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Estimation of erosion and sediment yield of Ekbatan Dam drainage basin with EPM, using GIS

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Abstract

Soil conservation and control of erosion is a basic problem in all countries. The goal of this research is to estimate erosion and sediment yield in Ekbatan Dam drainage basin by Erosion Potential Method (EPM), using Geographic Information System (GIS). The basin is located in Hamedan Province, west of Iran, in a cold and semi- arid region, with an average annual rainfall of 334mm. The study area is about 218 km^2 and is divided into 8 sub- basins. Sub- basins 1 and 6 are the largest (49.14 km^2), and smallest (9.92km^2), respectively. Elevation ranges between 1960 to 3580 m. The litho-units include schist, granite, hornfels, limestone, sandstone, (Pre- Jurassic to Neogene in age), conglomerate, and recent alluvium. Most sediment in the basin is generated from erosion of schist. The main factors in the EPM (slope average percent, erosion, rock and soil erosion and land- use) were evaluated using GIS software. Data layers used in this study were created from topographic, homorain, homotemp, geology, lithology maps, landsat TM digital images, and field observations. According to calculated results, the coefficient of erosion and sediment yield (z) for this basin fall into moderate and heavy erosion classes. For avoiding soil erosion in this basin, therefore, soil conservation operations should be performed.

Keywrds: *Ekbatan Dam, EPM, Erosion,GIS, Hamedan, Sediment yield.*

Introduction

Overpopulation in the world has lead to an increased demand for food and other necessities of human beings [1]. The gradual soil salinization along with the deterioration of vegetation covers has caused accelerating soil erosion and sedimentation in water reservoirs [2]. Soil loss in Iran has increased tremendously from 500 million tons to 2200 million tons per year, from 1950 to 1990 i.e. an increase of more than four folds in four decades [3]. The equilibrium between geological erosion and soil formation is easily disturbed by human activities [4]. It is estimated that 26.4 million hectares of land in Iran are under the influence of water erosion and 35.4 million hectares are under the influence of wind erosion [5]. Iran has more than 10 million hectares of cultivated land under irrigation [6] and more than 8 million hectares of agriculture land under dry farming [7]. Overgrazing, deforestation, cultivation, road construction, drought, civil and industrial development are possible causes that tend to accelerate the removal of soil material in excess of that which is removed by geological erosion[8]. Erosion is a process that separates soil and transports it to other places [9].

Water is the most important agent for transportation. Soil erosion can affect dynamically balanced watershed systems indirectly by increasing water runoff and degrade water quality and cause maldistribution of water in the watershed [10]. Thus, soil erosion is one of the important components of watershed management which also involves planning and managing of terrestrial and aquatic ecosystems, surface and groundwater, and land use planning[10, 11]. If a dam is constructed on a river that carries large amount of sediments, accumulation of sediments in dam reservoir is unavoidable. Rivers transport sediments that are generated by erosion; however, it is most important to identify the erosion types and sensitivity of the lithology of the basin to erosion and the capability of rivers for transporting sediments. By recognizing and controlling these factors, sediment yield decreases in the dam reservoir, which leads to an increase in the effective volume of reservoir.

2. Study area

The basin is located in the Hamedan province, west of Iran. The area of Ekbatan Dam drainage basin is 218 km^2, which is located between 48° 28' and 48° 40' E longitude, and 34° 35' and 34° 46' N latitude. The maximum and minimum altitudes of the basin area are 3580 (Alvand mountain) and 1960m (Ekbatan Lake), respectively. The area lies in a cold and semi-arid region (according to Ambergie climograph); with an average annual rainfall of 334mm (this includes the

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highest and lowest annual precipitation in 38 years period). The study area is a part of the Alvand batholith, which is a part of the Sanandaj- Sirjan Zone (Fig1- A). The Sanandaj- Sirjan Zone contains the metamorphic core of the Zagros continental collision zone in western Iran [12]. The Hamedan metamorphic rocks are in the northern part of the pre- Jurassic Sanandaj- Sirjan Zone complex and the first deformation was due to early Cimmerian movements [13]. The litho-units include schist, granite, hornfels, limestone, sandstone, (pre-Jurassic to Neogene), conglomerate and Recent alluvium [Fig1- B, 14] The drainage basin area is divided into 8 sub-basins [15]. Sub- basins 1 and 6 are the largest (40.38 km^2) and smallest (9.54km^2), respectively (Fig2- A). Yalfan (Abshineh) is the main river in the drainage basin, and the Ekbatan Dam is constructed on this river (Fig2- B). Only one hydrometric station exists at the Yalfan River, from where the data of sediment and discharge were used in the present study. Drainage basin characteristics such as morphological and drainage properties are shown in Table 1.

