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Effects of Gully Erosion on Soil Quality Indices in Northwestern Iran

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ABSTRACT

Gully erosion affects soil properties in different ways. One of the most important effects of gully erosion is destruction of soil structure and reducing its quality. The objective of this research was to study the effects of gully development on soil properties and quality indices in areas adjacent to the gullies. For this purpose, 15 soil properties and 5 soil quality indices including Integrated Quality Index (IQI), Nemero Quality Index (NQI), Cumulative Rating (CR), and Sustainability Index (SI) were compared between gully wall and outside gully lands in three sites of Ardabil province, northwestern Iran. T-test method with three replications was used for comparison. The results showed that in all three sites, 8 out of 15 soil properties changed near the gully walls, mainly indicating the reduction of soil structure, organic carbon, and S index (slope of retention curve at inflection point) and increasing the Cation Ratio Of soil Structural Stability (CROSS) and soil erodibility index. Also, near the gullies, most of the soil quality indices decreased due to gully development in the study sites. Therefore, gully formation and development in these sites reduced soil quality near the gully walls.

Keywords: CROSS, Erodibility index, Soil degradation, Soil structural stability.

INTRODUCTION

Sustainability of human societies depends on the wise use of natural resources. Soils are key factors for storing and transmitting water to plants, atmosphere, groundwater, lakes, and rivers (Keesstra *et al.*, 2018). Also, soils play an important role in basic human needs such as global food security, water resources, biodiversity, climate change, and clean air (Keesstra *et al.*, 2016). On the other hand, soil erosion is a key factor for land degradation; and it is a worldwide threat that must be solved by means of nature-based solutions in order to achieve sustainability (Cerdàa *et al.*, 2017; Keesstra *et al.*, 2018). Steep slopes, erodible soils, rill and ephemeral gullies, and compaction are common features that result in high soil erosion rates (Rodrigo-Comino *et al.,* 2016). Better understanding of the complex function of the soil system will lead to better and sustainable soil management (Mol and Keesstra, 2012). In this regard, understanding the effect of gully erosion on soil physical quality indices and functions can lead to better and sustainable soil management.

Gully erosion is a hazardous form of water erosion that creates various environmental damages. Loss of soil fertility, loss of crop productivity, development of badlands and water loss due to low water holding capacity of soil are some negative effects created by gully erosion (Dlapa *et al.*, 2012; Liu *et al.*, 2013). In the research by Liu *et al*. (2013), gully erosion caused reductions of soil

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depth and soybean yield significantly. Filling the gullies with the soil from adjacent areas resulted in substantial land productivity reduction. The soybean yield was reduced by 0.70 and 3.87 t ha^{-1} due to ephemeral gully and classic gully erosion, respectively. Because of gully erosion and gully filling, soybean yield was reduced by 34.5% in the gully's influenced area and by about 2.6% over the entire soil region. Kumar and Pani (2012) concluded that the Chambal valley in India was severely affected by ravine and gully erosion and degraded land was expanding at an alarming rate. Because of long and continuous fluvial erosion, a huge share of fertile land has gone out of plough. As a result, crop productivity has declined in villages that are severely affected by land degradation. The encroachment of arable land by land degradation has adversely affected crop productivity of the region. Kumar and Pani (2012) found a clear relationship between land degradation and agricultural productivity, and gross value per land area was lower in villages severely affected by land degradation. Yakutina *et al*. (2015) found a critical decrease of soil fertility and plant productivity in strongly eroded soil. Li *et al*. (2016) calculated economic loss in terms of crop yield reduction due to topsoil reduction and concluded that topsoil loss due to filling ephemeral gullies negatively impacted farming in the long term.

Changes in physical properties of the soil and decrease in soil quality indices by gully erosion have also been reported by Chen *et al.* (2015) and Xu *et al.* (2016). One of the factors affecting the sustainability of the soil is physical quality that is determined by soil quality indices. The soil physical quality may be changed due to changes in land use, management practices, soil erosion, etc. Soil organic carbon may be used as an indicator of soil physical quality on similar soil types where soil structural parameters play an important role in relation to soil erodibility (Singh *et al.,* 2012). There is a significant relationship between reduction in soil quality and increase of its susceptibility to water erosion (Singh and Khera, 2009). Properties of soils adjacent to gullies may change more than areas farther away. Therefore, soil quality within or near gullies may be significantly different than the undisturbed soil outside the gully (Zhu *et al.,* 2008; Xu *et al.,* 2016).

