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Case Study

The effect of aggregates stability and physico-chemical properties of gullies' soil: a case study of Ghori-chai watershed in the Ardabil province, Iran

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ABSTRACT:

Soil erosion, "particularly gully erosion" is considered as the most important factors of land degradation in semi-arid regions, since Iran is located in a semi-arid region, it is highly susceptible to degradation and erosion. The current study done on land was exposed to erosion in the Ghori-chai watershed, Ardabil province. In order to know the soil samples, they were collected from the gully heads of two depths (0-30, 30-60 cm) (the active points of gullies). Physico-chemical properties of soil samples were analyzed in the field and laboratory. GMD (Geometric Mean Diameter) and MWD (Mean Weight Diameter) factors were used to determine the sensitivity of the gullies' soil to erosion. Using the statistical software R, multivariable regression, and simple linear stepwise regression were applied in order to determine the relationship between soil physico-chemical properties and aggregates stability. Chi-square was used to compare parameters and differences test. Aggregate stability was low on the gullies land, and soil stability has severe and very severe limitations in this region. However the considerable organic carbon is a positive factor in aggregates stability, but high SAR (Sodium Absorption Ratio) and unsuitable land use have recognized to aggregates instability. The amounts of SAR and OM (Organic Matter) and silt/(clay+sand) also were analyzed in both the depths and showed that the amount of SAR and OM have significant alternation (changes) in various depths and gullies. However, the amounts of MWD did not show any significant alternation in deeps and gullies.

Keywords:

Aggregate stability, Geometric Mean Diameter (GMD), Mean Weight Diameter (MWD), Soil sensitivity, R software.

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INTRODUCTION

Soil erosion by water is one of the most important processes of land degradation, particularly in semi-arid areas is considered. Among the different types of water erosion, gully erosion is one of the most important events contributing to the destruction of soil, change the perspective of land and water resources and lands are regressive (Ahmadi, 2006). Gully erosion, a severe type of soil erosion, is a process whereby runoff water accumulates and often recurs in narrow 'V' or 'U' shaped channels with considerable depth (Poesen *et al*., 2003). Gully erosion starts with overland flow, which erodes small rills as flow concentrates in separate channels. Over time, rills may develop into gullies, causing significant soil loss and land degradation (Poesen *et al*., 2003; Valentin *et al*., 2005). Gullies are composed of several continuous or discontinuous channels and rills with varying slopes, which may later develop into deep trenches, inhibiting effective remediation by tillage (Bocco 2016; Knighton 1998; Thomas *et al*., 2004; Vanwalleghem *et al.,* 2005). Gully formation and growth are governed by natural and anthropogenic factors such as: topography, soil type and texture, vegetation type and cover, precipitation amount and duration, freeze-thaw cycles, and agricultural activities (Lal,1994; Janeau *et al*., 2003; Reusser *et al.,* 2015). Approximately two third of the 3031 million hectares of potential arable land worldwide is degraded.

Globally, natural erosion is estimated to a total of 9.9 billion tons of soil a year (Lal, 1990). Based on the results of the recent research, this type of erosion effect on the environment from two aspects: a) the destruction of the surface and underlying soil horizons, is leading to large sediment production and destruction of the bed, b) exacerbated discharge of surface runoff and reduce the volume of groundwater flow through the short connections between upstream and downstream areas (Poesen *et al*., 2003).

According to the changes in the contribution of this type of erosion in sediment production in different watershed, the range of gully erosion is estimated between 10-94 percent in different parts of the world (Poesen *et al*., 2003). The contribution of gully erosion in land degradation and soil erosion is not only lower

