STUDY SOIL DEVELOPMENT AND CLASSIFICATION IN ERBIL PROVINCE, KURDISTAN, IRAQ USING MATHEMATICAL INDICES

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ABSTRACT

The study area located at Erbil province, Kurdistan, Iraq, seven pedons were elected. Twenty-one soil samples were collected in the study area. Different physiochemical and fertility indices have been used to determine the soils development, despite of generating interpolated maps for them. The results indicated that the low values of clay were found in the less pedon developed and argillic horizon existed in development pedons. Study soils were non-saline, slightly to moderately alkaline, and had relatively high bulk density values. Organic matter is concentrated at the soil surface. Considerable total carbonates are found in studied soils and have irregular distribution manner, as well as have high CEC values. Low C/N ratio due to highly decomposed organic matter. The active $CaCO_3$/total $CaCO_3$ increases with depth in all pedons, while, slightly fluctuated in one pedon. The ratio of total clay in BH /AH was found just in some pedons and more than (1) therefore these soils are considered development, and are more developed depending on the ratio of fine clay/total clay. Soils are classified into three groups the first was the least developed soils, the second group has the most development. Third group are intermediate in their development. Pedogenic processes included leaching, illuviation, eluviation, alkalization, humification, lessivage, desalinization, calcification, decomposition, and littering. Studied soils classified as Inceptisols and Mollisols.

Keywords*:* **clay, active carbonate, total carbonate, horizons**

دراسة تطور وتصنيف الترب في محافظة اربيل– كردستان – العراق بأستعمال مؤشرات رياضية

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المستخلص

تقع منطقة الدراسة في محافظة اربيل – كردستان –العراق وتم انتخاب سبع بيدونات. جمعت أحدى وعشرون عينة تربة استخدمت مؤشرات كيميائية و فيزيائية و خصوبية لدراسة تطور الترب وتصنيفها فضلا عن استخدام احدى طرق الاستكمال المكاني لانتاج الخرائط. واشارت النتائج ان قيم الطين المنخفضة وجدت في البيدونات القليلة التطور والافق الطيني أرجلك وجدت في البيدونات المتطورة. ترب الدراسة كانت غير ملحية وقليلة الى متوسطة القاعدية وكانت لها قيم كثافة ظاهرية عالية نسبيا. المادة العضوية تركزت عند سطح التربة.كمية كبيرة من الكاربونات الكلية وجدت في الترب المدروسة ولم تكن لها سلوك توزيع غير منتظم وكذلك ذات قيم سعة تبادلية كاتيونية عالية. نسبة الكاربون الى النتروجين المنخفضة تعزى الى التحلل العالي للمادة العضوية . نسبة الكاربونات النشطة \الكاربونات الكلية تزداد مع العمق في جميع البيدونات بينما تذبذبت قليلا في بيدون واحد. نسبة الطين الكلي في الافقِ (B)\الافق (A) وجدت فقط في بعض البيدونات وكانت اكثر من واحد لذلك تعتبر ترب متطورة وتكون اكثر تطورا اعتمادا على نسبة الطين الناعم\ الطين الكلي. الترب صنفت الى ثلاثة مجاميع الاولى كانت الاقل تطورا والمجموعة الثانية هي الاكثر تطورا والمجموعة الثالثة كانت متوسطة التطور. العمليات البيدوجينية شملت الفقد والكسب والغسل والكسب داخل جسم البيدون والقاعدية والتدبل (تكوين الدبال) والهجرة الميكانيكية وعدم التملح والتكلس والتحلل وتراكم المخلفات العضوية. الترب المدروسة صنفت الى ترب الانسبتيسولز وترب الموليسولز.

***الكلمات المفتاحية*: الموليسولز. الانسبتيسولز. الطين. الكاربونات النشطة. الكاربونات الكلية. الافاق**

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INTRODUCTION

Climate, soil parent material, and vegetation type are the three major factors that affect soil development (21, 33), and soil development is heavily influenced by temperature and rainfall (27). Rainfall influences leaching and decalcification rates (51), as well as weathering, fracturing, and comminution of rock into mineral soil particles, are all part of the soil development process (40). Furthermore, soil development is determined by carbonate content and disturbance frequency, management regime, environmental factors such as direction of wind speed, and physical factors that change microclimate such as slope and aspect (25). The rate of decomposition of organic matter is influenced by both temperature and soil moisture (41). Wetter and colder conditions tend to have slower decomposition and, as a result, faster soil development. Decomposition rates are highly influenced by the chemical composition of plant litter, especially the C/N ratio and complex organic molecules (9). Additional nitrogen improves plant production and decreases the C/N ratio of litter, which typically accelerates mineralization rates where nitrogen is the main limiting nutrient (8). On the other hand, (17) proved horizons of calcareous soil, are generally believed to have formed as the subsurface calcic or petrocalcic horizon of soil. Accumulation of clay by illuviation in soils is a proven reality since the occurrence of the illuvial clay (argillic) horizon (11). Similarly, clay accumulation is an indicator of pedogenic development, and if alluvial parent materials contain a high quantity of carbonate, argillic horizon development can be prevented (18). Soil genesis is used in many soil classification methods (36), while soil characteristics and morphological properties are used in some (35). Soils of Iraq are markedly different from each other because of differences in soil-forming factors. In general, the degree of soil development decreases from northern to southern Iraq (2, 22, 43). Iraqi soils show varying degrees of development depending on the predominant local circumstances, namely climatic and geological factors (34). The majority of soils in Iraq are of secondary origin, meaning they are made up of materials that have been transported from their initial weathering site and deposited elsewhere (12). The nature of Erbil province has considerable variations in terms of topography, vegetation covers and types, rainfall rates, slopes, aspect ratios, elevations, agriculture practices (45). The objectives of this study are determining the degree of soil development using different criteria, furthermore, performing soil classification of studied pedons using the USDA-NRCS soil taxonomy system (48).

