determined from the peak discharge at the hydrological units divided by area) ($Q_{p,}$) in $m^3\ s^{-1}\ km^{-2}$ for the 30 years period (1976–2005) were used for long-term simulations, and corresponding values for each of 5-year periods were used for short-term simulations.

2.1.5. Topography (X_5)

Topography factor (X_5) was determined based on average slope of the watershed (S) in percent. The map of average slope was generated from digital elevation model (Fig. 2d) using ArcGIS. The topography factor was calculated using $0.33 \times S$ relationship.

2.1.6. Ground cover (X_6)

Main features in the ground cover are vegetation, litter and rocks. The effect of these features is summarized as a bare ground factor denoted by P_b in percentage. Then, X_6 is assumed to be equal to 0.2 P_b. Ground bare value for a watershed is related to the normalized difference vegetation index (NDVI). The NDVI of an area critically depends on the presence of vegetation in the area. The vegetation reflects major part of electromagnetic energy within the near-infrared band (NIR), while the minimum energy reflection would be close to red wavelengths. Using this property, several indices have been developed in the past which can give a perspective on the presence of vegetation in a cell (Jain & Das, 2010). Among all of such indices, NDVI is the most famous one, and defined as the normalized difference between Near-Infra Red (NIR) and Visible Red (RED) (Rouse, Haas, Schell, & Deering, 1974):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{2}$$

The possible range of values for NDVI is theoretically between −1 and 1, but the typical range is between approximately −0.1 (for an area with the least amount of green vegetation) to 0.6 (for a very green area) (Kidwell, 1990). Ground bare value derived from two satellite images (LISS3 and TM) (Dwivedi, Kumar, & Tewari, 1997; Fuller, 1998; Jain & Das, 2010; Wellens, 1997) for all hydrological units were compared in Fig. 3a. This figure shows that for most of the units, the land cover did not change significantly over the course of 10 years from 1996 to 2005.

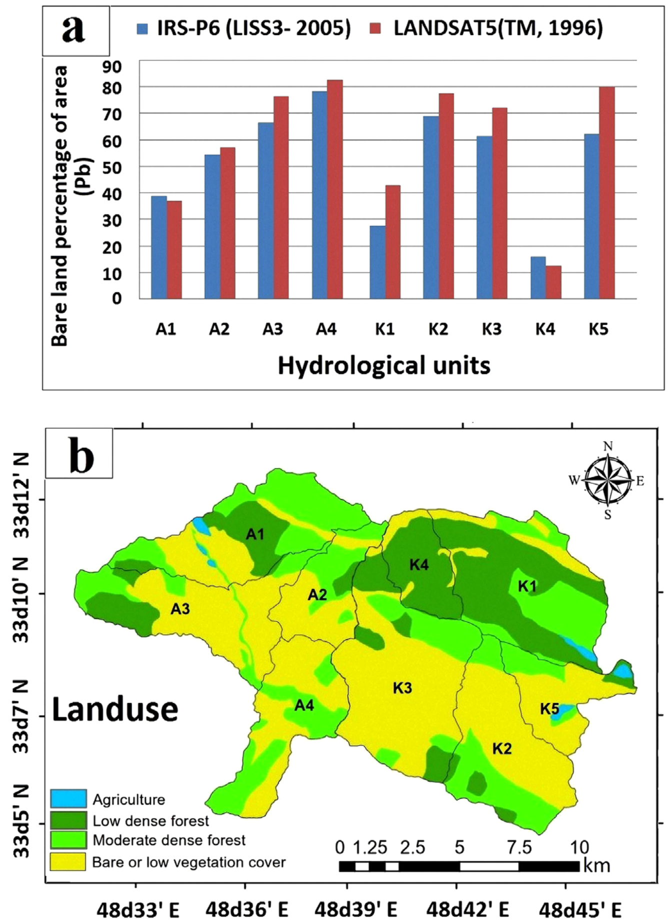

Fig. 3. (a) Bare land percentage in hydrological units using remote sensing for 1996 and 2005; (b) the predicted vegetation cover for the study area.

