

INVESTIGATING THE RELATIONSHIPS BETWEEN CHEMICAL INDICES OF SOIL DEVELOPMENT AND WEATHERING IN VARIOUS PARENT MATERIALS IN URMIA LAKE CATCHMENT

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Abstract: According to recent environmental crisis and drying of Urmia Lake that affecting surrounding lands, this study was conducted to evaluate the physico-chemical properties, weathering rates and evolution of soils by using various weathering indices and forms of iron in Miandoab township. Thirteen soil profiles were described on different parent material. The results showed that the studied soils were in the orders of Inceptisols and Entisols and the difference in the type of parent material, physiography and aspect were effective on the soil physicochemical characteristics. Also the results in the iron part showed that a significant portion of the iron is in crystalline form. Considering the high correlation between the two factors of weathering intensity and iron mobility index, profiles 3, 2, 8, 7 and 10 had higher evolution rates with respect to other profiles. The geochemical result showed that the geology and composition of the soil parent materials had largely affected the amount of chemical weathering. The negative correlation between Na₂O, Cao and K₂O and chemical index of alternation indicates weathering of the plagioclases and feldspars in this area. Also weathering indices where the ratio of immobile element to the mobile oxides is incorporated in their formula were more appropriate for estimating the weathering intensity.

Keywords: Fe forms, Weathering rate, Soil development, Urmia Lake, parent material

1. INTRODUCTION

Soil formation on the ground surface is the result of interaction between five pedogenic factors including the climate, vegetations or organisms, parent material, topography and time. Where the amount of each factor could result in formation of soils with different properties and horizons (Jenny 1941). The attributes which are used to express the degree of development are often created by weathering or are prone to changes. Some of these features are: index of accumulation of Clay (Singh et al., 1998) and Iron oxide (Simon et al., 2000), and deformation of

pedogenic iron and aluminum (Birkeland et al., 1989). Some researchers believe that regarding that during weathering of the parent materials containing the iron mineral, this element is released and again in the soil is deposited in the form of oxide, iron hydroxide and/or iron oxyhydroxide, therefore the amount and distribution of extracted iron together with oxalate and dithionite and comparison of the two types of iron could exhibit the degree of soil development (Zielhofer et al., 2009). In most of the soils the morphologic characteristics, clay content and pedogenic iron could be used for estimation of the soils age (Constantini & Damiani, 2004).

Determining the amount and distribution of various forms of iron, Free iron oxides (Fe_d), amorphous iron oxides (Fe_o), crystalline form ($Fe_c = Fe_d - Fe_o$) and silicate iron ($Fe_s = Fe_c - Fe_d$), is one of the applied methods for investigating soil evolution in the soil profile. These indices could be used for determining the soil formation processes and identification of the soil type (Róžański et al., 2013). In the weathered environments the mobility of iron is affected by its oxidation situation. The divalent iron has a high mobility which after being released from the composition of initial minerals, is deposited as the pedogenic iron or Fe_d (which could be distilled by citrate-bicarbonate-dithionite) while trivalent iron is immobile (Price & Velbel, 2003).

During the weathering, the parent materials containing iron are released and again are deposited in the soil in the forms of amorphous, oxide or crystallized iron oxide (Alexander, 1974). The amorphous iron oxide could be measured through distillation by oxalic acid. Compounds of free or pedogenic iron could be measured by dithionite bicarbonate citrate (Mckeague & Day, 1996). The iron released by the dithionite method should be equal or greater than the iron released by the oxalate method. The difference between the two values which is the same as Fe_c , is the iron existing in the crystalline form. A higher value of this difference indicates the soil age (Degórski, 2011).

The ratio of amorphous iron to free iron, Fe_o/Fe_d , is called the activity ratio. This ratio is used for investigating the soil development. Studies have shown that the amounts of pedogenic iron oxides and their crystallization increases with increase in the soil age and the rate of weathering that results in to reduction of the activity ratio indicates the soils with higher evolution. A higher activity ratio is associated with reduction in the secondary iron oxide value in the crystallized form which indicates lower evolution of the soils (Schwertmann, 1964; Alexander, 1974, Olatunji et al., 2015).

The proportion of free iron content to total iron, Fe_d/Fe_t , or the iron mobility index shows the rate of changes in the initial minerals which could be used for determining the removed iron from the initial minerals containing iron. A high value of this ratio indicates the intensity of the weathering which is a precise index for identifying soil development (Blume & Schwertmann, 1969; Rebertus & Buol 1985). Also, for identification of weathering intensity one could use the ratio of difference free iron from amorphous iron to total Fe content. By increase in the weathering intensity the value of this index increases (Arduino et al., 1984; Alexander, 1985; Baumann et al., 2014). The chemical weathering indices are used for investigating the soil development (Zhu & Yang

2009; Abbasi-Kalo et al., 2014) and determining the soil formation processes (Schaeztl et al., 2006).

In fact, weathering process is one of the initial mechanisms which controls the materials cycle. This process is a combination of physical processes and chemical reactions which converts the initial minerals into more stable forms (Aide & Smith-Aide 2003). Many indices have been defined for determining the soil weathering. The general basis of these indices is the ratio of mobile elements to the immobile elements, where by increase in weathering process of the mobile metal oxides such as ($Al_2O_3 \cdot Fe_2O_3 \cdot TiO_2$) it remains constant and concerning oxides such as $SiO_2 \cdot Na_2O \cdot K_2O \cdot CaO$ and MgO which are assumed as mobile it is reduced. Also the LOI of the structured water increases (Duzgoren-Aydin et al., 2002). The results related to investigation of the above indices show that the soil horizons often have higher weathering rates with respect to the underlying bed rock and the surface horizons are also more weathered with respect to the underlying horizons (Munroe et al., 2007; Bétard., 2012).

In some of the indices of chemical weathering use is made of the very mobile elements such as the alkaline and alkaline-earth elements. These indices are very effective for determining the effects of chemical weathering with respect to a bed rock that is not weathered. Also, they are appropriate for application in the non-homogeneous weathered remnants (Price & Velbel., 2003). Regarding that Miandoab Township is located south of the Urmia Lake and within the Simineh-Rood catchment and is accounted as one of the main populated areas and also one of the centers of cropping the strategic products in West Azerbaijan Province, this research is performed for investigating and studying development of the Miandoab Township soils.

2. MATERIALS AND METHODS

2.1. Study area

Miandoab Township is located south of the Urmia Lake and south east of West Azerbaijan Province. The sedimentary formations are mostly comprised of limestone, Jurassic and Cretaceous dolomite rocks which are extended to the southern and eastern parts of the region. Also, Mesozoic limestone formations are seen in the southern parts of the region. The metamorphosed formations-the metamorphosed rocks in the region are mostly comprised of schist, mica-schist, gneiss, marble and metamorphosed limestone. Igneous formations-they include acid intrusive igneous rocks like granite and micro-granite and igneous rocks like diorite and micro diorite seen mostly at the south eastern parts of the region. The mean annual