Usually, in the early stages of erosion, degradation of soil physical properties occurs as decrease in shear strength, silt content, and Mean Weight Diameter (MWD) of aggregates, while in the later stages, soil degradation happens mainly as a result of soil nutrients loss (Xu *et al.,* 2016). Papiernik (2005) found that areas with high erosion had high inorganic carbon contents in the surface soil because of the incorporation of calcareous subsoil material by tillage. The physicochemical properties of the soil may change due to gully formation, but usually soil physical properties are more pronounced than chemical properties (Liu *et al.,* 2013). Wang *et al.* (2009) simulated the loss of surface soil to assess the impact of gully erosion on soil physical properties and found that gully erosion reduced the silt content from 46 to 33%, and as a result, nutrient content at a depth of 0 to 70 cm was decreased. Generally, it has been reported that soil properties of more than 70 percent of lands between the gullies are affected by gully erosion, and this may have a role in degradation of 35 to 85% of the soils on sloping lands (Tang, 2004; Qin *et al.*, 2010).

Based on the relationship between soil physical properties and soil quality, changes in soil physical properties as a result of gully development often reduce the quality of the soil adjacent to the gully (Xu *et al.,* 2016). To determine soil quality, soil properties that impact its function are considered as indicators of soil quality (Qi *et al.,* 2009). The necessary steps required for developing a soil quality index are: selection of the most important factors affecting soil quality, weighting and scoring the properties, combining them in the form of an index with a model and, finally, evaluating the model (Chen *et al.*, 2015). Different soil properties and models have been presented for indices of soil quality, such as Integrated Quality Index (IQI), Nemero Quality Index (NQI) (Qi *et al.*, 2009; Ranjbar *et al.*, 2016), Cumulative Rating (CR), Sustainability Index (SI) (Singh and Khera, 2009), Soil Quality Index (SQI) (Xu *et al.*, 2016), slope of water retention curve at inflection point (S index) (Dexter, 2004; Emami *et al.*, 2012; Emami and Astaraei, 2012; Emami *et al.*, 2014).

Despite the studies on soil erosion and soil quality in recent years, the impact of gully erosion on soil properties, degradation of soil quality and the key factors of soil quality influenced by gully erosion are still not entirely known. Research in this field is rare and there is no general opinion regarding the impact of gully erosion on soil properties and soil quality indices (Xu *et al.*, 2016). Xu *et al.* (2016) compared soil quality indicators adjacent to gullies with the ones taken from the gully drainage area nearby. They found a significant reduction in soil quality for the soils near the gully and attributed the decline in *SQI* to changes in physical properties of the soil due to gully erosion. Chen *et al*. (2015) reported that due to desolation of gully walls, significant changes in soil structure, sensitivity to erosion, water holding capacity and soil organic carbon occurred that reduced soil quality in soils adjacent to gullies. In recent years, researchers have noticed changes in physical properties of soil due to gully development (Xu *et al.*, 2016; Chen *et al.*, 2015). Therefore, it is necessary to evaluate the effects of gully erosion on soil quality in different environmental conditions.

The objective of this research was to determine the effects of gully erosion on soil properties and soil physical quality within and adjacent to gullies and to ascertain the changes of soil quality and physical properties of gully walls and lands outside the gully.

MATERIALS AND METHODS

Study Area

To study the effect of gully erosion on soil properties and quality in various soil conditions, three sites were selected in Ardabil province of Iran with active gully erosion. The selected sites were Orta Dagh, Molla Ahmad, and Sarcham, located in north, center, and south of Ardabil province of northwestern Iran, respectively (Figure 1). Soil types and geographic and climatic characteristics are shown in Table 1.

