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Elemental Composition and Weathering Indices of Selected Wetland Soils of Akwa Ibom State, Nigeria

AKPAN, U. S, & NKANGA, N. A
[1]Dept. of Soil Science and Land Resources Mgt.,
University of Uyo. Akwa Ibom State, Nigeria
Corresponding author:** ***Akpan U.S. (udyakpa2k2@yahoo.com)

ABSTRACT
Elemental composition and weathering indices of selected wetland soils of Akwa Ibom State were investigated with the aim of identifying elemental composition, the degree of weathering and stage of soil development for effective and sustainable soil management. Three wetland soil types (river floodplain, inland depression and coastal swamp) were selected for the study. In each of the wetland soil type, three soil profile pits were sited at representative location and described in accordance with FAO (1990) guidelines for soil profile description. Soil samples were collected based on genetic horizons for energy dispersive x-ray analysis (EDX / EDS). The results revealed that coastal swamp soils had the highest accumulation of SiO_2, followed by floodplain soils while inland depression had the least. Soils of inland depression had the highest accumulation of Al_2O_3, followed by floodplain soils while coastal swamp soils had the least. Soils of inland depression had 0.69 % K_2O, 5.46 % CO_2, 1.60 % F_2O and 0.23 % SO_2 in the subsurface horizons while floodplain soils had 0.98 % K_2O, 2.12 % CO_2, 2.69 % F_2O, 0.90 % MgO, 1.08 % CaO and 11.7 % Fe_2O_3 in the subsurface horizons. Based on the elemental composition of the B-horizon, soil development was more pronounced in river floodplain soils followed by inland depression while coastal swamp soils were less developed. Based on weathering index of Ruxton ratio, soils of inland depression were in advanced stage of weathering, followed by floodplain soils while soils of coastal swamp were in early stage of weathering. Based on the accumulation of forms of Fe and Al, soils of coastal swamp were in juvenile stage of soil development (younger soils) followed by inland depression while soils of river floodplain were in advanced stage of soil development (older soils). In term of soil fertility, river floodplain soils were more fertile, followed by inland depression, while coastal swamp soils were less fertile.
Keywords: Weathering indices, elemental composition, and wetland soil.

INTRODUCTION

Weathering is the process of alteration and breakdown of rocks and mineral grains (primary minerals) at and near the earth's surface by physical, chemical and biotic effects to form soil (secondary minerals) (Chittleborough, 1991). Mineral weathering during pedogenesis (pedon formation) results in translocation and accumulation of major elements in soils (Kabata-Pendias and Pedias, 1992). The wide range of elements concentrations observed in soils is the result of interaction between various factors affecting weathering and soil forming processes (Scarciglia *et al.* 2011; Achyuthan *et al.* 2012). The concentration of elements in soil is controlled solely by the degree of weathering and pedogenic processes. As the intensity of weathering and pedogenic processes increased, oxides of certain major elements such as Al_2O_3, Fe_2O_3 and TiO_2, considered as 'immobile', increases in the soil or remain constant while elements like Si_2O, Na_2O, K_2O, CaO and MgO, considered as 'mobile', decreased in the soil (Duzgoren-Aydın *et al*. 2002). Different elements exhibited different enrichment/depletion patterns in a given pedon based on the intensity of weathering and soil-forming processes. Therefore, the degree of weathering and soil-forming processes determines the fertilizer needs, lime requirements and general soil management for crop production.

Weathering indices have been used to quantify the degree of weathering and soil-forming processes, evaluate soil fertility, as well as understanding elemental mobility during weathering (Delvaux *et al*., 1989). Several weathering indices have been developed over the years to study the degree of in-situ weathering profile. Among them includes: Ruxton ratio (R), which relates silica loss to total element loss and considers alumina (and other sesquioxides) to be immobile during weathering (Chittleborough, 1991). Weathering Index of Parker (WIP) is based on the proportion of alkali and alkaline earth metals (Ca, Mg, Na and K) accumulation in horizon and take into account the individual mobilities based on their bond strength with oxygen (Humdan and Burnham, 1996). Chemical Index of Alteration (CIA) measures the extent of conversion of feldspars to clay such as kaolinite (Nesbitt and Young, 1982). Chemical Index of Weathering (CIW) is similar to CIA except that K_20 is eliminated from the equation because it does not account for Al associated with K-feldspar. As alternative to CIW, Plagioclase Index of Alteration (PIA) is used to monitor plagioclase weathering (Fedo *et al.*, 1995). As weathering progresses, index values of CIA, CIW and PIA increase while index values of R and WIP decreased (Fedo *et al.*, 1995). McKeague and Day, (1966) used profile distribution of different forms of Fe and Al oxides particularly dithionite and oxalate extractable Fe and Al as useful indicators to identify the horizon of accumulatiaon of secondary oxides (The Fe and Al released during the weathering of Fe and Al bearing parent materials are reprecipitated in the soils as oxides or hydroxides and oxyhydroxides of iron and aluminium). The quantities of these alternation products generally increase with soil age (Dolui and Bera, 2001) and their distribution in soil profiles indicate the stage and degree of weathering and soil development (Mahaney and Fahey, 1988). Therefore, comparative movement of silica and sesquioxide down the profile as well as their ratios calculated from the total composition of soils provide basis for understanding soil profile development in relation to parent material.