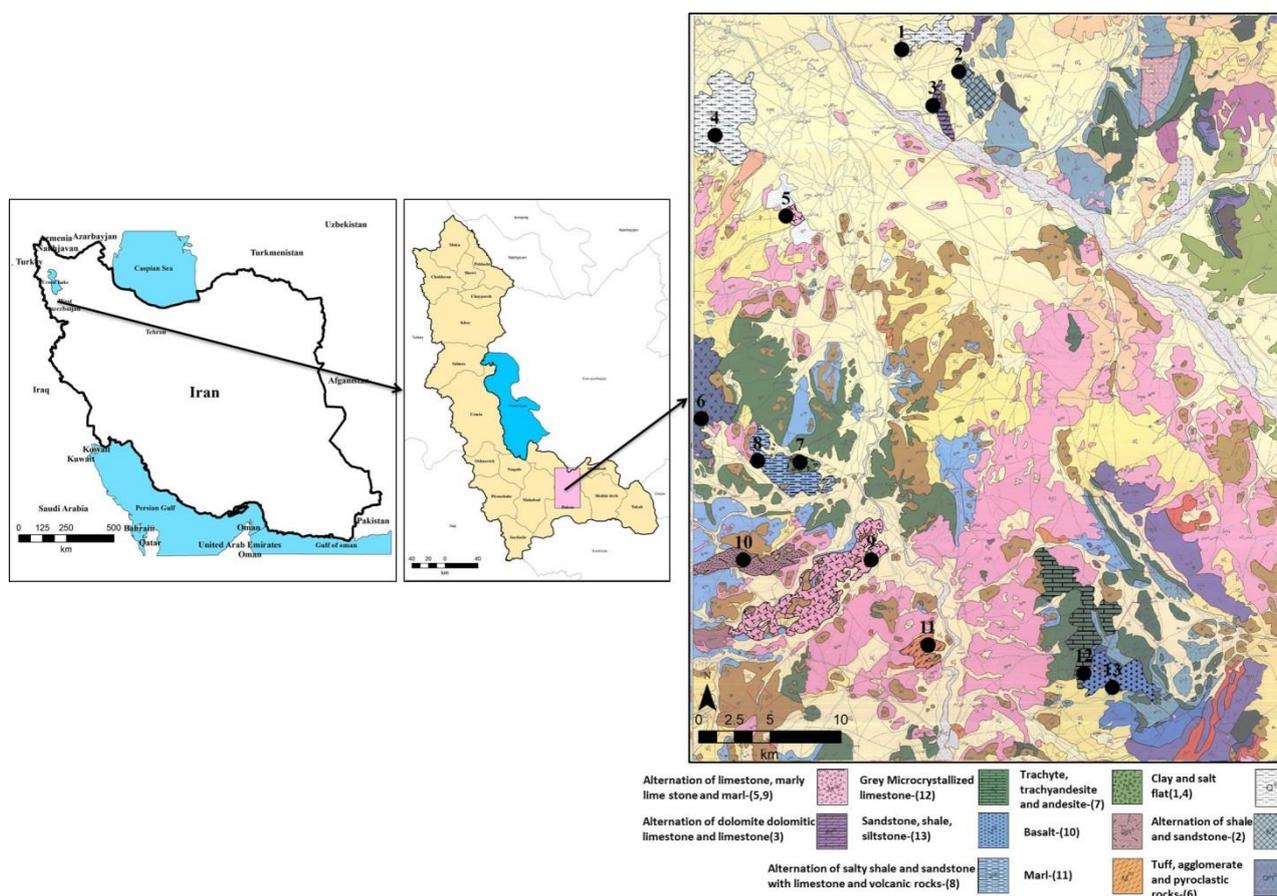


Figure 1. Study area and Location of soil Profiles

temperature is 11.7 Celsius degrees. The mean annual precipitation in the region is 320 mm (35-years meteorological statistics). According to the maps of soil moisture and temperature regime of Iran's soils, the moisture regime belongs to the xeric area and its temperature regime is Mesic.

2.2. Field studies and sampling

First, using the digital elevation model (DEM) of the area, the slope, direction of slope, and elevation maps were prepared and then by overlaying these layers on the geology map the study points in various rheological materials were selected so that they had minimum changes in terms of elevation and the slope direction. On each parent rock two soil profiles were drilled and described, but only one soil profile is used in the results section of the article. 13 different soil profiles were drilled which included lime, shale, sand stone, siltstone, marl, basalt, volcanic rocks, Trachyte, Trachyandesite and andesite, tuff, agglomerate and detrital rocks, clayey and salty plains and dolomite (Fig. 1). After describing each soil profile, sampling was performed from each horizon, soil classification was done using the Soil Taxonomy 2014 systems.

2.3. Laboratory studies

After collecting the samples, air drying them and passing them through a 2-mm sieve, the necessary laboratory analyses were performed on them. For this purpose the soil texture was measured using the hydrometer method (Gee & Bauder, 1986), pH measurement was done using the glass electrode (McLean, 1982) and the soil electrical conductivity was measured in a saturated soil-paste extract (ECE) (Rhoades, 1982). Organic carbon was measured by the wet oxidation method (Nelson & Sommers, 1982), Calcium carbonate was measured by acid neutralizing method using hydrochloric acid (Nelson, 1986) and gypsum was measured by the acetone method (Nelson, 1986). Cationic Exchange Capacity (CEC) measurement was performed using sodium acetate at pH=8.2 and neutral ammonium acetate (Sumner et al., 1994). The total amount of major elements including (Si, Al, Fe, Ca, Mg, K, Na, P, Mn, CL and Sr) was determined using the XRF equipment: Philips Magix-pro model with a tube power of 4000 watts (Table 1). The amount of pedogenic iron was determined by the Citrate-dithionite-bicarbonate (CBD) method (Jackson et al., 1982) and the amorphous iron (Fe_o) was extracted using the acidified ammonium oxalate and extraction in

darkness (Mckeague & Day, 1966) and the available iron was read by the atomic absorption spectrometer. The correlation coefficients between various forms of iron and also different weathering indices in the normal data were determined by the Pearson method and in the abnormal data by the Spearman method incorporating the SPSS23 software.

The used indices in this article are the R, WIP, PWI, CIA, CIW, PIA and STI. The values of these indices were determined using the corresponding formula for that index and using the major elements concentrations. For the proper application of the indices, they should be examined for different regions with respect to the climatic conditions and the parent rock of that region. In calculation of the indices use has been made of the molecular proportion of the elements which is the percentage of each oxide divided by its molecular weight. CaO^* is the available calcium in the silicate portion.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical properties

Soil development has a close relation with the slope degree. So that in sloping lands, where the soil depth is low the rate of development decrease, but in the flat lands the soils have a higher profile development with higher clayey coverage, stronger structure, and possess higher degradation index and higher alkaline saturation degree (Munn & Boehm 1983). Some of the physical and chemical characteristics including the exchangeable cations, CEC, pH and the amount of organic substance, due to their difference in the parent material and topographic situations could be different (Schaefer et al., 2005).

Also, the soils with different parent materials, due to difference in the minerals available in the structure of their parent rocks and difference in the

strength of their constituent minerals against degradation, would have different features (Buol et al, 2003). In this study also the results of physical and chemical characteristics of profiles (Table 3), at the geomorphological levels showed that difference in the type of parent material has caused significant changes in some of the soil characteristics.

The investigated soils in this study were in the orders of Inceptisols and Entisols. In soil profile 1 which was located on the salty and clayey plains and land type R.A.P, the BW and Bk horizons were formed. The SAR and EC values of this profile had the highest values equal to 167.73 and 7.8 dS/m, respectively. These values were compatible with the study performed in Tabriz Plain which was done on the parent material of sandstone, marl and alluvial material (Jahanbazi et al., 2016). In fact, soils located at the low points had highest salinity and fine texture and the soils located at high levels have low salinity and coarse texture (Abtahi & Solhi, 1992). In these areas, in addition to the effect of parent material, fine texture causes capillary movement of water and accumulation of salts at the soil surface. Also, in soil profile 4 located on the same parent material and land type, Bw horizon was formed and there were evidences of carbonate calcium in the field. In addition to increase in the salinity and amount of sodium in the soil, the amounts of clay and cation exchange capacity were increased when moving from the hills to the lower lands (Rezaei Hosseinabad et al., 2013).

The highest value of the soil cation exchange capacity also belonged to this soil profile which was 36.82 meq in 100g soil at Bk horizon where 60% clay was observed in this horizon which indicates that cation exchange capacity value follows the clay amount (Simon et al., 2000). The results showed that these two soil profiles having similar parent material and located at low level lands have higher pH values in comparison to soil profiles.

