

Factors Controlling the Morphology and Volume –Length Relations of Ephemeral Gullies in the Western Arid Regions of Iran

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Received: 26 January 2014 / Accepted: 29 December 2014 / Published Online: 13 April 2015

ABSTRACT Understanding the development of gully volumes requires the empirical relations between gully volume (V) and length (L) to be established in the field. So far, such V–L relations have been proposed for a limited number of gullies/environments and were especially developed for ephemeral gullies. In this study, V–L relations were established for ephemeral gullies in southern Ilam. In order to take the regional variability in environmental characteristics into account, controlling factors of gully cross-sectional morphology were studied for 90 cross-sections. The results indicated that the soil properties were the most important controls of gully cross-sectional shape and size. Cross-sectional size could be fairly well predicted by their drainage area. The V–L relationship for the complete dataset was $V=15.45 L^{0.12}$ ($n = 90, R^2=0.06$). In addition, gully volume was also related to its catchments area (A) and catchment slope gradient (S_c). This study demonstrated that the V–L and V–A× S_c relations were not suitable to assess ephemeral gully volume.

Key words: Dehloran, Gully morphology, Gully volume, Permanent gullies

1 INTRODUCTION

Gully erosion is one of the important forms of soil degradation especially in semi-arid areas. Gullies are occupying 13 percent of Ilam province area (Nourmohammadi *et al.*, 2008). Gully is defined as an erosion channel with cross-sectional area of more than 1 ft² (929 cm²) (Poesen *et al.*, 1996) that cannot be obliterated by conventional tillage (FAO, 1965). Contribution of gully erosion to total sediment yield in the watershed scale varies between 10 and 94% (Poesen *et al.*, 2003). Below this threshold value of the cross-sectional area, the channel is classified as rill. The volume of gullies shows the contribution of

gully erosion in sediment yield (Kompani-Zare *et al.*, 2011). Gully erosion is extended on an area larger than 500 km² across Fars Province, Southwest of Iran (Soufi, 2004). Field observations carried out in a variety of agricultural environments over the last decade indicate that, besides interrill and rill erosion, gully erosion is often an important sediment source (Di Stefano and Vito Ferro, 2011).

Prediction of gully volume by indirect methods is preferred by researchers (Nachtergaele *et al.*, 2001a, b; Capra and Scicolone, 2002; Capra *et al.*, 2005; Zucca *et al.*, 2006). Nachtergaele *et al.* (2001a, b) in their researches in Portugal and Spain, and

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Capra *et al.* (2005) in Italy used EGEM (Ephemeral Gully Erosion Model) and multiple regression analysis to predict the volume of gully erosion and find the most important factors of An ephemeral gully (EG) can be defined as a channel of different sizes, which is mainly located in natural drainage lines (thalwegs of zero-order basins or hollows) or along (or in) linear landscape elements such as, for instance, dead furrows coinciding with parcel borders, tractor tracks, unpaved access roads, and so on (Poesen *et al.*, 1996). These erosion features are continuous, temporary channels, which are often refilled by tillage equipment normally used on farms (Casali *et al.*, 1999, 2006; Capra and Scicolone, 2002; Poesen *et al.*, 2003; Capra *et al.*, 2009). The relationship between the gully's cross-sectional area and the gully length has also been studied by Nachtergaele and Poesen (1999). The effect of soil and watershed characteristics, surface slope, and season on ephemeral and deep gullies' characteristics including gully volume and length was investigated (Morgan, 2005; Wanwalleghen *et al.*, 2005; Zhang *et al.*, 2007; Nazari Samani *et al.*, 2009).

The formation of EG cross section is controlled by several factors (Vandaele *et al.*, 1996) such as the rainfall intensity, size of the watershed, morphology of zones of runoff concentration and so on (Di Stefano and Vito Ferro, 2011). The maximum width that the EG can assume, named Final width, depends on the magnitude, the gradient and the critical value of the soil shear stress (Frankl *et al.*, 2013).

Capra *et al.* (2005) in Italy used EGEM (Ephemeral Gully Erosion Model) and multiple regression analysis to predict the volume of gully erosion and find the most important factors of watershed and gully morphology. They also evaluated the performance of EGEM in prediction of gully erosion. Both authors believe that empirical model predictions show a better agreement with observations than those

of EGEM. Capra *et al.* (2005) in a research in Sicily, Italy showed that EGEM overestimated the volume of gully erosion. Overestimation of gully volume by EGEM has been reported by Nachtergaele *et al.* (2001a, b) in Spain and Portugal. The following empirical power equation was determined between the volume of gully erosion, "V" (m³), and length, "L" (m), by Capra *et al.* (2005):

$$V = 0.0082 L^{1.416} \quad R^2 = 0.64 \quad (1)$$

They found that the simple empirical equation showed a better performance in predicting the amount of erosion than EGEM. The relatively high coefficient of determination suggests a strong relationship between gully volume and length. Capra *et al.* (2005) used multiple regression analysis to relate gully volume, as a dependent variable, to watershed area above the heads, watershed length and slope, gully length and slope, 24-h rainfall, three days of Antecedent moisture and 37 mm threshold rainfall. They revealed that only the gully length and 24-h rainfall correlated with the volume of gully eroded as follows:

$$V = 10^{-4.91} L^{1.557} r_{24h}^{1.327} \quad R^2 = 0.72 \quad (2)$$

Where V is gully volume, L is gully length and r_{24h} is the 24-h rainfall

Comparing this relationship with previous researches indicates that there is a little improvement in the coefficient of determination. It underlines the importance of gully length for prediction of the volume of gullies (Kompani-Zare *et al.*, 2011).

