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Full Length Research Paper

Influence of soil physical and mineralogical properties on erosion variations in Marlylands of Southern Guilan Province, Iran

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Marls are the most talented geological formation of erosion and produce large amount of sediments that annihilate fertile soil and deduct the capacity of dams. Erosion in marls depends on external factors such as distribution of rainfall and internal factors which include soil physical and mineralogical properties. Therefore, the objective of this research was to determine the changes of physical and mineralogical properties of marls because of erosion variations in arid regions of Guilan Province (Gilevan region) of Northern Iran. The concerned soil physical properties of Marlylands were percentage of saturation, surface gravels, sands, silts, clays, fine sands, fine clays, and the level of bulk density, mean weight diameter (MWD) of soil aggregates (dry sieve), liquid limit, plastic limit, activity and ratio of fine clay to total clay. In addition, four samples from Marly soils and one sample from parent material were prepared for X-ray diffraction analysis. Comparing the average of physical factors with different type of erosion by means of Duncan multiple range test showed that the percentage of clays, fine clays, saturation, and the level of MWD, liquid limit and activity showed significant changes ($p < 0.05$) in some types of erosion, whereas other measured parameters had no significant effect on the form and type of erosion. Furthermore, results of X-ray diffraction showed the presence of smectitic group, double-layer clay minerals that are dispersive (2:1 clays), in badland and gully areas, while these types of clay minerals were not found in areas with rill and sheet erosion. Hence, with respect to the results of this research, it can be concluded that mineralogical properties as well as some soil physical characteristics are the main factors controlling the shape and form of erosion in Marlylands of Northern Iran.

Key words: Clay minerals, erosion types, Guilan province, physical factors.

INTRODUCTION

Soil erosion is a serious and widespread land degradation problem throughout the world. Steep slopes of Marlylands are so vulnerable to water erosion. Transport of eroded material from these lands has received significant attention, as sediment is both a pollutant and an effective vector for contaminant transport (Roswell, 2002). Other aspects of adverse damages of soil erosion and its hazards originated from Marlylands. Different features of natural resources have been discussed by many researchers (Mashhadi, 2001; Rey and Berger, 2006; Ries and Hirt, 2007; Lesschen et al., 2007). Earlier research on Marly landscapes showed that these formations were affected differently by mass-wasting processes and by rill erosion. Mass-wasting was often found to be prevalent in more cohesive soils because of their higher retention capacity, whereas gully erosion is commonly observed on more silty soils (Maquaire et al., 2003). However, some aspects of mineralogical properties as well as physical properties of Marlylands have received considerable attention in literature but there has

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been much less research on the behavior of these soils.

Imeson et al. (1982) believe that in areas in which physical and mineralogical properties of Marlylands are the main factors controlling the shape and form of erosion, the hydrological variables have lower importance in erosion processes. It has long been recognized that the local Mediterranean climate, tectonics and human impact interact to determine the gross morphology and surface conditions of highly eroded lands (Piccarreta et al., 2006). Revisiting early interpretations by Alexander (1982), attention has recently been given to the explanatory role of lithology, in particular sediment size and clay mineralogy, in explaining the different forms of erosion, especially the badlands erosion. For instance, on biancane sites, Battaglia et al. (2002) found clay fractions to be over 65%, significantly higher than on the calanchi sites; whereas the latter were coarser with sand fractions between 6 and 18%. Both sites have been reported to possess clay minerals in the smectitic group. Smectitic (2:1 clays) swells on wetting, sometimes sealing the surface, and encouraging overland flow and rill erosion. It was found that the percentage presence of the swelling clays in the overall material mass is very important. Where clay percentages are high, the material mass is rendered impermeable on swelling, encouraging surface wash erosion and reducing infiltration. Where clay percentages are low, the deflocculation of the clay fraction merely destructures a material already lacking in other sources of cohesion, encouraging subsurface erosion (Piccarreta et al., 2006). Smaeil Zade (2002) studied the influence of silt, sand and clay fractions on formation of different shapes of erosion. He reported that there was no logical relationship between these soil physical properties and shape of erosion. Wakindiki and Ben-hur (2002) believe that increasing of clay particles will enhance the aggregates stability. They expressed that in soils containing more than 20% clay, the clay particles act as a cementing agent and will increase aggregate stability against rain drops impact and decrease surface sealing. They also pointed out that soils having montmorillonite are more susceptible to water erosion than those containing kaolinite. Similarly, Ramarao and Smart (1990) reported that all of the dispersive soils having expansive behavior probably are containing quantitative amounts of montmorillonite minerals. They also expressed that in this types of soils the level of moisture in shrinkage limit is very less than saturation percentage. Therefore, decreasing soil moisture in these kinds of soils leads to their less volume and occurrence of more cracks on soil surface. Bouma and Imeson (2000) believed that the main factor in formation of unstable badlands in Marly soils is the presence of expandable clay minerals including smectite group like montmorillonite. Also, Ouhadi and Yong (2003) mentioned the role of two other clay minerals such as palygorskite and sepiolite in instability of calcareous Marly soils. Mbagwu (2003) introduced the sand ratio to clay as the main soil physical factor controlling the aggregate stability against erosion. Ezochi (2000) reported that increase in sand content in soils will decrease their susceptibility to gully erosion. He also pointed out that heavy soils containing large amounts of clay and silt particles due to increase in the saturation water and water holding capacity, the formation of gully erosion and their frequency are more expected. Seed et al. (1988) suggested that increase in soil activity level leads to its more swelling. Gromko (1974) found that the liquid limits are more than 30% and they cause lots of difficulties in respect to its swelling.

Marl parent materials develop the most erodible surfaces in arid environments including arid regions of Northern Iran and produce more sediment yield compared to the other parent materials. Also, in Marly soils the volumes of initial runoff and runoff coefficient is completely high and the infiltration rate is so negligible (Cerda, 2002). Moreover, erosional processes in relation to marls are very intensive, so that different figures of erosion particularly; badlands are the obvious characteristics at Marlylands (Thornes, 1980). Therefore, with proper recognition of some characteristics of Marlylands such as their physical and mineralogical soil properties, we are able to fight against the harms received by erosion from these vulnerable lands. The present study was, therefore, carried out with objective to investigate the changes of some physical and mineralogical soil properties of marls on erosion processes in arid regions of Northern Iran. These changes may affect the rate and severeness of erosion and may create different forms of erosion in this region.

MATERIALS AND METHODS

Study area

The study area is located between 49°, 26' and 49°, 31' E longitude and 36°, 25' and 36°, 46' N latitude in South of Guilan Province (Gilevan Region) of Iran (Figure 1). The climate of the region is arid with the mean annual precipitation of 245.18 mm. The mean annual temperature is also 17.4°C. The soil moisture and temperature regimes of the region by means of Newhall software are aridic and thermic, respectively. These lands produce large amount of sediments that enter the Sefidrood Dam. The soil profiles in the Marly regolith materials are poorly developed. The maximum local relief of the badland area is about 90 m. This area shows various degrees of sheet, rill, gully erosion and mass movements. Soil surface processes are dominated by rill erosion, the effect of swelling and shrinking, and the development of shallow bridge piping. Shallow slips are a secondary process caused by soil surface developments. The regolith materials in this study are named marls, which show a different surface morphology and colors. In some regions, because of severe erosion, Marlylands have state of plain. Moreover, the studied marls had a variety of colors. These Marlylands especially in badlands were chromatic. On the surface of some Marly hillslopes, especially in gullies and badlands, accumulations of salts are considerable. These areas which were more affected by soluble salts, due to having property of high absorption of humidity, were darker than other areas (Figure 2). In general in the study area as a reason of high salinity and sodicity, distribution of different vegetation types are very low and only special species of plants such as *Salsola*, *Gypsophylla viygata*, *Stipa* and *Ayuga chemeosituis* are worthlessly scattered.