Research Method

Gullies shallower than 3 feet depth at their head are classified as small gullies, in which soil erosion is active and have the greatest impact on neighboring soil (Poesen *et al.*, 2003). In order to study the effect of gullies on soil physical properties and soil quality indices, a number of small gullies with similar surface conditions were selected. Percentages of vegetation cover, gravel, and bare soil were measured in 10 one-square-meter plots randomly selected along a transect i.e. outside the gullies. For this purpose, a 1×1 m^2 frame was laid down randomly to mark out a specific area. Within the quadrat frame, the occurrence of vegetation and gravel was recorded. Furthermore, the final soil water infiltration rate was measured at three sites by single ring method with three replications, and the hydrologic group of soil was determined (Reynolds *et al.*, 2002). The Curve Number (CN) that indicates the severity of runoff was determined using the cover type and soil hydrological group (Rafahi, 2006). Digital Elevation Model (DEM) with pixel size of 5 m for each site was determined using Global Mapper 14 Software. Surface area, perimeter and Miller shape coefficient were also

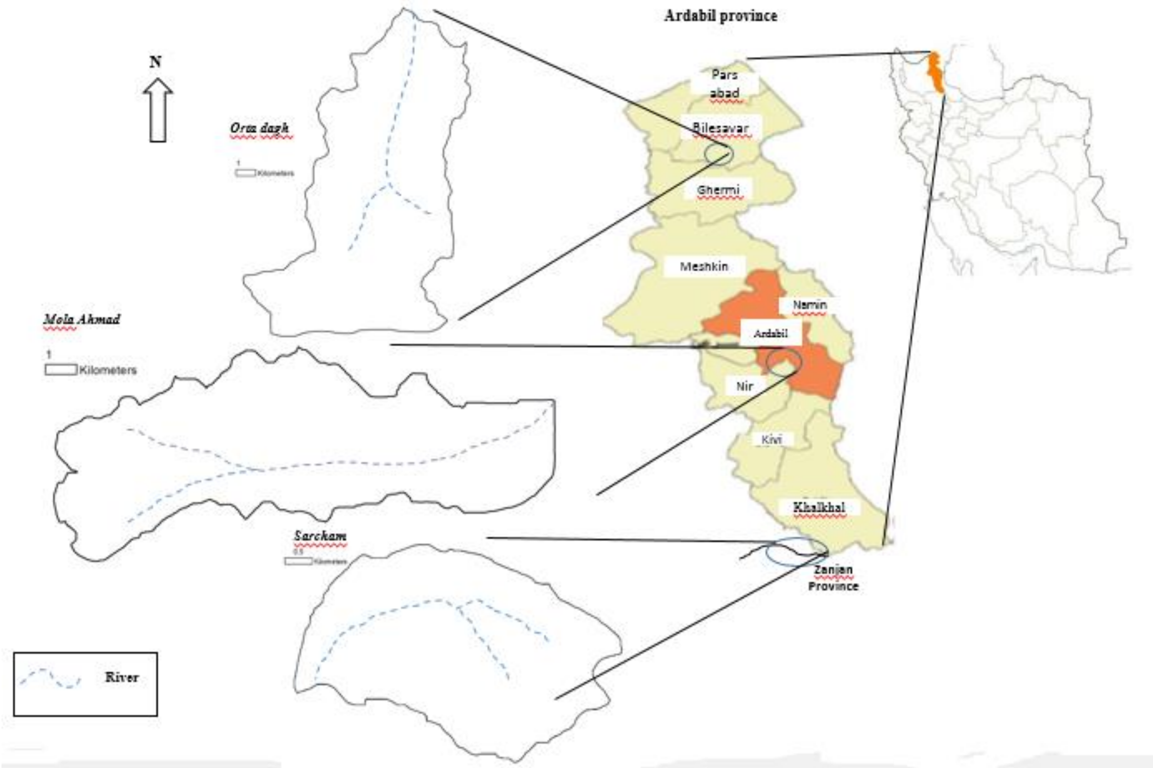

Figure 1. Location of the study areas in Iran and Ardabil province.

Table 1. Study area climate and geographic conditions.

(Site)	Area (ha)	Longitude	Latitude	Annual mean precipitation (mm)	Annual mean Temperature (°C)	Climate classification (Do marten developed)	Soil group
Orta Dagh	2727	47°56'41" to 47°52'47"	39º14'06" to 39°18'42"	271.2	15.1	Semiarid	Haplocalcids
Mola Ahmad	5038	48°12'14" to 48°21'50"	38°04'57" to 38°07'37"	303.9	9	Semiarid	Calcixerepts
Sarcham	1108	47°55'54" to 47°59'06"	37°08'11" to 37°10'10	384.6	8	Semiarid	Calcixerepts

measured. With the slope map layer in Geographical Information System (GIS), average slope of each site was determined.

