The relationship between drainage density and soil erosion rate: a study of five watersheds in Ardebil Province, Iran

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Abstract

Drainage density is one of the parameters that can be considered as an indicator of erosion rate. This study analysed the relationship between drainage density and soil erosion in five watersheds in Iran. The drainage density was measured using satellite images, aerial photos, and topographic maps by Geographic Information Systems (GIS) technologies. MPSIAC model was employed in a GIS environment to create soil erosion maps using data from meteorological stations, soil surveys, topographic maps, satellite images and results of other relevant studies. Then the correlation between drainage density and erosion rate was measured. The mean soil loss rate in the study areas were 1 to 6.43 $t.h^{-1}.y^{-1}$ and drainage density values varied 1.44 to 5.43 Km Km^{-1}.The results indicate that the relationship between these two factors improved when the types of sheet erosion, mechanical erosion and mass erosion was ignored because these types of erosion were not mainly influenced by the power of runoff. There was a high correlation between drainage density and erosion in most of the watersheds. Finally a significant relationship was seen between drainage density and erosion in all watersheds. Based on the results obtained, the present method for distinguishing soil erosion was effective and can be used for operational erosion monitoring in other watersheds with the same climate characteristics in Iran.
Keywords: surface erosion, drainage density, MPSIAC model, GIS.

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1 Introduction

Soil erosion by water plays an important role in the process of land degradation and is linked to a number of environmental and socioeconomic problems worldwide. The effects of water erosion can be observed both on-site and off-site. On-site impacts are important in soils for agriculture, which leads to greater applying fertilizers and later may cause the abandonment of agriculture. The off-site impacts creates different problems associated with the deposition and consolidation of sediments in reservoirs, navigation canals, storm water pipes systems, retention ponds, floodplains, etc. [1]. Factors affecting water erosion and sediment production in the basin include: Types of geological formations, weather and climate, soil, topography, vegetation and land use. One of the parameters that can be regarded as an indicator of erosion is drainage density, which is the total length of streams per unit area of the watershed and depends on the factors such as lithology, permeability, vegetation. Drainage density varies in different tissues and depends on the soil type [2]. A study on erosion in geomorphology facies done by Ahmadi *et al.* [3] stated the relationship between the density of drainage and erosion. Spatial analysis of drainage network was performed by using GIS by Mishra [4]. During the study, priority areas for erosion control [5] and surface erosion and drainage basin development [6] were investigated. The effect of type of drainage on reduction and storage of surface runoff and capacity of the soil was reviewed by Irwin and Whiteley [7]. The aim of this study was to examine the relationship between drainage density and intensity of erosion in the different watersheds of Ardebil province.

2 Materials and methods

2.1 Sites description

A. Narghashlaghy watershed with the area of 4,548.09 hectares is in the northern city of Ardebil and with coordinates, 47°, 59', 8" to 48°, 6', 10" east longitude and 39°, 12', 22" to 39°, 16', 7" the north latitude.
B. Bargchay watershed of MeshkinShahr with the area of 4,541.7 hectares, located in the north of Razi, one city of the Ardabil province, in geographic coordinates 48°, 0', 37" to 48°, 9', 48" east longitude and 38°, 39', 56" to 38°, 46', 16" the north latitude.
C. Siahpoush watershed with the area of 10,103.4 hectares is one of the southern cities of Ardebil located in geographic coordinates 48°, 6', 35" to 48°, 16', 46" east longitude and 37°, 46', 8" to 37°, 54', 0" north latitude.
D. Saghezchichay watershed with the area of 6,607 hectares with coordinates 47°, 54', 7" to 48°, 42', 44" east longitude and 38°, 9', 11" to 38°, 16', and 53" north latitude is located in the eastern of Ardabil.
E. Alucheh-Fuladlu watershed with the area of 5,466.1 hectares is located in the south east of Ardebil with coordinates 48°, 7', 21" to 48°, 25', 56" east longitude and 38°, 58', 6" to 38°, 6', 2" north latitude.

2.2 Methods

The drainage density was measured using satellite images, aerial photos, and topographic maps by Geographic Information Systems (GIS) technologies. The MPSIAC model was employed in a GIS environment to create soil erosion maps using data from meteorological stations, soil surveys, topographic maps, satellite images and results of other relevant studies. Then the correlation between drainage density and erosion rate was measured. The following equation was used to calculate the drainage density.

$$D = \frac{\sum L}{A} \tag{1}$$

where ΣL is the total length of the hydrographic network (km) and A is the hydrographic basin area (km^2).

