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SPATIAL AND TEMPORAL VARIABILITY IN SOIL PROPERTIES OF HYDRIC SOILS IN THE LOWER NIGER REGION

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Abstract: The availability of essential nutrients for plant growth has a strong influence on which plants are reliant in wetlands. The study aimed at determining the distribution of Fe and Zn fractions as imperative to aid proactive decisions for intensified and sustainable agricultural use of wetland soils. Saturated soils vary in their textural characteristics which depend primarily on their genesis and location. Low electric conductivity (Ec) values of <1 dSm^{-1} observed within the study area indicate low soluble ions and low saline nature of the soils. Soil reaction (pH) has been slightly acidic across the soils and ranged from 6.42 to 6.23. Organically Bound Zinc Fraction (OrgZn) has been moderate to low and varied between 2.66 to 0.24 $mgkg^{-1}$ for surface soils.

Keywords: ecosystem, hydrophytes, soil health, soil properties, vegetation, wetlands

Introduction:

Wetland ecosystems are sites of rapid biogeochemical cycling due to the interactions between the oxic soil surfaces and deeper anoxic soils (Weiss et al. 2003). Wetland soils are soils formed of a variety of parent materials that are commonly associated with saturated moisture conditions (Mitsch and Gosselink 2000). Wetlands are heterogeneous environments which can exhibit substantial spatial and temporal variability in soil properties. Ogban et al. (2011) described wetlands as terrestrial ecosystems subjected to excessive wetness and poor drainage for a considerable period of the year to the extent that the wet conditions influence the possible land use. Wetlands are widely distributed throughout the world in all climates and are usually characterized by the presence of hydrophytic vegetation, wetland hydrology and hydric soils (Cowardin et al. 1979; Mitsch and Gosselink 2000). Wetland soils or hydric soils are soils with aquic soil moisture regime (Soil Survey Staff 1999). The occurrence of hydric soils is conditioned by hydrology, lithology, physiography, rainfall amount and distribution pattern (Ogban et al. 2011). Wetlands have multifarious potentials as seen in other parts of the world (Ojanuga et al. 1996). Izac et al. (1990) and Ogban et al. (2011) reported that wetlands are reputable for producing over 90% of the crops grown on upland farms, suggesting that the potentials of wetlands can be used

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for agricultural production on a sustainable basis.

Saturated soils develop several unique morphological characteristics as a result of several oxidation-reduction reactions influenced by the nature and content of the organic matter, temperature (Ann et al. 2000), the nature and content of electron acceptors and pH (Ponnamperuma 1972). The development of hydric soils is driven by anaerobic conditions and an active microbial biomass (Vepraskas 2001).

The reduction of a submerged soil proceeds roughly in the sequence predicted by thermodynamics (Ponnamperuma 1972). Irmak et al. (2008) revealed that in oxygen depleted soils, facultative and force anaerobic microbes become ascendant, utilizing oxidized forms of nitrogen (N), manganese (Mn), iron (Fe), sulfur (S), and carbon (C) as terminal electron acceptors. The redox potential (Eh) of soils controls the stability of various oxidized components [oxygen, nitrate, manganese (Mn IV), ferric (Fe III) iron, sulphate (SO_2^{-4}), and carbon dioxide] in submerged soils and sediments (Sahrawat 2005).

Sahrawat and Narteh (2002) showed that in submerged soils, the soil electric conductivity (E_C) solution was highly correlated with the total concentration of macro and micronutrient elements released in the soil solution.

Narteh and Sahrawat (1999) reported that, mean E_C value of the soil solution was significantly correlated with the mean total concentration of Ca, Mg and K in the soil solution in saturated soils. Fe reduction has important chemical consequences which affect the soil's pH, electrical conductivity, cation exchange capacity, sorption and desorption processes, the increase in the solubility of phosphates and silica and the formation of new minerals (Ponamperuma 1972; DeLaune and Reddy 2005).

Sahrawat (2005) showed that at four weeks after soil saturation, the pH of the soil could be predicted from the soil solution redox potential and the concentration of Fe (II) in the soil solution by the following equation: $Eh = 409 - 4.09 \log Fe^{2+} - 59 pH$; $R^2 = 0.99$.

The pH value in submerged soils profoundly influences the hydroxide, carbonate, sulfide, phosphate, and silicate equilibrium (Ponnamperuma 1972). Uddin et al. (2012) concluded that the decomposition and mineralization of organic matter are interrelated with successive changes in the chemical reduction of the soils resulting in the lowering of redox potential and changes of pH to near neutrality. In reduced soil conditions, ferrous iron can form minerals such as siderite, vivianite or iron sulfide under weakly acidic to neutral conditions (Straub et al. 2001). Under the submerged conditions, Zn is transformed into amorphous sesquioxide precipitates or franklinite ($ZnFe_2O_4$) (Sajwan and Lindsay 1988). Alloway (2004) reported that the occurrence of insoluble Zinc sulphide in soils with strongly reducing conditions may be partly responsible for the low availability of Zn in soils. Fluctuating aerobic and anaerobic conditions of soils and sediments can also cause transformation of crystalline Al and Fe compounds to more amorphous forms under anaerobic conditions (Sah and Mikkelsen 1986a, 1986b).

The reduction and dissolution of iron and its reprecipitation to form ferrous minerals ($Fe_3 (PO_4)_2$) is thought to be the dominant process controlling P solubility. In anaerobic systems featuring a strong reductive condition in oxygen depleted soils depressed the availability of various nutrients. Hydric soils were emphasized to supplement the uplands due to population growth and rising food demands (Obi 1996), infrastructural developments and their declining fertility status. Little studies have been made on wetlands which represent a considerable impediment for their utilization on sustainable basis. Hydric soils pose management challenges when utilized for cultivation of crops particularly with regards to soil acidity, nitrogen transformation, organic matter decomposition and transformation of Iron, manganese and sulphur. Therefore, the objective of working in this soil was to carry out proper inventory of submerged soils in the lower region of South Eastern Nigeria and to determine the distribution of Fe and Zn fractions as imperative to aid proactive decisions for intensified and sustainable agricultural use of wetland soils.