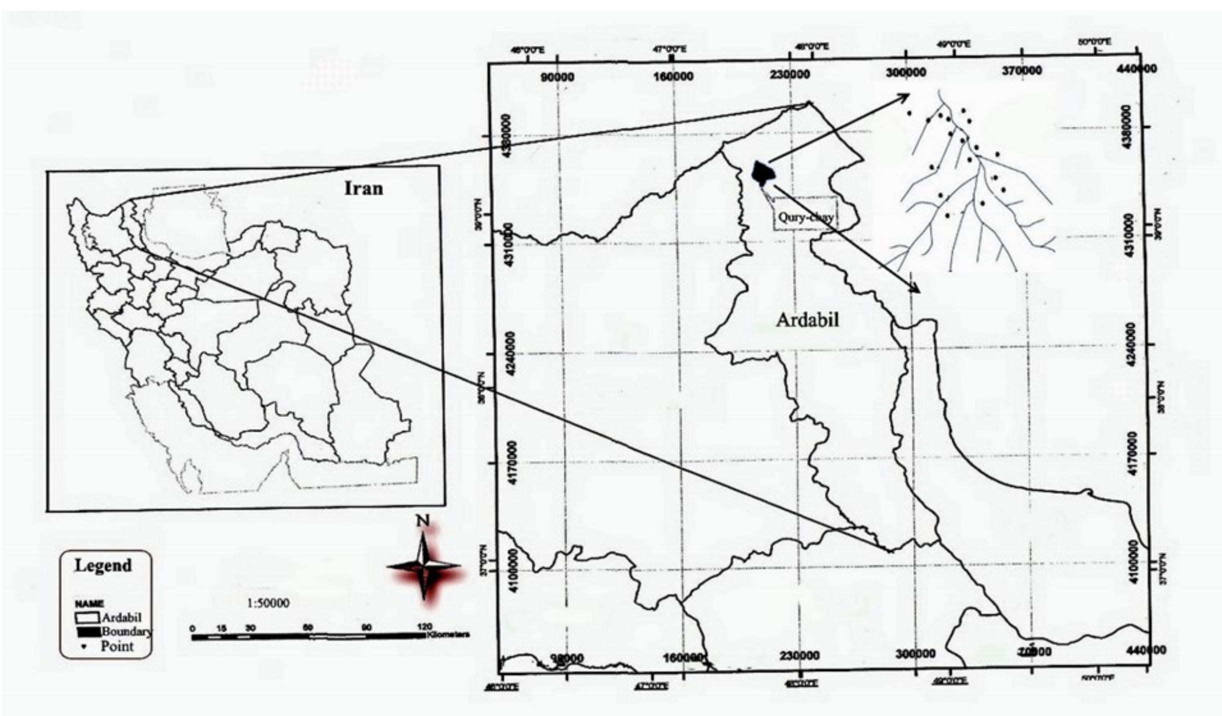

Figure 1. Location of the study area

Table 1. Testing difference within and between data, using Chi-square test

Parameters		MWD		OM		SAR	
Depth (cm)		0-30	30-60	0-30	30-60	0-30	30-60
Different test	Within data	4.74	1.50	78.3**	60.2**	87.2**	76.3**
	Between data	19.9		77.3**		124**	

** The significant level at 99 percent
(OM: Organic Matter; MWD: Mean Weight Diameter; SAR: Sodium Absorption Ratio)

than other erosions types, but also in many cases this type of erosion, is the source of much sediment production in watersheds. For example, the contribution of the gully erosion in Australia was of 37 percent (Wasson *et al.,* 1996) and in China and Belgium it was 78 and 30-40 percent, respectively (Vandaele *et al.,* 1996). So soil structure has important influences on edaphic conditions and the environment. The structure is often measured by the stability of soil aggregates (Six *et al*., 2000; Bronick and Lal, 2005). Stable aggregates are vital to erosion resistance, water accessibility, and root development. Soils with stable aggregates at the surface are more impervious to water erosion than other soils, both due to the fact that soil particles are more averse to be separated and in light of the fact that the rate of water infiltration has a tendency to be higher on well aggregated amassed soils. In addition to, soil aggregation protects soil organic matter from mineralizing because it physically reduces the availability of organic compounds for microorganisms, extracellular enzymes, and oxygen (Lützow *et al*., 2006; Spohn and Giani, 2010). A stability is one of the best marker of organic matter content biological activity, and nutrient cycling in the soil. The amount of organic matter increases after the decomposition of litter and dead roots begins. In fact, stability of soil aggregates is closely related to the erosion resistance of soil and, therefore, is the effective indicators of erosion sensitivity (Guo *et al*., 2007; Rachman *et al*., 2003; Valmis *et al*., 2005).

