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Geomorphology and Soil Properties at the Middle and Lower Eastern Clay Plains - Nuba Mountains. South Kordofan, Sudan

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Abstract: ***This research study aimed to describe the geomorphology and characterize the soil properties at the middle and lower clay plains located at the eastern parts of Nuba Mountains, Sudan. Soil samples were collected from nineprofile pits alonga transect stretching from Abbasyia to Megenis through Terter (64 Km). The area is a broad, slightly sloping to undulating upland clay plains. The plains are dissected by Khors and Wadis (Khor and Wadi are water course in Arabic language) draining the Nuba Mountains hilly area, numoures low ridges (viens and dykes) separated by shallow depressions running through the area. The majority of the soils identified belong to the dark cracking clays.The soils are formed insitu and on colluviums and alluvium derived from basement complex rocks. The origin of these clays is thought to belong to Quarternary alluvial deposits probably similar in time to other dark cracking clays of central Sudan but but under different forming processes (Showgi et al 2016).These deposits form well developed Vertisols (Pacheco and Dawoud, 1976;Ahmed 1983; Abedine and Robibson 1970).Wide cracking, gilgae microrelief and very dark grayish colours dominate the surfaces.Topsoil structure has loose granular mulch, the subsoil has subangular blocky structure, below that the structure is massive. Subsoil and substrata layers have parallelepiped and wedge shaped structure aggregates. Slickensides was also observed in all profiles, reflecting expansion and contraction upon wetting and drying of the soil. Fine and medium tubular pores, small and large whitish irregular $CaCO_3$ concretions were noted. Fine and medium sand grains and polished quartz pebble arecommon. The soil reaction is slightly alkaline in all profilesincreasing with depth. The sois are non saline and nonesodicon middle plains but mildly sodic and sodic at lower plains. Cation exchange capacity is high at top horizons and very high below indicating presence of illiticand montmorillonitic clay minerals. Sodium Adsorption Ratio (SAR) is lowand the soilsare non - calcareous with low amount of $CaCO_3$.Organic matter is low decreasing with depth and the total nitrogen is also low.Nutrient status expressed as extractable cations meq/100 g soil is generally high: Soil texture is clay throughout the profile and clay content increases with depth.The bulk density (BD) is high increasing with depth, and porosity results coincidewith bulk density trend.Although most of the cracking clay soils in Sudan are sharing similar origin (basaltic igneous materials) but their subsequent depositional processes, landscape geomorphology and local climate have affected their mineralogical, physical and chemical properties. This applies to the clay plains of Nuba Mountains as most soils are characterized by lower CEC, mild alkalinity and low calcium carbonate content.***

Keywords: Nuba Mountains, Middle and Lower Clay Plains, Soil Properties

1. Introduction

In the Sudan, Vertisols occur on large tract of land, totaling perhaps 50 million ha in area, is divided naturally into four separated areas: the central clay plain (Gezira), the eastern clay plain (El Gadarif), the Nuba Mountains region and the southern clay plain (Abyei-Bahr Al Arab). Vertisols in the Nuba Mountains region occur on gently undulating plains and have better surface drained than those in extremely flat landscape of the other three clay plains (Blockhuis et al 1964; Eswaran et al 1999; FAO 1970). Dark cracking clay soils “Vertisols” cover not only large areas of the low lying plains but also they occur on undulating higher plains and in many intermountain valleys throughout the Nuba Mountains area(Vail, J.R. 1973). Some of these clays, notably those in eastern and southern lower clay plains, Khor Abu Habil, Wadi Al Ghalla and the clays of Bahr el Arab valley, can only be alluvial. But some other clay, for instance, on undulating high plains in the Nuba Mountains uplands area indicate a non-alluvial origin(Showgi 2011; Doka et al 2016).

