Geomorphological Variation and Its Role in Pedogenic Development and Soil Classification of River Terraces in Al-Khalidiyah Subdistrict, Al-Habbaniyah District, Al-Anbar Governorate, Iraq

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Abstract

This study aims to study the effect of geomorphological variation in pedogenic development and soil classification of river terraces in Al-Khalidiyah Subdistrict, Al-Habbaniyah District, Al-Anbar Governorate, Iraq. Two example soil pedons of varying geomorphological ages on river terraces were studied in the field and laboratory. The pedons were morphologically documented using the USDA Soil Survey Manual and samples of all the genetic strata were obtained for physical and chemical analyzes following routine laboratory procedures.

The morphological description showed obvious difference in development of soil profile between the two pedons. A cambic (Bw) and a calcic (Bk) horizon were present representing the first pedon, which suggests limited pedogenic development. The second pedon, however, showed an argillic horizon (Bt) and a calcic horizon indicating a more advanced stage of soil development related to the older river terrace.

The physical analysis showed that soil texture ranged from silt loam to silty clay loam and clay, with clay content and bulk density increased and total porosity decreased with depth. Chemical analyzes revealed neutral to slightly alkaline soils with electrical conductivity, calcium carbonate and gypsum contents rising lower through the profiles and organic matter decreasing with depth. Clay-enriched horizons had the maximum cation exchange capacity. ESP and SAR values were below diagnostic thresholds for sodic soils.

The main pedogenic processes identified in the research region were calcification, clay illuviation in the older terrace, gypsification, moderate salinization and decomposition of organic waste. These processes are directly related to the geomorphological stability and age of the river terraces.

According to the diagnostic strata and the morphological, physical and chemical features, the soils were classified according to the USDA Soil Taxonomy [22] into the order Aridisols, with several lower taxonomic categories representing the degree of pedogenic development. The investigation revealed that the geomorphological variance has a crucial role in determining soil genesis, horizon differentiation, pedogenic processes and soil classification in the river terraces of the studied area.

Keywords: Geomorphological variation; Pedogenesis; Soil classification; River terraces; Al-Khalidiyah; Aridisols; Alluvial plain.

1. Introduction

Soil is one of the most significant natural resources supporting agricultural and environmental activity. Soil is the product of a complex interplay of the soil formation variables of parent material, climate, organisms, relief and time. One of the most important of these factors influencing soil properties and their distribution in space is relief (geomorphology). Relief influences the nature of deposition and erosion, the movement of surface and ground water, and the degree of land surface stability. All of these factors are directly reflected in the paths of pedogenic processes and development of diagnostic soil horizons.

Some of the most visible geomorphic units that illustrate the evolutionary history of rivers and depositional settings are river terraces, which represent past river surfaces created by multiple episodes of deposition and incision during distinct geologic periods. The terraces differ from each other in geological age and in elevation above the present river level, and in depositional conditions and parent material, resulting in marked differences in physical, chemical, mineralogical and morphological properties of the soils, and hence in their degree of pedogenic development.

Pedogenic development is a set of natural processes that change primary sediments into soils with characteristic features. This transformation occurs through the processes of addition, loss, translocation and transformation and is significantly controlled by geomorphic, climatic and hydrological variables. The processes of calcium carbonate, gypsum and soluble-salt buildup are dominant in arid and semi-arid environments because of limited leaching and high evaporation. These processes contribute to the formation of diagnostic strata that constitute the basis of soil classification and interpretation of developmental stages.

Al-Khalidiyah sub-district is included in Al-Habbaniyah district. It is located in the central part of the Iraqi alluvial plain which is characterized by a variety of geomorphic units evolved by the historical activity of the Euphrates River, where the river terraces of different elevations and ages are common, in addition to recent floodplains and different fluvial sediments. This geomorphic diversity in combination with the prevailing arid to semi-arid climatic conditions has produced a variety of soils which differ in their morphological, physical and chemical properties and degree of pedogenic development making the area a suitable setting for studying the relationship between geomorphology and soil formation.

Geomorphological variation and its relationship with pedogenic development is a subject of great scientific and applied importance. It helps to explain the distribution and properties of soils, clarifies the processes responsible for soil formation and identifies productive potential. It also provides a scientific basis for sustainable land-use planning and management. Results of such research also help in updating soil maps, evaluating suitability of agricultural land and aiding land reclamation programs in arid and semi-arid regions.

Therefore, the present research is directed toward the study of the geomorphological variation of river terraces in Al-Khalidiyah Subdistrict, Al-Habbaniyah District, and analysis of its role in the direction of pedogenic processes and soil development, through the morphological description of the pedons and the required physical and chemical analysis, relating the results to the different geomorphic units, and the ultimate classification of the soils of the study area under the USAD Soil Taxonomy, so as to advance scientific understanding of the

properties of the Iraqi alluvial-plain soils and provide information of use in agricultural planning and land-resource management

2. Materials and Methods

2.1 Study Area

The research region is located in Al-Khalidiyah Subdistrict, Al-Habbaniyah District, Al-Anbar Governorate, and belongs to the Iraqi alluvial plain, which is characterized by the diversity of geomorphic units originating from the river activity of the Euphrates River. Two locations with different geomorphic properties and degree of soil development on river terraces were selected in an effort to explore the influence of geomorphological variation on pedogenic processes and soil classification.

2.2 Selection of Pedon Sites

The pedons were selected after preliminary research of geomorphological maps and satellite imagery and field reconnaissance . Two sites reflecting the primary geomorphic units of the study area were selected:

- Pedon 1 (P1): located on the young river terrace, representing the less-developed soils.
- Pedon 2 (P2): located on the relatively old river terrace, representing the more-developed soils.

Sites were selected to be representative of their geomorphic unit and free from fill material or direct anthropogenic disturbance.

2.3 Field Work

Field survey was carried out during the study season when two pedons of about 1.5 × 1.5 m were dug to a depth of around 150-180 cm, or to the parent material or water table where met.

Pedon faces were cleaned and morphological descriptions were made according to the Soil Survey Manual [21]. A GPS receiver was used to take coordinates and elevation above sea level was measured for each location.