3. Materials and Methods

3-1EPM, using GIS

Lack of information to prepare erosion maps for quantitative and qualitative sediment evaluation is a major problem for watershed management in Iran [16]. There are not enough sediment measurement stations in most watersheds of the country, which makes it more difficult to provide specific models based on local watershed characteristics. 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 analyzed by mathematical models. EPM is an empirical model to estimate the quantity and quality of sediment [16]. Systematic investigation of the intensity of erosion and torrents were begun in former Yugoslavia sixty years ago ["Jaroslav Černi" Institute for the Development of Water Resources, 1947], and they enabled the development of The Method for the Quantitative Classification of Erosion (MQCE) in 1954. During the investigation work, it was noted that erosion intensity could be used for computing the amount of sediment that reaches the downstream part of a river so that the investigations were extended to include the observations of the transport of the sediments to the control profiles. During the last fifty years, continued development of the process has resulted in a complex methodology for investigation of erosion process, mapping, sediment calculation, and torrent classification. This method has been named the “Erosion Potential Method", since 1968. EPM has become a standard method for erosion and torrent engineering in water management [17, 18] and wider applications [19]. The EPM method consists of:

Quantitative classification of erosion (1954)
Quantitative sediment regime (1955)
Torrent classification (1956)

Methods of optimizing calculations of the volume of erosion control have been developed [19]. The Erosion Potential Method (EPM) is a model for qualifying the erosion severity and estimating the total annual sediment yield of a catchment area [20]. EPM was introduced for the first time in the River Stream International Conference [21]. The main factors in the EPM i.e. slope average percent (I), erosion (Ψ), rock and soil erosion (Y), and land- use (Xa), were evaluated using GIS software.

Since the EPM model considers only four factors for erosion potential assessment, it could readily be used for fast estimation of erosion potential in a sub-catchment area, for which the database layers are limited [22]. The Erosion Potential Method has been already applied on some watersheds in Iran and the results obtained are in agreement with the field investigations [23]. An important evolution of the Gavrilovic EPM model is its application based on spatially distributed input data in a Geographic Information System (GIS) environment [24]. Applications of Geographic Information Systems (GIS) and remote sensing techniques in erosion and sediment yield assessment have been developed recently [22]. 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 [25, 26].

4. Results and Discussion

Sediment estimation in this method is based on the following four factors (Table 2):
Y: The coefficient of rock and soil erosion, ranging from 0.25- 2
Xa: The land use coefficient, ranging from 0.05- 1
Ψ: The coefficient for present erosion type, ranging from 0.1- 1
I: Average- land slope in percentage [9]

The information necessary for these factors are: Geology and lithology, land use, slope and erosion maps. The Erosion Potential Method (EPM) calculates the coefficient of erosion and sediment yield (Z) of a sub- basin area by the following equation [22]:

$$Z = Y . Xa \, (\Psi + I^{0.5}) \quad (1)$$

in which Y is the coefficient of rock and soil erosion (Fig3- A), Xa is the land use coefficient (Fig3- B), Ψ is the coefficient for the present erosion type (Fig3- C) and I is the average land slope in terms of percentage (Fig3- D).

Table 1. Drainage basin characteristics

Sub-basins	Area (km^2)	Perimeter (km)	Average-slope (percentage)	High length of river (km)	Maximum elevation (m)
1	40.38	34.64	18	15.5	3580
2	38.07	27.16	26.5	10	3424
3	14.36	18.43	15	7	2615
4	20.8	25.15	21.5	10.8	3308
5	38.64	28.73	22	9.6	3408
6	9.54	13.76	10	5.5	2523
7	24.87	26.13	11	7.3	2522
8	31.41	37.54	14.5	10	2670
Basin	218.1	64.3	18.5	23.5	3580

Table 2. Descriptive factors used in EPM [19]

