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RESEARCH ARTICLE

Assessment of Catena Relationships in Soil Properties within a Transitional Landscape: A Case Study from Northwestern Türkiye

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ABSTRACT

This research was carried out to classify soils located between Gökyaka and Sarpdere villages in the Demirköy district of Kırklareli province (NW Türkiye). Soil profile definitions were made by determining the morphological, chemical and physical properties of 7 profiles. In the HS-1 and HS-4 profiles located around the Balaban stream, the upper part of the sampling area is sloping, and the slope continues at the bottom (slope land). In these profiles, the soil order was Inceptisol. The subgroup of HS-1 was Typic Humixerept due to its high organic matter content, and HS-4 was Typic Haploxerept. The sample points around the HS-2 and HS-5 profiles were at the head of the sloping land. The pH of the soil is generally slightly acidic, no salinity problem is observed, the lime content is usually very low, the organic matter is found to be high in the upper layers, and the textures are clay, clay loam and silty clay loam. According to Soil Taxonomy of Soil Survey Staff, soils are classified as Entisol, Inceptisol and Alfisol. Thus, topography seems to be the main pedologic factor for the formation of soils in a short distance and under the same climatic conditions, in Gökyaka and Sarpdere villages of the Yıldız Mountain in NW Türkiye.

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1. Introduction

Rapidly increasing urbanization and industrialization also increase the use of natural resources (İkiz, 2020; Ozsahin & Ozdes, 2022). This rising consumption causes the depletion or decrease of natural resources (Tufan et al., 2023).

Soil formation does not occur in a short time. First, rocks weathers to soil parent material and then into soil. Soils are formed over many years under the influence of many soil formation processes (Arrouays et al., 2020; Yüksel & Ekinci, 2021).

Başayiğit et al. (2004) stated that soil is a natural resource formed by complex interactions and emphasised that soil is a living, dynamic, three-dimensional system. Actors such as mineral weathering/alteration, displacement and losses play a major role in soil formation from the parent material, and because of these processes, horizon differentiation occurs in the soil (Camacho et al., 2020). For this reason, it is emphasised that the effects and contributions of biological, chemical, and physical events in different environments should be considered when determining soil properties (Pacci et al., 2021).

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Soil formation varies over time depending on the effects of soil formation stages. Russian scientist Dokuchaev stated that different soil types are formed depending on climate, living organisms, topography, and time (Pritchett, 1980).

Changes in the geochemical properties of soils, mineral weathering, and soil-plant-water cycle are discussed, and the changing characteristics of soil formation over time are emphasised (Alaboz et al., 2021). Weathering rates of minerals can vary widely due to changes in soil properties and differences in environmental conditions. Also time affected soil properties and weathering/alteration rates and that changes occur in physical, chemical, and mineralogical properties during soil formation (Soluk & Özcan, 2020), In these processes, the chemical structure of soils is controlled by the parent material, while the chemical properties of mature soils reflect the effects of the weathering environment.

Determining agricultural lands' morphological, physical, and chemical properties is essential for sustainable management of soils (Nalan & Ekberli, 2020). The productivity of agricultural lands is not infinite (Özden et al., 2022). Therefore, it is necessary to interpret the properties of the soil well to enhance the productivity and sustainability of agricultural lands. For this reason, it is essential to determine the morphological, physical, and chemical properties of the soil well, and to produce detailed soil maps for their better management (Ormancı et al., 2023; Sokolov et al., 2021). In addition, classification and mapping of land use, erosion, and productivity for particular purposes can be carried out by referencing soil maps (Akgül, 1992; Tağil & Danacioğlu, 2021).

The properties of soils may meet only slightly the requirements of some types of uses while meeting all the requirements of other types of uses. To efficient use of soils with different characteristics, it is essential to plan by considering different types of management (Dent & Young, 1981; FAO, 1976).

The study on seven soil profiles in an approximately 50 km^2 area between Bayramiç and Çan (W. Türkiye) examined the profiles' physicochemical and mineralogical properties. Researchers found the highest clay content (47.75%) and the highest cation exchange capacity (CEC) (47 mmol.kg^{-1}) in the Vertisol profile in the soils formed on the old lake terrace. In addition, the soils of the research area were classified as Alfisol, Mollisol, Inceptisol, Entisol and Vertisols of the Soil Taxonomy (Soil Survey Staff, 2022), and Phaozems, Luvisols, Calcisols, Cambisols, Fluvisols and Vertisols reference groups in the IUSS Working Group (WRB, 2022) classification system (Başarlar & Ekinci, 2019).

Martin (2016) examined the integration of local and scientific knowledge in soil classification. This research investigates how farmers in Imugan, Philippines, use their traditional knowledge to classify soils and compares this with soil classification systems. The study highlights the importance of incorporating local knowledge into soil classification frameworks.

Catena is defined as a series of soils formed from the same parent material, in the same climate and over a similar period of time, but with different characteristics due to differences in relief and drainage. (Conforti et al., 2020).

FAO (1976) and Dent and Young (1981) state that some lands cannot adequately meet the requirements of all types of management but can suitable for specific type of use. For example, some soils may be suitable for agricultural production, while others are better suited for growing forests or for natural habitats (Çalişkan & Göl, 2022). For this reason, they stated that planning should consider soil properties and usage types for sustainable use of lands efficiently.

The Yıldız Mountains in the study area are the highest point of the region and the height of Mahya Mountain, which is the summit, is 1035 metres. The research area was selected in the northeastern part of the Yıldız Mountains and the aim was to determine the soil types in this region. Although some studies have been carried out in the eastern part of the region, there is no study on this part. This study was carried out in order to fill this gap and contribute to the literature.

2. Materials and Methods

The study area was located at a distance of 15 km between Sarpdere village of Demirköy district, Kırklareli province, and the total study area is 68 km^2. The location of the study area and the sample points displayed on the Google Earth Satellite image are given in Figure 1. The coordinates of the sample points are given in Table 1.