2.1.7. Land use (X_7)

Land use factor (X_7) was estimated based on plant canopy (P_c) in percent using the following equation:

$$X_7 = 20 - 0.2P_c \tag{3}$$

To determine P_c, a relation between canopy and NDVI was developed for this area (Ziaei & Rangzan, 2005). The equation is as follows:

$$P_c = 64.1NDVI + 15.9 \tag{4}$$

The final map of the land use is shown in Fig. 3b.

2.1.8. Upland erosion (X_8)

Upland erosion (X_8) factor was obtained based on the method suggested by Bureau of Land Management (BLM) (Johnson & Gebhardt, 1982). The first six factors in the soil surface factors (SSF_1–SSF_6) were obtained from field observations. The seventh factor, SSF_7 was estimated from the relation between precipitation and gully formation (Ahmadi, 1995). The value of each of these factors ranges between 0 and 15. The total score for SSF was derived by summing the values of all seven factors (SSF_1–SSF_7), and then, the upland erosion factor (X_8) was equal to $0.25 \times$ SSF. (Johnson & Gebhardt, 1982).

2.1.9. Channel erosion (X_9)

Channel erosion factor (X_9) was obtained based on gully erosion factor from the BLM method, and by employing the relation between annual rainfall (in mm) and gully erosion. The Channel erosion (X_9) was calculated using $1.67 \times SSF_7$. As mentioned in the previous section, SSF_7 was obtained from method suggested by BLM (Johnson & Gebhardt, 1982).

2.1.10. Sediment flux

Finally in MPSIAC model, the total sum of the nine abovementioned factors are expressed by R, and the rate of the sediment yield were predicted using the following equation (Johnson & Gebhardt, 1982):

$$Q_S = 38.77e^{0.0353R} \tag{5}$$

where Q_s was the rate of the sediment yield at each sub-basin in $m^3\ km^{-2}\ y^{-1}$.

2.2. EPM model

The Erosion Potential Method (EPM) was developed originally from an investigation in Yugoslavia by (Gavrilovic, 1988). This method considers six factors: surface geology, soils, topographic features, climatic factors (including mean annual rainfall, and mean annual temperature), and land use. The EPM calculates the coefficient of erosion and sediment yield (Z-factor) of a sub-catchment area by the following equation:

$$Z = Y \cdot X_a(\Phi + \sqrt{I}) \tag{6}$$

where Y is the coefficient of the rock and soil resistance to the erosion (function of geology and soil type), ranging from 0.25 to 2, X_a is the land use coefficient, ranging from 0.05 to 1.0, Φ is the coefficient of the observed erosion process ranging from 0.1 to 1.0 depending on the severity of erosion, and I in percent is the average slope gradient of the watershed. The values of $Z > 1.0$ show severe erosion while the values of $Z < 0.19$ show very slight erosion In EPM model, the erosion intensity is classified based on the Z values (Gavrilovic, 1988). According to this model, average annual specific production of sediments, W_{sp}, in $m^3\ km^{-2}\ y^{-1}$ can be determined using the following equation:

$$W_{SP} = T \cdot H \cdot \pi \cdot Z^{1.5} \tag{7}$$

where H is the mean annual precipitation (mm), and Z is determined from Eq. (6). Finally, T is the temperature coefficient calculated from the mean annual air temperature, t (°C), using the following equation:

$$T = \left(\frac{t}{10} + 0.1\right)^{0.5} \tag{8}$$

Note that only a portion of the total eroded materials from a watershed might reach to the lowest point of the watershed. It is necessary to determine the ratio between the sediments that reach to the lowest point and the entire eroded sediments to be able to perform a direct comparison with the measured sediment yield. Therefore, EPM model applies another coefficient, called sediment delivery ratio (R_u), to make a connection between the erosion and sedimentation (Gavrilovic, 1988). The sediment delivery ratio R_u is determined by:

$$Ru = \frac{4(P \times D)^{0.5}}{L + 10} \tag{9}$$

where P is perimeter of the catchment (km), L is the length of the catchment (km) and D is the difference between mean altitude of the catchment and the altitude of the catchment outlet (km).