Land use coefficient	Xa
Mixed and dense forest	0.05- 0.2
Thin forest with grove	0.2- 0.3
Coniferous forest with little grove, scarce bushes, bushy prairie	0.3- 0.4
Damaged forest and bushes, pasture	0.4- 0.6
Damaged pasture and cultivated land	0.6- 0.8
Areas without vegetal cover	0.8- 1
Coefficient of rock and soil erosion	Y
Hard rock, erosion resistant	0.25- 0.5
Rock with moderate erosion resistance, alluvium	0.5- 0.6
Black hydro morph soils	0.6- 0.8
Mountain soils	0.8- 0.9
Hard doll stone	0.9- 1
Clastic schist, mica schist, gneiss	1- 1.1
Red sandstone, serpentine, flysch	1.1- 1.2
Weathered limestone and marl	1.2- 1.6
Loess, tuff , salty soil, steeply soil	1.6 -2
Sand, granule, schist	2
Coefficient for present erosion type	Ψ
Little erosion on watershed	0.1- 0.2
Erosion in waterways on 20-50% of the catchment area	0.3- 0.5
Erosion in rivers, gullies and alluvial deposits, karstic erosion	0.6- 0.7
50-80% of catchment area affected by surface erosion and landslides	0.8- 0.9
Whole watershed affected by erosion	1

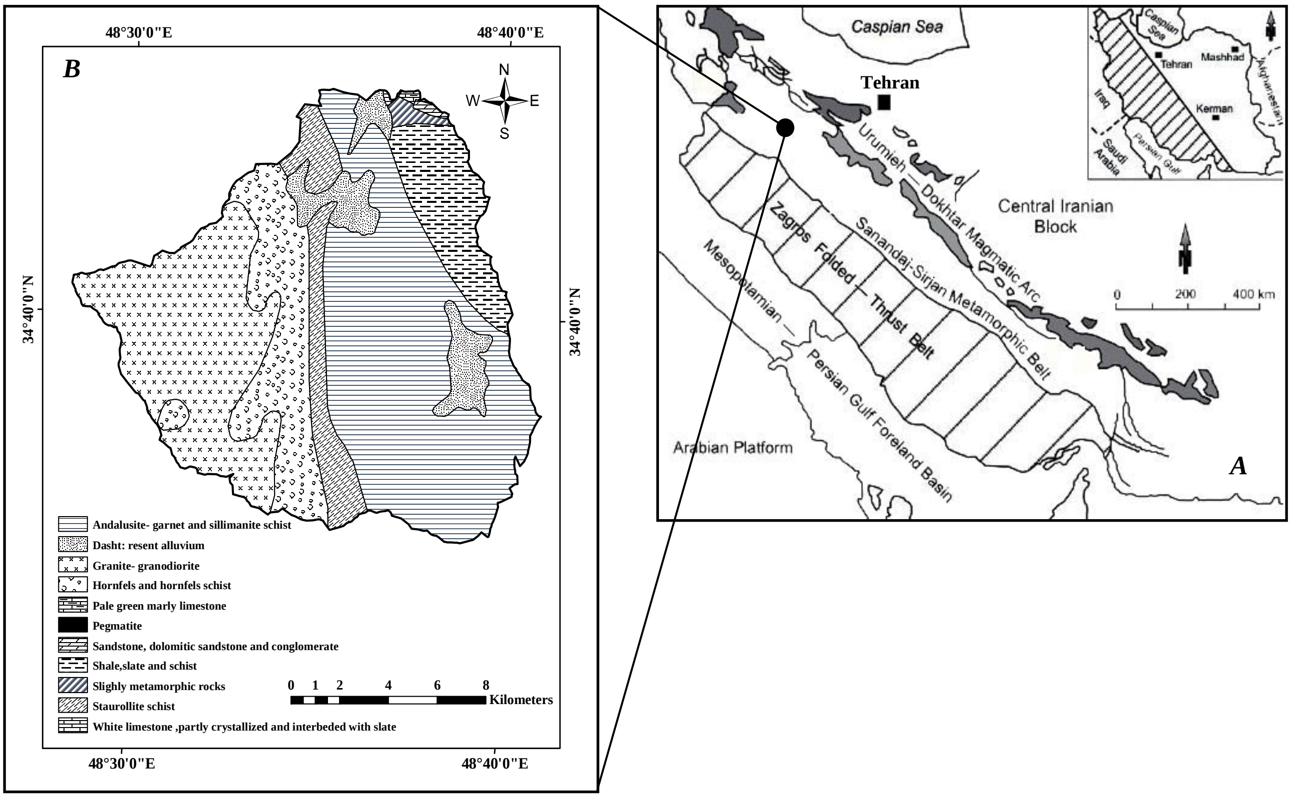

Fig. 1. A: Basin in Sanandaj- Sirjan zone [26]; B: The litho- units of Ekbatan Dam drainage basin