2.4 Sample Collection

Representative samples were taken from all genetic horizons of each pedon, placed in clean plastic bags, tagged by pedon and horizon number, and transferred to the laboratory for air-drying, grinding, and sieving through a 2-mm screen in preparation for laboratory analysis.

2.5 Laboratory Analyses

Physical and chemical analyses were carried out in the soil science laboratories and included the following:

Physical analyses

- Particle-size distribution (hydrometer method).
- Bulk density.
- Particle density.
- Total porosity.
- Moisture content.
- Texture.

Chemical analyses

- Soil reaction (pH).
- Electrical conductivity (EC).
- Calcium carbonate equivalent.
- Organic matter.
- Gypsum.
- Soluble cations (Ca^{2+} , Mg^{2+} , Na^{+} , K^{+}).
- Soluble anions (Cl^{-} , SO_4^{2-} , HCO_3^{-}).
- Cation exchange capacity (CEC).

- Sodium adsorption ratio (SAR).
- Exchangeable sodium percentage (ESP).

2.6 Interpretation of Pedogenic Processes

The interpretation of the pedogenic processes was based on the integration of morphological qualities and physical and chemical results, aiming to diagnose the dominating processes, such as:

- Calcification.
- Gypsification.
- Salinization.
- Desalinization.
- Clay translocation (lessivage), where present.
- Organic-matter accumulation.

2.7 Soil Classification

The soils of the two pedons were classified to the family level from the order level using the field diagnostic properties and laboratory results based on the current classification keys and the results were compared with the World Reference Base (WRB) classification system where relevant, according to the USDA Soil Taxonomy [22].

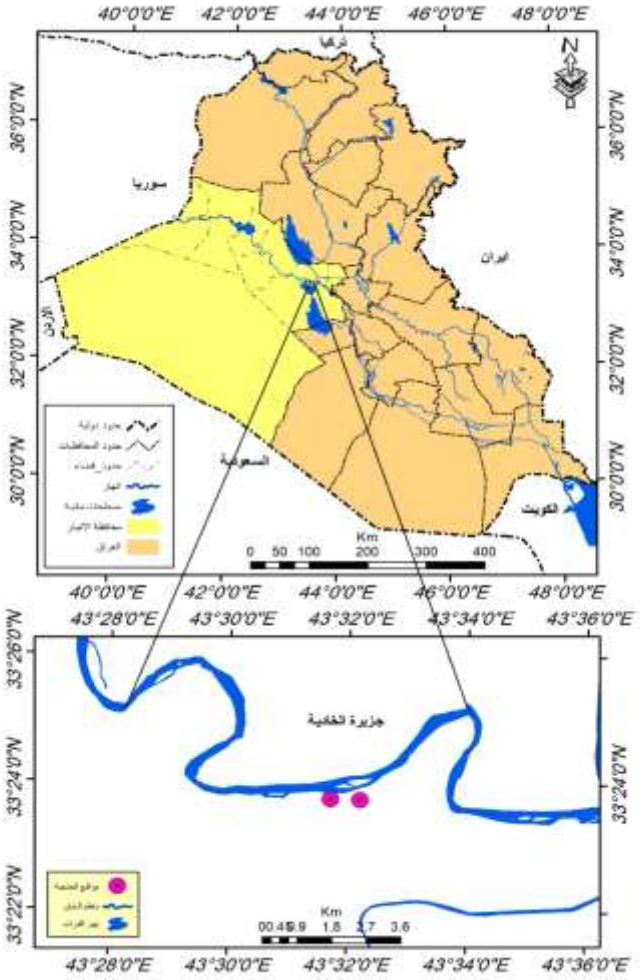

Figure 1. Location of the studied pedons within the study area.

3. Results and Discussion

3.1 Morphological Properties of the Study Area

The morphological description of the two pedons showed a pronounced contrast in the properties of the genetic horizons, which is explained by the different geomorphic position of the river terraces and their degree of stability, and this in turn reflects the intensity of the dominant pedogenic processes in the study area.

Table 1. Morphological properties of Pedon 1 (P1).

Horizon	Depth (cm)	Moist colour	Texture	Structure	Consistence	Roots	Calcareous features	Boundary
Ap	0-25	10YR 4/3	Silt loam (SiL)	Medium granular	Friable	Many	Very few	Clear, smooth
Bw1	25-55	10YR 5/4	Silt loam	Medium subangular blocky	Slightly hard	Moderate	Few	Clear, wavy
Bw2	55-90	10YR 5/6	Silty clay loam	Medium blocky	Hard	Few	Moderate	Gradual, smooth
Bk1	90-130	10YR 6/4	Silty clay loam	Coarse blocky	Hard	Rare	Many (mottles, filaments)	Gradual
Ck	130-160+	10YR 7/3	Silt loam	Structureless	Loose	None	Very abundant (parent material)	Diffuse

