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Geomorphology and Soil Properties at the Upper Eastern Clay Plains of Nuba Mountains - South Kordofan, Sudan

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Abstract: ***This research study was carried to describe the geomorphology and characterize the soil properties at the upper clay plains located at the eastern parts of Nuba Mountains, Sudan. Soil samples were collected from nine profile pits along a transect stretching from Habila Rainfed Mechanized Scheme to Dalami through Terter (110 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 (Vail, J.R. 1973). 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 (ELTom 1972 and Dawoud 1974; 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 are common. The soil reaction is slightly alkaline in all profiles increasing with depth. The sois are non saline and none sodicon 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 illitic and montmorillonitic clay minerals. Sodium Adsorption Ratio (SAR) is low and the soils are 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.***

Keywords: Nuba Mountains, Upper Clay Plains, Geomorphology, Soil Properties

1. Introduction

In the Sudan, Vertisols occur on large tract of land, totalling perhaps 50 million ha in area, is divided naturally into four separated areas: the central clay plain (Gezira), the eastern clay plain (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 in extremely flat landscape of the other three clay plains (). 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. 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 (Ahmed, N. 1996). But some other clay, for instance, on undulating high plains in the Nuba Mountains uplands area indicate a non-alluvial origin.

The Nuba Mountains Vertisols are considered to be derived from the underlying bedrock (Pacheco and Dawoud1976). Therefore, it is expected that the parent materials at upper clay plains have undergone through a shorter pedo-genetic processes compared to those on low alluvial plains. 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. These soils are plastic, sticky and have moderately high-to-high cation exchange capacities and a high capacity to shrink and swell with changes in moisture (Mc. Garry, D. 1996). 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 characterize the soils and geomorphological set up at upper clay plains in Nuba Mountains, which provide information on soil forming processes and development. Since the Vertisols in Nuba Mountains region occur in topographic sequence of plains (upper, middle and lower plains); then the soil characterization provided by this study will lay the bases for the subsequent research efforts to study these soils(ELtom 1972, Dawoud 1974; Khodary 1978; Blockhuis*et al* 1964 and Elias *et al* 2001). .

2. The Study Area

The study area is located in the Northern part of the Nuba Mountains in South Kordofan State. The sampling transect (110 Km), starts from Habila scheme (Samasim - height 774 m asl) in the south west and ending eastward at Dalami (height 628 m asl). It has tropical semi – arid (steppe) zone of summer rain. The rainfall is comparatively high as the survey area lies within isohyets 600 - 800 mm (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 C^{o} with coldest months being from early December to the end February. In Habila, relative humidity is 70% in July - August and falls to 20 - 25 % during winter (Van der Kevie. 1973.)

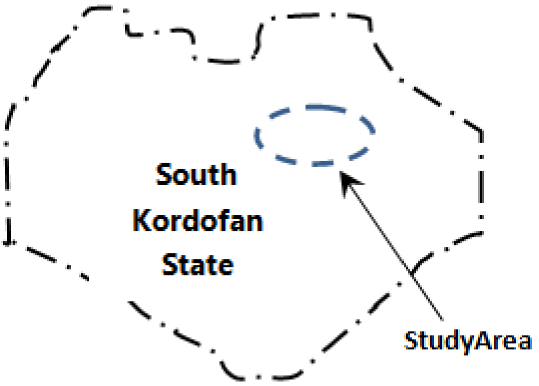


Figure 1: Location of Topographic Sequence at Northern Upper Clay Plains of Nuba Mountains

Table 1: Rainfall at the Study Area

Season	Dilling	Habila	Season	Dilling	Habila
1997 – 1998	564.5	460.5	2002 – 2003	727.5	695
1998 – 1999	840	840	2003 – 2004	526	566
1999 – 2000	735.5	488.6	2004 – 2005	606.2	513.5
2000 -2001	526.5	429	2005 – 2006	519.5	734
2001 – 2002	648.2	498	2006 – 2007	730	1143

