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Effect of incipient gullying mechanisms on topographic threshold conditions for gully initiation in southwestern Iran (Boushehr-Samal watershed)

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Abstract

Gully erosion is widespread process of land degradation in dryland regions and has attracted the interest of a large number of researches. Although much research has carried out on soil erosion in arid and semi arid regions of Iran, few studies have been conducted to understand the threshold conditions of gully incipient. This study was conducted on gullying mechanism and topographic threshold conditions of gullies in an arid region of Iran. Since the dynamics of gully development channel initiation and extension are controlled by a variety of processes and factors, the data collection and analysis consist of field studies to the determine predominance process responsible for incipient gullying and Digital Model Elevation (DEM) analysis to examine slope-area relationship. Soil attributes (EC and SAR) and landuse practices were known as major factors to initiate piping and the potential of this process to initiate gully is very significant for bank gullies. It seems that topography and soil attributes are the major factors determining the effective process for incipient gullying in our study area. In the other hand all of gullies occurred in the main drainage streams and consequently are the main processes for landscape evolution. Correlation analysis showed an inverse linear relationship in log-log plot of upslope area and local slope dataset related to permanent gully heads. However for dataset associated with landsliding the S-A relation was not significant. Results of S-A relation can be used to determine vulnerable areas to gullying.

Keywords: Gullying process; Slope-area relation; Threshold; Incipient process; Iran

1. Introduction

Gully erosion has major effects, both on-site and off-sites due to soil loss and sediment yield respectively. Gully erosion in dry lands regions of Iran, through retirement of instability of head cuts, is the main responsible for degradation of arable lands and construction such as: roads, bridges, home and pipe lines. Gully is a kind of water erosion processes consisting of several characteristics as follow: a steep incised channel with an active head cut, unstable side wall and temporary water flow (Nordstrom, 1988, Poesen *et al.*, 2003).

So far, many researches have been made on the contribution of gully erosion to overall soil loss and sediment production in a wide range of environments and climate at a various temporal and spatial scales. For instance of some such quantitative results, in western Europe sediment contribution of gully erosion has been measured 30% up to 80% (Poesen et al., 2003) while in Australia, with mainly rangelands, amounts of gully erosion is 16 x 10^9 t a^{-1} (Wasson et al., 2002). Although the relative importance of gully erosion has been well documented during many various different researches (Poesen *et al.*, 2003), most soil loss equations or erosion

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models do not include the soil loss due to different types of gully erosion processes.

Boushehr province (study region of current research) is located in south west of Iran and the biggest gas field of world (Asaloueh) is located in there. Therefore, gully erosion is the main real danger for the construction and gas pipe lines. While a gully is initiating and retreat the subsoil of gas pipe line will be evacuated and washed, consequently at that point pipe is subsidenceing and causes a huge catastrophe. Having knowledge about initiation and location of gully erosion is important for land managers to foresee the area that gullies expected to take place.

Gully erosion is perfectly a threshold phenomenon controlled by a wide range of factors (Patton and Schumm 1975; Vandaele et al., 1996; Bull and Kirkby, 2002; Poesen et al., 2003; Valentine et al., 2005). This means that to initiate gully it is necessary that environment attributes must reach to a minimum value to initiate gully head. On the other words gully erosion process occurs only when a threshold in terms of flow hydraulics, rainfall, topography, pedology and land use has been exceeded (Poesen et al., 2003). Offcourse the mentioned thresholds are different in various climates under different landuse, soil and land cover. Inverse relationship between the upslope drainage area (A) and slope gradient (S) of gully initiation ($S=\alpha A^{-\beta}$) is the simplest well-known and analytical models for channel initiation invented first time by Patton and Schumm (1975). In fact they stated that channel initiation is based on kinetic energy of concentrated overland flow which can define as a function of runoff and slope. However, difficulties in estimation of runoff on small watershed caused they used contribution area of gully head as a surrogate for runoff volume (Bull and Kirkby, 2002). After Patton and Schumm (1975), so many researches have been conducted several studies in different part of world and in different condition to address the effects of factors and different channel initiation mechanisms on this relationship. These influences can be summarised in differential of constant and exponent of model (α and -β respectively). The results of Begin and Schumm (1975); Montgomery and Dietrich (1988, 1994); Prosser and Abernethy (1996); Vandaele *et al.*(1997); Desmet *et al* (1999); Vandekerckhove *et al* (2000); Hancock and Evans (2006), are some of the main literature examples in this subject. These authors established diffrents values for α and, -β based on different data collection. Comparison of the results of different researches concerned with S-A relationship indicates that variation of α and, -β is independent from each other and their variation refers to different environment characteristics. For most relations the exponent -β are more constant and varies between -0.2 to -0.4, while the variation range of constant α (0.0035-0.35) are more then -β. Vandekerckhove *et al.* (2000) showed that the trend of threshold line will be clearer when the data from mass movement dominance separate from hydraulic erosion dominance (changing -β as slope of threshold line), while the constant 'a' varies by variation of environment attributes. Clearly, more research and data are needed to assess and elucidate effects of various environment attributes, i.e. soil, geology, climate and landuse, as well as different gullying incipient processes, i.e. hydraulic, piping and mass movement erosion, on gully erosion initiation in details.

The aims of this paper are to study gullying processes by using threshold S-A relationship in south west of Iran and evaluation of the effects of mechanisms controlling incipient gullying on topography threshold condition. As it mentioned before there is no much conducted research on gully threshold conditions and interaction between environment attributes and gully initiation in Iran, except a few ones (Ghoddousi, 2002 and Adelpour *et al.*, 2004). Our study area is a typical arid region in south west of Iran with annual average rainfall of 130 mm and high temporal variability. Furthermore, the data of this paper can be used as a complementary material for understanding the effects of different environment conditions on gully erosion threshold.