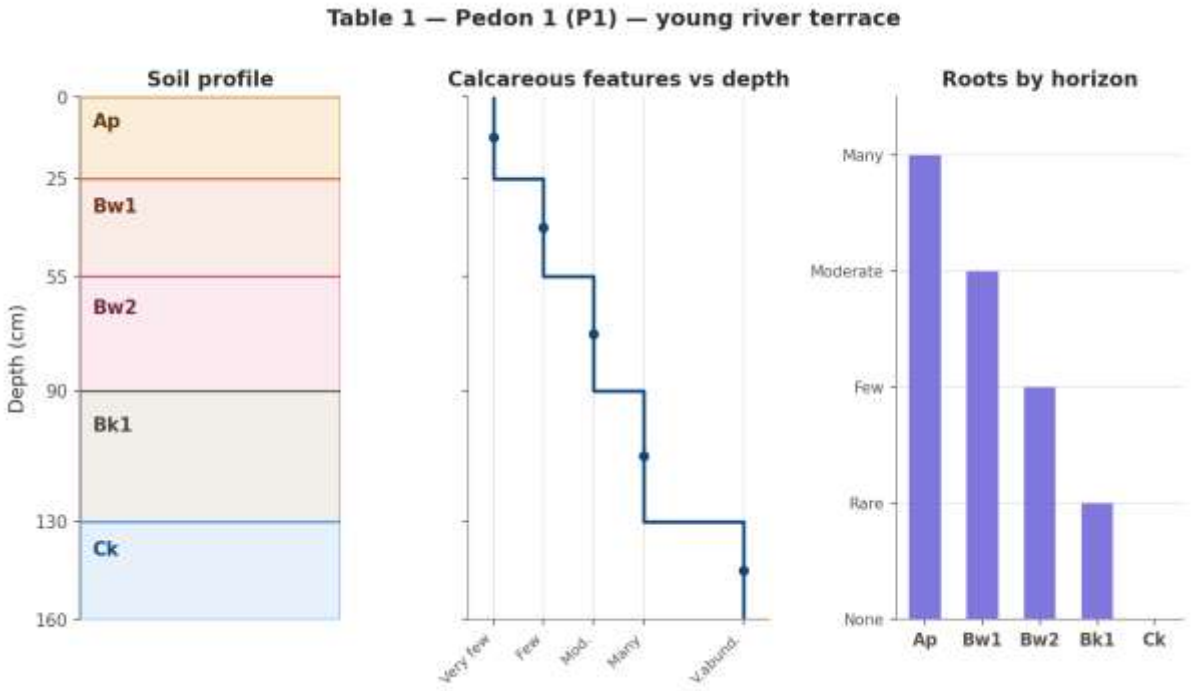

Figure 2. Soil profile of Pedon 1, with calcareous-feature intensity trend and roots by horizon. Calcareous accumulation increases steadily with depth while root abundance declines, consistent with a young, weakly developed profile limited to a cambic horizon.

Table 2. Morphological properties of Pedon 2 (P2).

Horizon	Depth (cm)	Moist colour	Texture	Structure	Consistence	Roots	Calcareous features	Boundary
Ap	0-20	10YR 4/2	Silty clay loam	Medium granular	Friable	Many	Few	Clear
Bt	20-55	7.5YR 4/4	Silty clay	Strong subangular blocky	Hard	Moderate	Few	Clear, wavy
Btk	55-95	7.5YR 5/4	Clay	Strong blocky	Very hard	Few	Moderate	Gradual
Bk	95-140	10YR 6/4	Silty clay loam	Coarse blocky	Hard	Rare	Very abundant (nodules)	Gradual
Ck	140-170+	10YR 7/4	Silt loam	Structureless	Loose	None	Very abundant	Diffuse

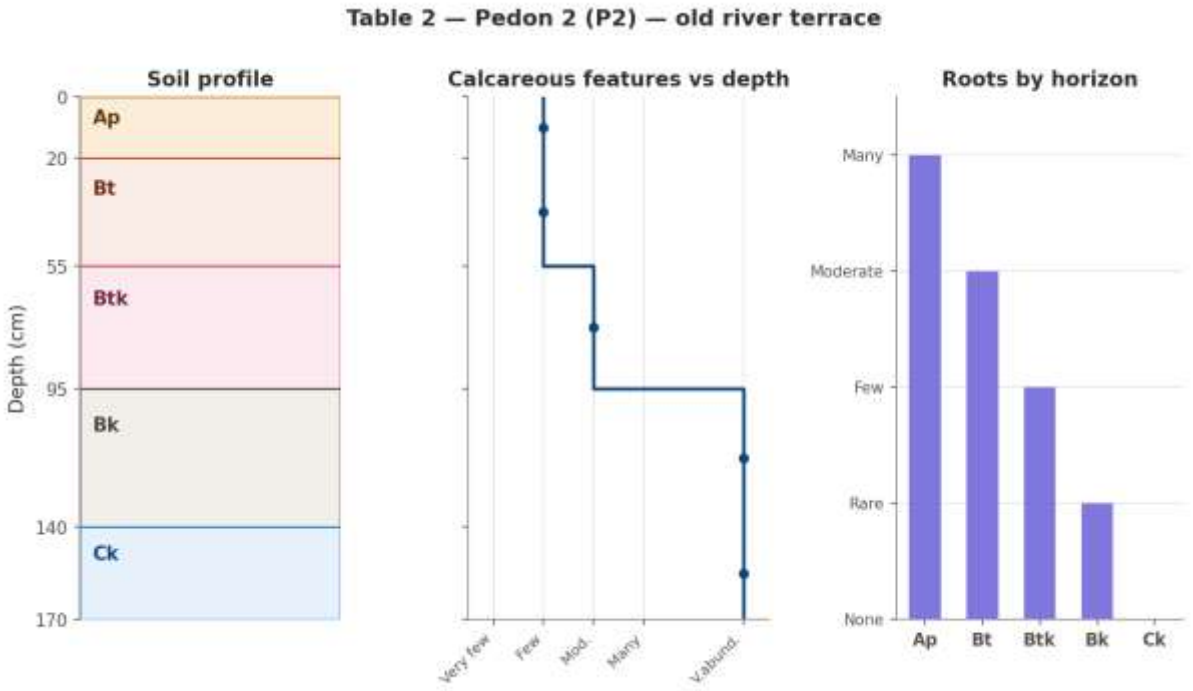

Figure 3. Soil profile of Pedon 2, with calcareous-feature intensity trend and roots by horizon. Calcareous accumulation is already elevated by the Bk horizon and roots decline sharply below the argillic (Bt) horizon, consistent with the more advanced pedogenic development of the older terrace.

Pedon 1 (P1) was characterized by a horizon sequence Ap-Bw1-Bw2-Bk-Ck, a sequence characteristic of a relatively young soil with limited pedogenic development, in which development was limited to the appearance of a cambic horizon (Bw), with the onset of color and structural change relative to the parent material, but without the formation of more advanced diagnostic horizons. This is indicative of the youthfulness of the river sediments on which the soil had developed and the continued influence of fluvial deposition that shortened the time for horizon development.

Conversely, Pedon 2 (P2) revealed a more developed sequence of horizons Ap-Bt-Btk-Bk-Ck. The presence of the argillic horizon (Bt) represents the movement and buildup of clay particles inside the profile, a pedogenic process requiring a longer time period and more geomorphic stability than that represented by Pedon 1. The Btk horizon also shows the overlap of clay translocation and calcium carbonate accumulation, showing more pronounced pedogenic growth on the older river terrace.