The Nuba Mountains Vertisols are considered to be derived from the underlying bedrock. Therefore, it is expected that the parent materials at upper clay plains have undergone through a shorter pedogenetic processes compared to those on low alluvial plains (Khoddarry 1978). These non-alluvial clays are thought to be moved slowly down slope by combined process of wash and mass movement. Bases are thought to be washed from higher areas to accumulate on the plains where they help in the formation of the higher base status clays. Because the lower horizons are subject to pressure when the soils swell, they are compact and very slowly permeable to water. They are usually neutral to slightly in reaction (Pacheco and Dawoud1976). This research study attempts to identify the chemical and physical properties of the Vertisols at Middle and Lower clay plains at Nuba Mountains to provide information about soil inherent and dynamic properties. Many research studies were carried to characterize the chemical and physical properties of Vertisols at different parts the alluvial lowland clay plains of Sudan which are mainly used for irrigated farming (Blockhuis et al 1964; Kevie and Buraymah; 1987 Khalil 1986). The clay soils at the rainfed lands found less detailed research attention and particularly the upper, middle and

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lower clay plains at Nuba Mountains region which need more understanding of their formation and behavior as related to their use and management.

2. The Study Area

The study area is located in the eastern part of the Nuba Mountains in South Kordofan State. The sampling transect (65 Km), starts from Al Abbasyia town (height 561 m ASL) in the northeast and ending towards southeast at Megenis (height 406 m ASL), Figure1 and Figure 2. The study area has tropical semi – arid zone of summer rain (Van der Kevie 1973). The rainfall is comparatively high as the survey area lies within isohyets 600 - 800 mm. The amount of rainfall increases from northeast to southwest (Table 1). The rainy season starts from late June and extends to early October month. Maximum temperatures range between 31C^{o} and 40 C^{o} with March to May as the hottest months and monthly minimum temperatures range between 17 C^{o} and 24 (Abbasyia) C^{o} coldest months being from early December to the end February (ELTom 1972 and Dawoud 1974).

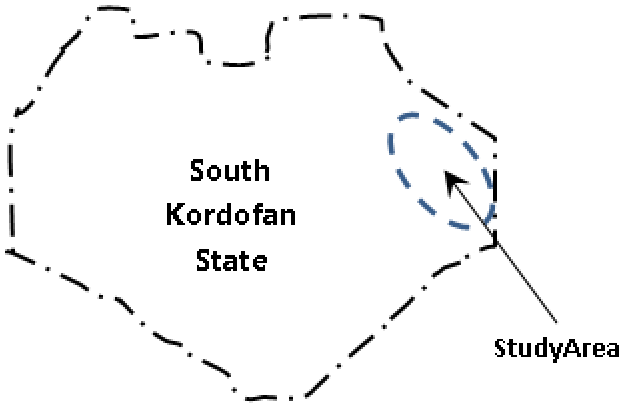


Figure 1: The Location of the Study Area at the Eastern Clay Plains of Nuba Mountains - South Kordofan State

Table 1: Rainfall at the Study Area

Season	Al Abbasyia	AL Terter	Abu Jubayhah	Season	Al Abbasyia	AL Terter	Abu Jubayhah
1997 – 98	482.4	667.4	573.5	2002– 03	510	509	526
1998 – 99	668	-	472	2003– 04	554.5	499.6	812
1999 – 00	555.6	506	568	2004– 05	532.5	414	661.5
2000 -01	477	483	614	2005– 06	555.7	427	662
2001 – 02	589	711	638	2006– 07	723.3	749.4	671.5

