Al-Muthanna J. For Agric Sci Print ISSN: 2226-4086 Online ISSN:2572-5149
Vol. 10 , Issue. 01. 2023
https://muthjas.mu.edu.iq/ http://doi.org/10.52113/mjas04/10.1/13

Geneses and development of Gypsiferous soils in Karma Island - Western Iraq

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Received on 10/5/2023 Accepted on 7/6/2023 Published on 15/6/2023

ABSTRACT

Nine pedons were selected that cover most of the secondary physiographic units in the Karma Island area in Anbar Governorate, western Iraq, located between longitudes 44°32′ 00″- 43°30′00″E and latitudes 33°43′05″- 33°28′50 ″N, to study the genetics and development of its soils.

The results indicated that there is a discrepancy in the degree of development of the study pedons between the different physiographic units, and this reflects the nature of the variation in the local factors of each soil and the role of pedogenetic and geomorphic processes in influencing the genetic of the study soil.

The difference recorded in the values of profile darkness is due primarily to the soil content of organic matter, clay and gypsum. It was noted a movement of the clay fraction by the lessivage process, the values of the clay accumulation index (CAI) in the studied soils were ranged between -344.4 and 674.7, bout no movement for this fraction was recorded in the pedon 8. There was a discrepancy in the values of carbonate accumulation index among the soils, its ranged between -268.1 and 379.5, the observed discrepancy in the values of this index is mainly due to the nature of the parent material and its impact on the geomorphological location.

The values of gypsum accumulation index was ranged between -523.1 and 833.4, which was indicated the presence of gypsum accumulation due to pedogenetic processes at most of the examination sites, while the location that did not show an accumulation of gypsum mainly due to the geomorphological location. Also there is interaction between Calcic and Gypsic subsurface horizons, which indicates that those soils passed through multiple stages of previous formation.

Two sub groups soils was noted in the region, Typic Haplogypsids, which constituted 74.3%, followed by Typic Calcigypsids with a percentage of 25.7% of the total area of the study area.

Keywords: Geneses of gypsiferious soils; Island of Karma; soil development index's; Pedogenetic processes in Arid regions.

INTRODUCTION

Gypsiferous soils are spread in large areas of the world, especially in arid and semi-arid regions, including Iraq, they are cover more than 12.5 million hectares and constitute about

28.6% of Iraq's soil (Jafarzadeh and Zinck, 2000).

The process of soil development includes the change, transformation and transfer of materials and energy between horizons forming soils under the influence of soil formation factors and processes, which lead to distinguishing each horizon from the next with distinctive morphological, physical, chemical and mineral features and a genetic relationship between these horizons(Al-Husseini, 2010).

The development degree of soil profile is used as a qualitative measure of the amount of change occurring in the original material, and it is a relative issue, but it is very useful to subject the values to a quantitative measurement by measuring the changes and developments that occurred in the horizons of the soil from which it was formed.

Mahmoud and Muhaimid (2011) indicated influence of local factor on soil formation by pedogenetic and geomorphological processes, and showed existence of three soil groups according to the degree of development, including the undeveloped, weakly developed and a high degree of development soils. Also there is an interaction between the endopedon diagnostic horizons (gypsic, calcic and argillic) within the same pedon, which indicates the multiplicity of the stages of formation of this soil during the last period.

Cortia *et al*.(2019) showed interrelationship between geomorphology and genetic processes in soil formation in the Guevara Plain, southern Tunisia, and the differences in soil formations at this region have produced distinct B horizons: poorly developed Byy horizon at Chenini Nahel, severely ruptured resistant Bw horizon at Matmata Nouvelle, and Bk horizons in depth due to intense precipitation with CA + BC horizons at the surface due to accumulation of Aeolian material in Menzel Habib.

Esfandiari *et al*.(2022) observed the presence of lenticular gypsum crystals in the By horizon with a clear collection of genetic gypsum in the soils of Lorestan Province – Iran, they suggested the necessity of adding subgroup Xerepts (Gypsic Calcixerepts) in soil classification.

Therefore, this study was carried out to identify the genesis and development of Gypsiferous soils in Karma Island, western Iraq.

MATERIALS AND METHODS

The study area: The Karma Island in Anbar Governorate, lies between longitudes 44° 32′ 00″- 43° 30′00″E and latitudes 33° 43′05″- 33° 28′50″N, its located on the eastern bank of the Euphrates river, bounded on the south by the Karma district, from the north by Salah al-Din governorate, on the west by Saqlawiya, and on the east by al-Khayrat, with area of 48927.8 hectares (Fig.1).