The color of the soils ranges from relatively dark brown in the surface horizons to light brown in the subsurface and deep horizons of both pedons. This is due to the decreasing organic-matter content with depth and increasing buildup of calcium carbonate in the lower horizons. Brown shades prevail and there is no gray or blue coloration which indicates appropriate drainage conditions, and no extended waterlogging.

Texture varied from silt loam to silty clay loam and clay, with a clay content rise in the intermediate strata of Pedon 2, which is compatible with the presence of the Bt horizon due to clay translocation. This textural gradation influences the circulation of water and air inside the soil and gives

indications of more evolved pedogenic processes relative to Pedon 1.

In the surface horizons the structure changed from granular to subangular blocky or blocky in the subsurface horizons, because to the rising clay content and the decreasing effect of cultivation with depth, as well as the involvement of calcium carbonate in strengthening the structural units. Blocky structure is a frequent feature in soils of arid and semi-arid climates.

at both pedons, root density dropped progressively with depth, being concentrated at the surface horizon because of biological activity and organic-matter availability, and decreasing in the lower horizons because of reduced aeration and increased calcareous characteristics. Such pattern is typical for agricultural soils in arid areas.

The results also showed an increasing distribution of calcareous features with depth starting from calcareous filaments or mottles in the Bk horizon and increasing to the Ck horizon especially in Pedon 2 due to the dominance of calcification because of the downward movement of calcium carbonate solutions and their precipitation at specific depths because of limited leaching and high evaporation - among the most important pedogenic processes dominant in the environments of the Iraqi alluvial plain.

Horizon boundaries were abrupt to gradual depending on the extent of pedogenesis; boundaries were more abrupt between surface and subsurface horizons due to their opposing properties and were more gradual in deeper horizons due to their relative similarity to the parent material.

The general morphological features show that the geomorphological variation between the river terraces was the main element controlling the difference in degree of soil development. Pedon 1 was a young soil with limited development, while Pedon 2 had more developed diagnostic properties, represented by the argillic horizon (Bt) and higher carbonate accumulation, indicating a longer period of geomorphic stability and higher influence of pedogenic processes. These results are consistent with the pedogenic idea of a relationship between age of land surface and degree of soil development. Weathering intensity and horizon differentiation increase with age and stability of the geomorphic unit.

3.2 Physical Properties of the Study Area

The physical analyzes showed a distinct variation in the soil properties between the two pedons and within the genetic horizons of each pedon because of the different geomorphic conditions and the age of the river terraces as well as the effect of pedogenic processes that resulted in redistribution of soil particles and formation of diagnostic horizons.

Table 3. Physical properties of Pedon 1 (P1) — young river terrace.

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Porosity (%)	Moisture content (%)
Ap	0-25	18	60	22	Silt loam	1.32	2.64	50.0	18.6
Bw1	25-55	17	57	26	Silt loam	1.36	2.65	48.7	17.2
Bw2	55-90	15	52	33	Silty clay loam	1.41	2.66	47.0	15.8
Bk	90-	14	50	36	Silty clay	1.47	2.67	44.9	14.2

	130				loam				
Ck	130-160+	16	51	33	Silty clay loam	1.50	2.68	44.0	13.5

Table 4. Physical properties of Pedon 2 (P2) — old river terrace.

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Porosity (%)	Moisture content (%)
Ap	0-20	16	56	28	Silty clay loam	1.34	2.65	49.4	19.1
Bt	20-55	12	48	40	Silty clay	1.40	2.66	47.4	20.3
Btk	55-95	10	45	45	Clay	1.46	2.67	45.3	21.0
Bk	95-140	13	46	41	Clay	1.51	2.68	43.7	18.4
Ck	140-170+	15	48	37	Silty clay loam	1.53	2.69	43.1	16.8

Particle-size distribution

Results showed soil texture from silt loam to silty clay loam and clay with a progressive rise in clay with depth, especially in Pedon 2. The clay content increased from 28% in the surface horizon to 45% in the Btk layer, whereas the silt content declined gradually. The sand percentage was comparatively low in all horizons.

This gradation in texture is caused by clay translocation (lessivage) in which fine clay particles are carried by leaching water from the surface horizons to the subsurface horizons where they are deposited and accumulated, forming the argillic horizon (Bt). This textural gradient indicates more advanced pedogenic processes in Pedon 2 compared to Pedon 1, which had a more uniform textural composition as a consequence of the youthfulness of its sediments and the shorter period of soil development.

Bulk density

Results demonstrated an increase in bulk density with depth in both pedons, from 1.32 to 1.50 Mg m^{-3} in Pedon 1, and from 1.34 to 1.53 Mg m^{-3} in Pedon 2.

This pattern is associated to decreased organic matter and root content in the deeper strata, and increasing particle packing and clay and carbonate concentration. Accumulations of calcareous in the lower horizons improve soil consistence and bulk density. The reported values of bulk density are within the typical range for mineral soils in dry and semi-arid situations.

Particle density

The particle density ranged from 2.64 to 2.69 Mg m -3 , with no significant differences between horizons and between pedons, owing to the similarity of the mineral composition of the parent material, since the soils of the alluvial plain are composed mainly of silicate and carbonate minerals, whose particle density is in this range .

The minor rise in particle density with depth may be attributed to the increasing quantity of calcium carbonate and the decreasing content of organic matter, since organic matter is less dense than the mineral ingredients of the soil.

Total porosity

Results showed that total porosity decreased progressively with depth from around 50% in the surface horizon of Pedon 1 to about 44% in the Ck horizon while porosity in Pedon 2 ranged from 49.4 to 43.1%.

The decline is inversely proportional to bulk density as higher particle packing and lower biological activity in the deeper horizons diminish pore volume. Further reduction of total porosity is due to the formation of calcium carbonate in the lower layers, which clogs part of the pore space.

Gravimetric moisture content

The results indicated variation of moisture content between the horizons. Higher moisture values were recorded in the clay rich horizons. The Bt horizon of Pedon 2 recorded the highest value due to its high clay content and increased specific surface area, increasing the soil's ability to retain water.

