



Research article

A Comparative Soil Survey of B Horizons Thickness and Soil Development across Toposequences: A Case Study of Soil Management in Erbil Province

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ABSTRACT

This study investigated the extent to which topography influence B horizons thickness and pedogenic development across three distinct toposequences in Erbil province, Iraq. The studied sites were Gomaspan, Zewe, and Sakran as three different locations inside the Erbil province. In each location, three positions of Summit, Backslope, and Toeslope have been selected to take the parameters related to B horizons. The research aimed to investigate how topography and elevation affected the B horizons. Statistical results demonstrated that both factors of location (which are represented by elevation) ($p=0.019$) and topographic position ($p<0.001$) are significant determinants of soil maturity. In the Sakran site the B horizons thickness were 25.4 cm at the Summit position to maximum of 58.3 cm at the Toeslope position. Gomaspan ranged from 22.3 cm to 49.2 cm. While, the lowest elevation of the location of Zewe showed the B horizon ranged from 20.1 cm to 51.7 cm. A clear pattern of the translocation of clay particles from the upper slope positions making thicker and more mature B horizons. This research clarifies the dominant role of topography in mountainous pedogenesis. Providing essential data for soil classification, better land use, and environmental management. The results emphasize that in semi-arid regions slope position and elevation variability act as the essential controls on the soil horizon development. To utilize the result of this research in a wider scale it should be re-make it for the entire region and the aim will be best agricultural practical for better land use.

1. Introduction

Topography is one of the important factors controlling soil formation which affects soil water movement, erosion rates, deposition, and the distribution of soil materials along slopes. The sequence of soils that develop from the different slope positions known as a toposequence provides a naturally developed sites to study how variations in relief affect pedogenic processes (Jenny, 1941). The study of toposequences helps pedologists understand the spatial variability of soils across different slope positions and their relationship to landscape evolution, hydrology, and land use suitability (Birkeland, 1992).

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In a typical toposequence, soil development and profile differentiation often follow a recognizable pattern along the slope. The Summit positions are usually well drained and subject to erosion that result shallower profiles with minor horizon differentiation. Conversely, the Toeslopes usually receives more water and sediment from upslope areas where the accumulation of clay, organic matter, and carbonates becomes more and therefore the formation of thicker and more developed B horizons will happen (Buol et al., 2011). The position of Backslope in a toposequences represents almost a center position where both process of erosion and deposition are equal. These variations are primarily due to differences in water holding capacity, drainage rates, and material transport amount which directly influence pedogenesis process quality and quantity (Brubaker et al., 1993) (Daniels and Hammer, 1992).

Usually, the B horizons represent a depth of accumulations that called the Illuviation phenomenon. This phenomenon can be considered as a diagnostic horizon that helps in soil classification in different systems such as the USDA Soil Taxonomy and the World Reference Base (WRB). It represents the accumulation of materials such as silicate clays, iron and aluminum oxides, humus, and carbonates which are translocated from overlying horizons that called the Elluviation phenomenon (Soil Survey Staff, 2014). The B horizons thickness and properties can be taken as a significant indicators of soil development and characteristic of pedogenic processes (Schaetzl and Anderson, 2005). Measuring and comparing the thickness of this horizon in the toposequences positions give important insights about the interaction between slope and topography and their effects on the soil formation.

Erbil Province specifically the north part usually considered as mountainous area comprised of the Zagros fold-thrust belt. This area contains various topographic conditions and different parent materials that helps to form a different type of soils under different conditions (Sissakian et al., 2025). There are a bunch of studies related to the effect of topography in the soil formation process in Iraq but still required more. Some of them have focused on studying of different criteria related to soil genesis and classification in various areas (Fayyadh and Ismail, 2021) (Razvanchy and Fayyadh, 2023). While the others have trying to study the morphological and chemical characteristic of the B horizons (Khaled and Yusof, 2022). Also, the relation between soil and landscape are significantly affected by the complex tectonic evolution of the Zagros basins (Forti et al., 2023), additionally influenced by the distinct climate changes from the plains to the high mountains (Khwarahm, 2021). Nevertheless, finding the relationship among soil development assessment during thickness of the B horizons, toposequences, and slope position still very limited. Having an enough knowledge about this relationship has a great scientific value. Besides, it has a practical value as a guideline to be used for many purposes such as land evaluation, agricultural planning, and soil conservation. This will be more valuable in areas where topography has a significant effect on water availability and erosion.

The study aims to address this knowledge gap by conducting a comparative survey and analysis of three toposequences located in the northern part of Erbil Province. The study focus on clarifying the extent to which topography drives variations in soil development across the landscape. The results will contribute to a more comprehensive understanding of the pedogenic dynamics of soils in semi-arid mountain environments and support future soil mapping and sustainable land-use strategies in the Kurdistan Region.

