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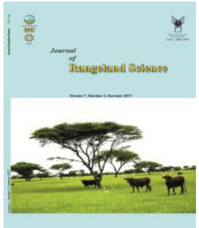

Research and Full Length Article:

Comparative Assessment of Gully Erosion and Sediment Yield in Different Rangelands and Agricultural Areas in Ghasr-e-Shirin, Kermanshah, Iran

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Abstract. Negative impacts of gully erosion in marly areas are severe due to improper landuse practices such as irrigation, tillage, overgrazing and degradation of vegetation cover. The objective of this research was to evaluate gully thresholds related to plant vegetation cover and landuse change in the Agriculture (AG), Fair Rangeland (FR) and Weak Rangeland (WR) areas of Ghaasr-e-Shirin, Kermanshah, Iran in 2015. The topographical parameters and vegetation cover were measured in the field. Furthermore, nine flumes were performed to determine the critical values of hydraulic parameter and sedimentation. Results revealed that cross-section, width, depth and gully branches length in the FR were significantly lower than those for AG and WR ($p<0.05$) affected by plant canopy and litter. The significant differences were found between three sits for soil organic carbon (SOC), electrical conductivity (EC) and hydraulic characteristics (inlet discharge, velocity, loaded sediment). Higher vegetation cover in the FR was attributed to the increased hydraulic thresholds and adversely limited cross-section enlargement. Finally, the sediment concentrations in AG, FR and WR were 15163, 9560 and 12000 ppm, respectively. Lower SOC was found in WR and AG due to higher concentration of load sediment. Hence, it was concluded that bare soil, poor vegetation and lower SOC are considerable reduction factors in gully thresholds and subsequently, off-site sedimentation and SOC loss in the study area.

Key words: Fair Rangeland, Gully Erosion, Weak Rangeland, Sediment Yield, Vegetation Cover

Introduction

Gully erosion is one of the critical problems in the terrestrial lands contributing to some effects such as loss of soil fertility and lowered water holding capacity, and off-site effects such as siltation and climate change worldwide. However, it is triggered by the concentrated run-off and fluvial incision due to anthropogenic landuse change, plant cover clearance overgrazing and improper agricultural activities (Valentine *et al.,* 2005; Wani and Sudi, 2006; Parkner *et al*., 2007). During recent years, the highest level of 530 t ha^{-1} yr^{-1} soil loss by gully erosion was reported in Ethiopia (Tebebu *et al.,* 2010).

Moreover, in the semi-arid regions, gully erosion resulted in the changes of geomorphic and hydrologic characteristics of the affected areas (Blanco and Lal, 2008; Lutengger *et al.*, 2008). The study by Bobrovitskaya (2000) revealed that converting rangeland to other land uses led to the clearance of vegetation cover attributed to a significant reduction in gully thresholds. In contrast, proper utility of rangeland without severe reduction in abundance and biomass of species caused control of gully erosion (Moradi *et al.,* 2012). In most part of Iran, landuse practices affect soil permeability and runoff coefficient controlling gully thresholds (Ghoddousi and Tavakoli, 2007; Ahmadi, 2011; Shadfar, 2015). Removal of native vegetation through converting rangelands to rain-fed areas contributes to the formation and enlargement of head-cut dimension. This process is more aggressive where plant cover is degraded promoting the runoff concentration (Agharazi *et al.,* 2013).

Overall, vegetation cover plays an important role in gully control via increasing hydraulic thresholds, particularly runoff velocity and shear tension. Plant cover is the key factor for gully control that increases gully threshold three times as compared with similar sites where vegetation cover is cleared (Prosser *et al.,* 1995; Poesen *et al.,* 2006). Removal of indigenous vegetation changes the hydraulic and morphometric characteristics of gully (Nogueras *et al.,* 2003).

In Mediterranean areas, the effect of rangeland vegetation on gully triggering was found more effective than climate factors (Vandekechove *et al.,* 2000). In these regions, high density of native vegetation curtails about 50% of gulling development (Rey, 2003) while in the sensitive land of the Loess Plateau, gully erosion dramatically developed cleared plant cover (Cheng *et al.,* 2007). The same results were obtained by Turkelboom *et al.* (2008) in a tropical region (Thiland). Due to the effects of vegetation cover on gully threshold, some most important characteristics such as vegetating form, density, root system, and stem for increasing the soil resistance against hydraulic tension and reducing flow velocity are considered by researchers (De Beats *et al.,* 2009). However, grasses were found as the possible factor affecting gully control via their flexible stems and root system that reduce overland flow velocity and capture the sediment particles (Munoz-Robles *et al.,* 2010).

