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SOIL EROSION HAZARD MAPPING IN CENTRAL ZAB BASIN USING EPM MODEL IN GIS ENVIRONMENT

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ABSTRACT
Soil losses and erosion are the primary concerns that decrease soil fertility, deposition materials in waterways, flooding, environmental pollution, and declining dam capacity. The aim of this study is zonation of soil erosion hazard and sediment yield in central Zab basin in southwest of West-Azerbaijan province in Iran. The Sardasht dam construction is established on its main branches that estimate amount of soil erosion and sedimentation of behind the dam is necessary. Hence EPM model have been used to soil erosion hazard mapping using series of GIS data, Landsat ETM+ satellite images, aerial photos in GIS environment. Required layers information was used in this research including slope, aspect, lithology, soil, land use, rainfall, and river erosion. Hence, GIS databases and their weighting of each map layers were extracted according to the hydrologic units. Also, GIS database was prepared based on EPM model to extract of erosion and sedimentation maps The obtained result using EPM model showed that south and southwest parts of central Zab basin near the Sardasht Dam construction are very highly eroded due to their soil erosion and lithology while the northern parts of case study are moderately eroded because of the intensive land cover.

Keywords: Satellite data, GIS, EPM model, Erosion, Sedimentation, Hazard mapping.

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Contribution/ Originality
This study contributes in the existing literature to determine the dominant erosion features in the mountainous catchment using satellite data and GIS techniques. This study documents can be used to estimate the amount of sediment reaching the dams, natural resource management and land use planning.

1. INTRODUCTION
Produced sediments in watershed, especially in mountainous basins are due to mass movements and surface erosion which becomes available for carry. Bare soil is highly susceptible to rain splash and erosion. Also, arid zones produce record suspended sediment concentrations (Jones, 1981). The sediment not only causes water quality to deteriorate but also affects physical and biological conditions in the receiving systems (Karr and Dudley, 1981). The water runoff and gravity on slopes as dynamic agents make erosion induced sediment yield (Daneshvar and Bagherzadeh, 2011). Sediment yield, the total amount of sediment generated within a watershed and reached at its outlet during any given time, has been considered as decisive factor in planning soil conservation and sustainable development of natural resources (Ownegh *et al.*, 2004; Borah *et al.*, 2008). This pervasive process shapes whole terrestrial, affects watershed topography and can cause major damage to the environment. According to Borah *et al.*

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(2008) the process reflects the influence of interactive factors; such as climate, geology, biology, time, and topography on watershed. It is now evident that significant efforts are required to manage and preserve global water and soil resources (Garg and Jothiprakash, 2012). The sediment available annually for erosion and transport in Zagros Mountains are due to changes in land cover, erosion-sensitive geological formations consisting largely of shale, marl and poor vegetation cover (Tangestani, 2006). The main factors that should be taken into account in planning renewable natural resource projects, are sediment yield and surface erosion (Gobin *et al*., 2004). Lack of information to prepare erosion maps for quantitative and qualitative sediment evaluation and shortage of enough sediment measurement stations are major problems for watershed management in Iran.

The objectives of this study were determining the dominant erosion features in the central Zab catchment, Iran. Also, prepare the soil erosion zonation in the study area by using satellite data and EPM model in GIS environment. Hence, the goals of the current study were achieved by applying the above mentioned techniques and frequent evaluations to estimate the amount of sediment reaching the Sardasht dam in central Zab basin.

2. REVIEW OF LITERATURE

Although the history of studies about erosion and sedimentation dates back to many years ago internationally, the first model was used by Universal Soil Loss Equation or USLE (Wischmeier and Smith, 1978). Recently, the most common models that were used in erosion and sedimentation including USLE (Mati *et al*., 2000; Erskine *et al*., 2002) WEPP (Water Erosion Prediction Project), RUSLE (Revised Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation) (Millward and Mersey, 2001; Raghunath, 2002), PSIAC (Pacific Southwest Interagency Committee) (Nelson and Rasele, 1989; Tangestani, 2006; Zakerinejad and Maerker, 2015) and EPM (Erosion Potential Method) (Refahi and Nematti, 1995; Panagos *et al*., 2014). Most of these models consider environmental factors to characterize a basin drainage in terms of sensitivity to erosion and sediment transport (Garg and Jothiprakash, 2012). Applications of geographic information systems (GIS) techniques and remote sensing data assist the evaluation of erosion processes and generation of land use maps (De, 1998). Furthermore, GIS models can be used to integration of such data layers with the generation of erosion-severity and sediment-yield maps (Yuliang and Yun, 2002; Martínez *et al*., 2003; Tangestani, 2006; Bahadur, 2009; Chen *et al*., 2011; Alexakis *et al*., 2013; Mallick *et al*., 2014).