Aggregate stability in different texture such as clay> clay loamy> loamy> sandy loam, are reduced respectively (Mbagwu, 1989). Clay stability is increased when the amount of sodium in the soil is low and the presence of sodium high negative impact on the stability. Wustamidin and Douglas (1985) in a research reported that there is a negative relationship between clay and aggregate stability. By increasing of Sodium

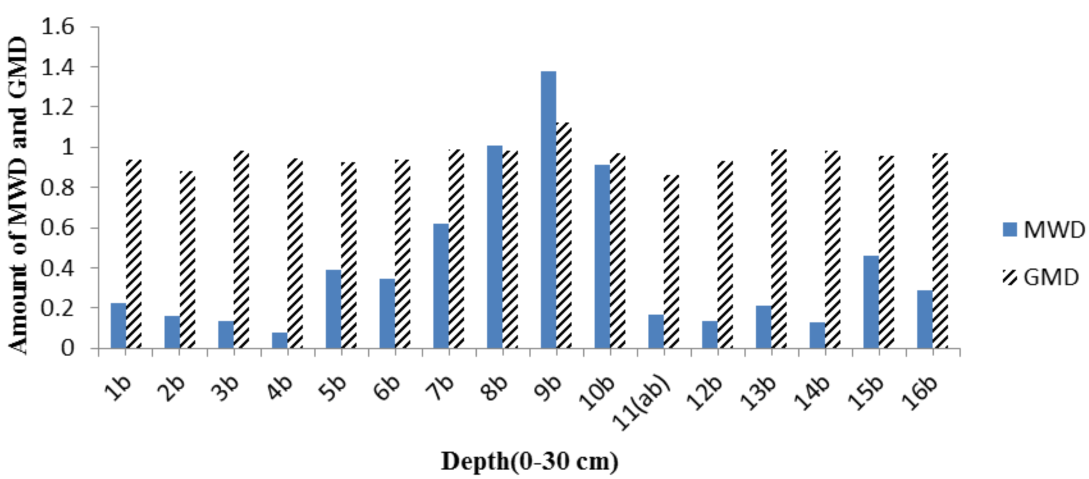

Figure 2. The amounts of MWD and GMD (mm) in soil sampling from head-cut part at a depth of 0-30 cm

Table 2. The results of soil chemical and physical tests on gully

Gully	Depth (mm)	EC (m. Semines /li)	PH	SAR	Mg (ppm)	Ca (ppm)	K (ppm)	Na (ppm)	O C (%)	Clay (%)	Sand (%)	Silt (%)
1	0-30	1.21	7.61	1.94	13.2	24.8	26.18	8.48	1.04	25	33	42
	30-60	1.04	7.72	3.85	15.2	24	16.32	17.05	0.78	27	15	58
2	0-30	1.01	7.8	4.01	13.6	24.4	4.14	17	0.78	15	39	46
	30-60	2.53	7.59	0.96	14	24	2.40	4.20	0.7	9	69	22
3	0-30	1.28	7.63	0.43	16	16	18.06	1.75	0.71	15	29	56
	30-60	4.96	7.63	6.82	14	22.8	13.42	29.29	0.84	29	33	38
4	0-30	1.21	7.73	4.13	10	24	10.52	17.05	1.07	25	51	24
	30-60	1.74	7.79	6.13	6	25.6	5.30	24.39	0.64	21	49	30
5	0-30	1.91	7.57	1.04	8.8	23.6	14.00	4.20	0.71	25	17	58
	30-60	3.19	7.58	4.63	15.2	27.2	8.20	21.33	0.95	15	19	66
6	0-30	1.59	7.83	1.55	8	22	60.40	6.03	1.25	21	63	16
	30-60	3.2	7.26	7.90	20.8	36	26.76	42.14	0.92	9	25	66
7	0-30	0.88	7.73	2.85	10.8	22	44.74	11.54	0.89	27	49	24
	30-60	0.63	7.92	5.17	10.4	23.6	26.18	21.33	0.7	25	51	24
8	0-30	0.69	8.24	5.60	12.4	20	20.38	22.56	0.89	15	75	10
	30-60	0.6	7.94	0.42	11.6	22	18.64	1.75	0.72	15	77	8
9	0-30	0.67	7.86	0.70	12.4	22.8	36.04	2.97	0.82	15	53	22
	30-60	1.32	7.68	2.26	12.4	20	29.08	9.09	0.92	17	75	8
10	0-30	2.3	7.7	4.07	44	68	72.40	30.51	0.78	7	35	58
	30-60	0.76	7.9	2.69	10.4	22.4	72.33	10.93	0.75	15	71	14