Table 1. Coordinates of sample points.

Coordinates of Sample Points		
Sample	**Latitude**	**Longitude**
HS-1	41°51'16.83"N	27°39'17.60"E
HS-2	41°50'23.16"N	27°39'35.73"E
HS-3	41°52'36.04"N	27°37'5.04"E
HS-4	41°52'20.37"N	27°36'35.59"E
HS-5	41°51'24.63"N	27°33'54.10"E
HS-6	41°51'35.47"N	27°34'18.17"E
HS-7	41°51'19.95"N	27°38'22.86"E

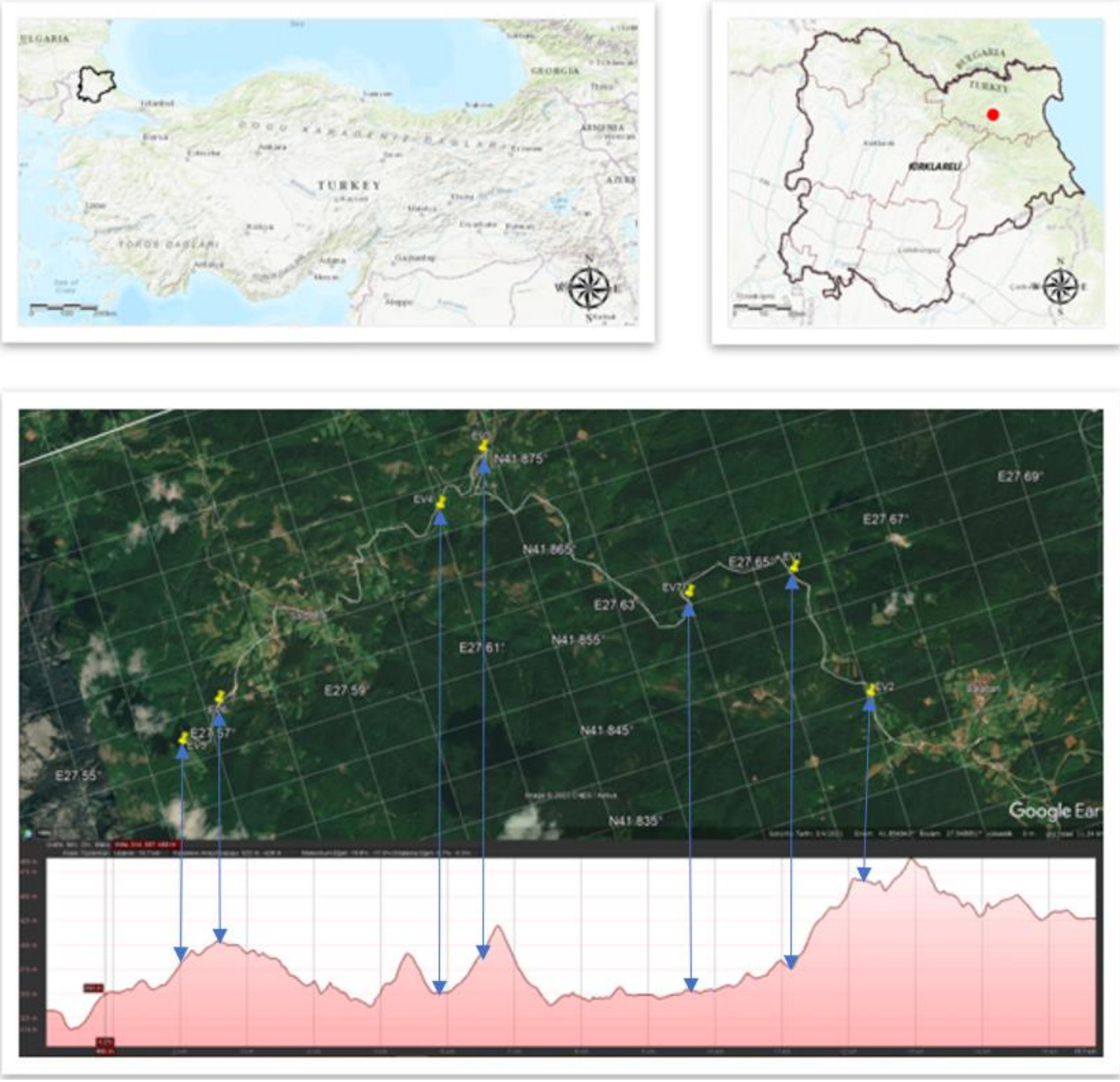

Figure 1. Map showing the study area and Remote Sensing Image Showing Balaban-Sarpdere Surroundings, sample points and elevation profiles of sample points according to Google Earth (2020 Image).

The 7 points determined between Demirköy and Sarpdere correspond to a section extended approximately 15 kilometres. Several soil types are determined at such a short distance most probably due to drainage, accumulation, and transportation events. These soils, which are formed as a function of topography, were evaluated using the Thorp and Smith (1949), Soil Taxonomy (Soil Survey Staff, 2022) and IUSS Working Group (WRB, 2022) classification systems.

Located in the south-eastern part of the Balkan peninsula, the Thrace region offers a wide variety of hilly landscapes. This diversity is created by mountains and hills with different elevations, plateaus with lower elevations, and plains have different sizes. Topographically, the mountainous are the Istranca mountain range in the north and northeast and the Ganos and Koru mountains in the south and southeast. The gently sloping, slightly hilly lands between these two mountainous lands, split by the branches of the Ergene River, constitute the basis of the Thrace peneplain (Kibaroğlu & Garipağaoğlu, 2022).

The soil samples, taken for the descriptive definition of the horizons defined in the study area and for the genetic characterisation of the soils, were air dried in the laboratory, crushed with a wooden mallet, sieved through a 2 mm sieve and prepared for analysis. Particle size distribution (texture) was determined using the hydrometer method (Bouyoucos, 1951). The texture triangle was used for nomenclature of texture classes (United States Division of Soil Survey, 1996).