Zucca *et al.* (2006) showed the relationships between the length and volume of gullies on the log-log graph. They concluded that the value of exponent "b" is greater than 1 and is similar to the one obtained by Nachtergaele *et al.* (2001a, b) with the quantity equal to 1.12. They

believed that “b” values greater than 1 correlate with the larger cross-sectional area of the long gullies. Their field observations revealed that the shape of the gullies was controlled by geological substratum. They grouped the gullies based on their geology and soil erodibility and presented two equations as follows:

$$V = 0.390L^{0.92} \quad R^2 = 0.57$$

Coarse grain granite (3)

$$V = 0.114L^{1.42} \quad R^2 = 0.76$$

Colluvial deposit. (4)

For gullies on coarse grained granite, the value of exponent “b” is near 1. This indicates that on granite, the cross-sectional area is constant. This was explained by the fact that the gully depth was limited by the presence of bed rock. The second equation for colluvial deposit was not affected by the bedrock presence; therefore, the value of exponent “b” is greater than 1. The relationship between the gully's cross-sectional area and the gully length has also been studied by Nachtergaele and Poesen (1999). The relationship between the gully length and volume and the effect of watershed characteristics and surface slope on it were investigated (Casali *et al.*, 1999; Nachtergaele and Poesen, 1999; Nachtergaele *et al.*, 2001a; Zhang *et al.*, 2007).

Prediction of gully volume and cross-sectional area based on the gully length is due to the fact that the gully length can be easily determined in aerial photographs (Kompani-Zare *et al.*, 2011).

The length of the gullies can also be easily determined on the satellite images. Unlike these two variables, the cross-sectional area of the gullies cannot be easily determined using aerial photographs or satellite images (Frankl *et al.*, 2013). It is therefore interesting to investigate the effect of geometric variables of gully on the relationship between the gully volume and

cross-section and the gully length (Kompani-Zare *et al.*, 2011).

In the case of ephemeral gullies, Poesen (1992) reported that the cross-sectional width/depth ratio (determined in the field) is mainly controlled by the thickness and resistance properties of the soil horizons. Knowing the average cross-section of ephemeral gullies for a specific area, in combination with their length, allows their volume to be calculated (e.g. Vandaele *et al.*, 1997; Nachtergaele and Poesen, 1999). Several authors explored the relationship between gully volume (V) and gully length (L). As a result, a number of power relations of the type $V = aL^b$ were proposed, that generally closely fit the datasets (e.g. Nachtergaele *et al.*, 2001a; Capra *et al.*, 2005; Zucca *et al.*, 2006; Zhang *et al.*, 2007; Kompani-Zare *et al.*, 2011).

Such relations reflect the fact that, when gullies increase in length, their volume increases by a power function, which the consequence of gullies is becoming deeper and wider as their catchment size increases downslope (Frankl *et al.*, 2013). The coefficients ‘a’ and ‘b’ reflect environmental characteristics (soil, lithology, land-use, and climate) that determine gully cross-sectional shape. To our knowledge, most studies established V–L relations for ephemeral gullies and did not consider permanent gullies. For the latter, larger values for the exponent ‘b’ can however be expected as ephemeral gullies are often reported as having a more or less constant cross-sectional area (CSA) (e.g. ‘winter gullies’ in Nachtergaele *et al.*, 2001a). In addition to V–L relations, which allow gully volume from their length to be calculated, our interest was also to investigate the relationship between gully volume and catchment area (A), as the latter is the only parameter that can easily be derived from a topographical map.

In this survey, the authors determined the relationship between gully volume and gully

morphometric characteristics to establish Volume-Length (V-L) and Volume–Area (V-A) relations for gullies in Dehloran region in Ilam province, western part of Iran.

2 MATERIALS AND METHODS

The study area located in southern part of Ilam Province, Iran which has 1200 ha area (Figure 1). Elevation range between 180 and 350 m above sea level.

The study area is located in the Zagros Folded zone. The oldest formations in this area are belonging to the Mesozoic and the Cretaceous period. In the period the Sarvak, Surgah and Gurpi formations formed and Then Pabdeh, Asmari, Gachsaran, Aghajari and Bakhtiari in Tertiary is comprised. A large part of the area has constituted of Quaternary alluvial deposits. According to coupon classification the climate of the region is considered dry climate with hot summers. The average of annual precipitation, evaporation is 264.4 mm and 3117 mm and the average annual temperature is 31.4 °C (Nourmohammadi *et al.*, 2008). Since the Dehloran region is arid region, so in the growth of vegetation and climate is a part of Iran and Turan. The difference in elevation is an effective factor that causes climate changes and leads to land cover diversity. Generally, due to the particular circumstances of ecology the study area in terms of vegetation and potential production is among the poor pastures. Because of high temperatures, high evaporation and

precipitation of 250-200 mm per year the fragile condition of pastures and ranges have been established. On the other hand, Excessive and uncontrolled grazing and also land use changes have effective role in this case. This is caused by the loss of vegetation cover that could have negative effect on environment equilibrium. The vegetation cover of the area are made up of permanent crops, mostly plants, shrubs and grasses, but in some parts the range of shrubs and larger trees to be seen.