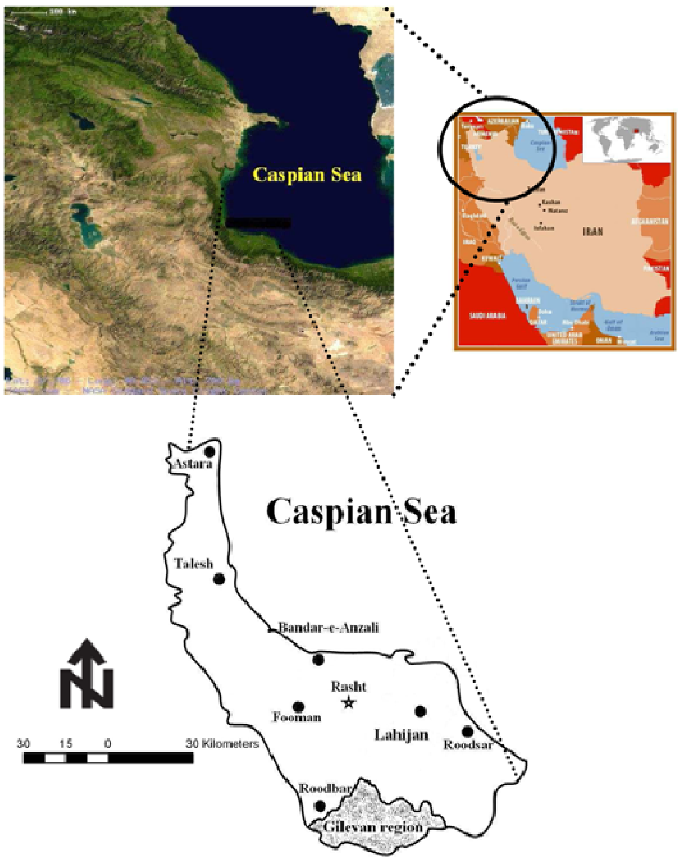

Figure 1. Study area in Guilan province of northern Iran (Gilevan region).

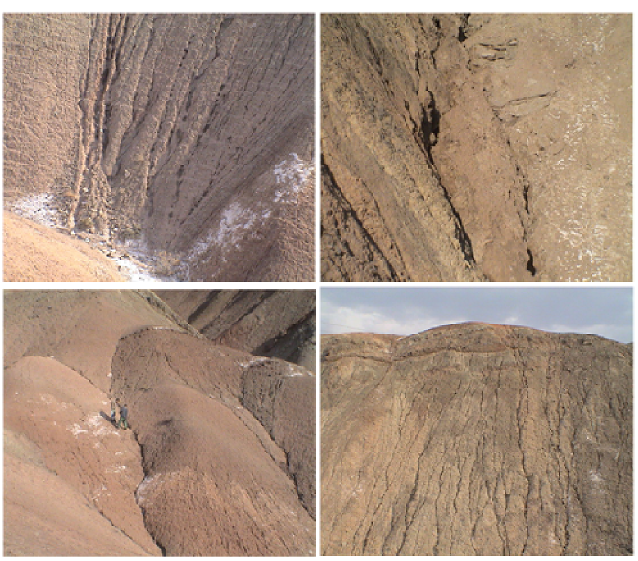

Figure 2. Study area showing different erosional forms.

Soil physico-chemical and mineralogical analysis

After preliminary studies of geological (1:100000, 1:250000) and topographic maps, and identification of Marlylands, using GPS, studying locations were appointed. Then, in some dominant Marly land forms (with uniform shape, direction and slope) 12 soil samples were taken from surface layer (0 - 30 cm) of sheet, rill, gully and badland erosion (total of 48 samples) and from underlying layer of gullies and badlands (total of 24 samples). Sampling from parent material was done contemporaneously, too. Parent material samples were air dried, then ground, sifted (2 mm sieve) and prepared for physico-chemical and mineralogical experiments.

Particle-size distribution was determined after dissolution of $CaCO_3$ with 2 N HCl and decomposition of organic matter with 30% H_2O_2. After repeated washing to remove salts, samples were dispersed using sodium hexametaphosphate for determination of sand, silt and clay fractions by the pipette method (Day, 1965). The total clay content and fine clay were determined by Kittrick and Hope (1963). The ratio of fine clay to total clay and bulk density were measured by excavation and cylinder methods; the percentages of fine sand, soil gravel and surface gravel, by volumetric method; the percentage of saturation water, by gravimetric method; and mean weight diameter of soil aggregates, by dry sieving method (Klute, 1986). Other soil characteristics such as Atterburg limitations and soil colour in wet and dry conditions were determined with respect to standard methods (Klute, 1986). Organic carbon (OC) was determined by Walkley-Black method (Nelson and Sommers, 1982); carbonate and bicarbonate were determined by Bernard's calcimetric method; pH in aqueous suspensions and 1 M KCl (Peech, 1965), cation exchange capacity (CEC) by the method of Chapman (1965); electrical conductivity (EC) of the saturated extract by the Bower and Wilcox (1965) method. Also, soluble and exchangeable basic cations (Na^+, K^+, Ca^{2+}, Mg^{2+}, $CaCO_3$, gypsum, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP)) were measured by standard methods (Page, 1986).

Four soil samples from surface layer (0 - 30 cm) of sheet, rill, gully and badland erosion and one sample from parent material of gully erosion for mineralogical experiments were selected. Chemical cementing agents were removed and clay fractions separated according to Mehra and Jackson (1960), Kittrick and Hope (1963) and Jackson (1975). Iron-free samples were centrifuged at 750 rpm for 5.4 min to separate total clay (< 2 µm) and at 2700 rpm for 40 min to separate fine clay (< 0.2 µm) (Kittrick and Hope, 1963). The fine and coarse-clay fractions were analyzed mineralogically by X-ray diffractometry (Mehra and Jackson, 1960). The same concentration of clay suspensions was used for all samples to give reliable comparisons between relative peak intensities. Two drops of the prepared suspension were used on each glass slide. The (001) reflections were obtained following Mg saturation, ethylene glycol solvation and K saturation. The K-saturated samples were studied both after drying and after being heated at 330 and 550°C for 4 h. Clay minerals were estimated semiquantitatively from the relative X-ray peak areas of glycol-treated samples (Johns and Grim, 1954).

Soil samplings were collected randomly from sheet, rill, gully and badland erosion as a completely randomized design. Comparison of means were done using Duncan multiple range test by SAS software. The correlation coefficients were also measured using SPSS software in the way of step by step. For comparison of topsoil and subsoil in gullies and badlands, Student's *t*-test was also used.

RESULTS AND DISCUSSION

Characterization of the type of erosion in study area

Sheet erosion: The dominant form of erosion in this area is sheet erosion. This type of erosion is observable from bareness of shrub's roots and sparseness of vegetation cover. Chemical analysis of soil under sheet erosion shows that the amount of calcium carbonate is 7.4%, gypsum is 19.3%, OC is 2.1%, pH in 1:1 extract (with water) is 7.7, SAR is 11.1, and finally soluble sodium is more than 20.0 meq l^{-1}. The ratio of sodium absorption and total concentration of cations in soil extracts on the basis of Sherard diagram (Sherard et al., 1976) showed that the marls under the effect of sheet erosion are often located at undiffused region in Sherard diagram. These results showed that sheet erosion had low diffusive property of marl's particles. Hence, the marls under the effect of sheet erosion can be found as marls whose concentration of solved sodium ion or SAR in them is rather low. Moreover, the level of solved salts in them is moderate.

Rill erosion: The surface horizon of the soil under the effect of rill erosion has fine texture with micro and macroscopic rills. The rate of OC is 1.8%, $CaCo_3$ is 7.0%, gypsum is 19.8%, pH is 7.8, SAR is 41.8 and sodium concentration is 10.1 meq l^{-1}. These results indicated that the area under the effect of rill erosion was located at diffused region in Sherard diagram (Sherard et al., 1976).

Gully and badland erosion: Fine granular texture, impermeable and condensed ditches (gullies) were the most important characteristics of badlands. In these areas the amount of gypsum is 18.6%, $CaCo_3$ is 83.1%, OC is 1.1%, pH is 8.2 and SAR is 123.4, while the proportion of clays, silts and sands in comparison to the samples of sheet, rill and gully erosion did not show much change. With regards to the rate of absorbable sodium and total concentration of solved cations, the diffusion index at the field condition under the effect of badlands were located at diffused region in Sherard diagram (Sherard et al., 1976) that implies the hollowness of marls. This subject conforms to Benito theory, which believes, badlands take place in high levels of solved sodium, SAR more than 40 and mediate rate of salts (Benito et al., 1991).