MATERIALS AND METHODS

Study area and soil samples preparation

Study area located in Erbil province, Kurdistan region, Iraq, and covered seven districts with one pedon was elected in each district (Table 1). Twenty-one samples were collected from each soil horizon of all pedons in October and November 2019. All samples were air-dried, crushed, and sieved with a 2 mm sieve after that were kept in containers to be used for physical and chemical analyses. The average yearly rainfall amount for (15) years ((2006-2020) was (1390.1, 684.4, 776.4, 740.8, 322.5, 538.6, and 244.5) mm in (Goratu, Ruanduz, Galala, Shaqlawa, Qushtapa, Bawaqub, and Kawr) respectively, and the average yearly temperature was (15.7, 18.3, 15.3, 17.7, 21.5, 26.4, and 24.1) C^o in the previous locations respectively (Erbil meteorological station). The area of Erbil province is 14,485 km^2, and the geographical position extends from Latitude 35.436151N to 37.319894N and from Longitude 43.374316E to 45.080122E (Fig. 1).

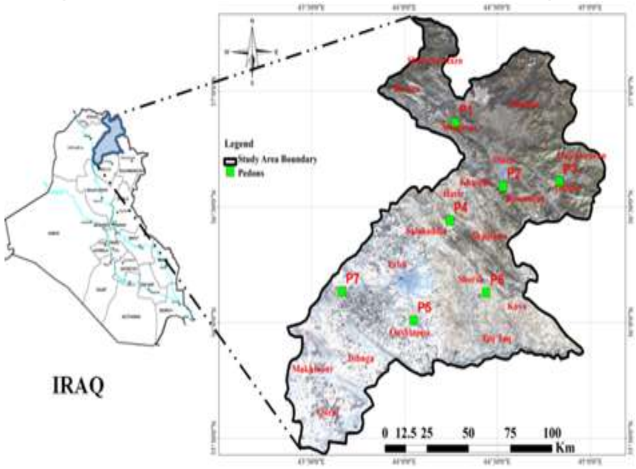

Figure 1. The location map of the study area

Laboratory analysis

Particles size distribution was determined using hydrometer method according (46), and soil bulk density by using clod method as described by (10). The separation of fine clay particles is conducted by centrifugation (32). Soil pH and Electrical Conductivity measured in soil suspension (1:1) (soil: water) using pH-meter and EC-meter (46), and soil organic matter was determined by wet combustion method with using potassium dichromate as an oxidizing agent (50). Total and active calcium carbonate determined by using the titration method (46) and by using ammonium oxalate (0.2) N according to (16), respectively. Cation exchange capacity was measured by using sodium acetate (1) N at pH (8.2) as described by (13). Exchangeable sodium and potassium are measured by flame photometer method as mentioned in (46). Exchangeable calcium and magnesium measured by titration method using EDTA (46). Gypsum content was determined depending on (14) and total nitrogen determined by Kjeldahl apparatus.

Table 1. GPS readings for the pedons

Pedon No.	Location	Latitude	Longitude	Elevation (m)
1	Goratu	36.863793°	44.273427°	950
2	Ruanduz	36.589920°	44.530456°	711
3	Galala	36.609481°	44.833081°	968
4	Shaqlawa	36.441845°	44.244508°	782
5	Qushtapa	36.009074°	44.048789°	405
6	Bawaqub	36.130416°	44.439638°	711
7	Kawr	36.134735°	43.662607°	263

Office works

Soil classification: Study soils have been classified by using the physical, chemical, morphological properties and climate conditions at the high categorical levels depending on the key to soil taxonomy (48).

Interpolated maps

The interpolated maps were produced for all the studied soil development criteria using the ArcMap 10.0 software. The Geostatistical Analyst has been used based on the Kriging/ CoKriging method (Ordinary type) as a method for generating the interpolated maps, as well as, the output maps divided into different classes depending on the magnitude of variation using Natural Breaks (Jenks) method for all of them (6).