The equation bellow calculates the amount of annual specific sediment yield (G_{sp}) in $m^3\ km^{-2}\ y^{-1}$.

$$G_{SP} = W_{SP} \cdot Ru \tag{10}$$

Table 1
The values of R and Z (erosion intensity factor) for each hydrological unit from MPSIAC and EPM methods respectively.

Erosion model Hydrological units	Area (km^2)	MPSIAC R	EPM Z
A1	26.18	80.028	0.733
A2	12.67	95.292	0.940
A3	24.99	102.675	1.000
A4	20.36	104.142	1.042
K1	31.96	82.544	0.896
K2	24.70	103.482	1.203
K3	35.67	103.765	1.235
K4	10.23	81.688	0.806
K5	12.44	102.75	1.300

3. Results and discussion

3.1. Long-term simulations

The mean total ranking values R resulted from the MPSIAC model and the mean value of the erosion coefficient Z calculated from the EPM model were categorized into slight, moderate, high and very high classes, respectively (see Table 1).

A detailed table has been prepared to show the relief type, area, lithology, ground cover, slope and the calculated X_a and Φ values in EPM model (Table 2). Similarly, Table 3 shows geology characteristics including lithology formation, area and obtained X_1 factor in MPSIAC model and Y factor in EPM model for the geology formation of the study area.

The average annual specific production of sediments, W_{sp}, was calculated using H and T parameters according to Eq. (7) and the annual specific sediments yield, G_{sp}, was evaluated using Eq. (10) in EPM model (see Table 4). Similarly, the amount of the sediment yield, Q_s, in MPSIAC model was predicted using Eq. (5) (see Table 4). Erosion intensity maps of both models for nine hydrological units were classified into four classes and the results are presented in Table 4. The results of both MPSIAC and EPM models demonstrated that more than 70% of the watershed was categorized as high to very high erosion type.

As illustrated in Fig. 4a and b high rates of the erosion occurred in the middle and south parts of the study area. The reason of such a high erosion rate is the geology and sparse vegetation cover of that portion. These parts are mainly composed of thick bedded limestone, shale and siltstone, which are not resistant to erosion. Due to forest and vegetation cover, and also strong geology formation, the erosion rate in the northern part is relatively smaller than the rate in the middle and the southern parts.

The highest and lowest amounts of predicted sediment yield in hydrological units using MPSIAC model occurred in A4 (56.747 (kton) y^{-1}) and K4 (10.423 (kton) y^{-1}) respectively as shown in Fig. 4c. The highest and lowest amounts for EPM model occurred in K3 (140 (kton) y^{-1}) and K4 (22.839 (kton) y^{-1}) units respectively. It is noteworthy that the predictions of EMP method were consistently higher in all units than those of MPSIAC method.

The amount of the measured sediment yield of the watershed in hydrometric station (Keshvar station) was approximately 612 (kton) y^{-1} as depicted in Fig. 4d. Comparison of the amount of total sediment yield predicted by MPSIAC and EPM models with the measured sediment yield indicated that the MPSIAC model underestimated the observed value, while EPM slightly

Table 2
Geo-morphology features with determined X_a and Φ coefficients used in the EPM model.

Geological formation	Relief type	Area (km^2)	Lithology	Ground cover	Slope gradient (%)	X_a	Φ
H1	Medium relief structural hill	67.36	k2, Mgs	Bare-low	30–50	0.7	0.65
H2	Low relief structural hill	26.00	KEa, Mgs	Bare-low	30–50	0.8	0.75
M1	High relief structural mount	18.11	Eoas, k1	Moderate	> 50	0.5	0.67
M2	Low relief structural mount	23.20	KEa, k1	Low- moderate	30–50	0.6	0.7
M3	Medium relief structural mount	22.10	Ek, KEa, Eoas	Moderate	30–50	0.5	0.7
M4	High relief structural mount	22.26	Ek, k2, Eoas	Low-moderate	30–50	0.6	0.7
M5	Very high relief structural mount	15.24	k1, k2	Moderate	> 50	0.6	0.7
P	Alluvial plain	4.92	Qal	Moderate	10–30	0.8	0.6

Table 3
Geology characteristics corresponding to Fig. 3b with determined X_1 factor and Y coefficient used in the MPSIAC and EPM models, respectively.