Qualitative estimation of erosion using bureau of land management (BLM) method

After filling out the BLM forms in barren region at the moment of sampling, the distinction of surface soil according to the total seven scores was calculated. On the basis of this kind of evaluation, sheet and rill erosion having mean scores of 49.0 and 60.0 were located in areas with average erosion. Also, gullies and badlands with mean scores of 75.0 and 96.0 were located in areas having intense and very intense erosion, respectively. Consequently in the study area low and partial classes of erosion were not found and therefore, all of the types of erosion were situated at the ranges of medium and very intense erosion classes. Also, by means of calculated marks that were related to soil surface feature or agent (S.S.F), the actual (present) condition of erosion in the study area was determined for different forms of erosion using the equation below:

$$\text{Actual condition of erosion} = 0.25\ (\text{S.S.F}) \quad (1)$$

Hence, the actual conditions of erosion for areas having sheet, rill, gully and badland erosion were 12.2, 15.0, 18.7 and 24.2, respectively. In average this score for arid regions of Northern Iran was 17.6, which can be used in evaluation of erosion for these areas by the PSIAC method.

Analysis of variance (ANOVA) for physical properties

Among all of the studied physical factors, some properties including sand, clay, fine clay, saturation water, liquid limit, soil activity, MWD and the ratio of fine clay to total clay showed significant difference ($p < 0.05$) between various erosional forms using Duncan multiple range test (Table 1). The mean of each soil physical property for different forms of erosion was also measured (Figure 3).

Particle size distribution

In sheet erosion measuring of soil texture showed that 30.0, 20.0 and 10.0% of the soil samples had the clay, sandy clay loam and loam clay silt texture, respectively, while in rill erosion 16.0, 50.0 and 4.0% of the samples had the clay, clay loam and sandy clay loam texture, respectively. So that in rill erosion, each of the soil textures including loam, sandy loam and silty clay loam comprises the 10.0% of samples. Moreover, in gully erosion 40.0, 40.0 and 16.0% of samples had the clay, clay loam and loam texture, respectively and also, 4.0% of samples had the silty clay texture. In addition, in badland 60.0 and 40.0% of samples had the clay and clay loam texture, respectively. Ghadimi Aroosmahale (1998), with consideration between soil properties and percentage of clay, silt and sand in creating erosion forms, did not find any logical relationship between soil texture and different erosion forms. Piccarreta et al. (2006) reported that the samples of both investigated sites in badlands of Southern Italy were clayey silts with a sandy fraction < 3%. Their analysis showed that (a) the percentage of the fraction smaller than 32 µm is about 90%; (b) more than 50% of particles are smaller than 8 µm; (c) the clay fraction < 2 µm represents about the 20% of the total. Martinez-Mena et al. (2002) believe that due to the rapid surface crusting on the tertiary Marly soil of semiarid Mediterranean area of Spain, there were no differences in the main erosion processes or in the particle size distribution of sediments.

Clay content: The mean values of clay content in sheet, rill, gully and badland erosions were 32.0, 34.1, 37.8 and 41.4%, respectively. So that, the least amount was related to rill erosion (18.0%) and the most value was related to badlands (48.0%) (Table 2), and there was a significant difference ($p < 0.05$) between sheet and badland erosion (Figure 3a). Clay particles have an important role in soil aggregating. If clay content is over 40.0%, small aggregates form and erode easily. This

Table 1. The results of ANOVA for some physical properties of studied soils.

S.O.V.		Treatment	Error	Total
df.		**3.0**	**44.0**	**47.0**
Sand	Mean square	364.87	68.25	
	F	5.35*		
Silt	Mean square	73.15	49.22	
	F	1.49ns		
Clay	Mean square	208.7	24.8	
	F	8.41*		
Fine clay	Mean square	117.6	3.3	
	F	35.5*		
Fine clay/total clay	Mean square	0.029	0.002	
	F	14.54*		
Fine sand	Mean square	4.2	5.16	
	F	0.81ns		
MWD	Mean square	0.21	0.007	
	F	30*		
Plastic limit	Mean square	2.67	1.48	
	F	1.81ns		
Liquid limit	Mean square	414.2	27.79	
	F	14.9*		
Soil activity	Mean square	0.013	0.004	
	F	3.25*		
Bulk density	Mean square	0.008	0.0042	
	F	1.9ns		
Gravel	Mean square	0.115	0.114	
	F	1.0ns		
Saturation water	Mean square	0.017	0.062	
	F	9.33*		

*: Significant at 5% and ns: non significant.

content (clay > 40.0%) was present in some samples with gully erosion and especially in badlands. In soils with clay contents of less than 10.0%, soil structure can not be formed, approximately, has a little adhesiveness and can be destroyed when exposed to rainfall. Moreover, the type of clays will probably have effect on form and severeness of erosion, too. In gully and badlands, expansible 2:1 clay minerals were presented. These expandable minerals adsorb more water and cause more erosion and runoff compared with the soils without these minerals (Emami and Ghazavi, 2002). Also, the infiltration rate has a negative correlation with increase of clay content in soils and hence leads to more erosion and run-off production (Descroix et al., 2001). Vandekerckhove et al. (2000) reported the minimum and maximum values of clay content in gullies of Southeast Spain between 0.6 to 36.9%, respectively. Also, the mean of clay content in these areas was measured as 15.6%. They showed that

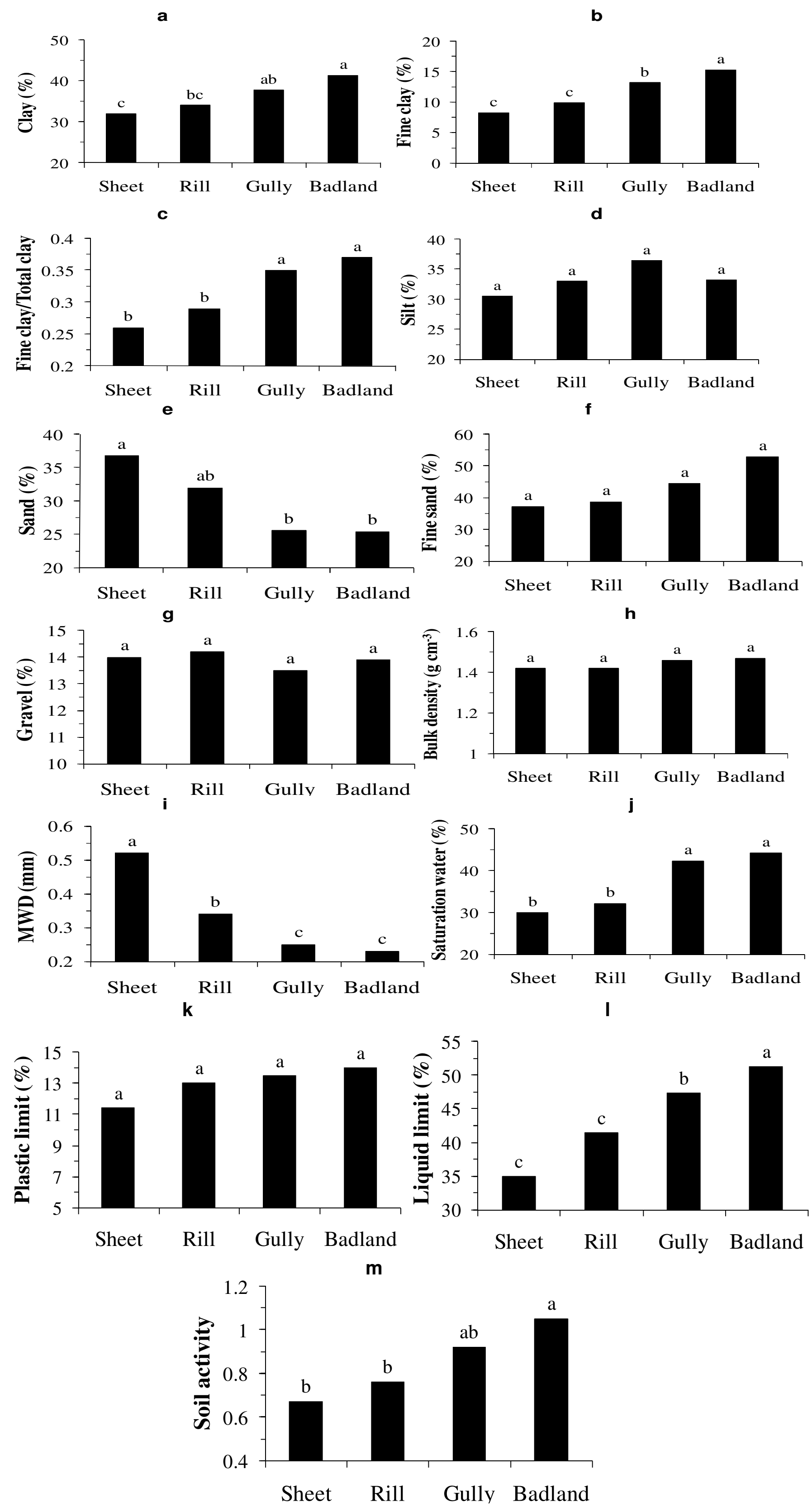

Figure 3. The mean values of studied soil physical properties for different forms of erosion (means, with similar letters are not significantly different at the 5% probability level using Duncan multiple range test).