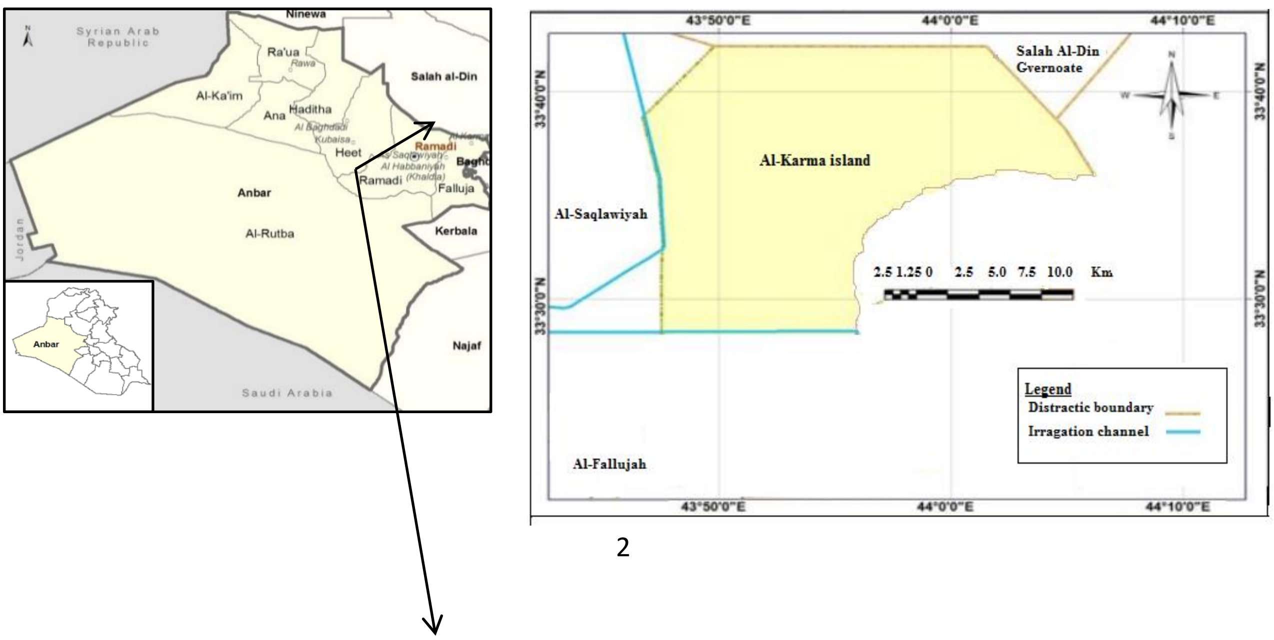

Figure (1) Location of Karma Island and its Administrator location from Anbar Governorate

Preliminary execution: In order to identify representative study sites within the region, some auxiliary tools were used, including a DEM digital elevation model from the ALOS PALSAR satellite for digital elevation determination.

Study the Natural components of the area: The geological formations of the study area back to the Lower Miocene period (about 23 million years) to the Middle Miocene era (about 7 million years), as it was deposited in a shallow coastal environment. During the Quaternary Pleistocene era (1.6 million years ago - until now), the region was characterized by the development of river systems, the formation of the current terrain, and the continuation of desert erosion processes. (Faiyad, 2014).In terms of topography, the heights of the study area ranged from 32-62 meters..

According to the available climatic information for Ramadi city for the period from 2001 to 2021, the climate of the study area is dry (Desert), the amount of precipitation as annual average was 76.4 mm, while the evaporation from the free surface was 3171.5 mm as annual average. The aforementioned climatic indicators directly affected on the natural vegetation cover in addition to being a determining factor for the

topographic and physiographic maps, as well as

cultivation of economic crops depending on the rainfall. The climatic data indicated that the average annual soil temperature at a depth of 50 cm is 25.9 °C, and since it is more than 22 °C, the soil temperature regime is Hyperthermic. In view of the fact that the soil remains dry for more than 90 consecutive days in the dry phase, as well as the difference between the average temperature for the summer and winter months is more than 5 ºC and at a depth of 50 cm; It can be concluded that the soil moisture regime of the study sites is of the type: Aridic (Torric) moisture regime, Soil Survey Staff (2014) . It became clear through field observations that the natural vegetation in the study area is low in density and poor in growth, due to the lack of rain and the dry climate

Field execution:. A semi-detailed survey was conducted in the free-lance method, depending on the transect method, it was included six transects covering the ground elevations and their secondary geomorphological units which located in the area, by digging 43 auger holes to a depth of one meter, after determining their geographical locations using a GPS device (Type Garmin (GPS map 60 CSX), (Fig.3).

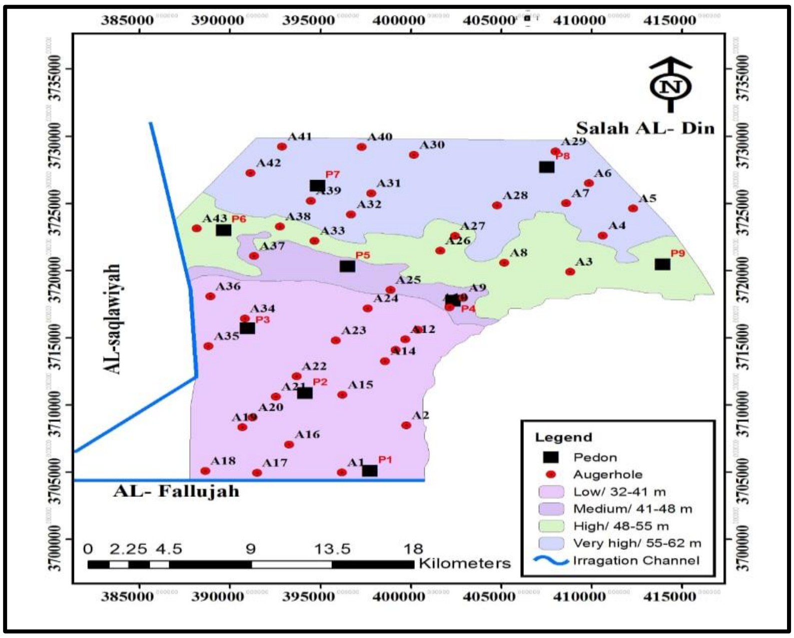

Figure (2) Selected transects according to the variance in the heights and locations of the augers and pedons sites within the study area.

9 pedons were identified according to the results of the field determination of soil texture classes and the gypsum vertical distribution. Disturbed soils samples were obtained from each horizon in a homogeneous manner placed in plastic bags, numbered, and brought to the laboratory for the purpose of conducting some physical and chemical measurements on them.

Laboratory execution: The soil samples were dried, then sieved through 2 mm a diameter sieve, the particle size distribution of soil was estimated by the pipet method described by (Kilmer and Alexander, 1949) and contained in Hesse (1976) Barium chloride treatment method. Clay particle separated according to Jackson (1979).

The electrical conductivity (ECe), and soil reaction pH estimated according to Page *et al*., (1982), while the total carbonate was estimated according to Piper (1971), and gypsum was estimated by the sedimentation method as in Richards (1954), the soil organic matter content according to Walkely and Black (1934).

The dissolved cations K^{+}, Na^{+}, $Mg^{+2}$and Ca^{+2} were estimated by titration with Fresnite, while sodium and potassium were estimated using a flame photometer. The sodium adsorption ratio was calculated by applying the mentioned relationship by (Richards, 1954).

$$SAR = Na / \sqrt{(Ca + Mg)}….(1)$$

The exchangeable sodium percentage ESP was estimated by applying the relationship mentioned before (Al-Zubaidi, 1989)

$$ESP = \frac{100(-0.0126+0.01475SAR)}{1+(-0.0126+0.01475SAR} * 100….(2)$$

Soil development index

Profile darkness index: This index was estimated using the equation proposed by Thompson and Bell (1996) as follows:

$$PDI= \text{A horizon thickness} / \sum(\text{Vi Ci}) +1…(3)$$

Whereas:

PDI=Profile darkness index

A=Thickness of A horizon (cm)

V=values of soil color value

C= Soil Chroma value
∑ =The sum of the total number of described A horizons.