Materials and methods:

Environment of study

This study has been conducted in selected wetland soils in Akwa Ibom State, southeastern Nigeria. Akwa Ibom State has a land area of 8,412 square kilometers. The area lies between latitudes 4° 30' and 5° 30' North and longitudes 7° 30' and 8° 30' East.

Climate

Akwa Ibom State enjoys a warm tropical climate that is influenced by the interaction of two air masses:

- the northeast trade winds (the tropical continental air mass);
- the southwest winds (moist tropical marine air mass) (Iloeje 2001).

According to Ibanga and Armon (1992), the area is typical of a rain forest climate characterized by relatively high temperature values throughout the year, with the mean annual temperatures varying between about 26 °C to 36 °C.

Hydrology and Soil

Akwa Ibom State comprises mainly low-lying plain as well as riverine areas with no portion exceeding 175 meters above the sea level. More than 75 percent of the State consists of level-to-gently undulating sandy plains where rivers are few and far between. Shallow depressions contain seasonal lakes that serve as sources of rural water supply in many areas. Large tracts of riverine swamp and flood plain environments with wetland features flank the Qua Iboe River valley through Etinan and Abak Local Government areas. Mangrove swamps also occupy the tidal mudflats laced with tidal channels, and the winding waterways, some about 20 m wide. Mangrove development can also be found at Jamestown, Ebughu, Oron and Nwaniba.

From the shoreline providing a wide sandy surf beach stretches a strip of recently deposited marine sand characterized by a succession of sub parallel sand ridges commonly known as beach ridge sands. The beach ridges cover most of Eket, Ikot Abasi, Eastern Obolo sections and a part of Mbo. Inland, a greater part of the state consists of coastal plain sands common in Ikono, Uyo, Abak, Oruk Anam, Etinan, Ikot Ekpene, Essien Udim, Ibiono and some parts of Itu Local Government areas. A belt of shale associated with sandstone and limestone, north of Nkari and Obotme extends down to some parts of Itu (SLUS-AK 1989).

Vegetation and Land use

The existing climatic conditions in Akwa Ibom State favour luxuriant tropical rainforests with teeming populations of fauna and extremely high terrestrial and aquatic biomass. The common vegetation here includes *Raphia* sp. (Raffia palm), *Alchornea* sp. (Malande), *Elaesis guinensis* (Oil-palm), *Khaya ivorensis* (Mahogany), *Pentandra* sp. (Bombax), *Chrysophyllum albidum* (Udara, Star apple), *Xylopia* sp. (Uda) etc. in the fresh water swamp. And the lowland forest zone displays large trees in the upper storey with sub-layers of shrubs, herbs, climbers and grasses. There is an array of common trees in this zone including: Silk tree (*Albizia* sp.), African pear (*Dacryodes edulis*), Uda (*Xylopia* sp.), Ogbono (*Irivingia gabonensis*) etc. The original vegetation within the region has been antropogenetically influenced**,** and commonly cultivated crops comprise Cassava (*Manihot* sp.), Cocoyam (*Xanthosoma* sp.), Yams (*Dioscorea* sp.), *Musa* sp. (plantain and banana), Maize (*Zea mays* L.), rice (*Oryza* sp.), Sweet potatoes (*Ipomoea batatas*), Melon (*Cucurbitaceae*), Okra (*Abelmoschus esculentus*), Pawpaw

(*Carica papaya*), Pineapples (*Ananas comosus*), groundnut and vegetables. Major tree crops typical here are oil palm, rubber and raphia palms (Oyenuga 1967).

Field Study

Reconnaissance field trip was undertaken to identify study sites of wetland soils. Soil samples were collected from nine locations to represent wetland soils formed from Shale/ Sandstone parent materials (Ikpe Ikot Nkon, Grandy-Usuk Akpabo, Mbiaobong Ikot Udofia), Coastal Plain Sand parent materials (Oruk Anam river basin, Ikot Ebidang, Ekpene Ukpa) and Beach Ridge Sand parent material (Ikot Usop, Ikot Akpaden and Okoroette). Six (6) surface samples from 0-15 cm and six (6) subsurface samples from 15-30 cm were collected using soil auger (Fig. 1), and were described based on the guidelines of FAO (1990) from the wetlands located across each named parent material.

Figure no. 1 Field study in one of the hydric soil locations

Samples obtained were bagged in well labelled clean polyethylene bags and taken to the laboratory for analysis of important soil properties. A total of thirty-six (36) soil samples were used for data analysis.

Laboratory Methods

The bulk soil samples were air dried, ground and passed through a 2 mm sieve and used for physicochemical analysis. Particle size distribution was determined using the Bouyoucos hydrometer method as described in Udo et al. (2009) and the sand, silt and clay values were expressed in grammes per kilogram.

Soil Chemical Properties

Soil pH was determined in laboratory using 1:2.5 soil in water suspension as described in Udo et al. (2009). Organic carbon soil was determined by the Walkley Black dichromate titration method as outlined by Nelson and Sommers (1982). Available phosphorus was extracted using Bray P1 method as described in Udo et al. (2009). Exchangeable acidity (Al^{3+} and H^{+}) was determined as outlined by McLean (1982). Exchangeable bases (Ca, Mg, K and Na) were extracted using 1 M of NH_4OAc at pH 7 as described in Udo et al. (2009). Effective cation exchange capacity (ECEC) was obtained by the sum of exchangeable acidity and exchangeable bases as shown in the equation:

$$ECEC = EA + EB \qquad (1)$$

where,

EA = exchangeable acidity;
EB = exchangeable bases.