Due to the largest area of rangeland and its unique plant biodiversity in Iran, improper utility of rangeland significantly results in gully erosion and subsequently climate changes and siltation that are pointed by several investigations in different parts of Iran (Refahi, 2009; Ahmadi, 2011; Soleimanpour *et al.,* 2015). They addressed overgrazing, converting natural forest and rangeland to rain-fed area and improper agricultural practices such as up-down the slope tillage and crop residue burning as the affecting factor on gully triggering and development.

The objectives of this research were to assess the effects of vegetation cover on different land uses (mainly rangelands) concerning gully development and sediment yield in Ghasr-e-Shirin, Kermanshah, Iran.

Materials and Methods

Study Area

This study was conducted at Ghasr-e-Shirin, Kermanshah province, Iran (Fig. 1) which is located within the winter-rangeland and agricultural lands. The study site has an area of 10710 ha that lies between 34º 25' and 34º 33' N and 45º 35' and 45º 46' E. The minimum and maximum elevations above sea level are 400 and 600 m, respectively. This area comprises mainly plains and hilly landforms geologically occupied by marl and fine grained materials of Aghajari Formation. This formation (upper Miocene) comprises sandstone and marl layers. The outcrop of marl layer is more considered.

The mean annual precipitation and temperature are 370 mm and 22.5°C, respectively. Land in this area is susceptible to gully erosion and piping phenomenon potentially related to its geological origin while being accelerated by improper agricultural activities, uncontrolled overgrazing and land use changes.

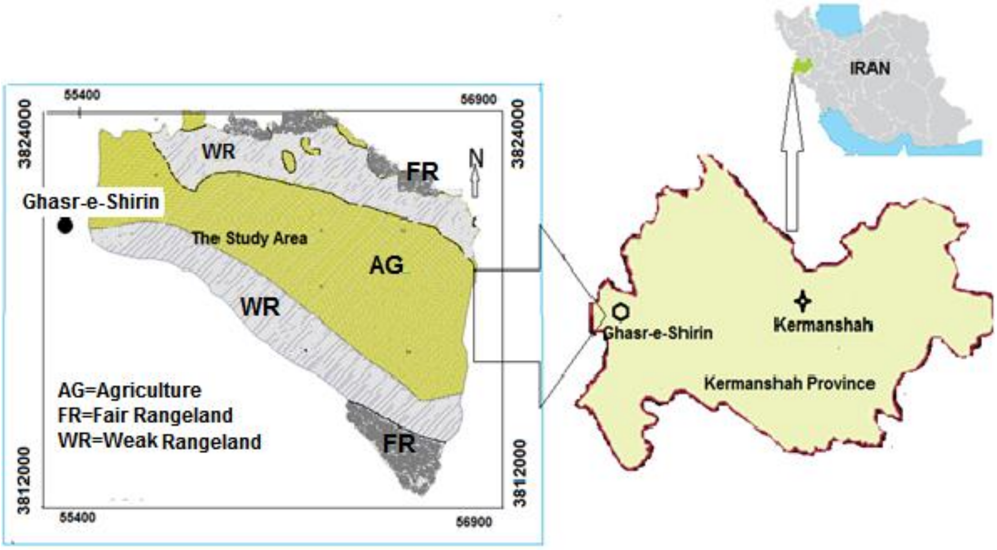

Fig. 1. Location of study area in Kermanshah province, Iran

Gully Erosion Location

Fifty-one gullies in three land uses including agriculture, fair rangeland and weak rangeland were measured within geomorphological facies. The geomorphological facies is a homogenous area in the catchment with specific characteristics of geology, topography, landuse and erosion layers as a homogenous unit (Ahmadi, 2011).

In this study, a geomorphological facies map was prepared by overlapping the mentioned layers using ArcGIS software (version 9.3). In this research, the geomorphological facies was mapped for 51 gullies in the agriculture (AG), fair rangeland (FR) and weak rangeland (WR).

Gully Morphometry

The morphometric parameters of each gully within geomorphological facies including lateral length, width, depth, cross-section, slope and catchment area as well as head-cut characteristics such as depth and surface area were recorded through a field survey.