Soil reaction pH was classified according to Jackson (1958) and salinity (%) according to Richards (1954). Electrical Conductivity (EC) was measured in the prepared saturation sludge using a Wheatstone Bridge conductivity meter (Tüzüner, 1990). Salinity (%) was determined by the equation provided by Tüzüner (1990). pH and salinity (%) were classified according to Richards (1954). Lime (%) was determined by the volumetric calcimeter method (Anonymous, 1988). Organic matter (%) was determined by the modified Walkley Black wet combustion method (Walkley, 1947) (Anonymous, 1988). Lime and organic matter contents of the soils were interpreted according to the limits of Sağlam (2008).

Nitrogen content (%) of soil samples was determined by calculation according to FAO (1976). Phosphorous (ppm) was measured by Olsen method (Olsen et al., 1954) and a spectrophotometer (FAO, 1976). K, Ca, Mg and Na (ppm) were extracted with ammonium acetate and determined by ICP (FAO, 1976). Fe, Cu, Mn and Zn (ppm) were analysed by extraction with DTPA followed by ICP (FAO, 1976; Follet 1969; Lindsay & Norvell, 1969). Nitrogen, phosphorus, potassium, calcium, magnesium and sodium were classified according to FAO (1976). Iron and copper were classified according to Lindsay and Norvell (1969). Zinc and manganese contents were also classified according to FAO (1976). Soil color was assessed as dry and moist (Nemcsics, 1994). IBM SPSS Statistics 22 software was used for correlation analysis of the results of the soil property analyses.

3. Results and Discussion

Seven soil profiles were opened in the study area. The topographic location and coordinates of the profiles given in Figure 1. The profile images are given in Figure 2. Profile descriptions of laboratory analyses of the profiles and morphological and other observations made during field studies are given in Tables 2 and 3 for each profile.

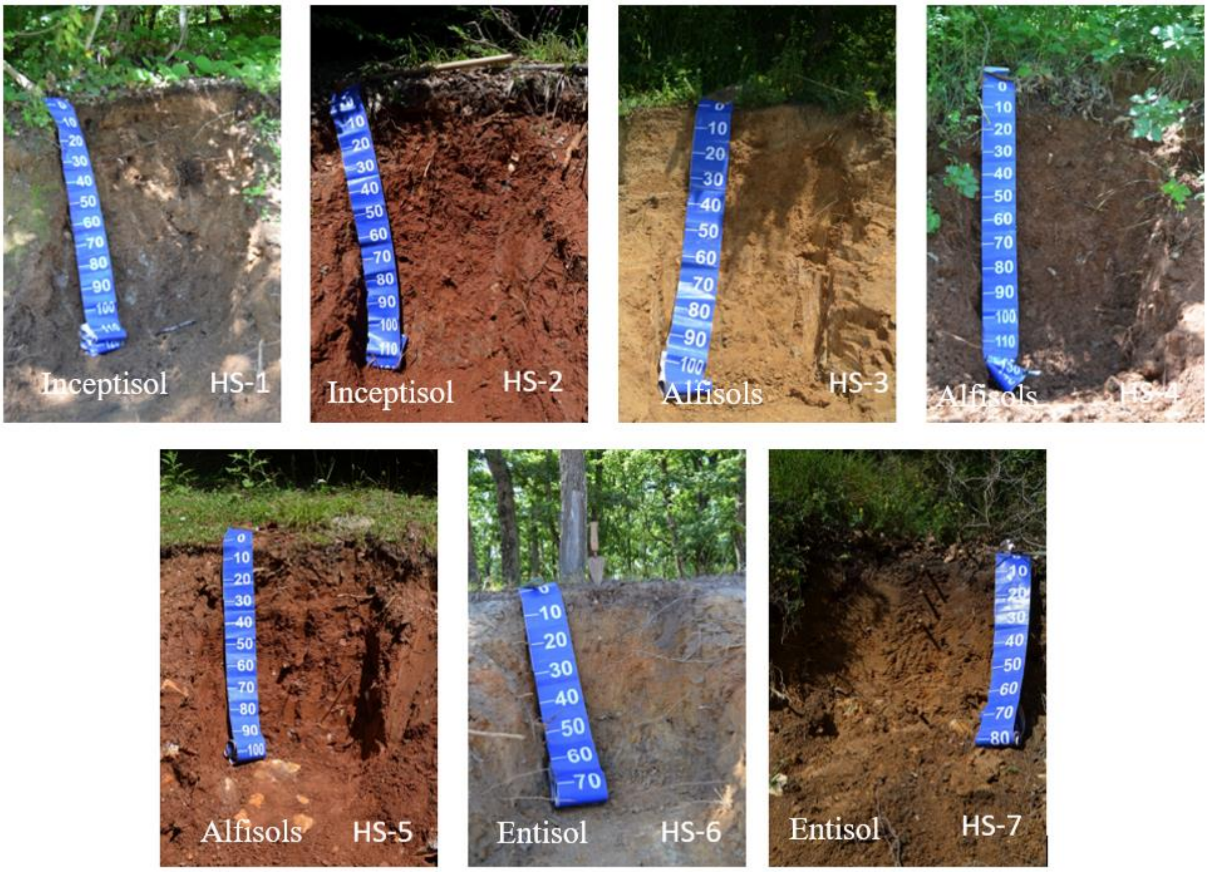

Figure 2. Photos of profiles.

3.1. Profile: HS-1

Region: Demirköy Dupnisa Cave Road, Location: Balaban-Gökyaka road junction 3rd km, Coordinates: 41°85'46.76' N 027°65'48.89' E, Altitude above sea level: 371, Vegetation: Hornbeam forest (forest undergrowth: short surface cover), Parent material: Granite, Physiography: valley ridge slope, Landform: Convex, Slope: 30% +, Drainage: good, Groundwater depth: Deep, Rocky soil: None, Land Use: Forest, Previous classification: Brown Forest Soil, Soil Taxonomy: Typical Humixerept.