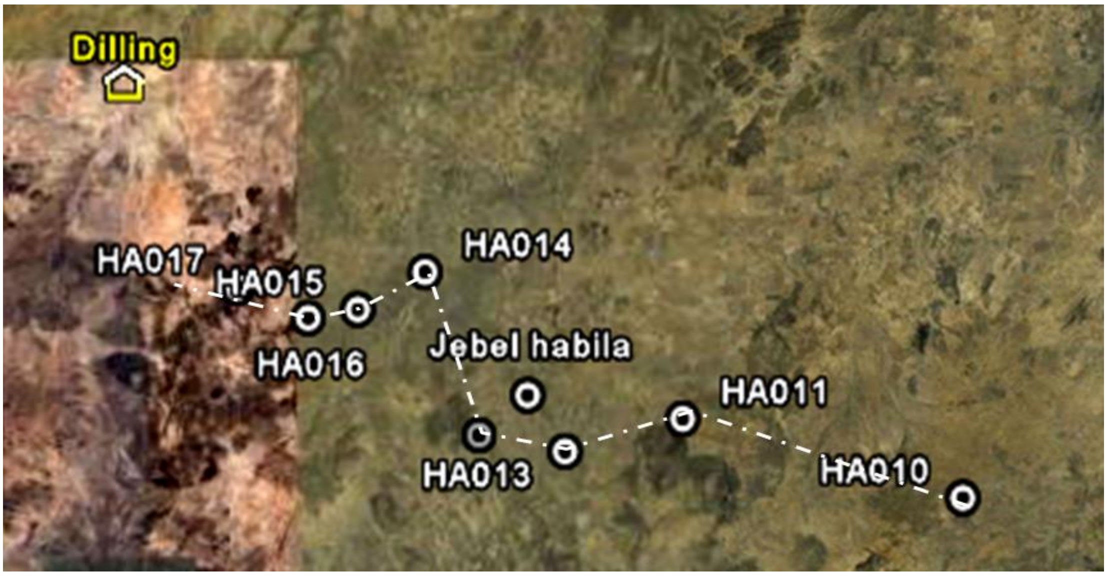
Source: Sudan Meteorological Authority

3. Materials and Methods

Trasect along the toposequence stretches in eastward direction from Habila scheme to Dalami. The area under study is situated between longitudes 32º40″ and 29º35″ East and latitudes 11º56″ and 12º09″ north. Eight 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.

Table 2: Soil Profile sites, location and elevation along the toposequence

Area	Sample site	North	East	Elevation (m)
Habila (intermountain upper clay plains)	HA017	11°53’06.00’’	29°35’47.00’’	774
	HA016	11°51’29.00’’	29°49’57.00’’	766
	HA015	11°51’58.00’’	29°52’56.00’’	747
	HA014	11° 3’54.00’’	29°56’54.00’’	734
	HA013	11°44’00.00’’	30°05’00.00’’	697
	HA012	11°45’01.00’’	30°01’04.00’’	663
	HA011	11°45’54.00’’	30°11’57.00’’	647
	HA010	11°51’46.00’’	30°28’14.00’’	628



HA017	HA016	HA015	HA014	HA013	HA012	HA011	HA010
Samasim	Habila 1	Habila 2	Habila 3	Fayo 1	Fayo 2	Fayo 3	Dalami

Figure 2: Showing Soil Profiles sites starting from Habila on the west to Dalami on the east

Eight profiles HA010, HA011, HA012, HA013, HA014,HA015, HA016 and HA017 were selected along the transect in the study area from Habila - Fayo toDalami (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 2014). 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) are separated by shallow depressions running through the area. The soils are formed insitu and on colluviums and alluvium materials 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.

Field study showed, common surface vertical cracks 1 - 7 cm wide and 50 -100 cm deep, polygons and cracks of variable shape and dimensions, 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 (Figure 2). 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 are common. These findings coincides well with the findings of Pacheco and Dawoud (1974**)** and EL-Tom (1972).