2. Study area

The study area is located in Dareh-koreh watershed of Boushehr province, southwest of Iran, at 29° 08′ 18″N and 51° 13′ 15″E (Fig. 1). The main geological formations are sedimentary rocks namely: Gori limestone, Aghajari marl, Bakhtiyari conglomerate and Quaternary alluvial. It has an arid climate condition; the annual average of rainfall is 150 mm with mean annual temperature of 14.5°C, and relative air humid is 52%. Generally about 80% of precipitation fall through 2-3 events and intense rainfall events, mainly concentrate at the end of autumn and winter with high temporal and spatial variability which is typical for arid regions. Based on American Soil Taxonomy and profile attributes all of the soil in study area categorised into Entisols. The soils are in the primary stage of development and are limited in depth and in most of profiles dug a continuous sand layer within 60 cm of the surface, with 20-35 cm depth, was distinguished. During filed study we found that there is a controversy between lithology in which gully are located with the map formations from the available geological map. It the other mean, all of hills landscape in study area which was defined Conglomerate formation on geological map interpreted as a kind of Hydro-Aeolian Quaternary deposits. This difference is mostly due to geological map scale (1:100000), which are not as detailed as our study scale (1:10000). According to filed study and visual interpretation of aerial photos gullies in study area in located in three main site and the main characteristics of these site are summarized in Table 1.

3. Martial and method

3.1. Field measurements

This lack of data compelled the authors to collect all of needed data. On the basis of optic interpretation of aerial photos the locations of permanent gullies have been recognised on the photos. This study is particularly concerned with permanent gully erosion with minimum depth of 0.7 m. Permanent gullies are generally found in rangelands and abandoned agricultural fields as well as down slope of agricultural lands where they are not easily ameliorated with ordinary farm tillage equipments after their initiation and development. These gullies generally have a vertical headcut and well defined break in slope.

Table 1: Main characteristics of the study area

Site number	Mean altitude, (a.s.l) (m)	Landuse	Lithology	Soil texture	Ec (ds/m)	Vegetation cover	Geomorphology
1	87	Rangeland	Quaternary alluvial	Sandy loam	2.6	Poor annual grass	Hill
2	72	Rangeland Cereal crop	Quaternary alluvial	Sandy loam	1.9	Poor annual grass	Hill
3	40	abounded land	Quaternary alluvial	Clay loam	40.8	Bare land	Alluvial pediment

