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Application of Gully and Rill Erosion Indicators for Estimating Soil Loss Using GIS Techniques (Case Study: Menderjan Watershed, Iran)

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Abstract

The problems of land degradation and soil loss are among the major problems of watersheds in Iran. For erosion and sediment estimation one can use statistical and empirical methods. For doing this, land unit map and the map of effective factors should be prepared. For erosion and sediment estimation one can use statistical and empirical methods. However, these empirical methods are usually time consuming and do not give accurate estimation of erosion. In this study, we applied GIS techniques to estimate erosion and sediment of Menderjan Watershed at upstream of Zayandehrud River in central part of Iran. Erosion features of each land unit were defined on the basis of land use, geology and land unit maps using GIS. The UTM coordinates of each erosion type with higher erosion intensities such as rills and gullies were inserted in GIS using GPS data. The frequency of erosion indicators of each land unit, land use and sediment yield of these indices were calculated. Also by using sediment yield changes in watershed outlet (hydrometric station), the effective parameters in sediment production were identified. The results of this study can be used for more rapid and more accurate estimation of erosion than traditional methods. These results can also be used for regional erosion assessment and can be applied by using remotely- sensed data.

***Keywords**:* Erosion and sedimentation; Rill; Gully; GIS; Menderjan Watershed; GPS-based measurement

1. Introduction

Erosion by water is a primary agent of soil degradation at the global scale, affecting 1094 million hectares, or roughly 56% of the land experiencing human induced degradation (Oldeman et al., 1991 and Hoyos, 2005). Soil erosion is the most important limitation for the sustainable development, optimal land and water management and development. The understanding of the most important factors on soil erosion and sediment yield are the main keys for decision making and planning.

Soil erosion has been recognized as the major cause of land degradation world wide.In the past decades, priority of research has been given to address agricultural issues at the plot scale and thus to rill and inter-rill erosion (Valentin et al, 2005). This is explained by an increasing concern for off-site impacts of soil erosion that can be tackled only at the catchment scale. It is now well recognized that increased exploitation of land resources in the upper parts of catchments results in increased sediment yield and elevated nutrient loads in runoff that reduce water quality and availability to downstream users. Furthermore, control of sedimentation in reservoirs requires that

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all the potentially significant sediment sources and sinks are known. Recent studies (e.g., Wasson et al., 2002; Krause et al., 2003; de Vente et al., 2005; Huon et al., 2005) indicate that gully erosion is often the main source of sediments. Gully erosion has been long neglected because it is difficult to study and to predict.

In recent years, most of the regions in the world are exposed to degradation and erosion caused by increasing population and over use of land resources. Logan et al., (1982) expressed the need for quantifying soil erosion processes and factors as an essential task for investigation. Land cover, soil conservation practices, and the presence of soil erosion control measures all influence actual soil loss. Land users can modify all of these. Measuring erosion is costly and time consuming whereas results may be conditioned by single events such as rain storms (Hudson, 1995); Lal (1994a) called it an art rather than a science. Calibration requires soil loss data from the full range of field situations for which the model will be applied. In practice, calibration is often based on data from few runoff plots with or without use of an artificial rainfall simulator (FAO, 1993), and/or on data from sites in other environments and/or measured according to nonstandard techniques (Lal, 1994b, 2001). All of these limit the predictive capacity of soil erosion models (de Bie, 2005). Monitoring schemes based on field measurement and the estimation of the volume of rills and gullies in a time span such as several years, are necessary in order to assess erosion at the landscape scale (Poesen et al., 1996).

Gully erosion is a serious problem in many parts of the world, and particularly in the Mediterranean basin, because of climate, lithology, soils, relief and land use/cover characteristics. The causes, processes, prediction and control of gully erosion have aroused the interest of many researchers in different countries.. Most research has been addressed to analyze gully morphology and the stages of gully development as a first step in evaluating gully processes and assessing the potential for gully erosion. Gully erosion modeling has focused more on development of qualitative and empirical–statistical models than in the formulation of physically based models (Bocco, 1991). Most recently, with the aid of digital elevation modeling, research has been addressed to predict the threshold contributing area and/or other topographic effects and limits on the initiation, distribution and location of ephemeral gullies in different conditions (Marti nez-Casasnovas, 2003).