2.1 Data collection

In this study spatial distribution of the gullies was determined by experienced experts from aerial photos on a scale of 1:40000. The selected gullies were used for fieldwork that involved their monitoring and measurement. These gullies had typical characteristics for climate, geological formation, vegetation and soil in each region. The selected gullies also had similar shape (Capra *et al.*, 2009). In total 30 gullies were selected (Figure 2). For each gully, three sections from the upper, middle and lower parts of the channel at spaces of 1 to 2 meters in length were determined. The sections were marked with wooden pegs on both sides (Sadeghi *et al.*, 2008). Different morphological factors of the gullies were identified including upper and lower width, depth, distance between sections, head cut height, distance of head cut, gully length, and slope of banks were measured using a thread scaled with 25 cm intervals tied to wooden pegs (Figure 3).

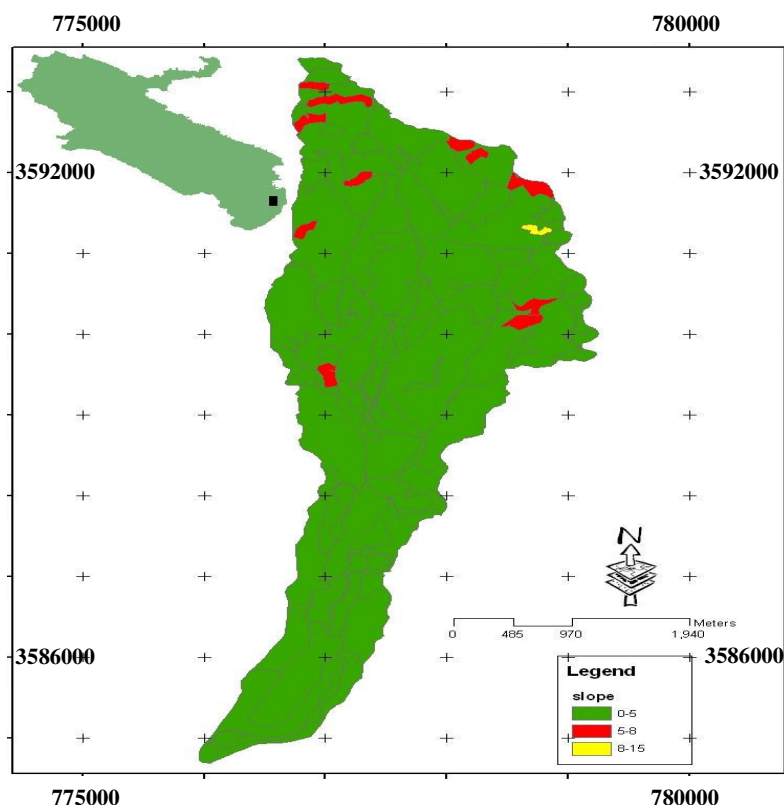


Figure 1 Study area in Ilam Province

The factors were measured for each gully. Each cross section was depicted and calculated using Auto CAD version 14. The next stage, was a calculation of the difference of area, it was calculated in Excel version 2003 and multiplied to the length between the cross section to compute the volume. Soil factors for each gully were determined from two samples, one of the surface horizon (0-50 cm) and the second of the sub-surface horizon (>50 cm) measurements were taken in the lab (Table 5). Soil texture was identified by a hydrometer, acidity of saturated soil by a pH meter model 744, and hydraulic conductivity was determined by an EC meter Jenway model of 3310. Moisture percentage of the saturated soil was determined by the weighted method, amounts of sodium and potassium in the saturated soil was evaluated by flame Photometry, and the amount of calcium

was quantified by the titration method then ratios of sodium adsorption were calculated using a formula. Calcareous content was determined using elimination of calcareous by acid, the neutralization of the surplus acid by Soda.

In order to quantify gully volumes and to acquire data on gully cross-sectional morphology, 811 cross-sections were quantified at an equal number of gully segments. This involved measuring the maximum depth (D, in meters), top width (TW, in meters) and bottom width (BW, in meters), of the bankfull channels. Where the gully cross-sectional shape was trapezoidal or wedge-shaped $[(TW+BW)/2]*D$ gave the Cross-Sectional area (CSA) (in m^2). Errors in the calculation of CSA are less than 2% (which is equal to a measurement error on TW and D of 0.01m for a gully of 1m deep and wide, and an error of 0.1m on a gully of 10m

deep and wide). When using the CSA to compute gully volume, it is however very important to carefully select the average cross-section of a gully segment, which can imply a much larger error (Frankl *et al.*, 2013).

Gully activity was assessed visually, by making a distinction between low- and high-

active channels. This was based on the cross-sectional shape of the channel, the presence of vegetation in the channel, the occurrence of mobile bed material, bank gully, and tension cracks or mass failure in the channel banks (Frankl *et al.*, 2011).