The MPSIAC model was used for erosion estimation. This model was created to estimate the soil erosion according to nine factors consisting of, geological characteristics, soil, climate, runoff, topography, vegetation cover, land use and present soil erosion (PSIAC, 1968). Johnson and Gembhart (1982) improved the original model to have a more accurate estimate of the sedimentation (eqn 2).

$$QS = 25.3*e^{\wedge}.036*R \tag{2}$$

where QS is sedimentation (t/km^2/year), R is sedimentation rate and e = 2.718.

Table 1: MPSIAC nine factors in erosion types of different studied watersheds.

No.	Description	Relationship
1	X_1: stone sensitive point	Y1 = x1
2	X_2: erodibility factor in USLE	Y2 = 16.67 x2
3	X_3: precipitation intensity with 2 year interval return	Y3 = 0.2 x3
4	X_4: annual runoff depth (mm), Qp: annual specific discharge	Y4 = 0.2(0.006 R+ 10QP)
5	X_5: average watershed slope (%)	Y5 = 0.33 x5
6	X_6: bare soil (%)	Y6 = 0.2 x6
7	X_7: canopy cover (%)	Y7 = 20 - 0.2 x7
8	X_8: points summation in BLM model	Y8 = 0.25 x8
9	X_9: point of Gully erosion in BLM model	Y9 = 1.67 x9

3 Results

By calculating drainage density and erosion rate in studied watersheds, the following information was obtained:

Table 2: Relationship between drainage density and erosion in Narghashlaghi watershed.

Erosion types	Area (km^2)	Drainage density (km/km^2)	Erosion ($TON/km^2/Y$)
S_1 R_1	3.97	3.42	129
S_2 R_1 W_1	4.84	1.44	208
S_2 R_2 W_1	12.30	2.89	250
S_2 R_2 W_2	8.04	2.09	249
S_3 R_3 W_2	11.24	1.57	282
S_3 R_3 W_3 M_1	5.11	2.44	375

Table 3: Relationship between drainage density and erosion in Bargchay watershed.

Erosion types	Area (km^2)	Drainage density (km/km^2)	Erosion ($TON/km^2/Y$)
S_3 M_2	7.05	3.88	420
S_4 R_2	10.51	4.76	643
S_2 R_1	10.53	3.32	271
S_3 R_1	5.85	4.02	365
S_3 M_1	11.46	4.75	384

Table 4: Relationship between drainage density and erosion in Siahpoush watershed.

Erosion types	Area (km^2)	Drainage density (km/km^2)	Erosion ($TON/km^2/Y$)
S_3 R_3	33.82	3.33	463
S_2	2.87	2.8	100
S_3 R_3 LS_1	32.03	2.88	63
S_2 R_3 LS_2	14.09	3.4	425
S_3 R_2 W_3 LS_2	7.78	4.42	618
S_3 R_3 W_2 LS_2	6.92	4.56	335

Table 5: Relationship between drainage density and erosion in Saghezchichay watershed.

Erosion types	Area (km^2)	Drainage density (km/km^2)	Erosion ($TON/km^2/Y$)
S_1 R_1	5.86	4.51	130
S_2 R_2 W_1	8.71	2.80	149
S_2 R_1 W_1 M_1	7.41	3.71	171
S_2 R_2 W_2 M_2	16.90	3.84	264
S_3 R_3	19.69	3.22	231
S_3 R_2 W_1 M_2	5.01	3.27	236

Table 6: Relationship between drainage density and erosion in Alucheh-Fuladlu watershed.

Erosion types	Area (km^2)	Drainage density (km/km^2)	Erosion ($TON/km^2/Y$)
S_1	2.62	5.43	103
$S_1 R_1$	16.58	4.23	163
$S_2 R_1 M_1$	5.15	3.18	153
$S_2 R_2 Gu_1$	3.02	4.22	200
$S_3 R_2 W_1$	6.81	5.03	316
$S_3 R_3 W_2 M_2$	2.48	4.21	491

(S: surface, R: rill, W: Channel, Gu: gully, M: mechanical, LS: land slide (mass movement) erosion and numbers present erosion intensity).

First, by the statistical analysis using SPSS software and charting the drainage density and erosion, it was observed that there is not a significant linear relationship between the drainage density and erosion.

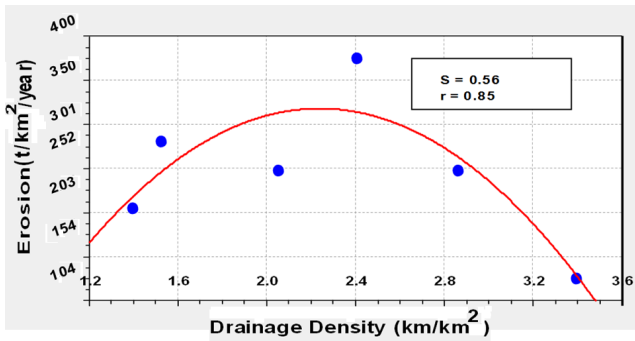

Figure 1: Relation between drainage density and erosion in watershed.