Experimental Flumes

As overland flow affecting gully triggering at the landscape is turbulence (non-uniform), the simulation of this flow in the field is more common and used in different regions of Iran (Adelpour and

Soufi, 2004; Nazari Samani, 2016). Thus, nine experiment flumes were performed within land uses. The flume is 15 m long, 0.4 m wide and 0.5 m high. Each flume was established carefully in the field without disturbance of both soil profile and vegetation cover. The sidewalls of flumes were beaten into the soil and sealed with plaster and cement. Water was supplied through a 16 m^3 tanker and a stilling pond was constructed at the upper ward of flume and sealed also by plastic.

The flow velocity was measured over the 9 m reach in the middle of the flume using a chronometer and surface flow was monitored carefully by photos. Every ditch or step-like incised erosion feature with a size over three cm was considered as a head-cut formation. Loaded sediment samples were taken from discharge at the outlet part for determining the sediment yield and organic carbon content.

Vegetation Canopy Measurement

Vegetation characteristics including species, frequency and density within each flume were measured. Furthermore, the ground surface cover including the percentages of plant canopy, litter, stoniness and bare soil around the flume also were estimated using the quadrate plot ($1m^2$).

Soil Sampling and Analysis

Soil samples were collected from surface layer within each geomorphological facies and their coordinates were recorded by global positioning system (GPS). The dried soil samples were sieved through 2 mm mesh sieve. Soil physico-chemical characteristics were determined in the laboratory. The particle size distribution and soil texture were determined by the hydrometer method (Soil Survey Laboratory Staff, 1991). Cation exchange capacity CEC and exchangeable sodium (Na) of soil were determined using ammonium acetate at pH=7 as outlined by Van Reeuwijk and Vente (1993). Similarly, soil organic carbon (SOC) was determined by the Walkley and Black method (Nelson and Sommers, 1982). The pH of saturated soil paste was measured by a pH meter.

Statistical Analysis

The collected data for gully morphometric parameters, vegetation canopy, soli characteristics were subjected to one-way analysis of variance. Means caparison between three land uses (sits) was made using Duncan method. The statistical analyses of data were carried out using SAS software (version 6.12).

Results and Discussion

Gully Morphometry in Land uses

The morphometry characteristics of 51 gullies including width, depth, channel length, slope and catchment area in the agriculture (AG), fair rangeland (FR) and weak rangeland (WR) were measured in the field (Table 1). The respective means of upper width of gully in AG, FR and WR were 2.25, 1.68 and 2.01 m, respectively while there were significant differences for bed width with the average values of 1.45, 0.92 and 1.52 m, respectively indicating higher values of AG than two other sites. There were no significant differences between gully depth in the AG, FR and WR with the average values of 1.29, 1.12 and 1.19 m, respectively.

The gully length including branches and main channel was measured in the field (Table 1). There were significant differences for gully branches in the AG, FR and WR with the average values of 216, 183 and 136 m, respectively. In contrast, the main channel length in that order was 995, 984 and 1110m, respectively. The result indicating that gully branches were significantly shorter and the channel length was longer in WR than that for other land uses. This is related to poor vegetation cover in WR especially early and heavy grazing (Ahmadi, 2011; Ghoddousi and Tavakoli, 2007).

The results of measured slope characteristic including head-cut (3m from head-cut), gully catchment and lateral slope were higher in WR indicating more aggressive as compared to AG and FR sits. Respective values of occupied lands by gully in the AG, FR and WR were 12.4, 14.1 and 21.6%, respectively indicating higher values in WR than two other lands. In addition, average gully catchment areas for AG, FR and WG were estimated as 5619, 5503 and 3668 m^2, respectively. Lower values for this critical characteristic were obtained in WG indicating the minimum area for gully threshold mainly due to the degraded vegetation and lower soil organic carbon. The study by Naghipour-Borj *et al.* (2011) showed that SOC in a native rangeland with proper management was significantly higher than that other land uses positively affecting soil conservation.

Vegetation Cover

Measurement of the ground surface cover including the percentages of plant canopy, litter, stoniness and bare soil was carried out using the quadrate plot (1 m^2). As shown in Table 1, plant canopy in the AG, FR and WF was estimated as 28.9, 35.9 and 28.7%, respectively. The plant litter was 9.2, 10.1 and 7.8%. Both these characteristics in WR were significantly lower than two sites. Adversely, the bare soil with the average values of 43.7, 52.7 and 56.6% were obtained in FR, AG and WR, respectively indicating lower values in FR than two other sites (Table 1).