Table 2. Maximum and minimum values of some soil physical properties in different forms of erosion.

Variables	Sheet erosion		Rill erosion		Gully erosion		Badland erosion	
	Min	Max	Min	Max	Min	Max	Min	Max
Sand (%)	14.0	57.0	15.0	53.0	14.0	32.0	20.0	32.0
Silt (%)	17.0	44.0	15.0	45.5	30.2	44.0	26.0	41.3
Clay (%)	26.0	42.0	18.0	43.5	26.0	46.0	38.0	48.0
Fine clay (%)	3.3	11.76	5.4	13.1	9.6	15.8	13.3	16.9
Fine clay/total clay	0.11	0.36	0.23	0.35	0.32	0.4	0.3	0.43
Fine sand (%)	42.0	60.0	40.0	53.0	35.6	42.1	32.3	43.0
MWD (mm)	0.39	0.65	0.21	0.56	0.13	0.34	0.12	0.31
Plastic limit (%)	9.7	13.5	10.5	14.6	10.1	16.5	12.5	16.5
Liquid limit (%)	32.0	39.0	32.0	49.0	42.2	54.0	46.5	57.0
Soil activity	0.6	0.79	0.57	0.88	0.79	1.1	0.94	1.2
Bulk density (g cm^{-3})	14.32	1.5	1.29	1.6	1.39	1.58	1.43	1.5
Gravel (%)	10.0	12.5	10.0	11.5	8.0	11.0	9.2	11.1
Saturation water (%)	29.1	37.3	29.1	46.5	40.1	51.5	43.1	55.0

most studied bank gullies were characterized by a fine earth texture belonging to the silt, silt loam, silty clay loam, loam and sandy loam class.

Fine clay content: The mean values of fine clay content in the studied soils were 15.3, 13.2, 9.9, and 8.3% for the badland, gully, rill, and sheet erosion, respectively. Also, all of the erosional forms had the significant differences ($p < 0.05$) except rill and sheet erosion (Figure 3b).

Ratio of fine clay to total clay: The ratio of fine clay to total clay from badland to sheet erosion was 0.37, 0.35, 0.29 and 0.26, respectively and had a descending trend from badland to sheet erosion. These findings probably confirm the increasing of expansible clay minerals in areas with gully and badland erosion. In addition, statistical analysis identified a significant difference ($p < 0.05$) between gully and badland with rill and sheet erosion, while these differences were not significant between badland with gully erosion and also between rill with sheet erosion (Figure 3c). The fine clay minerals due to having smaller diameter are more mobile than other minerals and can be translocated by the runoff as suspension form (Amiri, 2001).

Silt content: The gully erosion had the highest mean of silt content (36.5%) between all of the erosional forms. After gully erosion, the badland, rill and sheet erosion were in subsequent orders in respect to their silt content, respectively. However, statistical analysis did not show any significant differences between all of the erosional forms in respect to their silt content (Figure 3d). With increase in silt content within the soils, their erodibility increases. Also, soils having 40 - 60% silt contents are the most vulnerable soils against erosion (Refahi, 2000). Furthermore, the relationship between soil silt content and soil erodibility is influenced by the level of organic matter and clay content. Vandekerckhove et al. (2000) measured the minimum and maximum values of silt content in gullies of Southeast Spain between 17.3 to 88.4%, respectively. The mean of silt content in these areas was measured as 65.5%. They pointed out to the important role of silt content in controlling gully development in these areas. According to Martin-Penela (1994), the most decisive factors for piping and gulling are the presence of poorly indurated silty-clayey materials containing cracks, fractures or other discontinuities, such as (gypsum-filled) joints and faults. According to these findings, it can be concluded that due to the level of silt in average in all of the studied erosional forms, they were less than 40.0% hence, there were not any significant differences between forms of erosion.

Sand content: The mean of sand content in badland, gully, rill and sheet erosion were 25.4, 25.6, 32.0 and 36.8%, respectively. Statistical analysis also showed that just the sheet erosion had significant difference ($p < 0.05$) with badland and gully erosion (Figure 3e). Also the measurements revealed that the highest value of sand (57.0%) was related to sheet erosion and the lowest (14.0%) was associated with sheet and gully erosion (Table 2). In general, with increase of sand content in soils their erodibility will decrease. This behavior is probably because of increasing of infiltration rate and decreasing of runoff at the presence of sand particles in soils. Similarly in the present study, the badland and gully erosions, with the most erosion rates, had the lowest content of sand particles compared with the rill and sheet erosions. Li (2003) believes that use of gravel-sand mulch changes the hydrological process and improves soil productivity, which is effective in reducing evaporation and runoff; thereby improving infiltration and soil temperature, checking wind and water erosion as well as enhancing biological activity and soil fertility. Vandekerckhove et al. (2000) measured the minimum and maximum values of sand content in gullies of southeast Spain between 2.6 to 63.1%, respectively. Also, the mean of sand content in these areas was mea-

Table 3. Correlation coefficients between some soil physico-chemical properties with MWD.

OC (%)	Clay (%)	Silt + Fine sand (%)	ESP (%)
0.505**	- 0.310*	- 0.485**	- 0.689**

* and **: Significant at 5% and 1%, respectively.

sured about 18.9%. Also, their physical analysis showed that piping occurred in soil layers with a higher silt and lower sand content.

Fine sand: The most level (52.9%) of fine sand (0.05 - 0.1 mm) in average was related to badland erosion. But, statistical analysis did not show any significant differences between all of the erosional forms regarding fine sand (Figure 3f). Fine sand particles have the behavior similar to the silt particles and hence, the changes of fine sand content in studied soils were similar to the variation of silt particles, which were discussed above.

Gravel percentage

The highest gravel content (12.5%) was related to sheet erosion, while the lowest gravel content (8.0%) was related to gully erosion (Table 2). In relation with the soil loss, especially the interrill erosion, the washing of the fine soil particles occurs. This process may cause an increase in the rock fragment cover presence at the surface of the soils especially in areas having rill and sheet erosion (Menéndez et al., 2008). For example, Vandekerckhove et al. (2000) reported that the rock fragment content in 91% of the gullies in Southeast Spain were lower than 7%. Only 5 sites had a higher rock fragment content ranging between 20 and 57%. Moreover, in sheet erosion, with particles washed out selectively, the accumulation of gravel on soil surface will increase. But in the present study, there was not any significant differrence between different forms of erosion in respect to the mean of gravel percentage (Figure 3g).

Surface stone and rock fragments

The level of surface stone and rock fragments were estimated between ranges of 10.0 - 12.0% in the study area. There was not any difference between none of the erosional forms regarding this parameter. However, all of the shapes of erosion were different in the case of settlement style of stone and rock fragments on the soil surface. So that, in gully and badland areas, stones and rock fragments were embedded into the soil surface, while in sheet and rill erosion, most of the stone covers were simply placed on the soil surface (had the free style). Okoba and Sterk (2006) use the term of 'surface stoniness' in reference to the presence of loose stones lying on soil surface and they use this feature as a soil erosion indicator. Descroix et al. (2001) explained that the free type of stoniness enhances roughness and reduces therefore runoff and soil losses. It absorbs kinetic energy of raindrops and dissipates the overland flow one. Hence, the erosion rate in gullies and badland was more notable than sheet and rill erosion due to the lower content of this style of stoniness in present study.

Bulk density

Statistical analysis did not show any significant differences between all of the erosional forms and bulk density. However, this property had an increasing trend from sheet to badland erosion (Figure 3h).