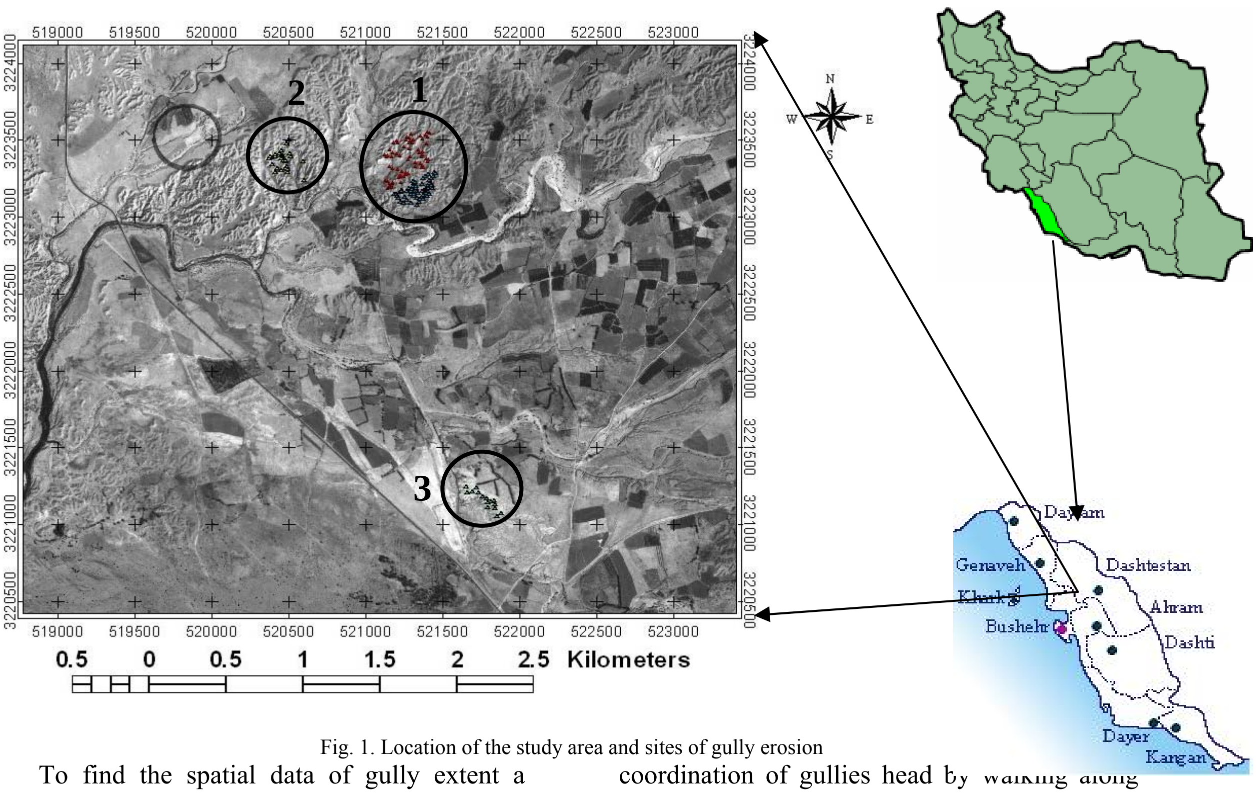

Fig. 1. Location of the study area and sites of gully erosion

To find the spatial data of gully extent a series of points were marked by GPS (Garmin Etrex Vista with a positional accuracy 4 m) within each gully channels as well as exact coordination of gullies head by walking along all drainage networks from outlet to catchment divide. Also at this stage we tried to collect the data of active gullies based on pre-defined criteria as follows; abrupt and steep morphology, sharp edge, active plunge-pool and evidence of tension crack, flow marks as well as lack of vegetation cover on the bed, side wall and head cut of gully (Oostwoud Wijdenes and Bryan, 1999, Oostwoud Wijdenes et al 2000). At the next stage all of collected data was converted to GIS and the gullies stream networks were created and overlayed on aerial photos and based on neighbourhood distance between gullies three sites were recognised. In the second stage the entire environment data of upland area of gullies were, including: land use, ground cover, and gully head slope collected and finally in each site a soil profile was dug and soil samples were taken from different horizons to determine soil attributes. According to the literature reviews the negative trend of threshold lines between upslope area and slope is controlled not only by environment characteristics but also by dominant of mechanisms of incipient gullying, i.e. hydraulic erosion by concentrated overland flow, seepage flow and mass movement processes (Montgomery and Dietrich, 1994; Vandaele et al., 1997 and Vandekerckhove et al., 2000).

Vandekerckhove et al. (2000) showed that by separating the dataset includes gullies initiated by Hortonian overland flow the trend of thresholds line is more pronounced. Based on the models of Montgomery and Dietrich (1994) channel initiation in steep areas (i.e. >45%) would be dominated by landsliding, whereas in low gradient area overland flow would dominated. In our study area we used some criteria to identify the dominance processes as follow. In gullies that landsliding is the main process we could find a heap of soil collapsed on the foot of gully head and the same ground vegetation cover could be seen over it, while in gullies with piping processes we saw hole and sign of sand boiling at the base of gully head as well side walls and finally the exciting of plunge-pool were used to identify overland flow dominance (Fig. 2). It is noticeable that in real situation channel head initiation is controlled by a complex interaction of mentioned processes, for instant in our field survey we found that in most cases the landsliding process and seepage erosion in bottom layer take place at the same time.

Fig. 2. Abrupt gully head associated with overland flow. Poor vegetation at upland area cause to generate water flow and plunge-pool at the base of gully head

All of the soil samples were analysed at laboratory to determine the chemical and physical attributes through standard method of soil analysis. Ground cover and vegetation cover were estimated visually in the field. Detailed rainfall records were not available for this study area; however, because of proximity of sites we assumed that there is not any significant difference between rainfalls.

3.2. Data processing

All of collected data obtained from field studies were transferred to spreadsheet and Geographic Information System to extract the gully channel network map with high accuracy. The further analysis of these data was based upon the ($S=\alpha A^{-\beta}$) relationship introduced by Vandaele et al. (1996), Desmet et al. (1999) and Vandekerchkhove et al. (2000). All of these researchers derived their relationship from Patton and Schumm (1975) and critical shear stress indicator of Begin and Schumm (1979). Different methods have been applied by various authors to calculate the local slope and contribution area for each point. However each measurement methods can cause different results.

In this study a Digital Elevation Model (DEM) was constructed by interpolation of large scale (1:10000) digital contour lines (DGN) and elevation points of National Cartographic Centre (NCC) of Iran with accuracy of 10x10 m. The local slope gradients were calculated sing the method invented by Zevenbergen and Thorne (1987) and based on flow line and flow accumulation map the upslope drainage area was assessed with the help of ArcHydro extension. Finally all of data concern with slope and contribution area were extracted and transfer to SPSS statistical software to assess S-A relationship.

4. Results and discussion

4.1. Gullying process and general characteristics of sites

In this study area all of identified gullies are continuous and occurred in the drainage stream channel and mostly their sharp headcuts are the start point of tributaries. Totally 97 active headcuts were identified in all sites in which, 63 of these gullies located in site one, 16 in site two and 24 in site three. Although the numbers of gully in three sites are different, the densities of them in unit area are comparatively similar. In site one and two overland flow and landsliding are the predominance process in gully initiation, while in site three just piping was identified as a major process. Moreover, there is a significant difference between dominance possess of gully initiation and physical-environment characteristics of site one, two and three. Results of Table 2 indicates that how topography of the landscape can effect the process of incipient gullying. On the other word, as the slope of area increases the frequency of gully initiation by landslide will increase. Although based on channel evolution model invented by Montgomery and Dietrich (1994) the threshold slope for channel head associated with landslide is >45%, we found many channels heads initiated by landsliding in areas with 28-40% slope. Offcourse as a preliminarily note it should be mentioned that in sites one and two we found a combination of seepage and landsliding at a same place which in gully initiated. In the next sections we will discuss about that in detailed. However, similar to previous studies (Montgomery and Dietrich, 1994 and Vandekerckhove et al., 2000) depending on the slope of area the contribution effects of different mechanisms associated with gully initiation will be different.

