Relationship between Gully Development and Characteristics of Drainage Area in Semi-Arid Region, NW Iran

Ali Reza Vaezi, Ouldouz Bakhshi Rad

***Abstract*—**Gully erosion is a widespread and often dramatic form of soil erosion caused by water during and immediately after heavy rainfall. It occurs when flowing surface water is channelled across unprotected land and washes away the soil along the drainage lines. The formation of gully is influenced by various factors, including climate, drainage surface area, slope gradient, vegetation cover, land use, and soil properties. It is a very important problem in semi-arid regions, where soils have lower organic matter and are weakly aggregated. Intensive agriculture and tillage along the slope can accelerate soil erosion by water in the region. There is little information on the development of gully erosion in agricultural rainfed areas. Therefore, this study was carried out to investigate the relationship between gully erosion and morphometric characteristics of the drainage area and the effects of soil properties and soil management factors (land use and tillage method) on gully development. A field study was done in a 900 km^2 agricultural area in Hshtroud township located in the south of East Azerbaijan province, NW Iran. Toward this, 222 gullies created in rainfed lands were found in the area. Some properties of gullies, consisting of length, width, depth, height difference, cross section area, and volume, were determined. Drainage areas for each or some gullies were determined, and their boundaries were drawn. Additionally, the surface area of each drainage, land use, tillage direction, and soil properties that may affect gully formation were determined. The soil erodibility factor (K) defined in the Universal Soil Loss Equation (USLE) was estimated based on five soil properties (silt and very fine sand, coarse sand, organic matter, soil structure code, and soil permeability). Gully development in each drainage area was quantified using its volume and soil loss. The dependency of gully development on drainage area characteristics (surface area, land use, tillage direction, and soil properties) was determined using correlation matrix analysis. Based on the results, gully length was the most important morphometric characteristic indicating the development of gully erosion in the lands. Gully development in the area was related to slope gradient ($r = -0.26$), surface area ($r = 0.71$), the area of rainfed lands ($r = 0.23$), and the area of rainfed tilled along the slope ($r = 0.24$). Nevertheless, its correlation with the area of pasture and soil erodibility factor (K) was not significant. Among the characteristics of drainage area, surface area is the major factor controlling gully volume in the agricultural land. No significant correlation was found between gully erosion and soil erodibility factor (K) estimated by the USLE. It seems the estimated soil erodibility cannot describe the susceptibility of the study soils to the gully erosion process. In these soils, aggregate stability and soil permeability are the two soil physical properties that affect the actual soil erodibility and in consequence, these soil properties can control gully erosion in the rainfed lands.

***Keywords*—**Agricultural area, gully properties, soil structure, USLE, Universal Soil Loss Equation.

I. Introduction

GULLY erosion is the formation and subsequent expansion of erosional channels in the soil as a result of concentrated water flow. Gullies are defined as open, unstable channels that have been cut more than 30 cm deep into the ground [1]. Formation of gully is influenced by various factors including the factors that exceed the threshold level in an area. Drainage surface area, slope gradient, vegetation cover, land use, soil properties, along with climate variables are some main factors influencing gully development in catchments. Morphometric characteristics of gully such as length, width, depth, cross section area, and volume can be applied to study gully development. Gully erosion is also one of the most important types of water erosion in semi-arid regions, where vegetation cover is weak and soils are weakly aggregated.

Many researchers have attempted to study gully development and influencing factors to make some programs to control it around the world. For example, result of a study on the effect of soil physical properties on the development of gullies showed that clay and topography are the most important factors influencing gully development [1]. In other study, researchers found that rainfalls with intensity higher than 40 mm/h a long with human factors are the most important factors in the development of gully erosion [2]. Land use is also a major factor influencing water erosion in most regions. The change of pasture to agricultural land and conventional tillage are two major factors controlling soil erosion in the region [3]. Gully erosion is a major environment problem in semi-arid regions, where soils have lower organic matter and are weakly aggregated. Intensive agriculture and tillage along slope can accelerate soil erosion by water in the lands. There is little information on development of gully erosion in agricultural areas in semi-arid regions. Therefore, this study was carried out to quantify gully development and find the relationship between gully formation and morphometric characteristics of drainage area in an agricultural area of semi-arid region in Iran.