Symbol	Ek	KEa	k1	k2	Eoas	Mgs	Qal
Lithology	Sandstone, red marl, conglomerate	Shale, siltstone, sandstone, limestone, conglomerate	Thin bedded limestone	Marl limestone	Thick bedded limestone	Anhydrite, lime-stone, grey marl	Quaternary sediment
% of area	46.7	86.2	5.1	30.3	26.3	1.5	3.0
X_1 (MPSIAC)	7	6	1.6	2.1	0.7	9	10
Y (EPM)	1.2	1.2	1.2	1.2	0.9	2	2

Table 4
Estimated sediment yield Q_s and G_{sp} with total sediments yield and erosion intensity in each unit.

Erosion models	MPSIAC			EPM		
Hydrological units	Qs (m^3 km^{-2} y^{-1})	Total sediments ((kton) y^{-1})	Erosion intensity	Gsp (m^3 km^{-2} y^{-1})	Total sediments ((kton) y^{-1})	Erosion intensity
A1	982.7	36.0	High	1638.8	60.1	High
A2	1602.4	28.4	Very high	2189.2	38.8	High
A3	1847.2	64.6	Very high	2054.8	71.9	High
A4	1990.8	56.7	Very high	2363.0	67.4	Very high
K1	763.6	34.1	High	2168.3	97.0	High
K2	1534.8	53.0	Very high	2281.4	78.9	High
K3	1568.8	78.3	Very high	2803.6	140.0	Very high
K4	728.4	10.4	High	1594.7	22.8	High
K5	1480.9	25.8	Very high	2206.1	38.4	High
Entire domain	1374.6	387		2204.8	615	

overestimated the measured sediment yield of the watershed. According to Fig. 4d, both models estimated reasonable values; however the results from EPM model were more accurate.

3.2. Short-term simulations

The performances of models were also evaluated versus measured sediment yield over six 5-year periods (Fig. 5a). The first measurement peak (dashed line) was resulted from a severe flood in 23 December 1987 (1986–1990 period) in which the peak discharge was 260.58 m^3 s^{-1} during 93 h. The amount of measured sediment yield in 1987 was 3678.19 (kton) y^{-1}, which was much higher than the average annual measured sediment in the period of 1986–1990 (1123.866 (kton) y^{-1}). The next peak was a result of floods occurred in 13 April 2001 and 5 December 2003 (2001–2005 period). The peak discharge was 142 m^3 s^{-1} during the 87 h for the former storm, and 169 m^3 s^{-1} during 73 h for the latter one. The amount of measured sediment yield was 2629.43 and 1983.63 (kton) y^{-1} in 2001 and 2003 respectively while the average annual measured sediment in the period of 2001–2005 was 1059.163 (kton) y$^{-1,}$. These floods yielded much more sediment than fair weather conditions. The correlation coefficient and the root mean square difference for EPM were 0.93 and 297.5 (kton) y^{-1} respectively. The corresponding values for MPSIAC were 0.85 and 408 (kton) y^{-1} respectively; showing superior performance of EPM than MPSIAC. The EPM model overestimated the sediment values (except during severe floods). In contrast, MPSIAC demonstrated a better performance in normal years.

As shown in Fig. 5b, removing aforementioned floods from input data of both models and also from the measurements improved the performance of both models. After removing those sever events, the value of two measurement peaks at Fig. 5a is reduced to 485.28 and 227.59 (kton) y^{-1} respectively. Again, the EPM model overestimated the sediment values, whereas the values predicted by MPSIAC were closer to the measurements. However, MPSIAC model was too sluggish to respond promptly to the environmental forces. In other words, it was not sensitive-enough to the inputs and the temporal variations of sediment yield from MPSIAC was much less than measurements.

4. Conclusion

The MPSIAC and EPM models are well-known methods to estimate the soil erosion and the sediment production over watersheds. These models were applied to two sub-basins of Dez watershed and the results were compared with measured sediment yield at outlet of the watershed. The sub-basins were partitioned into hydrological units to improve the accuracy of sediment yield estimation. Moreover, satellite imageries were used to determine the ground cover (by using satellite-derived NDVI) and land use (by applying a local relation between canopy and NDVI).