In each study site, based on similarity of surface area, average slope, Miller shape coefficient, percentage of plant cover, and Curve Number (CN), the most similar gullies were selected using cluster analysis in SPSS19 software. The results of cluster analysis showed that 8 gullies in Ortadagh, 12 gullies in Molla Ahmad, and 10 gullies in Sarcham (total of 30 gullies) had the greatest similarity in properties. These sets of gullies were similar in surface cover and properties, but they had different soil types, therefore, their impacts on soil properties were studied. For this purpose, three points near the gully (less than 0.4 m from the gully wall, Figure 2) at linear distances of 25, 50, and 75% from the gully head were sampled. Three soil samples were taken from a transect outside the gullies (Figure 3) that served as

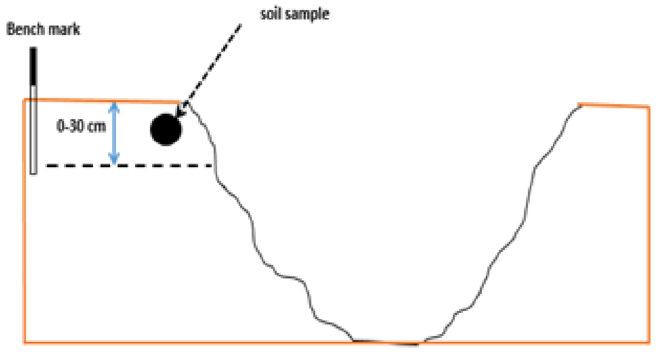

Figure 2. Schematic map of sampling from the gully wall.

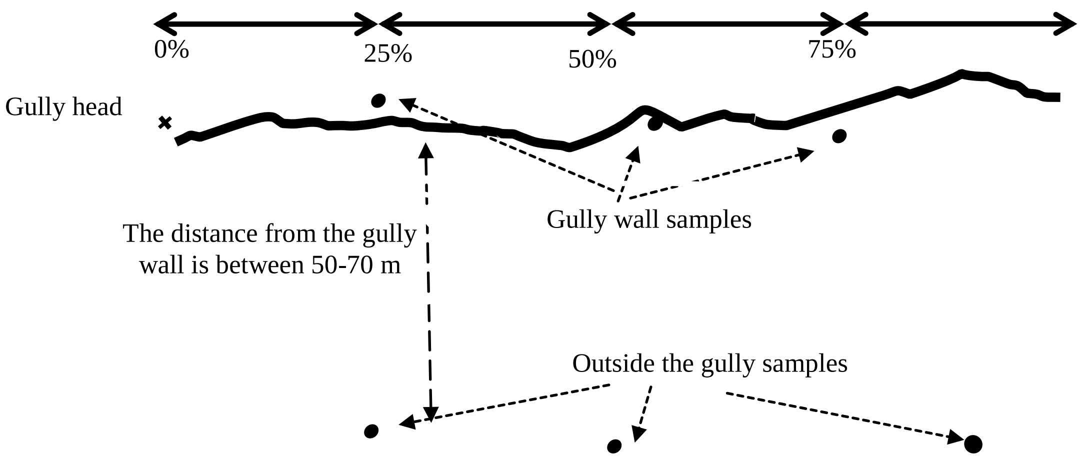

Figure 2. The position of soil samples along a transect and gully wall.

the baseline soil properties of the drainage area to compare with gully wall soil samples. Soil samples were collected from a depth of 0-30 cm. The reason for choosing the above three points along the gully length as replication of the soils in the vicinity of gullies, was that they were located in the middle reach of the gully stream and best represented the effects of gully erosion on soil quality.

The 15 soil physicochemical properties introduced in literature as factors affecting soil quality (Torbert *et al.*, 2008; Reynolds *et al.*, 2009; Qi *et al.*, 2009; Shahab *et al.*, 2013) were measured. These properties include the percentage of organic carbon (Walkley and Black, 1934), percentage of sand, silt, clay and dispersible clay (Gee and Bauder, 1986), Mean Weight Diameter (MWD) of aggregates by wet sieve method (Kemper and Rosenau, 1986), and structural stability index (Piei, 1950), Cation Rratio of Structural Stability (CROSS) (Marchuk and Rengasamy, 2010), bulk density and soil erodibility index (Wischmeier and Smith, 1978). Pressure plate apparatus was used to measure the water content of undisturbed soil samples at 0, 10, 30, 50, 100, 300, 500, 1,000, and 1,500 KPa pressure heads. The water retention curve was plotted using RETC6 software. Based on the data obtained from the retention curve, Air porosity (AC), Plant Available Water Content (PAWC), total porosity, Relative Field Capacity (RFC) (Reynolds *et al.*, 2009) and S index (Dexter, 2004) were determined. The 15 measured soil properties of gully walls and outside the gully soils were compared by *t*-test method (Xu *et al.*, 2016; Chen *et al.*, 2015). Based on analysis of variance test for normality (Shapiro and Wilk, 1965), the soil properties in this study were normally distributed.