II. Materials and Methods

This study was conducted in an agricultural area with 900 km^2 in area in Hashtroud township, in East Azerbaijan

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province, north west of Iran. The region was classified as a semi-arid climate with an average annual precipitation of 340 mm and a mean annual temperature of 13 °C. Lands are mostly located in 5 to 15% slopes. A square agricultural area of 30 km × 30 km was selected in the area and divided into 36 grids with dimensions of 5 km × 5 km (Fig. 1). In each grid, a drainage area involving one gully or several gullies was selected. Gully erosion is an important water erosion kind in the area that divides rainfed lands and decreases soil productivity (Fig. 2). In each study gully, three to five points were determined and gully properties consist of land length (R), width (W) and depth (D), the height difference, cross section area and volume were determined. The ratio of the width to depth of the gully as a factor form was computed. The difference height between the head cut and bottom of the gully (H) was measured and the horizontal length factor (L) was calculated by (1) and (2):

$$L^2 = R^2 - H^2 \tag{1}$$

$$S = (H / R) \times 100 \tag{2}$$

The cross-section area and volume of gully were determined using:

$$A = ½\, W \times H \tag{3}$$

Also, the volume of gully was determined using:

$$V = A \times R \tag{4}$$

Drainage areas for each or several gullies created in each drainage area were determined and their boundaries were drawn using the Global Positioning System (GPS). Some characteristics of drainage areas including the area of drainage surface, land uses (rainfed land and pasture), tillage direction (along slope and on contour lines) along with soil properties were determined. Kind of land uses (rainfed wheat and pasture) was identified in each drainage area and surface area for each one was determined.

In order to measure the soil physicochemical properties, soil samples were taken from a depth of 0-30 cm along the gully in each drainage area. Bulk density was determined in soil sample taken using a cylinder [4] at a height of 7 cm and a diameter of 7.4 cm. To determine the stability of aggregates, soil samples were sieved and aggregates with a diameter of 6 to 8 millimetres were selected. Particle size distribution was determined by the hydrometric method [5], soil pH was measured by pH meter in saturated mud [6] and electrical conductivity (EC) was measured in saturated mud extracted from soil sample by EC-meter [7]. In order to determine lime, the equivalent calcium carbonate was measured using acid acetic volume consumed to neutralize carbonate [8]. Organic carbon content was determined by the Walkley and Black method [9]. The stability of aggregates in 100 g of sieved soil samples was determined by isolating the stable aggregates in water [10] for 1 minute, and the weighted average diameter of stable aggregates in water was calculated. The permeability of the soil was determined by double ring method with a height of 30 cm and diameter of 30 and 60 cm [11].

In order to estimate the soil erodibility factor (K) in the USLE, five soil properties including very fine sand and silt, coarse sand, organic matter, soil structure code and permeability class were used based on [12]:

$$K = 2.8 \times 10^{-7} M^{1.4} \times (12\text{-OM}) + 4.3 \times 10^{-3} (b\text{-}2) + 3.3 \times 10^{-3} (c\text{-}3) \tag{5}$$

where M is the multiplication of (100- % clay) and (% silt + % very fine sand), OM is the percentage of organic matter, b is the soil structure class and c is the soil permeability class.

The correlation analysis (Pearson method) was used to investigate the relationship between gully development criteria (length, width, etc.) and the drainage area characteristics (surface area, land use, tillage direction and soil properties). Stepwise regression analysis was used to determine the most important factor in the development of gullies.

III. Results and Discussions

The results of gully morphometric properties were shown in Table I. The length of gullies varies from 52 to 2087 m and the difference height between head cut and gully bottom is about 43 m. They are mostly wide (3-30 m) and shallow (1-6 m). Gullies develop speedily in the area, so that their volume varies from 150 to 35088 m^3, indicating soil loss ranging from 200 to 4700 ton. It is in agreement with findings of [13] in Idah-Ankpa plateau of the Anambra Basin in Nigeria.

Among the morphometric characteristics, the gully length is the most important characteristic to express the development of gully erosion in the region. So, with an increase in the gully length, the volume of the gullies in the area increases drastically. In agreement to this result, in some studies, researchers concluded that gully length is a key factor in determining the extent of golly erosion [14], [15]. In another study, a strong correlation between sediment volume and gully length was found and was stated that gully length plays an important role in estimating gully volume [16]. Results indicated that a significant positive relationship is between the gully volume and gully width. This result is in consistent with the findings of previous study on gully erosion in Mediterranean environments [14].