The alluvial soils developed *on* relatively recent depositions or the loessal soils represent some of the most productive wetland soils of the world. Their high potential fertility is due to their weathering conditions that are in the early stage of weathering and under the full expression of the influence of the factors of chemical weathering, thus facilitating the rapid decomposition of primary minerals and the release of essential elements. The reverse is the case in later (older) stages of weathering (Nesbitt and Young, 1982). Hence, elements are removed from or added to the soil profile during weathering. The understanding of the stage of weathering and elemental composition of the soil is essential for effective and sustainable soil and environmental management. Therefore, this study was conducted to assess the elemental composition and stage of weathering (weathering indices) of wetland soils of Akwa Ibom State for effective and sustainable soil and environmental management.

MATERIALS AND METHODS

The Study Area

The study was conducted in Akwa Ibom State, which lie within latitudes $4^0 30'$ and $5^0 30'$N and longitudes $7^0 30'$ and $8^0 20'$ E. The state is underlain mainly by coastal plain sands, beach ridge sands; sandstone / shale and alluvial deposits parent materials. The climate is humid tropical with annual rainfall of about 2500 -3000 mm with 1-3 dry months in the year. Mean annual temperature varies between 26-28^{0}C with relative humidity of 75-80 % (Petters *et al*., 1989).

Field Work

Three wetland types (river floodplain, inland depression and coastal swamp) were selected for the study. In each of the wetland type, three soil profile pits were sited at representative locations and described in accordance with FAO (1990) guidelines for soil profile description. Soil samples were collected based on genetic horizons. A total of nine profile pits were sampled.

Laboratory Analysis

The soil samples were air dried before grinding and sieved with a 2 mm sized sieve. The following routine analyses were carried out: **Particle size analysis** was determined using the bouyoucos hydrometer method as described by (Udo *et al.*, 2009). **Organic carbon** was determined by the dichromate wet-oxidation method as described by Nelson and Sommers (1996). The value was multiplied by 1.732 to obtain organic matter content. **Exchangeable bases**: Ca, Mg, Na, K. were extracted using normal ammonium acetate (Thomas1996). The exchangeable K and Na were determined by flame photometer while Ca and Mg were determined using atomic absorption spectrometer. **Effective cation exchange capacity (ECEC)** was determined by summing up exchangeable cations and exchangeable acidity. **Percentage base saturation** was calculated using the formula:

$$\% \text{ base saturation} = \frac{\text{Summation of exchangeable bases x 100}}{\text{CEC}}$$

Analysis of Elemental composition

The XR-D and SEM were carried out by the Laboratory analytical services of South China Agricultural University, Guanzhou, P.R. China. A Philips XL30 environmental scanning electron microscope (ESEM), equipped with a LaB6 filament, was used to image and elementally analyse the samples. The ESEM was operated in low-vacuum mode, at a pressure of between 0.5 and 0.7 Torr under a water vapour atmosphere. Other operational parameters were as follows: working distance 10mm, and operating voltage 20kV. Sample particles (<0.5mm) were packed into disks, pressed firmly and scanned. The particles were mounted on SEM stubs using adhesive carbon tape and analyzed at 10 kV, 50 Pa. Imaging was predominantly carried out in backscattered electron mode (BSE). Elemental analysis was carried out by energy dispersive x-ray analysis (EDX / EDS), under the same operational parameters as for imaging. EDX analysis was carried out at each analysis point for 100 live seconds, and the elements present were both qualitatively and quantitatively measured.

RESULTS AND DISCUSSIONS

Morphological, physical and chemical properties of the study area

The morphological, physical and chemical properties of the three wetland soil types (river floodplain, inland depression and coastal swamp soils) under consideration are presented in Tables 1 and 2.