Statistical Analyses

Correlation Coefficient: Correlation coefficients (r) were calculated among soil physiochemical properties then with the soil development criteria as well (Table 6). For this purpose, the bivariate correlations (Pearson correlation coefficient) as a default method were adopted (7).

RESULTS AND DISCUSSION

Soil physical properties: Particles size distribution showed the clay content was ranged between (84) g Kg^{-1} in (C_k1) horizon in pedon (6) and (521) g Kg^{-1} in the (B_{tk}) horizon in pedon (2) (Table 2). The low values of clay were found in the less soil developed when absent of (B) horizon in pedons (1, 3, and 6) and the highest values of clay were found in horizons of pedon (2) (479, 521, and 411) g Kg^{-1} (A_p, B_{tk}, and C_k) horizons respectively. Argillic horizon existed in development pedons (2, 4, 5, and 7) because the clay content in the previous pedons corresponding to the requirement of Argillic horizon formation (48). Silt fraction ranged between (175- 391) g Kg^{-1} and there is no constant manner of silt distribution along studied pedons, which sometimes increase with depth (27), and in other times decreased with depth (2), additionally may be fluctuated between increase and decrease in other pedons (1). The results of sand content illustrate an increase in their amount in less developed soils and the absence of (B) horizon therefore the high sand values were found in pedons (1, 3, and 6). According to the particles size distribution, soil textures were sandy loam, sandy clay loam, loam, clay loam, and clay texture. Fine clay distribution has a similar manner of total clay distribution along study pedons, on the other hand, their content directly increases with increasing total clay content and the highest values of fine clay found in pedon (2) that has clayey texture, and contain a considerable amount of total clay in all horizons in this pedon. The lowest value of fine clay is 13 g Kg^{-1} existed in (C_k2) horizon in pedon (6) because of increased sand and silt fraction more than clay fraction (Table 2). Ordinarily, a high bulk density value correlated with coarse soil texture (40) (26) (25), therefore, the highest bulk density value was found in the (C_k1) horizon in pedon (6) which is equal to (2.03) that contain the highest sand fraction (693) g Kg^{-1} (21) (Table 2). On the other hand, despite high sand content in pedon (3) but relatively has a low bulk density value because of the effect of existing organic matter that acts to reduce bulk density (26) (3). The bulk density was relatively high in all studied pedons because of coarse textured soil.

Soil chemical properties

Soil pH was ranged between (7.39- 8.57) (Table 3) which means all studied soils were slightly to moderately alkaline, this was due to the increased in calcium carbonate and calcareous parent material (1) (26), and generally was low value in surface soil horizons (A) and increased in subsurface soil horizons. Electrical conductivity ranged between (0.127- 0.726) dS m^{-1} and the results proved that all study soils were none saline and this was due to the good drainage and deep groundwater table in addition to using none saline water for irrigation purposes (38). Organic matter concentrated at the surface soil horizon in study pedons and contain a considerable amount of organic matter then was gradually decreased towards downward of pedon. This was attributed to the accumulation of plant residuals (litter) at surface soil horizons and increase organisms activity that causes decomposition litter and the humification process that produces humus in biosphere at surface soil zone (39) (44) (20) (32). Total carbonates have not regular distribution manner and have high values at surface soil horizons and decrease with depth in pedons (1, 2, and 3) this may be due to the differences in intensity of weathering degree in each soil pedon particularly in pedon 1 and 3 (2). Whilst, in pedons (4, 5, 6, and 7) total carbonates fluctuated between increase and decrease in pedon horizons, commonly, studied soils consider calcareous because of were derived from limestone parent material and contain a considerable amount of carbonates (47). Despite there are no large differences in active carbonates content but there are concentrated at the surface horizon in pedons (1, 2, 3, 4, and 5) whereas increased with depth in pedon (6) but fluctuated in pedon 7, these differences in a distribution manner certainly due to the topography and microclimate conditions of each pedon. Cation exchange capacity ranged between (23.05- 47.12) Cmolec Kg^{-1}. Commonly, studied soils have high CEC values in all pedons this was due to high organic matter content and clay fraction (42). Whereas, the low values were found in pedons (3) and (6) and both of them have low development and contain low amounts of organic matter and clay fraction (Table 4). The pattern of total nitrogen distribution was in an agreement with organic matter distribution and was decreased in deep soil horizons because of decrease organic matter (39). The highest value was (5.6) g Kg^{-1} found in (A) horizon of pedon (4) and (B_{tk}1) horizon in pedon (5) but the lowest value was (1.4) g Kg^{-1} in (C_k) and (C_k2) horizons of pedons (4) and (6).

Development of the studied soils

All soil-forming factors affecting somehow on soil properties then become a part of soil development. Precipitation and temperature as climatic factors highly affecting soil properties through physical, chemical, and biological processes (15). Several parameters can be used as indicators for determining the degree of soil development (Table 4).