To evaluate the effect of gullies on soil quality, soil quality indices were determined and comparison made between soils outside of gullies and those adjacent to the gully wall. In this study, the effect of gullies on four soil quality indices, mainly *IQI*, *NQI*, *CR* and *SI*, were evaluated. The above mentioned indices were compared by *t*-test.

To determine the *IQI* and *NQI* indices, scoring and weighting of soil properties affecting soil quality is necessary. Selected properties need to cover an extensive range of soil characteristics and yet have direct effect on soil quality (Wang and Gong, 1998). The 15 measured soil properties qualified. Since the selected properties have various units, they were converted to dimensionless variables in order to combine them in an overall index. For this purpose, the fuzzy membership function was used (Torbert *et al.,* 2008; Qi *et al.,* 2009; Chaplot, 2013, Ghaemi *et al.,* 2014b). In these functions, the range of a property that was optimal quality had one membership and the range with lowest quality had zero membership. Therefore, a function was obtained that scored the property between zero (the least favorable for soil quality) and one (most favorable for soil quality) (Qi *et al.,* 2009; Chaplot, 2013). Membership functions of the 15 measured properties were determined using MATLAB2010 software and scored for soil quality indices. In order to determine the weight of each soil characteristic, Factor Analysis (FA) with Principal Component Analysis (PCA) was performed. Communality (COM) of each property was determined and the ratio of communality to sum of communalities represented the weight of each property (Qi *et al.,* 2009; Xu *et al.,* 2016; Ranjbar *et al.,* 2016).

After the score and weight were determined for each of the 15 characteristics affecting soil quality, *IQI* and *NQI* soil quality indices were calculated by Equations (1) and (2) (Qi *et al.*, 2009, Ranjbar *et al.*, 2016):

$$IQI = \sum_{i=1}^{n} W_i N_i \quad (1)$$

Where, W_i is Weight of each property, N_i is score of each property, and n is number of used properties.

$$NQI = \sqrt{\frac{p_{ave}^2 + p_{\min}^2}{2}} \times \frac{n-1}{n} \quad (2)$$

Where, p_{avr} is mean scores properties, p_{min} is the minimum score of properties, and n is the number of used properties.

The other index for soil quality presented by Shukla *et al.* (2004) is Cumulative Rating (CR). In this method, each property is divided into five groups based on the critical value provided by Lal (1994). Then, each group is assigned a score of 1 (lowest quality) to 5 (highest quality) for that property. Sum of those scores for soil properties represented the *CR* index. In this method, the *CR* increases as the soil quality decreases. Another soil quality index is the Sustainability Index (SI) which is obtained from the arithmetic mean of five properties, including soil depth, organic carbon percentage, bulk density, Plant Available Water Content (PAWC) and percentage of Water Stable Aggregates (WSA) (Singh and Khera, 2009, Ghaemi *et al.*, 2014a).

By comparing 15 soil physical properties and five soil quality indices (IQI, NQI, CR, and SI) between gully wall and outside the gully, the effect of gully erosion on soil physical quality was evaluated.

RESULTS AND DISCUSSION

After determining the physical properties of soils and soil quality indices of gully wall and outside the gully soils at each site, paired comparison (t-test) between the two gully areas was performed. Tables 2, 3, and

Table 2. Comparison of soil property means of gully wall and soil outside the gully in Orta Dagh site.

