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Identification of Critical Sediment Source Areas at Regional Scale for Environmental Management (Case Study: Dehnamak Basin, Iran)

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Abstract

To identify critical sediment sources in large catchments, using easily available terrain information at a regional scale, a methodology was developed to obtain a qualitative assessment necessary for environmental management. Fargas et al method was employed in the research. The study was carried out in one of the sub-basins of Hableh Rood basin called Dehnamak in the arid and semiarid climate of Iran. The main objective of the model is to use basic terrain data related to the erosive processes that contribute to the production, transportation and accumulation of sediments throughout the main water paths in the watershed. This model is based on a selection of homogeneous zones regarding drainage density and lithology, achieved through interrelating the basic units based on a rating system. The values of drainage density are rated according to an erosion class. The lithology is rated by erosion indexes, adapted from FAO (1977). The combination and reclassification of the results brings about five qualitative classes of sediment risk according to Fargas et al (1997). The advantage of this method is that only two main factors of erosion, namely lithology and drainage density are employed in it, and these factors are available in our geological and topographic maps in Iran. This methodology has been employed for studying the watershed Dehnamak in NE Iran with an area of 248 km^2. The mapping scale was 1:50000 and the model implemented through a vector GIS (Arc View). The validation was carried out through interpretation of aerial photos and fieldwork which revealed a viability of 75.15%. The tested methodology has been proven useful as an initial approach for erosion assessment and soil conservation planning at regional level, as well as for a selection of priority areas where further analyses can be made to finally manage the environment.

Keywords: Dehnamak basin; Sediment sources; Aerial photos; GIS

1. Introduction

Existing methodologies for identification of sediment source areas at regional level usually need thematic information of several variables. These are frequently available in the form of existing maps at the required scale and/or for the whole study area. In some cases, these are based on models that have been developed to estimate soil erosion at a very detailed level. Then, the information available at semi detailed or reconnaissance level will not meet the requirement of the detailed models. Other methodologies are knowledge based, which is difficult to reproduce by different users (Fargas et al.1997).

The basis of the proposed methodology by (Fargas et al, 1997), is the use of basic terrain information, which is easy to acquire and is relevant in relation to erosion processes, the potentiality of sediment sources and the transport capacity from source to sedimentation areas, e.g. reservoir. In this sense, drainage network characteristics (scale 1:50000) and lithology at reconnaissance level (scale 1:100000) could be sufficient to identify critical sediment source to throw light upon the location

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of new reservoirs, to assess the environmental impact and or to determine priority areas of actuation in soil conservation projects. The model is implemented in a Geographical Information System environment and easy to be applied by users (Fargas et al; 1997). Fargas et al (1997), invented this method, tested and validated it for the watershed of the Joaquin Costa reservoir in NE Spain with an area of 1500 km^2. The validation was carried out by means of photo-interpretation and field work, which gave a viability of 78.5%. These zones are mainly coincident with the areas where important erosion processes have been detected and mapped by means of aerial photos interpretation as well as by field survey.

2. Materials & Methods

2.1. Description of the study area

Dehnamak basin is one of the sub basins of the Hableh Rood basin, Semnan province (Fig.1) located in the north of Dehnamak village in 52° 42′ 36″ to 52° 48′ East longitudinal and 35° 15′ 13″ to 35° 32′ 33″ North latitude with an area of 243.25 km^2. Main precipitation in the studied area is related to Mediterranean circulation that influences the area from west in autumn through spring. Since the upper land of the watershed is located on the southern slopes of central Alborz, arid and semiarid climate is predominant. The south of the watershed is adjacent to desert and so is influenced by desert climatic conditions. Eocene rocks have been extended to form the oldest alluvials in this area. To the east, west and north, 35° 30′ latitude, old rocks are seen as outcrops. Finally, in the studied area, (due to development of tertiary rocks) no older sediments can be seen. So no lithological variations can be observed. Totally ingenuous, evaporated and low pyroclastic content rocks related to Oligocene-Miocene (lower red and Qom and upper red formations) have been developed in this area (Fig.2). Different patterns can be observed, the main of which is dendritic and the other central pattern (Fig.3). The geological information and their drainage density are shown in Table 3. Geomorphologic, vegetation-covered pediment with flat areas and mountain-surrounded plains with gully erosion have a maximum percentage area of 59.77%.