Field verification revealed that during recent years, the fair rangeland (FR) was more subjected to being converted to other land uses such as rain-fed, orchard and non-agricultural ones. Otherwise, local stakeholders, particularly nomads and herders only participate in improper grazing that can be prioritized second affecting degradation factors. Livelihood dependence on rangeland is decreased among local inhabitants (Badripour *et al.*, 2016); consequently, agriculture practices instead of livestock grazing are preferred that results in converting more rangelands to rain-fed farms.

Table 1. ANOVA analysis of above ground cover and gully morphometric characteristics among three land uses in Ghasr-e-Shirin, Iran

Variable	Position	Landuse			Pr>F*
		Agriculture	Fair Rangeland	Weak Rangeland	
Gully number		25	16	11	
Gully width (m)	Upper	2.25 a	1.68 b	2.01 a	0.019**
	Bed	1.45 a	0.92 b	1.52 a	0.031*
Gully depth (m)		1.29 a	1.12 a	1.19 a	0.831
Gully channel length (m)	Branches	216 a	183 a	136 b	0.045*
	Main channel	995 b	984 b	1110 a	0.044*
Mean slope (%)	3 m from head-cut	3.67 b	4.86 a	5.34 a	0.045*
	Gully catchment	4.78 b	7.17 a	7.20 a	0.001**
	Lateral	4.30 b	7.10 b	6.90 a	0.005**
Occupied area by gully (%)		12.4 b	14.10 b	21.60 a	0.001**
Gully catchment area (m^2)		5619 a	5503 a	3668 b	0.001**
Above ground cover (%) #	Vegetation canopy	28.89 b	35.90 a	28.70 b	0.028*
	Plant litter	9.23 ab	10.11 a	7.81 b	0.004**
	Stoniness	9.52 a	10.25 a	6.92 ab	0.046*
	Bare soil	52.36 b	43.74 ab	56.58 a	0.007**

*, **=the difference between three landuses is significant at 5 and 1% probability levels.
Means of rows with the same letters are not significantly different (P< 0.05%)
in the agricultural lands, during cropping season

Soil Characteristics

In order to determine the effects of soil properties on gully threshold, important soil characteristics including particle size distribution (sand, silt and clay), Cation exchange capacity (CEC), EC, pH, SOC and Na were analyzed (Table 2).

The results of ANOVA showed significant differences between three sites for soil CEC, SOC and Na ($P<0.05$) while there were no significant differences for particle size distribution, EC and pH values. Consequently, the decreased SOC, and CEC and adversely increased Na in agricultural lands of study area were mainly related to improper land use practices; crop residue burring in weak rangelands related to heavy grazing of livestock confirmed by Elkhalili *et al.* (2013).

Table 2. ANOVA analysis of soil variables among three land uses, Ghasr-e-Shirin, Iran

Soil Variable	Landuse			Pr>F*
	Agriculture	Fair Rangeland	Weak Rangeland	
Sand (%)	21.70 a	26.70 a	23.40 a	0.313
Silt (%)	52.8 a	50.00 a	53.24 a	0.438
Clay (%)	25.52 a	23.32 a	23.47 a	0.476
CEC (cmolc kg–1)	17.9 b	22.3 a	18.3 b	0.038*
EC (dSm^{-1})	2.64 a	2.35 a	3.24 a	0.828
pH	7.42 a	7.41 a	7.47 a	0.649
Soil organic carbon, (%)	0.28 b	0.57 a	0.49 a	0.030*
Na $cmol_c\ kg^{-1}$	5.95 a	3.59 ab	4.75 a	0.085

Means of rows with the same letters are not significantly different at P< 0.05%
CEC= Cation exchange capacity

Vegetation Cover affecting Gully Threshold

The minimum and mean vegetation cover rates (canopy) in relation to gully length in different land uses have been presented in Table 3. The result showed that gully threshold based on minimum plant cover-gully length was significantly ($p<0.05$) different among three land uses. The minimum plant vegetation cover for gully length in AG, FR and WR was 5.0, 30.5 and 23.7%, respectively. Due to considerable vegetation canopy in the WR, the minimum gully length was about 40 m that was 2.5 to 7.5 times less than that for AG and WR sites.