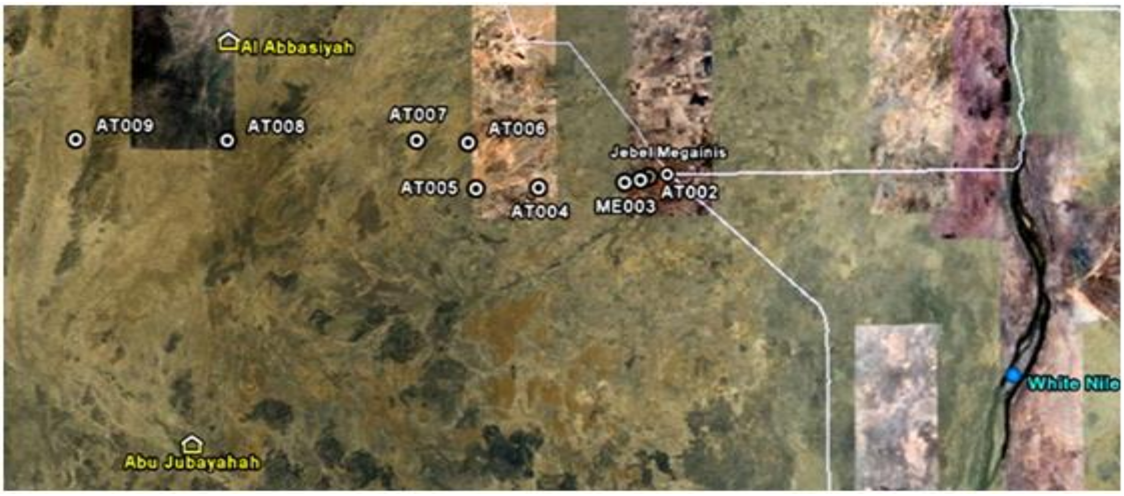
Source: Sudan Meteorological Authority

3. Materials and Methods

Transect stretches in eastward direction from Al Abbasyiato Megenis. The area under study is situated between longitudes 31º00″ and 32º35″ East and latitudes 11º56″ and 12º09″ north. Eight soil samples were collected from eight sites shown in Table 2 and represented in Figure 2. Sub-scenes of Landsat TM Satellite image 2010 covering the study area were used for locating the sampling sites.The elevation of the study sites ranges between 561 and 381 m ASL (Figure 3).

Table 2: Sample sites, location and elevation along the Toposequence of Middle and lower slopes

Area	Sample site	North	East	Elevation (m)
Al Abbasyia	AT009	12^{o}08'32.00''	31^{o}18'05.00''	561
	AT008	12^{o}09'21.00''	31^{o}27'41.00''	541
	AT007	12^{o}05'09.00''	31^{o}39'35.00''	523
	AT006	12^{o}03'51.00''	31^{o}44'42.00''	503
Terter	AT005	11^{o}55'52.00''	31^{o}45'20.00''	473
	AT004	11^{o}55'57.00''	31^{o}52'28.00''	451
Megenis	ME003	11^{o}56'02.00''	32^{o}15'43.00''	437
	ME002	11^{o}56'22.00''	32^{o}33'55.00''	406
White Nile Terrace	ME001	11^{o}56'52.00''	32^{o}40'43.00''	381



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AT009	AT008	AT007	AT006	AT005	AT004	ME003	ME002
Abbasyia 4	Abbasyia 3	Abbasyia 2	Abbasyia 1	Al Terter 2	Al-Terter 1	Megenis 3	Megenis 2

Figure 2: Landsat scene showing the sampling sites starting from Abbasyia (AT009) on the North East to Megenis (ME002) on the South East

Eight profiles AT009, AT008, AT007, AT006, AT005 and AT004, ME002 and ME003 were selected along the transect in the study area AL - Abbasiyia, AL - Terter and Meginis (Figure 2 and Table 2).A pit of about 1×2 m in length with 1.5 m depth was dug for sampling at each site. The face of the pit to be used for observation, photographing and sampling should face the sun. Notes on morphology, horizons sequence and soil classification were recorded following the standard procedures(FAO 2006 and USDA 1999). Soil samples, one from each soil horizon were taken for laboratory analyses.The soil samples were air dried and crushed using a wooden mortar and pestle and sieved to pass the 2 mm sieve and laboratory analyses were performed on the less than 2 mm fraction. All the physical and chemical determinations were carried out according to the international procedure of soil analysis (Showgi 2011).

4. Results and Discussion

The study area is a broad, slightly sloping to undulating upland clay plains. The plains are dissected by Khors draining the Nuba Mountains hilly area, numoures low ridges (viens and dykes) separated by shallow depressions running through the area. The soils are formed insitu and on colluviums and alluvium derived from basement complex rocks. The origin of these clays is thought to belong to Quarternary alluvial deposits probably similar to other dark cracking clays of central Sudan (Pacheco and Dawoud, 1976).They form well developed Vertisols (Plates 1, 2, 3 and 40.