C/N ratio

The carbon to nitrogen (C/N) ratio is an indicator for detecting the degree of organic matter decomposition (18), which is determined by total soil organic carbon (OC) and total nitrogen (TN). The results of C/N ratio (Table 4) shows that the values increasing with depth in pedons (2, and 4). This may be due to penetrating the tree roots through (B_{tk}) horizon and reached to (C_k) horizon and because of accumulation residuals of plant roots as a letter after plants died, in turn, to increase the C/N ratio. Whilst, decreasing in deep soil horizons in pedons (1, 3, 5, 6, and 7), and attributed to the existence of high organic matter content in (A) horizon with a high decomposition and humification by organisms activity because of this horizon consider as the root zone and biosphere of the soil system, and similar results have been found by (39). The higher value of C/N ratio is (5.7) for C_k horizon in pedon (4), and the lowest value is (1.1) in pedon 3; C_k2 horizon. The distribution pattern of C/N ratio (Figure 2) shows that the maximum values are located at southwest part of the study area and decreasing irregularly into north and northeast directions. Marty, et al., (39) reported that the C/N ratio has a negative relationship with precipitation. In this study, a positive significant correlation has been found between C/N ratio and each of fine clay particles, fine clay/total clay ratio, and organic matter (0.221, 0.243, and 0.398) respectively, and this is due to the close relationship between both organic matter and clay fractions because both of them consider as colloids. In contrast, negative significant correlation with total nitrogen (-0.492), as a result of an inverse relationship between of them.

Table 2. Some physical properties of studied soils

Pedon No.	Locations	Horizon	Depth (cm)	PSD ($g\ Kg^{-1}$) Sand	Silt	Clay	Texture	Density ($Mg\ Kg^{-1}$)	Fine Clay ($g\ Kg^{-1}$)
		A	0 - 40	400	241	359	CL	1.83	265
1	Goratu	C_k1	40 - 92	451	344	205	L	1.73	136
		C_k2	92 - 140	506	365	129	L	1.53	21
		A_p	0 - 25	263	258	479	C	1.67	311
2	Ruanduz	B_{tk}	25 - 57	254	225	521	C	1.79	510
		C_k	57 - 147	373	216	411	C	1.86	366
		A	0 - 28	564	220	216	SCL	1.44	66
3	Galala	C_k1	28 - 66	600	175	225	SCL	1.50	84
		C_k2	66 - 101	641	191	168	SL	1.62	59
		A	0 - 32	466	379	155	L	1.65	75
4	Shaqlawa	B_{tk}	32 - 109	479	290	231	L	1.76	171
		C_k	109 - 179	559	298	144	SL	1.72	117
		A_p	0 - 23	366	420	214	L	1.86	116
5	Qushtapa	$B_{tk}1$	23 - 81	266	391	343	CL	1.86	269
		$B_{tk}2$	81 - 135	276	383	341	CL	1.71	292
		A_p	0 - 34	575	266	159	SL	1.59	100
6	Bawaqub	C_k1	34 - 106	693	224	84	SL	2.03	45
		C_k2	106 - 156	638	266	96	SL	1.68	13
		A_p	0 - 30	366	375	259	L	1.53	217
7	Kawr	B_{tk}	30 - 114	301	380	319	CL	1.61	247
		C_k	114 - 152	477	239	284	SCL	1.71	245

Table 3. Some chemical properties of study soils properties

Pedon No.	Locations Name	Horizon	Depth (cm)	pH	EC dS/m	Organic Matter ($g\ Kg^{-1}$)	Total $CaCo_3$ ($g\ Kg^{-1}$)	Active $CaCo_3$ ($g\ Kg^{-1}$)	CEC $Cmolc.kg^{-1}$	Total Nitrogen ($g\ Kg^{-1}$)
		A	0 - 40	7.39	0.726	17.7	398.21	102.00	39.25	2.80
1	Goratu	C_k1	40 - 92	7.94	0.236	19.6	375.00	101.40	45.81	4.20
		C_k2	92 - 140	8.57	0.186	13.9	253.57	96.00	38.36	2.24
		A_p	0 - 25	7.61	0.495	20.3	508.93	110.40	37.36	3.64
2	Ruanduz	B_{tk}	25 - 57	7.82	0.316	18.9	392.86	108.00	42.21	2.72
		C_k	57 - 147	8.20	0.198	12.6	339.29	106.92	47.12	2.24
		A	0 - 28	7.97	0.224	25.6	419.64	106.80	28.30	3.08
3	Galala	C_k1	28 - 66	8.01	0.153	11.2	419.64	105.36	27.14	2.80
		C_k2	66 - 101	8.20	0.156	7.7	357.14	103.44	28.81	4.06
		A	0 - 32	8.57	0.329	27.52	348.21	104.40	36.90	5.60
4	Shaqlawa	B_{tk}	32 - 109	7.81	0.241	20.64	317.86	102.00	42.33	3.08
		C_k	109 - 179	8.24	0.229	13.76	264.29	97.20	43.45	1.40
		A_p	0 - 23	8.07	0.261	18.92	273.21	95.40	29.39	2.66
5	Qushtapa	$B_{tk}1$	23 - 81	8.25	0.236	18.92	217.86	93.60	30.21	5.60
		$B_{tk}2$	81 - 135	8.17	0.279	6.88	250.00	92.16	29.36	2.80
		A_p	0 - 34	8.30	0.127	9.5	335.71	97.20	23.05	1.96
6	Bawaqub	C_k1	34 - 106	8.50	0.149	7.7	321.43	99.00	27.71	2.66
		C_k2	106 - 156	8.17	0.170	5.3	357.14	101.40	29.81	1.40
		A_p	0 - 30	8.13	0.374	17.9	285.71	94.80	32.22	3.58
7	Kawr	B_{tk}	30 - 114	7.97	0.546	16.2	225.00	108.00	37.41	1.96
		C_k	114 - 152	8.07	0.498	6.5	241.07	92.40	35.56	2.74