Table 1. Weathering indices used in this research (Molecular proportions of elements oxides)

index	Formula	Optimal limit in the fresh materials	Optimal limit in the weathered materials	Resources
R	SiO_2/Al_2O_3	10>	0	Ruxton, 1968
WIP	$(100)[(2Na_2O/0.35) + (MgO/0.9) + (2K_2O/0.25) + (CaO/0.7)]$	100>	0	Parker, 1970
PWI	$[SiO_2/(TiO_2 + Fe_2O_3 + SiO_2 + Al_2O_3)] \times 100$	50>	0	Souri et al., 2006
CIA	$(100)[(Al_2O_3/Al_2O_3 + CaO^* + Na_2O + K_2O)]$	50<	100	Nesbitt & Young, 1982
CIW	$(100)[(Al_2O_3/Al_2O_3 + CaO^* + Na_2O)]$	50<	100	Harnois, 1988
STI	$(100) [(SiO_2/TiO_2)/((SiO_2/Al_2O_3)+(Al_2O_3/TiO_2+(SiO_2/TiO_2)))]$	90>	0	Jayawardena & Izawa, 1994

Table 2. Physical and chemical characteristics of studied Profiles

Horizon	Depth (cm)	Moist color of soil	Texture	ECe (dS/m)	pH	%O.C	CEC (meq/100g)	lime (%)	SAR(meq/L)
Soil profile 1, Salty and clayey plains,596016 mE and 4079741 mN Fine silty,mixed,superactive,mesic, Sodic Calcixerept									
Ap	0-15	10YR5/4	CL	7.80	10	0.37	28.4	7	167.7
Bk1	15-30	10YR5/4	CL	5.95	9.8	0.25	27.5	16	119.6
Bk2	30-65	10YR4/3	CL	6.50	9.9	0.23	26.7	21	140.9
Bw	65-90	10YR5/4	L	3.52	9.6	0.23	27.5	18	85.4
2Bx1	90-115	10YR4/3	L	2.72	9.3	0.23	21.7	8	69.4
2Bx2	115-150	10YR4/3	L	2.48	8.6	0.27	24.2	16	34.4
Soil profile 2, Alternation of shale and sandstone, 607846mE and 4089963mN Clayey skeletal, mixed, superactive, mesic,Typic Calcixerepts									
A	0-20	10YR4/3	CL	0.69	7.8	1.28	25.1	23	0.65
Bw	20-55	10YR5/6	CL	0.61	7.7	0.53	25.1	26	0.59
Bk	55-120	10YR5/6	CL	0.28	7.8	0.21	22.6	35	1.10
Soil profile 3, Alternation of dolomite, dolomitic lime and lime stone, 606077 mE and 4087468 mN Fine loamy, mixed, superactive, mesic, Typic Haploxerepts									
A	0-20	10YR4/4	L	0.22	7.6	1.93	24.1	22.5	0.66
Bw1	20-45	10YR4/5	L	0.13	7.8	0.17	18.0	12	1.3
Bw2	45-100	10YR4/6	L	-	7.9	-	18.	12.5	-
Bw3	100-135	10YR4/6	SL	2.20	7.7	0.05	15.4	16	0.79
By	135-160	10YR5/5	L	0.65	8.0	0.19	-	29.5	1.41
Soil profile 4, Salty and clayey plains ,591077 mE and 408568 mN Fine, mixed, active, mesic, Typic Haploxerepts									
Ap	0-25	10YR4/2	SiC	1.46	8.1	0.99	25.8	5.5	14.87
Bk	25-45	10YR3/2	C	1.45	8.0	0.66	36.8	8	14.67
Bw1	45-70	10YR5/4	SiC	1.14	8.4	0.39	33.4	12.5	21.37
Bw2	70-90	10YR4/3	SiC	1.02	8.5	0.29	25.0	14	33.55
Bw3	90-150	10YR4/3	SiC	-	8.5	0.27	22.5	21.5	-
Bw4	150-175	10YR4/4	SiCL	1.22	8.2	0.29	25.9	18.5	23.83
Bw5	175-200	10YR5/4	SiCL	1.20	8.2	0.16	18.3	16.5	19.86
Soil profile 5, Alternation of lime, marly- lime and marl, 596016 mE and 4079741 mN Loamy skeletal, carbonatic,active, mesic, Typic Xerorthents									
Ap	0-25	10YR5/4	L	0.13	7.9	1.11	16.6	60.5	0.89
C1	25-50	10YR5/4	L	0.08	8.0	0.49	10.8	83	0.70
C2	50-100	2.5Y7/2	SiL	-	8.1	0.27	5.7	96	-
C3	100-150	2.5Y7/2	L	0.17	7.9	0.10	8.3	86.5	1.94
Soil profile 6, tuff, agglomerate and pyroclastic rocks, 590077 mE and 4065468 mN Loamy skeletal over sandy skeletal, mixed, superactive, mesic, Typic Haploxerepts									
A	0-20	10YR4/3	L	0.18	7.5	1.46	10.8	1.5	0.67
Bw	20-42	10YR4/4	SCL	0.16	7.6	0.78	25.0	3	0.88
C1	42-85	10YR4/4	SL	0.09	7.9	0.64	26.7	18	1.08
2C2	85-150	2.5Y6/3	LS	0.10	8.2	0.11	-	12	1.42
Soil profile 7, Trachyte, trachyandesite and andesite, 597073 mE and 4062380 mN Loamy skeletal, mixed, superactive, mesic, Typic Haploxerepts									
Ap	0-15	10YR5/4	L	0.15	7.6	0.78	27.5	19.5	0.91
Bw	15-32	10YR5/4	CL	0.11	7.7	0.40	25.9	34.5	1.06
Cr	32-60	10YR5/4	L	0.15	7.7	0.31	28.4	37.5	0.67
Soil profile 8, shales, sandstone with lime stone, 594077 mE and 4062468 mN Loamy skeletal over Sandy skeletal, mixed, superactive, mesic, Typic Haploxerepts									
Ap	0-20	10YR4/4	L	0.14	7.7	0.79	34.3	12	0.77
Bw	20-35	10YR4/4	SiCL	0.12	7.7	0.54	33.4	13.5	0.73
C1	35-60	-	SCL	0.12	7.6	0.37	34.3	19.5	0.81
C2	60-150	-	LS	-	7.7	0.23	-	21.5	-