Clay accumulation index: This index was calculated according to the Levine and Ciolkosz equation (1983), according to the following formula:

$$CI= (B-C)T \quad ……(4)$$

Whereas:
CI= Clay accumulation index
B= Clay percentage in B horizon
C= Clay percentage in C horizon
T= Thickness of B horizon(cm)

Carbonate accumulation index:
Carbonate accumulation index=($CaCO_3$% in B horizon – $CaCO_3$% in A horizon) X B horizon thickness ….(5)

Gypsum accumulation index: This index was estimated according to the equation proposed by Levine and Cidkosz (1983) and modified by Machtes et al. (1985) according to the following equation:

$$Cs=CT \times CTbd \times CTt - CP \times CPbd \times CPt \quad ……(6)$$

Whereas:
CT= Gypsum percentage in the horizon
CTbd= Horizon soil bulk density
CTt= Horizon thickness(cm)
CP= Gypsum percentage in the parent material
CPbd = Bulk density of the parent material
CPt= Thickness of the parent material(cm)

Soil classification: Soils classified to family level according to Soil survey staff(2014) and to series level according to Al-Agaidi Suggestion(1981), Concerning the developed soils in Iraq.

RESULTS AND DISCUSSION

Morphological characteristics of the soils

The results of the morphological description of the studied soils indicated that the value for all the soils in both wet and dry cases were 10YR, except for some cases in which it was 5YR and 5Y, which were concentrated in the pedons 1, 2 and 3, in general the color of the soil tends to a light color, especially in the subsurface horizons, the reason for this is due to the low content of the soil of organic matter in compared to the surface horizons, as well as increase in the amount of calcium carbonate and gypsum with depth. It was noticed that the loam texture class dominated at the surface horizons, except the sandy clay loam class which was recorded at horizon Ay of pedons 5 and 6, while the sandy and sandy loam coarse textures classes were concentrated within the subsurface horizons (Tab.1). The results showed variation in the degree of soil structure grade between weak and structure less, while the class was between fine and medium, and the type varied between massive and angular blocky, with registration of the dominance of the mass type in all pedons, this is due to the increase the percentage of gypsum ($CaSO_4.2H_2O$), while the platy type was observed only in the Cy2 horizon of the pedon 6. It was observed the variation in consistence in the dry condition between loose and very hard, in the moist condition its ranged between loose and extremely firm, while in the wet condition a variation was recorded in the cases of stickiness only in the Ay horizon of 1 and 5 pedons, while the type slightly sticky and Non-sticky type was showed in all other horizons. The plasticity of all horizons were characterized as Non-plastic due to the low content of the studied soils of clay separate and rise gypsum content. The soil pores quantity were varied from few to many, and their sizes ranged from very fine to coarse, we showed dominance the pores between coarse to medium size, in addition to the predominance of the interstitial type, the reason for the predominance of this size and type is attributed to the coarse texture class.

The boundaries were characteristic of the width of boundary the presence of the clear type, whose thickness ranges between 2.5-6.5cm, followed by Abrupt type, whose thickness is less than 2.5 cm, and this type of boundary indicates an increasing in the intensity of pedogenic processes in the soil, followed by the gradual type, whose thickness ranges between 6.5 -12.5cm, and the absence of diffuse type, whose thickness is more than 12.5 cm in the study pedons, indicates that the severity of the pedogenic processes was slightly to moderate intensity. The topography of the boundaries between the horizons of the pedons, it was observed two types were smooth, which was dominant in most of the studied pedons, with an appearance rate of 80.6%, followed by the wavy type with an appearance rate of 19.4%, and it should be noted that the heterogeneity in the nature of the boundaries between horizons are mainly due to the nature of sedimentation in addition to the transport processes and their intensity and its effects on the shape of the boundaries between horizons.

Particles size distribution

The results of Table 2 indicate that there is a difference in the distribution pattern of the soil particles, in general within the same soil pedon or between soils in different sites, this is due to the variation in the sedimentary environment of each site. In general, it is noted the dominance of sand , its content ranged between 39.1- 78.3% , with 11.3 a coefficient of variation, then silt with a ranged between 9.6- 47.3%, with 23.4 a coefficient of variation and finally the clay particle with ranged between of 4.2- 23.7% and a coefficient of variation of 14.9, because the study sites is located within the desert areas, indicating that the silt is more spatially heterogeneous within the region compared to the sand and clay, and this reflects the effect of the sandy nature origin of these soils (Al-Jeboory ، 2012). It is also noticed that clay percentage is higher in the soil surface than in the subsurface horizons, and this is due to the effect of the continuation of the wind sedimentation processes of the clay particles on the soil surface and the lack of its transfer to the subsurface horizons.

Table (1) Some morphological characteristics of the studied pedons.