The models were used for two different timeframes: (1) long-term simulation in which entire time period of 1976–2005 was used, (2) short-term simulations in which the time period of 1976–2005 was partitioned into six periods of five years each. The

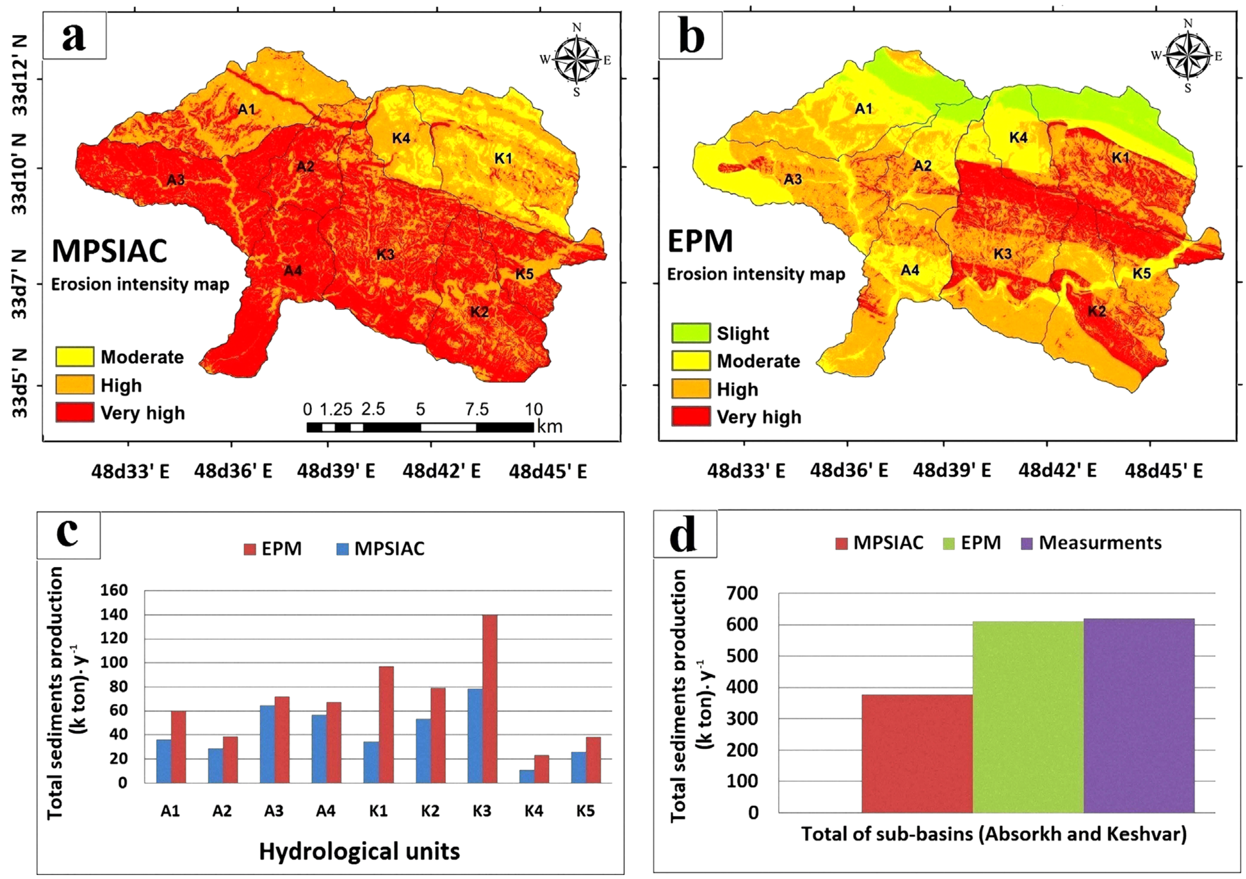

Fig. 4. (a) Spatial distribution of erosion intensity resulted from the MPSIAC model; (b) spatial distribution of erosion intensity resulted from the EPM model; (c) comparison of the amount of total sediment yield in each of hydrological units using the MPSIAC and EPM models; (d) comparison of the amount of total sediment yields predicted by MPSIAC and EPM models and the measured sediment yield.