TABLE I
Morphometric Properties of Gullies in the Study Area

Gully property	Average
Length (m)	464
Difference height (m)	43
Width (m)	12
Depth (m)	1.5
Volume (m^3)	5032
Soil loss (ton)	6790

Table II shows results of the drainage area characteristics in the area. The study of the drainage area characteristics showed that gullies have developed in the areas with 1.5 to 45 ha surface area. They are mostly developed in the two land use types:

pasture and rainfed lands. Pastures contain about 42% drainage surface area in the study area, whereas rainfed lands cover about 58%.

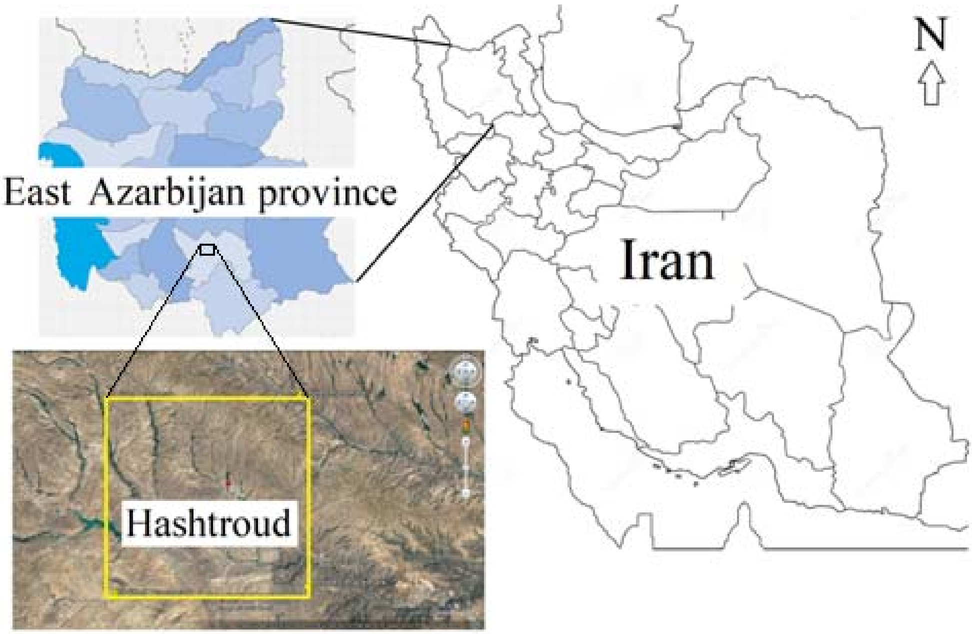

Fig. 1 Location of the study area in south of East Azerbaijan province, NW of Iran

(a) (b)

Fig. 2 An aerial view of gully development in the area (a) and a cross section view of gully erosion created in a rainfed land in the area, Hashtroud, NW Iran (b)

Gullies are mostly developed in rainfed areas (58%) and out of them about 67% are tilled along slope. This improper farming practice along with operation of conventional tillage increases the soil susceptibility to water erosion processes. More production of surface flows and their concentration in farm downstream causes channel erosion such as rill erosion. During early autumn and spring, heavy rainfalls produce more runoff and in consequence higher soil loss in the rills. Gully erosion in these lands is a result of development of the rill erosion especially in steep slopes. This result indicated that tillage up to down slope is a main factor controlling gully erosion in in rainfed lands in the area. The change of tillage direction from along slope to contour lines and conservation tillage are the first strategy to control water erosion in these lands. Study of effect of tillage direction on runoff and soil loss showed that both variables increased about 5.5 and 35 times in plots cultivated up to down slope as compared with contour cultivated plots [17].