Figure 2 A sample of the gullies in Dehloran region



Figure 3 Measurement of gully depth using a thread scaled with 25 cm intervals

2.2 Factors controlling gully cross-sections

In order to understand the determinants of gully cross-sectional shape, a first step was to analyze

the variability in gully TW, BW, D and CSA. This was done by producing boxplots and by computing minima, maxima, the interquartile

range and median of the frequency distributions (Frankl *et al.*, 2011).

Secondly, we assessed the effect of gully and environmental characteristics that were recorded during the field survey on gully CSA and gully morphology. The latter was explained by using the ratio between gully top width and depth (TW/D) and the ratio between gully bottom width and top width (BW/TW). Gullies that display a large TW/D ratio are much wider than they are deep, and vice versa, while the BW/TW ratio that ranges between zero and one determines whether the gully is V or U shaped.

An analysis of variance (ANOVA, $\alpha=0.05$; Kutner *et al.*, 2005) was performed on the logarithm of the morphologic ratios in order to compare the distributions at different levels of the explanatory variables (Frankl *et al.*, 2011).

Normality of the distributions and variance homogeneity was tested with a Kolmogorov-Smirnov test ($\alpha=0.05$) and a Levené test ($\alpha=0.01$). Finally, we investigated whether cross-sectional gully properties could be predicted on the basis of catchment characteristics.

With the purpose to efficiently transfer water and sediment downslope, channel shape and size mainly adjusts to peak discharges (Knighton, 1998). As a result, channel TW, D and CSA will generally increase downstream. Departures from this trend are caused by variations in slope gradient, gully bank material and vegetation cover (Knighton, 1998).

2.3 Establishing volume-length relations

Establishing relations between the present-day volume of the gully networks and their length was done by selecting 30 mutually exclusive drainage catchments, with areas varying between 2200 and 61000 m². For these catchments, the length of the gully networks varied between 106m and 18 366 m. Quantifying Volumes were done by summing-up the mathematical products of the length of

each gully section and its average CSA. Thus, V-L relations were produced by taking factors that determine gully cross-sectional size into account. In addition, the relationship between the volume of the gully networks and their catchment area (V-A) was also explored. The effect of the catchment slope gradient (S_c , in mm⁻¹) on the V-A relationship was also considered.

3 RESULTS

3.1 Factors controlling gully cross-sectional shape

For the 90 gully cross-sections surveyed in Dehloran, the gully TW varied between 0.3m and 3.8 m with a median of 1.3 m. The gully D varied between 0.22m and 1.8 m with a median of .625 m and the BW ranged between 0.1 m and 1.8 m with a median of 0.355 m. The median CSA was 0.534 m² and ranged between 0.05m² and 4.59 m². The median TW/D ratio was 2.12, while the median BW/TW ratio was 0.29 (Table 1). Note that for TW/D and BW/TW, median and mean do not differ much as the distributions are nearly normal. As shown in Figure 4, plotting D over TW shows wide scatter around a linear relationship purged through the origin (0, 0).

The results that are summarized in Table 1 show median values for the morphologic ratios and CSA. The latter were obtained by multiplying the standardized CSA of the different subgroups to the median TW (=0.533m) of the surveyed gullies and the reported statistics (Table 1) apply on the logarithmic transformation of TW/D, BW/TW and standardized CSA.

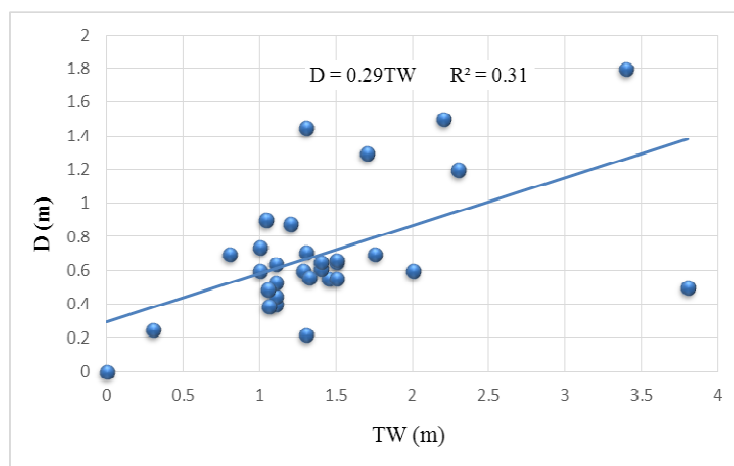


Figure 4 Gully depth (D) - gully top width (TW) linear relationship

Table 1 Statistical characteristic of the gully morphologic parameters

	L(m)	Tw (m)	Bw (m)	Hh (m)	D (m)	A (m ²)	CSA (m ²)	Tw/D	Bw/Tw	A*Sc
Mean	7.26	1.47	0.49	0.33	0.72	16364.93	0.82	2.30	0.32	168068
Max	23.4	3.8	1.8	1.65	1.8	61500	4.59	7.6	0.81	315600
Min	1	0.3	0.1	0.05	0.22	2200	0.05	0.89	0.14	12000
SD	11.55	1.78	0.88	0.85	0.80	30968.56	2.42	3.53	0.35	151820