2.2. Methods

The objectives of this model are:

a) Qualitative estimation of the sediment emission risk;

b) Identification of areas of different risks

c) Formulation of an empirical prediction model for sediment emission risk (Fargas et al.1997).

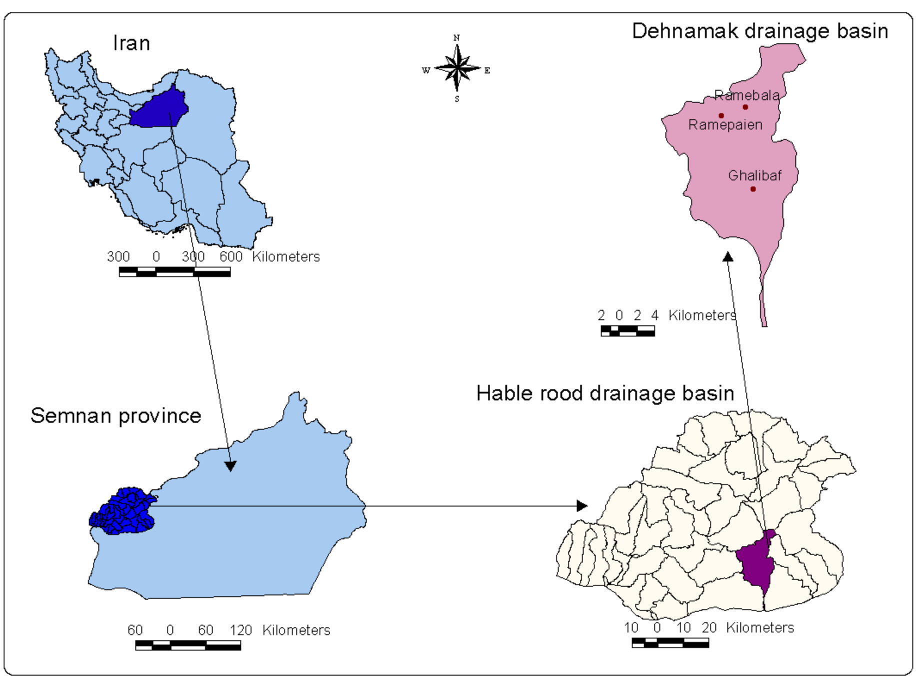

Fig. 1. Geographical location of Dehnamak basin

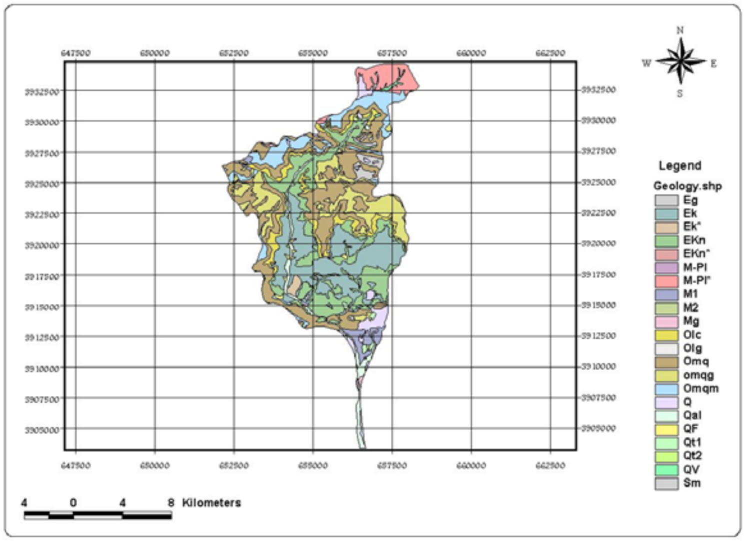

Fig. 2. Geology map of study area

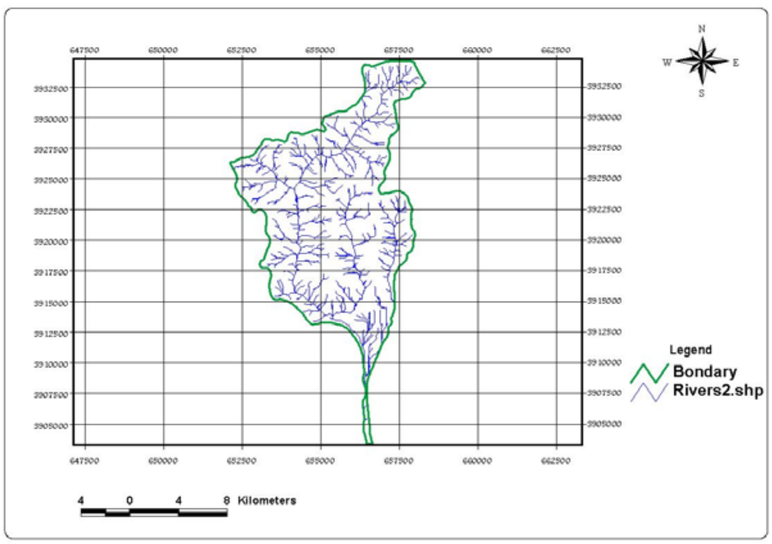

Fig. 3. Drainage network of the study area

One of the principal problems for the application of present erosion prediction models, at detailed as well as at regional scale, is the lack of terrain information on specific factors like soil, vegetation and clime (specially in mountainous environments). Nevertheless, there are topographic information that include contour lines and hydrographic, as well as geologic maps from which lithological information can be derived. From hydrographic and lithological information it is possible to study the problem of sediment source areas, prediction at a reconnaissance level. However, the prediction would have been accurate if the model had taken into account other variables like vegetation, relief characteristics (slope, orientation, concavity-convexity, relief amplitude, etc) (Fargas et al.1997).

The interaction between the degree of slope and length are related in the drainage density formula of Horton (1945), which measures the degree of dissection of catchments indicating the superficial runoff that is produced, this being a measure of the network transport capacity. It is also necessary to study the different aspects of an area, as well as their being lithological related with the resistance of materials to erosion and the infiltration capacity, factors that control runoff generation (Del Val, 1989). There are different indexes to measurement of soil erodibility, one of which directly relates erodibility with the lithology of the material (FAO, 1977 in Mopt, 1992). Since runoff is dependent upon soil infiltration capacity and on morphological terrain characteristics, the terrain can be classified in hydromorphological units as based on factors like slope shape and degree of dissection (Verstappen, 1983).