3.1.1. Profile description

Ah 0-6 cm; Brownish black (10YR 4/2 dry), black (10YR 2/2 moist), loam, strong small furrows, very abundant micro mesopores, straight, fine and very fine roots.

A 6-21 cm; Dull yellowish-brown (10YR 6/3 dry), Dull yellowish-brown (10YR 4/3 moist), sandy loam, weak medium half-angular block, abundant micro-abundant medium mesopores, straight and open, very medium and very fine roots, large medium 2-3 cm diameter cavities.

Table 2. Some analysis results of soil samples.

Horizon	Texture				%Organic Material	pH (1:2,5) Soil-Water Solution	%Salt	$\%CaCO_3$	Colour	
	%Sand	%Silt	%Clay	Texture					Dry	Moist
HS-1 - Ah 0-6	48.54	33.44	18.02	L	10.15	6.59	0.25	0.78	10YR 4/2	10YR 2/2
HS-1 - A 6-21	54.89	22.48	22.63	SCL	1.89	6.26	0.04	0.39	10YR 6/3	10YR 4/3
HS-1 - Bw 21-49	57.10	22.38	20.52	SCL	0.91	6.30	0.04	0.39	10YR 6/4	10YR 4/4
HS-1 - C1 49-78	50.94	24.45	24.61	SCL	0.49	6.23	0.04	0.78	10YR 6/4	10YR 4/4
HS-1 - C2 78-125	61.17	18.31	20.52	SCL	0.21	6.34	0.03	0.39	10YR 7/4	10YR 4/4
HS-1 CR 125+	61.06	16.33	22.61	SCL	0.91	6.21	0.04	0.00	10YR 7/6	10YR 5/6
HS-2 Ah 0-6	38.84	27.34	33.82	CL	10.85	6.43	0.32	0.39	5YR 4/6	5YR 2/4
HS-2 A 6-24	22.67	31.28	46.05	C	3.01	6.20	0.06	0.78	5YR 4/8	5YR 3/6
HS-2 Bt 24-60	21.15	19.14	59.71	C	0.91	6.48	0.03	0.00	2.5YR 4/6	2.5YR 3/6
HS-2 BC 60-103	26.79	22.96	50.25	C	0.77	6.45	0.03	1.17	2.5YR 4/6	2.5YR 3/6
HS-2 C 103+	58.03	2.09	39.88	SC	0.21	6.38	0.03	0.00	2.5YR 4/6	2.5YR 3/6
HS-3 A 0-17	44.53	26.63	28.84	CL	2.73	6.35	0.10	0.00	10YR 6/4	10YR 4/4
HS-3 AC 17-46	42.66	30.63	26.71	CL	1.05	6.15	0.04	0.39	10YR 7/4	10YR 4/6
HS-3 C 46+	44.26	28.81	26.93	CL	0.91	6.26	0.04	0.00	10YR 7/6	10YR 5/6
HS-4 A 0-16	9.73	25.14	65.13	C	3.01	6.45	0.15	0.39	5YR 4/6	5YR 3/4
HS-4 AB 16-31	8.97	23.24	67.79	C	1.89	6.63	0.09	0.00	5YR 5/6	5YR 3/6
HS-4 Bw 31-76	6.46	19.10	74.44	C	1.05	6.41	0.08	0.39	5YR 4/6	5YR 3/6
HS-4 C 76+	6.94	21.11	71.95	C	0.35	6.72	0.08	0.39	5YR 4/8	5YR 3/6
HS-5 A1 0-5	42.92	23.19	33.89	CL	6.09	6.10	0.11	0.00	7.5YR 6/6	7.5YR 4/6
HS-5 A2 5-20	40.25	20.55	39.20	CL	1.47	6.25	0.04	0.39	7.5YR 6/6	7.5YR 4/6
HS-5 Bt 20-57	23.45	10.61	65.94	C	1.19	6.46	0.04	0.39	2.5YR 4/6	7.5YR 3/6
HS-5 C 57+	26.59	16.74	56.67	C	0.77	6.43	0.06	0.39	2.5YR 4.6	7.5YR 3/6
HS-6 A 0-9	39.89	37.21	22.90	L	8.61	5.57	0.11	0.39	10YR 6/2	10YR 3/4
HS-6 CA 9-22	44.64	28.62	26.74	CL	1.61	5.51	0.08	0.00	10YR 7/4	10YR 5/6
HS-6 C1 22-45	26.43	27.26	46.31	C	1.75	5.28	0.05	0.39	10YR 7/6	10YR 5/8
HS-6 C2 45+	26.74	33.41	39.85	C	1.05	5.38	0.04	0.39	10YR 7/6	10YR 6/8
HS-7 Ah 0-6	51.29	31.66	17.05	L	11.14	5.51	0.13	0.39	10YR 4/3	10YR 2/3
HS-7 A 6-15	51.93	26.13	21.94	SCL	4.55	5.80	0.05	0.39	10YR 5/3	10YR 3/3
HS-7 AC 15-30	56.84	22.52	20.64	SCL	2.73	5.68	0.04	0.00	10YR 7/4	10YR 4/3
HS-7 C 30-74	57.04	22.42	20.54	SCL	1.61	5.94	0.04	0.39	10YR 7/4	10YR 4/3

Bw 21-49 cm; Brown (10YR 6/4 dry), Brown (10YR 4/4 moist), sandy loam, medium coarse semi-angular block, micro and mesopores, wavy and open, abundant medium roots, abundant 1-3 cm diameter insect burrows, 10-15 cm diameter surface material accumulated in cracks.

C1 49-78 cm; brown (10YR 6/4 dry), brown (10YR 4/4 moist) sandy loam, massive, very few micropores, wavy and open, medium roots.