Pedon No.	Horizon	Depth (cm)	Matrix color Dry	Matrix color Moist	*Texture class	**Structure	***Consistence Dry	***Consistence Moist	****Pores Qty Sz Shp	*****Boundary
P1	Ay	0-33	10YR7/3	10YR5/6	L	1fsbk	sh	vfr	2 co TU	CW
	By	33-69	5YR7/4	5YR8/2	L	ma	h	fi	3 m TU 1 co TU	CS
	Cy1	69-109	5YR7/2	5YR4/4	SL	ma	eh	vfi	3 m TU	GS
	Cy2	109-150	5YR6/4 5YR8/2	5YR4/4	LS	ma	h	fi	3 m IR 2 co IR	-
P2	Ay	0-30	2.5Y7/4	2.5Y7/8	L	0sg	lo	lo	2 m,f TU	GS
	By	30-74	10YR8/4 5Y8/1	10YR7/6	L	ma	h	fr	3 m,f TU 3 m,f VS	CS
	Cky1	74-105	10YR6/4	5YR4/6	SL	ma	h	fi	2 f,m TU	CS
	Cky2	105-150	5Y6/3 5YR8/1	5YR4/6	LS	ma	vh	fr	2 m,co TU 2 m,co VS	-
P3	Ay	0-28	2.5Y7/4	2.5Y6/4	L	0sg	sh	vfr	2 f,m VS	GW
	By	28-70	2.5Y7/4	2.5Y6/6	L	0sg	lo	lo	3 f IR 2 m IR	CS
	Cky1	70-101	2.5Y7/4	2.5Y6/4	L	0sg	lo	lo	2 m,co IR	CS
	Cky2	101-150	2.5Y6/4	2.5Y5/6	SL	0sg	lo	lo	2 co IR	-
P4	Ay	0-32	10YR8/3	10YR6/3	L	ma	h	fi	1 f,vf VS	AS
	By	32-71	10YR7/3	10YR5/2	L	ma	vh	fi	2 f,vf VS	CS
	Cy1	71-103	10YR7/4	10YR5/2	LS	ma	h	fr	3 m TU 2 f TU	CS
	Cy2	103-150	10YR7/2	10YR6/4	H.G	ma	vh	vfi	3 m,f VS 3 m,f TU	-
P5	Ay	0-29	10YR6/3	10YR4/4	SCL	1msbk	so	vfr	3 f IR	AW
	By	29-76	10YR7/4	10YR5/4	L	ma	eh	fi	2 f,m TU	GS

	Cy1	76-105	5YR6/3	5YR5/3	SL	ma	sh	fr	3 m,f VS	AW
	Cy2	105-150	2.5Y8/0	2.5Y8/2	H.G	ma	eh	efi	1 f,vf VS 1 f,vf TU	-
P6	Ay	0-32	10YR7/4	10YR6/4	SCL	0sg	sh	fr	3 f IR 2 m IR	GW
	By	32-79	10YR6/4 10YR8/2	10YR4/4	L	ma	h	fr	1 f,m IR	AS
	Cy1	79-103	10YR6/4 10YR8/2	10YR4/3	L	ma	h	fr	1 vf VS	CS
	Cy2	104-150	10YR7/3 10YR8/4	10YR4/3	SL	1mpl	vh	fi	1 f,vf TU 1 f,vf IR	-
P7	Ay	0-38	10YR8/4	10YR6/8	L	1fsbk	sh	vfr	2 f,vf IR 2 f,vf TU	GS
	By	38-66	10YR6/3 10YR7/4	10YR3/4	L	1msbk	sh	vfr	2 f,m IR	AS
	Cy1	66-94	10YR8/2	10YR6/6	LS	ma	sh	fr	2 m IR	AS
	Cy2	94-150	10YR7/3 10YR8/3	10YR6/4	H.G	ma	eh	efi	1 f,m IR	-
P8	Ay	0-22	10YR7/4	10YR6/4	L	1msbk	sh	vfr	2 m,f IR 2 m,f TU	AW
	By	22-63	10YR7/4 2.5Y8/2	10YR6/6	SIL	0sg	lo	lo	1 f,m TU	GS
	Cy1	63-100	10YR8/2 10YR8/3	10YR6/4	SCL	0sg	lo	lo	1 m,f IR 1 m,f TU	GS
	Cy2	100-150	10YR7/4 10YR8/1	10YR6/4	SL	0sg	lo	lo	2 co TU	-
P9	Ay	0-23	10YR7/4	10YR5/3	L	1msbk	sh	fr	2 co,m VS	AW
	Bky	23-59	5YR8/1	10YR6/4	SL	ma	vh	fi	1 vf TU	CS
	Cy	59-95	10YR7/3	10YR5/4	SL	ma	sh	fr	1 f,m TU	CS
	Cky	95-150	2.5YR7/1	2.5YR5/4	H.G	ma	vh	vfi	2 m,f VS 2 m,f TU	-

* **Texture class**- SL: Sandy loam, LS: Loamy sand, SCL: Sandy clay loam, SIL: Silty loam, L: Loam

** **Structure**/ **Grade**- 0:Structureless; 1:Weak **Size**- f: Fine, m:Moderate **Type**-sbk: Sub angular blocky, pl: Platy, sg: Single grain, ma: Massive.

*** **Consistence/ Dry**- sh: Slightly hard, h: Hard, vh: Very hard, eh: Extremely hard, so: Soft, lo: Loose, **Moist**- fi**:** Firm, fr: friable, Vfr: very friable , lo: Loose, efi: Extremely firm.

**** **Pores/Quantity**-1: Few and very few, 2: Common, 3: many **Size**- vf: Very fine, f: fine, m: Medium, co: Coarse **Shape**- IR: Interstitial, VS: Vesicular, TU: Tubular.

***** **Boundary/ Width**- A:Abrupt, C:Clear, G:Gradual **Topography**- S:Smooth, W:Wavy.

Table (2) Some physical characteristics of the studied soil pedons.

Pedon No.	Horizons	Depth(cm)	Drainage class	Particle size analysis(%)			Texture class
				Clay	**Silt**	**Sand**	
P1	Ay	0-33	Well	20.8	30.4	48.8	L
	By	33-69		18.2	38.7	43.1	L
	Cy1	69-109		11.0	35.1	53.9	SL
	Cy2	109-150		4.9	22.3	72.8	LS
P2	Ay	0-30	Well	18.8	36.0	45.2	L
	By	30-74		18.0	39.6	42.4	L
	Cky1	74-105		12.9	33.2	53.9	SL
	CKY2	105-150		5.1	18.6	76.3	LS
P3	Ay	0-28	Well	21.4	34.5	44.1	L
	By	28-70		20.5	38.9	40.6	L
	Cky1	70-101		17.9	38.2	43.9	L
	Cky2	101-150		13.0	27.5	59.5	SL
P4	Ay	0-32	Well	20.9	35.8	43.3	L
	By	32-71		21.5	32.4	46.1	L
	Cy1	71-103		4.2	16.6	79.2	LS
	Cy2	103-150			H.G		
P5	Ay	0-29	Well	23.4	28.1	48.5	SCL
	By	29-76		22.7	33.0	44.3	L
	Cy1	76-105		17.2	28.6	54.2	SL
	Cy2	105-150			H.G		
P6	Ay	0-32	Well	23.7	27.8	48.5	SCL
	By	32-79		20.3	36.4	43.3	L
	Cy1	79-103		17.9	40.1	42.0	L
	Cy2	103-150		18.1	27.7	54.2	SL
P7	Ay	0-38	Well	23.2	L	L	L
	By	38-66		20.6	L	L	L
	Cy1	66-94		5.5	LS	LS	LS
	Cy2	94-150			H.G		
P8	Ay	0-22	Well	21.1	L	L	L
	By	22-63		13.6	SIL	SIL	SIL
	Cy1	63-100		22.0	SCL	SCL	SCL
	CY2	100-150		14.7	SL	SL	SL
P9	Ay	0-23	Well	18.3	L	L	L
	Bky	23-59		19.5	SL	SL	SL
	Cy	59-95		16.2	SL	SL	SL
	Cky	95-150			H.G		