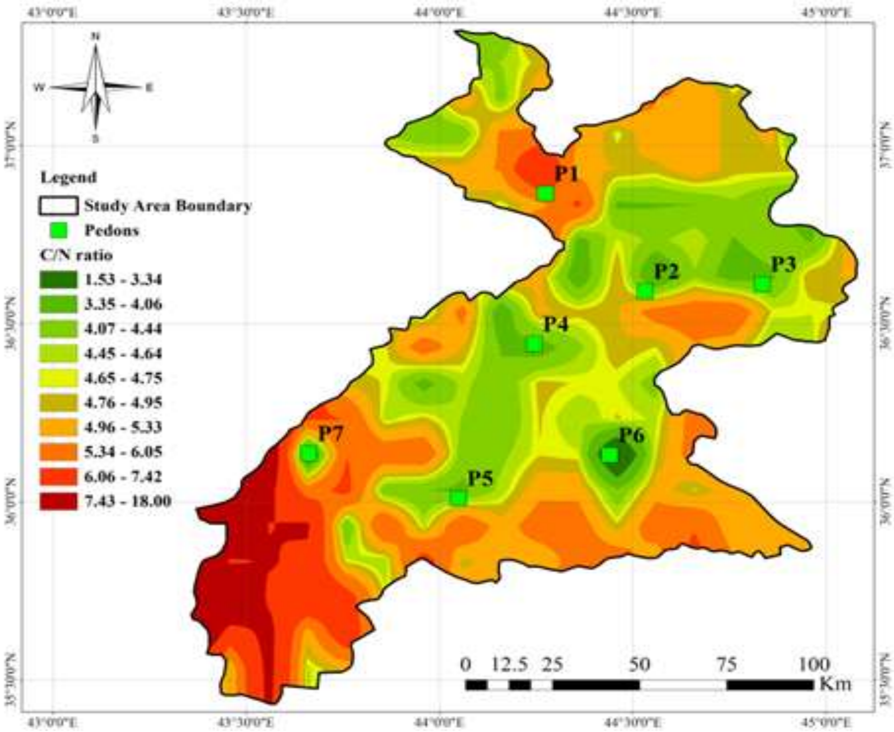

Figure 2. Interpolated map for C/N ratio

Increasing of C/N ratio is an indicator of the soil organic matter decomposition is slow, and littering is a common process that indicates a high C/N ratio and decrease in organic matter decomposition in the soil (1). In line with this idea, and as a result of low C/N ratio in study soils (1.1- 5.7), therefore, these soils have a highly decomposed organic matter and dominance of humification process this was related with high rainfall amount and the existence of considerable amount of plant residuals particularly for forest trees in study locations.

Active $CaCO_3$/Total $CaCO_3$

The ratio of active $CaCO_3$/total $CaCO_3$ is another index used for illustrating the degree of soil development. Increasing this ratio is an indicator for an increasing the intensity of pedogenic processes and soil horizons will be more distinct (1). The active $CaCO_3$/total $CaCO_3$ ratio increases with depth in pedons (1, 2, 3, 4, 5, and 7), while, slightly fluctuated with depth in pedon (6). The ratio ranged between (0.22-0.48) in (A_p) and (B_{tk}) horizons in pedon (2) and (7) respectively. This is due to the effect of high weathering intensity on the limestone parent material by rainfall that causes accumulation of a high amount of calcium carbonate. We can conclude that the study pedons were more developed with an increase of active $CaCO_3$/total $CaCO_3$ ratio as shown in pedons (4, 5, and 7).