Base saturation percent (BS%) was calculated as shown in the equation (IITA, 1979):

$$BS\% = (EB / ECEC) \times 100 \qquad (2)$$

Water soluble fraction was obtained using 5 g of soil, weighed and placed in a 50 mL polycarbonate centrifuge tube and extracted with 10 mL of deionized water for 2 h. A sequential extraction procedure using 5 g of soil was employed to separate Fe and Zn fractions in the soils as described by Shuman (1985): exchangeable fraction of Fe and Zn was obtained using 1 M magnesium nitrate

$Mg(NO_3)_2$ in a 1:10 soil-solution ratio, Fe-Mn fraction was obtained in a 1:20 soil-solution ratio using 0.2 M ammonium oxalate $(COONH_4)_2$ + 0.2 M oxalic acid $(COOH)_2$ at pH 3 + ascorbic acid; organic matter fraction associated with Fe and Zn was obtained in a 1:10 soil-solution ratio using 0.7 M sodium hypochlorite (NaOCl) at pH 8.5; the residual metal fraction of Fe and Zn was obtained using aqua regia (HF-HNO_3). Each soil suspension was filtered after shaking or digestion. Iron and Zn concentrations in the extracts were determined using Atomic Absorption Spectrophotometer (AAS) at Akwa Ibom State Ministry of Environment laboratory.

Data analysis

The data generated will be presented using descriptive statistics such as the means, standard deviation, kurtosis and skewness. Correlation and multiple regression analysis will be carried out to determine the relationships existing among the Iron and zinc fractions, physical and chemical properties obtained. Predictive equations will be deduced from the regression analysis and represented as follows:

$$Y^t = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n \qquad (3)$$

where:

Y^t represents the predicted variable (either Fe or Zn fractions);

$x_1, x_2, \ldots, x_n$ designate the predictor variables in the equations that may influence the fractions such as ECEC, pH, OM etc.;

x_n indicates the number of predictors included;

a represents the intercept when the values of the predictor scores are all zero;

b_1, b_2, b_n represents the regression coefficient.

Results and discussion:

Explorative statistics of some physicochemical properties for surface and subsurface soils are presented in Tables 1a and 1b (Annexes). Particle size distribution showed that texture ranged from sandy to loamy sand for surface and subsurface soils across the wetland soils in Sand Stone/Shales (SSS), Coastal Plain Sand (CPS) and Beach Ridge Sands (BRS). Sand fraction was the dominant soil separately ranging from 912 to 712 gkg^{-1} for surface soils (Tab. 1a, Annexes) and 924 to 724 gkg^{-1} for subsurface soils (Tab. 1b, Annexes). Mean sand fraction for surface wetland soils (894 g/kg) was the highest in CPS and the least (812.67 gkg^{-1}) in SSS (Tab. 2, Annexes). The trend of sand fraction on the surface and subsurface wetland soils was similar in the following order**:** CPS>BRS>SSS. Silt fractions varied moderately across the wetland soils in the study area ranging between 204 to 54 gkg^{-1} for surface soils (Tab. 1a, Annexes) and 192 to 42 gkg^{-1} for subsurface soils (Tab. 1b, Annexes). The highest mean value of 123.33 and 124.33 gkg^{-1} was observed for surface and subsurface wetland soils respectively in SSS (Tab. 2, Annexes).

The lowest mean value of 63.00 and 61.00 gkg^{-1} for surface and subsurface soils was obtained in wetland soils of CPS (Tab. 2, Annexes). Silt fraction on the surface and subsurface soils followed a similar trend in the order SSS>BRS>CPS. Egbuchua and Ojobor (2011) attributed moderate values of silt in wetland soils to constant fluviatile deposits and sedimentation processes. Clay fraction was low across the wetland soils and ranged between 84 to 34 gkg^{-1} for surface soils (Tab. 1a, Annexes). Mean clay value for surface soils was the highest (64 gkg^{-1}) in SSS and the lowest (42.33 gkg^{-1}) in CPS and BRS. Average clay fraction on surface and subsurface wetland soils followed the trend SSS>CPS = BRS and SSS>BRS = CPS ($LSD_{0.05}$ = 6.30) respectively (Tab. 3, Annexes). Electric potential (Ec) was generally low ranging between 0.14 to 0.01 dSm^{-1} across the wetland soils (Tab. 1a and 1b, Annexes). The highest average Ec for surface soils (0.07 dSm^{-1}) was obtained in SSS while mean Ec value for surface soils in

CPS (0.05 dSm^{-1}) and BRS (0.05 dSm^{-1}) wetlands were statistically not significantly different (LSD$_{0.05}$ = 0.01) (Tab. 1a, Annexes).

The trend for surface and subsurface soils was in the order SSS>CPS = BRS and SSS = BRS>CPS, respectively (Tab. 3a, Annexes). Low Ec values of <1 dSm^{-1} noticed across the study area indicate low soluble ions, and the low saline nature of the soils agrees with the study of Effiong and Ibia (2009). Soil Reaction (pH) was slightly acidic across the soils and ranged from 6.42 to 6.23 (Tabs. 1a and 1b, Annexes). Mean pH values of 6.37 for surface soils were recorded as the highest in CPS and the lowest 6.29 in SSS (Tab. 1a, Annexes). Average pH value of surface soils was in the trend of SSS<BRS<CPS, while the mean value for subsurface soils showed that wetland soils in SSS, CPS and BRS were statistically not significantly different (LSD$_{0.05}$= 0.02) (Tab. 3a, Annexes).

Total Nitrogen (TN) was generally low across the wetland soils and ranged from 0.16 to 0.03 for surface soils (Tab. 1a, Annexes) and 0.13 to 0.01 gkg^{-1} for subsurface soils (Tab. 1b, Annexes). Low TN mean value of 0.07 gkg^{-1} for surface soils and 0.05 gkg^{-1} subsurface soils were obtained in CPS (Tab. 3a, Annexes). Surface and subsurface trends for TN were in the following order: SSS = BRS>CPS and BRS>SSS>CPS, respectively (Tab. 3a, Annexes). Significantly negative correlation ($P<0.01$, $r = -0.449$) existing between TN and sand fraction infers that TN decreased with increased sand fraction across the study area. Boyer et al. (2006) noted that the low TN content of the soils may be attributed to the loss through denitrification which was probably due to the poor drainage condition of the soils. Available Phosphorus (Av.P) was low across the wetland soils and arrayed from 19.58 to 1.86 mgkg^{-1} for surface soils (Tab. 1a, Annexes) and 22.84 to 1.56 mgkg^{-1} for subsurface soils (Tab. 1b, Annexes). Mean Av.P for surface wetland soils was the highest (7.07 mgkg^{-1}) in BRS and the lowest (5.90 mgkg^{-1}) in CPS (Tab. 3a, Annexes). The highest mean Av.P value (6.86 mgkg^{-1}) for subsurface soils was obtained in SSS and the lowest mean value (5.05 mgkg^{-1}) was obtained in CPS. Low Av.P values in wetland soils maybe either due to high P-sorption of the soils (Udo 1985; Ibia and Udo 1993) or soil erosion losses (Ogban et al. 2011).