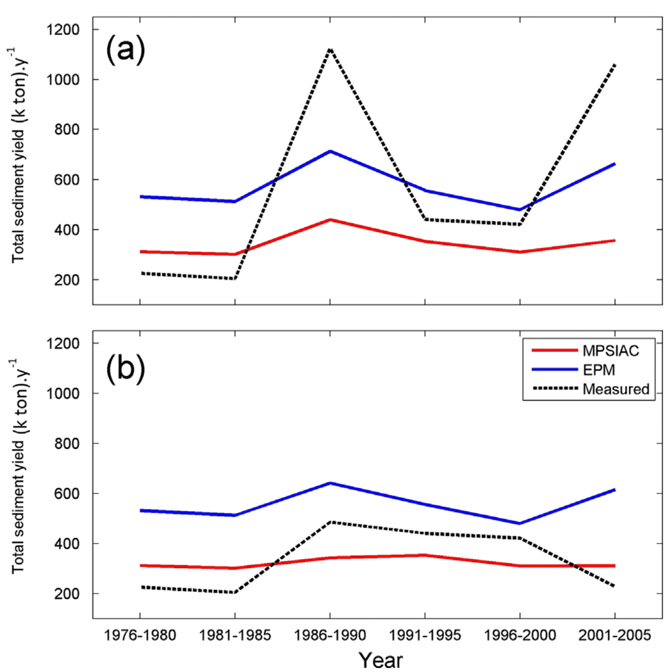

Fig. 5. (a) Sediment yield measured at Keshvar station compared to the models predictions for six periods of 5-year long. (b) The same as (a) but the floods data were removed from dataset.

results of long-term simulations showed that among nine hydrological units, the difference between the outputs of two models were insignificant; except for two units K1 and K3 (see Fig. 4c). Compared to the MPSIAC model, the predicted amount of total sediment yield at the basin outlet using EPM model was closer to the measured value. But, the erosion intensity map produced by MPSIAC model was similar to that of EPM model. Compared to MPSIAC model EPM demonstrate better performance in short-term simulations. Both models significantly underestimated the sediment yield during extreme floods. The MPSIAC model demonstrated superior performance when floods were removed from the data. However, the temporal variation of the sediment yield predicted by this model was less than hydrometric measurements.

In summary, erosion occurred over all parts of the study area. The results showed that the middle and southern parts of the watershed were highly susceptible to erosion due to their geology and land cover, while the northern parts were less subjected to erosion due to dense vegetation and stable geological formations. Therefore, construction of gabion to decrease the sediment production especially in the middle and southern parts of the area is suggested. This study provided valuable information on sediment yield of the Dez watershed, and demonstrated the usefulness of applying geospatial information in natural resources and soil conservation projects.

Acknowledgments

The authors wish to thank the Khuzestan Water and Power Authority for data sharing. The Arca Company is also acknowledged for their GIS support. The authors also thank valuable comments made on an earlier draft from M.N. Allahdadi, Louisiana State University.