The reason for the predominance of the coarse texture in most of the study pedons may be attributed to the increase in their content of gypsum and carbonate minerals and their presence in the volumes of sand, which helped to increase the degree of coarseness of the soil.

Through field characterization and the results of laboratory analyzes of the soils of the study pedons, Table 3 and the auger pits, we observed the dominance of the loam texture class in the surface horizons of the study pedons, with the appearance of the sandy clay loam in Ay horizon of pedons 5 and 6, while the coarse texture classes (sandy loam SL and loamy sand LS) were concentrated within the subsurface horizons, and in general, the coarse textures were prevalent in the study area.

Chemical properties of the soils

The results of Table 3 showed the soil salinity was ranged between the two classes Very slightly saline soil (S1) and Highly saline soil (S4) according to the American Salinity Laboratory, (Rachardes,1954), the values ranged between 4.0 to 13.9 dSm^{-1}, the lowest value was recorded at the By horizon in pedon 1 and the highest value at Bky horizon in pedon 9, it is noted that most soils of the study area were low to medium salinity content, except the soils of pedon 9, which was within the high salinity class soils. The results indicate that the proportion of soils unaffected by salinity was about 82% of the study area, and this is due to the fact that the soils of the area have good drainage due to the coarse texture, which is characterized by large pore sizes, which results in a high water conductivity that allows the washing of sodium and chloride ions from the soil body during rainfall and irrigation, especially since the ground water is far from the surface of the soil in the region, and this is consistent with Corwin (2021) when studying the effect of ground water on the salinity of agricultural lands, he was indicated the importance of the soil texture type and the depth of ground water in the salinization of agricultural soils, especially in dry environments.

Soil reaction values for the study pedons, ranged between 7.1 to 8.1. In general, a trend was observed for the relatively high values of this property in the study soil with increasing soil content of calcium carbonate, because there is a positive relationship between this characteristic and the content of soil calcium carbonate (Mohammed, *et al*. 2021), this confirmed the existence of a highly significant positive correlation relationship for the soil reaction with their calcium carbonate content, which amounted to r = 0.724**, while the observed decrease in some sites is mainly due to the increase in the soil content of gypsum, and this is consistent with what was stated by Fontoura *et al*. (2019) when they studied the effect of soil content of gypsum and calcium carbonate on soil reaction and its effect on the productivity of cereal crops under conditions of different types of tillage. The results of the simple correlation of this property with the soil content of gypsum, confirmed the existence of a significant negative correlation that amounted to r = -0.515 *. These results are consistent with what was stated by Eswaran and Al-Barzanji, (1974), when they studied Gypsiferous soils in Iraq. The results of Table 3 indicated that the organic matter content of the studied soils ranged between 0.1 - 3.4 $gmKg^{-1}$. The distribution of the soil content of organic matter in all the pedons showed a similar pattern because there is a clear trend of increasing the content of the surface horizons of this component compared to the subsurface horizons, the reason for this decrease is due to the lack of vegetation cover observed from the field tours carried out in the area and the limited only to the natural vegetation of this component. As well as high temperatures, which lead to oxidation and rapid decomposition of organic matter and its loss from the soil.

This is in agreement with Bakhsh *et al*. (2020) when they study the characteristics of pasture soils and the effect of agricultural exploitation on the soil organic matter content in arid and semi-arid areas in Iran.

The soil gypsum content ranged between 19.4 to 61.3 %,. In general the results indicate a decrease in gypsum content in the surface horizons and its rise in the subsurface horizons, due to the effect of the high content of gypsum in the source material as well as the relative effect of dissolution and transport of gypsum in the surface horizons and its combination in the subsurface horizons by the influence of the carrier factor (precipitation water), or perhaps the low content of gypsum in the surface horizons of pedons may be attributed to the activity of geomorphic processes, which helped to accumulate soil materials poor with gypsum over the old gypsum assemblies, as well as the weak dissolution processes and the role of gradient and erosion.

This is consistent with Voigt *et al*. (2020) when they studied the spatial distribution of dissolved salts and gypsum in the soils of dry and desert areas and their relationship to drought conditions. It was observed through field work that a Petrogypsic horizon appeared in the Cy2 horizon of pedons 4 and 7, knowing that this horizon appeared after 100 cm from the surface of the soil, so it did not appear in the classification as it does not affect the growth of most crops(Soil survey staff. 2014) , It is noting that this horizon is formed only in dry areas and develops from the parent material that is rich in gypsum (Soil Survey Manual, 2017).

Table (3) Some chemical properties of the Soils.