Soil texture properties are given in Table 2. Finer particle-size distributions of the gully sidewalls tended to have a positive effect on CSA and a negative effect on TW/D and BW/TW ratios. In other words, the finer the particle-size distribution gets, the larger the cross-section tends to be, which the result of the gully incising deeper while is becoming more V-shaped. When considering the cross-sectional morphology, sections incised in soil with sandy texture had a median TW/D ratio that was 86.8% smaller than sections in clay texture and 11.1% smaller than sections in silty texture (one-way ANOVA Scheffé test, $P < 0.05$). For the BW/TW ratio, gully segments that incised in sandy texture had a median BW/TW ratio that was 7.7 % smaller than sections in silty

texture, 87.3% larger than sections in clay texture (one-way ANOVA Scheffé test, $P < 0.05$). When considering the median CSA, Sections that developed in sandy and silty texture were 28% larger than sections which were in clay texture (one-way ANOVA Scheffé test, $P < 0.05$).

The local slope gradient of the soil surface had a positive effect on both TW/D and BW/TW ratios and a negative effect on CSA. Gullies that developed on gentle slopes tend to have cross-sections that are deeper, more V-shaped and larger than gullies that developed on steep slopes. The median TW/D ratio of gullies that developed on slopes ranging between 0 % and 10 % was 10.56 % smaller than gullies that developed on slopes ranging between 10 % and

20% (one-way ANOVA, $P < 0.05$). The BW/TW ratio was 12.1% larger than for slopes of 0% to 10% when compared to slopes of 10% to 20%. The combined effect on the median CSA was that on slopes of 0 % to 10 %, the CSA was 16.3% smaller than on slopes of 20 % to 30 (one-way ANOVA, $P < 0.05$; Table 1).

Explaining the variability in TW, D and CSA on the basis of the drainage area (A, in m^2) was done for active gullies without check dams and without rock exposure. Figures 5A-

4C shows the power relations between TW, D, CSA and A respectively. TW, D and CSA increase with increasing A. As the trend lines for 'all data' show, this increase is more marked for CSA than for TW and D. The rather low r^2 values indicate that the variability on this trend is rather high, as can also be visually observed. In addition, the effect of local slope gradient of the soil surface (S, mm^{-1}) and the soil texture on these relationships was analyzed.

Table 2 Soil properties of the gully banks and drainage area

Gully No.	Deep soil			Top soil		
	Clay	Sand	Silt	Clay	sand	Silt
1	0.01	0.73	0.26	0.05	0.53	0.40
2	0.02	0.61	0.30	0.09	0.58	0.32
3	0.04	73.03	0.22	0.05	0.44	0.50
4	0.02	0.48	0.49	0.16	0.61	0.22
5	0.25	0.70	0.05	0.03	0.65	0.31
6	0.25	0.43	0.31	0.20	0.37	0.41
7	0.03	0.32	0.64	0.22	0.48	0.29
8	0.21	0.58	0.20	0.08	0.17	0.73
9	0.23	0.65	0.11	0.17	0.53	0.28
10	0.22	0.34	0.43	0.21	0.43	0.35
11	0.39	0.60	0.00	0.04	0.51	0.45
12	0.03	0.55	0.41	0.10	0.19	0.70
13	0.11	0.46	0.42	0.16	0.62	0.21
14	0.11	0.46	0.42	0.17	0.75	0.06
15	0.17	0.46	0.35	0.12	0.75	0.12
16	0.20	0.62	0.17	0.12	0.65	0.23
17	0.23	0.56	0.20	0.28	0.50	0.21
18	0.20	0.53	0.26	0.02	0.60	0.37
19	0.01	0.62	0.36	0.20	0.72	0.07
20	0.04	0.65	0.30	0.04	0.48	0.46
21	0.36	0.32	0.31	0.23	0.61	0.16
22	0.30	0.34	0.34	0.43	0.32	0.23
23	0.23	0.56	0.20	0.23	0.57	0.19
24	0.37	0.34	0.27	0.29	0.30	0.39
25	0.33	0.50	0.16	0.03	0.76	0.20
26	0.53	0.17	0.30	0.36	0.41	0.21
27	0.36	0.21	0.42	0.45	0.27	0.26
28	0.54	0.10	0.34	0.27	0.24	0.49
29	0.52	0.35	0.13	0.29	0.26	0.45
30	0.48	0.33	0.29	0.41	0.30	0.29