According to these concepts, the tested model is based on the delineation of homogeneous units with respect to drainage density and lithology. An erosion class can be attached to an elementary catchment depending on its drainage density (Stroosnijder & Eppink, 1993; Table1).

Table 1. Erosion classes on the basis of drainage density (Bucko&Mazurova, 1958; in Stroosnijder&Eppink, 1993)

Class	Erosion degree	Drainage density km/km^2	Rating value
1	Slight	<0.1	2
2	Moderate	0.1-<0.5	4
3	High	0.5-<1.0	6
4	Severe	1.0-<2.0	8
5	Very severe	>=2	10

These erosion classes do not reflect the resistance of material to erosion, and therefore a combination of this information with lithology would be necessary. Then, at a reconnaissance level, a basic spatial unit of association, where a sediment emission risk class made out of an overlay between elementary catchments (with their erosion class based on the drainage density, Martines Casanovas, 1994) and lithological units (with information about their resistance to erosion) would be considered in the model. The value of the coefficient to determine the sediment emission risk class, for each lithologic unit, is obtained multiplying the erosion class according the drainage density and the weighting factor of the lithology according to the resistance of material (Table 2).

Table 2. Resistance of material to erosion (Adapted from FAO, 1977; in MOPT, 1992)

	Rock type	Resistance index
Hard rocks	Basic rocks	0-2
	Acid rocks	0-5
	Metamorphic rocks	2-4
	Consolidated sandstone	4-5
Soft rocks	Friable calcareous rocks	3-4
	Dolomites	3-5
	Very friable shale rocks	7-8
	Plastics rocks	6-7
	Marls and clays	8-10
	Gypsum	9-10
Old alluvial deposits		4-8
Recent alluvial deposits		7-9

A complete process to obtain this map can be easily implemented in a vector-based GIS like Arc/View. It requires a database containing the basic spatial information needed by the model (Fargas et al, 1997).

3. Results

Table 3 contains the information, needed to apply the developed methodology in Dehnamak drainage basin are.