C2 78-125 cm; Dull yellow orange (10YR 7/4 dry), Brown (10YR 4/4 moist) sandy loam, massive structure, porosity very few micropores, boundary wavy and open, base sat roots very few and very fine roots.

CR 125+cm; Light yellowish brown (10YR 7/6 dry), yellowish brown (10YR 5/6 moist), sandy clay loam, massive.

The A horizon in the HS-1 Profile is determined as the loam texture class, and the other horizons are determined as sandy clay loam. Soil reactions (pH) are neutral in the A horizon (6,59), slightly acidic (6,21-6,34) in the other horizons and contain few carbonate. While the amount of organic matter is high in the A horizons of this profile, which is in the saline class, it decreases towards the bottom (Table 2). When examined in terms of nutritional elements, P and Ca are in low amounts, while Na, Ca, Mg, K, Fe, Cu, Mn, and Zn are in sufficient amounts. These amounts decrease towards the lower horizons. Total nitrogen is present at sufficient levels (Table 3). The main reasons for low P and Ca levels are that the slightly acidic environment increases phosphorus fixation and calcium solubility. The sandy clay loam texture can reduce plant uptake by facilitating the binding of phosphorus to clay minerals (Zheng at al., 2003). The reduction of organic matter in the lower horizons limits the biological mineralization of phosphorus and has a negative effect on the retention of calcium. Adequate amounts of Na, Mg, K, Fe, Cu, Mn and Zn are favoured by the soil mineral structure rich in these elements, the high CEC and the A horizon rich in organic matter. However, the decrease of these elements in the lower horizons can be attributed to the loss of organic matter, poor microbial activity, the presence of an accumulation horizon and the washing effect of the drainage system.

3.2. Profile: HS-2

Region: Demirköy Dupnisa Cave Road, Location: Balaban - Gokyaka 1st Km, Coordinates: 41° 83'97.67' N 27°65'99.25' E, Sea level: 425, Vegetation: Beech, Parent material: Claystone (colluvial quartzite), Physiography: Valley ridge slope, Shape of the surrounding land: Convex, Slope: 35%+, Drainage: good, Groundwater depth: Deep, Rocky soil: None, Land Use: Forest, Humidity: Low, Former classification: Brown Forest Soil, Soil Taxonomy: Inceptic Haploxeralf.

3.2.1. Profile description

Ah 0-6 cm; reddish brown (5YR 4/6 dry), very dark reddish brown (5YR 2/4 moist), clay loam, very abundant micro and fine pores, straight and well defined, fine and very fine roots.

A 6-24 cm; reddish brown (5YR 4/8 dry), dark reddish brown (5YR 3/6 moist), clay, medium small semi-angular, medium macro and mesopores, wavy and open, less thick, medium thick less thin roots.

Bt 24-60 cm; reddish brown (2.5YR 4/6 dry), dark reddish brown (2.5YR 3/6 moist), clay, strong to medium prismatic, few micro-pores, wavy and open, medium roots abundant fine roots, 1.5 cm scattered clay stones.

BC 60-103 cm; reddish brown (2.5YR 4/6 dry), dark reddish brown (2.5YR 3/6 moist), clay, strongly small prismatic, slightly micropolar, rim wavy and clear, 1-7 cm diameter scattered clay pebbles.

C 103+ cm; reddish brown (2.5YR 4/6 dry), dark reddish brown (2.5YR 3/6 moist), sandy clay.

The texture class of the HS-2 profile is clay loam, and the pH is slightly acidic. The amount of lime is low, and the amount of organic matter is high in the upper horizon and decreases to a low level towards the bottom. In the case of salt, it is classified as salt-free soil (Table 2). Regarding nutritional elements, P and Ca are in low amounts, while Na, Mg, K, Fe, Cu, Mn and Zn are in sufficient amounts. The main reasons for the low P and Ca levels in the soil are the decalcification of these elements due to slightly acidic pH, the tendency of clay tissue to fix phosphorus and the decrease in soil organic matter in the lower horizon. On the other hand, adequate levels of Na, Mg, K, Fe, Cu, Mn and Zn can be explained by the rich mineral structure of the soil, the high CEC and the organic matter rich conditions in the upper horizon. The decline in nutrients in the lower horizons can be attributed to processes such as reduced organic matter and microbial activity, drainage-induced leaching and clay fixation. High total nitrogen in the upper horizon is associated with the accumulation of organic matter and the effective functioning of nitrogen-fixing microorganisms. These amounts decrease towards the lower horizons. Total nitrogen is present in high levels in the upper horizon (Table 3).

3.3. Profile: HS-3

Region: Demirköy Dupnisa Cave Road, Location: Gökyaka village entrance, Coordinates: 41° 87'66.78' N 27°61'80.66' E, Sea level: 414 m. Vegetation: Oak forest (the surface of the ground is covered with forest plants), Parent material: Granite, Physiography: High slope (mountain slope), Landform: Convex, Slope: 25%, Drainage: Deep, Groundwater depth: Deep, Rocky soil: None, Land Use: Forest, Humidity: Low, Former classification: Brown forest soil, Soil taxonomy: Typical Xereorthent.

3.3.1. Profile description

A 0-17 cm; Brown (10YR 6/4 dry), brown (10YR 4/4 moist), clay loam, weak small furda structure, few macro very micro polar, straight and open, few medium roots.

AC 17-46 cm; pale yellow-orange (10YR 7/4 dry), brown (10YR 4/6 moist), clay loam, weak small, semi-angular block structure, few macro and mesopores, border straight and open, very medium and very fine roots.

C 46 cm+; glossy yellowish brown (10YR 7/6 dry), yellowish brown (10YR 5/6 moist), clay loam, massive, less fine and very fine roots.