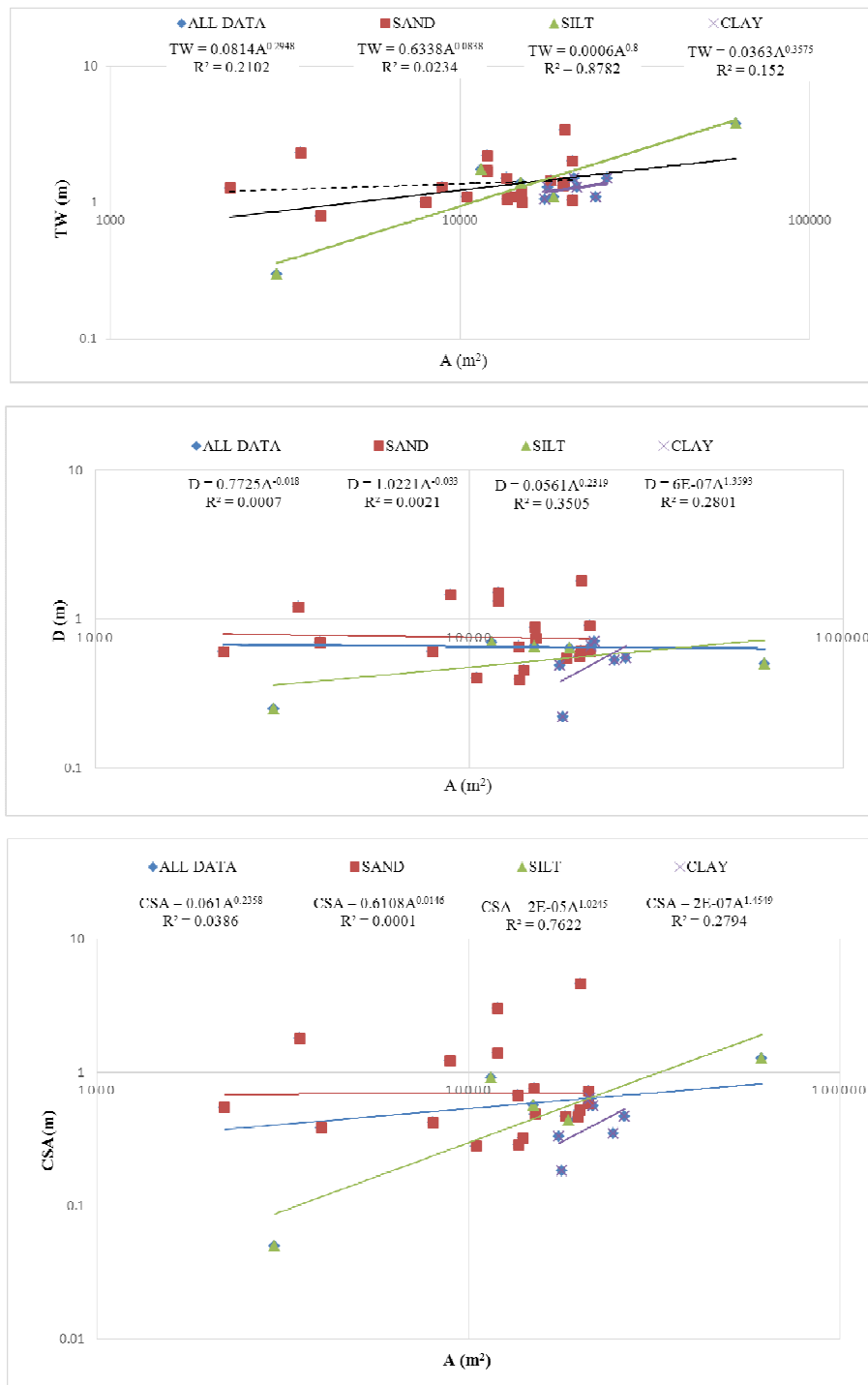


Figure 5 Power relationship between gully top width (TW), depth (D), cross-sectional area (CSA), and catchment area (A) for the entire data and different soil textures

3.2 V-L and V-A relations

The relationship between gully volumes to their length was best described by a power equation of the form $V = a L^b$. From the different parameters that influence gully cross-sectional size, we only considered the soil texture of gullied catchments. As shown earlier, these are the most important characteristics that explain the variability in CSA, both of which are rather easily observed in the field, or derived from topographic maps. Other parameters like gully bank material or land-use/cover; have similar distributions along gully networks, making different networks difficult to contrast in terms of V-L relations. Moreover, including such parameters, which are labor intensive to map, would make V-L relations difficult to apply in other areas or periods. The

resulting V-L equations for the different texture are (Figure 6):

$$V_{\text{all Data}} = 15.484 L^{0.1266} \quad (R^2 = 0.055) \quad (1)$$

$$V_{\text{sand}} = 15.468 L^{0.1233} \quad (R^2 = 0.0697) \quad (2)$$

The relations (Equations 1–2) are not valid for the region. The relations for gullies that located in silt and clay texture are not valid too. Due to the limited dataset, the V-L relations for study area were weak and not significant. As for the relationship between gully volumes and their catchment area, weak associations (with low r^2 values) could be established for all data (Figure 6). Adding S_c as an explanatory factor to these equations increased the r^2 values, but this amounts are weak and not significant too (Figure 7).