The proposed model by Fargas et al. (1997), was tested for Dehnamak catchment (NE Iran), with a surface area of the 248 km^2 and the risk class obtained through a reclassification of the coefficient values as according to the classes appearing in Table 4 (Fargas et al; 1997).

The methodology was applied to Dehnamak drainage basin. Fig. 4 shows the drainage network as overlaid on the lithological information related to the catchment. From this information and according to the Fargas et al. model, a sediment emission risk map of the Dehnamak drainage basin was obtained (Fig.5).

An approximately 85.15% of the area shows high risk of sediment emission. The global viability of the prediction model, estimated from the coincidence with the exiting erosion processes can be considered as acceptable, taking into account the basic information provided (Fargas et al, 1997).

Table 3. Some information items concerning the study area

Symbol on Map	Lithological Formation	Area (km^2)	Stream length (km)	Drainage density km/km^2
Eg	Gypsum	0.82	12.75	15.54
Ek	Marl, Lime	48.366	209.329	4.32
Ek*	Marl, Degradated Lime	1.163	6.578	5.65
Ekn	Marl, Lime, Gypsum	86.212	278.988	3.23
Ekn*	Marl, Lime, Degradated Gypsum	0.046	4.85	105.43
M-pl	Conglomerate with layers of sandstone and gray demarestone (Mio-Miocene)	2.502	2.85	1.139
M-pl*	Conglomerate with layers of sandstone and degradated gray demarestone (Mio-Miocene)	520.126	36.84	0.0708
M_1	Marl, Red gypsum	120.336	64.134	0.5329
M_2	Sandstone, Red conglomerated sandstone, Conglomerate	23.1449	3.484	0.15
Mg	gypsum, Marl	25.098	12.039	0.48
Ocl	Conglomerate, sandstone	22.271	123.266	5.53
Olg	Gypsum, Limited marl	0.423	4.453	10.527
Omq	Lime, Marl with limited layers of gypsum	171.496	242.482	1.414
Omqg	Marl, Gypsum	89.621	129.815	1.44
Omqm	Marly lime, Marl	841.296	71.246	0.084
Q	Alluvium and sediment	233.919	92.76	0.39
Qal	Bed of river alluvial, Abrupt flood deposit	8.396	121.37	14.45
Qf	Alluvial fan	0.718	17.866	24.85
Qt_1	Old alluvial fan	2.677	13.548	5.06
Qt_2	Young alluvial fan	0.117	1.273	10.88
Qv	Debris	0.669	13.385	20
Sm	Sandstone and marl-thin layer marl sandstone	9.127	19.286	2.12

Table 4. Criteria for a determination of the sediment emission risk classes (Fargas et al, 1997)

Class	Risk	Coefficient value
1	Low	<10
2	Moderate	10-20
3	High	20-30
4	Severe	30-40
5	Extremely severe	>40