		Outside the gullies		Gully walls	
Soil properties	Sig probe	Standard deviation	Mean	Standard deviation	Mean
OC	0.04	0.5	1.1	0.38	0.9
SI	0.4	2.27	4.7	2.28	4
AC	0.89	0.5	3.1	1.4	3
PAWC	0.03	7.6	39	7.3	34
RFC	0.5	0.04	0.93	0.02	0.92
MWD	0.02	1.4	2.9	1.3	2.3
CROSS	0.005	1	2	21	14
BD	0.4	0.18	1.44	0.13	1.4
S index	0.02	0.013	0.085	0.026	0.06
Porosity	0.4	0.07	0.54	0.04	0.53
Erodibility index	0.008	4	40	11	47
Dispersible clay	0.02	10	13	9	19
Clay	0.02	5.5	22	6.5	26
Sand	0.09	13	55	9	61
Silt	0.3	5	17	8	19

Table 3. Comparison of soil property means for gully wall and soils outside the gully in Molla Ahmad site.

		Outside the gullies		Gully walls	
Soil properties	Sig probe	Standard deviation	Mean	Standard deviation	Mean
OC	0.03	0.58	1.5	0.53	1
SI	0.4	3	5.8	2.9	5.2
AC	0.02	1.3	2.5	1.15	1.7
PAWC	< 0.001	7.8	0.51	7.6	0.44
RFC	0.01	0.02	0.97	0.03	0.94
MWD	0.04	1	1.8	1	1.2
CROSS	0.03	0.7	0.6	1	1.8
BD	0.7	0.17	1.3	0.16	1.3
S index	0.03	0.04	0.12	0.03	0.09
Porosity	0.7	0.06	0.52	0.07	0.51
Erodibility index	< 0.001	3.5	43	7	49
Dispersible clay	0.8	14	41	18	43
Clay	0.8	4	13	6	14
Sand	0.3	7	51	8	53
Silt	0.1	5	34	6	32

4 present the results of mean comparison for 15 soil properties for Orta Dagh, Molla Ahmad and Sarcham sites, respectively.

In Orta Dagh, eight soil properties changed significantly in the gully walls. *OC*, *PAWC*, *MWD* and S index decreased significantly in gully walls, but erodibility index, *CROSS*, percentage of clay and dispersible clay increased significantly. Reduction of the *MWD* indicates that gully erosion reduces aggregate stability, and the decreasing S Index confirms this. *S* Index represents the slope of the water retention curve at the inflection point, which mostly reflects the microstructural porosity. Therefore, it is proposed to govern directly many of the principal soil physical properties. The presence of structural pores and a corresponding large value of S index are essential for good soil quality (Dexter, 2004). Destruction of the soil structure and erosion of surface soil by runoff decreases *OC*, which in turn may intensify aggregates instability (Xu *et al.*, 2016). Decrease in *PAWC* may occur as a result of aggregate destruction and *OC* reduction. Lal (1998) reported that soil erosion could create significant changes in soil properties such as nutrient content, soil texture, soil structure, and water holding capacity.

In areas outside the gully, the higher clay content, as well as *CROSS*, may be due to differential erosion of fine particles from the gully, which leaves the coarse material on gully walls. As a result, fine particles and Na and K ions are transported by runoff into gullies from gully walls. Increase of *CROSS* causes aggregate instability, hence the dispersible clay. Xu *et al.* (2016) stated that the soil particles eroded from the gullies may be deposited, which further affects soil quality changes. It seems that destruction of the soil structure, decreases in soil organic matter, and changes in soil texture may occur as a result of depletion of the fine particles near gully walls. Weesies (1994) found that a little increase in the gully erosion led to 16-39% decrease in organic matter, 29-38% decrease in total P, and 11-35% increase in clay content in three types of soils in India. This is consistent with OC and clay content in our research. Fahnestock *et al.* (1995) also reported that soil erosion reduced organic matter by 67-72% and water stable aggregates 27-30%, while bulk density increased 20-23% which caused a severe reduction in soil quality.

Also, at the Molla Ahmad site, eight properties changed significantly in gully wall compared to outside gully soils. In this site, *OC*, *PAWC*, *RFC*, *MWD* and S index decreased but CROSS and soil erodibility increased. The decrease in the *MWD*, *S* index and *OC* reflects destruction of the soil structure due to gully development. According to Table 3, soil destruction in Molla Ahmad was more severe than Orta Dagh. In addition, *PAWC*, *RFC*, *AC* and *S* index are considered as soil physical indicators and they affect the plant growth. Obade and Lal (2016) emphasized the effect of organic carbon reduction and soil structure degradation on reducing soil quality. The *CROSS* on this site was significantly increased but it was less than at Orta Dagh. Shellberg *et al.* (2016) found that the development of gully in response to land use change increased soil salinity and decreased soil stability during a period of 70 years. In Molla Ahmad, as well as Orta Dagh, reduction of *OC* and destruction of soil structure increased soil erodibility. The impact of soil erosion on soil properties depends on soil type, soil fertility, management and the severity of gully erosion (Lal, 1998).