The lower moisture content of the deeper strata is also associated with increasing calcareous characteristics and bulk density which reduce the quantity of water retained in the pores, besides decreasing root activity in those horizons.

The comparison between the two pedons shows Pedon 2 is characterized by higher clay content, bulk density and moisture in its middle horizons, against lower porosity, compared to Pedon 1, reflecting the influence of the geomorphic age of the older terrace, whose long period of stability allowed more advanced pedogenic processes to occur, chiefly clay translocation and accumulation within the profile. Conversely, Pedon 1 showed more homogenous physical features due to recent deposition and weak horizon development.

Overall, the physical results demonstrate a strong relationship between geomorphological variability and soil properties. The variations between the age of the river terraces and their degree of stability led to a clear variation in particle-size distribution, bulk density, porosity and moisture content, which was reflected in the degree of pedogenic development and soil classification in the study area.

3.3 Chemical Properties of the Study Area

The chemical analyzes of the two pedons showed a clear difference between the genetic horizons and the two study sites, resulting from the influence of the geomorphological variation among the river terraces and the different degree of soil development, in addition to the effect of the arid to semi-arid climate prevailing in the study area, which favors the dominance of calcification and gypsification and the accumulation of soluble salts.

Table 5. Chemical properties of Pedon 1 (P1) — young river terrace.

Horizon	Depth (cm)	pH (1:1)	EC (dS m^{-1})	Organic matter (%)	$CaCO_3$ (%)	Gypsum (%)	CEC (cmol(+)/kg)	ESP (%)	SAR
Ap	0-25	7.62	3.45	1.12	18.4	0.35	19.6	5.4	3.10
Bw1	25-55	7.71	4.18	0.83	20.7	0.48	20.8	6.2	3.65
Bw2	55-90	7.82	5.37	0.56	24.5	0.61	22.4	7.3	4.18

Bk	90-130	7.93	6.82	0.31	29.8	0.84	23.7	8.7	5.22
Ck	130-160+	8.05	7.58	0.18	34.6	1.06	24.1	9.6	5.91

Table 5 – Chemical properties of Pedon 1 (P1) – young river terrace

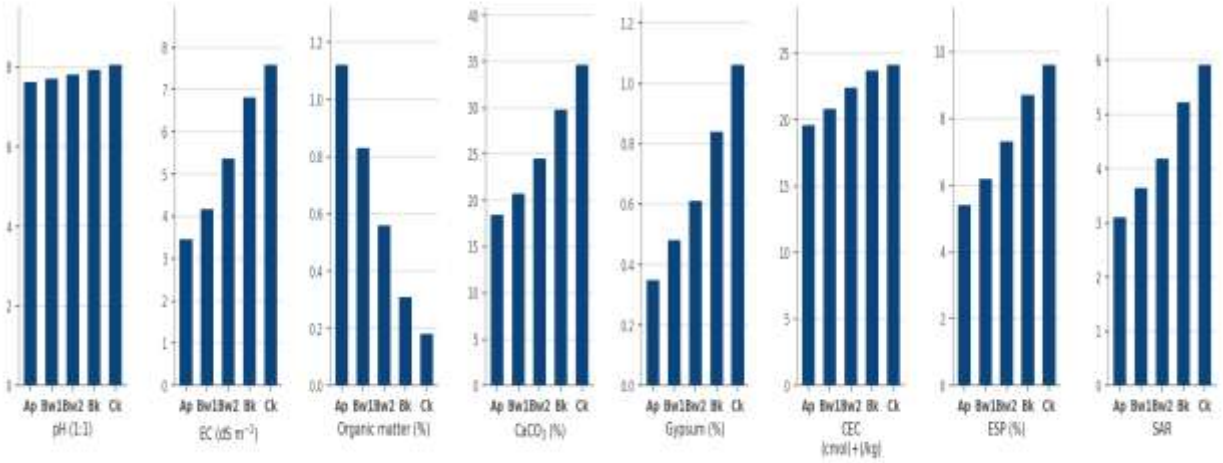

Figure 4. Bar charts of pH, EC, organic matter, $CaCO_3$, gypsum, CEC, ESP and SAR for Pedon P1.

Table 6. Chemical properties of Pedon 2 (P2) — old river terrace.

Horizon	Depth (cm)	pH (1:1)	EC (dS m^{-1})	Organic matter (%)	$CaCO_3$ (%)	Gypsum (%)	CEC (cmol(+)/kg)	ESP (%)	SAR
Ap	0-20	7.58	2.94	1.26	17.6	0.28	22.5	4.8	2.84
Bt	20-55	7.69	3.76	0.88	20.9	0.42	26.8	5.9	3.54
Btk	55-95	7.84	4.93	0.62	27.8	0.73	30.6	7.4	4.47
Bk	95-140	7.98	6.41	0.34	33.5	1.08	28.9	8.8	5.46
Ck	140-170+	8.10	7.13	0.19	37.2	1.34	27.6	9.7	6.12