References

Ahmadi, H. (1995). *Applied geo-morphology-water erosion*. Vol. 1. Tehran, Iran: Tehran University Press.
Bagherzadeh, A., & Daneshvar, M. R. M. (2011). Sediment yield assessment by EPM and PSIAC models using GIS data in semi-arid region. *Frontiers of Earth Science*, *5*(2), 207–216.
Bennett, H. H. (1939). *Soil conservation*. New York: Mcgraw-Hill Book Co.
Clark, R. D. (1980). Use of physical data for estimating sediment yield. In: *Paper presented at the Proceeding of the symposium on watershed management*. Boise, Idaho.
Daneshvar, M., & Bagherzadeh, A. (2012). Evaluation of sediment yield in PSIAC and MPSIAC models by using GIS at Toroq Watershed, Northeast of Iran. *Frontiers of Earth Science*, *6*(1), 83–94.
De Koning, G., Veldkamp, A., & Fresco, L. (1998). Land use in Ecuador: a statistical analysis at different aggregation levels. *Agriculture, Ecosystems Environment*, *70*(2), 231–247.
De Vente, J., & Poesen, J. (2005). Predicting soil erosion and sediment yield at the basin scale: scale issues and semi-quantitative models. *Earth-Science Reviews*, *71*(1), 95–125.
Dwivedi, R., Kumar, A., & Tewari, K. (1997). The utility of multi-sensor data for mapping eroded lands. *International Journal of Remote Sensing*, *18*(11), 2303–2318.
Elirehema, Y. (2001). *Soil water erosion modeling in selected watersheds in Southern Spain*. Enschede: IFA, ITC.
Estrany, J., Garcia, C., & Walling, D. E. (2010). An investigation of soil erosion and redistribution in a Mediterranean lowland agricultural catchment using caesium-137. *International Journal of Sediment Research*, *25*(1), 1–16.
Fuller, D. (1998). Trends in NDVI time series and their relation to rangeland and crop production in Senegal, 1987–1993. *International Journal of Remote Sensing*, *19*(10), 2013–2018.
Gavrilovic, Z. (1988). Use of an empirical method (erosion potential method) for calculating sediment production and transportation in unstudied or torrential streams. In: *Paper Presented at the international conference on river regime* (pp. 411–422). Wallingford, Oxon UK: Hydraulics Research Limited [5 fig, 4 tab, 8 ref].
Gebreslassie, H. (2014). Land use-land cover dynamics of Huluka watershed, Central Rift Valley, Ethiopia. *International Soilless and Water Conservation Research*, *2*(4), 25–33.
Ghosh, K., De, S. K., Bandyopadhyay, S., & Saha, S. (2013). Assessment of soil loss of the Dhalai river basin, Tripura, India using USLE. *International Journal of Geosciences*, *4*, 11.
Heininger, P., & Cullmann, J. (Eds.). (2015). *Sediment matters—the challenges*. Heidelberg: Springer.
Heydarian, S. (1996). Assessment of erosion in mountain regions. In: *Paper presented at the proceedings of 17th asian conference on remote sensing*.
Jain, M. K., & Das, D. (2010). Estimation of sediment yield and areas of soil erosion and deposition for watershed prioritization using GIS and remote sensing. *Water Resources management*, *24*(10), 2091–2112.
Johnson, C. & Gebhardt, K. (1982). *Predicting sediment yields from sagebrush rangelands*.
Karkheh Company of Soil Survey (2005). *Soil characteristics of Dez wateshed*. Khuzestan, Iran.
Khaledian, Y., Kiani, F., & Ebrahimi, S. (2012). The effect of land use change on soil and water quality in northern Iran. *Journal of Mountain Science*, *9*(6), 798–816.
Kidwell, Katherine B. (1990). *Global Vegetation Index Users Guide. National Oceanic and Atmospheric Administration, National Climatic Data Center* (p. 45) Washington DC 20233: Satellite Data Services Division.
Kothyari, U. C., Jain, M. K., & Ranga Raju, K. G. (2002). Estimation of temporal variation of sediment yield using GIS/Estimation de la variation temporelle de l′ exportation sédimentaire grâce à un SIG. *Hydrological Sciences Journal*, *47*(5), 693–706.
Le Bissonnais, Y., Montier, C., Jamagne, M., Daroussin, J., & King, D. (2002). Mapping erosion risk for cultivated soil in France. *Catena*, *46*(2), 207–220.
Martınez-Casasnovas, J. (2003). A spatial information technology approach for the mapping and quantification of gully erosion. *Catena*, *50*(2), 293–308.
Milliman, J. D., & Syvitski, J. P. (1992). Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. *The Journal of Geology* (pp. 525–544), 525–544.
Naqvi, H. R., Athick, A. M. A., Ganaie, H. A., & Siddiqui, M. A. (2015). Soil erosion planning using sediment yield index method in the Nun Nadi watershed, India. *International Soilless and Water Conservation Research*.