River floodplain soils

The soils of the river floodplains were located on nearly level to flat (0-2 %) topography. The elevation varied from 22 to 23 masl underlined by alluvium parent material. The soil colour varied from dark brown (7.5YR 3/2) to brown (7.5YR 4/2) with fine common faint reddish yellow (7.5YR 6/8) and fine few faint strong brown (7.5YR 4/6) mottles in the surface horizons overlain light reddish brown (5YR 6/4) or dark grey (5YR 4/1) or grey (7.5YR 5/1) or pinkish grey (5YR 6/2) with strong brown (7.5YR 4/6) or yellowish red (5YR 5/6) or reddish yellow (7.5YR 6/6) mottles in the subsurface horizons. The soil texture of surface horizons was loamy sand and /or sandy loam overlain sandy clay loam or clay loam in the subsurface horizons. The soil structure of the surface horizons was weak medium granular or moderate medium granular overlain moderate medium subangular blocky or strong coarse subangular blocky or strong coarse angular blocky in the subsurface horizons. The consistence of the surface horizons was friable or firm (moist), slightly sticky and slightly plastic or sticky and plastic (wet) overlain firm (moist), sticky and plastic (wet). The pores varied from common coarse pores to many coarse pores in the surface horizons overlain common fine pores in the subsurface horizons. The horizon boundaries ranged from abrupt smooth or gradual wavy to gradual smooths boundaries in both surface and subsoil horizons. The sand fraction varied from 73 to 89 % in the surface horizons and 51 to 71% in the subsoil horizons. The silt fraction varied from 5 to 17% in the surface horizons and 7 to 17 % in the subsoil horizons. The clay fraction varied from 6 to 10% in the surface horizons and 18 to 32% in the subsoil horizons. Clay fraction was higher in the subsoil than surface soil, indicating clay illuvation (argeluviation process). The soil pH in water varied from 5.7 to 6.1 (moderately acid) in the surface horizons and 5.5 to 6.1 (strongly acid to moderately acid) in the subsoil horizons. The organic carbon varied from 2.0 to 3.1% (very high) in the surface horizons and 0.1 to 1.9 % (very low to moderate) in the subsoil horizons. Organic carbon decreases with depth. The available P varied from 8.8 to 37.9 mg/kg (moderate to high) in the surface horizons and 0.3 to 26.7 (very low to high) in the subsoil horizons. The ECEC varied from 15.5 to 27.8 cmol/kg (moderate to high) in the surface horizons and 14.7 to 25.8 cmol/kg (moderate to high) in the subsoil horizons. The base saturation varied from 11 to 21 % (very low to low) in the surface horizons and 7 to 21 (very low to low) in the subsoil horizons.

Inland depression soils

The soils of the inland depression were located on nearly level to flat (0-2 %) topography. The elevation varied from 26 to 56 masl underlined by coastal plain sand parent material. The soil colour varied from dark brown (7.5YR 3/2) to brown (7.5YR 4/2) with fine common faint reddish yellow (7.5YR 6/8) and/ or fine few faint strong brown (7.5YR 4/6) mottles in the surface horizons overlain brown (7.5YR 4/3) or light brown (7.5YR 6/3) or pinkish grey (5YR 6/2) with medium common distinct dark red (2.5YR 3/6) or fine common faint strong brown (7.5YR 5/8) and/ or reddish yellow (7.5YR 6/6) mottles in the subsoil horizons. The soil texture of surface horizons was loamy sand overlain sandy loam and / or sandy clay loam in the subsoil horizons. The soil structure of the surface horizons varied from weak fine granular to moderate medium subangular blocky overlain strong coarse angular blocky or weak medium angular blocky or weak medium subangular blocky structure in the subsoil horizons. The consistence of the surface horizons was friable (moist), non sticky and non plastic or slightly sticky and slightly plastic (wet) overlain firm, (moist), slightly sticky and slightly plastic (wet) in the subsoil horizons. The pores ranged from common coarse pores to many coarse pores in the surface horizons overlain common fine pores in the subsoil horizons. The horizon boundaries ranged from abrupt smooth, gradual wavy to gradual smooth boundaries in both surface and subsoil horizons. The sand fraction varied from 83 to 87 % in the surface horizons and 67 to 93 % in the subsoil horizons. The silt fraction varied from 3 to 5 % in the surface horizons and 1 to 13 % in the subsoil horizons. The clay fraction varied from 8 to 12% in the surface horizons and 6 to 21% in the subsoil horizons. Clay fraction was irregularly distributed with depth. The soil pH in water varied from 6.2 to 6.5 (slightly acid) in the surface horizons and 6.2 to 6.7 (slightly acid to neutral) in the subsoil horizons. The organic carbon varied from 0.7 to 2.3% (low to high) in the surface horizons and 0.6 to 2.4 % (low to high) in the subsoil horizons. Organic carbon was irregularly distributed with depth. The available P varied from 37.3 to 66.2 mg/kg (high to very high) in the surface horizons and 6.9 to 85.7 (very low to very high) in the subsoil horizons. The ECEC varied from 8.3 to 12.2 cmol/kg (low to moderate) in the surface horizons and 7.4 to 18.9 cmol/kg (low to moderate) in the subsoil horizons. The base saturation varied from 7 to 10% (very low) in the surface horizons and 4 to 17 (very low) in the subsoil horizons.