Horizon	Depth (cm)	Moist color of soil	Texture	ECe (dS/m)	pH	%O.C	CEC (meq/100g)	lime (%)	SAR(meq/L)
Soil profile 9, Alternation of lime, marly- lime and marl, 602077 mE and 4055468 mN Fine, carbonatic, active, mesic, Typic Haploxerepts									
Ap	0-18	10YR5/3	SiC	0.92	7.5	0.99	27.6	37.5	1.27
Bw1	18-35	10YR4/4	SiC	0.40	7.6	0.95	28.4	37.5	1.51
Bw2	35-60	10YR4/5	SiC	0.35	7.6	0.56	28.4	43.5	1.74
Bw3	60-80	10YR6/5	SiC	-	7.6	0.39	27.6	52.5	-
Bw4	80-100	10YR6/5	SiC	0.41	7.6	0.25	30.2	59	1.71
CB	100-125	5YR6/4	SiC	0.37	7.7	0.27	30.2	55.5	1.43
Cr	125-155	5YR6/2.5	SiC	0.29	7.9	0.19	27.6	56	1.4
R	155-200	5YR6/2.5	Si	-	7.8	0.19	-	40.5	-
Soil profile 10, Basalt, 593077 mE and 4055468 mN Fine, Carbonatic, active, mesic, Typic Calcixerepts									
Ap	0-20	10YR5/4	SiC	0.16	7.6	1.01	35.1	5.5	0.92
Bw1	20-35	10YR4/5	SiC	0.15	7.6	0.68	31.7	9.5	0.96
Bw2	35-55	10YR5/4	C	0.14	7.6	0.48	24.2	32	0.41
Bk	55-98	10YR7/4	SC	-	8.1	0.46	13.3	49.5	-
Bw	98-120	10YR5/4	CL	0.15	8.2	0.27	11.6	44.5	0.91
2Bw	120-180	10YR5.5/4	L	0.10	8.3	0.11	14.1	38.5	0.90
Bw3	100-122	7.5YR5/5	C	0.46	7.7	0.31	25.9	42.5	0.78
B/C	122-145	7.5YR5/4	SiC	0.15	8.0	0.33	19.2	59.5	0.91
Cr	145-170	10YR7/3	SiC	0.14	7.8	0.23	12.5	77.5	1.17
Soil profile 11, Marl, 606077 mE and 4049468 mN Fine, mixed, active, mesic, Typic Haploxerepts									
Ap	0-22	10YR5/4	SiC	0.22	7.7	0.79	30.1	26	1.26
Bw1	22-50	7.5YR4/4	SiC	0.17	7.6	0.62	30.9	27	0.77
Bw2	50-65	7.5YR4/5	C	0.20	7.7	0.44	25.0	34	0.85
Bt	65-100	7.5YR4/5	C	0.17	8.1	0.37	27.5	38	1.34
Bw3	100-122	7.5YR5/5	C	0.46	7.7	0.31	25.9	42.5	0.78
B/C	122-145	7.5YR5/4	SiC	0.15	8.0	0.33	19.2	59.5	0.91
Cr	145-170	10YR7/3	SiC	0.14	7.8	0.23	12.5	77.5	1.17
Soil profile 12, Gray microcrystallized limestone, 617077 mE and 4047468 mN Fine, mixed, superactive, mesic, Typic Haploxerepts									
Ap	0-25	10YR4/4	SiCL	0.26	7.6	1.44	33.7	34	0.47
Bw1	25-45	10YR4/4	CL	0.20	7.7	1.09	31.9	34	1.06
Bw2	45-80	10YR4.5/6	SiC	0.18	7.7	0.72	30.2	35.5	1.27
Bw3	80-110	10YR4/6	SiC	0.23	7.8	0.39	31.1	40	1.16
Bt1	110-135	10YR5/6	SiC	0.27	7.8	0.35	28.4	39	1.02
Bt2	135-160	10YR4/5	SiC	0.26	7.8	0.29	27.6	40	0.94
Soil profile 13, lime stone, shale and silty rock 619077mE and 4046468 mN Fine, carbonatic, active, mesic, Typic Haploxerepts									
Ap	0-25	10YR4.5/4	SiC	0.24	7.6	1.36	31.1	30	0.64
Bw1	25-52	10YR5/4	C	0.16	7.7	0.93	27.6	37	1.03
Bw2	52-80	10YR5/6	C	-	7.8	0.50	18.9	61.5	-
Bw3	80-120	10YR5/6	SiC	0.16	8.0	0.35	12.8	73	0.95
Bt	120-155	10YR5/4	SiC	0.12	8.2	0.25	19.8	63.5	0.88

In soil profile 3, which was located on the parent material with sequences of dolomite and limestone on the hillside near the toeslope with 5% slope to the north direction, gypsum accumulation was observed. The highest amount of organic matter was also observed at the surface horizon of this soil profile. In all soil profiles except for soil profile 1, 3, 4 and 10 the amount

of carbon decreased with depth and the highest amount belonged to the surface horizon. Irregular distribution of organic carbon with depth in some profiles occur as a result of lithological discontinuity and alternation of sedimentation. In soil profile 12 with the parent material of fine crystalline lime on the toeslope, Bw horizon was formed and in the field, clay coatings were

observed in the horizons which indicated development of this soil profile. Whereas in soil profile 5 with the parent material of lime and lime - marl located on a hill with a back slope of over 8%, it had only Ap and C horizons. The highest amount of lime with a value equal to 96% was seen in this soil profile and the minimum amount was seen in the soil formed of tuff and agglomerate in soil profile 6 with a value equal to 1.5% which was expected regarding the parent material type.

3.2. Investigating soil development using different forms of iron

Table 3 shows the values of different forms of iron. The minimum value of the mean total iron in profile 5 was equal to 13.17 g/kg and the maximum value in profile 8 was equal to 88.61 g/kg. The amount of total iron in B horizon of soil profiles 1, 9 and 12 was higher than that in A and C horizons which was compatible with the results of Abbasi Kalo et al., (2014). In other profiles, variation of total iron value from the surface to the depth was irregular. Changes in the total iron values are dependent on many factors including concentration in parent material, different amounts of clay in the soils with different physiographic conditions, and iron contained minerals at the gravel and silt portions (Abbasi Kalo et al., 2014) (Rozanski et al, 2013). The total iron amount had significant correlation with the pedogenic iron ($r=0.782$, $p<1$).

Progressed weathering causes increase in the pedogenic iron or the free iron (Fe_d) in A and B horizons of the soils with respect to C horizon (Simon et al., 2000). In the profiles of the studied soils possessing C horizon also the amount of Fe_d in B horizons was much higher than that of C horizons. The minimum mean value of Fe_d like the total iron in profile 5 was equal to 0.8 g/kg and the maximum value was belonged to profile 7 with 10.75 g/kg. Low weathering of the initial iron contained minerals could result into reduction in the pedogenic iron in soil. In most of the Mediterranean soils the process of release and accumulation of iron follows the clay accumulation. Weathering of the clayey iron contained minerals and the clay amount in B horizon affects increase in the Fe_d value (Dethier et al., 2012). In all the profiles except for C3 horizon in profile 5, the amount of Fe_d was higher than that of Fe_o which indicates higher amounts of the crystalline iron (Alamdari et al., 2010).

The highest amount of Fe_o belonged to soil profile 4 with intermediate to weak drainage condition. Increase in this form of iron could occur due to the effects of changes in the oxidation condition, reduction and lack of crystallization

conditions and organic materials. Combination of Fe_o with organic functional groups causes lack of its free presence in the soil (Hosseini et al., 2015), (Alamdari, 2010). There was a significant correlation between this form of iron and the total iron at the 5% level ($r=0.645$, $p<0.05$).

As the absolute values of iron compounds, in addition to the soil making processes, also follow the parent material therefore indices of Fe_d - Fe_o (iron crystalline compounds), Fe_o/Fe_d (crystallization degree of iron oxides), $(Fe_d-Fe_o)/Fe_t$ (ratio of the crystalline iron) are used for comparing the soils development (Abbasi Kalo et al, 2014). In addition to these three indices, the indices of Fe_d/Fe_t and values of Fehydroxide were calculated and the correlation between them was determined. The Fe_d-Fe_o ratio indicates the amount of crystalline iron oxides (Fe_c) where increase in weathering and soil formation causes its increase (Lair et al., 2009). Therefore a higher value of this ratio indicates higher development of the soils. Also a higher value of the Fe_d-Fe_o ratio indicates good crystallization of iron compounds (Howard et al., 2012). The minimum value of the mean weight of this index was observed in profile 5 and its maximum value belonged to profile 7. In profiles 2, 8 and 10, by increase in the depth the Fe_c value was reduced and the highest value of Fe_c was seen in the surface horizon.

The crystallization degree of Fe_o/Fe_d iron oxides indicates share of the amorphous compounds of the pedogenic iron. Its value in the young soils is high and reduces with the soil evolution (Simon et al, 2000). In this study the highest value of mean total weight was seen in profile 5 which was an Entisol with low evolution profile, and the minimum value belonged to profile 7 where the results of this index are compatible with the crystalline iron value. In profiles 2, 8 and 10 the amount of Fe_o/Fe_d reduced with increase in the weathering rate.

The highest value of the Fe_o/Fe_t ratio was observed in BW2 horizon of profile 12 and the minimum value was seen in C2 horizon of profile 8 (Table 2). In profiles 2, 3, 7 and 10 the more we move from the surface horizons to deeper horizons, this ratio reduces.

The depth distribution of the two indices Fe_d/Fe_t and Fe_c/Fe_t was similar along the profiles. The statistical results also show a high correlation at the level of 1% between the two indices ($r=0.956$, $p<0.01$). Initially the released iron from the iron contained minerals and clayey minerals have weak crystallinity which by the passage of time is transformed to crystalline iron oxides. By weathering of the minerals first the ascorbate iron and ultimately hematite and goethite are produced (Shi et al., 2011).