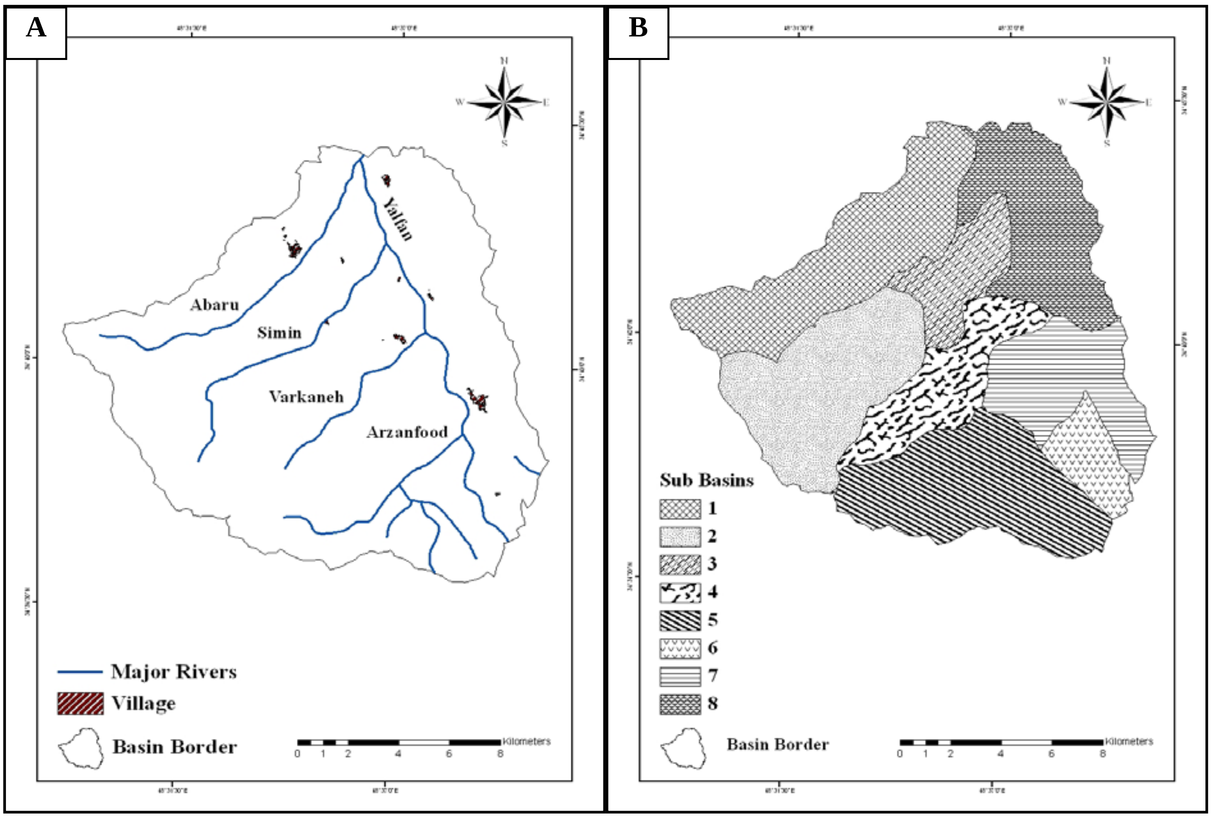

Fig. 2. A: Sub Basins; B: Major Rivers in drainage basin [15]