In Sarcham, like the other two sites, eight soil properties changed significantly in gully walls compared to outside the gullies. *OC*, Stability Index (SI), *MWD*, *S* index, total porosity, and silt content decreased and *CROSS* and soil erodibility index increased. These results showed that the effect of gully development on gully walls was similar to the other two sites with destruction of the soil structure through loss of organic carbon and changes in soil texture by differential erosion, increase in erodibility, and increase in salinity of soil. In this site, moisture properties reflecting the soil quality did not change. Xu *et al.* (2016) found that the decrease of organic matter near the gully soils was 4-6.9%, while changes in bulk density, *MWD*, and soil erodibility were 6.1-14.2%. Also, Shellberg *et al.* (2016) reported that soil organic matter increased in the second and third stages of gully formation, but obviously decreased in the first stage because of sediment deposition (Table 4).

In general, the effect of gully development on soil properties adjacent to gullies in all three sites was reduction in *OC*, *S* index, degradation of aggregates, shift in soil texture, increase in the *CROSS*, and increase in soil erodibility. Similar to our research, Chen *et al.* (2015) found that silt and clay content near the gullies increased due to sediment deposition. Xu *et al.* (2016) also found that soil erodibility increased 12-29%

Table 4. Comparison of soil property means for gully wall and soils outside the gully in Sarcham site.

		Outside the gullies		Gully walls	
Soil properties	Sig probe	Standard deviation	Mean	Standard deviation	Mean
OC	0.04	0.17	0.9	0.2	0.7
SI	0.03	1.3	3.6	1	2.7
AC	0.8	1.3	3.4	1.3	3.3
PAWC	0.7	0.07	0.35	0.06	0.33
RFC	0.9	0.04	0.92	0.03	0.92
MWD	0.02	0.3	0.9	0.5	0.6
CROSS	0.03	9	14	12	21
BD	0.4	0.2	1.4	0.2	1.5
S index	0.008	0.01	0.06	0.02	0.04
Porosity	0.004	0.06	0.55	0.07	0.44
Erodibility index	0.003	2	45	7	51
Dispersible clay	0.5	9	14	8	12
Clay	0.9	7	27	7	27
Sand	0.2	13	56	13	52
Silt	0.04	6	21	11	14

due to gully development. They also reported that clay content decreased and sand increased (Xu *et al.*, 2016). Liu *et al.*, (2013) showed that soil properties 10 m away from gullies edge changed completely.

Four cumulative indices of soil quality, including *IQI*, *NQI*, *CR* and *SI* were calculated based on the 15 soil properties. For this purpose, mean paired comparison of these indices was made between gully wall and outside the gully soils. The results are shown in Tables 5, 6, and 7 for Orta Dagh, Molla Ahmad and Sarcham, respectively. Analysis of data showed that formation and development of gullies reduced soil quality indices at gully walls, which corroborates with studies by others (Chen *et al.*, 2015; Xu *et al.*, 2016; Obade and Lal, 2016).

In general, at Orta Dagh site, all soil quality indices, except *CR*, at Molla Ahmad all four indices, and at Sarcham, all of the indices, except *SI* in gully walls, significantly changed compared to outside the gullies. The results revealed that soil quality outside the gullies was better than adjacent to gully walls; therefore, gully formation reduced soil quality in all three sites. As mentioned earlier, any increase in *IQI*, *NQI* and *SI* positively changes soil quality but increasing *CR* decreases soil quality. Although in several researches the effect of erosion on soil quality has been studied (Singh and Khera, 2009; Qi *et al.*, 2009; Obade and Lal, 2016), very few have worked on the effect of soil erosion, especially gully erosion, on cumulative soil quality indices. Xu *et al.* (2016) by comparing *SQI* (like IQI) between vicinity of gullies soils and lands without gully showed that gully development reduced soil quality index from 10.6 to 36.6%. They also showed that *SQI* in 30 cm depth changed more than in the 10 cm depth (Xu *et al.*, 2016). Among the cumulative indices in our study, CR and SI indices provided a quick estimate of soil quality and its changes (Singh and Khera, 2009; Shahab *et al.*, 2013). The relationship between these two indices and soil erosion has been expressed by Singh and Khera (2009). However, for determining these indices semi quantitatively, discontinuous and available reports of soil quality methods are used (Shukla *et al.*, 2004; Lal, 1994). Therefore, a semi quantitative i.e, partly based on personal judgment, assessment of soil quality was obtained. For *IQI* and *NQI* methods, fuzzy membership functions were used that are

Table 5. Comparison of mean soil quality indices for gully wall and soil outside the gully in Orta Dagh site.