Table 3. Different forms of iron for identification of soil development in some studied Profiles

Profile	Horizon	Fe _d	Fe _o	Fe _t	Fe _c	Fe _o /Fe _d	Fe _d /Fe _t	Fe _c /Fe _t	Fe-hydroxide
		g kg ⁻¹							
Profile 2	A	5.10	0.47	41.26	4.62	0.09	0.123	0.112	6.93
	Bw	4.77	0.38	42.66	4.39	0.08	0.112	0.102	6.58
	Bk	4.32	0.59	40.56	3.73	0.13	0.106	0.091	5.59
Profile 3	Ap	4.60	0.53	46.85	4.06	0.11	0.098	0.086	6.10
	Bw1	4.17	0.45	46.16	3.72	0.10	0.090	0.080	5.58
	Bw2	4.85	0.44	53.85	4.41	0.09	0.090	0.081	6.61
	Bw3	4.10	0.35	50.35	3.75	0.08	0.081	0.074	5.62
	By	3.52	0.30	39.16	3.22	0.08	0.090	0.082	4.83
Profile 4	Ap	3.22	1.42	64.34	1.80	0.44	0.050	0.027	2.7
	Bk	3.52	3.22	67.14	0.30	0.91	0.052	0.04	0.45
	Bw1	5.35	3.28	69.24	2.06	0.61	0.077	0.029	3.09
	Bw2	3.85	3.56	62.94	0.28	0.92	0.061	0.04	0.42
	Bw3	5.47	1.70	60.14	3.77	0.31	0.091	0.062	5.65
	Bw4	5.72	1.16	56.65	4.56	0.20	0.101	0.080	6.84
	Bw5	4.97	0.90	51.05	4.07	0.18	0.097	0.079	6.11
Profile 5	Ap	2.47	0.71	30.77	1.76	0.28	0.080	0.057	2.65
	C1	1.35	0.39	17.48	0.96	0.28	0.077	0.055	1.44
	C2	0.22	0.10	6.99	0.12	0.44	0.032	0.018	0.18
	C3	0.29	0.57	8.39	0.28	1.97	0.034	0.033	0.42
Profile 6	A	3.35	0.31	43.3	3.03	0.09	0.077	0.070	4.55
	Bw	2.87	0.30	52.4	2.57	0.10	0.054	0.049	3.85
	C1	2.10	0.22	41.26	1.88	0.10	0.050	0.045	2.82
	2C2	0.87	0.20	23.77	0.67	0.23	0.036	0.028	1.00
Profile 7	Ap	8.00	0.52	67.8	7.47	0.06	0.117	0.110	11.21
	Bw	5.77	0.77	55.9	5.00	0.13	0.103	0.089	7.51
	Cr	6.57	0.61	73.4	5.96	0.09	0.089	0.081	8.94
Profile 8	Ap	5.97	0.84	83.92	5.13	0.14	0.071	0.061	7.70
	Bw	5.75	0.93	77.63	4.82	0.16	0.074	0.062	7.23
	C1	4.42	0.81	75.53	3.61	0.18	0.058	0.047	5.42
	C2	1.55	1.57	95.11	0.02	1.05	0.016	0.00	0.03
Profile 10	Ap	4.65	0.56	50.35	4.08	0.12	0.092	0.081	6.13
	Bw1	4.42	0.49	46.16	3.93	0.11	0.095	0.085	5.89
	Bw2	2.77	0.31	38.46	2.46	0.11	0.072	0.063	3.69
	Bw3	0.90	0.09	14.68	0.80	0.10	0.061	0.054	1.20
	Bw4	0.95	0.20	18.18	0.75	0.21	0.052	0.041	1.12
	2Bw5	1.07	0.51	18.88	0.56	0.48	0.057	0.029	0.84

Fe_d- Free Fe; Fe_o- amorphous Fe; Fe_t- Total Fe; Fe_c- crystalline Fe; Fe_o/Fe_d-activity index; Fe_d/Fe_t-mobility index; Fe_{hydroxide}= 1.5*(Fe_c)

By increase in the weathering rate the values of goethite and hematite are increased. The amounts of iron hydroxides including goethite and hematite were calculated based on the (Nieuwenhuyse et al., 2000) formula ($1.5*(Fe_d - Fe_o)$) as shown Table 2. There was a positive significant correlation with Fe_c/Fe_t ($r=0.781$, $p<0.01$), Fe_d/Fe_t ($r=0.86$, $p<0.1$) and total iron ($r=0.811$, $p<0.01$) and a negative significant correlation with Fe_o/Fe_d index ($r=-0.79$, $P<5$). The maximum value of Fe-hydr(oxide) mean total weigh was observed in profile 7 and the minimum value belonged to profile 5. In profiles 2, 8 and 10, the maximum amount of Fe-hydroxide was observed in surface horizons and with increase in depth the amount of Fe-hydroxide decreased.

3.3. Investigating soil development using the weathering index

The results of geochemical analysis showed in Table 3. Considering that in most soils their morphologic characteristics, pedogenic iron and clay amounts could be used for estimating their age (Constantini & Damiani, 2004), therefore to examine the efficiency of these 6 indices, use was made of the clay and pedogenic iron which have a great role in determining soil evolution. The correlation of weighted mean of the weathering indices was investigated by the mean values of the two mentioned characteristics and a significant correlation was observed between the clay percentage and the weathering index CIW ($r=0.57$, $p<0.05$). Regarding the statistical results, the amount of

pedogenic iron had not a significant correlation with the studied indices. The mean amount of iron had significant correlation with the mean of total CIW index at the level of 1% and had a negative significant correlation with the mean WIP in B horizon. There was not any significant correlation between the clay amount and the mean of indices in C horizon.

CIA in fact indicates the amount of aluminum silicates weathering and transform of feldspar to clayey minerals. There was not a significant correlation between CIA and Al_2O_3 . Whereas the amounts of sodium, potassium and calcium had significant correlations with CIA ($r=-0.859$, $p<0.01$), ($r=-0.638$, $p<0.05$) and ($r=-0.7587$, $p<0.01$), respectively. With respect to the results we could reason that like the basis of Bowen's reaction series of weathering, the weathering of the plagioclases and feldspar is an important process in the region. Sodium and calcium had negative significant correlation with the CIW index ($r=0.943$, $p<0.01$) and ($r=0.826$, $p<0.01$), respectively.

Zhu & Yang, (2009), also in their studies in north-west of China which were performed on the clastic sediments in Taklamakan desert concluded that due to the negative correlation between Na_2O and CIA, weathering process was principally related to sodium feldspar weathering. As in the weathered regoliths, application of indices which contain iron in their formula is not appropriate therefore there were no good results of the PWI index in this study. Condition of oxidation and reduction in the amount of iron determine its mobility and there is likelihood of occurrence of these changes during the weathering process. In other words, oxidation of iron during the weathering causes increase in Fe_2O_3 and reduction in FeO and those weathering indices containing iron in their formula do not account for this difference (Eswaran et al., 1973).

Also, the element Si in the chemical formula of R, PWI and STI is considered as the mobile element. This element in the soils with low or intermediate weathering characteristics after being released from the initial mineral is not removed from the soil profile and does not remain in the secondary clay mineral structure. For this reason these three indices did not well exhibit the weathering trend and had not significant correlation with the studied clayey soil. The index R on the profiles made up of rocks with acidic to neutral compositions exhibited acceptable results. But they could not show the real rate of weathering in the silicate rocks, in an appropriate way (Duzgoren-Aydin et al., 2002).

The results of comparison made between the total mean and horizons A and B of the indices showed that the total means of the two methods of CIA and CIW have significant correlation ($r=0.96$, $p<0.01$) and the total mean of the CIA index at the level of 1% ($r=0.69$, $p<0.01$) and that of the CIW index at the level of 5%

have negative significant correlation with the WIP index ($r=0.62$, $p<0.05$).