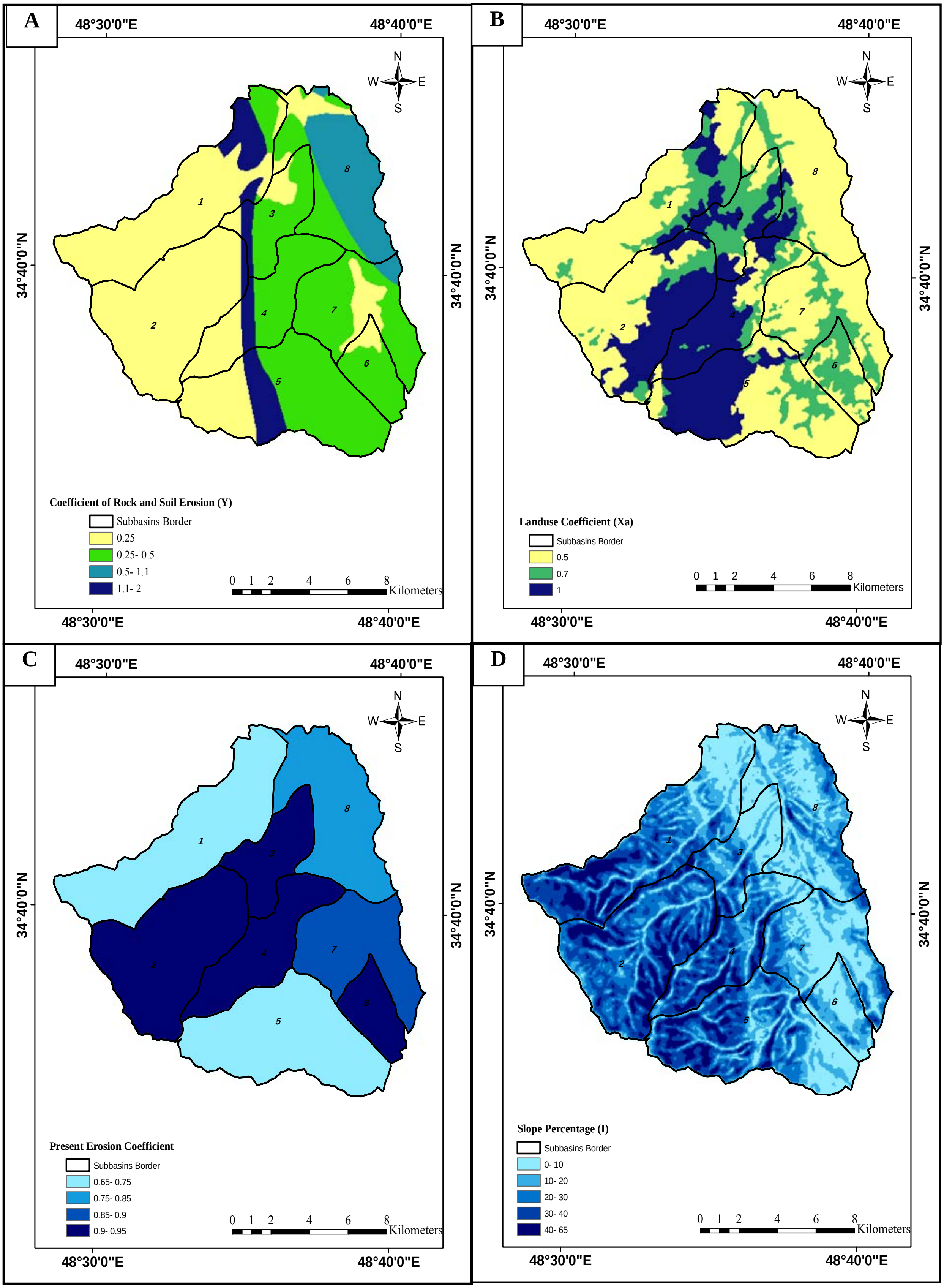

Fig. 3. Various maps of basin by GIS. A: Map of Rock and Soil Erosion Coefficient(Y); B: Map of Land use Coefficient (Xa); C: Map of Present Erosion Coefficient (Ψ) and D: Map of average- land slope in percentage (I).

The basic EPM value of the quantitative erosion intensity is the Erosion Coefficient (Z) [21]. The quantitative value of the erosion coefficient (Z) has been used to separate erosion intensity into classes or categories (Table 3). The mean value of the EPM erosion coefficient (Z) for the catchment area is the basic value for all EPM calculations [19]. The coefficients (Y, Xa, Ψ, I), are added to basic layers (rock and soil erosion, land-use, present erosion, slop average). The layers are overlain in Geographic Information System (GIS) (Fig5), and then the erosion-intensity map (Z) is produced (Fig4). The coefficient of erosion and sediment yield (Z) is classified into two erosion classes for sub- basins (Table4).
The volume of soil erosion is calculated by the following equation in this method:

$$W_{SP}= T.\ H.\ \pi\ .\ Z^{1.5} \quad (2)$$

in which, W_{SP} is the volume of soil erosion ($m^3/\ km^2.\ yr$), H is annual rainfall (mm), Z is erosion intensity and T is coefficient of temperature which is calculated as shown below:

$$T= (t / 10 + 0.1)^{0.5} \quad (3)$$

where t is the mean annual temperature (°C).