Absorption Ratio (SAR), required Electrolyte Concentration (EC) is to conclude of clay is more. Abu-Sharar *et al.* (1986) and Karimi *et al.* (2007) reported that soil aggregate stability and soil erosion potential in loamy and sandy clay loam soils stated that increase in aggregate instability due to the high concentration of sodium and lack of organic matter. The amount of organic matter increases after the decomposition of litter and dead roots begins. Similarly, Soil Organic Matter (SOM) is known to play a crucial role in soil structure formation and aggregate stability (Abid and Lal 2008; Chaney and Swift 1984; Bissonnais and Arrouays 1997; Soinne *et al.*, 2016; Benbi and Senapati 2010; Bandyopadhyay *et al.*, 2010; Karami *et al.*, 2012).

MATERIALS AND METHODS

Study area

The Ghori-chai watershed is located at 48° 06' 37" E and 38° 32' 33"N in the Ardabil province, a distance of 20 kilometers from the border of Iran and the measurement of aggregate stability is considered to be an indicator of soil quality that contribute to soil fertility and its capability to support crop growth (Six *et al.*, 2004; Pirmoradian *et al.*, 2005; Simansky *et al.*, 2008; Liu *et al.*, 2010; Spohn and Giani 2011; Blanco-Moure *et al.*, 2012; Zhang *et al.*, 2012). Soil aggregation may be determined by the Mean Weight Diameter (MWD), the Geometric Mean Diameter (GMD), which is obtained by breaking the soil into aggregate classes

Table 3. The MWD and GMD Multivariate linear regression and the factors affecting on aggregates stability by stepwise method

S. No	Equation	adj R^2	RMSEJ
1	MWD = 0.067 (% OM) + 0.518 (PH) - 3.97	0.134	0.307
2	GMD = 0.006 (% OM) + 0.045 (PH) + 0.607	0.041	0.072

Table 4. The MWD simple linear regression with affecting factors on aggregate stability at different depths (0-30, 30-60 cm)

S. No	Depth	Equation	Multiple R_squared	Adjust R_squared
1	0-30	$MWD = -0.12\left(\frac{silt}{clay + sand}\right) + 0.33$	0.889	0.881
2	30-60	$MWD = -0.066\left(\frac{silt}{clay + sand}\right) + 0.37$	0.520	0.111

by the wet sieving method (Yoder 1936; Kemper1965; Kemper and Chepil, 1965).

The objective of this study is to determine the effect of aggregates stability and physico-chemical properties of gullies soil in Ghourichai watershed in the Ardabil province. We aimed to use the Mean Weight Diameter (MWD) and Geometric Mean Diameter (GMD) to determine the sensitivity of soils in gullies erosion.

Gully erosion in Azerbaijan watershed, is causing damage to the desirable agricultural land rural residential land, road facilities and so on. Then, it is necessary to investigate these factors in the development of gully erosion in the watershed. Mean annual temperature, mean maximum and minimum are 13.9, 19.7 and 8.7°C, respectively. The average annual precipitation is 318.8 mm and its minimum and maximum precipitation are related to August (9.8 mm) and June (45.1 mm), respectively. The type of climate based on the hyetograph curve, Domarten modified and Emberger were determined cold semi-arid climate in this watershed.

In terms of geomorphology, the Ghori-chai watershed can be divided into two parts North (the plains and quaternary hilly is the location of gully erosion development) and the southern part (the mountain perspective and older altitude is related to Oligocene to Pliocene period). According to the data from meteorological stations inside and outside the study area and based on the map of Iranian soil moisture and thermal regimes, are xeric and mesic regimes, respectively. The number of sampling this study was