There is a correlation equal to 0.91 between the values of CIA and CIW indices at the level of 1% in A horizon. Also these two indices had negative significant correlation in A horizon and at the level of 1% with the WIP index having values of -0.71 and -0.86, respectively. There was a significant correlation between the CIA and CIW indices in B horizon at the level of 1% which was equal to 0.97 and there was a negative significant correlation with the WIP index at the level of 1% which was equal to 0.95.

In this article, the depth variation for the three indices of CIA, CIW and WIP were investigated in the soil profiles (Table 4). A value about 100 for the CIA index indicates existing depositions and soils resulting from the severely weathered material which contained remained clayey materials like kaolinite or gibbsite, a value between 75 to 90 indicates illite, a value about 75 indicates muscovite, a value about 30 to 50 indicates non-weathered rocks (Dhannoun et al., 2010). This value for the non-weathered materials of albite, anorthite and potassium feldspar was about 50, non-weathered basalt was 30-45, granite and granodiorite were 45-55 and for the shales was about 70-75 (Dhannoun et al., 2010; Nesbitt & Young, 1982). The minimum value of the mean CIA index belonged to soil profile 6 equal to 63.77 located on the tuff and agglomerate materials and soil profile 1 equal to 63.9 located on the salty and clayey plains.

The maximum value of the CIA index belonged to soil profile 8 equal to 77.63 with the parent material containing sequences of silty shales, sand stone with lime stone. A high value of the CIA means higher weathering of the soil profiles (Dhannoun et al., 2010). Weathering increases from depth to the surface and this trend is seen in profiles 3, 4 and 6. In soil profile 2, distinct changes were not observed but the CIA value was similar to the results of Nesbitt and Young which attributed this range to the existence of shale. The CIA value along different soil profiles had an irregular trend or it had not a noticeable change. Regarding the data corresponding to the composition of the parent material it was known that the value of this index varies in different parent materials and affects their amounts in the soil profile. In other words, the value of this index is dependent upon the chemical composition of their parent material. Therefore, comparison of the soil profiles with different parent materials is problematic (Ayoubi et al., 2013). For example, the CIA value in the rock with sequences of shale and sand stone in soil profile 2 is 84.15 and in the rock sample made of tuff and agglomerate which corresponds to soil profile 6 is 47.99, so it reveals that their initial amount has been effective on the CIA value.

Table 4. Geochemical analysis of some studied soil

No	Horizon	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅	TiO ₂	LOI
		%									
2	A	47.3	11.6	5.9	12.8	2.6	0.4	1.7	0.3	0.6	16.2
	Bw	44.9	11	5.9	15.4	2.6	0.3	1.5	0.2	0.6	16.7
	Bk	38.1	9.2	6.1	21.6	2.1	0.3	1.3	0.1	0.6	20.2
3	Ap	44.9	11.8	6.7	13.5	3	0.6	1.9	0.4	0.8	15.9
	Bw1	47.4	12.8	6.6	13.7	3.1	0.6	1.8	0.2	0.8	12.4
	Bw2	52.9	13.7	7.7	9.4	3.2	0.7	2.2	0.2	0.8	8.8
	Bw3	48.1	12.5	7.2	14.4	3	0.8	2.1	0.2	0.9	10.3
	By	34.4	9.5	5.6	21.8	2.8	0.4	1.3	0.2	0.7	17.3
4	Ap	50.2	13.6	9.2	7.3	3	1	2.3	0.3	0.9	11.1
	Bk	50	15.6	9.6	4.8	3.2	0.9	2.1	0.2	0.8	11.8
	Bw1	48.4	15.1	9.9	5.8	3.3	1	2.2	0.2	0.9	12.7
	Bw2	52.4	15.3	9	4.5	3.5	1.1	2.3	0.3	0.8	9.9
	Bw3	47.1	13.5	8.6	10.3	3.2	1.1	2	0.2	0.9	12.3
	Bw4	48.3	12.9	8.1	9.8	3.3	1	1.7	0.1	0.9	13.0
	Bw5	50.4	12.8	7.3	9.7	3.3	1.2	1.8	0.2	0.9	11.8
5	Ap	24.8	7.5	4.4	29.2	2.2	0.3	1	0.2	0.5	29.6
	C1	14.1	4.8	2.5	40.4	1.7	0.2	0.5	0.1	0.3	35.1
	C2	5.2	1.4	1	49.7	0.8	0.8	0.1	0	0	40.4
	C3	8	2.1	1.2	48.5	1	0	0.2	0	0	38.7
6	A	59.6	15.7	6.2	2.8	2.8	1.4	2.9	0.2	0.7	7.2
	Bw	60.6	16	7.5	5.1	3.2	1.1	2.9	0.2	0.8	1.9
	C1	46.5	11.5	5.9	17.1	2.4	0.9	2.1	0.2	0.6	11.9
	2C2	58	11.5	3.4	12.4	1.1	2.3	2.8	<0.1	0.4	7.4
7	Ap	42.7	13.3	9.7	12.6	3.4	0.6	1.2	0.2	0.9	15
	Bw	31.9	10.7	8	22.4	3.1	0.5	0.7	0.2	0.8	21.3
	Cr	27.3	10.3	10.5	24.2	2.8	0.6	0.4	0.1	1.1	21.69
8	Ap	42.7	14.1	12	8.9	5	0.6	1.3	0.2	1.2	13.69
	Bw	43.3	14.3	11.1	9	4.9	0.6	1.1	0.2	1.1	13.97
	C1	37.8	13	10.8	13.9	4.9	0.4	1.1	0.2	1.1	16.39
	C2	32.3	13.2	13.6	14.1	6.8	0.1	0.8	0.3	1.5	16.61
10	Ap	43.1	12.5	7.2	112.2	3.5	0.3	1.4	0.2	0.8	18.4
	Bw1	39.3	11.1	6.6	16.2	3.3	0.2	1.4	0.2	0.7	20.62
	Bw2	27.3	8	5.5	28	2.4	0.2	0.9	0.1	0.5	26.82
	Bw3	14.7	3.6	2.1	41	2.1	0	0.4	<0.1	0.3	35.17
	Bw4	18.4	3.9	2.6	38	2.9	0.1	0.4	0	0.2	33.14
	2Bw5	21.1	4.1	2.7	35.9	3	0	0.4	0	0.3	32.15

LOI: loss on ignition

The chemical index of weathering (CIW) is similar to the CIA index but with this difference that K₂O is removed from its formula. In rocks rich in potassium feldspar whether being weathered or not, due to not calculating the aluminum amount together with potassium feldspar, this index may exhibit a higher number (Fedó, et al., 1995). In soil profiles where the CIW value is closer to 100, weathering rate is higher. In other words, by increase in weathering the value of this index increases because of the constant amount of aluminum and removal of sodium and calcium (Harnois, 1988). This index value in the surface horizons of profile 4, 3, 6 and 7 was higher with respect to the underlying horizons and the results were similar to those of CIA except for soil profile 7 (Figs. 2, 3). This shows the higher rate of weathering

in these profiles which were compatible with the results of the study conducted by Tunçay & Dengiz in the year 2016 in Turkey which was conducted on various parent materials including marl, limestone, sandstone and alluvial and colluvial deposits.

The more the WIP index value approaches zero the higher is the weathering rate. Application of this index is in acidic, neutral and alkaline rocks and may not yield acceptable results concerning presence of soils with high rate of weathering. The reason is that the basis of this index is built upon the characteristics of alkaline and alkaline earth elements (Eswaran et al., 1973). This index value was lower only in surface horizon of profile 3 with respect to the deeper horizons.