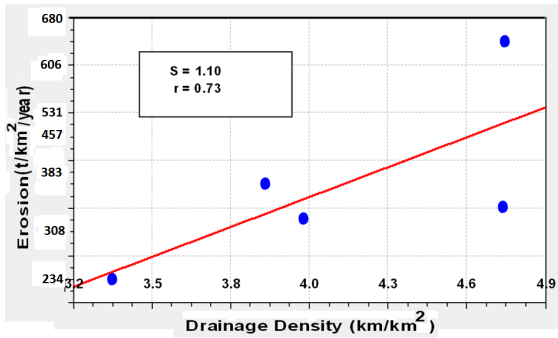

Figure 2: Relation between drainage density and erosion in Bargchay watershed.

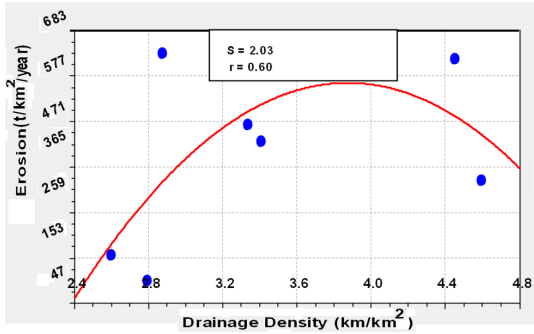

Figure 3: Relation between drainage density and erosion in Siahpoush watershed.

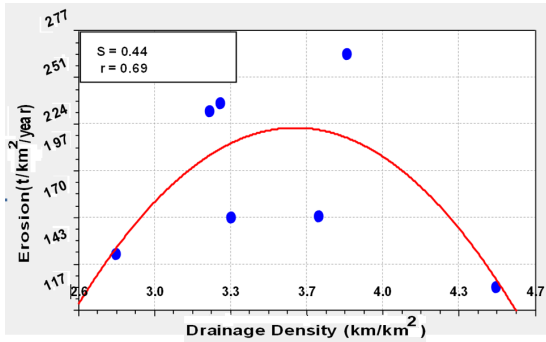

Figure 4: Relation between drainage density and erosion in Saghezchichay watershed.

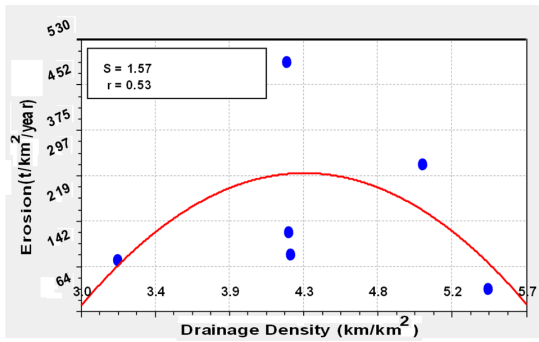

Figure 5: Relation between drainage density and erosion in Alucheh-Fuladlu watershed.

Since there is no relation between drainage density and mechanical, mass and surface erosion, then surface erosion in the Narghashlaghi watershed, surface erosion and weak mechanical in the Bargchay watershed, medium surface erosion and land slide (mass) in the Siahpoush watershed, weak surface erosion in the Saghezchichay watershed, poor surface erosion in the Alucheh-Fuladlu watershed, have not been considered.

With statistical analysis using SPSS software and charting drainage density and erosion, it was observed that the linear correlation between the drainage density and erosion is created.

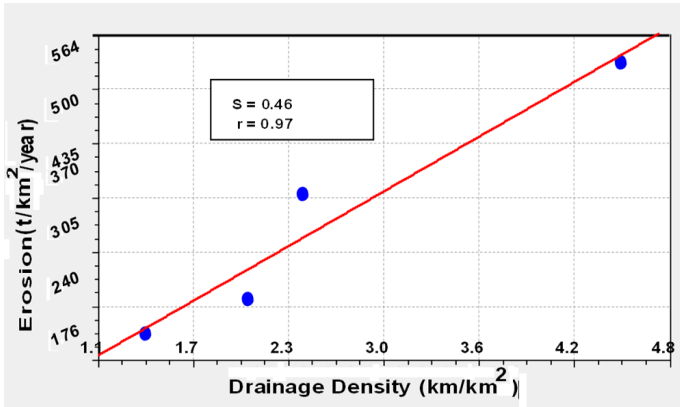

Figure 6: Relation between drainage density and erosion in Narghashlaghi watershed.