Mean weight diameter (MWD)

The MWD values for badland, gully, rill and sheet erosions were 0.23, 0.25, 0.33 and 0.52 mm, respectively. Also, all of the erosional forms had significant difference ($p < 0.05$) with respect to MWD, except gully with badland erosion (Figure 3i). The high levels of MWD in soils is a sign of the presence of high stable aggregates which are resistant to breakdown and therefore, the percentage of resistant aggregates naturally is high in these kinds of soils. Also, as MWD increases, resistance against wind and water erosion will increase (Refahi, 2000). Moreover, correlation coefficient between some soil properties and MWD showed that the percentage of silt + fine sand, clay, OC and ESP had significant effect on MWD (Table 3). Also, the relationship between these soil physico-chemical parameters and MWD is given by equation below:

$$MWD = 0.041\ OC - 0.003\ clay - 0.004\ (silt + fine\ sand) - 0.006\ ESP + 0.88 \quad R^2 = 0.68 \qquad (2)$$

With regard to the above equation, it is obvious that with increase in OC content the level of MWD will also increase, which shows the formation of larger aggregates. Organic carbon is one of the most important factors in aggregate stability and protects soil structure against raindrop impact or runoff (Le Bissonais, 1996). So that, Liu et al. (2003) believe that organic matter content plays the greatest role in aggregate stability. Therefore organic matter content is negatively correlated with runoff and soil losses (Descroix et al., 2001). Also, equation 2 demonstrates the negative effect of clay, silt + fine sand and ESP on MWD. In general, the main soil properties influencing aggregate stability are soil texture, clay mineralogy, organic matter content, type and concentration of cations, sesquioxide content and $CaCO_3$ content (Le Bissonais, 1996). So that, Mbagwu (2003) believes that with increase in sand contents (because of the large size of sand particles), detachment of aggregates occurs more easily compared with the other soil particles, especially fine sands that behave like silt particles. The presence of sodium in soils along with expansible clay minerals will enhance the negative correlation between clay particles and MWD, especially in badlands (McIntyre, 2000; Shinberg et al., 2000). The negative effect of ESP in aggregate stability has been discussed by many researchers. For example, Piccarreta et al. (2006) found that all the aggregates which were taken from badlands of Basilicata of Southern Italy had organic matter contents below the critical threshold of 20 g kg^{-1} and SAR values, exceeding the threshold of 15 g kg^{-1}. They reported that as a consequence they suffer physico-chemical breakdown on contact with water. Similar results were observed by Robinson and Phillips (2001).

Saturation water

The lowest (29.1%) and highest (55.0%) values of saturation water were related to sheet and badland erosion, respectively (Table 2). The comparison of mean for various types of erosion identified that there was a significant ($p < 0.05$) difference between gully and badland erosion with sheet and rill erosion (Figure 3j). The high levels of saturation percentage in gully and badland erosion is probably due to the presence of plentiful expansible (2:1) clay minerals having high tendency for moisture absorption (Williams et al., 1983).

Atterberg limits

Although the Atterberg limits do not provide a means of identifying potentially dispersive soils, the higher the values of plastic limit, liquid limit and plasticity index, the higher is the resistance to dispersion. They are a measure of how much water needs to enter the material before it attains liquid properties, especially in situations in which the exposure to water is of limited duration. This may be an important factor, since the ingress of water takes a certain amount of time. This is even more important as materials with a high plasticity index tend to be clayey (smectitic) and thus have low infiltration rates. Hence, a high requirement for water gives the material a certain degree of stability in certain situations (Rienks et al., 2000).

Plastic limit

The mean values of plastic limit for sheet, rill, gully and badland erosions were 11.4, 13.0, 13.5 and 14.0, mm respectively. Also, the comparison of mean for the various types of erosion indicated that there was not significant difference ($p < 0.05$) between them with respect to their plastic limit (Figure 3k). However, the maximum and minimum levels of plastic limit were related to badlands and rills, respectively (Table 2). Rienks et al. (2000) showed that the plasticity index in a gully in Southern Africa ranged from 0 to 0.23. Also, Jegede (2000) showed that soils which were sensitive to failure on steep slopes their plastic limits were ranged between 14.32 to 20%.

Liquid limit

The lowest (32.0%) and highest (57.0%) values of liquid limit were related to rill and badland erosion, respectively (Table 2). The comparison of mean also showed that all of the erosional forms had significant difference ($p < 0.05$) with each others, except sheet with rill erosion (Figure 3l). Therefore, the variations of liquid limit in studied soils were more than plastic limit. Results also showed that the increasing trend of liquid limit was in harmony with increase of clay content. However, the increasing of liquid limit was not proportional to the clay type in studied soils. Because, the X-ray analysis con-firmed the occurrence of lots of smectitic clay minerals in badlands, while sheet and rill erosion did not contain these clay minerals. With regard to this issue specific surfaces of montmorilonite are at least 40-fold more than kaolinite hence, this difference in moisture of liquid limit must be more than that observed in this study. But the moisture of liquid limit in badlands is lower than two fold of liquid limit of sheet erosion. Hence, liquid limit can not be considered as a simple function of moisture on the clay surfaces. Jegede (2000) introduced the soils with liquid limit between 43 - 60.5%, just as sensitive to failure on steep slopes.

Soil activity: Soil activity can be defined as the ratio of plastic index to clay percentage. Plastic index can be derived by taking the difference between liquid limit and plastic limit. The maximum and minimum levels of soil activity were related to badlands and rills (Table 2). The comparison of means also revealed that there was only a significant difference ($p < 0.05$) between gully and other types of erosion (Figure 3m). With regard to these results the soil activity in all of the studied soil will remain in medium group and consequently, illite minerals are probably the prevalent clay minerals in the studied soils. The X-ray diffraction results also confirmed the presence of illite in the studied soils. With increasing activity, the swelling potential in soils will increase (Seed et al., 1988).

The correlation between liquid limit, plastic limit and plastic index with some soil physico-chemical properties are given in Table 4. Also, relationship between Atterberg limits with percentages of clay and saturation (SP) and CEC level for all of the studied soils are estimated through the following equations:

$$LL = 0.824\ clay + 0.028\ CEC + 0.261\ SP + 7.18; \quad R^2_{adj} = 0.869 \tag{3}$$

$$PL = 0.04\ clay + 0.007\ CEC + 0.127\ SP + 5.5; \quad R^2_{adj} = 0.654 \tag{4}$$

$$PI = 0.864\ clay + 0.035\ CEC + 0.125\ SP - 1.4; \quad R^2_{adj} = 0.630 \tag{5}$$

Table 4. Correlation coefficients between some soil physico-chemical properties with Atterberg limits.

Atterberg limits	Clay (%)	$CaCO_3$ (%)	OC (%)	CEC (meq $100g^{-1}$ soil)	SP (%)
liquid limit (LL)	0.923**	- 0.151	0.361	0.307*	0.783**
plastic limit (PL)	0.291*	- 0.146	0.253	0.299*	0.493*
plastic index (PI)	0.932*	- 0.03	0.332	0.293*	0.749*

* and **: Significant at 5% and 1%, respectively.

All of these three functions (Equations 3, 4 and 5) are significant at 5% probability level. Also, according to the above equations clay, CEC and SP are three important factors influencing of Atterberg limits. Between clay, CEC and SP, the clay content can be the most effective factor because, the CEC and water retention are so dependent on the amount and types of clays. Moreover, the comparison of measured correlation coefficients shows that the increasing of clay content in soils (reduction in particle size distribution) will increase both the liquid limit and plastic limits. However, this enhancement in liquid limit is more notable than plastic limit and consequently, the increasing trend of liquid limit with clay rise is more than plastic limit (Table 4). With regard to the important role of clay content in SP, the same procedure was observed between the correlation of SP with liquid and plastic limits. Also, the positive correlation between CEC with liquid and plastic limits shows the effect of clay content and clay type through CEC on these limits (Table 4). Also, the correlation between Atterberg limits with OC and $CaCO_3$ was not significant (Table 4). According to the work done by of Rienks et al. (2000), the OC content has a positive correlation with Atterberg limits. Because with increase of OC in soils the CEC level will increase and hence, increasing of CEC leads to more water absorption and water retention (Refahi, 2000). In the present study the levels of OC in eroded soils were very low and especially in some forms of erosion such as gully and badlands OC was nondetectable. Consequently, OC had no significant effect on CEC, water retention and Atterburg limits. Also according to the results, the $CaCO_3$ content showed negative correlation with Atterberg limits (Table 4). Similar to the OC, low level of $CaCO_3$ in studied soils was not able to improve soil structure, produce stable aggregates and increase soil porosity and therefore, $CaCO_3$ did not decrease Atterberg limits.