Table 4. Soil Development Indicators

Pedon No.	Horizon	Depth (cm)	C/N	A.CaCo$_3$/ T.CaCO$_3$	Clay in BH/Clay in AH	Fine Clay/ Total Clay
1	A	0 - 40	3.7	0.26	-	0.74
	C_k1	40 - 92	2.7	0.27	-	0.66
	C_k2	92 - 140	3.6	0.38	-	0.16
2	A_p	0 - 25	3.2	0.22	1.09	0.65
	B_{tk}	25 - 57	4.1	0.27	-	0.98
	C_k	57 - 147	3.3	0.32	-	0.89
3	A	0 - 28	4.8	0.25	-	0.31
	C_k1	28 - 66	2.3	0.25	-	0.37
	C_k2	66 - 101	1.1	0.29	-	0.35
4	A	0 - 32	2.9	0.30	1.49	0.48
	B_{tk}	32 - 109	3.9	0.32	-	0.74
	C_k	109 - 179	5.7	0.37	-	0.81
5	A_p	0 - 23	4.1	0.35	1.60	0.54
	$B_{tk}1$	23 - 81	2.0	0.43	-	0.78
	$B_{tk}2$	81 - 135	1.4	0.37	-	0.86
6	A_p	0 - 34	2.8	0.29	-	0.63
	C_k1	34 - 106	1.7	0.31	-	0.53
	C_k2	106 - 156	2.2	0.28	-	0.14
7	A_p	0 - 30	2.9	0.33	1.23	0.84
	B_{tk}	30 - 114	4.8	0.48	-	0.77
	C_k	114 - 152	1.4	0.38	-	0.86

Figure (3) shows the distribution of active $CaCO_3$/total $CaCO_3$ ratio along the study area, and the area that has a maximum value of the active $CaCO_3$/total $CaCO_3$ ratio was located approximately near the center of the study area more precisely at pedons (4, 5, and 7). The parent materials of these pedons and the areas around them are derived from limestone, similar results were illustrated by (47). A positive correlation relationship was found between carbonate ratio and each one of silt particles, and fine clay/total clay ratio (0.305 and 0.249) respectively, and this attributed to the active carbonate has ordinarily existed in the fine silt and clay fractions, in turn, led to increasing carbonate ratio. In contrast, the negative correlation relationship was detected between the carbonate ratio and each of organic matter, total $CaCO_3$, and slope (-0.344, -0.886, and -0.273) respectively. This is because there is no role of organic matter in carbonate ratio and total carbonate commonly existed in all soil fraction sizes particularly in the coarse fractions, in reverse with active carbonate. Therefore, decrease carbonate ratio, as well slope led to decrease carbonate ratio as result of the erosion process that is attributed to loss of active carbonate which existed in fine silt and total clay sizes. Despite the soil pedons in most studied locations were less developed but the active $CaCO_3$/total $CaCO_3$ ratio indicated an increased intensity of the calcification pedogenic process.