2. Materials and Methods

2.1 Overview of the Study Area

The studied sites are located in the middle and northern part of Erbil Province in the Kurdistan Region of Iraq. The study area has a different topography and a semi-arid climate condition. Also, the soil-forming factors and processes affected by relief and parent material variability (Razvanchy and

Fayyadh, 2022). The Erbil province located in an extent of latitude $35^{\circ} 26' 10.14''$ to $37^{\circ} 19' 11.61''$ N and from longitude $43^{\circ} 22' 27.53''$ to $45^{\circ} 04' 48.43''$ E (Figure 1). The Erbil province has a very diverse topography starts around 400 to over 3000 meters of elevation (Gaznayee et al., 2022). Because of these differences in the topography it is ideal for studying toposequences. The study area experiences an average annual rainfall ranging from 400 mm and up to 900 mm which concentrated between November and April. About the average annual temperature there are ranging between 15 to 20 from as show in Table 1. The soils of the study area were formed from parent materials that were derived from Limestone, Sandstone, Mudstone, and Marl. However, Limestone is the major bedrock from which the parent material was derived therefore the soils tend to be calcareous (Table 2) (Sissakian, 2013).

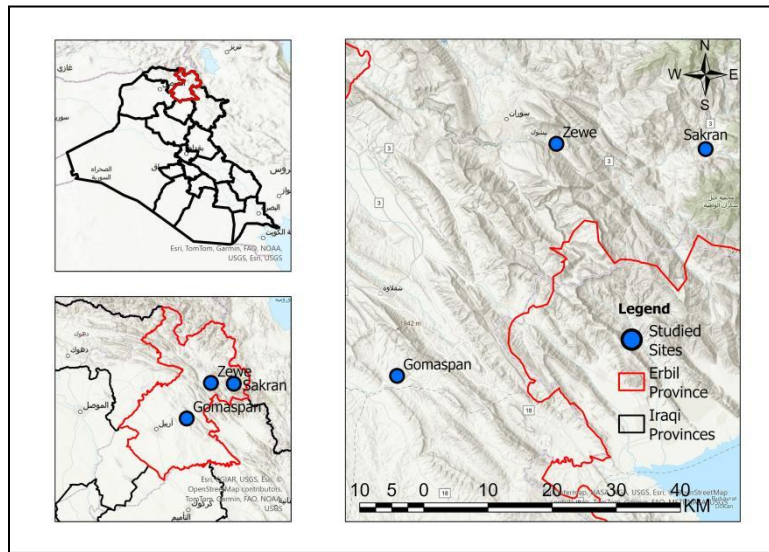


Figure (1). The locations of the studied sites

Table (1). The average annual precipitation and temperature of the study sites

Year	Parameter	Gomaspan	Zewe	Sakran
2020	Precipitation (mm)	567.2	610.5	812.4
	Temperature (°C)	17.8	19.2	15.9
2021	Precipitation (mm)	266.4	295.2	388.5
	Temperature (°C)	19.1	20.5	17.2
2022	Precipitation (mm)	410.5	450.8	595.3
	Temperature (°C)	17.6	19.0	15.7
2023	Precipitation (mm)	543.9	693.4	890.6
	Temperature (°C)	17.1	18.5	15.2

2024	Precipitation (mm)	620.8	740.2	945.1
	Temperature (°C)	17.4	18.8	15.5
Avg.	Precipitation (mm)	481.8	558.0	726.4
	Temperature (°C)	17.8	19.2	15.9

Table (2). The parent materials and geological formation (Sissakian, 2013)

Location	Parent Material	Common Formations	Geological
Gomaspan	Limestone & Marly Limestone	Derived from the Pila Spi and Gercus formations; characterized by well-bedded limestone and red clastics.	
Zewe	Calcareous Alluvium & Mudstone	Derived from the Injana (Upper Fars) and Mukdadiyah formations; consists of siltstone, sandstone, and claystone.	
Sakran	Hard Limestone & Dolomite	Derived from the Qamchuqa or Aqra-Bekhme formations; massive carbonate rocks that are highly resistant to weathering.	