Effective Cation Exchange Capacity (ECEC) varied across the wetland soils ranging between 13.92 to 5.08 cmolkg^{-1} for surface soils (Tab. 1a, Annexes) and 11.68 to 4.96 cmolkg^{-1} for subsurface soils (Tab. 1b, Annexes). The highest mean ECEC of 10.14 cmolkg^{-1} for surface soils and 9.22 cmolkg^{-1} for subsurface soils were obtained in SSS (Tab. 3a, Annexes), while the lowest mean ECEC of 7.31 cmolkg^{-1} was obtained in BRS. The mean ECEC obtained for surface and subsurface wetland soils in CPS and BRS was statistically not significantly different. The trend was similar in the order SSS>CPS = BRS for surface soils and subsurface soils (LSD$_{0.05}$ = 0.84).

Distribution of Iron and Zinc bound fractions among the parent materials

Water Soluble Iron Fraction (WsFe) was moderate to low across the wetland soils ranging between 21.0 to 2.63 mg/kg for surface soils (Tab. 2a, Annexes) and 11.82 to 0.25 mgkg^{-1} for subsurface soils (Tab. 2b, Annexes). The highest mean WsFe of 11.29 and 8.62 mgkg^{-1} constituting 1.82 % of total-Fe fraction was obtained for surface and subsurface soils in SSS (Tab. 3b, Annexes). The lowest mean WsFe of 3.94 and 3.49 mgkg^{-1} for surface and subsurface wetland soils constituting 1.06% of total-Fe was obtained in BRS. Mean WsFe trend for surface and subsurface soils was similar in the order SSS>CPS>BRS. Exchangeable Iron Fraction (ExFe) was low across the wetlands arraying between 11.82 to 1.58 mgkg^{-1} for surface soils (Tab. 2a, Annexes) and 14.97 to 0.15 mgkg^{-1} for subsurface soils (Tab. 2b, Annexes).

The highest mean ExFe for surface soils (6.56 mgkg^{-1}) and subsurface soils (7.67 mgkg^{-1}) was obtained in BRS, while the lowest ExFe values (2.73 and 1.99 mgkg^{-1}) was obtained for surface and subsurface soils, respectively in SSS (Tab. 3b, Annexes). Mean ExFe values of 3.15 mgkg^{-1} for surface soils in CPS and 2.73 mgkg^{-1} SSS wetlands were statistically not significantly different ($LSD_{0.05}$=0.89). Average values for surface and subsurface soils followed the trend BRS>CPS = SSS and BRS>CPS>SSS across the wetland soils, respectively.

Organically Bound Iron Fraction (OrgFe) was moderate to low across the study area ranging from 30.0 to 1.67 mgkg^{-1} for surface soils (Tab. 2a, Annexes) and 29.55 to 0.56 mgkg^{-1} for subsurface soils (Tab. 2b, Annexes). Average surface OrgFe of 11.80 mgkg^{-1} constituting 1.06% of total-Fe for surface soils was the highest in SSS and the lowest mean value of 3.87 mgkg^{-1} representing 0.45% of total-Fe for subsurface soils in CPS (Tab. 3, Annexes). Mean OrgFe for surface soils followed the trend SSS>BRS>CPS (Tab. 3b, Annexes). Average OrgFe for subsurface soils was statistically not significantly different ($LSD_{0.05}$ = 2.69). For surface and subsurface soils, the residual iron fraction (ResFe) was generally greater than the amorphous iron fraction (AmFe) across the wetland soils in the three parent materials (Tabs. 2a, 2b, Annexes). ResFe fractions for surface soils in CPS were similar in trend (WsFe>OrgFe>ExFe) with subsurface soils in SSS, while ResFe fractions for surface soils in SSS were similar in trend (OrgFe>WsFe>ExFe) with subsurface soils in CPS. The trend for ResFe fraction on surface soils in BRS was different in the order OrgFe>ExFe>WsFe as well as ExFe>OrgFe>WsFe.

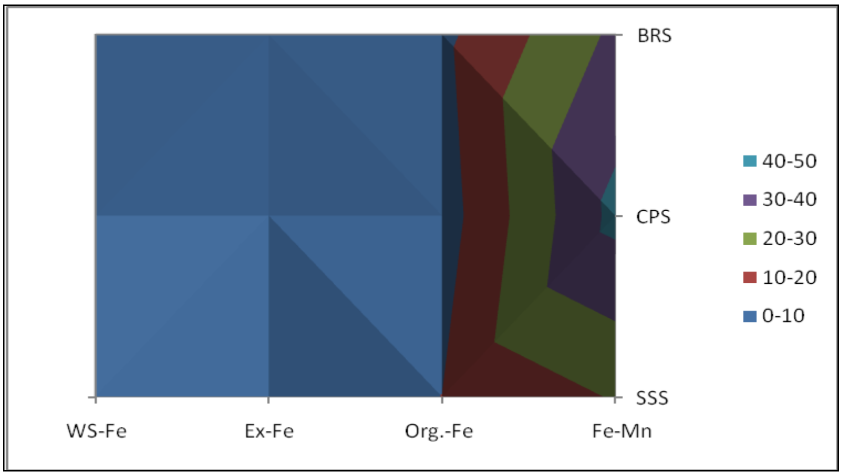
Water Soluble Zinc Fraction (WsZn) was generally low across the wetland soils varying between 5.14 to 0.09 mgkg^{-1} for surface soils (Tab. 2a, Annexes) and from 0.36 to 0.08 mgkg^{-1} for subsurface soils (Tab. 2b, Annexes). The highest average WsZn of 1.03 mgkg^{-1} representing 3.58% of total-Zn fraction (28.79 mgkg^{-1}) for surface soils was obtained in BRS. The lowest mean WsZn for surface soils of 0.15 mgkg^{-1} was obtained in CPS (Tab. 2a, Annexes). Mean WsZn trend for surface and subsurface soils was in the order BRS>SSS = CPS and SSS = CPS = BRS ($LSD_{0.05}$ = 0.337) (Tab. 3b, Annexes). Exchangeable Zinc Fraction (ExZn) was low across the wetlands ranging between 0.204 to 0.01 mgkg^{-1} for surface soils (Tab. 2a, Annexes) and from 0.18 to 0.02 mgkg^{-1}for subsurface soils (Tab. 2b, Annexes). Mean Ex-Zn value of 0.12 mgkg^{-1} for surface soils comprising <0.30% of total-Zn and subsurface soils 0.13 mgkg^{-1} was highest in SSS (Tab. 3, Annexes). Mean value trend for surface and subsurface soils was in the order SSS>CPS>BRS and SSS>CPS = BRS ($LSD_{0.05}$ = 0.016) (Tab. 3b, Annexes).