The texture of the HS-3 profile falls into the clay loam class. The pH is slightly acidic, with very few lime. In this non-saline soil, organic matter is low in the upper horizons and low in the middle bottom (Table 2). Colour varies between yellowish-brown and brown. While K, P, Zn and Ca are in low amounts, Na, Mg, Fe, Cu and Mn are in sufficient amounts. These amounts decrease towards the lower horizons. Total nitrogen is present at very good levels (Table 3). Ca, K, P and Zn levels were found to be low. The low organic matter content prevents the biological release of these nutrients. The reason for the sufficient levels of Na, Mg, Fe, Cu and Mn is the mineral richness of the soil parent material (granite) and the high CEC. The decrease of these elements in the lower horizons can be explained by the loss of organic matter and leaching by water movement. Total nitrogen is well represented in the upper horizons due to efficient mineralisation processes.

Table 3. Analysis results of soil samples.

HORIZON	Available Phosphorus (ppm)	Available Calcium (ppm)	Available Potassium (ppm)	Available Magnesium (ppm)	Available Sodium (ppm)	Available Copper (ppm)	Available Iron (ppm)	Available Manganese (ppm)	Available Zinc (ppm)	Total N (%)
HS-1 - Ah 0-6	7.63	150.80	62.50	29.34	2.70	0.62	22.64	12.64	2.09	0.50
HS-1 – A2 6-21	9.04	67.15	18.80	12.10	2.80	0.75	40.64	22.52	0.39	0.09
HS-1 - Bw 21-49	7.24	65.08	15.50	12.08	2.50	0.69	49.40	11.01	0.35	0.04
HS-1 - C1 49-78	3.81	55.85	12.40	12.67	2.10	0.59	35.07	5.25	0.33	0.02
HS-1 - C2 78-125	2.32	52.53	13.10	8.58	2.30	0.71	23.61	1.90	0.24	0.01
HS-1 CR 125+	4.55	61.97	14.40	12.35	2.40	0.75	20.15	4.64	0.25	0.04
HS-2 Ah 0-6	7.45	119.92	70.50	20.47	2.90	1.84	36.45	128.55	3.82	0.54
HS-2 A2 6-24	12.66	80.10	52.10	13.04	2.30	2.65	16.78	18.95	1.12	0.15
HS-2 Bt 24-60	12.24	80.67	19.00	15.36	2.80	1.22	5.51	1.08	0.34	0.04
HS-2 BC 60-103	10.42	71.49	16.70	13.05	2.20	1.51	6.53	1.07	0.46	0.03
HS-2 C 103+	10.72	54.86	14.90	11.26	2.40	1.26	3.35	1.16	0.36	0.01
HS-3 A 0-17	10.95	52.20	49.60	9.78	3.10	1.15	14.02	36.25	0.54	0.13
HS-3 AC 17-46	10.73	75.75	16.90	14.51	2.50	1.36	27.60	79.84	0.52	0.05
HS-3 C 46+	11.62	11.17	15.40	2.16	3.60	0.94	14.80	4.16	0.54	0.04
HS-4 A 0-16	10.29	107.56	70.30	19.28	2.60	3.10	10.95	54.26	1.28	0.15
HS-4 AB 16-31	11.47	132.74	44.20	23.00	3.70	3.42	13.96	50.23	1.37	0.09
HS-4 Bw 31-76	11.39	163.21	19.40	27.90	3.50	2.49	11.22	51.88	1.69	0.05
HS-4 C 76+	13.72	140.58	17.20	27.67	2.90	2.42	17.96	82.67	4.38	0.01
HS-5 A1 0-5	10.26	108.83	56.00	20.42	2.10	1.16	60.05	40.26	1.15	0.30
HS-5 A2 5-20	12.31	83.40	18.10	15.92	1.70	1.84	29.30	27.48	0.65	0.07
HS-5 Bt 20-57	10.85	148.34	18.70	25.84	3.40	1.95	9.06	19.83	0.49	0.05
HS-5 C 57+	12.26	131.12	15.80	28.26	2.50	2.03	14.79	35.56	0.72	0.03
HS-6 A 0-9	13.34	119.20	49.30	24.94	3.00	1.03	85.42	7.54	1.32	0.43
HS-6 CA 9-22	12.29	68.31	14.20	12.91	2.20	0.86	46.98	4.70	0.44	0.08
HS-6 C1 22-45	13.78	160.05	19.00	27.41	3.30	0.87	14.83	1.60	0.30	0.08
HS-6 C2 45+	12.82	178.80	17.40	34.58	3.80	0.83	17.83	1.65	0.34	0.05
HS-7 Ah 0-6	14.93	141.15	46.50	25.07	2.50	0.87	81.11	12.52	2.97	0.55
HS-7 A2 6-15	12.25	105.57	15.00	19.66	1.80	0.81	87.36	1.07	0.72	0.22
HS-7 AC 15-30	10.91	36.48	12.40	6.21	1.10	0.82	79.05	0.80	0.44	0.13
HS-7 C 30-74	11.78	43.82	13.00	7.32	0.90	0.77	10.17	0.40	0.21	0.08

3.4. Profile: HS-4

Region: Demirköy Dupnisa Cave Road, Location: Balaban-Sarpdere, 13 km after the junction, Coordinates: 41° 87'23.26' N 27°60'98.86' E, Altitude above sea level: 377, Vegetation: Forest (oak wood), Parent material: Clay stone, Physiography: Slope terrain (mountain slope), Shape of the surrounding terrain: Convex, Slope: 25-30%, Drainage: Deep, Groundwater depth: Deep, Rocky soil: None, Land Use: Roadside, Humidity: Low, Former classification: Brown forest soil, Soil taxonomy: Typical Haploxerept.

3.4.1. Profile description

A 0-16 cm; reddish brown (5YR 4/6 dry), dark reddish brown (5YR 3/4 moist), clay, weak small furrows, very good macro and mesopores, fracture open.

AB 16-31 cm; light reddish brown (5YR 5/6 dry), light reddish brown (5YR 3/6 moist), clay, strong medium sized block, medium micro and mesopores, 1-2 cm diameter clays, slightly wavy.