Coastal swamp soils

The soils of the coastal swamp were located on nearly level to flat (0-2 %) topography. The elevation varied from 10 to 15 masl underlined by marine alluvium parent material. The soil colour varied from brown (7.5 YR 4/3) to Strong brown (7.5YR 4/6) with fine common distinct red (2.5YR 4/8) and/ or fine few faint reddish yellow (7.5YR 6/8) mottles in the surface horizons overlain pink (7.5YR 7/3) or very dark grey (7.5YR 3/1) or reddish yellow (7.5YR 7/6) with fine few faint red (2.5YR 4/8) or medium many prominent yellowish red (5YR 4/6) or fine few faint reddish yellow (7.5YR 6/8) mottles in the subsoil horizons. The soil texture varied from sand to loamy sand in both surface and subsoil horizons. The soil structure varied from weak medium granular to moderate medium subangular blocky overlain structureless or weak medium granular in the subsoil horizons. The consistence of the surface horizons was friable (moist), non sticky and non plastic (wet) overlain loose and / or friable (moist), non sticky and non plastic (wet) in the subsoil horizons. The pores ranged from many coarse pores to many very coarse pores in both surface and subsoil horizons. The horizon boundaries ranged from abrupt smooth to clear smooth boundaries in both surface and subsoil horizons. The sand fraction varied from 87 to 91 % in the surface horizons and 87 to 92% in the subsoil horizons. The silt fraction varied from 1 to 6% in both surface horizons and subsoil horizons. The clay fraction varied from 7 to 8% in the surface horizons and was 7% in the subsoil horizons. Clay fraction was irregularly distributed with depth. The soil pH in water varied from 5.7 to 6.3 (moderately acid to slightly acid) in the surface horizons and 4.3 to 6.6 (extremely acid to neutral) in the subsoil horizons. The organic carbon varied from 1.7 to 2.3% (moderate to high) in the surface horizons and 0.2 to 3.3 % (very low to very high) in the subsoil horizons. Organic carbon was irregularly distributed with depth. The available P varied from 2.4 to 14.7 mg/kg (very low to moderate) in the surface horizons and 2.1 to 9.1 (very low to moderate) in the subsoil horizons. The ECEC varied from 9.8 to 12.8 cmol/kg (low to moderate) in the surface horizons and 7.8 to 24.5 cmol/kg (low to moderate) in the subsoil horizons. The base saturation varied from 3 to12 % (very low) in the surface horizons and 3 to 29 (very low to low) in the subsoil horizons.