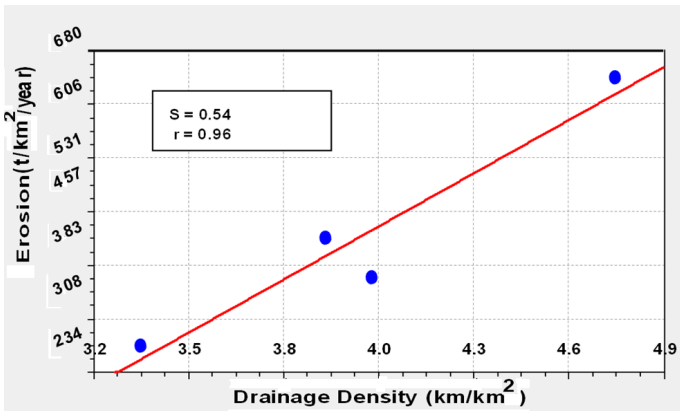

Figure 7: Relation between drainage density and erosion in Bargchay watershed.

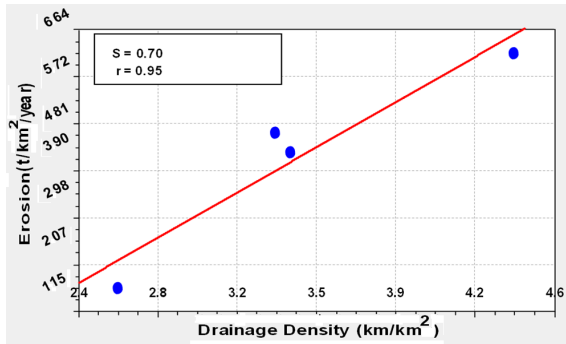

Figure 8: Relation between drainage density and erosion in Siahpoush watershed.

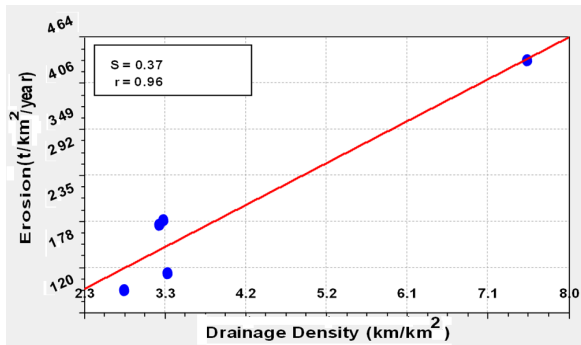

Figure 9: Relation between drainage density and erosion in Saghezchichay watershed.

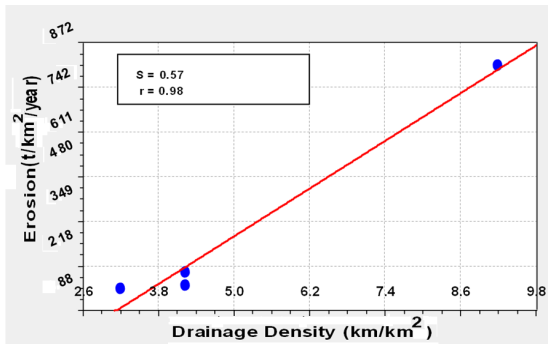

Figure 10: Relation between drainage density and erosion in Alucheh-Fuladlu watershed.

With statistical analysis using SPSS software and charting drainage density and erosion in all watersheds, it was observed that there is a linear correlation between the drainage density and erosion.

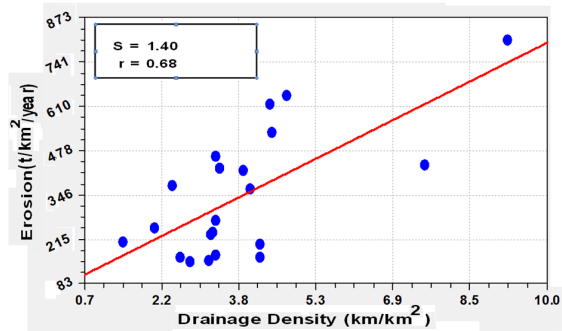

Figure 11: Relation between drainage density and erosion in all mentioned watershed.

4 Conclusion

Drainage density is an important factor that affects erosion process. Therefore, its management can cause erosion control in the region. Drainage density depends on soil type and amount of flow through the channel, that is compatible with results of Germanoski *et al.* [2] who compared the drainage density in areas with different textures (shale, slate) in East Pennsylvania. Drainage density has not any role in the surface, mechanical and mass erosion, because these types of erosion was not be affected by stream. Finally, there is a significant correlation between the drainage density and erosion that corresponds with Ahmadi *et al.* [3] results, which examines the relationship in Sarvelayats watershed. On the other hand; we can estimate the rate of erosion with using of drainage density.

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