Organically Bound Zinc Fraction (OrgZn) was moderate to low and arrayed between 2.66 to 0.24 mgkg^{-1} for surface soils in the study area (Tab. 2a, Annexes) and from 2.68 to 0.22 mgkg^{-1} for subsurface soils (Tab. 2b, Annexes). The highest mean OrgZn of 2.37 mgkg^{-1} for surface soils and 2.59 mgkg^{-1} for subsurface soils was obtained in CPS**,** while the lowest mean Org-Zn of 1.10 mgkg^{-1} for surface and subsurface soils (0.88 mg/kg) was obtained in BRS (Tab. 3b, Annexes). The trend for OrgZn was similar for surface and subsurface soils in the order CPS>SSS>BRS. Amorphous Zinc Fraction (AmZn) was moderate to low across the wetland soils ranging between 25.40 to 2.63 mgkg^{-1} for surface soils (Tab. 2a, Annexes), and from 25.40 to 2.90 mgkg^{-1} for subsurface soils (Tab. 2b, Annexes). The highest average AmZn of 20.32 mgkg^{-1} constituting approximately 35% of total-Zn fraction of 28.79 mgkg^{-1} for surface soils was obtained in SSS. The lowest mean AmZn for surface soils of 2.63 mgkg^{-1} and 2.90 mgkg^{-1} subsurface soils was obtained in BRS (Tabs. 2a and 2b, Annexes). AmZn trend for surface and subsurface soils was similar in the order SSS>CPS>BRS (Tab. 3b, Annexes).

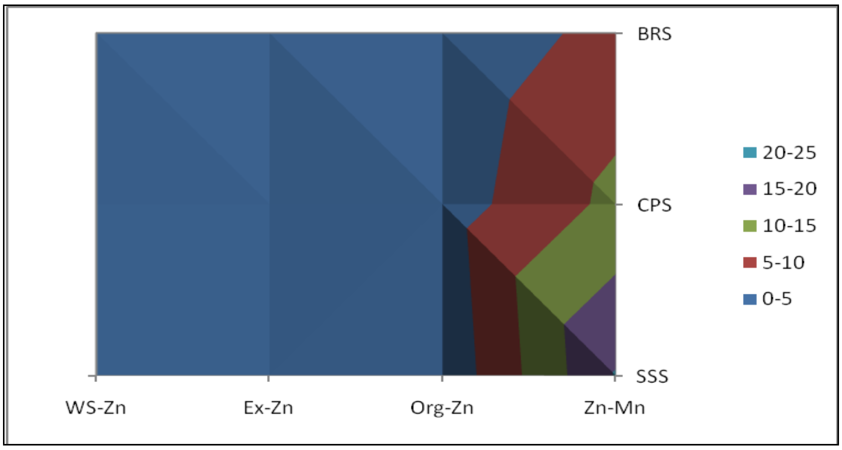
According to Figure 2, an association that may be the result of heavy equipment usage on the field all the year round would cause compaction in the fine sandy layer. Similarly, contour maps of Sandstone (SSS), Coastal Plain Sand (CPS) and Beach Ridge Sand (BRS) parent materials with high flat mud on the surface and subsurface were found in 40-50 mgkg^{-1} (iron-bound) and 20-25 mgkg^{-1} (zinc-bound) region.

Figure no. 2 Spatial distribution of Iron (a) and zinc (b) fractions in hydric soils

a.



b.



Water soluble Fe fraction (WsFe) represents <1.2% of total Fe of each parent material. Correlation analysis has shown that WsFe decreased as sand fraction increases across the studied soils (Tab. 4, Annexes). WsFe has correlated in a highly positive way with silt ($P<0.01$, r = 0.535**) and clay ($P<0.01$, r = 0.413**) thus suggesting that a significant quantity of WsFe has been reserved on the silt and clay particles of the soils. WsFe has also shown significant positive correlation with ExZn ($P<0.05$, r = 0.311*) and AmZn ($P<0.01$, r = 0.594**). According to Mescouto et al. (2011), this relationship expected since Fe was found in soil may be associated with Zn in the form of oxides and hydroxides. The ResFe fraction has been dominant across the parent materials with percentages ranging from 92.31 to 96.27. The highest ResFe percent was obtained in SSS for both surface and subsurface soils, while the lowest percent of

ResFe was obtained in BRS for both surface and subsurface soils. Available Fe content for surface and subsurface soils across the study area has been above the critical value of 4.5 mgkg^{-1} as recommended by Lindsay and Norvell (1978) for crop production means considering the fact that Fe deficiency is not likely for crops grown on these soils.