Field study showed, common surface vertical cracks 1 - 4 cm wide and 50 -100 cm deep, polygons and cracks of variable shape and dimensions were measured, surface gilgai microrelief were observed, soil color is dominantly very dark grayish brown (10YR 3/2) when moist throughout the profiles. The soils are of nearly uniform clay texture. Topsoil structure has loose granular mulch of thickness ranging from 3-5 cm, the subsoil has weak to moderate coarse and very coarse subangular blocky structure, below that the structure is massive. subsoil and substrata layers have parallelepiped and wedge shaped structure aggregates. Slickensides was also observed in all profiles, reflecting expansion and contraction upon wetting and drying of the soil. It was also noted the presence of fine and medium tubular pores, small and large whitish irregular $CaCO_3$ concretions, fine and medium sand grains and polished quartz pebblse arecommon.

Chemical and physical analyses of soil samples are represented by two profiles; AT004 and ME002. The results at profile AT004 (Table 3) show that the soil reaction is slightly alkaline in allprofiles, pH ranging between 7.4 to 8.3 increasing with depth. The soil is non – saline, ECe values ranges between 0.4 to 0.83 dS/m**.** It is also none – sodic as indicated by exchangeable sodium percentage (ESP) range is between 0.56 and 10.18. Cation exchange capacity is higher and it coincides with the clay content, increasing with depth, it ranges between 51 to 79.3 mel/100 g. Sodium Adsorption Ratio (SAR) range is 3.04 – 7.81. The soil is slightly - calcareous with low amount of $CaCO_3$ (5.2 – 8.9 %). Organic matter is low decreasing with depth (0.554 – 1.46 %). Total nitrogen is also low (0.02 – 0.059%). Nutrient status expressed as extractable cations meq/100 g soil is generally high: Ca^{++} range is 11.55 – 3.4; Mg^{++} 2.2 – 17.4; K^{+} 0.175 – 0.782; Na^{+} 0.41 – 5.45. Soil texture is clay throughout the profile. clay content increases with depth, then it decreases at the lowest horizon. range is (55.2 - 78 %), silt increases with depth, it ranges between 13.44 – 30.8 %, the sand fraction is higher in the top and lower horizons than in the two middle horizons, (8.26 – 24.66%). The textue of the lower most horizon 94 – 125 cm is relatively lighter as it has the highest sand content, a high silt content and the lowest clay content. it looks similar to the top – most horizon**.** The bulk density (BD) is relatively and high increasing with depth, (1.29 - 1.72 g\ cc). Porosity is relatively high at the topsoil decreasing with depth, ranges (33 – 51%) - (Tables 3).

Plate 1: Grass and Wood Land around Gadoom Al –Gattar Hill.

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Plate 2: Wood and Grass land vegetation (Acacia Seyal) on Flat Vertisols at AL – Terter Area

Table 3: Laboratory data for profile No. AT004

Depth Cm	Horizon	Particle size distribution %			pH paste	ECe dS\m	$CaCO_3$%	OC %
		Sand 2000-50	Silt 50-2	Clay <0.2				
0 – 22	A11	6.44	33.29	60.27	7.80	0.58	4.6	1.40
22– 68	A12	3.83	25.62	70.55	7.77	0.42	4.5	0.936
68 –94	A13	2.73	25.92	71.35	7.75	0.6	6.72	1.24
94-125	AC	10.63	31.00	58.37	7.82	0.65	6.5	1.08

N%	C/N ratio	CECmeq/100 g	ESP	SAR	Sat%	P%	B.D g\cc	Porosit%
0.030	46.6	63.94	0.569	5.21	54.4	0.030	1.42	47
0.025	37.4	64.17	1.175	4,41	61.49	0.030	1.63	39
0.027	45.9	73.36	7.306	5.3	53.5	0.019	1.68	37
0.020	54	72.82	7.333	5.76	59.3	0.020	1.74	35

Extractable cations, meq/100 g				Exch. Na	Saturation extract, soluble (meq/l) meq/100 g			
Ca^{++}	Mg^{++}	Na^{+}	K^{+}		Ca^{++}	Mg^{++}	Na^{+}	K^{+}
1.55	1.45	0.55	0.41	0.364	3	1.0	7.34	0.870
2.45	1.90	0.37	0.86	0.754	2	1.0	5.38	0.580
1.80	1.55	0.34	5.43	5.36	1	1.0	5.30	0.580
1.90	2,02	0.34	5.43	5.34	2	1.5	7.60	0.058