Most parts of semiarid regions of Iran such as study areas both converted rangelands to the rain-fed and common agricultural lands are subjected to heavy moldboard tillage practices of damaging keys of soil characteristics and whole native plant clearance. This tillage subsequently accelerates severe erosion hazard of gully with a high amount of sediment yield (Blanco and Lal, 2008; Igwe, 2015).

Table 3. Vegetation covers and gully length in different land uses, Ghasr-e-Shirin

Variable	Agriculture		Fair rangeland		Weak rangeland	
	Minimum	Mean	Minimum	Mean	Minimum	Mean
Vegetation cover (%)	5.0	34.5	30.5	36.5	23.7	28.6
Gully length (m)	100.0	644.4	40.2	985.0	300.0	1110.0

Hydraulic Discharge and Velocity

The hydraulic parameters including inlet-flow, velocity, and out-flow as well as loaded sediment, SOC and EC through nine flumes in three land uses of study area and their statistical analysis (ANOVA) are summarized in Table 4. The respective inlet-flow for gully initiation in the AG, FR and WR was 2.38, 7.17 and 5.25 li^{-1} indicating significant differences among them with higher values for FR. Considerable higher level of this key parameter in the FR is due to three plant driven factors including plant canopy, plant litter and SOC that is in agreement with other researches (Soleimanpour, 2012; Kohestani and Yeganeh, 2016; Badripour *et al.*, 2016).

In addition, the results from trapped sediment at the out-let flow, its SOC content and EC revealed significant differences among AG, FR and WR for hydraulic flow discharge and velocity. Thus, the respective sediment concentrations in AG, FR and WR were 15163, 9560 and 12000 ppm, respectively.

Table 4. ANOVA analysis of hydraulic flow, velocity and sediment yield in different land uses, Ghasr-e-Shirin

Variables	Landuse			Pr>F
	Agriculture	Fair rangeland	Weak rangeland	
Inlet-flow dis. (lis^{-1}) *	2.38 a	7.17 a	5.25 ab	0.026
Velocity (ms^{-1})	0.173 b	0.331 a	0.337 a	0.011
Out-flow dis. (lis^{-1}) **	4.09 c	11.22 a	6.71 b	0.002
Sediment (ppm)	15163 b	9560 c	12000 a	0.001
Sediment EC	661.8 a	491.2 b	401.9 b	0.001
Sediment SOC (ppm)	1.80 a	0.25 c	0.50 b	0.003
SOC/sediment	0.012%	0.0028%	0.0042%	-

* measured discharge in upper (inlet) of flume

** measured discharge in outlet (downward) of flume, sampling sediment

Means of rows with the same letters are not significantly different (P< 0.05%)

Gully Volume, Sediment Yield and SOC Loss

Gully volume was calculated based on gully cross-section, gully length, density (number per ha) and morphometry parameters (Table 5). Thus, the net gully volume (One ha gully multiplied by affected gully area) in AG, FR and WR was 5927, 1761 and 3881 m^3ha^{-1}, respectively. In fact, there was loss soil from study area, revealing the importance of vegetation cover in FR that was 2.5 to 3.5 times less than that in other sites (Fig. 2).

Out-let discharge was sampled for determining loaded sediment (siltation potential), SOC content and EC. As presented in Table 5, the sediment concentrations in AG, FR and WR were 15163, 9560 and 12000 ppm, respectively reveling significant differences among them. Due to effects of vegetation cover and litter on sedimentation, out-side sediment level in FR was at least 12 time less than other sites. Similarly, both EC and SOC of load sediment were different in the study sites. Obviously, higher SOC loss in WR and AG is due to higher concentration of load sediment (mainly clay and silt). There were no significant differences for soil EC among three land uses. The Na in AG was higher than other sites (Table 3). In all sites, it was found less than 6 $cmol_c\ kg^{-1}$. Na is a key factor for soil aggregates dispersion when its level reaches more than 10 $cmol_c\ kg^{-1}$ (Blanco and Lal, 2008).

Tillage practice and overgrazing result in out-site impacts of land degradation, especially siltation and SOC emission (Nael *et al.*, 2007; Wilson *et al.*, 2008; Li and Pag, 2010). Moreover, field observation revealed that head-cut formation and enlargement were more frequent where soil crust and piping phenomena are aggressive due to either absence of plant cover or tillage practice. The study by Marden *et al.* (2012) showed that tillage practice via moldboard plow and crop residue burning caused SOC deficit and thereby accelerating piping process and severe erosion. In agricultural lands of Mediterranean area, the hazardous gully erosion is related with bare soil and poor plant cover (Elkhalili, 2013). In contrast, fair vegetation cover of rangeland, particularly grasses is attributed to control of gully erosion (Dong *et al.*, 2011).