First studies on gully erosion goes back to 1960 in the United States of America, and then other studies in some countries such as Spain, Japan, etc have been performed (Ahmadi et al, 2008). Ghoddusi (1994) has described that main effective factors in creation and development of gullies (in case study of Sarcham region in Zanjan province, Iran) are: Dissolved materials of soil, concentration of surface runoffs, soil properties, precipitation intensity, vegetation cover, geological formations, soil type and land use. Harley and Ronalds (1999) used digital data and three series of aerial photos in two regions in New Zealand and determined average gully growth about 0.73 to 0.01 meters per year.

Application of GIS techniques in the study of erosion in watershed has high potential for decreasing computer time used and increasing accuracy of the sediment and erosion estimation. (Nasri et al, 2006).

The aim of this study is estimating volume of transported soil from gullies and rills using positioning by GPS and GIS techniques in order to distinguish and manage the critical erodible areas in the catchment. Also in this study the potential of error related to evaluation of soil loss volume of gullies and rills that can affect these measurements in general is considered.

2. Materials and Methods

2.1. Study area

The study area is Menderjan Watershed located in Esfahan Province with coordinates, 50°, 27´ to 50°, 40´ eastern longitude and 32°, 45´ and 32°, 57´ northern latitude, having 229.44 sq km areas and altitude ranging from 2060 m to 3639 m (average elevation of 2396 m) above sea level, and is located 120 kilometers west of Esfahan city near Zayandehrud Dam Lake. The villages of the watershed are Aliarab, Marufabad, Ghergherehe, Samandegan, Analujeh, Mansurieh, Menderjan and Rozveh. The location of the studied area in Esfahan province and Iran is shown in Figure 1.

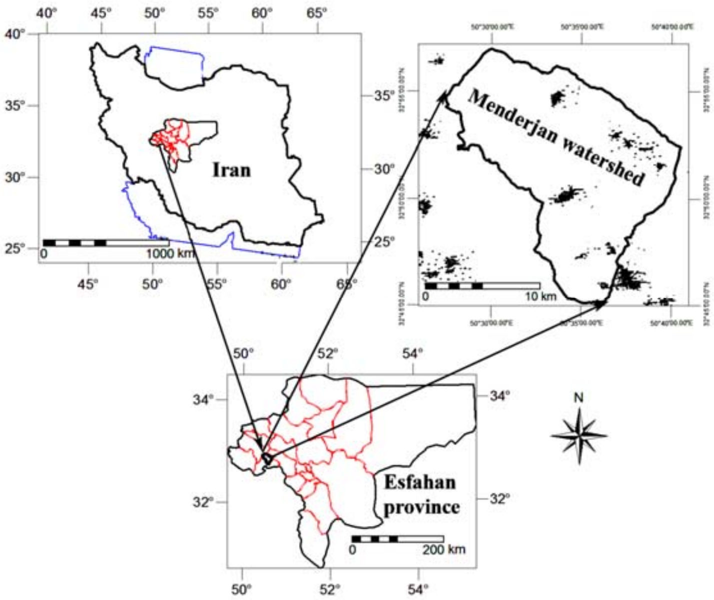

Fig. 1. The location of the studied area in Esfahan province and Iran

Some of the physical characteristics of the studied area are described below. Average slope is 12.67%, most important land uses are:Rangelands (43.21%), rainfed farming lands(6.59%), irrigated lands (20.65), rainfed and rangeland mixture (20.55%), arbor lands (0.78 %) and stone cover (7.27%), cultivated crops are barley, wheat, potato and forage plants and cereal. Average annual precipitation is 362 mm, volume of annual water discharge 83.8 MCM, average temperature 8.7º C.

Geological formations of the area are mainly alluvial terraces and marly units and in the mountainous parts Lower Cretaceous limestone formations are dominant (Fig. 2).