Saturation extract soluble (meq/ 100 g)						
cations						anions
Ca^{++}	Mg^{++}	K^{+}	Na^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}
0.163	0.054	0.040	0.046	0.0	0.122	0.144
0.123	0.061	0.036	0.106	0.0	0.122	0.153
0.053	0.053	0.031	0.069	0.0	0.093	0.080
0.110	0.089	0.034	0.083	0.0	0.110	0.133

Soil Taxonomy: Typic Haplusterts, isohyperthermic, fine clayey, montmorillonitic, calcareous (USDA 1999)

World Reference Base (WRB): Haplic Chromic Vertisols (Grumic/Mazic) – (FAO 2014)

The Chemical and physical analyses results forprofileME002 at Megeinis (Table 4) show that the soil reaction is slightly alkaline, pH ranging between 7.49 to 8.53 increasing with depth and the soil is none saline with ECe values ranges between0.45 to 0.68 dS/m.The soils are slightly and highly sodic; ESP range is between 10.61 and 36.07. Cation exchange capacity is high and it coincides with the clay content, increasing with depth, it ranges between 44.4 to 72.28 mel/100 g. Sodium.

Adsorption Ratio (SAR) range is 3.44 – 6.83. The soil is slightly calcareous with low amount of $CaCO_3$ (4.18 – 6.66 %).Organic matter is low decreasing with depth (0.52 – 1.34 %). Total nitrogen is also low (0.02 – 0.08%). Nutrient status expressed as extractable cations meq/100 g soil is

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generally high: Ca^{++} range is 38.74 – 69.99; Mg^{++} 13.74 – 19.99; K^{+} 0.481 – 0.613;Na^{+} 5.17 – 21.04.Soil texture is clay throughout the profile except in topsoil'**s** it is clay loam. Clay content increases with depth. range is between (33.2 – 65.24 %), silt decreases with depth, it ranges between 20.12 – 34.72 %, the sand fraction is higher in the top and decreases with depth, (4.10 – 32.08%). So texture – wise the higher horizon 0 – 25 cm is relatively lighter - texture, has the highest sand content, a high silt content and the lowest clay content.The bulk density almost (BD) is high increasing with depth, (1.44 - 1.71 g\ cc). Porosity is relatively high at the topsoil decreasing with depth, ranges (35.5 – 45.7%) - (Table 4).

Plate 3: Abandoned Cultivated Flat Land atMegeinis Area

Plate4: Regenerated Vegetation on Cultivated Flat Land (Vertisols) atMegenis Area

Table 4: Laboratory data for profile No. ME002

Depth Cm	Horizon	Particle size distribution %			pH paste	ECe dS\m	$CaCO_3$%	O C%
		Sand 2000-50	Silt 50-2	Clay <0.2				
0 - 26	A11	28.26	28.66	43.08	7.67	0.63	4.94	1.34
26 - 43	A12	16.04	25.92	58.04	8.03	0.62	5.58	0.72
43 – 87	A13	18.05	20.12	61.83	8.53	0.63	5.3	0.52
87 -125	AC	18.84	20.95	60.21	7.71	0.64	6.66	0.93

N%	C/N ratio	CEC	ESP	SAR	Sat%	P%	B.D g\cc	Porosity %
0.08	3.00	44.40	13.08	4.35	53.06	0.861	1.54	41.9
0.05	24.20	55.55	20.42	5.29	62.26	0.846	1.58	40.4
0.03	26.00	59.83	36.07	5.22	68.48	0.846	1.60	39.7
0.04	23.25	72.85	16.00	6.13	63.49	1.504	1.71	35.5

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Extractable cations meq/100g Exch.									
				Na Saturation extract soluble(meq/l) meq/100g					
Ca^{++}	Mg^{++}	K^{+}	Na^{++}		Ca^{++}	Mg^{++}	Na^{+}		K^{+}
6.75	1.37	0.481	5.912	5.80	1.3	0.75	5.420	0.40	
6.75	1.87	0.542	12.37	12.22	1.0	0.50	4.558	0.39	
6.50	1.62	0.613	21.04	20.83	1.0	0.50	4.490	0.66	
3.87	1.99	.0.553	11.776	11.66	1.0	0.50	5.280	0.56	