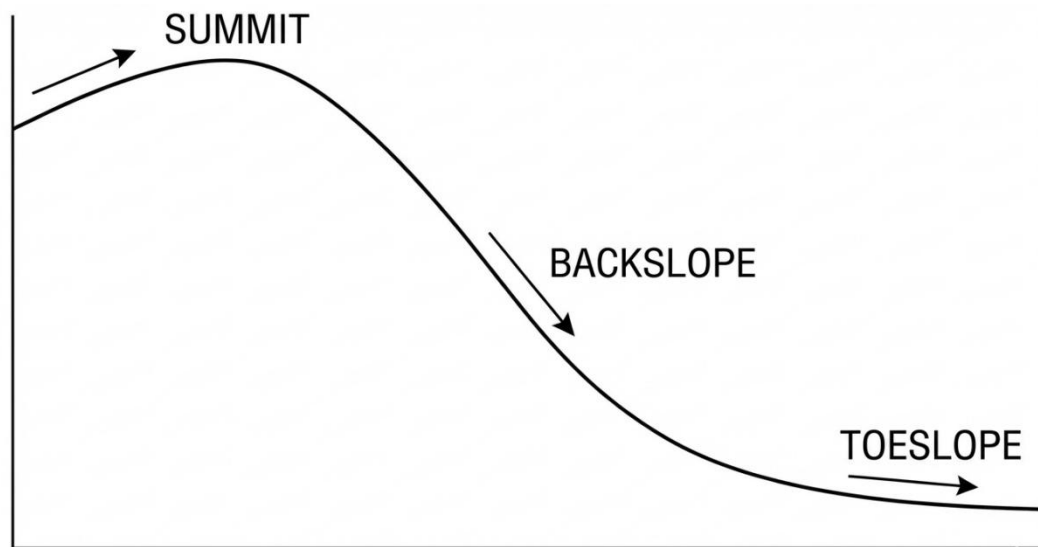
2.2 Field Works

Three representative locations were selected based on their geomorphological contrast, accessibility, and presence of distinct slope gradients with observable soil profile development. The selection have been performed based on intense office works. Each location includes a complete toposequence composed of Summit, Backslope, and Toeslope positions, ensuring a full representation of relief-driven soil variation. The locations are mentioned in Table 3 and Figure 1. At each of the three locations, one complete toposequence has been delineated consisting of three slope positions. Summit which is the upper convex part of the slope. Backslope which is the middle section. Toeslope which is the lower concave part as shown in Figure (2). In this study soil pits have been dug for each position in a depth of the presence of the B horizons and the horizon beneath (around 1 meter or Solum depth). As well as the roadcut soil profile and soil exposure have been utilized around the locations for assurance of the work. This roadcuts used as a ready soil profile after peeling off the outer crust. The thickness of the B horizon measured in situ using a measuring tape, and detailed field descriptions (color, texture, structure, root density, and horizon boundaries) have been recorded according Soil Survey Staff, 2017. From each identified B horizon a composite soil samples (about 5 kg) collected for laboratory analysis. The entire field works conducted in October and November of 2025.

Table (3). The study sites

Location names	Elevation (Masl)	Latitude (Degree)	Longitude (Degree)	Land Cover
Gomaspan	908.9	36.2933426	44.354274	Shrubs
Zewe	696.8	36.6211127	44.629226	Shrubs
Sakran	1,183.5	36.6143144	44.8896657	Shrubs/Rocks

Masl: meters above sea level

**Figure (2).** The three positions of the toposequence used in this study

2.3 Laboratory Analysis

The collected soil samples air-dried, gently crushed, and sieved (2 mm). The following analysis have been conducted for all soil samples; particle size distribution by the hydrometer method (Gee and Bauder, 1986), soil pH and electrical conductivity (EC) in a 1:2.5 soil-water suspension (Rhoades, 1996), organic matter (OM) using the Walkley Black method (Nelson and Sommers, 1996), calcium carbonate equivalent ($\text{CaCO}_3\%$) determined by calcimeter method (Allison and Moodie, 1965), cation exchange capacity (CEC) measured with ammonium acetate extraction at pH 7.

2.4 Data Analysis

All data were statistically analyzed to determine the effect of topography and location on soil development. The impact of slope position on B horizon thickness was initially assessed for each location (Gomaspan, Zewe, and Sakran) using a one-way Analysis of Variance (ANOVA). To evaluate the broader landscape dynamics, a two-way ANOVA was employed to examine the main effects of slope position (Summit, Backslope, and Toeslope), geographical location, and their interaction on soil morphological and chemical properties. Significant differences between means were identified using

Duncan's Multiple Range Test (DMRT) test at a significance level of $p < 0.05$. Furthermore, the interrelationships between B horizon thickness and physical/chemical parameters (clay content, CEC, OM, and CaCO_3) were quantified using Pearson correlation analysis (r). All statistical procedures were performed using SPSS v.26.