		Outside the gullies		Gully walls	
Soil quality indices	Sig probe	Standard deviation	Mean	Standard deviation	Mean
SI	0.04	1.6	10.8	1.5	9.3
CR	0.1	5	22	3	24
IQI	0.005	0.03	0.39	0.02	0.34
NQI	0.002	0.03	0.35	0.02	0.31

Table 6. Mean comparison of soil quality indices for gully wall and soils outside the gully in Molla Ahmad site.

		Outside the gullies		Gully walls	
Soil quality indices	Sig probe	Standard deviation	Mean	Standard deviation	Mean
SI	< 0.001	1.5	11.2	1.5	8.1
CR	0.04	5	21	4	24
IQI	0.001	0.04	0.38	0.03	0.31
NQI	< 0.001	0.05	0.36	0.03	0.29

Table 7. Mean comparison of soil quality indices for gully wall and soils outside the gully in Sarcham site.

		Outside the gullies		Gully walls	
Soil quality indices	Sig probe	Standard deviation	Mean	Standard deviation	Mean
SI	0.1	1.5	8	1.3	7.1
CR	0.02	3	20	2	16
IQI	0.001	0.02	0.33	0.01	0.27
NQI	0.02	0.02	0.33	0.02	0.31

quantitative and continuous (Chaplot, 2013). Hence, *IQI* and *NQI* indices are more precise, but need complicated calculations (Ranjbar *et al.*, 2016).

CONCLUSIONS

The effect of gully development on soil quality indices at gully walls in semi-arid areas, especially in Iran, has not been studied previously. For this purpose, five soil quality indices, including Integrated Quality Index (IQI), Nemero Quality Index (NQI), Cumulative Rating (CR), and Sustainability Index (SI) were compared between gully wall and undisturbed soils outside the gullies of three sites in Ardabil province in northwestern Iran. The results showed that in all three sites, 8 out of 15 soil properties negatively changed in gully walls. Most soil quality indices decreased due to gully development. According to the results of this research, it can be concluded that gully formation and development reduced soil quality in soils adjacent to gully walls.

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تاثیر فرسایش آبکندی بر شاخص های کیفیت خاک در شمال غرب ایران

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چکیده

فرسایش آبکندی به روش‌های مختلف بر ویژگی‌های خاک تاثیر می‌گذارد. یکی از مهم‌ترین اثرات فرسایش آبکندی، تخریب ساختمان خاک و کاهش کیفیت آن است. هدف این پژوهش مطالعه اثرات توسعه آبکند بر ویژگی‌ها و شاخص‌های کیفیت خاک مجاور آبکندها بود. برای این هدف ۱۵ ویژگی و ۵ شاخص کیفیت خاک شامل شاخص کیفیت تجمعی (IQI)، شاخص کیفیت نمرو (NQI)، رتبه تجمعی (CR) و شاخص پایداری (SI) بین خاک‌های دیواره آبکندها و خارج آبکندها در سه ناحیه از استان اردبیل واقع در شمال غرب ایران مقایسه شدند. روش t-test با سه تکرار برای مقایسه مورد استفاده قرار گرفت. نتایج نشان داد در هر سه ناحیه، ۸ ویژگی از ۱۵ ویژگی خاک دیواره آبکندها تغییر یافتند، که عمدتا نشان دهنده کاهش ساختمان خاک، کربن آلی و شاخص S (شیب منحنی رطوبتی در نقطه عطف) و افزایش نسبت کاتیونی پایداری ساختمان خاک (CROSS) و شاخص فرسایش پذیری خاک است. همچنین بیشتر شاخص‌های کیفیت خاک در اثر توسعه آبکندها در هر سه ناحیه کاهش یافتند. بنابراین تشکیل و توسعه آبکندها در هر سه ناحیه کیفیت خاک در دیواره آبکندها را کاهش داد.