The volume of soil erosion (W_{SP}) in the drainage basin varied from 494 to 1190 $m^3/\ km^2.yr$. The sediment production rate in this model is calculated based on the ratio of eroded material in each section of the stream to the total erosion in the whole watershed area (Equation No.4):

$$R_U= 4\ (P.\ D)\ 0.5/\ L+ 10 \quad (4)$$

where P is the circumference of the watershed, L is watershed length (km), D is the height difference in the watershed area (km). After calculation of the R_U value, the spatial sediment rate is estimated by equation No.5 [16]:

$$G_{SP}= W_{SP}.\ R_U \quad (5)$$

where ,G_{SP} is the spatial sediment rate, W_{SP} is the volume of special erosion, and R_U is the coefficient of sedimentation. The volume of the spatial sediment rate (G_{SP}) in the drainage basin varies from 178 to 642.7$m^3/\ km^2.\ yr$ (Table5).

Table 3. EPM Erosion and torrent categorization [19]

Erosion and torrent category	Qualitative name of erosion category	Range of values of coefficient (Z)	Mean value of coefficient (Z)
I	Excessive erosion- deep erosion process (gullies, rills rockslides and similar)	Z > 1	Z= 1.25
II	Heavy or milder forms of excessive erosion	0.71 <Z< 1	Z= 0.85
III	Medium erosion	0.41 <Z< 0.71	Z= 0.55
IV	Slight erosion	0.2 <Z< 0.4	Z= 0.30
V	Very slight erosion	Z< 0.19	Z= 0.10

Table 4. Coefficient of Erosion and Sediment yield (Z) for all sub basins of Ekbatan Dam basin

Sub basins Coefficient	1	2	3	4	5	6	7	8	**Basin**
Z	0.52	0.73	0.97	0.89	0.72	0.71	0.72	0.75	0.76
Erosion Intensity	Moderate	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy

Table 5. The Volume of Soil Erosion (WSP), and spatial sediment rate (GSP), calculated for all sub- basins of Ekbatan Dam basin

Sub basins Coefficient	1	2	3	4	5	6	7	8	Basin
W_{SP} ($m^3/km^2.yr$)	494.35	670.67	1190.09	768.67	725.84	584.13	668	805.79	942.29
G_{SP} ($m^3/km^2.yr$)	177.9	529.83	642.65	568.82	580.67	181.08	340.68	596.28	810.37