3. Results and Discussion

3.1 Morphological properties of the B Horizons

Clear differences in B horizon expression were observed among slope positions within each of the three studied toposequences. In the location of Gomaspan the B horizon thickness increased downslope which ranging from a mean of 22.3 cm at the Summit to 34.7 cm at the Backslope and 49.2 cm at the Toeslope. A similar pattern has been found in the location of Zewe. Which the thickness values were 20.1 cm, 35.8 cm, and 51.7 cm at the Summit, Backslope, and Toeslope, respectively. The Sakran toposequence showed the most significant horizon development. Which the B horizons were 25.4 cm at the Summit, 36.0 cm at the Backslope, and 58.3 cm at the Toeslope. In the all three locations, the Toeslope positions have the thickest B horizons. While the Summit positions showed limited horizonation and weaker structural development (Figure 3).

The morphological characteristics have been described in detail in the Table 4. The systematic increase in B horizon thickness from a minimum of 20.1 cm at the Zewe summit to a maximum of 58.3 cm at the Sakran Toeslope is caused by the transition or movement from areas of high erosion rate to more deposition and decreased movement. The summits with high runoff rate and sediment loss result in shallower profiles (Jenny, 1941). These profiles have abrupt boundaries and coarser textures as there is insufficient residence time for significant clay translocation. While in the Toeslope positions with darker colors, finer textures, and angular blocky structures (Birkeland, 1999). These is due to the accumulation of fine particles transported from upslopes which is key indicator of a well-developed of illuviation (Buol et al., 2011) (Soil Survey Staff, 2017). The thickness of the B horizons at the Toeslope match with findings of Mehnatkesh et al., 2013. The changes from weak structure at the Summits to strong at the Toeslopes is directly related to the higher clay and calcium carbonate content which act as binding agents for formation (Khaled and Yusof, 2022). Moreover, the transition to gradual horizon boundaries and higher root densities in the lower landscape positions indicates greater pedogenic maturity in this position and this can be taken as indicator for fertile soils. This occurs because in the Toeslopes there will be more moisture retention and nutrient accumulation. It will cause raising in biological activity and diffuse transition between the B and underlying horizons compared to the sharp horizons that found at higher elevations (Daniels and Hammer, 1992) (Schaetzl and Anderson, 2005).

Table (4). The morphological properties of the studied locations

Location	Position	Horizon	Depth (cm)	Color (Moist)	Texture	Structure (Grade, Size, Type)	Consistency	Boundary	B-Horizon Thickness (cm)
Gomaspan	S	A	0 - 15	10YR 4/2	Silty Clay Loam	Weak, fine, granular	Friable	Abrupt smooth	22.3
		Bw	15 - 37.3	10YR 5/3	Silty Clay	Weak, fine, subangular blocky	Firm	Clear wavy	
		Cr	37.3 +	10YR 7/2	Weathered Rock	-	Very hard	-	

BS	A	0 - 22	10YR 3/2	Silty Clay	Moderate, fine, granular	Friable	Clear smooth	34.7
	Bw	22 - 56.7	10YR 4/3	Clay	Moderate, medium, subangular blocky	Firm	Clear smooth	
	C	57 +	10YR 5/4	Silty Clay	Massive	Hard	-	
TS	A	0 - 28	10YR 3/1	Clay	Strong, medium, granular	Friable	Clear smooth	49.2
	Bw	28 - 77.2	10YR 4/2	Clay	Strong, medium, subangular blocky	Very firm	Gradual wavy	
	C	77.2 +	10YR 5/2	Clay	Massive	Hard	-	
S	A	0 - 15	10YR 4/3	Silty Clay	Weak, fine, granular	Friable	Clear smooth	20.1
	Bw	15 - 35.1	10YR 5/4	Clay Loam	Weak, medium, subangular blocky	Firm	Gradual wavy	
	C	35.1 +	10YR 6/4	Loamy	Massive	Hard	-	
Zewe BS	A	0 - 20	10YR 3/3	Clay Loam	Moderate, fine, granular	Friable	Clear smooth	35.8
	Bw	20 - 55.8	10YR 4/4	Clay	Moderate, medium, subangular blocky	Firm	Clear wavy	
	C	55.8 +	10YR 5/4	Clay Loam	Massive	Very hard	-	
TS	A	0 - 25	10YR 3/2	Clay	Moderate, medium, granular	Friable	Clear smooth	51.7
	Bw/Bt	25 - 76.7	10YR 4/3	Heavy Clay	Strong, coarse, subangular blocky	Extremely firm	Gradual smooth	
	C	76.7 +	10YR 5/3	Clay	Massive	Hard	-	
S	A	0 - 20	7.5YR 3/2	Silty Clay	Moderate, fine, granular	Friable	Clear smooth	25.4
	Bw	20 - 45.4	7.5YR 4/4	Clay	Moderate, medium, subangular blocky	Firm	Clear wavy	
	C	45.4 +	7.5YR 5/6	Clay Loam	Massive	Hard	-	
Sakran BS	A	0 - 24	7.5YR 3/2	Clay	Moderate, medium, granular	Friable	Clear smooth	36.0
	Bw	24 - 60	7.5YR 4/3	Heavy Clay	Strong, medium, subangular blocky	Very firm	Clear smooth	
	C	60 +	7.5YR 5/4	Clay	Massive	Very hard	-	
TS	A	0 - 30	7.5YR 2/2	Clay	Strong, medium, granular	Very friable	Clear smooth	58.3
	Bt	30 - 88.3	5YR 3/4	Heavy Clay	Strong, coarse, angular blocky	Extremely firm	Gradual smooth	
	BC	88.3 +	7.5YR 4/4	Clay	Massive	Hard	-	