Table 1: Morphological properties of soils of the study area

Pedon / Location	Horizon Designation	Depth (cm)	Colour (moist)	Mottles	Texture[1]	Structure[2]	Consistency (Moist)[3]	Consistency (Wet)[4]	Root[5]	Pores[6]	Boundary[7]
					Floodplain soils						
Ibam Ukot	AP	0 - 14	7.5YR 4/3	None	S	w m, gr	Fi	SS, SP	f f	c c	a,s
(FP)	Bt_1	14 - 30	5YR 6/4	7.5YR 4/6	SL	m m, sbk	Fi	S, P	-	c c	g,w
	Bt_2	30 - 110	5YR 4/1	5YR 5/6	SCL	m m, sbk	Fi	S, P	-	c m	
Ekoi	Ap	0 - 13	7.5YR 3/3	7.5YR 6/8	LS	m m, gr	Fi		f f	m c	a,s
(FP)	Bt_1	13 - 30	7.5YR 5/1	7.5YR5/8	SL	s c, sbk	Fi	S, P	-	m c	g,s
	Bt_2	30 - 120	7.5YR 7/1	7.5YR 6/6	SCL	s c, sbk	Fi	S, P	-	c m	
Ikpe Ikot Nkon	AP	0 - 20	7.5YR 4/3	7.5YR 4/6	SL	m m, gr	Fr	S, P	m f	m c	a,s
(FP)	B_1t_1	20 - 60	7.5YR 4/1	5YR 6/6	LS	s c, sbk	Fi	S, P	m f	m c	a,s
	B_2t_1	60 - 90	5YR 6/2	5YR 5/8	SCL	s c, sbk	Fi	S, P	-	c m	g,s
	B_3t_2	90 - 140	5YR 6/1	5YR 5/8	CL	s c, sbk	Fi	S, P	-	c f	
					Inland Depression soils						
Ikot okoro	Ap	0-12	7.5YR 3/2	5YR 4/6	LS	w f, gr	Fr	SS, SP	c f	m c	a, s
(ID)	AB	12-40	7.5YR 4/3	2.5YR 3/6	LS	w f, gr	VFr	S,P	m f	m c	s, s
	C_1	40-95	7.5YR 7/3	None	S	ma	L	NS,NP	m f	m, v c	s, w
	C_2	95-130	7.5YR 4/1	2.5YR 3/6	SL	m m, gr	Fi	S, P	-	m c	
Ndot	Ap	0-15	7.5YR 4/2	7.5YR 5/8	LS	w f, gr	Fr	SS, SP	f m	m c	a, s
(ID)	AB	15-50	7.5YR 7/1	7.5YR 5/8	LS	m m, sbk	Fr	SS, SP	f m	m c	a, s

	Bt	50-90	7.5YR 6/3	2.5YR 4/8	SL	s c, abk	Fr	SS, SP	-	m c	a, s
	C	90-130	7.5YR 6/4	7.5YR 5/8	LS	s c, abk	Fr	SS, SP	-	m c	
Ikot Akpaetok	Ap	0-20	7.5YR 5/1	None	LS	w m, sbk	VFr	NS,NP	m f	m c	c, s
(ID)	AB	20-74	7.5YR 6/2	None	S	w m, sbk	Fr	NS,NP	f m	m c	g, s
	Bt_1	74-132	7.5YR 7/2	7.5YR 5/6	SL	w m, abk	Fr	S, P	-	c c	g, s
	Bt_2	132-180	7.5YR 7/1	7.5YR 6/8	SCL	s c,abk	Fi	SS, PP	-	c m	
					Coastal swamp soils						
Uta-ewa	Ap	0-15	7.5YR 5/2	None	LS	m m, sbk	Fr	NS,NP	f f	m c	a, s
(CS)	AB	15-55	7.5YR 4/3	2.5YR 4/8	LS	m m, sbk	Fr	SS, SP	m m	m c	c, s
	B	55-90	7.5YR 7/3	2.5YR 4/8	S	ma	L	NS.NP	m m	m, v c	c, s
	BC	90-130	7.5YR 3/1	None	S	s c, abk	Fi	NS,NP	c f	m, v c	
Ikot Okwo	Ap	0-15	7.5YR 4/6	5YR 4/6	S	w m, gr	Fr	SS, SP	m f	m, v c	a, s
(CS)	B	15-26	7.5YR 7/6	5YR 4/6	S	ma	L	NS,NP	f f	m, v c	a, s
	Bg	26-50	7.5YR 5/2	5YR 4/2	LS	w m, gr	Fr	SS, SP	f f	m c	c, s
	C	50-120	7.5YR 3/2	None	S	s c, sbk	Fi	SS, SP	f f	m, v c	
Odu Ebughu	Ap	0-10	7.5YR 4/4	7.5YR 6/8	S	w m, gr	Fr	NS,NP	m m	m, v c	a, s
(CS)	B	10-45	7.5YR 7/4	7.5YR 6/8	S	ma	L	NS,NP	m f	m, v c	a, s
	C	45-80	7.5YR 5/1	7.5YR 6/8	S	ma	Fr	NS,NP	f f	m, v c	