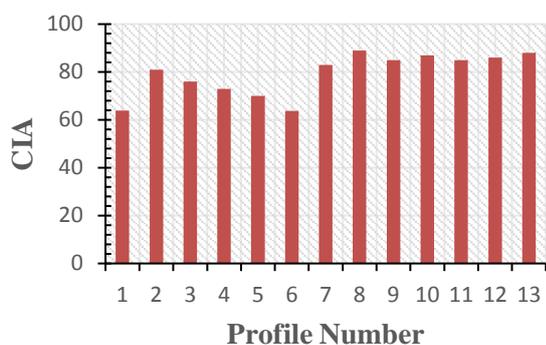


Figure 2. Mean value of CIA weathering indices

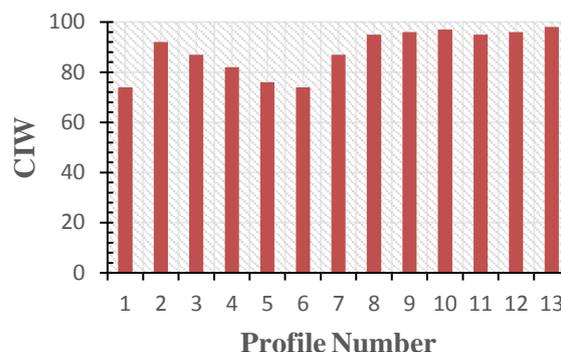


Figure 3. Mean value of CIW weathering indices

4. CONCLUSION

The results showed that the studied soils were in the orders of Inceptisols and Entisols and the difference in the type of parent material and difference in the physiography and slope were effective on the physicochemical characteristics of the soils. Also the results of this study in the iron part showed that a significant portion of the iron is in crystalline form and in all the soil profiles except for the soil profile 5 the Fe_d value exceeded the Fe_o value. Also the results showed a lower iron activity in the Entisols with low profile development. Considering the high correlation between the two factors of Fe_c/Fe_t and Fe_d/Fe_t which are among the important indices of soil development, profiles 3, 2, 8, 7 and 10 had higher development rates with respect to other profiles. The results of the evolution indices of Fe_c , Fe_o/Fe_d and $Fe_{hydroxide}$ were similar and included profiles 2, 8 and 10 and those containing Ferrihydrate were profiles 10, 6 and 3. Considering the results, the Fe_c/Fe_t and Fe_d/Fe_t indices among these could be used in the area to investigate the soil evolution. In this study the amount of pedogenic iron had not correlation with the chemical weathering indices. The geochemical results in this study which were used for investigation of the soil evolution showed that the geology and composition of the soil parent materials had largely affected the amount of chemical weathering (Bluth & Kump, 1994).

The negative correlation between Na_2O , CaO and K_2O and CIA indicates weathering of the plagioclases and feldspars in this area. Also with respect to the obtained results it was known that in terms of the chemical weathering indices, those indices where the ratio of immobile element to the mobile oxides is incorporated in their formula were more appropriate for estimating the weathering intensity.

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REFERENCES

- Abbasi Kalo, A., Jafarzadeh, A.A., Karimian Eqbal, M., Avestan, Sh. & Jahangiri, A., 2014. *Effect of the different geomorphologic levels on the soils development using the pedogenic changes and various forms of iron in Marand region, East Azerbaijan*, Water and soil sciences publication, 24, 85-101.
- Abtahi, A. & Solhi M., 1992. "Effects of topography and time on soil formation with parent material of lime under semi-arid condition of Bajgah in Iran," Pgs. 1-24. Excerpts of the articles presented in the third congress of soil sciences of Iran, August, Tehran University.
- Aide, M. & Smith-Aide, C., 2003. *Assessing soil genesis by rare-earth elemental analysis*. Soil Sci. Soc. Am. J., 67(5), 1470-1476.
- Alamdari, P., Jafarzade, A A., Oustan, S., & Toomanian, N., 2010. *Iron oxide and distribution in a transect of Dasht-e-Tabriz soils, northwest Iran*. Food, Agriculture & environment, 8, (3&4), 976-979.
- Alexander, E.B., 1974, *Extractable iron in relation to soil age on terraces along the Truckee River, Nevada*: Soil Science Society of America Proceedings, 38, 121-124.
- Alexander, E.B., 1985. *Estimating relative ages from iron-oxide/total-iron ratios of soils in the western Po Valley, Italy-a discussion*. Geoderma, 35, 257-259.
- Arduino, E., Barberis, E., Carraro, F. & Forno, M.G., 1984. *Estimating relative ages from iron-oxide/total-iron ratios of soils in the western Po valley, Italy*. Geoderma, 33, 39-52.
- Ayoubi, S., M. Yousefifard., & Jalalian. A., 2013. *Weathering intensity and investigation of weathering indices in some soils developed on igneous rocks in West-north of Iran*. Water and Soil, 27, 2, 266-288. (In Persian).
- Baumann, F., Schmidt, K., Dorfer, C., He, J., Scholten, T. & Kuhn, P., 2014. *Pedogenesis, Permafrost, substrate and topography: plot and landscape scale interrelations of weathering process on the central-*

Eastern Tibetan plateau.