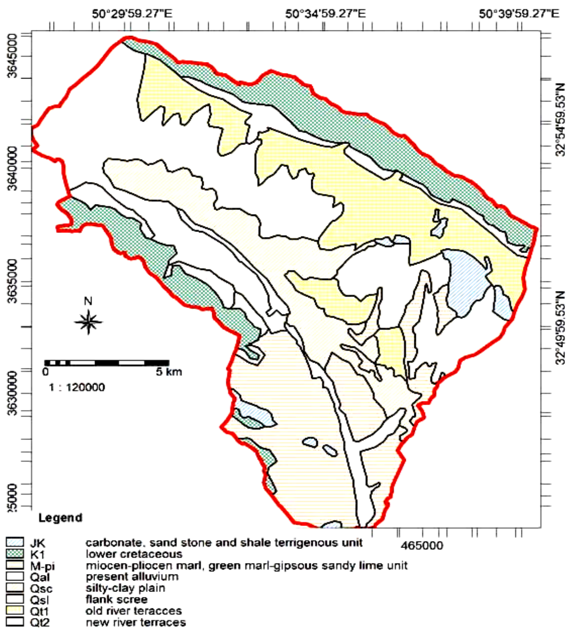

Fig. 2. Geology map of study area

2.2. Methods

There are many indicators that are in use in estimating soil loss related to erosion types in the field assessments, such as rills, gullies, pedestal, armoured layer, tree mound, plant/tree root exposure, rock exposure, sediment in drains etc (Vigiak, 2005 a,b and Stocking, Murnaghan, 2001) . The most prominent erosion features in the studied area are rill and gullies, therefore in the next sections only these indicators will be described (Fig. 3).

1

2

Fig. 3. A view of rill (1) and gully (2) in the study area

In this study by using field surveying and many observations, measurements of gullies, rills, and pedestals were recorded.
We used GPS for determining s rill and gully position for distinguishing their locations on topographic map and drainage network map in GIS which was used for calculation of basin area y of each rill or gully and extraction of the needed data and maps. In the field surveying the dimensions (width, length, depth etc in various sections) of rills and gullies using meter, ruler, tiltmeter, etc., were measured.

Rill: A rill is a shallow linear depression or channel in soil that carries water after recent rainfall. Rills are usually aligned perpendicular to the slope and occur in a series of parallel rill lines.
Gully: A gully is a deep depression, channel or ravine in a landscape, looking like a recent and very active extension to natural drainage channels. Gullies may be continuous or discontinuous; the latter occurs where the bed of the gully is at a lower angle slope than the overall land slope.
Calculations steps of soil loss from rill and gully are shown in Tables 1 and 2.

Table 1. Steps of rill calculations

(1) Covert the average width and depth of the rill to meters (by multiplying by 0.01). Thus, an average horizontal width of 12cm is equal to 0.12m and an average depth of 4.2cm is equivalent to 0.042m.
(2) Calculate the average cross-sectional area of the rill, using the formula for the appropriate cross-section: the formula for the area of a triangle (i.e. ▯ horizontal width x depth); semi-circle (1.57 x width x depth); and rectangle (width x depth). Thus, assuming a triangular cross-section it is:
[ ] x WIDTH(m) [ ] x DEPTH(m) [ ] = CROSS-SEC AREA [ ]
(3) Calculate the volume of soil lost from the rill assuming that the measurements above were taken from a rill measuring 2.5 meters in length.
CROSS-SEC AREA (m2) [ ] x LENGTH (m) [ ] = VOLUME LOST [ ]
(4) Convert the total volume lost to a volume per square meter of catchment.
VOLUME LOST (m2) [ ] ÷ CATCHMENT AREA (m2) [ ] =SOIL LOSS(m3/m2) [ ]
(5) Convert the volume per square meter of catchment.
SOIL LOSS (m3/m2) [ ] x BULK DENSITY (t/m3) [ ] x [10000] =SOIL LOSS(t/ha) [ ]

Table 2. Steps of gully calculate-0-0ons

(1) Calculate the average cross-sectional area of the gully, using the formula (w1+w2)÷2 x d.							
	(AV WIDTH W1 + AV WIDTH W2)		x DEPTH(m)		= CROSS-SEC AREA		
(2) Calculate the volume of soil lost from the gully assuming that the measurements above were taken from a gully measuring 200 meters in length.							
CROSS-SEC AREA		x LENGTH (m)		= VOLUME LOST			
(3) Convert the volume lost to a per meter equivalent, assuming a catchment area of 1 km2, or 1,000,000 m2.							
VOLUME LOST		÷ CATCHMENT AREA (m2)		= SOIL LOSS (m3/m2)			
(4) Convert the volume lost to tones per hectare over the whole catchment area.							
SOIL LOSS (m3/m2)		x BULK DENSITY (t/m3)		x	10000	= SOIL LOSS	t/ha

3. Results

3.1. Preparing erosion facies map

Using aerial photo interpretation, topographic map data, satellite images and also field surveying of all watershed surfaces, erosion type/facies map was prepared.