1. S = Sand, SL = Sandy loam, SLC =Sandy clay loam, LS = Loamy sand, CL =Clay loam

1. w m=weak medium, m m=moderate medium,s c= strong coarse, w f = weak fine, w m=weak medium, gr= granular,
2. sbk=subangular blocky, abk=angular blocky, ma=massive (structurekless)
3. Fr= Friable, Fi= Firm, loose
4. S=Sticky, P=plastic, SS=Slightly sticky, SP=Slightly plastic, NS=Non sticky, NP=Non plastic
5. f f= few fine, m f= many fine, c f= common fine, f m= few medium, m m= many medium
6. c c= common coarse, common medium, m c=many coarse, c f= common fine, m vc= many very coarse
7. a s=abrupt smooth, c s= clear smooth, s m=sharp smooth, s w= sharp wavy, g s= gradual smooth

FP = River floodplain soils, ID = Inland depression soils CS = Coastal swamp soils

Table 2: Some physico- chemical properties of soils of the study area

Pedon / location	Hor.	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class	pH (H_2O)	Org. C . (%)	Av. P (mg/kg)	ECEC (cmol/kg)	Base Sat. (%)
			Floodplain soils								
	AP	0 - 14	89	5	6	Sand	5.70	3.29	8.81	20.58	11
(Ibam Ukot)	Bt_1	14 - 30	71	11	18	SL	5.60	3.23	26.7	16.14	8
	Bt_2	30 - 110	67	11	22	SCL	5.70	3.29	0.27	15.69	7
	Ap	0 - 13	87	7	6	LS	6.10	3.52	30.71	15.49	13
(Ekoi)	Bt_1	13 - 30	69	11	20	SL	6.10	3.52	12.28	17.32	16
	Bt_2	30 - 120	61	13	26	SCL	6.00	3.46	9.80	18.80	16
	AP	0 - 20	73	17	10	SL	5.80	3.35	37.91	27.84	21
(Ikpe Ikot	B_1t_1	20 - 60	59	15	26	LS	5.80	3.35	25.10	14.68	12
Nkon)	B_2t_1	60 - 90	67	7	26	SCL	5.70	3.29	18.69	16.25	11
	B_3t_2	90 - 140	51	17	32	CL	5.50	3.18	6.41	25.80	21
			Inland Depression soils								
	Ap	0-12	87	5	8	LS	6.20	3.58	37.32	12.15	10
(Ikot okoro)	AB	12-40	81	7	12	LS	6.30	3.64	46.65	18.91	17
	C_1	40-95	93	1	6	Sand	6.70	3.87	27.06	10.10	9
	C_2	95-130	73	13	14	SL	6.20	3.58	6.94	7.36	4
	Ap	0-15	87	3	10	LS	6.50	3.75	66.24	11.50	10
(Ndot)	AB	15-50	87	5	8	LS	6.50	3.75	89.02	14.39	12
	Bt	50-90	75	11	14	SL	6.20	3.58	81.17	11.83	8
	C	90-130	81	11	8	LS	6.30	3.64	85.70	11.38	9
	Ap	0-20	83	5	12	LS	6.20	3.58	48.52	8.33	7
(Ikot Akpaetok)	AB	20-74	91	1	8	Sand	6.20	3.58	23.25	12.65	10
	Bt_1	74-132	81	6	13	SL	6.40	3.70	71.84	7.73	6
	Bt_2	132-180	67	12	21	SCL	6.30	3.64	47.58	17.01	12

			Coastal Swamp soils								
	Ap	0-15	87	6	7	LS	6.30	3.64	2.94	12.83	13
(Uta-ewa)	AB	15-55	87	6	7	LS	6.10	3.52	6.41	7.84	8
	B	55-90	92	1	7	Sand	4.30	2.48	3.20	18.70	19
	BC	90-130	92	1	7	Sand	6.50	3.75	3.74	13.26	13
	Ap	0-15	91	2	7	Sand	5.70	3.29	14.69	9.79	10
(Ikot Okwo)	B	15-26	92	1	7	Sand	6.10	3.52	9.08	24.50	25
	Bg	26-50	87	6	7	LS	6.60	3.81	6.14	15.25	5
	C	50-120	92	1	7	Sand	6.10	3.52	2.67	14.40	4
	Ap	0-10	91	1	8	Sand	5.90	3.41	2.40	11.59	12
(Odu Ebughu)	B	10-45	92	1	7	Sand	5.80	3.35	2.14	11.74	12
	C	45-80	92	1	7	Sand	5.80	3.35	2.94	12.25	12