- Bétard, F.**, 2012. *Spatial variations of soil weathering processes in tropical mountain environment: the Baturite massif its piedmont (Ceará, NE Brazil)*. Catena, 93, 18-28. <http://dx.doi.org/10.1016/j.geoderma.2014.02.019>
- Birkeland, P. W., Burke, R. M. & Benedict, J. B.**, 1989. *Pedogenic gradients for iron and aluminum accumulation and phosphorus depletion in arctic and alpine soils as function of time and climate*. Quaternary Research Vol. 32, 2, 193-204.
- Blume, H.P. & Schwertmann, U.**, 1969. *Genetic evaluation of profile distribution of aluminium, iron and manganese oxides*. Soil Sci. Soc. Am, Proc, 33,438-444.
- Bluth, G.J.S. & Kump, L.R.**, 1994. *Lithologic and climatologic controls of river chemistry*. Geochimica et Cosmochimica Acta, 58, 10, 2341-2359.
- Buol, S. W., Southard, R.J., Graham, R.C. & McDaniel, P.A.**, 2003. *Soil Genesis and classification*. 5nd ed., Iowa State Press. 360p.
- Constantini, A.C., & Damiani, D.**, 2004. *Clay minerals and the development of Quaternary soils in central Italy*. Revista Mexicana de Ciencias Geológicas ,21, 144-159.
- Degórski, M.**, 2011. *The relationships between different forms of iron and aluminium in soils as indicators of soil-cover development on India s Cherrapunji Spur (Meghalaya Plateau)*. Geographiya Polonica, 84, 1, 61-73
- Dethier, DP., Birkeland, P.W. & McCarth, J.A.**, 2012. *Using the accumulation of CBD-extractable iron and clay content to estimate soil age on stable surfaces and nearby slopes, Front Range, Colorado*. Geomorphology, 173-174, 17-29.
- Dhannoun, HY., Othman, SM. & Al-Dabbagh, SM.**, 2010. *The relationship between chemical index of alternation and some major and trace elements content in rocks of Injana Formation of Northern Iraq*. Iraqi Nat J Earth Sci 11, 1, 1-22.
- Duzgoren-Aydin, N.S., Aydin, A. & Malpas, J.**, 2002. *Re-assessment of chemical weathering indices: case study on pyroclastic rocks of Hong Kong*. Eng. Geol, 63, 1-2, 99-119.
- Eswaran, H., Stoops, G. & De Paepe, R.**, 1973. *A contribution to the study of soil formation on Isla Santa Cruz, Galapagos*. Pedologiei, 23, 100-122.
- Fedo, C. M., Nesbitt, H. W. & Young, G. M.**, 1995. *Unraveling the effect of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance*. Geology, 23, 921-924.
- Gee, G.W. & Bauder J. W.**, 1986. *Physical and mineralogical methods*, second Edition 383-441. In: Method of soil Analysis, Part I.
- Harnois, L.**, 1988. *The CIW index: a new Chemical Index of Weathering*. Sedimentary Geology 55, 319-322.
- Hosseini, S. S., Esfandiarpour Borujeni, I. & Farpoor, M.H., & Karimi, A.R.**, 2015. *Comparson of different soil development indices along kerman-baft transect*. Soil management and sustainable production, Vol. 5, 2, 1-24.
- Howard, J.L., Clawson, C.R. & Daniels, L.W.**, 2012. *A comparison of mineralogical techniques and potassium adsorption isotherm analysis for relative dating and correlation of Late Quaternary soil chronosequences*. Geoderma 179: 180, 81-95.
- Jahanbazi, L., Jafarzadeh, A. A. & Foroghifar, H.**, 2016. *Relationship between soil evolution and variety in the land forms in Tabriz plain*. Soil and water sciences publication, 26, 1, 191-204.
- Jackson, M.L., Lim, C.H. & Zelazny, L.W.**, 1982. *Oxides, hydroxides and aluminosilicates*. In: A. Klute(Editor), *Methods of soil analysis. Part 2. 2nd ed.* Agronomy Monograph. ASA and SSSA, Madison,WI, 9, pp.101-150
- Jayawardena, U. de S. & Izawa, E.**, 1994. *A new Chemical Index of Weathering for metamorphic silicate rocks in tropical region: a study from Sri Lanka*. Engineering Geology, 36, 303-310.
- Jenny, H.**, 1941. *Factors of Soils Formation*. McGraw-Hill, New York. 218p.
- Lair, G.J., Zehetner, F., Hrachowitz, M., Franz, N., Maringer, F.J & Gerzabek, MH.**, 2009. *Dating of soil layers in a young floodplain using iron oxide crystallinity*. Quaternary Geochronology, 4, 260-266.
- McLean, E.D.**, 1982. *Soil pH and lime requirement*. In: A.L. Page (Editor), *Methods of soil analysis. Part 2. 2nd edition*. Agronomy Monograph, Vol 9. ASA and SSSA, Madison, WI, 199-224
- Mckeague J.A. & Day J. H.**, 1966. *Dithionite and Oxalate-extractable Fe and Al As aid in differentiating various classes of soil*, Can. J. Soil Sci. Vol. 46, 1, 13-22.
- Munn, L. C. & M. Boehm.**, 1983. *Soil genesis in Natrargids- Haplargids complex in northern Montana*. Soil Sci. Soc. Am. J. 47,1186-1192
- Munroe, J.S., Farrugia, Gianian. & Ryan, P. C.** 2007. *Parent material and chemical weathering in alpine soils on Mt. Mansfield, Vermont, USA*. Catena, 70,39-48.
- Nelson, D. W., & L.E. Sommers.** 1982. *Total carbon, organic carbon, and organic matter*. In A.L. Page et al. (ed). *Methods of soil analysis. Part 2. Agron. Monogr. 9. 2nd ed.* ASA and SSSA, Madison, WI. PP: 539-579.
- Nelson, RE.**, 1986. *Carbonate and gypsum*, In: A. L. Page et al (Ed). *Methods of soil Analysis. Part 2.2nd ed.* Agron. Monogr. 9. ASA and SSSAJ Madison WI, Pp. 181-197
- Nesbitt, H. W. & G. M. Young.**1982. *Early Proterozoic Climates and Plate Motions Inferred from Major Element Chemistry of Lutites,* Nature 299.
- Nieuwenhuys, A., P. s. J. Verburg & A. G., Jongmans.**, 2000. *Mineralogy of a soil chronosequence on andesitic lava in humid tropical Costa Rica*. Geoderma 98, 61-82.
- Olatunji, O.O., Oyeyiola, Y., & Oyediran, G.O.**, 2015.

- Assessment of dithionite and oxalate extractable Iron and Aluminium Oxides on a landscape on basement complex soil in soil-western Nigeria.* Open Journal of soil science, 5, 266-275.
- Parker, A.,** 1970. *An index of Weathering for Silicate rocks.* Geological magazine 107, 501-504
- Price, J.R., & Velbel, M.A.,** 2003. *Chemical weathering indices applied to weathering profiles developed heterogeneous felsic metamorphic parent rocks.* Chemical geology, 202, 397-416.
- Rebertus, R. A. & Buol, S. W.** 1985. *Iron distribution in a development sequence of soils from genesis and schist.* Soil Sci. Soc. Am. J, 49, 713-720.
- Rezaei Hosseinabad, M., Farpoor, M. H. & Hejazi, M.,** 2013. *Soil physical and chemical properties as affected by topography in Zahmatkeshan Plain, Kerman Province.* 13th Iranian soil science congress, January, Shahid chamran University.
- Rhoades, J.D.,** 1982. *Cation exchangeable capacity.* In: Page, A. L., Miller, R.H., Keeney, D.R. (Eds.), *Methods of soil Analysis: Part2. Chemical and Microbiological Properties.* Agronomy Monograph, Vol. 9. ASA and SSSA, Madison, WI, 149-157.
- Rózański, S., Bartkowiak, A. & Jaworska, H.,** 2013. *Forms of iron as an indicator of pedogenesis in profile of selected soil types of the northern area of Kujawsko-pomorkie province Poland.* soil science annual. 64, 98-105.
- Ruxton, B. P.,** 1968. *Measures of the Degree of Chemical Weathering of Rocks,* J. Geol. 76, 518-527.
- Schaetzl, R.J & Anderson, S.,** 2005. *Soils: Genesis and Geomorphology.* Cambridge University Press, Uk.
- Schaetzl, R. J., Mikesell, L.R & Velbel, A.,** 2006. *Soil characteristics related to weathering and pedogenesis across a geomorphic surface of uniform age in Michigan.* Physical Geograghy, 27, 2, 170-188.
- Schaefer, C.E.G.R., Simas, F.N.B., Filho, E.L.F., Chagas, A.C. & Brandao, P.C.,** 2005. *Chemistry, mineralogy and micropedology of highl and soils on crystalline rocks of Serrada Mantiqueira, southeastern Brazil.* Geoderma, 125, 187-201.
- Shi, A., Krom, M.D., Bonneville, S., Baker, A.R., Bristow, C., Drake, N., Mann, G., Carslaw, K., McQuaid, J.B., Jickells, T., & Benning, L.G.,** 2011. *Influence of chemical weathering and aging of iron oxide on the potential iron solubility of Saharan dust during simulated atmospheric processing.* Global biochemical cycle, Vol.25, GB2010.
- Schwertmann, U.,** 1964. *Differentiation of iron oxide in soils by a photochemical extraction with acid ammonium oxalate.* Zeitschrift für Pflanzenernährung und Bodenkunde, 105, 194-201.
- Simon, M., Sanchez, S. & Garcia. I.,** 2000. *Soil-landscape evolution on a Mediterranean high mountain.* Catena 39, 211-231.
- Singh, L.P., Parkash, B., & Singhvi, AK.,** 1998. *Evolution of the Lower Gangetic Plain landforms and soils in West Bengal, India.* Catena, 33, 75-104.
- Souri, T. M. Watanabe, & K. Sakagami.** 2006. *Contribution of Parker and Product Indexes to Evaluate Weathering Condition of Yellow Brown Forest Soils in Japan,* Geoderma, 130, 346-355.
- Sumner, M.E., L. de Ramos, & U. Kukier.** 1994. *Modification to compulsive exchange method for determining cation exchange capacity of soils,* Comm. Soil Sci. Plant Anal, 25, 567-572.
- Tunçay, T. & Dengiz, O.,** 2016. *Chemical weathering rates and geochemical mineralogical characteristics of soils developed on heterogeneous parent material and toposequence.* Carpathian journal of Earth and Environmental Sciences, 11, 2, 583-598.
- Zhu, B. & Yang, X.,** 2009. *Chemical weathering of detrial sediment in the Taklamakan Desert, Northwestern China,* Geographical Research, 47(1), 57-70.
- Zielhofer, C., Espejo, J.M.R., Granados, M.A.N. & Faust, D.,** 2009. *Durations of soil formation and soil development indices in Holocene Mediterrean floodplain.* Quaternary International, 209, 44-6.
- USDA,** 2014. *Keys to soil taxonomy,* 12th edn. USDA-Natural Resources Conservation service, Washington DC.

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