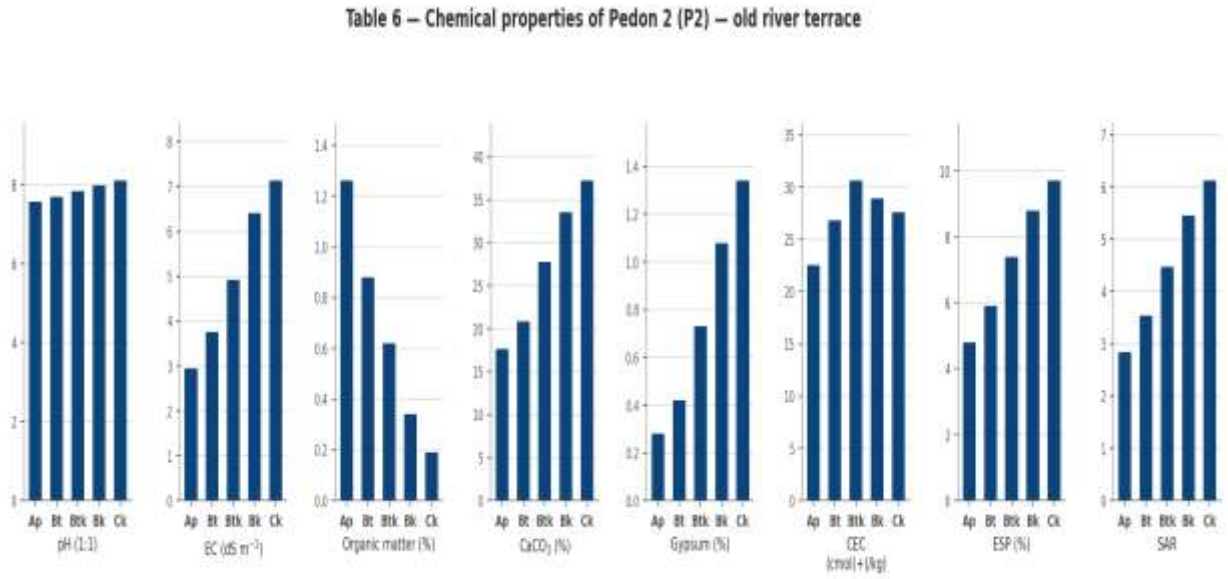

Figure 5. Bar charts of pH, EC, organic matter, $CaCO_3$, gypsum, CEC, ESP and SAR for Pedon P2.

Table 7. Soluble cations and anions in the saturation-extract paste of Pedon 1 (mmolc L^{-1}).

Horizon	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
Ap	15.2	6.8	5.2	0.42	3.8	6.7	17.1
Bw1	17.4	7.3	6.1	0.39	3.5	8.5	19.2
Bw2	19.3	8.1	7.4	0.36	3.2	10.4	21.6
Bk	21.5	9.4	9.1	0.33	2.8	13.7	23.8
Ck	23.4	10.2	10.5	0.31	2.5	15.6	25.9

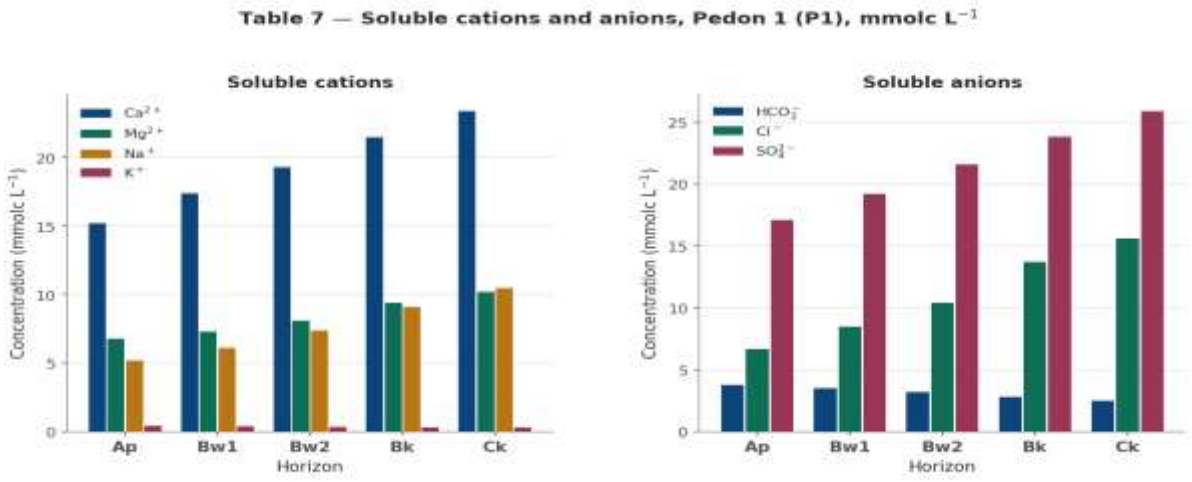

Figure 6. Soluble cations and anions by horizon for Pedon P1.

Table 8. Soluble cations and anions in the saturation-extract paste of Pedon 2 (mmolc L^{-1}).

Horizon	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
Ap	14.7	6.3	4.8	0.40	3.6	5.8	15.8
Bt	16.8	7.5	5.9	0.37	3.3	7.9	18.4
Btk	20.1	8.9	7.8	0.34	3.0	10.6	22.0
Bk	22.6	10.4	9.5	0.31	2.7	13.8	25.4
Ck	24.8	11.6	11.2	0.29	2.4	16.1	28.7

Table 8 — Soluble cations and anions, Pedon 2 (P2), mmolc L^{-1}

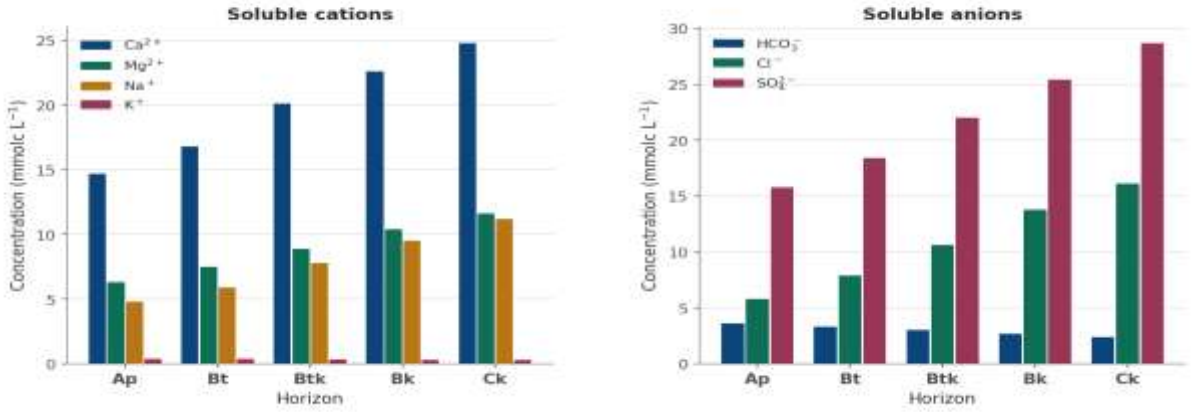

Figure 7. Soluble cations and anions by horizon for Pedon P2.