S= Summit, BS=Backslope, TS=Toeslope

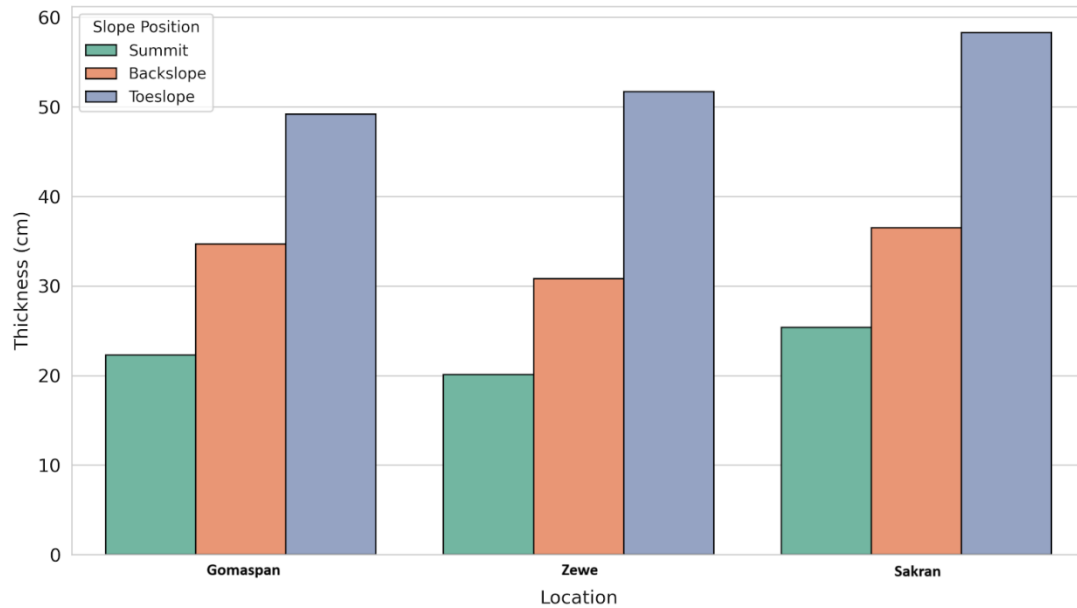


Figure (3). The B horizon thickness across the toposequences

3.2 Physical Properties of the B Horizons

In all locations the Summit positions were dominated by sandy loam textures whereas the Backslope positions tend from loam to sandy clay loam textures. Toeslope positions contained the highest clay contents which is over 40% in Sakran and 38 to 42% in Zewe and Gomaspan (Table 5). The highest clay percentage was found in the Toeslopes of Sakran (41.7%). While the Summits of Zewe displayed the least developed textures with clay contents around 20%. The inverse relationship between bulk density and B horizon development is primarily controlled by physical and morphological changes along the toposequence (Figure 4). At the Summits the higher bulk density (1.53 g cm⁻³) is a result of coarser sandy loam textures and weak structural development whereas a lack of aggregates leads to a more compact soil matrix (Jenny, 1941). As the location of soil profile moves toward the Toeslopes the increase in clay content and the accumulation of organic matter facilitate the development of strong angular blocky structures.