According to Lindsay and Norvell (1978) and Esu (1991), available Fe content >10 mgkg^{-1} in soils is said to be high. Surface soils in BRS and SSS with subsurface soils in BRS, CPS and SSS have conveyed available Fe fraction >10 mgkg^{-1}. Soils with excessive Fe content are characterized by a general low fertility status and the crops grown on these soils may likely suffer from multiple nutritional stresses. Ogban et al. (2011) reported that Fe toxicity is evident in the shale and sandstone wetland areas characterized by reduced Fe concentrations in waterlogged soils. The presence of high Fe content in soils could lead to its precipitation and accumulation, and complex chemical reactions may lead to the formation of phlintite which could restrict root penetration and nutrient uptake by crops (Esu 2010).

Significant correlations between WsZn and some soil properties have not been observed across the studied soils. ExZn fraction comprising <0.28% total Zn across the study area have correlated in a high negative way with sand fraction (P<0.01, r = -0.446**) and available Phosphorus (P<0.05, r= -0.317*). Phosphate salts will decrease zinc concentrations usually where the supply capacity of the soil for both zinc and phosphorus are marginal (Loneragan and Webb 1993). ExZn fraction showed significant positive correlation with silt (P<0.01, r = 0.477**) and clay (P<0.05, r = 0.292*). Amorphous zinc (AmZn) showed significant positive correlation with silt (P<0.01, r = 0.634**), clay (P<0.01, r = 0.524**) and ExZn (P<0.01, r = 0.540**).

Mustafa and Fagam (2007) obtained similar results between extractable zinc and clay. The critical limit of 0.6 mg Zn kg^{-1} in soils, precisely the studied soils (except for surface soils) in BRS, could be classified as deficient in available Zn content.

Conclusions:

The physicochemical properties with iron and zinc fractions across the wetland soils in shale/sandstone, coastal plain sands and beach ridge sands have been studied and evaluated. The soil texture across the wetlands has revealed the soils were either sandy or sandy-loam. Low electrical conductivity obtained from the study area has inferred low soluble ions and a low saline nature of the soils. Soil pH across the study area was in general slightly acidic. The soils were low in total nitrogen content and available phosphorus.

Hydic soil can sustain agriculture under continuous and intensive cultivation in the lower Niger region. With the current increase in demographic pressure in the region, continuous and intensive cultivation of land has consequently caused land degradation and this has hindered a sustainable cropping system. It is important to know that the tropical soils are extremely delicate and lack resilience once degraded. Therefore, cultivation of hydric soil will reduce the burden on tropical soil and intensify agricultural use of wetlands.

Rezumat:

VARIABILITATEA SPAȚIALĂ ȘI TEMPORALĂ PRIVIND PROPRIETĂȚILE SOLULUI ÎN SOLURILE HIDRICE DIN REGIUNEA NIGERULUI INFERIOR

Disponibilitatea nutrienților esențiali pentru creșterea plantelor are o influență puternică de care plantele depind în zonele umede. Scopul studiului a fost de a determina distribuția fracțiilor de Fe și Zn, în vederea luării unor decizii proactive pentru folosirea intensivă și durabilă a solurilor umede în agricultură. Solurile saturate variază în

caracteristicile lor de textură, care depind îndeosebi de geneza și localizarea lor. Valorile scăzute ale conductivității electrice (Ec) <1 dSm^{-1} observate in cadrul ariei de studiu indică prezența unor ioni solubili scăzuți dar și salinitatea scăzută a solurilor. Reacția solurilor (pH) a fost ușor acidă și s-a situat între 6.42 și 6.23. Limitele Organice ale Fracției de Zinc (OrgZn) au fost moderate până spre minime și au variat între 2.66 și 0.24 $mgkg^{-1}$ pentru suprafața solurilor.

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Annexes:

Table no. 1 Explorative statistics for physicochemical properties of wetland soils in the study area

a. Surface wetlands soil

PM		Ec	pH	Sand	Silt	Clay	OC	TN	AvP	Ca	Mg	Na	K	Al	H	ECEC	BS%
		dSm^{-1}		←	gkg^{-1}	→	← gkg^{-1}	→	mgkg^{-1}	←				cmolkg^{-1}			→
SSS	Mean	0.07	6.29	812.67	123.33	64.00	2.68	0.12	6.29	6.00	1.91	0.08	0.16	1.38	0.60	10.14	80.01
	minimum	0.04	6.25	712	82	44	1.52	0.07	1.86	3.36	1.40	0.06	0.05	0.65	0.13	7.99	62.06
	maximum	0.14	6.36	872	204	84	3.39	0.15	19.58	9.12	2.88	0.11	0.26	2.49	1.29	13.92	88.87
	CV%	59.52	0.69	7.21	36.20	24.21	24.17	22.36	108.13	32.30	27.87	23.77	45.76	48.35	76.06	24.02	13.40
CPS	Mean	0.05	6.37	894.67	63.00	42.33	1.66	0.07	5.90	3.76	1.74	0.08	0.17	1.06	0.56	7.38	75.97
	minimum	0.01	6.27	884	54	34	0.70	0.03	4.63	1.44	1.40	0.05	0.06	0.52	0.25	5.08	59.45
	maximum	0.06	6.42	912	74	54	2.93	0.13	7.46	7.20	2.40	0.13	0.47	1.42	0.77	11.6	88.39
	CV%	42.71	0.85	1.25	13.58	23.23	47.61	48.53	16.35	56.18	29.39	40.22	91.37	32.75	31.83	36.76	13.86
BRS	Mean	0.05	6.34	875.00	83.00	42.33	2.75	0.12	7.07	2.97	1.46	0.09	0.20	1.32	0.75	6.79	69.43
	minimum	0.02	6.26	54	54	34	2.02	0.09	2.79	2.40	0.96	0.06	0.08	0.93	0.39	5.34	64.53
	maximum	0.08	6.40	122	122	54	3.63	0.16	16.78	4.32	2.40	0.16	0.56	1.68	1.42	9.92	72.28
	CV%	49.68	0.97	29.54	29.54	23.23	24.86	25.28	73.03	25.73	39.13	42.34	86.27	24.21	48.07	25.86	4.78