It was obvious that although sheet erosion is dominant according to its indexes (such as pedestal, armour layer, plant root exposure, rock exposure, soil color change, etc.) in the watershed, but with regard to the aim of this paper, rill and gully indexes are more important from the view point of soil loss volume and they are representative of rapid land use changes and intensive and over capacity usage of natural resources in recent decades in the watershed. In table 1 the area of each erosion feature is shown, so, gully and rill effected area are 28.31 and 24.93 sq km respectively.

By field surveying the data were recorded for 28 gullies and 90 rills. Then the volume and weight of transported soil by gullies and rills were calculated separately (Fig. 4).

3.2. Field measurements of soil loss assessment from gully and rill

According to calculation steps that mentioned above, the volume of soil loss was calculated. These are shown in Tables 3 and 4 for some gullies and rills of the catchment.

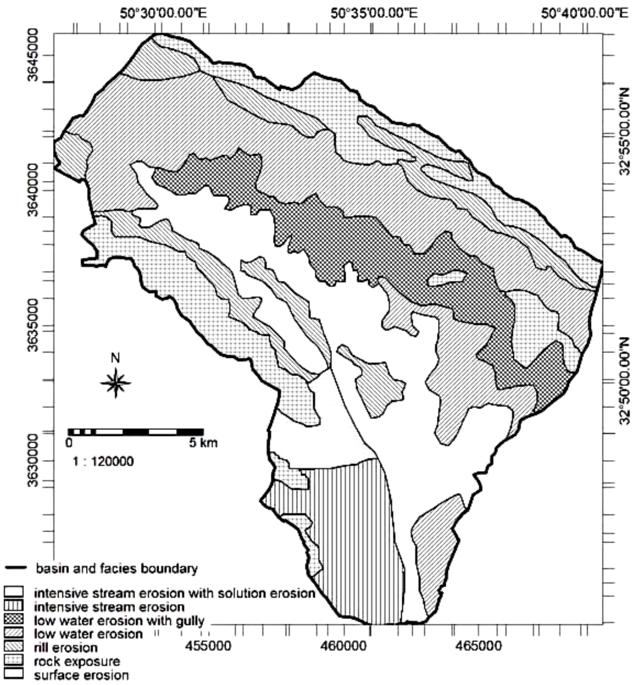

Fig. 4. Erosion form map of the studied area

Table 3. erosion type/facies in Menderjan watershed

erosion type/facies	Area (sq km)	Area (%)
rock exposure	38.38	16.73
rill erosion	24.93	10.87
low stream erosion with gully	28.31	12.34
low stream erosion	63.49	27.67
sheet erosion	47.74	20.81
intensive water erosion with solution erosion	7.39	3.22
intensive water erosion	19.19	8.36
total	229.44	100

Table 4. Characteristics of some gullies in the catchment (bulk density=1.3)