3. STUDY AREA

The central Zab basin was located in the mountainsides in the southwest of West-Azerbaijan province and the northwestern part of Kurdistan province in Iran. The geographical position of study area located between the latitudes of 36° 8' 25" N and 36° 26' 27" N and the longitudes of 45° 21' 21" E and 45° 40' 44" E. The central Zab basin has a north-south orientation and stretches almost 30 km in an east-west direction (Khezri, 2011). The study area covers some 520km² of its total area (Figure 1).

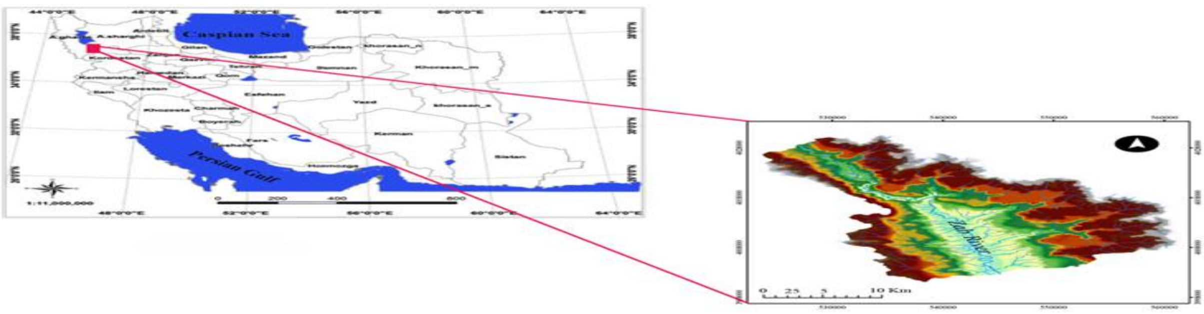

Figure-1. Geographical position of central Zab basin

Source: Shahabi and Hashim (2015)

In the aspect of tectonic movement, since the study region is located in major Zagros thrust direction, faults are the main causes of slope failures. The study area based on morphology and tectonic forces are strongly affected by faults that located in the Sanandaj-Sirjan region, and its north-east region is located in the Mahabad-Khoy zone (Shahabi *et al.*, 2012). Also, because of the steep cliffs as well as the existence of several faults, steep and layer lengths are different (Figure 2). The central Zab basin based on climate condition located in semiarid with strong vertical gradients in precipitation, so the area is cold. The coldest and hottest months of study area are February (temperature average of 7.7 °C) and August (temperature average of 24.1 °C) respectively (Moghimi *et al.*, 2013; Shahabi *et al.*, 2014).

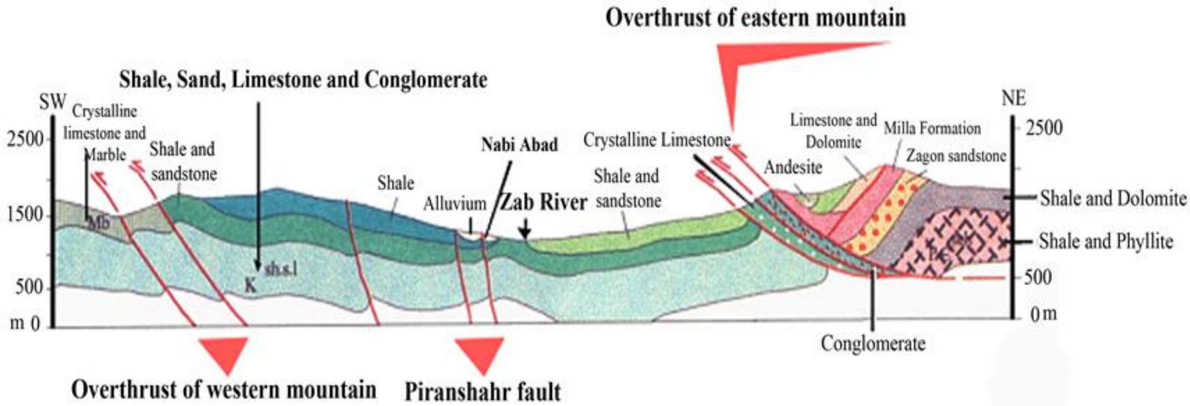

Figure-2. Cross-section in 1:100,000 geological mapping across the Zab valley in the northern part of the study area
Source: Shahabi *et al.* (2013)