Table 2: Some characteristics of studied sites

Attributes	Site 1		SITE 2		SITE 3
Gullying process	Overland flow	Landsliding	Overland flow	Landsliding	Piping
No. of gully	41	22	9	7	18
Percentage	65.1	34.9	56.3	43.7	100
Area (ha)	31.5		10.2		5
Mean slope (%)	13.3		19.8		0.8

Since gully initiation is controlled by various environmental characteristics we decided to compare the other factors in our sites. Also because the sites are under similar climate condition, changing of gully initiation process between sites arising from other environment conditions such as landuse and soil attributes.

Basically the existence of such particular geologic structure (Fig.3) in this area may explain that why the landsliding has been taken place in lower slope in comparison to Montgomery and Dietrich (1994) report. In another words, the nature of materials at depth, particularly presence of differential strength and cohesionless of sand layer, together with dried and wet these layers creating tension or desiccation cracks during dry season and after a rain event the water flow into the soil washes the bottom sand layer through seepage processes and causes to increase the shear stress and consequently collapse the top layers. Poesen *et al.* (2002) stated that in dryland areas two types of mass failure can be identified, one is the continuous failure over long time and the other is catastrophic shear failure in cohesive layers. However, in site one and two the latter with combination seepage are the most frequent processes of gully initiation and development.

Fig. 3. General view of a hilly landscape in site one and two. Different layers are identified in Quaternary materials. Primary evidence shows that this landscape is intermittently a complex of Hydro-Aeolian deposits. Layer A mostly contains silt, clay and poor sand while the layer B is a pure layer of sand stuff. Currently in down area adjusted to our research area we saw the sand dunes and wandering wind deposits

In site three the situation is completely different from other sites. The gullies in this site were categorized into bank gullies. Bank gullies are frequent features in arid and semi-arid regions (Poesen et al., 2002) and occur in river bank or terrace and retreat into gentle slope pediments or bank terraces or arable lands. In contrast to hillslope gullies that are formes due to critical flow shear stress at the soil surface, they are formed because of runoff overfalling from littoral bank area and tunnel or piping erosion caused by hydraulic gradients occur in dispersive materials (Poesen et al., 2002). Oostwoud Wijdenes et al., (2000) and Vandekerchkove et al., (2000) carried out an investigation on spatial distribution and factors controlling the active bank gullies in southwest Spain. They showed a strong influence of landuse, physico-chemical attributes of bank materials as well as lithology on bank gully development. In our study area with regard to same climate condition in all sites we tried to find another environment factors such as geology and soil conditions controlling differences between site three and other sites. Table 3 shows the results of the mean value of measured soil parameters for the samples taken in soil profiles.

Table 3: Summery of some measured parameters of soils at different sites

Site	Texture Class	OM%	EC dS/m	pH	Na meq/lit	K ppm	Ca meq/lit	Cl meq/lit	SAR	ESP %
1	Sandy loam	0.22	2.63	7.7	9.2	28.0	27.8	4	2.3	2
2	Sandy loam	0.27	3.64	7.5	12.6	24	26.2	18.2	2.4	2.2
3	Sandy Clay loam	0.55	40.86	6.8	566.7	433.3	149.5	154	48.2	40.5

With a short glance on Table 3 it can be drawn that soil in site three is entirely different from site one and two. Offcourse we measured a lot of soil parameters but according to literature we just focused on affecting attributes concerned with piping. The majority of previous researches conducted on piping issue have shown that high levels of soil chemical properties namely: electric conductivity (EC), SAR[1] and ESP[2] value are the crucial factors in development of piping (Romero Diaz et al., 2007, Vandekerckhove et al., 2000 and Poesen et al., 2002). The potential of this process to initiate gully is very significant for bank gullies. In our study area bank gullies are located in low gentle slope pediment in which the run off generated from littoral lands particularly farmlands moves slowly at this surface and can infiltrate through the soil. At this time in presence of high levels of sodium clay fraction will be deflocculated and extremely vulnerable to erosion, consequently the subsurface flow creates tunnels and pipes. Dispersion usually results from high levels of sodium and EC values such as saline (Ec 10-26 dS/m) and sodic (SAR 20-35) soils. In the site tree the Ec (40.86 dS/m) and SAR (48.2) values indicating high sodic soil. These results consistent with previous research carried out by Poesen et al. (2002) and Romero Diaz et al. (2007). Base on studies of Harvey (1982) and Martin Penela (1994) nature of materials in depth and presence of fragile silty-clay material containing cracks

1. Sodium Absorption Ratio
2. Exchangeable Sodium Percentage

and discontinuities joints and faults filled by gypsum cause to differential infiltration of soil profile. In our study we did not do a detailed study about soil properties because site three located in arable and abounded lands we could find no intake area with original and no disturbance soil (Fig 4). But, we took samples from depth of soil (>70cm) that can not easily be disturbed by ordinary farm equipments. Results from this samples shows that the bottom material is clay loam with high levels of gypsum (41 meq/100 g of soil).

Landuse practice is another important factor in site three which accelerates the piping processes. Tillage processes cause to change bulk density and increase the infiltration of top soil, together with rainfall regime develop the piping more quickly. In our study area, October and mostly April are the rainiest months, so after preparation the land for agriculture in December by increasing infiltration of surface most of heavy rain in April penetrates into the soil and dissolve the soluble material in depth layers and increase piping risk. This becomes more obvious when we pay attention to landuse of site three (Table 1). Because of piping in this area the crop fields became degraded and abandoned (Fig. 4), consequently a shifting agriculture pattern is being seen.