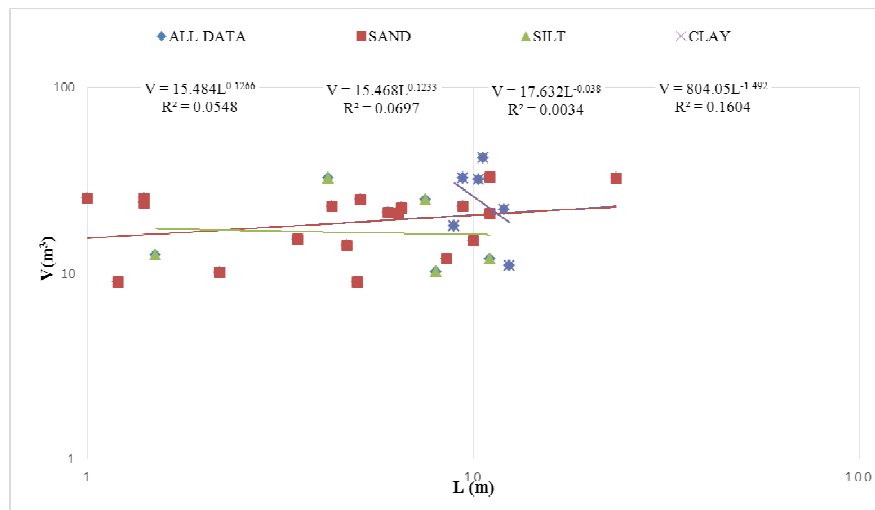


Figure 6 V-L relations for gullies in study area for entire data and different soil textures

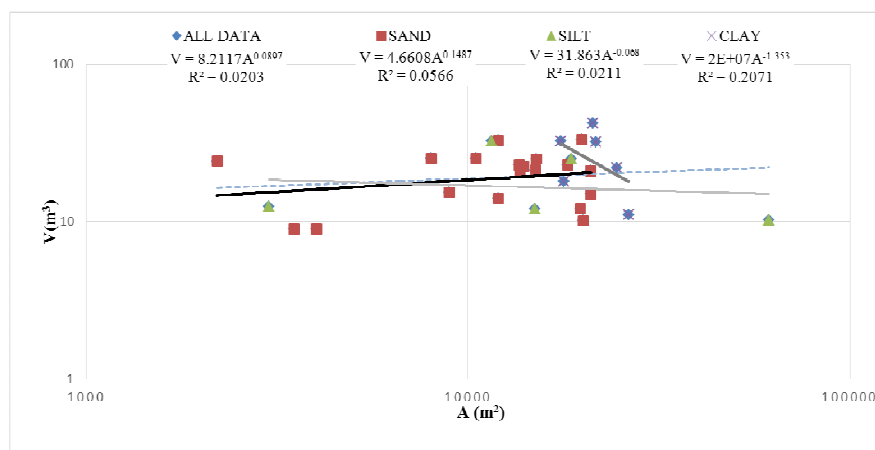


Figure 7 V–A relations for gullies in study area for entire data and different soil textures

4 DISCUSSION

As pointed out by Knighton (1998, p. 167), ‘the cross-sectional form of natural channels is characteristically irregular in outline and locally very variable’. Understanding the variability in gully morphology and size therefore mostly requires large datasets to get the general trend. This is well illustrated in Figure 4, which displays a large scatter around the trend line when plotting gully D over TW for 90 cross-sections of permanent gullies.

Natural channels will adjust their shape and size to the hydrological regime, i.e. the quantity of water delivered to the channel and the characteristics of runoff discharge (Knighton, 1998; Schumm, 2005).

Empirical approaches to understand the variability in TW and D along channels therefore mainly take runoff discharge (annual, peak, bank full) into consideration. For example, in semi-arid areas, where the hydrological regime is dominated by the occurrence of flash floods, channels tend to develop wider than in humid regions (Knighton, 1998). Hence, TW and D are explained as a power function ($Y = aX^b$) of runoff discharge. Such relations were essentially developed for rivers, indicating that TW varies approximately

as the square root of discharge (b coefficient ~ 0.5; Knighton, 1998; Poesen *et al.*, 2003). For ephemeral gullies, Nachtergaele *et al.* (2002) demonstrated that the equation $W = aQ_{\text{peak}}^b$ has a b coefficient of approximately 0.4.

Given the discharge properties, channel shape and size will adjust to the constraints imposed by local controls. As discussed by Knighton (1998) and Schumm (2005), these are especially the gully bank material, vegetation growing on the banks and the local slope gradient of the soil surface. Numerous studies reported by these authors indicate that the TW/D ratio of rivers will be larger for non-cohesive (sand) soils than for cohesive soils (silt-clay), smaller with increasing vegetation cover, and larger when the slope gradient increases. As for gullies, this study and the findings of Muñoz-Robles *et al.* (2010) confirm the increasing effect of local slope gradient on the TW/D ratio. Regarding the gully bank material, this study also confirms that particle fining causes the TW/D ratio to decrease. As gullies become deeper, they also tend to become more V-shaped. Despite our findings, some studies claim that the TW/D ratio for gullies in cohesive soils is larger than for non-cohesive soils (Radoane, 1995). The soil

properties have an important effect of the TW/D ratio, with higher ratios in clay and silt when compared to sand. The effect of vegetation on the cross-sectional shape could not be demonstrated in this study. This was also not expected for the reason that the free grazing system restricts the development of dense vegetation and because most gullies are older than the enclosures which they incise.

In order to predict the variability in gully cross-sectional shape and size, the use of catchment area as a proxy of discharge was assessed in this study. This shows that indeed, channel TW, D and CSA are positively related to catchment area according to a power relationship (Figures 5A-4C). However, the large scatter around the trend lines indicates that predicting channel shape and size at a specific location upon these equations can be in gross error.