Soil reaction (pH)

Results indicated that pH values in the research region ranged from 7.58 to 8.10 indicating that the soils of study area are neutral to slightly alkaline. In both pedons, a minor increase in pH with depth was detected and attributed to the increase in calcium carbonate concentration in the lower layers and the decrease in effect of organic matter. Such values are characteristic of soils in arid and semi-arid environments where limited leaching permits the exchangeable bases to be in the profile and to present a moderately alkaline reaction.

Electrical conductivity (EC)

Results indicated gradual increase in EC values with depth and ranged from 2.94 to 7.58 dS m-1 with maximum values seen in the Bk and Ck horizons. This is explained by the accumulation of soluble salts, because of excessive evaporation and weak leaching, and also by the transfer of salts with the leaching water, and their subsequent redeposition in the lower layers. This gradient also reflects the prevailing climatic conditions and the comparatively shallow water table in areas of the alluvial plain.

Organic matter

Organic-matter content dropped steadily with depth in both pedons, with the highest levels in the surface layers, reducing to less than 0.20% in the deep horizons. This is due to the concentration of plant residues and biological activity in the surface layer which decreases with depth. In addition, the high temperatures in the region hasten the

decomposition of organic materials, thereby minimizing its accumulation in the profile.

Calcium carbonate ($CaCO_3$)

Results demonstrated a significant rise in calcium carbonate contents with depth from 17.6% to 37.2%, the greatest values were found in the Bk and Ck layers. This is indicative of the dominance of calcification, one of the most important pedogenic processes in dry conditions. Calcium carbonate is dissolved in leaching water during periods of wetness and then re-precipitated at depth due to greater evaporation and restricted movement of water. This distribution is in agreement with the morphological description with well characterized calcic horizons .

Gypsum

Gypsum concentration gradually rose with depth and was higher in Pedon 2 than Pedon 1. This is because to restricted leaching and rising concentration of sulfate and calcium in the soil solution which causes the precipitation of gypsum in the lower layers. These results are consistent with the characteristics of Iraqi alluvial-plain soils impacted by the arid climate and buildup of secondary salts.

Cation exchange capacity (CEC)

The CEC values ranged from 19.6 to 30.6 cmol(+)/kg with the maximum value in Pedon 2 Btk horizon. This is due to the increased clay content of this horizon (the quantity and kind of clay minerals and organic matter determine the exchange capacity). CEC was increased mostly by increasing clay content . Organic matter decreased with depth showing soil formation on the former river terrace .

Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR)

Results indicated a gradual increase in ESP and SAR values with depth but within limits which do not qualify the soil as sodic as ESP values were not more than the diagnostic threshold of 15%. The increase in these values is due to the accumulation of sodium salts in the lower layers because of restricted leaching. Calcium and magnesium remained the dominating cations and this is due to the structural stability and non-dispersion of clay particles.

Soluble cations and anions

The findings of the saturation-extract analysis revealed that calcium was the major cation followed by magnesium and sodium with potassium recording the lowest concentration. The major anions were sulfate, chloride and bicarbonate.

The high abundance of calcium and sulfate ions indicates the strong influence of gypsum and calcium carbonate deposits on soil formation. This influence explains the gradual increase in the concentration of these ions with depth, as well as the associated increase in the electrical conductivity and salt content in the deeper horizons. The loss of bicarbonate with depth is accompanied by the precipitation of calcium as calcium carbonate in the profile.

Comparison of the two pedons showed Pedon 2 to be greater in clay content, cation exchange capacity, calcium carbonate and gypsum than Pedon 1, indicating a higher degree of pedogenic development due to the prolonged stability of the old river terrace. In contrast, pedon 1 retained characteristics closer to the parent material with comparatively minimal carbonate and salt accumulation indicating recent deposition and limited horizon development.

Overall, the chemical results confirm that the geomorphological variation between river terraces was the main factor controlling the difference in soil properties. The

variation in the age and stability of the terraces resulted in a clear variation in the intensity of the pedogenic processes, especially calcification, gypsification and moderate salinization, which in turn was reflected in the chemical properties and the soil classification of the study area.

3.4 Dominant Pedogenic Processes in the Soils of the Study Area

Interpretation of the pedogenic processes in the research region was based on the geomorphic characteristics of the river terraces, the results of the morphological description and the physical and chemical properties of the two pedons. The variation in the intensity of pedogenic processes was mainly determined by the difference between the age of river terraces and their degree of stability, and these processes were more clearly expressed in Pedon 2 located on the older river terrace than in Pedon 1 located on the young terrace.

Calcification

One of the most important pedogenic processes that affect the soils of the study area is calcification, as evidenced by the progressive increase of calcium carbonate content with depth, from about 18% in the surface horizon to more than 34-37% in the lower horizons, together with the appearance of the diagnostic Bk and Ck horizons, and the calcareous filaments and nodules recorded during the morphological description.

This is due to the dry to semi-arid climatic conditions with high evaporation and limited rainfall, which allow calcium carbonate to dissolve during wet times and then be re-precipitated at deep by capillary rise and evaporation of water. Calcification was more well shown in Pedon 2, which suggests that the lengthy stability of the former river terrace gave adequate time for the accumulation of carbonate inside the profile.

Gypsification

Chemical analyzes demonstrated a gradual increase in gypsum content with depth and an increase in sulfate (SO_4^{2-}) concentration in the saturation extract, confirming the gypsification inside the profile.

This is due to the precipitation of calcium sulfate in the lower layers due to restricted leaching and excessive evaporation. It is widespread in soils of arid locations. This process was more advanced in Pedon 2 than in Pedon 1, suggesting that the soil had been exposed to pedogenic processes for a longer time.

Salinization

Electrical conductivity rose progressively with depth in both pedons. Chloride, sulfate and sodium increased in the lower horizons showing considerable salinization within the profile.

This is due to excessive evaporation and weak leaching as well as the capillary rise of ground water which carries soluble salts and precipitates after the water evaporates. However, the values of ESP and SAR were lower than the diagnostic level of sodic soils, which means that the sodification was less severe than the salinization. .