4. MATERIAL AND METHODS

The important layers that have been used in this study are the topographic map, geology and soil map, vegetation and land use. In the first step, topographical maps (1:50,000 scale) with a contour interval of 20 m was used to extraction of digital elevation model (DEM) and generate a triangulated irregular network (TIN) model. The ILWIS 3.3 software was used to DEM of study area generation (cell size: 20m×20m) by "Inverse distance" interpolation. The slope and aspect parameters were obtained from the generated DEM. Also, lithology factor was derived from 1:100,000 scale geology maps from the Iran Geological organization.

Furthermore, Landsat ETM$^+$ satellite images (spatial resolution: ~30 m) on the 21 April 2009 that was used to extraction of land use map, which was modify the boundaries by supervision classification with ERDAS (Earth Resource Data Analysis System) software to develop a statistical characterization of the reflectance of each information class. The obtained land use map validated based on field observations. Despite image pre-processing by Landsat ETM$^+$ imagery that included geo-referencing, ortho-rectification and geo-rectification, accuracy was further improved by using 15 ground control points (GCPs) obtained during field visits.

The rainfall was another factor that used in this research from a 30- year period (1980-2010). The annual precipitation of the central Zab basin is 865 mm based on the records from the Iranian Meteorological Department. The mean annual rainfall is around 1310 mm, most of which falls between the months of April and May. Measurements of daily rainfall data by a Kriging process within Arc GIS 10.1 were utilized to create an average annual rainfall contour map. Finally, the influence of factors on the soil erosion hazard mapping was evaluated qualitatively to select positive factors and the erosion map was produce by EPM model and reclassifies the raster data. The following sections describe the techniques used to generate the data layers and to evaluate the erosion factors for EPM model based on the data layers.

4.1. EPM Model

The Erosion Potential Method (EPM) for first time in 1988 introduced by Gavrilovic in Yugoslavia. This model can be used for estimating the total annual sediment yield of a sub-catchment area and qualifying the erosion severity (Gavrilovic, 1988). The surface geology and soils, topographic features, climatic factors (including mean annual rainfall, and mean annual temperature), and land use are main factors that can be used in EPM model. Three naturally occurring factors control erosion development (exposed rock and soil, topography, and climate), while land use is entirely man-dependent (Tangestani, 2006).

One of the most important problems with empirical models of soil erosion is their lack of accuracy in processing large number of data, which must be digitalized by the Geographic Information System (GIS) and analysed by mathematical models (Amini *et al*., 2010).

Furthermore, important evolution of the EPM model is its application based on spatially distributed input data in a Geographic Information System (GIS) environment (Fanetti and Vezzoli, 2007). Geographic Information System (GIS) can also provide linkages between maps and other information related to the geographic location for environmental modelling purposes especially for watershed management (Worboys and Duckham, 2004).

The EPM model is able to measure erosion amounts and also can estimate of sediments behind the reservoirs based on sediment carrying capacity. The coefficient of erosion intensity (Z) is calculated by the following equation in this model:

$$Z = Y.X_a(\psi + I^{0.5}) \qquad (1)$$

Where; Y: Rock and soil susceptibility coefficient, Xa: Land use coefficient, ψ: Erosion coefficient of watershed, I: average slope (percent) (Gavrilovic, 1988) were evaluated using GIS software.

The volume of soil erosion is calculated by the following equation in this method:

$$W_{sp} = T.H.P.Z^{3/2} \qquad (2)$$

Where, W is the weight and W_{sp} the average annual specific production of sediments per km^2 in m$^{3/year}$, T is a temperature coefficient, calculated as:

$$T = \sqrt{\frac{t}{10}} + 0.1, \qquad (3)$$

with *t*=the mean annual temperature in degrees Celsius (°C), *H* the mean annual amount of precipitation (mm/year), and *Z* the erosion coefficient calculated from Eq. (1).