Nearing, M. A., Unkrich, C. L., Goodrich, D. C., Nichols, M. H., & Keefer, T. O. (2015). Temporal and elevation trends in rainfall erosivity on a 149 km 2 watershed in a semi-arid region of the American Southwest. *International Soilless and Water Conservation Research*.
Onstad, C., & Foster, G. (1975). Erosion modeling on a watershed. *Transactions of the ASAE*, *18*(2), 288–0292.
Onyando, J., Kisoyan, P., & Chemelil, M. (2005). Estimation of potential soil erosion for river perkerra catchment in Kenya. *Water Resources Management*, *19*(2), 133–143.
Ouyang, D. & Bartholic, J. (1997). Predicting sediment delivery ratio in Saginaw Bay watershed. In: *Paper presented at the proceedings of the 22nd national association of environmental professionals conference*.
Pandey, A., Chowdary, V., & Mal, B. (2007). Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. *Water resources management*, *21*(4), 729–746.
Rafaelli, S. G., Montgomery, D. R., & Greenberg, H. M. (2001). A comparison of thematic mapping of erosional intensity to GIS-driven process models in an Andean drainage basin. *Journal of hydrology*, *244*(1), 33–42.
Refahi, H., & Nematti, M. (1995). Erodibility assessment of the Alamout subcatchment and its effect on the sediment yield. *Journal of Agricultural Sciences, Iran*, *26*, 48–56.
Refahi, H. G. (1996). *Water erosion and conservation*. Tehran: University Of Tehran Publication,.
Renard, K. G., Foster, G. R., Weesies, G. A., & Porter, J. P. (1991). RUSLE: revised universal soil loss equation. *Journal of Soilless and Water Conservation*, *46*(1), 30–33.
Rouse, J., Jr, Haas, R., Schell, J., & Deering, D. (1974). Monitoring vegetation systems in the Great Plains with ERTS. *NASA Special Publication*, *351*, 309.
Şahin, Ş., & Kurum, E. (2002). Erosion risk analysis by GIS in environmental impact assessments: a case study—Seyhan Köprü Dam construction. *Journal of environmental management*, *66*(3), 239–247.
Solaimani, K., Modallaldoust, S., & Lotfi, S. (2009). Investigation of land use changes on soil erosion process using geographical information system. *International Journal of Environmental Science Technology*, *6*(3), 415–424.
Stone, R. P. (2000). *Universal soil loss equation, USLE*. Ontario: Ministry of Agriculture, Food and Rural Affairs.
Tangestani, M. H. (2006). Comparison of EPM and PSIAC models in GIS for erosion and sediment yield assessment in a semi-arid environment: Afzar Catchment, Fars Province, Iran. *Journal of Asian earth sciences*, *27*(5), 585–597.
Veldkamp, A., & Fresco, L. (1996). CLUE: a conceptual model to study the conversion of land use and its effects. *Ecological Modelling*, *85*(2), 253–270.
Wang, G., Gertner, G., Fang, S., & Anderson, A. B. (2003). Mapping multiple variables for predicting soil loss by geostatistical methods with TM images and a slope map. *Photogrammetric Engineering Remote Sensing*, *69*(8), 889–898.
Wellens, J. (1997). Rangeland vegetation dynamics and moisture availability in Tunisia: an investigation using satellite and meteorological data. *Journal of Biogeography*, *24*(6), 845–855.
Wischmeier, W. H. & Smith, D. D. (1978). *Predicting rainfall erosion losses – a guide to conservation planning*.
Yuliang, Q., & Yun, Q. (2002). Fast soil erosion investigation and dynamic analysis in the loess plateau of China by using information composite technique. *Advances in Space Research*, *29*(1), 85–88.
Zhang, W., Zhou, J., Feng, G., Weindorf, D. C., Hu, G., & Sheng, J. (2015). Characteristics of water erosion and conservation practice in arid regions of Central Asia: Xinjiang Province, China as an example. *International Soilless and Water Conservation Research*.
Zhang, X., Wenhong, C., Qingchao, G., & Sihong, W. (2010). Effects of landuse change on surface runoff and sediment yield at different watershed scales on the Loess Plateau. *International Journal of Sediment Research*, *25*(3), 283–293.
Zhu, C., & Li, Y. (2014). Long-term hydrological impacts of land use/land cover change from 1984 to 2010 in the Little River Watershed, Tennessee. *International Soilless and Water Conservation Research*, *2*(2), 11–21.
Ziaei, H. R., Rangzan, K., & M., V. (2005). Erosion intensity using GIS technique and satellite information. In: *Paper presented at the geomatics*.