Clay translocation (lessivage)

One of the most essential processes to distinguish Pedon 2 was clay translocation. A clearly expressed Bt horizon evolved with clay content increased from 28 % in the surface horizon to 45 % in the Btk horizon with the formation of subangular blocky structure in these horizons.

The results show that fine clay particles are translocated together with leaching water

from upper to lower strata, where they concentrate to produce the diagnostic argillic horizon. The expression of this mechanism indicates advanced pedogenic growth and long-term geomorphic surface stability.

In contrast, pedon 1 did not show any clear indications of clay translocation, its development being restricted to the presence of a cambic horizon (Bw), indicating the recency of deposition and brief period of soil formation.

Organic-matter decomposition (humification and mineralization)

The results indicated a steady decline in organic-matter content with depth in both pedons, with the highest values concentrated in the surface horizons as a consequence of the accumulation of plant wastes and root growth, falling sharply in the lower horizons.

This is due to decreasing biological activity with depth and the high temperatures, which increase the decomposition of organic matter and its conversion into mineral compounds, a phenomena prevalent in dry environments .

Structural development and horizon evolution

Morphological characterization demonstrated progression of structure from granular in surface strata to blocky in subsurface horizons. Occurrence of Bw, Bt, Bk and Ck horizons indicates the effect of weathering processes and redistribution of soil contents.

The long period of geomorphic stability led to a more evident expression of horizon development in Pedon 2, whereas Pedon 1 preserved features more similar to parent material, indicating weaker pedogenic development.

3.5 Relationship between Pedogenic Processes and Geomorphological Variation

The results of the study suggest that the main reason for the difference in intensity of pedogenic processes was the geomorphological diversity of the river terraces. The young river terrace (Pedon 1) was poorly developed with only initial development of a cambic horizon and simple carbonate accumulation. The old river terrace (Pedon 2) was more developed with the presence of the argillic horizon (Bt) and calcic horizon (Bk), and increasing accumulation of calcium carbonate and gypsum and increasing cation exchange capacity due to higher clay content ..

On this basis, the dominant pedogenic processes in the study area can be ranked in order of importance as follows:

1. Calcification.
2. Clay translocation (lessivage) — clearly expressed in Pedon 2.
3. Gypsification.
4. Salinization.
5. Organic-matter decomposition (humification and mineralization).

These results confirm that the difference in age of the river terraces and their degree of stability produced a clear difference in the intensity of pedogenic processes, which was directly reflected in the development of the genetic horizons and the physical and chemical properties, and in the soil classification of the study area.

3.6 Classification of the Soils of the Study Area under the USDA Soil Taxonomy [22]

The classification of the soils of the study region was based on the morphological, physical and chemical features and the

pedogenic processes diagnosed in the two pedons according to the current classification keys of the USDA Soil Taxonomy [22] .

The results showed that the Pedon 1 is characterized by a cambic horizon (Bw) and a calcic horizon (Bk) without the development of a diagnostic argillic horizon, indicating restricted pedogenic growth due to its location on a relatively young river terrace. The soil was categorized in the order Aridisols, suborder Cambids, great group Haplocambids, subgroup Typic Haplocambids.

Pedon 2, in contrast, showed more pedogenic development as evidenced by the presence of the argillic horizon (Bt) as a consequence of clay translocation and accumulation, and the calcic horizon (Bk) indicating the long stability of the old river terrace and the continuous action of pedogenic processes, especially clay translocation and calcification. This soil was categorized in the order Aridisols, suborder Argids, great group Haplargids, subgroup Typic Haplargids.

The classification results confirm that the geomorphological variation between the river terraces was the main factor controlling the degree of soil development. The intensity of pedogenic processes increased with increasing age and stability of the river terrace, which was reflected in the development of diagnostic horizons and the different taxonomic placement of the soils .

Table 9. Taxonomic classification of the soils of the study area.

Pedon	Order	Suborder	Great group	Subgroup
P1	Aridisols	Cambids	Haplocambids	Typic Haplocambids
P2	Aridisols	Argids	Haplargids	Typic Haplargids

4. Conclusions

On the basis of the field and laboratory results obtained for the river terrace soils of Al-Khalidiyah Subdistrict, Al-Habbaniyah District, the following conclusions can be drawn:

6. Geomorphological variation among the river terraces exerted a clear influence on soil properties and degree of pedogenic development, with differences in terrace age and stability reflected in the differentiation of genetic horizons and in physical and chemical properties.
7. Pedon 1, located on the young river terrace, was characterised by weak pedogenic development, its profile being limited to a cambic horizon (Bw) with the initial accumulation of calcium carbonate in the Bk horizon, indicating the recency of the parent material and the short duration of soil formation.
8. Pedon 2, located on the old river terrace, showed a higher degree of pedogenic development, represented by the presence of an argillic horizon (Bt) and a calcic horizon (Bk), indicating longer land-surface stability and more effective pedogenic processes.
9. The soils of the study area were characterised by the dominance of silt loam, silty clay loam and clay textures, with increasing clay content in the subsurface horizons of Pedon 2 as a result of the translocation of clay particles within the profile.

10. Bulk density increased with depth, while total porosity decreased, related to decreasing organic matter, increasing clay content, and calcium carbonate accumulation in the lower horizons.
11. pH values fell within the neutral to slightly alkaline range, reflecting the dominance of exchangeable bases and the elevated calcium carbonate content of the area's soils.
12. Electrical-conductivity results showed a progressive increase with depth, indicating the accumulation of soluble salts in the lower horizons as a result of limited leaching and high evaporation.
13. Organic-matter content decreased progressively with depth in both pedons, as a result of the concentration of biological activity and roots in the surface horizons, in addition to the rapid decomposition of organic matter under arid climatic conditions.
14. Calcium carbonate and gypsum content increased with depth, confirming the dominance of calcification and gypsification, two of the most important pedogenic processes affecting the soils of the study area.
15. Classification of the soils under the USDA Soil Taxonomy [22] showed that the soils of the study area belong to the order Aridisols, with differing lower categories reflecting the degree of pedogenic development and the diagnostic properties of each pedon.

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