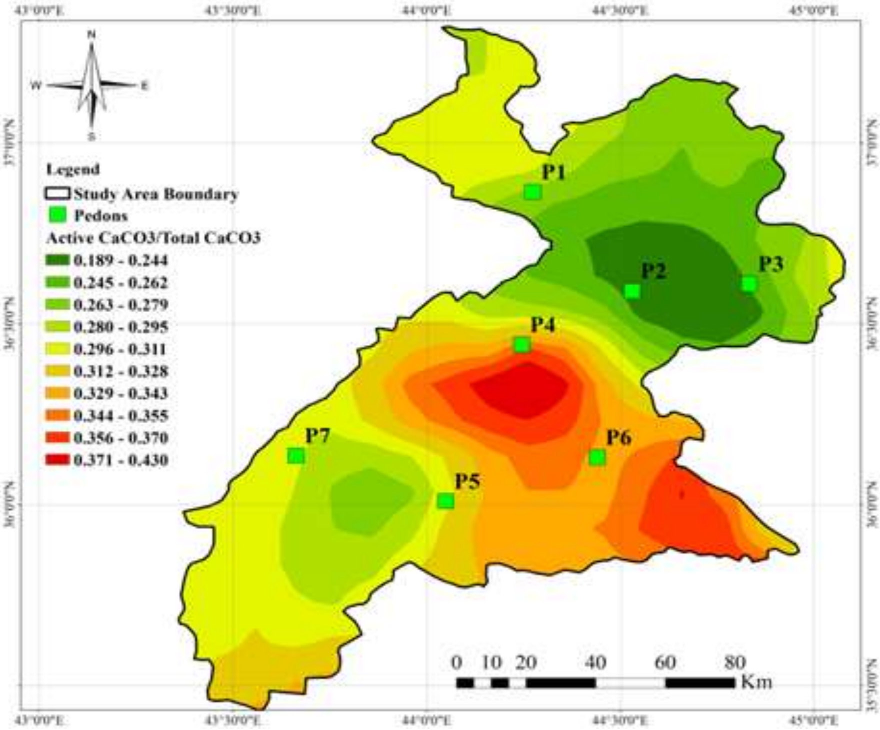

Figure 3. Interpolated map of Active $CaCO_3$/ Total $CaCO_3$

Total clay in BH/Total clay in AH

The ratio of total clay in BH/total clay in AH is also one of the important criteria to indicate soil development degree in the study pedons. This ratio is found in the soil pedons (2, 4, 5, and 7) (Table 5) because the other pedons do not have a B horizon. The values of the total clay in BH/total clay in AH ratio range between (1.09- 1.60) in pedon (2) and pedon (5), respectively. Gunal and Ransom (26) reveal that when the ratio is more than 1 the soil considers development, while, if this ratio is less than 1 then the soil can be called low or no development. Accordingly, all pedons as mentioned above-considered development soils because the ratio values are more than 1, with exception of pedons (1, 3, and 6). The reason for this is a translocation of clay particles from surface horizons to subsurface horizons and there is an accumulation process that eventually encourages the formation of an illuvial horizon that contains a considerable amount of clay and is considered as an indicator of soil development. The important factor that causing this process is the climate that helps in the mechanical migration of clay particles by water (Lissivage) from the surface horizons to the subsurface (B) horizon and formation of Argillic diagnostic horizon these results agreed with similar results that are proved by (27).

Fine clay/Total clay ratio

The results showing that the ratio of fine clay/total clay increases with depth in pedons

(2, 3, 4, 5, and 7) (Table 4). The same results were reported by (20), he said that the humus could have migrated in association with the fine clay. Moreover, these ratios decreasing with depth in pedons (1 and 6) because both of them have low clay contents and less degree of soil development. Almeida, et al., (4) proposed that the ratio of fine clay/total clay was increasing with soil depth when the B_t horizon existed (clay accumulation horizon) whereas, was decreasing with depth when C horizon existed. In addition, the fine clay accumulation does not always coincide with the illuvial horizon. In studied pedons, B_{tk} horizon was found in pedons (2, 4, 5, and 7), whilst, was absent in pedons (1, 3, and 6) that have C_k1 horizon directly under the (A) horizon. The highest value of this ratio is (0.98) was found in pedon (2); horizon (B_{tk}), and the lowest value was (0.14) in pedon (6); horizon (C_k2). The results showed the soils in study pedons (2, 4, 5, and 7) are more developed depending on the ratio of fine clay\total clay because of increase the value of this criterion in previous pedons as comparison with remaining pedons (1, 3, and 6) and an increase the value of this ratio indicates soil be more development. A positive significant correlation relationship has been found between this ratio and each of silt particles, fine clay particles, C/N, and active $CaCO_3$/total $CaCO_3$ ratio by (0.361, 0.717, 0.308, and 0.249) respectively. This was due to the previous criteria were related to fine particles and highly decomposed soil organic matter and an increase soil weathering process intensity. In contrast, a negative significant correlation was found with each of the sand particles, and total $CaCO_3$, by (-0.304, and -0.344,) respectively, because both of these variables were ordinarily related to coarse soil fragments. Through the interpolated map (Figure 4), the lower value of this ratio is located almost at the middle of the study area and increasing toward northwest, southeast, and southwest.