Bw 31-76 cm; reddish brown (5YR 4/6 dry), dark reddish brown (5YR 3/6 moist), clay, strong coarse semi-angular block, few micro and mesopores, 1-5 cm diameter clays, wavy light.

C 76+ cm; Reddish brown (5YR 4/8 dry), dark reddish brown (5YR 3/6 moist), clay, massive structure, with black spots covering the surface of clay structures between 0.2-5 cm.

The texture of the HS-4 profile is clay. The pH is slightly acidic, and they are salt-free soils. While organic matter is enough at the top, it is at lower horizons (Table 2). Colour varies from dark greyish brown to bright reddish brown. When examined in terms of nutritional elements, P and Ca are in low amounts, while Na, Mg, K, Fe, Cu, Mn, and Zn are in sufficient amounts. These amounts decrease towards the lower horizons. Total nitrogen is present at high (Table 3).

3.5. Profile: HS-5

Region: Demirköy Dupnisa Cave Road, Location: Sarpdere - Dupnisa 2 km, Coordinates: 41° 85'68.42' N 27'56 50.27' E, Altitude above sea level: 344, Vegetation: Forest (hornbeam - oak), Parent material: Marble, Physiography: Sloping, Shape of the surrounding land: Convex, Slope: 25%, Drainage: Deep, Groundwater depth: Deep, Rocky soil: None, Land Use: Forest, Humidity: Low, Former classification: Brown Forest Soil, Soil Taxonomy: Typical Haploxeralf.

3.5.1. Profile description

A1 0-5 cm; Orange (7,5YR 6/6 dry), Brown (7,5YR 4/6 moist), Clay loam, weak small furrows, abundant macro, micro and mesopores, straight open, very fine and very fine roots.

A2 5-20 cm; orange (7,5YR 6/6 dry), brown (7,5YR 4/6 moist), clay loam, weak to medium semi-angular, porosity less meso and micro pores, wavy open, less to medium very fine roots very few very fine roots.

Bt 20-57 cm; reddish brown (2.5YR 4/6 dry), dark reddish brown (2.5YR 3/6 moist), clay, very coarse, semi-angular, few meso and micro pores, wavy open, less to medium thick very fine to very fine to very fine roots.

C 57+ cm; reddish brown (2.5YR 4/6 dry), dark reddish brown (2.5YR 3/6 moist) clay, strong small block structure when broken into massive fragments, very few micropores, few fine roots, bedrock fragments 2+ cm in diameter.

The texture classes of the HS-5 profile are clay loam in the upper horizons and clay in the lower parts. The pH is slightly acidic, and there is very few lime. Organic matter is high in the upper horizon and is in the non-saline soil class (Table 2). While P and Ca are in low amounts, K and Mg are in medium amounts, Na, Zn, Fe, Cu and Mn are in sufficient amounts. These amounts decrease towards the lower horizons. Total nitrogen is high in the A1 horizon (0.3), sufficient in the A2 and Bt horizons (0.07-0.06) and low in the C horizon.

3.6. Profile: HS-6

Region: Demirköy Dupnisa Cave Road, Location: Sarpdere Dupnisa 1st Km, Coordinates: 41° 85'98.53' N 27°57'17.14' E, Sea level: 357, Vegetation: Forest (oak), Parent material: Chalcchist, Physiography: Hilly, Shape of the surrounding terrain: Convex, Slope: Flat, Drainage: Good, Groundwater depth: Deep, Rocky soil: None, Land Use: Road cut, Humidity: Low, Previous classification: Brown forest soil, Soil taxonomy: Typical Xereorthent.

3.6.1. Profile description

A 0-9 cm; Greyish-yellowish brown (10YR 6/2 dry), dark brown (10YR 3/4 moist), loam, weak, small, semi-angular block, abundant micro- and mesopores, straight cut, very abundant and very fine roots.

CA 9-22 cm; Dull yellow-orange (10YR 7/4 dry), yellowish brown (10YR 5/6 moist), loam, massive, few micro-pores, wavy and open, special features few fine and very fine roots.

C1 22-45 cm; light yellowish brown (10YR 7/6 dry), yellowish brown (10YR 5/8 moist), clay, massive, wavy and open, many medium roots.

C2 45+ cm; light yellowish brown (10YR 7/6 dry), light yellowish brown (10YR 6/8 moist), clay, massive, few medium roots, may have traces of iron reduction.

In the HS-6 profile, the texture is loam in the upper horizon and changes between clay loam and clay towards the bottom. The pH is slightly acidic to moderately acidic, and the soil is salt-free. While the amount of organic matter is high at the top, it decreases towards the bottom (Table 2). Colour varies between bright yellowish brown and dark brown. Regarding nutritional elements, P and Ca are in low amounts, K and Mg are in medium amounts, while Na, Ca, Zn, Fe, Cu and Mn are in sufficient amounts.

These amounts decrease towards the lower horizons. Total nitrogen is present at high (Table 3).

3.7. Profile: HS-7

Region: Demirköy Dupnisa Cave Road, Location: Balaban-Gokyaka 4th Km, Coordinates: 41° 85'55.43' N 27°63'96.82' E, Sea level: 369, Vegetation: Forest (oak), Parent material: Granite, Physiography: valley slope, slope: 20-25%, Drainage: Deep, Groundwater depth: Deep, Rocks: None, Land Use: Forest, Humidity: Less, Old classification: Brown forest soil, Soil taxonomy: Typical Xereorthent.

3.7.1. Profile description

Ah 0-6 cm; dull yellowish brown (10YR 4/3 dry), brownish black (10YR 2/3 moist), loam, weak structure, small furrows, many macro and micro pores, straight open, very abundant and very fine roots.

A 6-15 cm; Dull yellowish-brown (10YR 5/3 dry), dark brown (10YR 3/3 moist), sandy loam, weak small half-spherical block, few macro, few micro, border wavy and clear, few medium and very fine roots.