Table 5. Cross-section and volume of gully in three land uses in Ghasr-e-Shirin

Gully Variables	Landuse		
	Agriculture	Fair rangeland	Weak rangeland
Gully dimension Width (m)	1.92 a	0.92 b	1.21 a
Gully dimension Depth (m)	2.49 a	1.36 b	1.48 b
Gully cross-section (m^2)	4.78 a	1.25 b	1.80 b
One ha gully volume (m^3)	47800 a	12500 b	18000 b
Occupied area by gully (5)	12.4 b	14.09 b	21.56 a
Gully volume (m^3ha^{-1}) (4×5)	5927 a	1761 c	3881 b

Means of rows with the same letters are not significantly different at P< 0.05%

Fig. 2. Gully erosion in the study area. A= fare rangeland, B= weak rangeland and C= agricultural area

Conclusion

Results of this research showed that morphometric and hydraulic thresholds of gully erosion significantly have been affected by anthropogenic land use changes and thereby native plant degradation as well as improper agricultural practices. Similarly, plant canopy and litter in FR were higher than that for WR and AG but adversely, its stoniness and bare soils were higher than other sites. In addition, negative changes in soil CEC, SOC and Na are attributed to the enlargement of gully depth, width and cross-section in AG and WR as compared with FR. Finally, performance of flumes showed that sedimentation with a high level of SOC content is resulted from gully erosion in AG and WR due to bare soil, poor vegetation and lower soil properties affecting considerable off-site sedimentation and SOC loss in the study area.

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چکیده. پیامدهای منفی فرسایش خندقی به ویژه در اراضی مارنی به دلیل کاربری غیر اصولی، از جمله آبیاری نامناسب، شخم، چرای بی‌رویه و تخریب شدید پوشش گیاهی قابل توجه است. هدف از انجام این پژوهش مقایسه میزان رسوبزایی در اثر فرسایش خندقی در مراتع و اراضی کشاورزی شهرستان قصرشیرین تحت سه نوع کاربری کشاورزی، مرتع متوسط و مرتع فقیر در سال ۱۳۹۵ بود. به این منظور مشخصات مورفومتری خندق‌ها شامل عمق، پهنا، سطح مقطع، شیب، مساحت حوزه بالادست، سطح اشغال شده و پوشش سطح زمین اندازه‌گیری شد. سپس با استقرار ۹ فلوم مشخصات هیدرولیک جریان شامل سرعت، دبی ورودی، دبی خروجی، غلظت رسوب و محتویات آن (کربن آلی و هدایت الکتریکی) مورد ارزیابی قرار گرفت. نتایج نشان داد تاج پوشش گیاهی و لاشبرگ در کاربری مرتع متوسط بطور معنی‌داری (در سطح ۵٪) بیشتر از دو کاربری دیگر بود و به همین دلیل ویژگی‌های مورد اندازه‌گیری مورفومتری از جمله سطح مقطع و طول خندق‌ها نیز کمتر بود. همچنین کربن آلی، هدایت الکتریکی و برخی از مهمترین ویژگی‌های هیدرولیک جریان (دبی ورودی، سرعت جریان و غلظت رسوب) در هر سه کاربری با هم تفاوت معنی‌داری داشتند. نهایتا مقدار غلظت رسوب به ترتیب کاربری‌های کشاورزی، مرتع متوسط و مرتع فقیر ۱۵۱۶۳، ۹۵۶۰ و ۱۲۰۰۰ ppm بود که مقدار قابل توجه آن در کاربری کشاورزی و مرتع فقیر به دلیل شخم نامناسب، سوزاندن بقایای گیاهی (در اراضی کشاورزی) چرای شدید دام و سطح خاک لخت (مرتع فقیر) بود. این روند موجب کاهش آستانه‌های فرسایش خندقی به دلیل تخریب شدید پوشش گیاهی و بهره‌برداری زیاد از اراضی است که رسوبزایی و هدر رفت کربن آلی از پیامدهای مهم آن در منطقه مورد مطالعه می‌باشد.

کلمات کلیدی: پوشش گیاهی، فرسایش خندقی، رسوبزایی، مرتع فقیر، مرتع متوسط