TABLE II
THE CHARACTERISTICS OF THE DRAINAGE AREA COVERING GULLIES IN THE STUDY AREA

Drainage area characteristic	Average
Surface area (ha)	9.6
Slope gradient (%)	10.6
Pasture area (%)	42
Rainfed area (%)	58
Shape factor	9

Physicochemical analysis of soil properties showed that the soils in the area are clay loam with 36.7% sand, 31.6% silt and 32% clay. The soils have lower organic matter content (1.1%) which is related to intensive culture and conventional soil tillage. The soils are calcareous with 12.7% calcium carbonate equivalent. The water-aggregate stability of the soils is very low indicating the soils are weakly aggregated and soil structure code is 3, on average. Soil infiltration rate is about 3.5 cm/h and soil permeability class is mostly 3. The soil erodibility factor values estimated using the USLE nomograph were also between 0.025 and 0.049 t h MJ^{-1} mm^{-1} with an average of 0.035 t h MJ^{-1} mm^{-1}. Lower organic matter content and weaker aggregate stability make the soils sensitive to erosive factors (Table III).

Results of the correlation matrix indicated that the gully development was significantly correlated with slope gradient ($r = -0.26$, $p < 0.05$), surface area ($r = 0.71$, $p < 0.01$), rainfed surface area ($r = 0.23$, $p < 0.05$) and surface area of rainfed lands tilled along slope ($r = 0.24$, $p < 0.05$), while no significant correlations were found between gully development and pasture area, tillage on contour line and soil erodibility factor, K (Table IV). Negative correlation between gully development and slope gradient in the area can be related to lower slope gradient of rainfed lands as compared with pasture. In other words, steep slopes in the area are under pasture cover while pastures with gentle slopes have mainly changed to rainfed farms in the past decades.

Previous research on the effects of the change of pasture to winter wheat farm on runoff and soil loss in semi-arid in Iran showed that runoff and soil loss increased in the change lands by 13 and 60 times compared to pasture [17]. The results indicated the gullies mostly developed in both large drainage surface area and the lands under rainfed cultivation. Tillage along slope is a main factor influencing gully erosion in these lands in the area.

There was no significant relationship between gully erosion and soil erodibility factor (K) estimated in the USLE mode. Previous study in the area showed that the USLE nomograph over-estimates the soil erodibility in the semi-arid soils, because of the soils are calcareous and have lower organic matter content [3]. In this area, the positive role of aggregate stability and soil permeability in decreasing the soil susceptibility to water erosion has well known. However, the estimated soil erodibility could not describe the susceptibility of the study soils to gully erosion process.

TABLE III
PHYSICOCHEMICAL PROPERTIES IN THE AREA

Soil property	Mean value
Sand (%)	36.4
Silt (%)	31.6
Clay (%)	32.0
BD (g/cm^3)	1.4
MWD (mm)	1.1
K_S (cm/h)	8.1
Gravel (%)	9.9
OM (%)	1.1
$CaCO_3$ (%)	12.7
Infiltration (cm/h)	3.5
Soil erodibility factor (t h /$MJ^{-1}mm^{-1}$)	0.035

TABLE IV
CORRELATION MATRIX BETWEEN GULLY DEVELOPMENT AND DRAINAGE AREA CHARACTERISTICS IN THE STUDY AREA

	Slope gradient	Surface area	Pasture area	Rainfed area	Tillage along slope	Tillage on contour line	Soil erodibility factor	Gully development
Slope gradient	1							
Surface area	-0.11	1						
Pasture area	0.17*	0.01	1					
Rainfed area	-0.08	0.11	-0.21*	1				
Tillage along slope	-0.07	0.02	-0.76**	0.17*	1			
Tillage on contour line	-0.11	0.01	-0.46**	0.09	-0.21*	1		
Soil erodibility factor	0.09	-0.04	0.07	0.13	0.18*	0.07	1	
Gully development	-0.26*	0.71**	0.03	0.23*	0.24*	-0.10	0.01	1

IV. CONCLUSION

Gully erosion was investigated in an agricultural area in a semi-arid region in north west of Iran to find factors controlling gully erosion. Toward this, gully development was quantified based on the gully volume in 222 gullies created in rainfed lands. Additionally, morphometric characteristics, soil properties and soil management factors (land use and tillage direction) were determined for each drainage area covering gully erosion. Significant correlations were found between gully development and slope gradient, drainage surface area, the area of rainfed lands, and surface tillage along the slope. Drainage surface area is the major factor controlling gully development in the area. No significant correlation was found between gully erosion and soil erodibility factor (K), while aggregate stability and soil permeability are the two soil physical properties influencing gully erosion in the rainfed lands. Therefore, the hillslopes with large drainage surface area and having lower structure stability and soil permeability are the most susceptible lands to gully development in the semi-arid regions.

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