The EPM model is used ratio of eroded materials in each section of the stream to the total erosion in the whole watershed area to calculate of sediment production rate (Eq. 4)

$$Ru = 4(P.D)0.5/L + 10 \qquad (4)$$

Where:

P: circumference of the watershed, L: watershed length (Km), D: height difference in the watershed area (Km). After calculation of Ru value, the special sediment rate is estimated by equations Eq. 5 and 6:

GSP=WSP.Ru (5)

GS=GSP.F (6)

Where:

G.S.P: Special sediment rate, WSP: volume of special erosion (m^3/km2/yr), Ru: Sedimentation coefficient, GS= total sediment rate (m3/yr), F= Total watershed area (km^2) (Amiri and Tabatabaie, 2009).

5. RESULTS AND DISCUSSION

The soil erosion hazard mapping in EPM model was performed by Arc GIS 10.1 software based on four factors. The factors that used in EPM model consisting, *Ψ*: Erosion coefficient of watershed, *X*: Land use coefficient, *Υ*: susceptibility of lithology and soil to erosion, *I*: mean watershed slope each one of these factors will receive a proper value according to its contribution to erosion process (Amiri, 2010) (See Table 1).

Table-1. The contributing factors in EMP model to estimate the soil erosion

Factor	Necessary information	Results
1	Slope map	I: mean basin slope
2	Aspect map	Ψ: value for different erosions
3	Land use	Xa: value for different land uses
4	Lithology and soil susceptibility to erosion	Y: value for Lithology and soil susceptibility

Source: Amiri (2010)

5.1. Slope

Slope is viewed as the major controlling factor in erosion formation. It is frequently used in the calculation of soil erosion mapping (Morgan, 2009). Land slopes (Figure 3) were calculated using 1:5,000 topographic maps produced by the Iran Cartographic Organization were used to build up a DEM of the sub-catchment area.

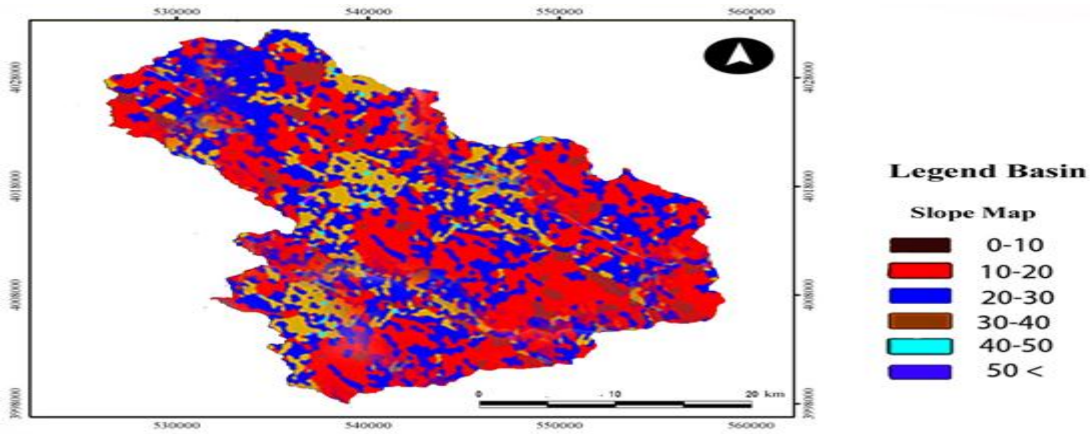

Figure-3. Slope map of central Zab basin

Source: Shahabi *et al.* (2013)

The slope map of the study area was divided into six slope categories. Arc GIS 10.1 software was used for this classification and for the calculation of the relationships to soil erosion mapping. The mean values of each slope class were assigned in decimal system (Table 2) to determine the '*I*-factor' (Gavrilovic, 1988).

Table-2. Slope classes and the assigned 'I-factor' for each map class used in EPM model

Slope class	Slope (%)	*I*-factor
1	0-10	0.050
2	10-20	0.075
3	20-30	0.150
4	30-40	0.200
5	40-50	0.350
6	50<	0.400

Source: Calculated by Authors

5.2. Aspect

Aspect in mountainous basins accelerated role in a soil erosion event, which slope aspect has controlled the amount of water in the slopes and hillsides. Aspect regions of study area are classified in nine categories according to the aspect class as; "at (−1°), north (0°–25.5°; 315°–360°), northeast (22.5°–59.5°), east (59.5°–135.5°), southeast (135.5°–153.5°), south (153.5°–215.5°), southwest (215.5°–251.5°), west (251.5°–298.5°), and northwest (298.5°–341.5°) (See Figure 4).