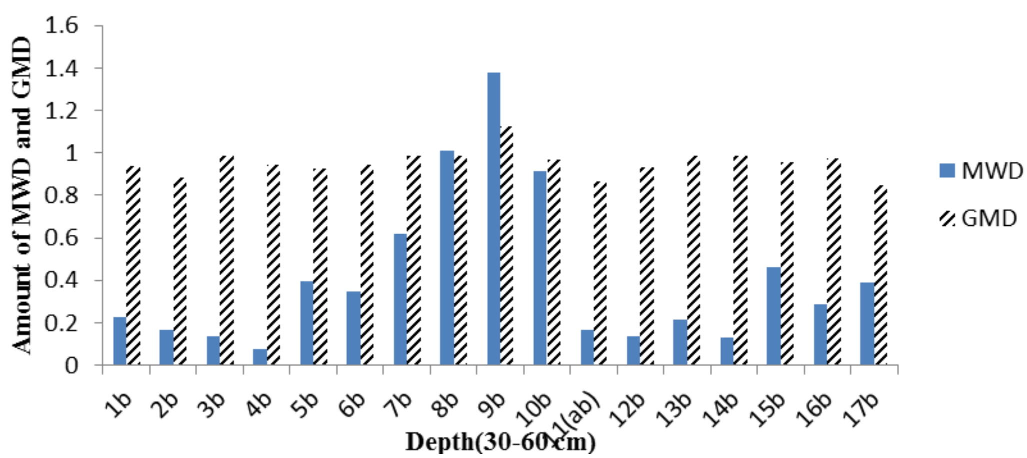

Figure 3.The amounts of MWD and GMD (mm) in soil sampling from head-cut part at depth of 30-60 cm

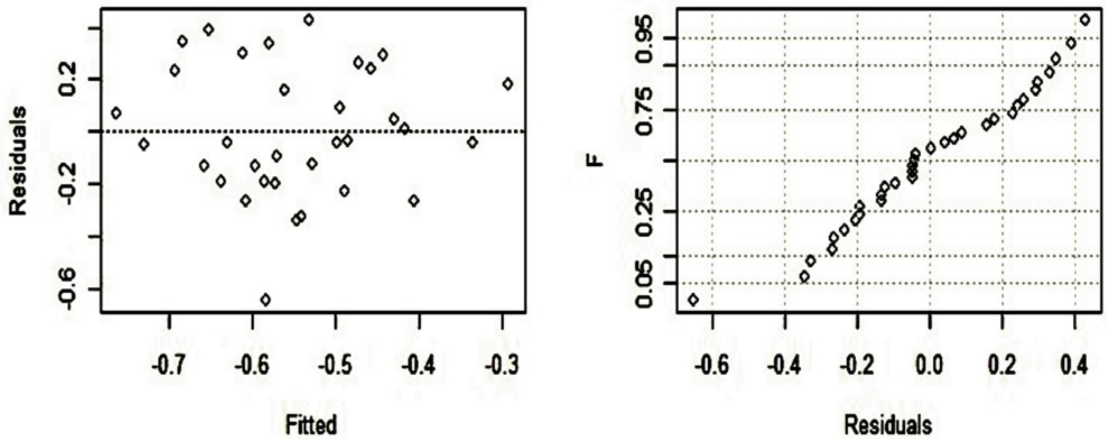

Figure 4. Left: the residual distribution pattern; Right: The residual normal in against of the model estimated amounts (PH, OM and MWD)