Pedon No.	Horizon	Depth (cm)	ECe dSm^{-1}	pH	O.M	$CaCO_3$	$CaSo_4.2H_2O$	SAR	ESP
					$gmKg^{-1}$				
P1	Ay	0-33	4.9	7.4	3.4	176	200	1.16	1.88
	By	33-69	4.0	7.2	2.0	191	223	1.49	2.27
	Cy1	69-109	5.5	7.2	1.0	179	256	1.49	2.27
	Cy2	109-150	5.5	7.4	0.2	131	260	1.29	2.03
P2	Ay	0-30	4.6	7.7	2.1	260	237	2.62	3.60
	By	30-74	4.2	7.5	1.1	130	204	1.87	2.72
	Cky1	74-105	4.4	7.6	0.6	211	198	1.76	2.59
	Cky2	105-150	5.3	7.7	0.1	265	220	0.93	1.61
P3	Ay	0-28	5.0	7.5	2.3	241	194	2.24	3.15
	By	28-70	4.6	7.5	1.1	203	221	2.19	3.09
	Cky1	70-101	4.8	7.4	0.3	301	256	2.23	3.14
	Cky2	101-150	5.0	7.2	0.1	320	242	2.47	3.42
P4	Ay	0-32	4.8	7.6	1.8	203	273	2.75	3.76
	By	32-71	5.2	7.4	0.9	215	253	2.73	3.73
	Cy1	71-103	4.8	7.3	0.2	205	370	2.24	3.15
	Cy2	103-150	4.8	7.1	0.1	215	611	2.48	3.44
P5	Ay	0-29	4.2	7.4	1.6	151	300	1.77	2.60
	By	29-76	4.8	7.3	0.7	106	336	3.41	4.53
	Cy1	76-105	3.6	7.2	0.2	114	398	3.77	4.96
	Cy2	105-150	11.9	7.1	0.1	121	605	3.87	5.08
P6	Ay	0-32	5.0	7.5	2.0	200	322	2.11	3.00
	By	32-79	5.3	7.5	0.8	126	309	2.17	3.07
	Cy1	79-103	5.0	7.4	0.3	118	314	2.11	3.00
	Cy2	104-150	4.6	7.4	0.1	124	303	2.02	2.89
P7	Ay	0-38	4.8	7.4	1.4	192	305	3.03	4.09
	By	38-66	5.0	7.4	0.7	189	298	2.76	3.77
	Cy1	66-94	4.2	7.3	0.3	150	373	2.48	3.44
	Cy2	94-150	7.3	7.1	0.1	161	613	2.64	3.63
P8	Ay	0-22	4.7	7.6	1.3	251	224	3.97	5.19
	By	22-63	5.2	7.4	0.6	257	320	3.98	5.21
	Cy1	63-100	4.8	7.3	0.1	210	363	3.34	4.45
	CY2	100-150	5.7	7.3	0.0	204	380	3.50	4.64
P9	Ay	0-23	6.1	7.6	1.2	233	286	2.83	3.85
	Bky	23-59	13.9	8.0	0.6	281	330	2.77	3.78
	Cy	59-95	8.5	7.9	0.1	279	351	2.73	3.73
	Cky	95-150	7.7	8.1	0.0	354	408	2.09	2.98

It is evident from the Table 3 that the calcium carbonate content of the studied soils ranged between 101-354%. The variation in the region's content of this component is due to the nature of the transported parent material that forms the soil, with no homogeneity in the distribution of carbonates in the soil profile. This is due to the fact that the source of carbonates in these soils is the erosion and mechanical weathering of limestone rocks, the transfer of products by running water and ground attraction, as well as wind erosion and its deposition in the region.

It is noted that the content of carbonate minerals in the study soils was opposite to the distribution of calcium sulfate minerals, and the reason for this is due to the process of gypsum substitution (Gypsification) during the soil formation processes, which led to an increase in gypsum in most horizons at the expense of other soil components, including carbonates, due to the discrepancy in the solubility of both minerals, as the solubility of carbonates ranges between 0.01-0.05 gmL^{-1}, while the solubility of gypsum ranges between 2.2-2.6 gmL^{-1} (Hesse,1971), in addition, some of the carbonates are transformed into gypsum due to the vital activity of the roots of plants, as the carbonates close to the root hairs dissolve, causing a decrease in the degree of soil reaction in the area and the resulting calcium ion unites with the sulfate ion present in high concentrations in the soil solution and then precipitates it in the form of gypsum (Al-Jubouri, 2012). The increase in the carbonate content in some horizons is due to the process of removing gypsum (Degypsification) in the surface horizons by rain water, irrigation water and groundwater and transporting it to the down, which leads to the concentration of carbonate in the washed horizons. These results are consistent with what was found by Al-Barzanji (1973) and Salim (2001).The morphology diagnosis was showed the presence of lime horizon specifications in some examination sites.

The results of table 3 indicate a decrease in the exchangeable sodium ratios in the horizons samples for all studied pedons, its ranged between 1.88 - 5.08, the reason for this is due to the low salt content of the studied soils. It is noticeable from the results of the study of this indicator that there is no problem for the danger of sodium in these soils because its values did not exceed 15, and this is one of the characteristics of gypsiferious soils recorded by Al-Jubouri (2012).

Soil formation Factors, processes and its development indexes

The factors of parent material and topography are among the most important and prominent factors of soil formation affecting the study area, as the dry climate in the area did not record a distinct role in the formation of the soil of the region, due to the low amount of rainfall, high temperatures and monthly and annual evaporation rates recorded in the area, which in turn was reflected on the natural vegetation factor, which showed clear weakness in the region. The gypsum parent material reflected this on the formation of gypsiferious horizons in all the soils of the region, as well as its impact on the morphological, physical and chemical characteristics. The effect of the topographic factor influence emerged through the general decline of the region, which had a clear impact on the erosion and sedimentation processes.

The most important processes prevailing in the study area, it is the Gypsification, which was formed as a result of the presence of the gypsum origin material rich in calcium sulfate with the presence of the chronological age for the occurrence of such a process. For the calcification process, it arose as a result of the richness of the parent material in calcium, which in turn contributed with the prevailing climatic conditions in the formation and accumulation of calcium carbonate and the formation of calcareous and gypsiferious horizons resulting from the interaction of gypsum and lime in the formation of such horizons. It is noted from the table 3 that the gypsic horizons are formed within all the study pedons, and the Calcigypsids horizon, whose presence was diagnosed in the P2, P3 and P9 pedon.

The geomorphology of the region, through the effect of variation in the topography of the land and the degree of its slope, has contributed to increase in the activity of erosion and sedimentation processes, and through the horizontal and vertical movement of dissolved materials within the soil bodies distributed over it. And based on the equation (Levine and Ciolkosz, 1983), it was possible to study and classify the study soil pedons in terms of their degree of development.

The degree of soil development was varied between well-developed through the formation of the B horizon in all the study pedons, except for the pedon P9, which was observed in that region and showing the character of development through diagnosing the presence of the Bky horizon, its development is attributed to its occurrence within the high areas and the acquisition of the character of equatorially and the lack of its slope, which made the erosion and sedimentation processes of a closed type, which made the movement of falling water from rain slow moved in horizontal direction and fast in the vertical direction and in the presence of the time factor.