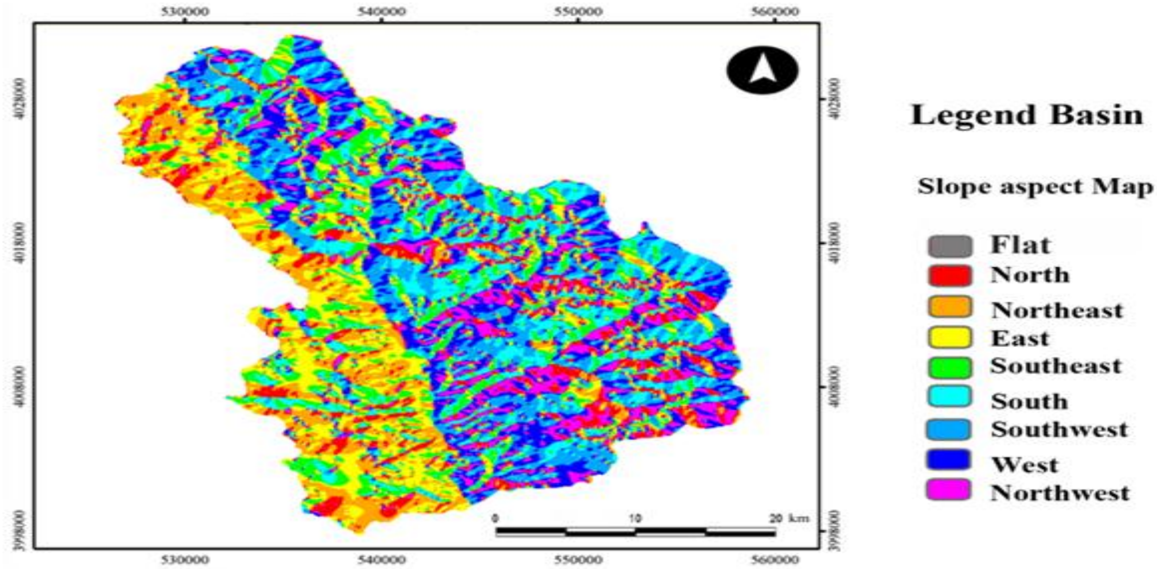

Figure-4. Slope Aspect map of central Zab basin

Source: Shahabi *et al.* (2014)

The slope aspect map of the study area was divided into nine slope categories. The mean values of each aspect class were assigned in decimal system (Table 3) to determine the 'Ψ-factor' (Gavrilovic, 1988).

Table-3. Slope Aspect classes and the assigned 'Ψ-factor' for each map class used in EPM model

Aspect class	Aspect	Ψ-factor
1	Flat	0.10
2	North	0.30
3	Northeast	0.35
4	East	0.45
5	Southeast	0.65
6	South	0.55
7	Southwest	0.75
8	West	0.85
9	Northwest	0.90

Source: Calculated by Authors

5.3. Geology and Soil Types

Geology factor according to lithology structures in basin has an important variable in erosion formation, which structures tend to lead to a variation in stone stability and strength and also to a varied soil texture (Zhang *et al.*, 2004). The main soil types of study area are sandy clay, sandy loam and loam covering the mountains and hills. It is important to note that the lithology and geology units of study area comprise several formations and very complex. The lithology map of study area were therefore classified in ten categories with respect to soil erosion (Figure 5).

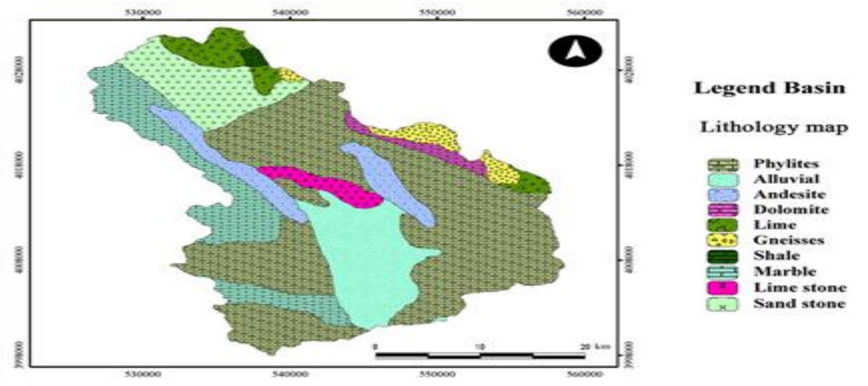

Figure-5. The Lithology map of central Zab basin
Source: Shahabi *et al.* (2014)