Saturation extract soluble (meq/ 100 g)						
cations				anions		
Ca^{++}	Mg^{++}	K^{+}	Na^{+}	CO_3^-	HCO_3^-	Cl^-
0.042	0.024	0.013	0.112	0.0	0.165	0.231
0.53	0.530	0.020	0.15	0.0	0.266	0.266
0.048	0.024	0.081	0.217	0.0	0.290	0.290
0.063	0.031	0.035	0.116	0.0	0.380	0.444

Soil Taxonomy: Typic Haplusterts, fine clayey, montmorillonitic, isohyperthermic, calcareous(USDA 1999)

World Reference Base (WRB): HaplicChromic Vertisols (Grumic/Mazic, sodic) –(FAO 2014)

5. Conclusions

This research was conducted to characterize and investigated the chemical, physical and morphological properties of cracking clays at Middle and Lower clay plains of Eastern Nuba Mountains. Ninesite locations were selected for this study; these sites were along a transect starting at the Middle clay plains (Al-Abbasyia and Terter area) and ending at Lower clay Plains (Megenis area) to compare the different types of clay soils in these plains.

Themorphological and surface features observations showed that the soils are dominantly cracking clay soils formed on sloping, undulating and flat clay plains. The surface features are characterized by common surface vertical cracks 1 - 4 cm wide and 50 -100 cm deep and forming polygons of variable shape and dimensions.Surface gilgai microrelief were observed at islated virgin areas. Soil color is dominantly by very dark grayish brown (10YR 3/2) when moist throughout the profiles. The soils are of nearly uniform clay texture. Topsoil structure has loose granular mulch of thickness ranging from 3-5 cm, the subsoil has weak to moderate coarse and very coarse subangular blocky structure, below that the structure is massive. subsoil and substrata layers have parallelepiped and wedge shaped structure aggregates. Slickensides was also observed in all profiles, reflecting expansion and contraction upon wetting and drying of the soil. fine and medium tubular pores, small and large whitish irregular $CaCO_3$ concretions and fine and medium sand grains, polish quartz pebble arecommon.

The analytical data for soils from middle clay plains (represented by profile AT004) reflected that the soil textures are dominantly very fine clay particles (> 60%). The soil reaction is slightly alkaline in allprofiles increasing with depth. The soil is non – saline and it is also none sodic as indicated by exchangeable sodium percentage (ESP) Cation exchange capacity is higher and it coincides with the clay content, increasing with depth. Sodium Adsorption Ratio (SAR) is low to moderate. The soilsare slightly calcareous with low amount of $CaCO_3$.Organic matter is low decreasing with depth and the total nitrogen is also low.Nutrient status expressed as extractable cations meq/100 g soil is generally high. Soil texture is clay throughout the profile, clay content increases with depth, silt increases with depth and the sand fraction is higher in the top and lower horizons than in the two middle horizons. The bulk density almost (BD) is high increasing with depth and porosity is relatively high at the topsoil decreasing with depth, ranges.

The analytical data for soils from lower clay plains (represented by profile ME002 reflected that the soil textures are dominantly very fine clay particles (> 60%) but slightly lower at topsoil (<45%). The soil reaction is slightly alkaline in all profiles, pH ranging between increasing with depth. The soils are none saline but slightly sodic and sodic as indicated by exchangeable sodium percentage (ESP. Cation exchange capacity is lower and it coincides with the clay content, increasing with depth. Sodium Adsorption Ratio (SAR) is low to moderate. The soil is slightly calcareous with low amount of $CaCO_3$. Organic matter is low decreasing with depth and the total nitrogen is also low. Nutrient status expressed as extractable cations meq/100 g soil is generally high.Soil texture is clay throughout the profile except in topsoil's it is clay loam. Clay content increases with depth. range is between, silt decreases with depth and the sand fraction is higher in the top and decreases with depth. The bulk density almost (BD) is high increasing with depth and porosity is relatively high at the topsoil decreasing with depth.

Although most of the cracking clay soils in Sudan are sharing similar origin (basaltic igneous materials) but their subsequent depositional processes, landscape geomorphology and local climate have affected their mineralogical, physical and chemical properties. This applies to the clay plains of Nuba Mountains as most soils are characterized by lower CEC, mild alkalinity and low calcium carbonate content. More research is required to investigate the behaviour of these soils under different land use types and management.

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