Profile darkness index

It is noticed from the results of Table 4 there are significant differences between the study pedons in terms of the values of the profile darkness index, the highest value was recorded at the pedon P5, while the lowest value was at the pedon P8. The difference in the values of this indicator is primarily due to the soil content of organic matter, clay and gypsum. The study of the correlation between this pedological index and the clay content of the study soils confirmed a positive significant correlation with a value of r = 0.699 *, and with the organic matter content r = 0.784 *, while the relationship was negative between the soil content of gypsum reached r = -0.302, which indicates the role of soil content of the three components in the values of this characteristic. This is consistent with Thompson *et al*. (1997) and Bingwen *et al*. (2017).

Table (4) Profile darkness index values for studied Soils.

Pedon No.	Thickness (cm)	Value	chroma	PDI*
P1	33	7	3	1.50a
P2	30	7	4	1.03b
P3	28	7	4	0.96b
P4	32	8	3	1.28a
P5	29	6	3	1.52a
P6	32	7	4	1.10b
P7	38	8	4	1.15ab
P8	22	7	4	0.75c
P9	23	7	4	0.79bc
		$L.S.D_{0.05}$		0.238

Calcium carbonate accumulation index

It is evident from the results of Table 5 that there is a discrepancy in the values of this index between the studied pedons soils, its ranged between -268.1 and 379.5, which indicates the presence of carbonate accumulation in the pedons P4, P5, P6, P7 and P8, while the pedons P1, P2, P3 and P9 did not appear carbonates accumulation. The observed discrepancy in the values of this indicator is mainly due to the nature of the parent material and its influence on the geomorphological location and the nature of the sedimentary materials and their influence on the carrier factor (Al-Rawi, 2003). Note that most of the Iraqi soils show the presence of carbonates in different degrees that reflect the nature of the geological materials transferred from them, which is characterized by its high content of limestone (Buringh, 1960). Taalab *et al*. (2019) noted the existence of calcium carbonate accumulation index in limestone Soils in the Arab Republic of Egypt, and the values of this index ranged between 32-421.

Ortiz *et al*. (2022) observed an accumulation of carbonate in the agricultural soils of dry agricultural areas in the southwestern USA of up to 10% by weight of calcite after 100 years of cultivation. These rates are likely to increase in the future due to the combined effects of climate variability (reduced rainfall and increased amounts of evaporation),and the use of more slightly salinity groundwater for irrigation, and the diagnosed decrease in soil porosity are associated with carbonate accumulation rates with the release of large amounts of carbon dioxide from irrigated dry lands to the atmosphere. This indicates the need for extensive field studies to determine the amount of these flows at the local, regional and global levels associated with the accumulation of carbonates in the soil.

Table (5) Values of carbonate accumulation index in the studied Soils

Pedon No.	%$CaCO_3$ in B horizon	Thickness of B horizon	ρb of B horizon	%$CaCO_3$ in C horizon	Thickness of B horizon	ρb of C horizon	CS
P1	19.0	36	1.30	17.9	40	1.53	-201.6
P2	13.0	44	1.32	21.1	31	1.50	-226.1
P3	20.3	42	1.36	30.1	31	1.53	-268.1
P4	21.5	39	1.32	20.5	32	1.62	44.1*
P5	10.6	47	1.40	11.4	29	1.63	158.6*
P6	12.6	47	1.43	11.8	24	1.65	379.5*
P7	18.9	28	1.37	15.0	28	1.49	99.2*
P8	25.7	41	1.32	21.0	37	1.43	279.8*
P9	28.1	36	1.42	27.9	36	1.56	-130.4

Gypsum accumulation index

It is evident from Table 6 that there is a clear difference in the gypsum accumulation index in the studied Soils, its value ranged between -523.1 and 833.4, this results indicated the presence of gypsum accumulation as a result of the pedogenic process at P2, P3, P5 and P6 pedons, clearly through quantity measurements for this index, while no evidence of gypsum accumulation was recorded in P1, P7, P8 and P9 pedons. This variation in the evidence is mainly due to the geomorphological location and the movement of this component in the soil body (Robson *et al*. 2017). Funakawa *et al*. (2007) indicated that rain and periodic irrigation lead to washing out most of the gypsum and soluble salts downstream from the soil body, in the opposite cases, when the amount of water passing through the soil body decreases, gypsum accumulates in large quantities in the surface layers of the soil, in addition to soluble salts (Al-Jubouri, 2012). From the foregoing, the results indicate that the dry conditions and the limited rain and irrigation water in the region have generally limited the removal of soluble gypsum, which in general allowed the features of the upward movement of water to dominate in the region, which determined the movement and distribution of gypsum and its accumulation and gave a clear role for geomorphological processes to take their role in the region. These results were consistent with Hashemi *et al*. (2011) when they studied gypsiferious soils in the south Iran, and the observed gypsum index value was ranged between -456.8 and 756.4.

Table (6) Gypsum accumulation index values in the studied Soils.

Pedon No.	% $CaSo_4.2H_2O$ in B horizon	Thickness of B horizon	ρb of B horizon	% $CaSo_4.2H_2O$ in C horizon	Thickness of B horizon	ρb of C horizon	CS
P1	22.3	36	1.30	25.6	40	1.53	-523.1
P2	20.4	44	1.32	19.8	31	1.50	264.1*
P3	22.1	42	1.36	25.6	31	1.53	48.1*

Table (7) clay accumulation index Values of the studied Soils

P4	25.3	39	1.32	37.0	32	1.62	-615.6
P5	33.6	47	1.40	39.8	29	1.63	329.6*
P6	30.9	47	1.43	31.4	24	1.65	833.4*
P7	29.8	28	1.37	37.3	28	1.49	-412.9
P8	32.0	41	1.32	36.3	37	1.43	-188.8
P9	33.0	36	1.42	35.1	36	1.56	-284.2

Clay accumulation index

The results of Table 7 showed that there is a transfer of clay particle by the lessivage process, depending on the equation of Levine and Ciolkosz (1983), the value of the clay accumulation index (CAI) in the study soils was ranged between -344.4 and 674.7. The succession of the pedons in terms of clay accumulation index was following the sequence: P4, P7, P1, P5, P2, P9, P6 and P3, while the results did not show the existence of a transition of clay in the pedon P8, due to the fact that the content of the horizon C of clay is higher than it is in the B horizon, and more the value of the clay accumulation index is very small, the difference was greater between the two horizons, therefore negative values do not reflect a transition of clay in the pedon. This is agreement with Collins and Fenton (1982) and Vidic and Lobnik (1997), where they indicated that the development of soil horizons is due to pedogenic processes that lead to the redistribution and arrangement of soil particles with depth, especially the content of clay due to the activity of loss and gain processes, especially in the gain horizon (B) due to the effect of the amount of rainfall and the topography.