In this research, examining rock and soils from 50 test sites were used to estimating the coefficient of rock and soil resistance to erosion (y-factor), representative of the major rock and soil map units. The coefficients of rock and soil resistance to erosion (y-factor) were assigned for each map class. The soil type layer and rock type data (Quaternary alluvial deposits) were combined in a single data layer that converted to a raster format (cell-size of 20×20 m). Table 4 showed the results obtained from examinations and evaluations were implemented in all the test sites.

Table-4. Evaluated coefficients of rock resistance to erosion (*y*-factor) and the coefficient of observed erosion processes of the study area

Main lithology	***y*-factor**	***Φ*-factor**
Phylites	1.2	0.8
Alluvial	0.6	0.3
Andesite	1.3	1.0
Dolomite	0.6	0.9
Lime	0.8	1.2
Gneisses	1.1	0.5
Shale	-	0.7
Marble	1.5	0.8
Limestone	0.8	1.0
Sandstone	0.9	1.2

Source: Calculated by Authors

5.4. Land Use

The lack of appropriate cover such as vegetation is related to an increase in soil erosion. In this study seven categories of land use were determined and compared to soil erosion. To determine the 'Xa-factor', and 'land use' values utilized by the EPM method, a land-cover map was generated by ETM^{+} images taken on 21 April 2009 which were calibrated using field observations using supervised classification. After geo-referencing the resultant image, a combination of bands 1, 4 and 7 was used to recognize the unique spectral signatures associated with those land features (Figure 6).

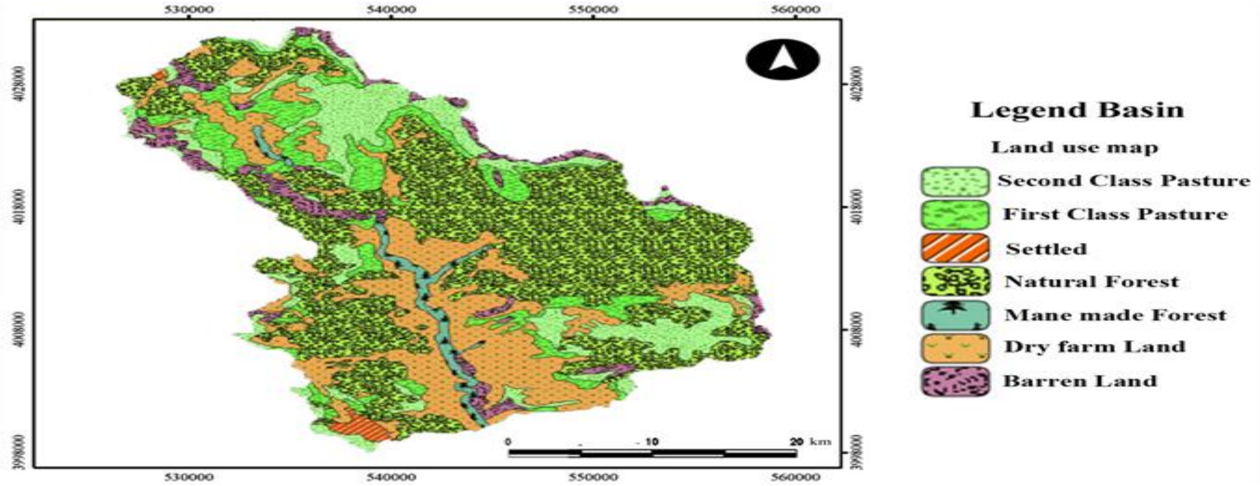

Figure-6. Land use map of central Zab basin

Source: Shahabi *et al.* (2014)

The land use coefficient (Xa) representing the each land use class was calculated by the use of EPM Guide Table (Gavrilovic, 1988) (Table 5). This model classifies land use into 7 categories and evaluates the coefficient 'Xa' from 0.1 (for first class pasture) to 1.0 (for Settled).