Empirical V-L relations reflect the environmental setting (climate, topography, lithology, soil, vegetation) of the area they were developed for, and can thus not easily be applied to wider regions or similar areas worldwide (Graf, 1988). This is especially true when the datasets used to produce these relations are limited or when the area taken into consideration is small. In such cases, the risk exists that the sampled gullies do not reflect the regional variability in gully morphology.

The discussed V-L relations can roughly be subdivided in two groups. The first group represents the ephemeral gullies, equations for study areas (e)-(i). As ephemeral gullies do not grow subsequently but are erased after tillage, these lines plot lower on the graph. The second group represents the permanent gullies, which increase in size after subsequent rainfall events. The equation for study area includes ephemeral gullies and is somewhat transitional.

As observed in figure 6, the b coefficients for the different equations are very different, ranging between 0.14 and -1.35. The larger the

b coefficient, the more important the increase in CSA becomes with increasing length, and thus, the more erodible the incised deposits are. Gullies with coefficients close to one will thus display relatively constant CSAs along their channel. In Zucca *et al.* (2006), b coefficients close to one for a subgroup of gullies that developed in coarse granites was Explained by the presence of bedrock at shallow depths limiting the deepening of gullies. The larger b coefficient for summer gullies than winter gullies in Belgium was explained by the occurrence of higher rainfall intensities during summer months, thus producing stronger floods and creating larger Channels (Nachtergaele *et al.*, 2001a). As a result of the large similarity for the V-L relations for summer gullies in Belgium and for gullies in Portugal and Spain, Nachtergaele *et al.* (2001a) presented an equation including both datasets. Given the b coefficient, the coefficient determines the height of the power relationship on the Y-axis and therefore reflects the general environmental vulnerability of the area. As can be observed on Figure 6, gullies in Dehloran is small. The study presented by Muñoz-Robles *et al.* (2010) considers an area with undulating terrain for which precipitation is uniformly distributed throughout the year with an annual mean of 264.4 mmyr⁻¹ and storms having low to moderate intensities.

Applying V-L relations to assess gully volume still requires to map gully networks in the field or to derive them from aerial photographs. For general planning purposes, collecting data on gully lengths might be too labor intensive. Therefore, the value of catchment characteristics that are easy to quantify was assessed in this study. We found that catchment area is a fairly good predictor of gully erosion volume. Including average slope gradient of the catchment yields even better results, as network density proved to increase with Sc. For gullies that developed in deposits

derived from sand, silt and clay, $V-A*Sc$ relations (Figure 7) gave very low r^2 -values. The limited dataset of small gully networks in area did not allow a satisfactory relationship to be developed. The A could be mapped from topographical maps and Sc could be determined from SRTM data.

As is the case for the V-L relations, the V-A and V-A*Sc relations defined here take environmental characteristics into account. Developing such relations was also done elsewhere in the world, for example, by Khosla (1953) in India ($V=0.00323A^{0.72}$) and by Vandekerckhove *et al.* (2000) for bank gullies in Spain ($V=175A^{0.59}$). Differences in the a and b coefficients of such equations are the result of higher gully densities or a higher erodibility of the deposits the gullies developed in (~ V-L relation). The good association between V and A is not surprising, as many studies indicated that A is the major control of gully head retreat (Poesen *et al.*, 2003; Frankl *et al.*, 2012).

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عوامل کنترل کننده مورفولوژی و روابط حجم-طول آبکندهای موقتی در مناطق خشک غرب ایران

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تاریخ دریافت: ۶ بهمن ۱۳۹۲ / تاریخ پذیرش: ۸ دی ۱۳۹۳ / تاریخ چاپ: ۲۴ فروردین ۱۳۹۴

چکیده درک فرایند توسعه حجم در آبکندها نیازمند برقراری ارتباط منطقی بین عوامل طول و حجم آنها می‌باشد. برای این منظور، روابط حجم-طول برای آبکندهای موقتی ارائه گردیده است. در این تحقیق، روابط حجم-طول برای بخش از آبکندهای موقتی در جنوب استان ایلام ارائه گردید. به منظور شناخت متغیرهای منطقی محیطی مؤثر بر مورفولوژی مقاطع عرضی آبکندها، مجموعاً ۹۰ مقطع عرضی انتخاب و مورد مطالعه قرار گرفتند. این موضوع نشان داد که خصوصیات خاک بیش‌ترین تاثیر در شکل و اندازه سطح مقطع آبکندهای مورد مطالعه را داشته‌اند. مساحت حوزه زهکشی آبکندها نیز توانست تخمین نسبتاً خوبی از اندازه سطح مقطع آبکندها را ارائه نمایند. رابطه بین حجم و طول در آبکندهای مورد مطالعه به صورت $(n = 90, r^2 = 0.06)$ $V = 15.45 L^{0.12}$ بود. علاوه بر این حجم آبکند با مساحت حوزه زهکشی و درجه شیب آن نیز ارتباط داشت. نتایج این تحقیق نشان داد که رابطه حجم-طول و همچنین رابطه حجم-مساحت، شیب نمی‌تواند برای دستیابی به حجم آبکندهای موقتی مناسب باشد.

کلمات کلیدی: آبکند دائمی، حجم آبکند، دهلران، ریخت‌شناسی آبکند