Table (5). The physical properties of the studied locations

Location	Position	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk Density (g cm ⁻³)
Gomaspan	Summit	46.8	31.0	22.2	Loam	1.53
	Backslope	40.9	28.7	30.4	Clay loam	1.46
	Toeslope	35.1	24.7	40.2	Clay	1.39
Zewe	Summit	49.2	30.4	20.4	Loam	1.54
	Backslope	42.6	27.3	30.1	Clay loam	1.47

	Toeslope	34.8	24.0	41.2	Clay	1.40
	Summit	44.5	30.8	24.7	Loam	1.51
Sakran	Backslope	39.4	26.7	33.9	Clay loam	1.45
	Toeslope	33.6	24.7	41.7	Clay	1.38

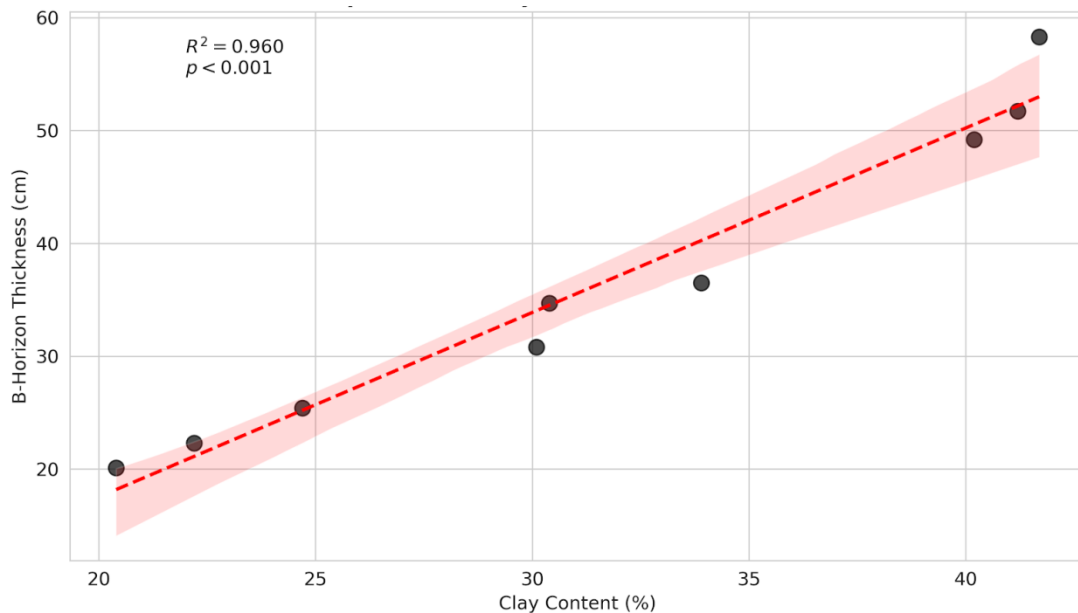


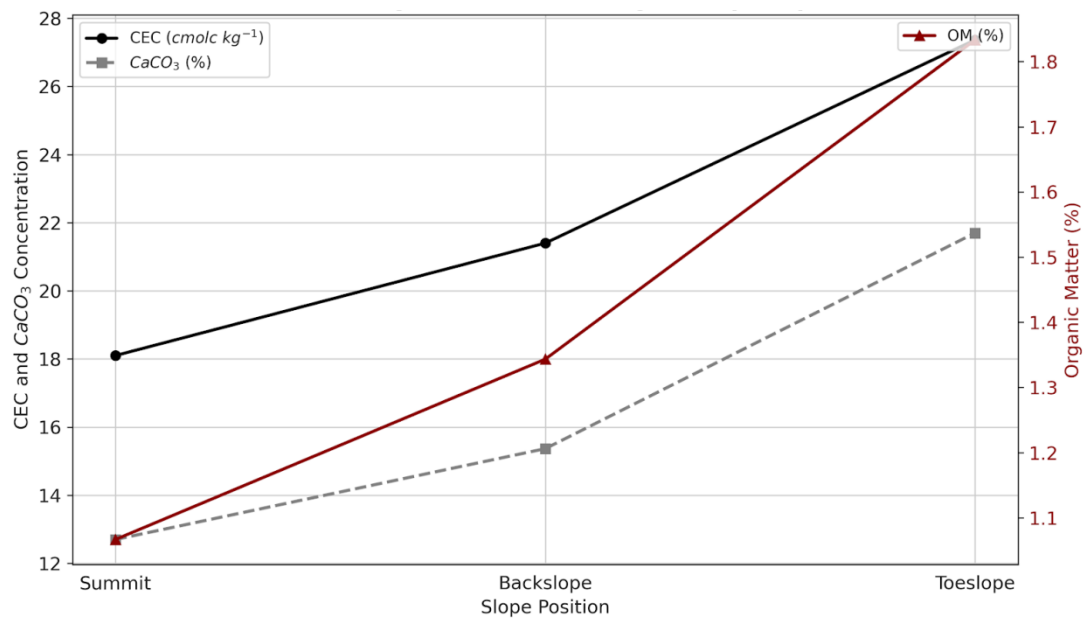
Figure (4). The B horizon thickness and clay content