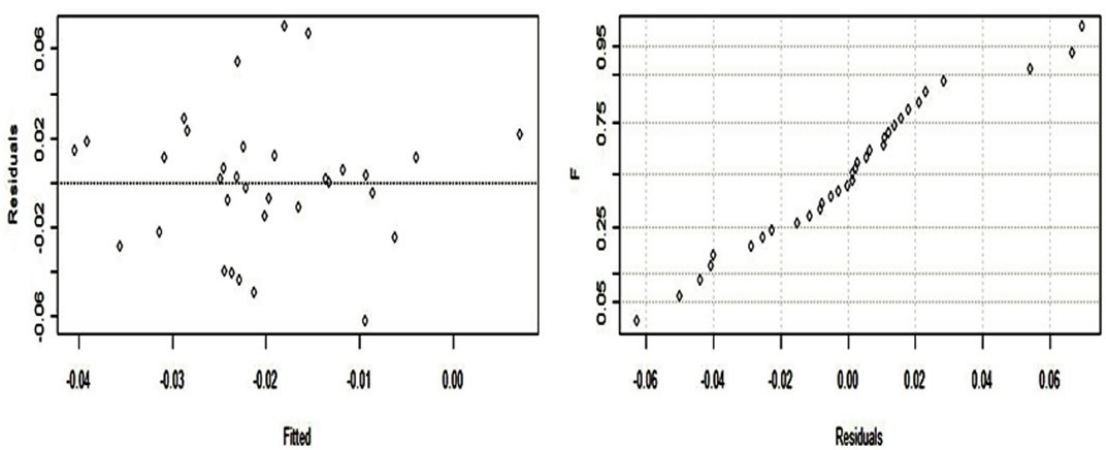

Figure 5. Left: the residual distribution pattern; Right: The residual normal in against of the model estimated amounts (PH, OM and GMD)

carried out 34 samples in 17 gullies from the depth of 0-30 and 30-60 cm of the head cut and in order to determine the aggregates stability and some chemical and physical characteristics as well as the aggregate resistance rate against water entry. So as to prepare samples and mean weight diameter was measured and the diameter until aggregates to be wet capillary suction effect, why that rapid getting wet is causing disintegration and dispersion of the aggregates (Movahedi and Rezaei, 2008).

Van (1949) found out mean weight diameter (MWD) of aggregates as a statistical aggregation index. The mean weight diameter is comparable using the area under the curve graph of the cumulative weight percent of the aggregates different sizes. This number is an estimation of the aggregate mean weight size and it presents the aggregates analysis. The mean weight diameter is a sensitive indicator of soil conditions and treatments. However, most available methods are divided to two parts: (1) The amount of aggregates available and (2) To some extent; silt and clay have been transformed to the aggregate. To determine the mean weight diameter used the wet- sieved method, the soil slowly were wet for 30 min by capillary properties and the air dried aggregates passed 8 mm sieve and then gradually moisten it with atomizers for half an hour, two series sieves of 4.76, 2, 1, 0.5 and 0.21 mm which is equivalent to 4, 10, 18, 35 and 60 meshes, respectively, are placed in a rotating sieve apparatus. Sieves for 30 min an interval of 3.18 cm a frequency of 30 to 35 rpm were used in the water up and down; it was observed that after 60 consecutive immersions, the available weight of the soil in each sieve for more soils with each next immersion changed to a flat rate. It is a result of mechanical friction sieving and this number as a correction factor was used at the end of trial. After dispersing the mechanical components of the same series has passed the sieve and the actual weight of aggregates were calculated per screening. Then dispersion ratio values, the state of aggregation, degree of aggregation and mean weight diameter (Van, 1949) were identified for the contents of each sieve.

To measure the geometric mean diameter, we separate air-dried samples and aggregates 1-2 mm in diameter, then two sample of the 25-gram weighted the aforementioned aggregates and it is transferred on a sieve with a hole diameter of 250 microns and insert the sieve into a container which half filled with distilled water, then up and down of the sieve in the water as much as three centimeters once for five min per sec and it dried in an oven of 105°C for 24h and weighed it. Therefore, sand particles larger than 250 microns are separated from the soil dried. Similarly, drying aggregate take place at the sec sample 25 g in the oven at 105 degree of centigrade for 24h to determine and correct the dry weight of aggregates.

The measurement of aggregate dispersion and stability is considered to be an indicator of soil quality (Six *et al*., 2000). Furthermore, aggregate stability measurements are an important parameter in determining the resistance of soil aggregates against environmental factors (Hillel, 1982). Soil aggregation may be determined by the Mean Weight Diameter (MWD), the Geometric Mean Diameter (GMD) which is obtained by breaking the soil into aggregate classes by the wet sieving method (Yoder, 1936; Kemper, 1965; Kemper and Chepil, 1965). Gardner (1956) has shown that the aggregate size distribution rather than a normal distribution is a normal distribution logarithmic.

Computation of stability indices

The Mean Weight Diameter (MWD)

Mass of aggregates on individual sieves was used to compute the following indices:

(i) The Mean Weight Diameter (MWD) of aggregates (Kemper and Rosenau 1986):

$$\mathrm{MWD} = \sum_{\mathrm{I}=1}^{\mathrm{n}} \bar{\mathrm{x}}_{\mathrm{i}}\, \mathrm{w}_{\mathrm{i}} \qquad (1)$$

where, 'Wi': is the proportion of each aggregate class; 'i': to the weight of soil sample and '$\bar{x}_I$': the mean diameter (mm) of the class.