Elemental composition of soils of the study area

The elemental compositions of soils of the study area are presented in Table 3. The mean SiO_2 content of soils of inland depression was 37.8% in the surface soil and 25.4 % in the subsoil. In soils of river floodplain, mean SiO_2 content was 55.4 % in the surface soil and 27.3% in the subsoil. In soils of coastal swamp, mean SiO_2 content was 50.3 % in the surface soil and 45.3 % in the subsoil. The concentrations of SiO_2 decreases with depth in all the wetland types, indicating little or no loss or leaching of the element as SiO_2 is considered as 'mobile element' in the soil and is not a major component of organic matter (Duzgoren-Aydın *et al*. 2002). Some of the free silicon ions that existed during weathering of the rocks formed clay minerals and the others moved away as colloid in a solution. (Sidhu *et al*., 2000). Coastal swamp soils had the highest accumulation of SiO_2 in both surface and subsoil, followed by river floodplain soils while inland depression had the least. The high accumulation of SiO_2 content of the coastal swamp soils compared to others could be attributed to the high sand fraction of coastal swamp soil with high quartz bearing mineral (Gardner, 1992).

The mean Al_2O_3 content of soils of inland depression was 22.2% in the surface soil and 20.3 % in the subsoil. In soils of river floodplain, mean Al_2O_3 content was 14.2 % in the surface soil and 15.9 % in the subsoil. In soils of coastal swamp, mean Al_2O_3 content was 6.0 % in the surface soil and 3.8 % in the subsoil. The concentration of Al_2O_3 decreases with depth except in river floodplain in which the content of Al_2O_3 increases with depth. The accumulation of Al_2O_3 in the B-horizon of soils of river floodplain is an indication of the mobilization of Al_2O_3 within the profile due to active soil forming processes (Sidhu *et al*., 2000). The mean Al_2O_3 content was 21.3% in soils of the inland depression, 15.1% in the floodplain soils and 4.9 % in the coastal swamp soils. Soils of inland depression had the highest accumulation of Al_2O_3 content, followed by floodplain soils while coastal swamp soils had the least. The high accumulation of Al_2O_3 content of soils of inland depression is an indication of the high content of gibbsite bearing mineral in the soil (Gardner, 1992).

Soils of inland depression had 0.69 % K_2O, 5.46 % CO_2, 1.60 % F_2O and 0.23 % SO_2 in the subsoil horizons. The oxides of these elements (K_2O, CO_2, F_2O and SO_2) increased down the profile suggesting loss of these elements from the A- horizon to the B- horizon (Burt *et al*., 2003). Floodplain soils had 0.98 % K_2O, 2.12 % CO_2, 2.69 % F_2O, 0.90 % MgO, 1.08 % CaO and 11.7 % Fe_2O_3 in the subsoil horizons, indicating loss of these elements from the A- horizon to the B- horizon. Coastal swamp soils had 5.0 % CO_2, 2.0 % F_2O in the subsoil suggesting loss of these elements from the A-horizon to the B- horizon. The total base percentage (CaO + MgO + K_2O +Na_2O) was 0.69 % in soils of inland depression, 3.04 % in soils of river floodplain and 0% in soil of coastal swamp. The 0 % total base percentage of coastal swamp soils is an indication of juvenile stage of pedogensis. The high content of Fe_2O_3 in the B-horizon of floodplain soils (about 11.7 %) than the surface horizon could be attributed to Fe- migration from the A-horizon to B-horizon (cheluviation process), indicating active soil forming processes (Burt *et al*., 2003). The presence of these elements and Al_2O_3 and SiO_2 in the B-horizon is an indication of the presence of minerals such as K-feldspar, kaolinite, fluorite, carbonate, bucite, calcite and hematite in the study area that have been subjected to weathering and pedogenic processes. Based on the elemental composition of the B-horizon, pedogenic processes is more active and pronounced in floodplain soils followed by inland depression, while it is less active in coastal swamp soils. Fertility wise, floodplain soils are considered to be more fertile, followed by inland depression, followed by coastal swamp soils.

Weathering index

Weathering index of the study area are presented in Table 3. Ruxton ratio (SiO_2 / Al_2O_3) was 1.7 in the Ap- horizon and 1.2 in the B-horizon of soils of inland depression. In river floodplain soils, Ruxton ratio was 3.9 in the Ap- horizon and 1.7 in the B-horizon. In coastal swamp soil, Ruxton ratio was 8.3 in the Ap- horizon and 11.8 in the B-horizon. Ruxton ratio was higher in the surface horizon than subsoil horizon except coastal swamp soils that the reverse was the case. The mean Ruxton ratio of both surface and subsoil horizons of soils of inland depression was 1.5, soils of river floodplain was 2.8 while soil of coastal swamp was 10.1. According to Fedo *et al.*, (1995), as weathering progresses, Ruxton ratio decreases. Based on Ruxton ratio, soils of inland depression had the lowest ratio indicating advanced stage of weathering, followed by floodplain soils while soils of coastal swamp had the highest ratio indicating juvenile stage of weathering. The juvenile stage of weathering of coastal swamp soils compared to others could be attributed to the source of materials which are mostly transported sediments with high quartz content and are deposited in different cycles. Similar observation was reported by Raghu Mohan and Rao (1981) in some alluvial-derived soils of India.