Gully No.	coordinate(UTM) by GPS		Length (m)	Slope %	sections	Up width (cm)	Middle width (cm)	Down width (cm)	Depth (m)	basin area (ha)	volume of transported soil(m^3)	weight of transported soil(ton)
	latitude	longitude				in two sections						
1	453485.15	3641101.9	572.09	6	sec. 1	150	100	70	110	80	571	742
					sec. 2	130	70	50	100			
2	454155.3	3641375.35	942.44	6	sec. 1	420	220	100	300	86	4,354	5,660
					sec. 2	280	200	100	120			
3	454622.01	3641323.5	418.89	6	sec. 1	100	75	60	120	166	449	584
					sec. 2	150	80	50	130			
4	455269.88	3640750.87	434.12	5	sec. 1	120	80	60	110	99	349	454
					sec. 2	100	60	40	100			
5	455919.29	3640643.86	368.24	5.5	sec. 1	150	100	80	170	102	566	736
					sec. 2	120	90	75	130			
6	455919.29	3640643.86	418.76	6.8	sec. 1	120	100	60	70	113	484	629
					sec. 2	220	170	100	110			
7	455919.29	3640643.86	599.7	6.8	sec. 1	85	60	50	100	113	478	622
					sec. 2	100	80	60	120			
8	456699.58	3640014.7	465.83	6	sec. 1	160	88	62	130	151	522	678
					sec. 2	130	70	50	110			
9	456778.93	3639988.48	275.69	6	sec. 1	260	200	160	180	205	860	1,118
					sec. 2	200	120	100	180			
10	458266.57	3641795.98	564.74	7.2	sec. 1	150	110	100	160	32	797	1,036
					sec. 2	100	80	65	120			
11	457444.84	3639410.16	496.81	3.5	sec. 1	85	65	40	100	63	363	472
					sec. 2	100	78	50	110			
12	457680.19	3639162.85	431.83	6	sec. 1	130	100	80	150	43	495	643
					sec. 2	95	80	65	100			
13	458414.16	3638223.24	875.53	3.5	sec. 1	90	80	60	110	644	958	1,245
					sec. 2	110	90	75	150			
14	460168.63	3637307.57	531.76	7.1	sec. 1	130	100	80	150	93	622	809
					sec. 2	100	80	50	110			
15	461398.88	3635891.07	471.22	3.6	sec. 1	120	90	65	130	62	654	850
					sec. 2	140	100	80	150			
16	461355.01	3635418.17	604.87	2.5	sec. 1	150	100	75	110	59	609	791
					sec. 2	120	80	50	100			
17	463445.46	3638274.54	174.9	8.2	sec. 1	250	150	90	170	11	541	703
					sec. 2	300	220	150	150			
18	467617.1	3634894.76	612.59	7.1	sec. 1	290	200	100	76	388	1,030	1,339
					sec. 2	260	175	60	110			
19	450072.14	3641774.13	112.99	8.5	sec. 1	220	160	90	140	11	199	259
					sec. 2	180	160	70	100			
20	450064.64	3641674.51	160.32	8.5	sec. 1	200	150	70	70	7	122	158
					sec. 2	180	100	60	50			
21	450230.98	3641860.88	133.38	8.1	sec. 1	250	180	80	120	4	198	257
					sec. 2	180	130	70	80			
22	450144.67	3641480.81	135.49	9	sec. 1	210	170	110	170	5	238	309
					sec. 2	110	100	80	100			
23	450221.65	3641356.75	173.04	8.6	sec. 1	260	200	160	180	15	540	702
					sec. 2	200	120	100	180			
24	450658.97	3641180.15	365.77	8	sec. 1	100	70	50	100	12	315	410
					sec. 2	110	80	60	120			

Table 4. Continued

Gully No.	coordinate(UTM) by GPS latitude	coordinate(UTM) by GPS longitude	Length (m)	Slope %	sections	Up width (cm)	Middle width (cm)	Down width (cm)	Depth (m)	basin area (ha)	volume of transported soil(m^3)	weight of transported soil(ton)
						in two sections						
25	450034.87	3640999.73	238.81	6.1	sec. 1	260	200	160	180	4	745	969
					sec. 2	200	120	100	180			
26	451778.05	3641143.33	633.39	3.8	sec. 1	150	120	80	100	35	963	1,252
					sec. 2	170	140	100	140			
27	450002.96	3640872.08	159.21	6.3	sec. 1	250	180	150	160	2	396	514
					sec. 2	200	175	110	120			
28	450617.26	3640098.22	728.57	7.5	sec. 1	80	60	50	100	35	535	696
					sec. 2	95	70	65	110			
sum	-	-	12100.98	-	-	-	-	-	-	2,637	18,954	24,640

sum length of all observed gullies=12100.98 m
sum volume of transported soil by the gullies=18954 m^3
sum weight of transported soil by the gullies=24640 ton

It is important to note that the above mentioned values of volume and weight of soil loss is related to time length of gully generation not for one year that it can not be used use for calculation of average annual soil loss.