The Geometric Mean Diameter (GMD).

The results of wet-sieved analysis can be expressed using the geometric mean diameter. This index is calculated the following as:

$$GMD = \exp(\sum_{i=1}^{n} W_i\, log_{10}.X_i) \qquad (2)$$

where 'n' is the number of aggregate fractions, 'X_i' is the mean diameter (mm) of aggregate fraction 'i' and 'W_i' is the mass proportion of aggregate fraction 'i'.

RESULTS AND DISCUSSION

The results of the measurement MWD and other physical and chemical parameters obtained from experiments at two different depths (0-30 centimeters) and (30-60 cm) of each gully were analyzed by statistical software R. The multivariate linear regression and chi-square method were used to determine the factors influencing the aggregate stability.

Chi-square test

Chi-square test (non-parametric) is a solution available to goodness of fit test of the nominal scale variables with more than two categories. This test was used to assess differences between soil properties at different depths (within data) and differences between Gullies (between data) and the results are presented in Table 1.

As seen in Table 1, MWD index at various depths of within and between data (0-30 cm) and (30-60 cm) is not significant. It means that soil texture is the same or so did not show significant changes in different gullies of this study. However, OM and SAR are significant level 99 percent at depth of (0-30 cm) and (30-60 cm), because these two parameters in depth of (0-30 cm) and (30-60 cm) in gullies were significant. Some soil chemical and physical tests on gully presented in Table 2 that shows amount of cations and anions in the study area.

The amount and type of organic matter are considered as important factors in stabilizing soil structure. Because the aggregate stability of soils are influenced by quality and quantity of organic matter and soil texture. In fact, organic matter together the particles of soil organic act as binding factor and prevent from the break down of aggregate (Tajik, 2004). The soil properties and especially soil organic related properties were significantly different in terms of land use type. On the one hand, soil organic matter is significantly affected by the land use (John *et al*., 2005; Li *et al*., 2015) on the other hand, soil organic matter plays deeply important roles in the stability and size distribution of soil aggregates (Abiven *et al.*, 2009; Alagöz and Yilmaz, 2009). It is suspected that the effects of land use on soil aggregates are driven by the soil organic matter or its components.

As seen in Table 2, with increasing value of Na and EC, the value of SAR is increased as well. The high SAR is caused to created instability in soil aggregate (Tajik, 2004). Therefore, understanding aggregate formation and stabilization in the soils can help to manage soils appropriately, maximizing aggregate stability, which is essential for the success of agricultural systems as well as for preserving environmental quality.

Multivariate linear regression

Multivariate linear regression parameters for relationship between aggregate stability (Mean Weight Diameter (MWD) and Geometric Mean Diameter (GMD)) with the factors influencing on the aggregate stability and related formulas by stepwise method are presented in Table 3. Stepwise regression analysis is another way to regression analysis where they show all independent variables that effects on the dependent variables. According to Table 3, the results of multivariate linear regression showed that the amount of MWD has more correlated than GMD with the percentage of pH and Organic Matter (OM). On the other hand, in the GMD, the amount of RMSE is lower than MWD. Hence, GMD model is better than MWD. According to equation, the amount of OM is the most important factor influencing on the aggregate stability and MWD. Increasing the amount of organic matter caused that increased the stability aggregate, so that supported this discussion (Soane, 1990; Guo *et al*. 2007; Rachman *et al*. 2003).

Simple linear regression

Simple linear regression is a measurable strategy that enables us to outline and study connections between two continuous (quantitative) variables. As it were, a single linear regression model demonstrates endeavors to clarify the relationship between at least two variables utilizing a straight line. Table 4 explain about the MWD simple linear regression with factors of influencing on aggregate stability at different depth Table 4. The MWD simple linear regression with affecting factors on aggregate stability at different depths (0-30 and 30-60 cm).