Table-5. Land use coefficient (Xa) used in EPM model

Land use	Xa
Second class pasture	0.25
First class pasture	0.10
Settled	1.00
Natural forest	0.55
Manmade forest	0.35
Dry farm land	0.85
Barren land	0.95

Source: Calculated by Authors

5.5. Rainfall

The rainfall has an important role to make erosion and sediment in basins. The annual and mean annual rainfall of study area is 865 mm and 1310 mm, respectively which fall between the April and May. Rainfall map of central Zab basin was generated from annual statistics by Kriging method within Arc GIS 10.1 (Figure 7).

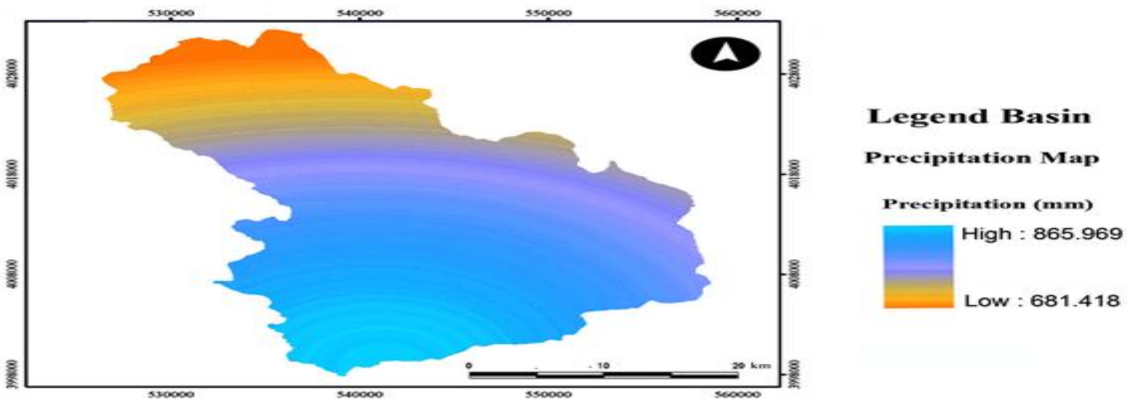

Figure-7. Precipitation map of central Zab basin

Source: Shahabi *et al.* (2014)

The area was subdivided into four 100 mm-interval rainfall levels, ranging from 0 to 800< mm that derived directly from the 30-year (1980-2010) rainfall statistics. Table 6 showed the EPM method uses annual rainfall as 'H' in Eq. (2) for erosion severity.

Table-6. Rainfall and '*H*' Parameter used in EPM model

Rainfall (mm)	*H*
0-600	355
600-700	375
700-800	425
800 <	475

Source: Calculated by Authors

The quantitative output of erosion severity (parameter Z) in the EPM model was evaluated mathematically by solving Eq. (1) for values of factor classes, and was then collapsed into four ordinal classes to generate the erosion potential map, using the method described by Gavrilovic (1988).

Areas with Z>1.0 are those with the potential for very high erosion, while areas with Z<0.18 correspond to a low erosion potential. The average annual specific production of sediments per km^2 in m3/year (Wsp), was predicted using Eqs. (2) and (3). The volume of erosion (W_{SP}) was then calculated by Eq. (2). Finally, produced map of Wsp for central Zab basin was classified in four erosion categories eroded (low, moderate, high and very high) using EPM model (Figure 8).