About rills in the catchment, it was recognized that the sum of soil loss related to rills is 2691 m^3 which is equal to 3499 ton in the time of rill generation.

Sum length of rills in the catchment is 23991 m which was calculated using GPS coordinate in the beginning and end of several cross-sections across the rill in the field measurements.

According to various measurements in the field and calculations, the average depth of rills was 17cm (centimeter) and average width of them was 66 cm. Average basin area of rill is about 2000 m^2 that has been calculated in the field by tools such as meter and assessment estimations using width and length and their figures in the nature by mathematical methods, however using GIS techniques can be more precise and correct these assessments (Fig. 5).

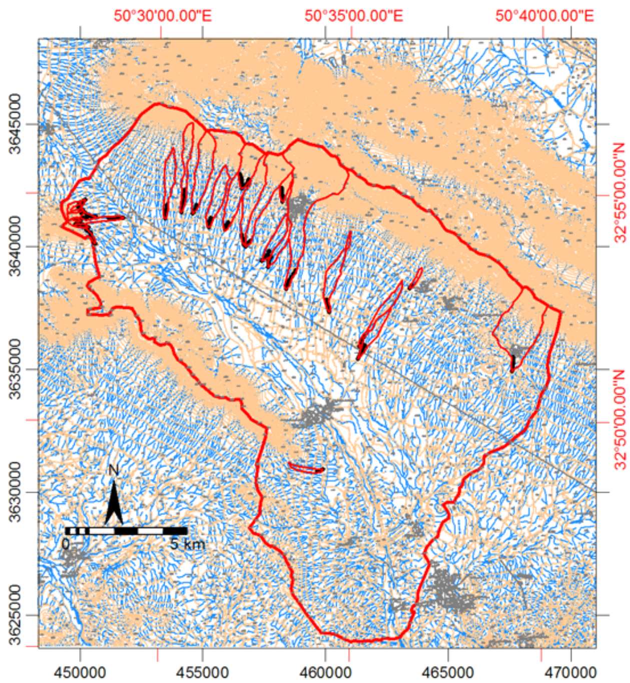

Fig. 5. Location map of gullies and their basin areas

3.3. Statistical relationships of gully field measurements

In this part, based on gully properties, especially soil loss calculations from them, statistical relationships between physical characteristics of gullies were obtained. This is shown in Figure 6.