Although the previous researches have discussed the role of piping on gully initiation particularly bank gullies (Poesen et al., 2002, Vandekerckhove et al., 2000, Bull and Kirkby 2002) few study have focused on upslope contribution area and slope relationship threshold for gully initiation. For instance, results presented by Vandekerckhove et al., (2000) indicate that a negative power relationship between the local slope and the present upslope drainage area. However, they stated that because of different influence processes of gully initiation and sudden height drop at the rambla or barranco bank in one side and difficulties related to accurate measuring in field the assumed S-A relationship could not be verified in their stuffy area (Vandekerckhove et al., 2000). Similarly in our study area we can not find a suitable numbers of gullies have just started and the barranco banks are still intact to calculate S-A relationship, consequently we neglect this area for S-A relationship.

Fig: 4. Illustration of a bank gully in site three. Initiation of this gully caused to abandoned crop land. Note embankment levee on the up land of gully head constructed by farmers to prevent advancement

4.2. Area- slope relationship

All of the gullies in site two and three occurred in the main channel networks, so we determine the catchment of them. All of gullies in site one were located in two adjusted watersheds while in site two they located in one watershed. Actually the gullies merge with the downstream drainage network and consequently it was difficult to recognize gully network from drainage channels. In other words, the extensions of stream channels are associated with headword retreat of headcuts. Leopold et al., (1964) stated that surface runoff and subsurface seepage as well as head ward erosion of headcuts are three major modes of physical process of drainage extension. The migration of headcuts leads to increase the drainage density in our study area and consequently slope will increase in steepness (Leopold et al., 1964). It means that gully development in our study area not only cause to sever erosion and land degradation but also increase the drainage density and create steepness hillslope by decreasing the length of hillslope. Under this circumstance the time entry of runoff from hillslope to stream declines which results in increasing the discharge at the outlet of catchment (Bull and Kirkby 2002). On the other hand gullies cause to decrease of the base flow and ground water resources through decreasing aquifer recharge and lead to increase trend of desertification (Vandekerckhove et al., 2000 and Martineli Costa and Prado Bacellar 2007). The previous discussion clearly indicates that gully erosion in our study area not only leads to land degradation and soil loss but also can influence the intensity of drought and desertification through some hydrological processes. This result is consistent with the results reported by Vandekerckhove et al. (2000). Therefore; intensity of gully erosion can be as a clear indicator of desertification and catchment drainage evolution.

We extracted the area and slope for all of catchments and plotted the headcuts of gullies on it for each site two. Fig.5 shows the area-slope relationship for two sites with observed gully data.

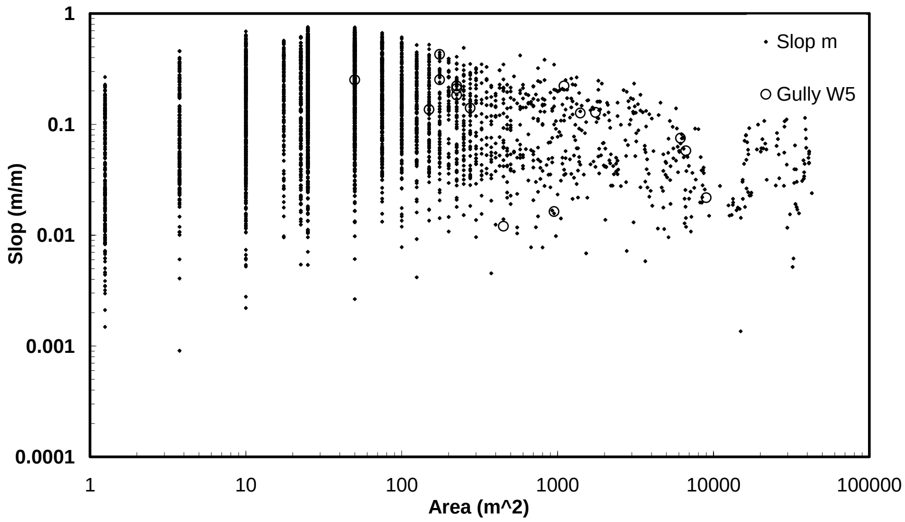

Fig. 5. Area-slope relationship for the site one (catchments W2, W3) and site two (bottom) with gully head data overlaid

Fig. 5 clearly demonstrates that in all sites gully heads distribute in all part of catchment. Previous research conducted by Willgoose et al., (1991), Hancock and Evans (2006) indicate that two process namely diffusive and fluvial process are responsible for hillslope evolution in catchment.

The first process takes place mostly on the upslope region of catchments (Horton erosion belt) includes iterrill, rainsplash, creep and other erosive processes that tend to round or smooth that landscape. Whereas the catchment area becomes larger we can see a turning point in area-slope curves that slope decrease as area increase and this region of catchment is dominated by fluvial or incisional erosive process (Hancock and Evans 2006). Hancock and Evans (2006) in a research about gully poison in an undisturbed catchment in northern Australia showed that the first process is located in the convex part of area-slope curve with area less than 10 pixels while the fluvial process has taken place at area approximately grater than 10 pixels.

But, in our study area we found that in natural vegetation cover all of gullies initiated by landsliding and seepage process are located at the convex components of area-slop curve with area approximately less than 250 square meters (10 pixels). Two reasons may explain this difference between our results and Hancock and Evans (2006): (1) related to physical properties of study area particularly climate and geology structure and (2) related to research methodology such as DEM size and algorithm used for generating slope map. Our study area is located in a very susceptible lithology structure with a sparse vegetation cover (less than 10%) under an arid climate condition whereas they study area has a wet/dry tropical environment with an annual rainfall of 1389 mm and forest vegetation cover.