Figure 3: Slickensides and surface cracking of the vertisols of the study area

Chemical and physical analyses of soil samples are represented by two profiles; HA014 and HA011. The results at profile HA014 (Table 3) show that the soil reaction is slightly alkaline in all profiles, pH ranging between 7.41 to 7.63 increasing with depth. The soil is non – saline, ECe values ranges between 0.69 to 0.822 dS/m**.** It is also none – sodic as indicated by exchangeable sodium percentage (ESP) range is between 0.69 and 1.12. Cation exchange capacity is high and it coincides with the clay content, increasing with depth, it ranges between 70.88 and 71.96 mel/100 g. Sodium Adsorption Ratio (SAR) range is 6.80– 7.78. The soil is slightly - calcareous with low amount of $CaCO_3$ (8.7 – 9.7 %). Organic matter is low decreasing with depth (0.470 – 0.540 %). Total nitrogen is also low (0.021 – 0.024%). Nutrient status expressed as extractable cations meq/100 g soil is generally high: Ca^{++} range is 0.039 – 0.109; Mg^{++}0.039 – 0.073; K^{+} 0.007 – 0.010; Na^{+} 0.419 – 0.569. Soil texture is clay throughout the profile. clay content increases with depth, then it decreases at the lowest horizon. range is (70.70–76.53 %), silt increases with depth, it ranges between 16.33 – 20.20 %, the sand fraction is higher in the top and lower horizons than in the two middle horizons, (10.00 – 11.48%). The textue of the upper most horizon 0 – 19 cm is relatively lighter as it has the highest sand content, a high silt content and relatively lowe clay content. it looks similar to the horizon below it**.** The bulk density (BD) is relatively low and increases with depth, (1.41 - 1.51 g\ cc). Porosity is relatively high at the topsoil decreasing with depth, ranges (44 – 50%) - (Tables 3).

Figure 4: Vegetation (grasses and Acacia trees) in Habila Area

Figure 5: Fallow burned land at the edge of dense vegetation in Habila Area.

Table 3: Laboratory data for profile No. HA014

Depth Cm	Horizon	Particle size distribution (*u*) % Sand 2000-50	Silt 50-2	Clay <0.2	pH paste	E.C. e d S\m	$CaCO_3$ %	O C %
0 - 19	A11	11.48	18.62	70.90	7.41	0.69	9.7	0.505
19 - 52	A12	10.00	19.30	70.70	7.58	0.78	8.9	0.520
52 – 86	A13	07.14	16.33	76.53	7.60	0.73	8.7	0.470
86– 25	AC	05.44	20.20	73.36	7.63	0.82	9.2	0.540

N%	C/N ratio	CEC meq\100g soil	ESP	SAR	Sat %	P %	B.D (g per cc)	Porosity %
0.022	22.95	71.67	0.763	68	73.00	0.030	141	47
0.024	21.66	70.88	0.692	7.92	71.90	0.020	1.39	48
0.021	22.38	72.3	1.121	7.41	81.00	0.080	133	50
0.021	25.7	71.96	0.883	7.78	78.00	0.020	151	44

Extractable cations, meq/100 gExch Na Saturation extract, soluble (meq/l) meq/100 g								
Ca^{++}	Mg^{++}	K^{+}	Na^{+}		Ca^{++}	Mg^{++}	Na	K
23.35	11.40	0.177	1.08	0.547	1.5	1	7.31	0.14
23.15	11.49	0.141	1.06	0.491	1.0	1	7.92	0.11
22.70	11.50	0141	1.239	0.811	0.5	0.5	5.18	0.10
22.30	11.50	0141	1.06	0.636	0.5	0.5	5.44	0.10

Saturation extract soluble (meq/ 100 g) cationanions						
Ca^{++}	Mg^{++}	K^{+}	Na^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}
0.109	0.073	0.010	0.533	0.0	0.109	0.200
0.072	0.072	0.007	0.569	0.0	0.161	0.197
0.040	0.040	0.008	0.419	0.0	0.121	0.222
0.039	0.039	0.007	0.424	0.0	0.117	0.156

Soil Taxonomy: Typic Haplusterts, isohyperthermic, fine clayey, montmorillonitic, calcareous(USDA 2014)
World Reference Base (WRB): Haplic Chromic Vertisols (Grumic/ Mazic) – (FAO 2014)