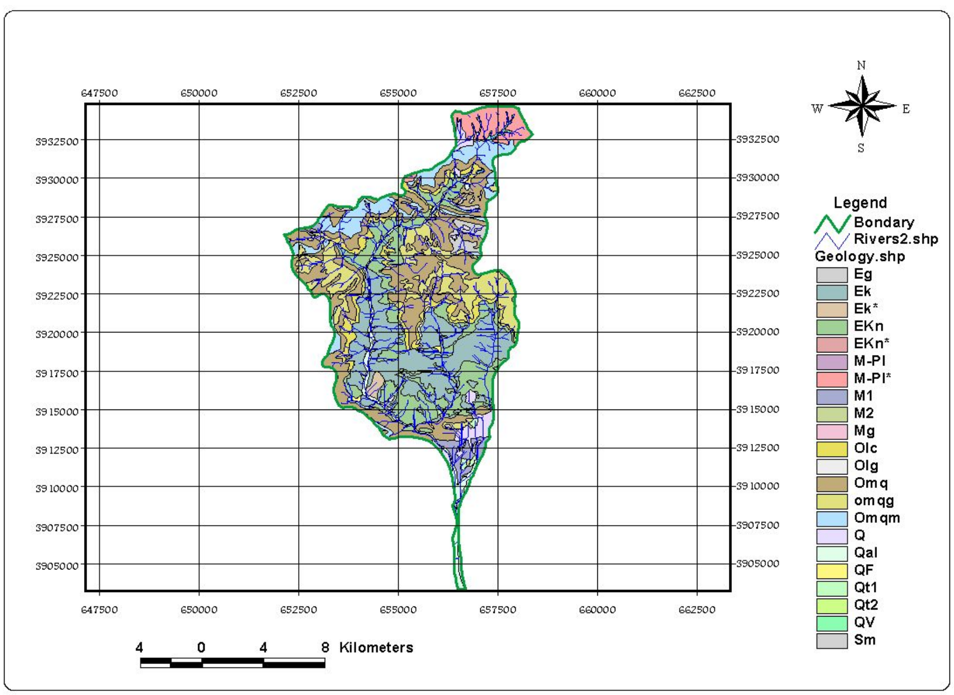

Fig. 4. Drainage network overlaid on the geologic map

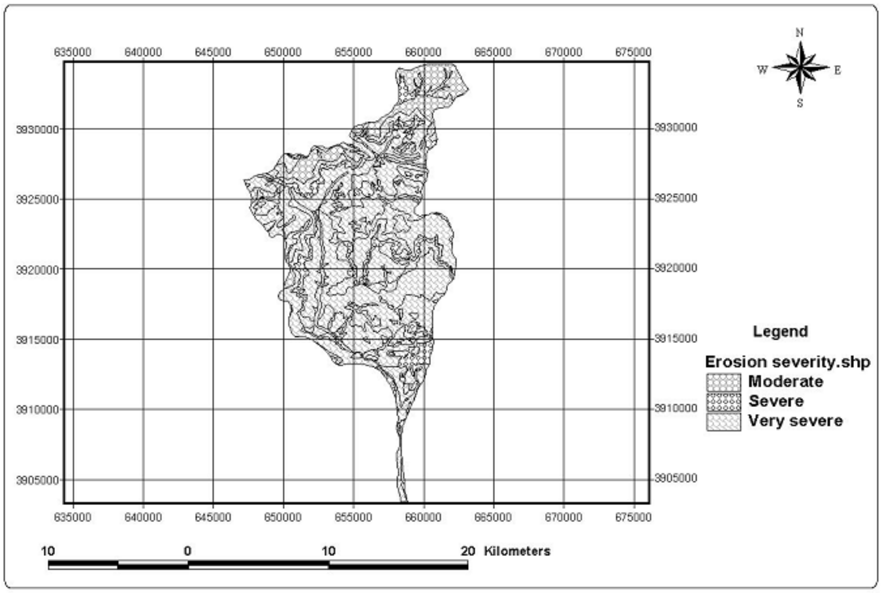

Fig. 5. Sediment emission risk map of the study area

4. Discussion

Erosion and sediment phenomena emanate from two factors of erodibility and erosivity which in general, are regarded in the developed method as in as in Table1 (drainage density) for erosivity and Table 2 (resistance of material) for erodibility factor.

According to this methodology, which is based on two base maps of topographic - channel and geology - resistance of material, one can conclude the applicability of the method. With regard to this fact, this method was to be used for an initial study and recognition. But the simplicity may not provide a proper response in some areas. For instance, a presentation of more detailed rocks in connection with Table 2 of the paper would be recommended for more analytical details. In this table consolidated sand stones, can be detailed into sand stone with Glauconitic, Lime, Pelitic and Silicone cements and also as regards schematic ranges in Table 2 they could be divided into further subdivisions.

5. Conclusions

From such basic terrain information as drainage network characteristics and lithology, it is possible to identify, at regional or reconnaissance level, the areas of high risk of sediment emission (Fargas et al., 1997). This information can be used to make decisions concerning environmental management, such soil conservational plans (biological or constructural work) in different sections of a catchment area, make economic plans and determine location of new reservoir(s), etc. One limitation of this model is the use of few terrain variables, but it can at the same time be a privilege because some countries are not in possession of sufficient data. However, it is open to employ other terrain characteristics like vegetation, landform, slope, etc. in order to improve the predicted results. The application of the methodology can be easily implemented in a GIS environment to automate the preparing of the sediment emission risk map (Fargas et al.,1997), which is one of the advantages of the method and as well the method could be considered for initial research in identification of critical sediment source(s) and finally give a helping hand to a more proper management of the environment.

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