Comparison of topsoil and subsoil in gullies and badlands

Due to the fact that the subsoil and topsoil of gullies and badlands are affected by the erosion processes, some physical characteristics of subsoil of study area also were investigated. In gullies and badlands percentage of clays, fine clays, and the level of liquid limit, plastic limit, plastic index, bulk density, and ratio of fine clay to total clay had an increasing procedure (without any significance) from topsoil to subsoil, whereas percentages of sands, silts, fine sands, and the level of MWD had a decreasing procedure (without any significance) from topsoil to subsoil. However, the mean of physical factors for topsoil and subsoil in badlands and gullies did not show any significant difference (Table 5). But, the results showed that the level of SAR in subsoil of badlands was significantly ($p < 0.05$) more than topsoil (Table 5). Therefore, sodium had a dispersive effect on soil structure in subsoil of badlands compared with the overlying horizon. Bork et al., (2001) recognized two main reasons of gully formation in saline areas due to development of pits in subsoil horizons. The first was dispersion of clay particles in presence of sodium and the second was formation of an impermeable layer in the depth of gullies because of occurrence of lots of clay minerals.

Table 5. The results of ANOVA for mean values of some soil physico-chemical properties of topsoil and subsoil in badlands and gullies using Student's *t*-test.

Variables	Gully (t)	Badland (t)
Sand	1.0 ns	1.0 ns
Silt	0.5 ns	0.6 ns
Clay	1.6 ns	1.3 ns
Fine clay	0.6 ns	0.6 ns
Fine clay/total clay	0.03 ns	0.03 ns
Fine sand	0.7 ns	1.2 ns
MWD	0.06 ns	0.04 ns
Plastic limit	0.1 ns	0.0 ns
Liquid limit	1.4 ns	0.08 ns
Plastic index	0.3 ns	0.3 ns
Soil activity	0.0 ns	0.02 ns
Bulk density	0.3 ns	0.03 ns
SAR	1.6 ns	2.0*

*: Significant at 5% and ns: non significant.

Mineralogical results

Sheet erosion: The dominant minerals were a mixture of chlorite-vermiculite and illite-vermiculite, and quartz. The basal reflection (peak) at 9.9 Å in the diffraction pattern of Mg treatment and its consistency in all of the treatments confirmed the presence of some illite minerals in the surface parts of soils that were related to sheet erosion.

The non-existence of conjunction in Mg and K treatments shows the transformation of some of the mica to vermiculite minerals. The consistency of some of the parts of reflection at 14.6 Å in the heating of 550˚C (K-550 treatment) was related to chlorite. However, the presence of reflection at 12 Å for the treatments of K-330 and K-550 showed a mixture of chlorite-vermiculite. Almost certainly, the peaks of 3.3 and 3.5 Å were mainly related to the quartz and cholorite. Also, the removing of 7.0 Å peak in the heating of 550˚C probably was related to the kaolinite (Figure 4a).

Rill erosion: The dominant minerals were chlorite, mica, quartz and also, the mixed minerals such as mica-vermi-culite and chlorite-vermiculite. There is the occurrence of a peak at 10.0 Å in Mg treatment after K treatment + heating at 550˚C (K-550 treatment), thus confirming the presence of illite. The existence of a well-defined peak at 14.5 Å in K treatmentafter K treatment + heating at 550˚C confirmed that chlorite was the dominant mineral phase. However, the gradual increase of the peak of 10.0 Å and reduction of the peak of 14.5 Å in the heating of 330 ˚C (K-330 treatment) showed the presence of a partial amount of vermiculite in the mineral phase. Also, the removing of 7.1 Å peak in the heating of 550 ˚C was related to the kaolinite and the reflection at 3.3 Å was related to quartz. Moreover, the lack of conjunction for the peaks of 10.0 and 14.0 Å in Mg treatment showed a mixture of illite-vermiculite and chlorite-vermiculite (Figure 4b).

Gully erosion: Smectitic group, chlorite (having less quantity), mixed minerals such as chlorite-smectite and illite-smectite (illite having less quantity) and quartz were the dominant mineral phase. Intense diffraction lines at 14.0 Å in Mg saturated specimens, which shifted to 17.0 Å after glycol salvation confirmed the presence of dominant expansible 2:1 clay mineral (smectite) in gullies. However, the occurrence of shoulder in both right and left sides of the peak of 14.0 Å and its lack of conjunction and the appearance of a wide reflection (peak) at 10.0 to 14.0 Å in K treatments were related to the mixtures of chlorite-smectite and illite-smectite. Also, the presence of a weak and wide reflection at 10.0 Å in Mg treatment and consistency of some of the parts of 14.0 Å peak in K-550 treatment confirmed the existence of the mixtures of chlorite-smectite and illite-smectite. But the amount of illite was so partial and its value was significantly less than chlorite. Consequently, probably the majority parts of illite are transformed to smectite. Furthermore, the reflections of 3.3 and 7.0 Å were related to quartz and kaolinite, respectively (Figure 4c).

Badland erosion: The dominant clay minerals were smectite, chlorite and mica, but the mixed minerals such as illite-smectite and chlorite-smectite were probably presented in these areas. Intense diffraction lines at 14.4 Å in Mg saturated specimens, which shifted to 16.5 Å after glycol salvation confirmed the presence of some dominant expansible 2:1 clay minerals (smectite) in badlands. However, presence of a shoulder at the side of lower degree (left side) of 14.4 Å in Mg saturated specimens and the lack of conjunction of peaks of 10.0 and 16.5 Å in Mg and Mg-ethylene glycol solvation treatments were related to some of the smectites that were mixed with other minerals such as chlorite and mica (chlorite-smectite or mica-smectite). A well-defined reflection at 10.0 Å and its consistency in all of the treatments showed the presence of mica (illite) as a dominant mineral phase. Moreover, because of the intense peak at 14.4 Å in Mg treatment left after K-550 treatment, chlorite was the dominant mineral phase. In addition, the reflection at 7.0 Å in Mg treatment was related to kaolinite and also the reflection at 3.3 Å in all of the treatments showed the presence of quartz as the dominant mineral in this sample (Figure 4d).

Parent material: In this sample mica, quartz, calcite, feldspar and halite were identified. The reflections at 2.8, 2.0 and 1.6 Å were related to halite (Figure 5). Hence, some salts such as gypsum and $CaCO_3$ which were so abundant in Marly lands of northern Iran had probably the pedogenesis origin. The levels of gypsum and $CaCO_3$ in this stone were about 15.5 and 7.5%, respectively. Piccarreta et al., (2006) reported that phyllosilicates were dominated in badlands of Basilicata, of Southern Italy, followed in order of abundance by quartz, calcite, feldspars and dolomite. Traces of gypsum and hematite were present only in some samples in their study area. Also, they believe that clay mineralogy is dominated by illite and kaolinite, followed by chlorite and expandable clays.