b. Subsurface wetland soils

PM		Ec	pH	Sand	Silt	Clay	OC	TN	AvP	Ca	Mg	Na	K	Al	H	ECEC	BS%
		dSm^{-1}		←	gkg^{-1}	→	← gkg^{-1}	→	mgkg^{-1}	←				cmolkg^{-1}			→
SSS	Mean	0.04	6.35	810.00	124.33	65.67	2.00	0.09	6.86	4.32	1.67	0.09	0.20	2.13	0.82	9.22	68.83
	minimum	0.01	6.27	724.00	54.00	34.00	0.96	0.04	1.56	2.40	1.40	0.04	0.05	0.77	0.26	7.36	37.93
	maximum	0.07	6.42	912.00	192.00	84.00	3.01	0.13	22.84	7.20	2.40	0.16	0.37	5.16	1.68	11.68	86.73
	CV%	47.27	0.90	9.08	46.95	37.82	40.11	41.71	118.99	39.13	24.30	49.82	61.60	77.08	60.67	19.22	26.83
CPS	Mean	0.03	6.35	893.14	61.43	46.86	1.03	0.05	6.39	3.84	1.80	0.06	0.11	1.26	0.76	7.84	74.31
	minimum	0.01	6.30	844.00	42.00	34.00	0.10	0.01	3.26	2.40	1.30	0.04	0.05	0.77	0.39	4.96	63.49
	maximum	0.07	6.40	924.00	74.00	74.00	2.41	0.11	14.45	5.76	2.40	0.12	0.30	1.48	1.16	10.22	81.02
	CV%	49.91	0.50	3.03	17.70	31.93	69.96	70.16	61.43	32.27	22.83	44.73	78.38	19.19	39.37	22.02	8.52
BRS	Mean	0.04	6.35	868.00	83.00	49.00	2.47	0.11	5.71	3.52	1.58	0.05	0.10	1. 35	0.71	7. 31	71.37
	minimum	0.02	6.23	832.00	54.00	34.00	2.06	0.09	3.26	2.40	1.00	0.05	0.09	1.03	0.51	5.09	65.20
	maximum	0.07	6.39	912.00	124.00	64.00	2.99	0.13	14.45	4.32	1.92	0.06	0.10	1.55	1.00	8.80	76.68
	CV%	42.65	0.94	3.72	33.07	21.40	14.96	14.79	75.64	25.39	24.80	9.68	5.77	13.67	26.53	20.05	5.56

Table no. 2 Explorative statistics for Iron and Zinc fractions in wetland soils in the study area

a. Surface wetlands soil

PM		WsFe	ExFe	OrgFe	AmFe	ResFe	TFe	WsZn	ExZn	OrgZn	AmZn	ResZn	TZn
		←			mgkg^{-1}		→	←			mgkg^{-1}		→
SSS	Mean	11.29	2.73	11.80	20.48	1067.77	1114.07	0.21	0.12	1.35	20.32	36.07	58.07
	minimum	6.57	1.58	4.22	3.53	305.82	351.80	0.11	0.08	0.68	10.30	16.11	42.60
	maximum	21.00	4.58	30.00	98.48	1611.65	1735.30	0.33	0.20	2.17	25.40	71.33	84.10
	CV%	47.79	37.88	81.42	186.70	48.71	48.27	42.67	40.71	36.38	38.01	65.01	28.40
CPS	Mean	5.73	3.15	3.87	39.73	815.19	867.67	0.15	0.08	2.37	10.57	16.93	30.10
	minimum	3.94	2.36	2.11	4.85	447.60	469.00	0.09	0.07	1.28	2.90	6.74	22.60
	maximum	9.19	4.73	6.33	91.45	1224.41	1242.90	0.24	0.09	2.66	15.40	27.36	41.00
	CV%	31.16	27.44	37.75	99.15	39.70	37.53	39.22	13.05	22.68	39.57	40.32	21.50
BRS	Mean	3.94	6.57	7.60	29.31	568.80	616.22	1.03	0.06	1.10	5.99	20.61	28.79
	minimum	2.63	2.36	1.67	2.10	130.63	140.70	0.13	0.01	0.24	2.63	1.18	13.04
	maximum	5.30	11.82	14.38	91.45	979.73	1000.50	5.14	0.13	1.80	10.28	57.57	61.00
	CV%	21.42	46.59	70.44	138.34	48.71	45.16	195.78	85.94	50.28	49.25	103.93	66.14

b. Subsurface wetland soils

		Fe						Zn					
PM		WsFe	ExFe	OrgFe	AmFe	ResFe	TFe	WsZn	ExZn	OrgZn	AmZn	ResZn	TZn
		←			mgkg^{-1}		→	←			mgkg^{-1}		→
SSS	Mean	8.62	1.99	8.32	21.00	1030.97	1070.90	0.24	0.13	1.11	20.30	29.92	51.70
	minimum	6.57	0.15	4.22	2.83	470.68	492.50	0.18	0.09	0.85	10.25	11.30	32.70
	maximum	11.82	3.15	14.07	105.53	1659.16	1688.30	0.36	0.18	1.30	25.40	61.99	74.00
	CV%	27.89	51.75	40.17	197.25	45.46	45.12	27.72	25.55	15.34	38.03	61.43	31.36
CPS	Mean	6.34	4.20	6.68	46.20	855.06	918.48	0.13	0.08	2.59	12.05	18.62	33.47
	minimum	5.25	3.15	2.81	4.23	240.78	351.80	0.08	0.02	2.50	7.03	9.45	24.60
	maximum	9.19	7.09	9.85	91.45	1453.71	1477.40	0.18	0.12	2.68	15.40	28.01	41.60
	CV%	24.20	34.91	41.47	96.39	54.08	46.59	30.96	45.47	3.17	23.72	37.56	20.80
BRS	Mean	3.49	7.67	7.60	34.70	786.88	840.33	0.18	0.07	0.88	7.47	22.85	31.45
	minimum	0.25	4.73	0.56	2.10	148.34	164.20	0.14	0.02	0.22	2.90	0.89	13.17
	maximum	7.58	14.97	29.55	105.50	1475.06	1524.30	0.26	0.15	1.78	12.70	53.83	61.40
	CV%	69.14	48.52	143.15	142.96	57.04	53.37	29.04	77.60	69.46	51.47	101.58	64.75

Table no. 3 Some physical and chemical properties (a) and Iron and Zinc fractions (b) of wetland soils in Akwa Ibom State

a.