Forms of Fe and Al and their ratios

Forms of Fe and Al and their ratios are presented in Table 3. In all the wetland types, the concentrations of crystalline and amorphous Fe was higher than that of Al in both surface and subsoil. The ratios of amorphous Fe to crystalline Fe and amorphous Al to crystalline Al varied from 0.9 to 1.3 (mean 1.1) in the surface soil and 1.1 to 1.6 (mean 1.4) in the subsoil of inland depression. In river floodplain soils, the ratios varied from 0.4 to 0.9 (mean 0.7) in the surface soil and 0.9 to 1.1 (mean 1.0) in the subsoil. In coastal swamp soils, the ratios varied from 1.1 to 1.6 (mean 1.4) in the surface soil and 1.0 to 2.5 (mean 1.8) in the subsoil. According to Mahaney *et al*, (1991), soils with high ratios are younger soils while low ratios are older soils. Based on these ratios, soils of coastal swamp had higher ratios in both surface and subsoil, indicating juvenile stage of soil development (pedogenesis) (younger soils). This is followed by soils of inland depression while soils of river floodplain had the least ratios, indicating advanced stage of soil development (pedogenesis) (older soils) with well-defined pedogenic horizons. Generally, crystalline form of Fe and Al was more in soils of river floodplain while amorphous form was more in soils of coastal swamp and inland depression with few exceptions.

CONCLUSION

The study revealed that coastal swamp soils had the highest accumulation of SiO_2 content, followed by floodplain soils while inland depression had the least. Soils of inland depression had the highest accumulation of Al_2O_3 content, followed by floodplain soils while coastal swamp soils had the least. Soils of inland depression had accumulation of K_2O in the subsurface horizons while floodplain soils had accumulation of K_2O, MgO, CaO and Fe_2O_3 in the subsurface horizons. Based on the elemental composition of the B-horizon, soil development was pronounced in floodplain soils followed by inland depression, while coastal swamp soils were less developed. Based on weathering index of Ruxton ratio, soils of inland depression were in advanced stage of weathering, followed by floodplain soils while soils of coastal swamp were in early stage of weathering. Based on the accumulation of forms of Fe and Al, soils of coastal swamp were in juvenile stage of soil development (younger soils). This is followed by soils of inland depression while soils of river floodplain were in advanced stage of soil development (older soils). In term of soil fertility, river floodplain soils were more fertile, followed by inland depression, while coastal swamp soils were less fertile.

Table 3: Elemental composition of soils of the study area

Wetland Type	Horizon	Chemical Composition																
		SiO_2 (Quartz)	Al_2O3 (Gibbsite)	SO_2	K_2O	Co_2 (carbonate)	F_2O	MgO (periclase)	Ca_2O	Fe_2O_3 (Hematite)	Crystalline Fe	crystalline Al	Amorphous Fe	Amorphous Al	Fe_o/Fe_d	Al_o/Al_d	Ruxton ratio	Likely Mineral
Inland Depression	Ap	37.80	22.22	-	-	-	-	-	-	-	0.136	0.053	0.117	0.070	0.9	1.3	1.7	Kaolinite
Mean	B	25.35	20.30	00.23	00.69	05.46	01.60	-	-		0.124	0.047	0.194	0.054	1.6	1.1	1.2	K-Feldsper Fluorite Pyrites
Floodplain	Ap	55.40	14.16	-	-	-	-				0.179	0.110	0.153	0.039	0.9	0.4	3.9	Kaolinite
Mean	B	27.33	15.86	-	00.98	02.12	02.69	00.90	01.08	11.72	0.116	0.058	0.133	0.054	1.1	0.9	1.7	Orthoclase Fluorite Calcite
Coastal swamp	Ap	50.25	06.04	-							0.127	0.049	0.142	0.076	1.1	1.6	8.3	Kaolinite
mean	B	45.32	03.83	-		05.04	01.99				0.143	0.060	0.150	0.151	1.0	2.5	11.8	Fluorite Kaolinite

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