Conclusion

1. Results showed that the percentage of saturation, clays, fine clays, and the level of MWD, activity and liquid limit had significant ($p < 0.05$) changes in some types of erosion, whereas other physical parameters had no significant effect on the form and type of erosion. Also, the correlations between liquid limit, plastic limit and plastic index with some soil physico-chemical properties indicated that clay content, CEC level and percentage of saturation were three important factors for estimating of Atterberg limits.
2. Comparison of surface and underlying (near the bedrock) layers in gullies and badlands indicated that the percentage of clay, fine clay, and the level of liquid limit, plastic limit, plastic index, bulk density, and ratio of fine clay to total clay had an increasing procedure (without any significance) from topsoil to subsoil, whereas percentages of sand, silt, fine sand, and the level of MWD had a decreasing procedure (without any significance) from topsoil to subsoil. However, the mean of physical factors of topsoil and subsoil in badlands and gullies did not show any significant difference. But, the results showed that the level of SAR in subsoil of badlands was significantly ($p < 0.05$) more than topsoil.
3. The X-ray diffraction patterns of the clay fraction from

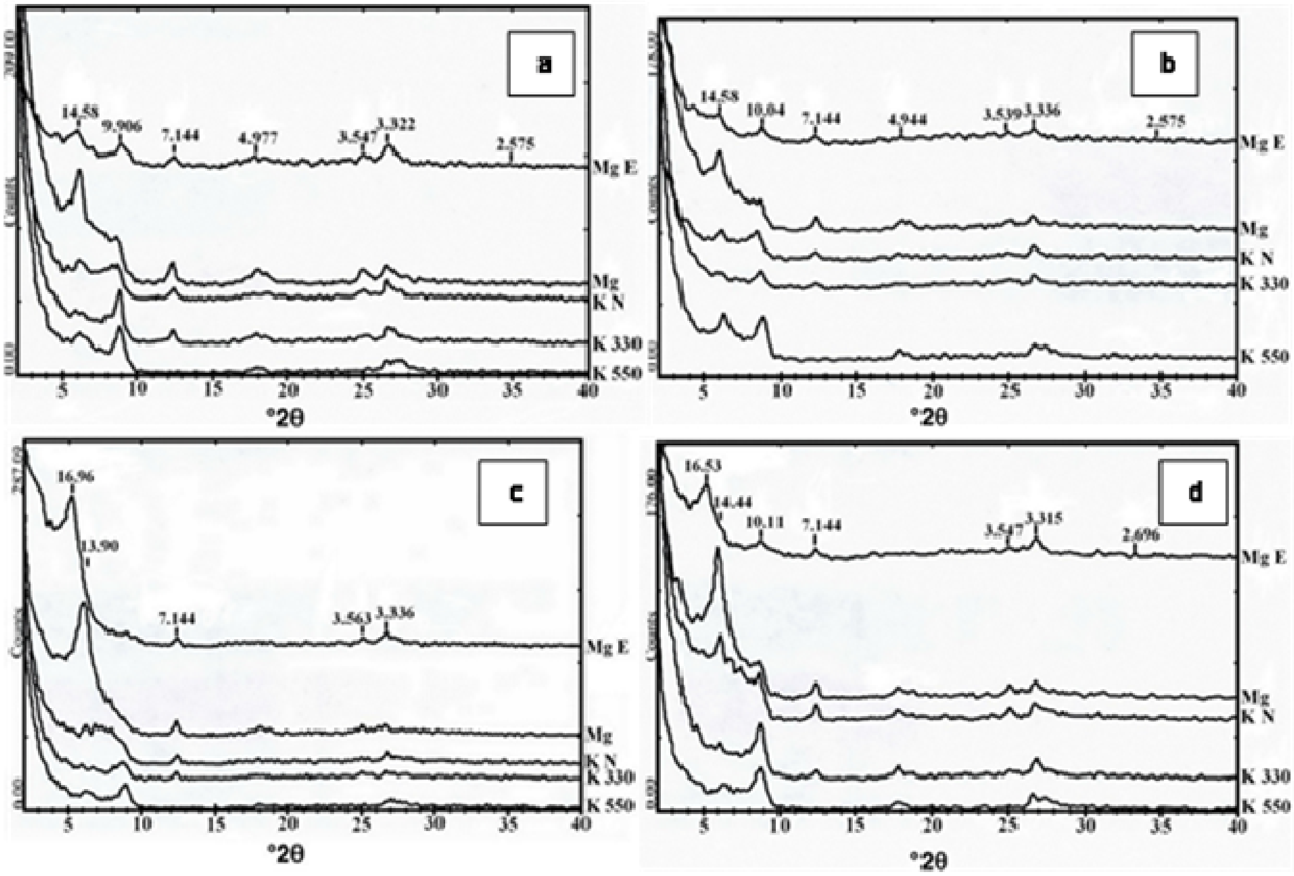

Figure 4. X-ray diffractogram of clay fraction (< 2 µm) from surface layers of: (a) sheet, (b) rill, (c) gully, and (d) badland erosion (in these diagrams Mg E, Mg, K N, K 330, and K 550 are treatments of saturated by ethylene glycol solvation, Mg, K at 25 ºC, K at 330 ºC, and K at 550 ºC respectively).

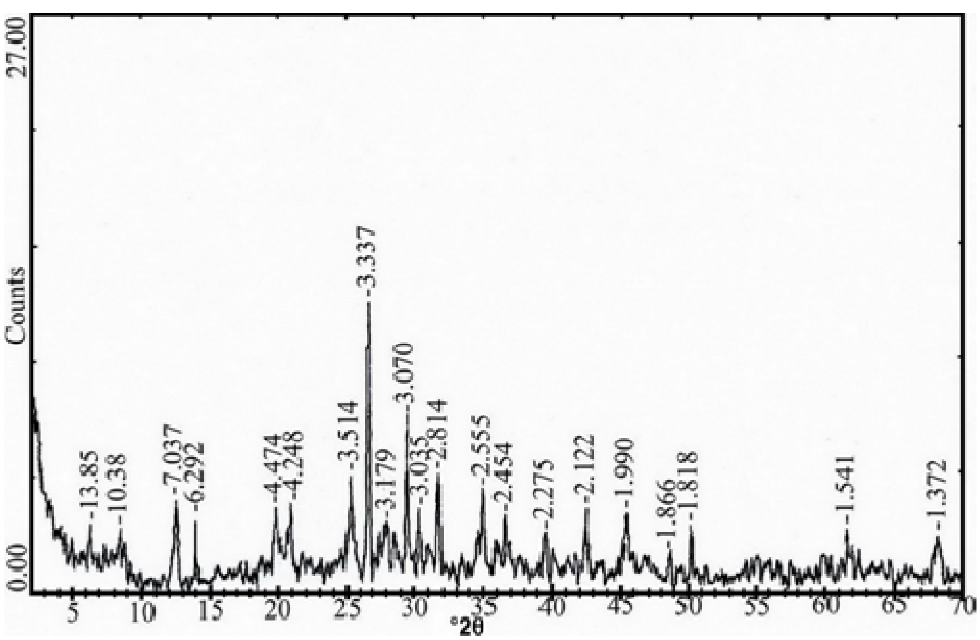

Figure 5. X-ray diffractogram of clay fraction (< 2 µm) from parent material of badland erosion.

surface layers showed an intense diffraction lines at 14.0 Å in Mg saturated specimens, which shifted to 17.0 Å and 16.5 Å after glycol solvation and confirmed the presence of dominant expansible 2:1 clay mineral (smectite) in gullies and badlands, whereas the expandable clay minerals were not identified in rills. Since, the smectitic group minerals have high potential for more shrinkage, swelling and mobility which present dominantly in fine clay fraction; so, it can be concluded that with increasing the ratio of fine clay to total clay, retention of moisture increases and infiltration of water decreases which in turn, enhances the soil erodibility. Also with respect to the X-ray diffractogram of parent material of badland erosion, the salts of these areas had probably pedogenesis origin. Also, sodium ions which are able to increase the thickness of diffuse double layer of clay fraction bring about the condition for more soil dispersing, intensifying soil erosion.

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REFERENCES

Alexander D (1982). Difference between “Calanchi” and “biancane” badlands in Italy. In: Bryan R and Yair A (Eds.), Badland Geomorphology and Piping. Geo Books, Norwich, UK, pp. 71-88.

Amiri M (2001). Finding the origin of colloidal clays and silt particles in Tasran station by trace elements. International congress of soil erosion, land management and sustainable development, Arak, Iran.

Battaglia S, Leoni L, Sartori F (2002). Mineralogical and grain size composition of clays developing calanchi and biancane erosional landforms. Geomorphol. 49: 153-170.

Benito G, Gutirerrez M, Sancho C (1991). Erosion pattern in rill and interrill area in badland zones of the middle Ebro Basin (NE-Spain). Soil Erosion Studies in Spain, pp. 41-45.

Bork HR, Li Y, Zhao Y (2001). Land use changes and gully development in the upper Yangtze River Basin, SW-China. J. Mt. Sci. 19(2): 97-103.

Bouma NA, Imeson AC (2000). Investigation of relationship between measured field indicators and erosion possesses on badland surfaces at petrer, Spain. Catena 40: 147-171.

Bower CA, Wilcox LV (1965). Soluble salts. In: Black CA (Ed.), Methods of Soil analysis. American Society of Agronomy, Madison, WI, USA, pp. 933-940.

Cerda A (2002). The effect of season and parent material on water erosion on highly eroded soils in eastern Spain. J. Arid. Environ. 52: 319-337.