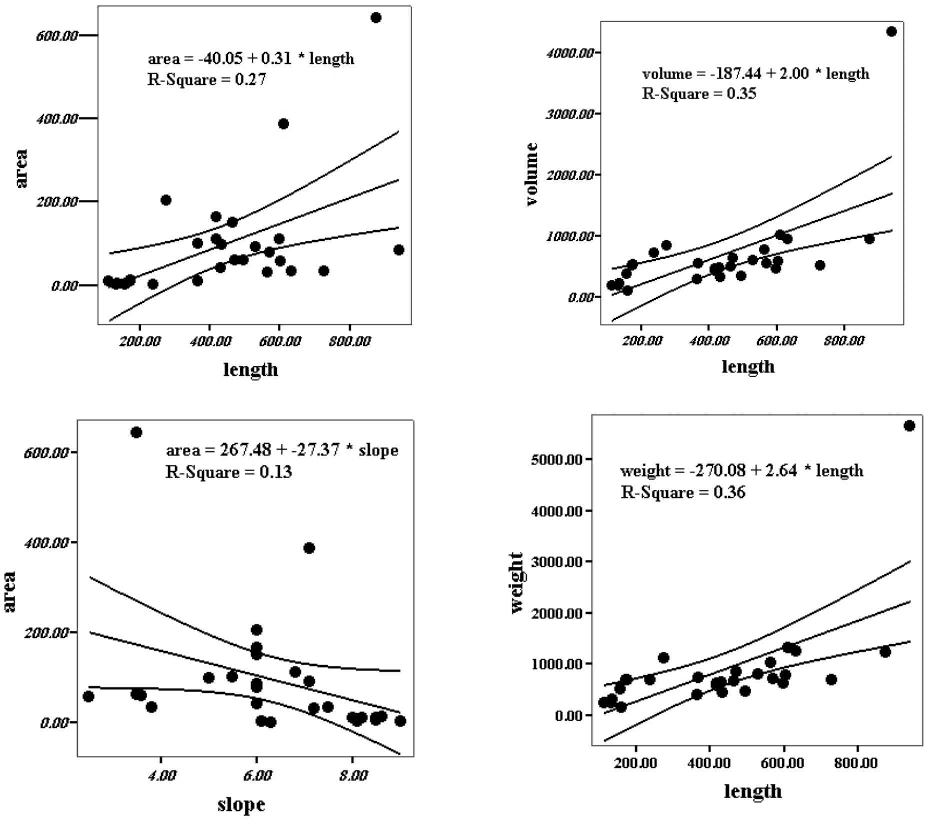

Fig. 6. Relationship between gully physical properties (Volume in cubic meter, length in meter, area in hectare, weight in ton and slope in percentage)

4. Discussion and conclusion

Because of important role of soil loss determination in natural and agricultural lands in order to obtain sustainable management of those areas for land use system improvement, this study investigated some soil loss indicators such as gully and rill using GPS, GIS and field measurements. These indices not only show erosion rate in catchment but also show sediment yield that is transported downstream. Measurement in catchment helps to propose a suitable model for estimating erosion and sediment yield. With using these kinds of results, the empirical methods of erosion assessment can be improved to give more precise estimations and provide regional models. The linear regression model shows that the length of the gully is directly related to the area of the gully basin. However this relationship is not very strong in the studied are, having very low correlation coefficient (R2=0.27). On the other hand, the slope of the gully shows inverse, but small (R2=0.13) relationship to the basin area. Therefore, it is excepted that the relationship between soil weight and volume loss is directly related to the length of the gully which represent the volume of the gully.

However, if the mentioned field measurements are combined with other indices of erosion and sediment yield, using satellite pictures and remote sensing techniques, the method will be improved greatly (Feiznia et al, 2002).

It is important to mention the potential of error because of the nature of field studies and recording data of various effective factors that some of them may not be known yet. With this point of view, some of potential errors about gullies and rills measurements are described below:

1) Gullies very often visually dominate the landscape. Many conservation schemes erroneously focus on the gully, rather than the reason for the gully development. It is easy to forget that sheet erosion is likely to be ongoing and probably being more important in total sediment production.

2) Care needs to be exercised in measuring the catchment for gullies in order to make assessments of soil loss per hectare. In particular, the contributing area providing runoff decreases as the gully head extends up valley. Large gullies can be assessed from aerial photography or even maps.

3) Where rill erosion is evident, this is not the only form of erosion occurring. Rills are merely a visible symptom of sheet erosion. Therefore, it is important that any measurement of soil loss from a rill should not be treated as the total amount of soil loss from a particular area. The rill is indicative of the poor state of the immediate catchment of the rill, and wherever feasible, field assessments of soil loss due to sheet erosion should be made. Experience indicates that the soil removed from the rill is usually only a small fraction of the total soil loss from the catchment of the rill. This may not be the case if there is a dense network of rills.

4) Averaging cross-sections down the length of the rill, and then multiplying by the length of the rill, will give only an approximation of total volume, the more cross-sections measured and the closer the measurements are to the actual shape of the rill, the more accurate will be the rill erosion estimate.

According to gully investigation in the studied watershed, it can be said that:

a) Under many circumstances gully erosion is the main source of sediment at the catchment scale.

b) Gully erosion is most often triggered or accelerated by a combination of inappropriate land use and extreme rainfall events.

c) Once gullies formed, they can continue to generate sediment long after the triggering causes have ceased.

d) Although many strategies to prevent and combat gully erosion have proved to be effective, they are rarely adopted by farmers in the long run and at a large scale.

e) Research priorities should include subsurface erosion processes, prediction models, and the causes of adoption or not adoption of conservation strategies by the farmers.

f) A global research network should be established to assess the global state of gully erosion and to monitor gully erosion in the selected long-term bench mark sites (Valentin et al, 2005).

On the other hand, according to the landforms that are shaped in regional scale, it is necessary to consider the potential of error and reduction of this error using more precise methods such as GIS techniques. In this point of view, it can be expressed that in data recording in rills and gullies, RS and GIS techniques should be used for more reliable data gathering.

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