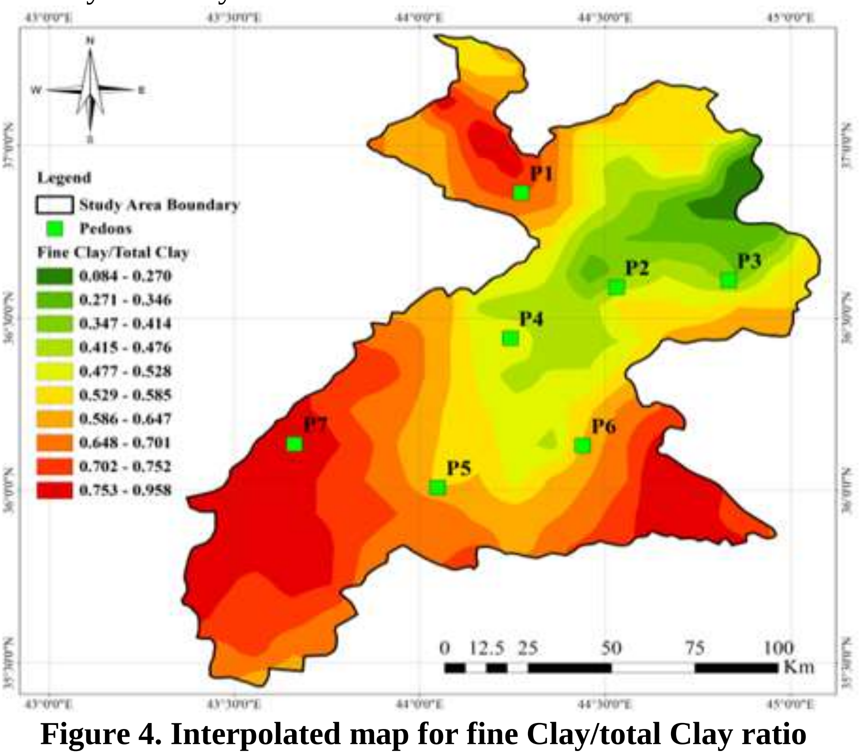

Figure 4. Interpolated map for fine Clay/total Clay ratio

The soil pedons can be concluded classified in term of development into three groups, the first group soil were the least development soils, in pedon (1 and 3) that have (A, C_k1, C_k2) horizons, then followed by soil in pedon (6) that has (A_p, C_k1, and C_k2) horizons. Whereas, the second group has the most development soil that was found in pedon (5), that has horizons (A_p, $B_{tk}1$, $B_{tk}2$) according to different criteria that are adopted for use to specify soil development. Third group of developing soils included soils in pedons (2 and 7) that have (A_p, B_{tk}, C_k) and pedon (4) that has (A, B_{tk}, C_k) which are considered intermediate in their development according to pedon differentiation into different horizons and soil development criteria.

Soil classification

Studied soils were classified based on the physical, chemical, morphological properties, and climate conditions at family level according to (48) by using keys to soil taxonomy (12^{th} edition, 2014) as shown in Table (5) and followed Inceptisols in pedon (1, 3, and 6) whereas soil in pedons (2, 4, 5, and 7) followed Mollisols.

CONCLUSIONS

C/N ratio was more effective in an A horizon in most study pedons as an indicator of soil development. Low C/N ratio in study soils (1.1-5.7), with highly decomposed organic matter and dominance of humification process in an A horizon. The active $CaCO_3$/total $CaCO_3$ ratio increases with depth in study pedons and the study soils are more developed with increasing active $CaCO_3$/total $CaCO_3$ ratio. Soils in study pedons (2, 4, 5, and 7) more developed, according to the ratio of total clay in BH/total clay in AH, because this ratio is more than (1) and these pedons contain (B_{tk}) horizon. Whereas, the remaining pedons are considered as a low development because of the absence of (B) horizon and just contain (A and C) horizons. The lessivage process occurs in pedons (2, 4, 5, and 7) when the clay is translocated by rainfall from the surface horizons to the subsurface horizons by illuviation process and formed a clay-enriched, subsurface horizon, known as argillic horizon. The soil development increases with an increase in the ratio of fine clay\total clay in study pedons. Studied soils have been classified as Inceptisols in pedons (1, 3, and 6) and as Mollisols in pedons (2, 4, 5, and 7). Pedogenic processes that have been detected in studied soils include leaching, illuviation, eluviation, alkalization, humification, lessivage, desalinization, calcification, decomposition, and littering.

Table 5. Soil classification in studied pedons

Pedon No.	Order	Sub-order	Great Group	Sub-group	Family
1	Inceptisols	Xerepts	Calcixerepts	Typic Calcixerepts	Fine-loamy, Mixed, Superactive, Calcareous, Thermic
2	Mollisols	Xerolls	Argixerolls	Calcic Argixerolls	Fine-clayey, Mixed, Superactive, Calcareous, Thermic
3	Inceptisols	Xerepts	Calcixerepts	Typic Calcixerepts	Fine-loamy, Mixed, Superactive, Calcareous, Thermic
4	Mollisols	Xerolls	Argixerolls	Calcic Argixerolls	Coarse-loamy, Mixed, Superactive, Calcareous, Thermic
5	Mollisols	Xerolls	Argixerols	Calcic Argixerolls	Fine-loamy, Mixed, Superactive, Calcareous, Hyperthermic
6	Inceptisols	Xerepts	Calcixerepts	Typic Calcixerepts	Sandy, Mixed, Superactive, Calcareous, Hyperthermic
7	Mollisols	Xerolls	Argixerolls	Calcic Argixerolls	Fine-loamy, Mixed, Superactive, Calcareous, Hyperthermic

Table 6. Correlation coefficient among used variables

	Silt	Fine Clay	F.Clay/T.Clay	Total $CaCO_3$	Total Nitrogen	$A.CaCO_3/T.CaCO_3$	C/N	Organic Matter	Slope
Sand	-.393**	-.684**	-.357**	0.007	-0.035	-0.09	-0.095	-0.131	.219
Silt		0.038	.409**	-.397**	-0.227	.279*	0.122	-0.262	-.550**
Fine Clay			.745**	-0.096	-0.223	0.128	0.185	0.129	.053
F.Clay/T.Clay				-.405**	-.487**	.289*	.273*	-0.138	-.195
Total $CaCO_3$					.504**	-.907**	-0.258	.266*	.354**
Total Nitrogen						-.406**	-.577**	.449**	.257
$A.CaCO_3/T.CaCO_3$							0.226	-0.228	-.273*
C/N								.273*	-0.083
Organic Matter									.338*

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

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