Chapman HD (1965). Cation exchange capacity. In: Black CA (Ed.), Methods of Soil analysis. American Society of Agronomy, Madison, WI, USA, pp. 891-900.

Day PR (1965). Particle fractionation and particle-size analysis. In: Black CA (Ed.), Methods of soil analysis: Part 2. Monogr. Ser., vol. 9. American Society of Agronomy, Madison, WI, pp. 545-566.

Descroix L, Viramontes D, Vauclin M, Gonzalez Barrios JL, Esteves M (2001). Influence of soil surface features and vegetation on runoff and erosion in the Western Sierra Madre (Durango, Northwest Mexico). Catena 43: 115-135.

Emami J, Ghazavi A (2002). Landslides and ruptures in saturated fine soils of Chaharmahal and bakhtiari province of Iran. J. of Earth Sci. 35: 42-44. (In Persian).

Ezochi JI (2000). The influence of runoff, lithology, and water table on the dimensions and rate of gullying processes in eastern Nigeria. Elsevier, Catena verlage, Cremlingen.

Ghadimi Aroosmahale F (1998). Study the relation between different forms of erosion and physico-chemical properties of marls. J. Pajoohesh and Sazandegi 40: 95-99. (In Persian).

Gromko GJ (1974). Review of expansive soils. J. Geotech. Eng-ASCE 667-687.

Imeson AC, Kwaad FJ, Wereraten JM (1982). The relationship of soil physical and chemical properties to the development of badland in Morocco. In: Brayan R and A Yair. Badland geomorphology and piping. Geobooks. No, 47: 231-239.

Jackson ML (1975). Soil chemical analysis. Advanced Course. Univ. of Wisconsin, College of Agric., Dept. of Soils, Madison, WI.

Jegede G (2000). Effect of soil properties on pavement failures along the F209 highway at Ado-Ekiti, south-western Nigeria. Constr. Build. Mater. 14: 311-315.

Johns WD, Grim RE (1954). Quantitative estimation of clay minerals by diffraction methods. J. Sediment. Petrol. 24: 242-251.

Kittrick JA, Hope EW (1963). A procedure for the particle size separation of soils for X-ray diffraction analysis. Soil Sci. 96: 312-325.

Klute A (1986). Methods of soil analysis. Part 1: Physical and mineralogical methods. Soil Sci. Soc. Am. J. Madison, Wisconsin, USA.

Le Bissonais Y (1996). Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. Eur. J. Soil Sci. 47: 425-437.

Lesschen JP, Kok K, Verburg PH, Cammeraat LH (2007). Identification of vulnerable areas for gully erosion under different scenarios of land abandonment in Southeast Spain. Catena 71: 110-121.

Li XY (2003). Gravel-sand mulch for soil and water conservation in the semiarid loess region of northwest China. Catena 52: 105- 127.

Liu G, Xua M, Ritsema C (2003). A study of soil surface characteristics in a small watershed in the hilly, gullied area on the Chinese Loess Plateau. Catena 54: 31-44.

Maquaire O, Malet JP, Remaitre A, Locat J, Klotz S, Guillon J (2003). Instability conditions of Marly hillslopes: towards landsliding or gullying? The case of the Barcelonnette Basin, South East France. Eng. Geol. 70: 109-130.

Martinez-Mena M, Castillo V, Albaladejo J (2002). Relations between interrill erosion processes and sediment particle size distribution in a semiarid Mediterranean area of SE of Spain. Geomorphol. 45: 261-275.

Martin-Penela AJ (1994). Pipe and gully systems development in the Almanzora basin (Southeast Spain). Zeitschrift fur Geomorphol. 38(2): 207-222.

Mashhadi N (2001). Study of the water erosion in the marl formation based upon climatic data and vegetation. Case study: south of Birjand, Iran. Soil and fertilizers (CAB abstracts) 65(7): 13-55.

Mbagwu JSC (2003). Environmental control of soil structure in Mediterranean soils. Lecture given at the college on soil physics. LNS0418023, pp. 255-259.

McIntyre D (2000). Exchangeable sodium, subplasticity and hydraulic conductivity of some Australian soils. Aust. J. Soil Res. 17(1): 115-101.

Mehra OP, Jackson ML (1960). Iron oxide removal from soils and clays by a dithionite citrate system with sodium bicarbonate. Clays Clay Miner. 7: 317-324.

Menéndez Duarte R, Wozniak E, Recondo C, Cabo C, Marquínez J, Fernández S (2008). Estimation of surface roughness and stone cover in burnt soils using SAR images. Catena 74: 264-272.

Nelson DW, Sommers LE (1982). Total carbon, organic carbon, and organic matter. In: Page AL, Miller RH and Keeney DR (Eds.), Methods of Soil Analysis. Part II, 2nd ed. American Society of Agronomy, Madison, WI, USA, pp. 539-580.

Okoba BO, Sterk G (2006). Quantification of visual soil erosion indicators in Gikuuri catchment in the central highlands of Kenya. Geoderma 134: 34-47.

Ouhadi VR, Yong RN (2003). The role of clay fraction of Marly soils on

their post stabilization failure. Eng. Geol. 70: 365-375.
Page AL (1986). Methods of soil analysis. Part 2: Chemical and microbiological properties. Soil Sci. Soc. Am. J. Madison, Wisconsin, USA.
Peech M (1965). Hydrogen-ion activity. In: Black CA (Ed.), Methods of Soil analysis. American Society of Agronomy, Madison, WI, USA, pp. 914-916.
Piccarreta M, Faulkner H, Bentivenga M, Capolongo D (2006). The influence of physico-chemical material properties on erosion processes in the badlands of Basilicata, Southern Italy. Geomorphol. 81: 235-251.
Ramarao R, Smart P (1990). Significance of particle size distribution similarity in prediction of swell properties. Proceeding of the conference on expansive soils. Published by ASCE, pp. 96-105.
Refahi HGh (2000). Water erosion and conservation (In Persian). Tehran University Press, p. 551.
Rey F, Berger F (2006). Management of Austrian black pine on Marly lands for sustainable protection against erosion (Southern Alps, France). New Forest. 31: 535-543.
Rienks SM, Botha GA, Hughes JC (2000). Some physical and chemical properties of sediments exposed in a gully (donga) in northern KwaZulu-Natal, South Africa and their relationship to the erodibility of the colluvial layers. Catena 39: 11-31.
Ries J, Hirt U (2007). Permanence of soil surface crusts on abandoned farmland in the Central Ebro Basin/Spain. Catena 72(2): 282-296.
Robinson DA, Phillips CP (2001). Crust development in relation to vegetation and agricultural practice on erosion susceptible, dispersive clay soils from central and southern Italy. Soil Till. Res. 60: 1-9.
Roswell CG (2002). Potential sources of sediments and nutrients: sheet and rill erosion and phosphorous sources, state of the environmental, technical paper series, Australia.
Seed HB, Woodward RJ, Lundgren R (1988). Pressure of swilling soil against retaining walls. Soil Mech. and Found. Eng. 25(3): 101-105.
Sherard JL, Dunnigan LP, Decker RS (1976). Identification and nature of dispersive soils. J. Geotech. Eng. Div. Proc. ASCE, LOZ (GT4) 287-301.
Shinberg I, Levy G, Levin J, Goldstein D (2000). Aggregate size and seal properties. Soil Sci. 162: 470-478.
Smaeil Zade H (2002). Marl soils and different types of erosion n Iran. 17th WCSS. Tailand, 22351: 1-8.
Thornes LB (1980). Erosional processes of running water and their spatial and temporal controls: a theoretical view point; In: Kirby M J and Morgan R P C (editors). Soil erosion, Wiley, pp. 128-129.
Vandekerckhove L, Poesen J, Oostwoud Wijdenes D, Gyssels G, Beuselinck L, de Luna E (2000). Characteristics and controlling factors of bank gullies in two semi-arid mediterranean environments. Geomorphol. 33: 37-58.
Wakindiki IIC, Ben-hur M (2002). Soil mineralogy and texture effects on crust micromorphology, infiltration and erosion. Soil Sci. Soc. Am. J. 66: 597-605.
Williams J, Prebble RE, Williams WT, Hignett CT (1983). The influence of texture, structure and clay mineralogy on soil moisture characteristics. Aust. J. Soil Res. 21: 15-32.