PM	Depth	Sand	Silt	Clay	Texture	Ec	pH	OC	TN	Av.P	Ca	Mg	Na	K	Al	H	ECEC	BS%
	cm	←	g/kg	→		dS/m		←	g/kg →	mg/kg	←			cmol/kg				→
SSS	0-15	812.67	123.33	64.00	LS	0.07	6.29	2.68	0.12	6.29	6.00	1.91	0.08	0.16	1.38	0.60	10.14	80.01
	15-30	810.00	124.33	65.67	LS	0.04	6.35	2.00	0.09	6.86	4.32	1.67	0.09	0.20	2.13	0.82	9.22	68.83
CPS	0-15	894.67	63.00	42.33	S	0.05	6.37	1.66	0.07	5.90	3.76	1.74	0.08	0.17	1.08	0.56	7.38	75.97
	15-30	893.33	61.00	47.33	S	0.03	6.35	0.80	0.04	5.05	3.84	1.86	0.07	0.11	1.23	0.76	7.86	74.31
BRS	0-15	875.00	83.00	42.33	S	0.05	6.34	2.75	0.12	7.07	2.97	1.46	0.09	0.21	1.32	0.75	6.79	69.43
	15-30	868.00	83.00	49.00	LS	0.04	6.35	2.47	0.11	5.71	3.52	1.58	0.05	0.10	1.35	0.71	7.31	71.37
	LSD $_{0.05}$	18.09	13.91	6.30		0.01	0.02	0.26	0.01	2.13	0.63	0.20	0.01	0.05	0.31	0.15	0.84	4.20

Note: PM=Parent Material; SSS=Sand Stone Shales; CPS=Coastal Plain Sands; BRS=Beach Ridge Sands; Ec=Electrical Conductivity; OC=Organic Carbon; TN=Total Nitrogen; Av.P=Available Phosphorous; Ca=Calcium; Mg=Magnesium; Na=Sodium; K=Potassium; Al=Aluminium; H=Hydrogen; ECEC=Effective Cation Exchange Capacity; BS%=Percent Base Saturation; LS=Loamy sand; S=sand.

b.

		Fe						Zn					
PM	Depth	WsFe	ExFe	OrgFe	AmFe	ResFe	TFe	WsZn	ExZn	OrgZn	AmZn	ResZn	TZn
	cm	←			mgkg		→	←		mgkg			→
SSS	0-15	11.29	2.73	11.80	20.48	1067.78	1114.07	0.21	0.12	1.35	20.32	36.07	58.07
	15-30	8.62	1.99	8.32	21.00	1030.97	1070.90	0.24	0.13	1.11	20.30	29.91	51.70
CPS	0-15	5.73	3.15	3.87	39.73	815.19	867.67	0.15	0.08	2.37	10.57	16.93	30.10
	15-30	6.35	4.20	6.68	46.20	855.06	918.48	0.13	0.08	2.59	12.05	18.62	33.47
BRS	0-15	3.94	6.56	7.60	29.31	568.80	616.22	1.03	0.05	1.10	5.99	20.61	28.79
	15-30	3.49	7.67	7.60	34.70	786.88	840.33	0.18	0.07	0.88	7.47	22.85	31.45
	LSD $_{0.05}$	1.14	0.89	2.69	17.33	173.76	174.04	0.34	0.02	0.19	2.16	7.42	6.24

Note: WsFe=Water Soluble Iron; ExFe=Exchangeable Iron; OrgFe=Organically Bound Iron; AmFe =Amorphous Iron; ResFe=Residual Iron; TotalFe=Total Iron; WsZn=Water Soluble Zinc; ExZn=Exchangeable Zinc; OrgZn=Organically Bound Zinc; AmZn=Amorphous Zinc; ResZn=Residual Zinc; TotalZn=Total Zinc.

Table no. 4 Correlation between Fe and Zn fractions and some selected soil properties in the study area

	Ec	pH	Sand	Silt	Clay	TN	Av.P	WsZn	ExZn	OrgZn	AmpZn	ResZn	WsFe	ExFe	OrgFe	AmpFe	ResFe
Ec	1																
pH	-0.307*	1															
Sand	-0.241	0.325*	1														
Silt	0.227	-0.298*	-0.967**	1													
Clay	0.188	-0.303*	-0.816**	0.653**	1												
TN	0.476**	-0.201	-0.449**	0.462**	0.291*	1											
Av.P	0.107	-0.007	0.278	-0.288*	-0.179	-0.135	1										
WsZn	-0.065	0.104	0.164	-0.150	-0.167	0.233	-0.042	1									
ExZn	-0.036	-0.103	-0.446**	0.477**	0.292*	0.054	-0.317*	-0.183	1								
OrgZn	-0.044	0.081	0.388**	-0.421**	-0.207	-0.601**	0.136	-0.211	-0.221	1							
AmpZn	0.248	-0.116	-0.649**	0.634**	0.524**	0.160	-0.234	-0.219	0.540**	-0.039	1						
ResZn	-0.006	-0.117	0.014	-0.006	-0.021	-0.022	0.033	0.112	0.113	-0.292*	-0.158	1					
WsFe	0.097	-0.087	-0.540**	0.535**	0.413**	0.007	0.070	-0.065	0.311*	0.025	0.594**	0.141	1				
ExFe	-0.256	0.056	0.333*	-0.325*	-0.229	0.134	-0.146	0.107	-0.296*	-0.303*	-0.587**	0.011	-0.528**	1			
OrgFe	-0.042	0.115	-0.088	0.071	0.085	0.206	-0.080	0.153	0.144	-0.347*	0.215	0.055	0.065	0.357*	1		
AmpFe	-0.235	0.041	0.030	-0.058	0.061	-0.130	-0.200	0.137	-0.306*	0.240	-0.002	-0.183	-0.194	0.003	-0.027	1	
ResFe	0.117	-0.056	-0.266	0.191	0.375*	-0.015	-0.050	-0.144	0.179	-0.135	0.178	0.328*	0.377*	-0.065	0.159	-0.109	1