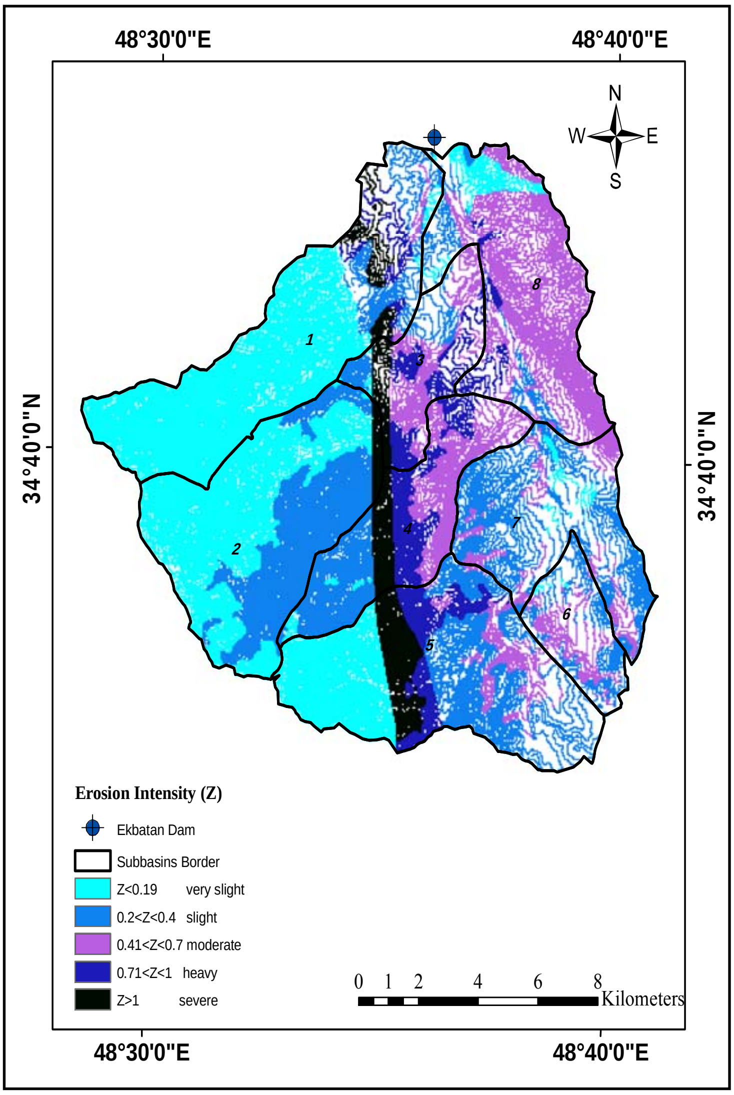

Fig. 4. Erosion intensity map of study area (Z)

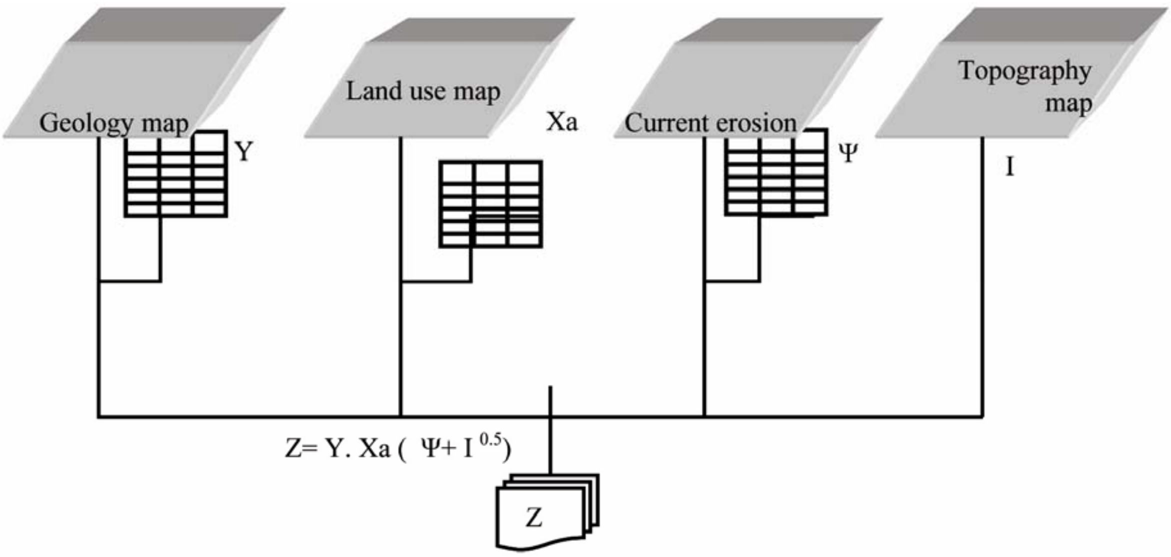

Fig. 5. EPM in Geographic Information System (GIS)

5. Conclusions

Based on the results, the coefficient of erosion and sediment yield (Z) obtained, the Ekbatan Dam Basin shows moderate and heavy erosion. The most important effective factor affecting erosion in this basin is the geology and lithology according to the calculated coefficients and the field observations. The observed sediment yield in the basin (based on station data) is about 6.43 tons/ hectare. yr; and the calculated sediment yield by EPM is about 9.72 tons / hectare . yr. The EPM tends to overestimate the sediment yields and is not an ideal method, because it poorly reflects the influence of the granulometric structure and the humus concentration of the soils. The morphology of slopes, which strongly influences the erosion rates, is not taken into account in this method. There are not any coefficients in the equations of EPM, which would reflect the volume and temporal non-uniformity of a runoff as the main factor- agent of erosion intensity. Nevertheless, application of this method is one of the alternatives for the existing methods and, consequently, deserves wider attention and could be used for other basins.

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