These results were consistent with Zhang *et al*. (2023) who indicated that the values of the clay accumulation index (CAI) in all physiographic units soils in Iraq were between 407.4 and 5451.4. Under high humidity conditions more than the current conditions, which helps in the activity of the processes of eluviation and illuviation and formation of B horizon in Iraq. This means that a case of genetic transfer of clay from the surface horizons to the subsurface horizons occurred in earlier periods under conditions of high humidity than the current conditions, which helps in the activity of eluviation and illuviation processes and the formation of the B horizon. These results were agreement with what was recorded by Al-Rubaie (2011) and Al- ubouri (2012) when they studied the movement of clay fraction in gypsiferious soils in Iraq.

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Pedon No.	% Clay in B horizon	% Clay in C horizon	Thickness of B horizon	CAI
P1	18.2	11.0	36	259.2
P2	18.0	12.9	44	224.4
P3	20.5	17.9	42	109.2
P4	21.5	4.2	39	674.7
P5	22.7	17.2	47	258.5
P6	20.3	17.9	47	112.8
P7	20.6	5.5	28	422.8
P8	13.6	22.0	41	-344.4
P9	19.5	16.2	36	118.8

Soils classification

The soils of the region were characterized by being located within the Aridic moisture regime, as the rate of water loss through evaporation processes in the region is more than the amount of rain falling in most months of the year, as the amount of rainfall amounted to 76.4 mm annually, compared to the amount of high annual evaporation which is 3171.5 mm, so the soil is dry and moisture is not available for a long time.

As for the soil temperature regime, according to climatic data, it was Hyper thermic. It is clear from the results of Figure 3 and the results of the cartographic analysis Table 8 for the region soil classification, that all the soils of the region belong to the order of Aridisols. They are well-developed desert soils due to the presence of the B horizon, especially the gypsic horizon, which was diagnosed in all study pedons. It was among the sub-order Gypsids, which was characterized by the predominance of the light color resulting from the decrease in the amount of organic matter and the increase in the proportions of gypsum and carbonates, as well as the predominance of medium to coarse texture varieties in all horizons of the study pedons.

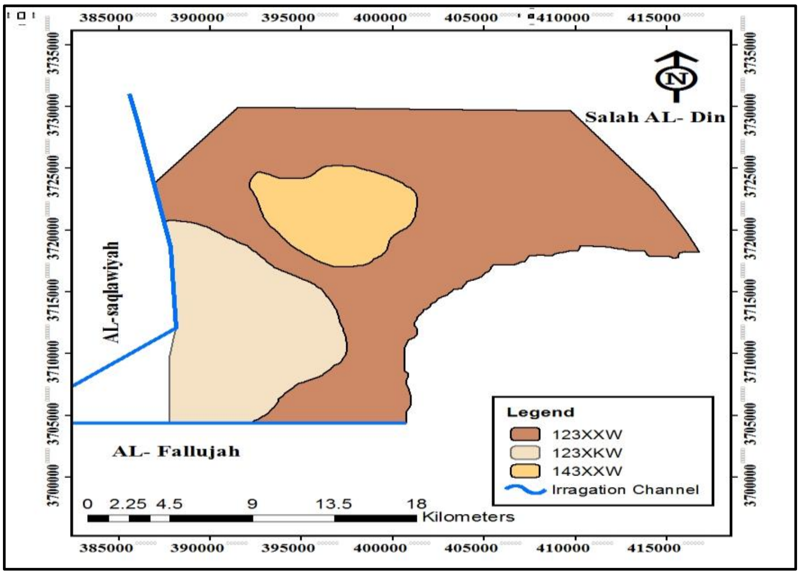

Figure 3. Map of the spatial distribution of soil series diagnosed in the study area.

Table 8. Cartographic analysis of the soil series of the studied area

Soil series	Area	%
143XXW	5259.96	10.75
123XKW	11359.62	23.21
123XXW	32308.22	66.04

As for the soil great group which diagnosed in the study area, they were Haplogypsids, which are gypsiferious soils that do not have a calcic horizon, whose upper limit is within the first 100 cm of the soil surface. In addition to the Calcigypsids, which are gypsiferious soils containing a calcic horizon, whose upper limit is within the first 100 cm of the soil surface. Under the sub-great group, the results of classifying the study soils, as shown in Figure 6 and the cartographic analysis table 10, showed the presence of two groups: Typic Haplogypsids, which constituted 74.3% of the study area, followed by Typic Calcigypsids with a percentage of 25.7%, of the total study area.

Figure 3 shows the spatial distribution of the soil series diagnosed in the study area, it is

clear from the results of Table 10 that there are three soil series, 123XXW, 123XKW and 143XXW, the series 123XXW formed the largest percentage of the area amounting to 66.21% (32308.22 hectares), while the series 143XXW constituted the least percentage of the total area 10.75% (5259.96 hectares), and it was represented only by pedon 5, while the pedons 2 and 3 those belonging to the series 123XKW occupied 23.21% (11359.62 hectares).

COCULUTION

1- It was observed that there was a variation in the degree of soil development according to the geomorphological location.
2- It was noticed that there was a variation in the soil content of organic matter, gypsum and carbonates, and evidence of their accumulation, according to the variation of the secondary physiographic unit in the study area.
3- The morphological diagnoses referred to the interaction between subsurface gypsum and calcareous horizons in some of the examination sites.
4- Most the region soils were within sub group Typic Haplogypsids.

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