AC 15-30 cm; dull yellow-orange (10YR 7/4 dry), dull yellow-brown (10YR 4/3 moist), sandy loam, structure massive, few macro, border wavy and open, special features very many medium and thick roots.

C 30-74 cm; dull yellow-orange (10YR 7/4 dry), dull yellow-brown (10YR 4/3 moist), sandy loam, massive, broken and transitional, anthills 2-5 cm diameter, insect and animal tracks 1-5 cm diameter.

In the HS-7 profile, the texture varies between clay loam and silt loam. In this profile, where the pH is slightly acidic, there is a high amount of organic matter at the top and a small and medium amount at the bottom (Table 2). In terms of colour, it varies between dull yellowish brown and brownish black. Regarding nutritional elements, P and Ca are in low amounts, K is in medium amounts, while Mg, Na, Ca, Zn, Fe, Cu and Mn are in sufficient amounts. These amounts decrease towards the lower horizons. Total nitrogen is present at high (Table 3).

The distribution of low and sufficient nutrients in the HS-4, HS-5, HS-6 and HS-7 profiles varies according to the pH, organic matter content and textural characteristics of the soils. The main reason for low phosphorus (P) and calcium (Ca) levels is that the slightly acidic pH causes phosphorus to bind to soil minerals and calcium causes decalcification. The clay content of soils can also reduce the availability of these elements for plants. The moderate levels of potassium (K) and magnesium (Mg) are due to the mineral structure and calcium-magnesium balance of the soils. Sodium (Na), zinc (Zn), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) are present in sufficient quantities because these elements are naturally present in sufficient quantities in the soil and the soils have a high cation exchange capacity (CEC). However, the decrease of these elements in the lower horizons can be explained by the decrease of organic matter and the effect of leaching by water movement. The very good total nitrogen levels are due to the high organic matter content of the upper horizons and efficient biological mineralisation.

Figure 2 shows photos of all profiles. All profiles show characteristics suitable for the growth of plants that can grow in slightly acidic environments, except for cultivated plants with extreme preferences in terms of productivity. Their current situation is a forest with oak and beech trees.

When the soils of the research area are classified according to the classification of Thorp and Smith (1949), "Brown Forest Soil" falls into the Great Soil Group. When classified according to Soil Taxonomy (Soil Survey Staff, 2022), it is classified in 3 orders: Entisol, Inceptisol and Alfisols. Profiles numbered HS-1 and HS-4 are in the Inceptisol order and are classified in the HS-4 Typic Haploxerert subgroup due to their being in the xeric moisture regime and their typical feature. HS-1 is included in the Typic Humixerept subgroup with its dark colour and high organic matter content. HS-2 and HS-5 profiles are in the Alfisols order and are in the Inceptic Haploxeralf subgroup due to high clay accumulation. The soils in the Alfisol order are in a xeric moisture regime. Profiles numbered HS-3, HS-6, and HS-7 are in the Entisol order, and all profiles are in the xeric moisture regime. These profiles are included in the Typic Xereorthent subgroup. In addition, according to the WRB (2022) classification system, HS-1 and HS-4 are Humic Cambisol, HS-2 and HS-5 are Haplic Luvisol, HS-3, HS-6, HS-7 are Haplic Regosol. Table 4 shows the classification of the soils of the research area according to Soil Taxonomy (Soil Survey Staff, 2022), WRB (2022) and Thorp and Smith (1949) Systems.

Table 4. Classification of research area soils according to Soil Taxonomy (Soil Survey Staff, 2022) and Thorp and Smith (1949) systems.

Thorp and Smith (1949) (Great Soil Group)	**Soil Taxonomy (Soil Survey Staff, 2022)**				**WRB (2022)**	**Profile Number**
	Order	Sub Order	Great Group	Subgroup		
Brown Forest Soil	Inceptisol	Xerepts	Humixerept	Typic Humixerept	Humic Cambisol	1
Brown Forest Soil	Inceptisol	Xerepts	Haploxerept	Typic Haploxerept	Haplic Cambisol	4
Brown Forest Soil	Alfisols	Xeralfs	Haploxeralf	Inceptic Haploxeralf	Haplic Luvisol (Inceptic)	2
Brown Forest Soil	Alfisols	Xeralfs	Haploxeralf	Typic Haploxeralf	Haplic Luvisol	5
Brown Forest Soil	Entisol	Orthents	Xereorthent	Typic Xereorthent	Haplic Regosol	3
Brown Forest Soil	Entisol	Orthents	Xereorthent	Typic Xereorthent	Haplic Regosol	6
Brown Forest Soil	Entisol	Orthents	Xereorthent	Typic Xereorthent	Haplic Regosol	7

4. Conclusion

When the catena relations of the soils are examined in the study area, which starts at 2 km of Kırklareli/Demirköy Balaban-Gökyaka villages and extends to the 3rd km of Sarpdere village - Dupnisa cave, it observed that different soil properties occur over a short distance. Although they occur under the same climatic conditions, they differ in slope, parent material, drainage network system, topography, and water movement in the soil profile. The change in the profile properties of the research area soils is due to the Balaban stream and the drainage network system around it, which is effective in the region.

The contribution of slope change to water movement, organic matter accumulation and nutrient distribution can be more specifically addressed to explain the detailed effects of catenation on soil properties. It should be discussed how the drainage network system, in particular the Balaban stream, shapes differences in soil ordo groups and the possible implications of these processes for agricultural productivity, water management and erosion resistance. In addition, comparison of the research results with regions with similar climates and topographies may help to improve the generalisability and specificity of the findings. Finally, long-term monitoring studies are recommended to understand the time-dependent dynamics of the profiles, in particular the effects of slope and water movement on soil physical and chemical evolution processes.

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Conflict of Interest

The authors declare that they have no conflict of interest in relation to this study.

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