Results of plotted of integrated collected dataset together with previous results taken from literature are shown in Fig. 6 and Table 4. Results in Fig.6 show a clear variation in threshold conditions for gully incipient and it may be resulted from type of gully, mechanisms of incipient gullying and environmental characteristics controlling gully development as well as methodology used to assess A and S, as it mentioned by former researches (Vandaele et al. 1996, Desmet et al., 1999, Vandekerckhove et al., 2000 and Poesen et al., 2003). Montgomery and Dietrich (1994) reported that they collected all of their dataset by field surveying; also they stated that the landsliding and overlanflow are the dominance processes for channel initiation in Oregon and Nevada respectively. They separated their data based on dominance process into overland flow, landsliding and seepage erosion but they found that in all dataset, landscape and process an inverse relationship between area and slope is consistent with the form of $A_{cr} \propto S^{-2}$. In other words they concluded that the AS^2 is the best indicator for predicting channel head location on the landscape and the form of $A_{cr} \propto S^{-2}$ relationship is not affected by other environment factors such as soil and climate conditions and dominance process for gullying (Montgomery and Dietrich 1994).

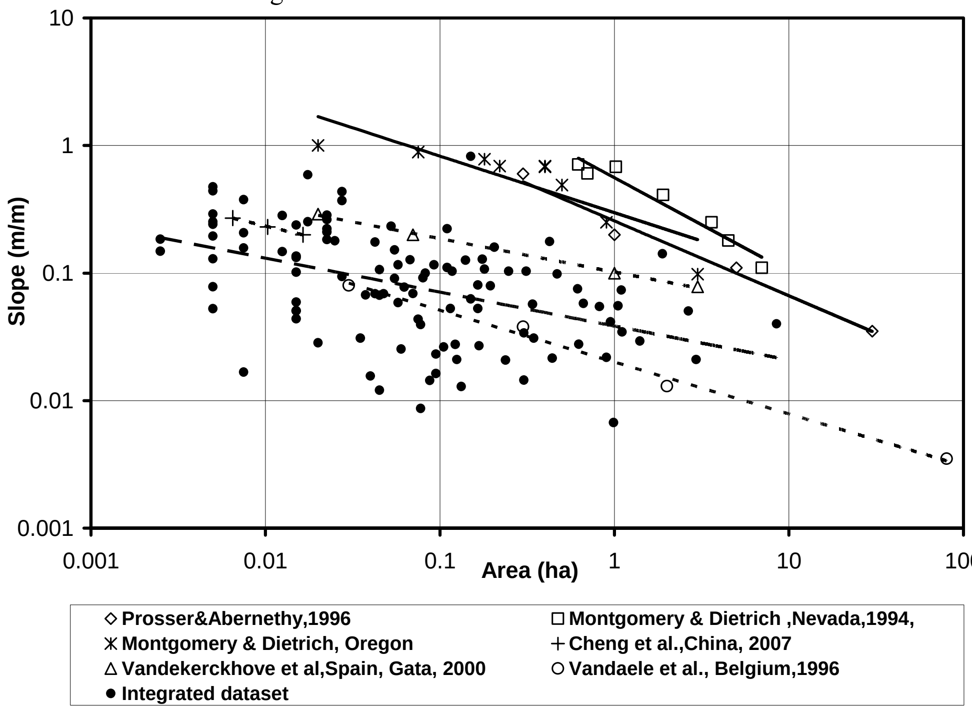

Fig. 6. Relationship between upslope area and local slope of soil surface at the channel head in a variety of environments. Dashed line indicates threshold for our integrated dataset. Dotted lines show threshold condition for ephemeral gully and solid lines indicated channel initiation with different predominated process

Table 4: Regression coefficient (intercept) α and exponent (slope) –β of the fitted equation ($S=\alpha A^{-\beta}$), Coefficient of determination (R^2), Correlation coefficient (r) and significant level (P) of the dataset. In dataset column the data were separated based on predominance mechanism of incipient gullying

Dataset	α	−β	R^2	r	P
Integrated (1)	0.0384	-0.2661	0.29	0.54	0.000^{**}
Overland flow (2)	0.0377	-0.1923	0.33	0.6	0.000^{**}
Landsliding (3)	0.0941	-0.1278	0.026	0.16	0.252^{ns}
Overland flow without farmland (4)	0.0432	-0.1824	0.467	0.68	0.000^{**}

ns: Non significant **: significant correlation in 0.01 confidence level

According to their results the value of AS^2 varies between 500 and 4000. However in this research we found that AS^2 for gully heads vary between 0.9 to 425 and the average of that for gullies initiated by overland flow is 11 and for landsliding process is about 48. Therefore it seems that in drylands area with sever arid climate condition the threshold value for AS^2 should be less than other area.

Comparison of our result to other results in Fig. 7 shows that the slope of fitted line to our data is only similar to data reported by Vandekerkchove et al (2000). They studied the effect of environmental characteristics on threshold condition for ephemeral gullies in Mediterranean region and indicated that for Sierra de Gata site in southeastern Spain with average rainfall of 180mm the S-A relationship is $S=0.101A^{-0.267}$. In our study we found a similar exponent for A ($S=0.0328A^{-0.257}$) but different constant. Various carried out research in different regions have reported different values for constant and exponent of ($S=\alpha A^{-\beta}$) relationship. Vandaele et al. (1996) reported that range of exponent $-\beta$ varies between -0.26 and -0.6, but in most relations it is more or less constant and equals -0.4. They also stated that in comparison to exponent $-\beta$ the constant α shows important variation and rages over several orders of magnitude. However, results of research after Vandaele et al. (1996) indicated more variation of exponent $-\beta$, for instant Vandekerckhove et al. (2000) obtained the minimum values (-0.104) for $-\beta$. With due attention to the differences between reported values for constant and exponent it can be implied that exponent $-\beta$ is controlled by erosion process and, possibly, predominated mechanisms of incipient gullying, i.e. overland flow, landsliding and seepage, whereas the influence of the methods used to assess A and S as well as characteristics of study areas are believed to be reflected in the value of constant α (Vandaele et al., 1996, Poesen et al., 2003). However, under natural conditions it is very difficult to recognize the headcuts that initiated by only one mechanism and normally a complex of mechanism are responsible for gully initiation.