3.3 Chemical Properties of the B Horizons

The increase in pedogenic development downslope is driven by the redistribution of water, sediments, and solutes, creating a distinct chemical gradient across the toposequence (Table 6 and Figure 5). The rise in pH values (7.5 to 7.9) and calcium carbonate content (11% to 23%) in Toeslope positions is by the lateral translocation of carbonates from well-drained Summits and their subsequent precipitation in lower landscape positions where drainage is restricted and evaporation is higher (Gunal and Ransom, 2006). Similarly, organic matter increases in Toeslopes (up to 2.0%) due to higher biomass production supported by moisture run on and the physical deposition of organic rich eroded sediments from upslope (Birkeland, 1999) (Boul et al., 2011). The slightly higher electrical conductivity in these lower positions is a result of the accumulation of soluble ions leached from the Summits (Rhoades, 1996) (Schaetzl and Anderson, 2005). While the strong correlation between cation exchange capacity (CEC) and B horizon thickness peaking at $28.4 \text{ cmolc kg}^{-1}$ in Sakran reflects the increased surface area provided by higher clay and organic matter concentrations (Nelson and Sommers, 1996) (Fayyadh and Ismail, 2021).

Table (6). Chemical properties of B horizons across the three sites

Location	Position	pH	EC (dS/m)	OM (%)	CEC (cmolc kg ⁻¹)	CaCO ₃ (%)
Gomaspan	Summit	7.5	0.38	1.08	18.2	12.7
	Backslope	7.6	0.41	1.31	20.9	15.3
	Toeslope	7.8	0.54	1.75	26.8	20.8
Zewe	Summit	7.5	0.37	0.97	17.5	11.9
	Backslope	7.6	0.39	1.29	21.2	14.7
	Toeslope	7.8	0.53	1.82	26.9	21.9
Sakran	Summit	7.6	0.40	1.15	18.6	13.5
	Backslope	7.7	0.44	1.43	22.1	16.1
	Toeslope	7.9	0.56	1.93	28.4	22.4

**Figure (5).** The chemical properties of the B horizons in the toposequences

3.4 Statistical Analysis

The statistical evaluation confirmed that topographic relief is the primary driver of soil profile differentiation in the study area. The results have been separated into the influence of slope position, the interaction between different geographical locations, and the relationship between physical and chemical soil properties.

3.5 One Way ANOVA: Impact of Slope Position per Location

The results of one way ANOVA table for each location as shown in Table 7 reveals that topographic has a statistical significant on B horizon thickness within all locations. With F-values ranging from 28.6 to 34.3 and p-values consistently below 0.001. The data present that the differences in soil development among all positions are not random but are related to the slope position. This result ensure that the catena concept, where the erosion dominates at the Summit and deposition dominates at the Toeslope is active and noticeable at each site (Brubaker et al., 1993).

Table (7). One way ANOVA table

Location	Source of Variation	df	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Gomaspan	Slope Position	2	385.4	193.0	28.6	< 0.001***
	Error (Within)	6	40.5	6.76		
Zewe	Slope Position	2	524.1	262.1	31.4	< 0.001***
	Error (Within)	6	50.0	8.3		
Sakran	Slope Position	2	536.9	268.4	34.3	< 0.001***
	Error (Within)	6	47.0	7.8		

***Significant at $p < 0.001$

3.6 Two Way ANOVA: Factorial Analysis (Location and Position)

The results of the two way ANOVA table shown in the Table 8. It shows that the slope position is the dominant factor ($F = 106.5$, $p < 0.001$) controlling soil thickness among the other factors. While the location plays a secondary role ($F = 21.6$, $p < 0.001$). The importance of the location factor is considered to the Sakran site where higher elevations of 1,183.5 meters and deeper pedogenesis development compared to the other areas (Fayyadh and Ismail, 2021). The significant relationship between position and location ($F=6.80, p=0.0016$) indicates that the pattern of B horizon thickening downslope occurs at the same relative rate in the all locations. This variation happened by the Sakran and Zewe sites which have thicker B horizon compared to Gomaspan. The both locations of Sakran and Zewe are located in a mountainous area that receives higher annual precipitation and expected lower evapotranspiration rates compared to the Gomaspan. The increased moisture availability in these two sites accelerates chemical weathering and the leaching which leading to a more rapid thickening relatively of the sub-surface horizons (Lin et al., 2024). In these high mountain environments the lower temperatures retard the decomposition of organic matter which in turn

produces more organic acids that helps the downward transportation of clay and iron resulting in more B horizon thickness (Schaetzl and Anderson, 2005).