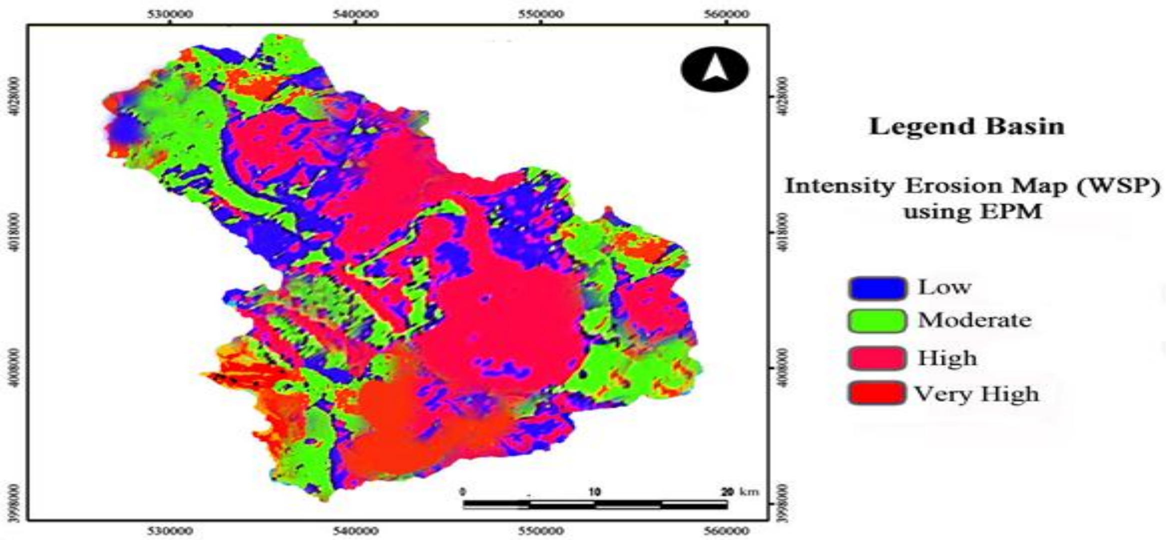

Figure-8. The Intensity Erosion Map (WSP) using EPM model in central Zab basin
Source: Extracted by Authors results

In this research, ten sample points were randomly assigned to each sub-unit that obtained results was used to determine the accuracy of EPM model. Amounts of sediment yield can be estimated from available sediment concentration data collected at sedimentary gauge in the sub-watershed outlet in central Zab basin. The t-student test was employed to compare the estimated erosion and sediment values by EPM model with measured values using SPSS statistical package. The obtained results in Table 7 showed that there were no significant differences (P<0.05) between the estimated and measured values. These results support the pervious achievements by the other researchers (Gavrilovic, 1988; Amiri and Tabatabaie, 2009; Eisazadeh *et al.*, 2012).

Table-7. The statistical analysis and mean comparisons in EPM model

Statistical characters	**Erosion statistical analysis**			
	C1	**C2**	**C3**	**C4**
d_i	5345.2	98.6	2321	6729.234
$\bar{d}$				1375.267
S_{n-1}				4328.336
$S_{\bar{d}}$				1176.975
calculated t				1.26*
Statistical characters	Sedimentation statistical analysis			
	C1	C2	C3	C4
d_i	2324.8	2567.9	2175.4	-921.4
$\bar{d}$				998.315
S_{n-1}				3784.332
$S_{\bar{d}}$				1126.349
calculated t				0.986*

t: from table of $P<0.05$ for df=5
di: The difference between erosion and sediment (measured and estimated) (ton/ha/yr)
*: no significant difference between calculated t and t from table ($P< 0.05$)
Source: Calculated by Authors

6. CONCLUSION

The EPM model is normally applied to estimate the soil erosion and the sediment production in rehabilitation plans of basins. Also, GIS and Satellite data are effective tools for calculating the mathematical equations of a soil erosion hazard mapping. GIS and remote sensing data can also be used to present the results from yield analyses graphically using EPM model. Although the EPM is method for rapid and easy access to the erosion severity and sediment yield but this method is completely knowledge based, and the accuracy of analyzed data primarily depends on the experience and knowledge of the experts who determine the values of erosion coefficients. Analysis of variables indicated that region has active morphodynamic and morphotectonic in terms of tectonic activity with existence of Piranshahr fault, lithological variety, slope changes and in terms of flow dynamicity with existence of high discharges and in relation to sedimentation load. The study area can be categorized into low, moderate, high and very high erosion zones. Furthermore, subsidence and development of Zab tensional basin by Piranshahr fault along with discharge load and sedimentation role entering from water flow of sub-basins of Rabt and Kanigoyz are influential in its morphology. The obtained result from EPM model shows that, south and southwest parts of central Zab basin near the Sardasht Dam construction are very highly eroded due to their geology and soil erodibility while the northern parts are moderately eroded because of the intensive land cover. The result of comparing erosion and sediment values using an EPM model with measured values showed that no significant difference was observed between the estimated and measured values ($P <0.05$). The results of this study can be used to estimate the amount of sediment reaching the Sardasht dam will be built. The obtained information can also be used in natural resource management and land use planning programs in mountainous watersheds.

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