Shape of cloud points for integrated dataset on Fig.6 indicates a heterogeneous distribution among data, furthermore, the coefficient of determination (R^2) illustrated on Table 4 shows a relatively weak correlation between A and S. Although the confidence level indicates to exist of significant inverse relationship between A and S the value of R^2 implies that only 29 percent of changes in A can be illustrated by S. Vandekerckhove et al. (2000), Montgomery and Deitrich (1994) tried to enhanced this relationship by grouping data according to dominance process.

We examined the S-A relationship for separated dataset based on predominance mechanism for initiation. Results in Table 4 reveal the negative relationship between A and S, but this correlation is not significant for landslide mechanise. Moreover, by separating data based on mechanise it can be implied that coefficient of determination (R^2) increase from 0.29 to 0.33. Fig. 7 shows the scattergram and fitted line to separated data illustrated on Table 4. As it shown in Fig.7 (A) in comparison to integrated dataset the relationship was enhanced and we can see more uniform cloud points, but we saw five outlay red points under fitted lines shown by circle. Field study revealed that all of these gully head located at agricultural lands. The effects of landuse and vegetation cover on gully initiation were discussed in details in several conducted researches such as Poesen et al. (2002) an Vandekerckhove et al. (2000). From the results of these mentioned researches it can be drawn that just a small relatively changes on land cover in response to climate or landuse changes as well as soil disturbance leads to decrease critical shear stress and consequently will dramatically decrease the upslope area. Since of small number of these points we could not examine the effects of landuse on threshold conditions, instead of that we removed them to increase the uniformity of data. Fig. 7 (B) illustrate that by neglecting the dataset collected in farm land the correlation will be more clear and increasing R^2 is the best witness of this assumption.

Montgomary and Ditrich (1994) have divided landscape into overland flow, seepage and saturation erosion as well as landsliding based on dominance process responsible for channel initiation. They reported that in all cases the relation between A and critical S is a linear inverse one, but soil saturation and seepage erosion. In our study area in all cases landsliding and subsurface process coupled to incipient gullying and consequently, the effects of seepage and subsurface processes weakened the inverse trend line of landsliding and this relationship have not been significant statistically. In other words, lithological nature and presence of cohesionless-sand layer (Fig. 4) lead to seepage and smooths the progress of landsliding. This finding is consistent with the previous results reported by Vandekerckhove et al. (2000).

Many critical S-A relations have been established by different studies conducted in different environmental conditions to investigate gully initiation (e.g. Patton and Schumm, 1957; Montgomery and Dietrich, 1992; Vandaele et al., 1996; Prosser and Abernethy, 1996; Desmet et al.; Vandekerckhove et al., 2000; Hancock and Evans, 2006; Cheng et al., 2007). Although, all of these research have emphasized on inverse relationship of A-S, the diversity of coefficient α and -β are considerable. As a common conclusion all of mentioned studies approved that a relative small differences of environment factors such as climate, soil, geology and hydrologic process as well as methodology use to assess A and S lead to great variation of constant α and exponent $-\beta$.