The Chemical and physical analyses results forprofileHA011 at Fayo (Table 4) show that the soil reaction is slightly alkaline, pH ranging between 6.59 to 7.44 increasing with depth and the soil is none saline with ECe values ranges between0.61 to 0.88 dS/m.The soils are non- sodic; ESP range is between 1.36 and 3.49. Cation exchange capacity is high and it coincides with the clay content, increasing with depth, it ranges from68.43 to 78.36 mel/100 g. Sodium Adsorption Ratio (SAR) range is 5.56 – 8.69. The soil is slightly calcareous with low amount of $CaCO_3$ (5.7 – 9.7 %). Organic matter is low decreasing with depth (0.452 – 0.847 %). Total nitrogen is also low (0.025 – 0.035%). Nutrient status expressed as extractable cations meq/100 g soil is generally high: Ca^{++} range is 20.68 – 25.40; Mg^{++}8.6 – 12.25; K^{+} 0.33 – 0.39;Na^{+}0.925 – 2.52.Soil texture is clay throughout the profile except in topsoil'**s** it is clay loam. Clay content increases with depth. range is between (68.25 – 77.92 %), silt decreases with depth, it ranges between 8.0– 15.19 %, the sand fraction is higher in the top and decreases with depth, (11.30 – 16.56%). So texture at horizon 97 – 125 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, (1.27 - 1.59 g\ cc). Porosity is relatively high at the topsoil decreasing with depth, ranges (37 – 53%).

Table 4: Laboratory data for profile No. HA011

Depth Cm	Horizon	Particle size distribution (*u*) %			pH paste	ECe dS\m	$CaCO_3$ %	O C %
		Sand 2000-50	Silt 50-2	Clay <0.2				
0-22	A11	12.94	12.51	74.55	6.59	0.61	7.2	0.847
22-59	A12	14.08	8.00	77.92	7.35	0.88	5.7	0.452
59–97	A13	11.30	13.19	75.51	7.21	0.85	9.7	0.814
97–125	AC	16.56	15.19	68.25	7.44	0.74	5.9	0.724

N %	C/N ratio	CEC meq\100g soil	ESP	SAR	Sat %	P %	B.D (g per cc)	Porosity %
0.031	27.30	71.2	2.15	5.56	74.5	0.015	1.27	53
0.025	18.00	72.1	1.36	8.58	70.9	0.020	1.57	41
0.032	25.40	78.36	3.49	8.69	69.8	0.018	1.68	37
0.035	20.68	68.34	1.35	7.64	69.9	0.012	1.59	40

Extractable cations, meq/100 gExch Na Saturation extract,soluble(meq/l) meq/100 g								
Ca^{++}	Mg^{++}	K^{+}	Na^{+}		Ca^{++}	Mg^{++}	Na^{+}	K^{+}
27.30	12.25	0.358	1.08	1.533	2	1.6	7.35	0.7
18.00	10.9	0.39	1.08	1.072	2	1.5	11.33	0.5
25.40	8.6	0.39	3.26	2.520	2	1	10.61	0.5
20.68	7.75	0.33	1.63	0.925	2.5	1	10.09	0.87

Saturation extract soluble (meq/ 100 g) cationanions						
Ca^{++}	Mg^{++}	K^{+}	Na^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}
0149	0.119	0.052	0.547	0.0	0.150	0.218
0.141	0.106	0.035	0.844	0.0	0.177	0.124
0.139	0.069	0.034	0.790	0.0	0.129	0.162
0.174	0.069	0.055	0.751	0.0	0.174	0.157

Soil Taxonomy: Typic Haplusterts, isohyperthermic, fine clayey, montmorillonitic, calcareous(USDA 2014)
World Reference Base (WRB): Haplic Chromic Vertisols (Grumic/ Mazic) – (FAO 2014)

5. Conclusions

This research was conducted to characterize and investigated the chemical, physical and morphological properties of cracking clays at upper clay plains of Eastern Nuba Mountains. Eight site locations were selected for this study; these sites were along a long transect at the upper clay plains (Samasim -Habila) and ending at Dalami area so as to characterize and compare the different types of clay soils in these plains.

The morphological 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 HA014 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 soils are 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 HA011 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 (FAO 1970 and Khalil, A.R. 1986). 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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