As shown in Table 4, the MWD is significant positive correlation, with the ratio of silt / (clay + sand) at the depth of 0-30 cm (r=88.9%); however this ratio has significantly weakened the MWD at depth of 30-60 cm. As the clays 2: 1 due to have a specific surface area and high CEC are more effective than other clays on their aggregate stability, on the other hand, a main percentage of these clays are placed in the fine clay soil. Thus, clays have the greatest effect on aggregation and aggregate stability. Therefore, in aforementioned equation, the clay is the more correlated with MWD, in the other words, significant correlation was obtained with MWD (Barzegar *et al*., 1995; Abdulqadir and Mahmood, 2016). The amounts of MWD and GMD (mm) in soil sampling from head-cut part at the depth of 0-30 and 30-60 cm are showed in Figure 2 and 3.

In above the Figures (2 and 3) *a, b* and *ab* are as depth of (0-30 cm), (30-60 cm) and transitional horizon respectively. At times, layers of soil were noted which are very peculiar from overlying or underlying horizons and which have attributes in excess of one master soil horizon, however can't easily be settled into two horizons. These layers are helpfully portrayed as transitional horizons. As seen in Figure 2 and 3, the mean weight diameter (MWD) are variable from 0.14 to 0.79 and from 0.07 to 0.61, at depth of 0-30 cm and 30-60 cm, respectively which is representing severe limitation of the aggregate stability based on Lal classification (Lal, 1994) at lower depths. As well as, the Geometry Weight Diameter (GMD) is variable from 0.84 to 1.12 and from 0.84 to 0.98 at a depth of 0-30 cm and 30-60 cm respectively. According to Figure 2 and 3, the soil aggregates stability in this area have severity and very severity limitations. Therefore, poor aggregate stability has led to gully erosion in the region.

Residuals versus fits plot

Once compute a fitting model, it is used for any of the regression diagnostics commands. Graphs are drawn against the residuals and the values fit are one of them. Residuals are appraisals of trial errors acquired by subtracting the observed responses from the predicted responses. The predicted response is figured from the chosen model, after all the unknown model parameters have been assessed from the trial data. Investigations at residuals is a key piece of all statistical modeling. Careful consideration of the residuals can reveal whether our suspicions are reasonable and our choice of model is appropriate. It is a scatter plot of residuals on the 'y' axis and fitted values (estimated responses) on the 'x' axis (Figure 4 and 5). The plot is utilized to identify non-linearity, unequal error variances, and outliers and enhance the regression. In fact a residual versus fit plot determine assumptions of underlying that the regression model is useful in understanding the most common types of inappropriateness. In other words plots residuals help to understand and improve regression model. If the model is appropriate to point out this chart should '$ei = 0$' is symmetrical and evenly dispersed locations around the point. It means that the error variance in this state is constant.

If graphs similarly spread residuals around a horizontal line without distinct patterns that is a good sign it didn't have non-linear relationships. It can be stated that the good model data are simulated in a way that meets the regression assumptions very well, while the bad model data are not. In a well-fitted model, there should be no pattern to the residuals plotted against the fitted values-something not true of our model. According to Figure 4 and 5, the normal residual and the residual distribution pattern in the MWD with PH and OM showed better results than GMD with OM and pH. Therefore, MWD with PH and OM have the nearly symmetrical and evenly dispersed locations around the point and the error variance is roughly constant in this state. On the other hand, there is a high correlation between MWD and OM.

CONCLUSION

In this study, we assessed the effect of aggregates stability and physico-chemical properties of gullies soil in Ghori-chai watershed in the Ardabil province. The aggregate instability is one of the most important factors in the development of gully erosion in the Ghori-chai watershed. To do so, we compared the size of the Mean Weight Diameter (MWD) and Geometric Mean Diameter (GMD). According to the results, MWD has a severe and very severe limitations to create aggregate stability. There are different causes that can be contributed in the aggregate stability of gullies in term of physical and chemical test results on soil samples showed that high level of sodium and increasing the sodium absorption ratio in the study area is caused by the aggregate instability. The results of this study showed that the aggregate stability in the surface depths are greater than the subsurface deep. In conclusion, the high organic matter can cause adhesions and aggregates whereas and high correlation with MWD, as well as the normal residual in MWD have the nearly symmetrical and evenly dispersed locations around the point.

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