A

B

C

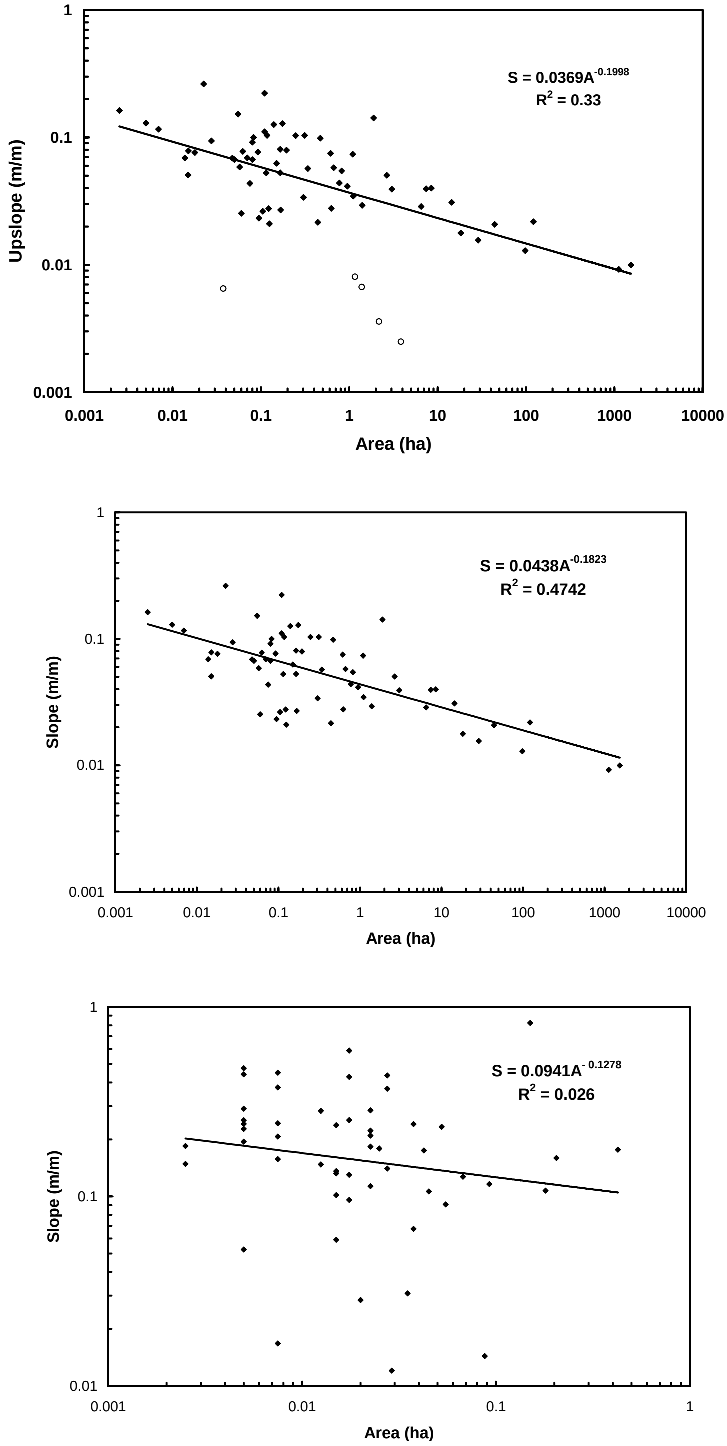

Fig. 7. Scattergram and fitted line of separated dataset based on mechanism. Fig A (top) shows the relationship for overlanflow, the outlay circle points under fitted line related to gully head in agricultural lands. Fig B (middle) shows the relationship for overland flow without agricultural gully and fig C (Bottom) shows the relationship for landsliding and seepage data associated with mechanism.

The most important reasons that may explain the difference between our results and some other ones refer to environment characteristics of our study area and our methodology in comparison to cited researches. None of the cited studies are located under arid condition similar to our study area. Montgomery and Dietrich (1988) stated that in dry regions the thresholds line plot above the wet regions. In other words they concluded that for a given local slope, the source area size required to initiate a channel head should increase with increasing aridity to produce the same critical combination of runoff and local slope at the channel head (Montgomery and Dietrich, 1988). But, Vandekerckhove et al. (2000) reach to this point that mentioned principle does not apply in their study area and consequently stated that the relative position of threshold line is controlled by other factors excepts of climate condition. On the other hands, the vegetation cover of our study area is very small and disperses particularly in autumn season; therefore during a storm event a small size of area can produce sufficient amounts of runoff to initiate a gully.

The exponent of -β for integrated dataset (-0.266) is similar to Sierra de Gata (-0.267) (Vandekerckhove et al., 2000), but after grouping dataset and separating landslide from total data the trend of threshold line was became clear and similar to Lesvos Island. Although Sierra Nevada, the study area of Montgomery and Dietrich (1988), located under arid climate condition with 260 mm annual rainfall, it is covered by open oak woodland and grassland and underline by old granitic rocks. But, in our study area the vegetation cover is very disperse and less than 10 percent with a susceptible lithology. Similar to their results we found that overland flow is dominance process in low gentle gradient and landsliding is responsible for channel initiation at steep region. These authors illustrated that limitation of dominance process for overland flow and landsliding can be established by slope of area (e.i. S>50% is for landsliding), but in our study since of combination of two process namely seepage and landsliding we could not determine this limitation.

However this discrepancy among findings around the different environment conditions indicates that different criteria as well as complex modelling approaches are needed for location of permanent gully head location as it founded by previous resecures such as Desmet et al., (1999); Poesen et al., (2003); Hancock and Evans (2006).

5. Conclusion

Gully erosion in dryland regions of Iran, is the main responsible factor for degradation of arable lands and construction. Despite the importance of gully erosion in arid and semi arid regions of Iran no study has been conducted to understand the threshold conditions of gully incipient. In the other hand most of conducted research have examine the threshold condition for ephemeral gully. This research has focused on gullying processes by using threshold S-A relationship for permanent gullies in south west of Iran and applying that to determine the vulnerable area to gully initiation. Dominance processes of gully initiation were identified based on morphology and pre-defined criteria. The further analysis of these data was based on the ($S=\alpha A^{-\beta}$) relationship and the results revealed the following conclusions:

1-Dominance process for incipient gullying is controlled by soil material characteristics and topography of the landscape. On the other word, as the slope of area increases the frequency of gully initiation by landslide will increase. But the limitation of topography for landsliding is determined by particular lithological structure and soil in our study area. We found many channels heads initiated by landsliding in areas with 28-40% slope. All of bank gullies were found in high sodic soil with Ec (40.86 dS/m) and SAR (48.2) values. In addition tillage process causes to increase the infiltration of top soil through changing bulk density and, together with rainfall regime develop the piping more quickly.

2- Correlation analysis between upslope area and local slope indicates a significant relationship between A and S for gully initiated by overland flow, but not for landsliding. All of gullies situated throughout the stream channel and are the main processes for landscape evolution. Because of combination of seepage and landsliding the S-A relationship was not significant, so by grouping data based on dominant process and landuse the coefficient of determination (R^2) increased. Examination of threshold S-A relation for predicting vulnerable area to gullying revealed that we can determine the prone area to gullying with an acceptable accuracy. However, due to complexity of gully erosion mechanisms and particularly in arid regions more research efforts are needed as well as more environment factors other than area and slope should be taken into account to understating gullying processes and gully hazard zonation.

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