Table (8). Two way ANOVA table

Source of Variation	df	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value	Significance
Slope Position (A)	2	4,190.2	2,095.1	106.5	<0.001	*** (Highly Sig.)
Location (B)	2	85.2	42.6	21.6	<0.001	*** (Highly Sig.)
Interaction (A × B)	4	53.6	13.4	6.8	0.0016	** (Significant)
Error (Residual)	18	35.4	2.0			
Total	26	4,364.3				

Significant at $p < 0.01$, *Significant at $p < 0.001$

3.7 Correlation Analysis of Soil Properties

A Pearson Correlation matrix (r) (Table 9) was calculated to determine the relationships between the physical and chemical properties within the B horizons in all locations. This analysis shows how strongly soil development (thickness of B horizons) is related to the accumulation of minerals and organic matter. The statistical correlations revealed the very strong positive correlation between B horizon thickness and clay content with $r = 0.83$. This confirms that translocation of fine particles is the primary driver of horizon thickness in these toposequences. This development is concluded by the accumulation of carbonates ($r = 0.73$). This is focuses the process of calcification as a secondary but significant horizon formation process in semi-arid environments (Khaled and Yusof, 2022). Moreover, there is a strong negative relationship between thickness and bulk density ($r = -0.71$). It is indicated that the morphological changes from the compact massive structures at the Summits to more porous angular blocky structures at the Toeslopes (Brubaker et al., 1993) (Soil Survey Staff, 2017). Finally, the high correlation between CEC and clay ($r = 0.88$) demonstrates that the nutrient holding capacity of these soils is linked to the topographic distribution of fine materials reaching its maximum potential in the mature profiles of the lower slopes (Fayyadh and Ismail, 2021).

Table (9). Pearson Correlation matrix (r)

Variables	B Thickness	Clay %	OM %	CEC	CaCO ₃ %	Bulk Density
B Thickness	1.00					
Clay %	0.83**	1.00				
OM %	0.76**	0.81**	1.00			
CEC	0.79**	0.88**	0.84**	1.00		
CaCO ₃ %	0.73**	0.68**	0.71**	0.65**	1.00	
Bulk Density	-0.71**	-0.78**	-0.82**	-0.75**	-0.62**	1.00

*Significant at $p < 0.05$, **Significant at $p < 0.01$

The results in the all aspects showed that the topography has a significant role in controlling soil development in the study area. All three toposequences as rigid evidence revealed a strong pattern in which B horizons became higher thickness and high clay content from the position of Summit the position of Toeslope. This exactly reflecting how the topography will affect as a soil forming factor, aslo, its impact of soil development throughout soil forming processes. These weaknesses in the B horizons across all locations in the Summit positions showed the great impact of soil erosion and lack of clay translocation. In contrast, the Toeslope positions in all three locations serve as depositional environments where clay particles, organic matter, and carbonates accumulate. This leads to the formation of thicker B horizons exhibiting blocky structure, visible clay skins, higher CEC, and greater carbonate concentrations. The results in this research are parallel with general idea of the catena which described by Jenny, (1941). Also, the results will be supported by findings of the followed researches (Birkeland, 1999) (Schaetzl and Anderson, 2005) (Adhikari and Hartemink, 2016). In the location of Sakran this relationship has been seen clearly. This is because of its elevation which affects directly on the temperature and leads to soil moisture retention and enhance chemical weathering at the end. The valley setting of Zewe created a similar pattern but with higher variability due to localized colluvial processes. The locstion of Gomaspan with its steeper slopes and Limestone-Marl parent material, showed more pronounced carbonate accumulation but slightly thinner B horizons (Bellat et al., 2026). The powerful correlations between the thickness of B horizons and the other variables focused the pedogenic connection between material that translocated and the position on the toposequences. This is supports the previous researches in this area that emphasizes the role of parent material and topography in soil differentiation (Fayyadh and Ismail, 2021) (Khaled and Yusof, 2022) (Razvanchy and Fayyadh, 2023).

4. Conclusion

This study provides clear evidence that slope position have a dominant influence on B horizon development in three representative toposequences of northern Erbil. In all locations the Toeslope positions are the thickest and most pedogenic developed B horizons while the Summits showed the weakest development. The increase in clay percent, CEC, organic matter, and carbonate downslope reflects the strong interaction between erosion, deposition, and moisture distribution in the study area. The similarity of patterns across Gomaspan, Zewe, and Sakran indicates that topographic controls on soil formation are widely applicable across the study area. These findings have practical

mean for land-use planning, agricultural suitability assessment, and soil conservation practices. Particularly in areas where slope processes strongly regulate soil productivity.

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