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TERRESTRIALIZATION, PALUDIFICATION AND PEDOGENESIS OF SOILS OF A POLLUTED WETLAND

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Abstract: We investigated soil properties of terrestrializing and paludifying land units of a wetland in 2010 as these properties relate with heavy metal contamination. A transect of unequal inter-pedon distances were used to align profile pits. Soil samples were collected and analyzed according to routine techniques. Analytical results were subjected to mean and correlation analyses. Results show that total heavy metal concentrations were above WHO permissible limits in the study site. We also found that elevated levels of heavy metals were observed in soils nearer to the main course of the river (paludifying soils of profile pit 3) when compared with transitional and terrestrializing land units. Soil pH, organic matter, sesquioxides and clay had very good relationships with heavy metal distribution. Further studies should consider a geostatistical analysis of this relationship and this can improve predictiveness more so if intensive sampling is conducted.

Keywords: contamination, floodplain, soil formation, tropical soils, wetland soils.

INTRODUCTION

A lot of drastic changes are currently taking place in most tropical aquatic ecosystems, especially those closest to urban and peri-urban settlements. These changes are results of interactions between water, vegetation and peat (1). In wetlands, water level is stable near the surface leading to poor decomposition of dead plants and formation of peatlands with production, carrier and regulative functions. In peatlands two major formations are frequently observed, namely terrestrialization and paludification. Terrestrialization develops in open water due to deposition of dead plant materials while paludification occurs when peat accumulates directly over a former dry mineral soil.

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Increasing population (2) and consequent geographical expansion of agricultural frontier accelerate these formations (3). Vegetation is vulnerable due to human activities (4). Sand mining activities and deforestation alter the natural landscape leading to new small-scale habitats. Landscape alterations are further promoted by urban constructions near aquatic ecosystems. Although topography is an indirect factor in vegetation distribution (5), it creates a patchwork-like pattern of small scale habits and realized niches within the ecological space (6).

Furthermore, fluvial activities influence the terrestrial edge (7) as inundations kill forest species (8) and dead plants increase organic matter content of geomorphic surfaces(9) especially when it retreats freshwater wetlands are nutrient sinks that efficiently process and store N and P (10) thereby reducing eutrophication (11) of water bodies. Fluvial activity in addition to fluctuating moisture status of surrounding soils influence mineralogy of wetland soils. The development of hydric soils in wetland is driven by annual flooding, prolonged periods of soil saturations, abundant organic carbon and mild temperatures that facilitate reductive dissolution and segregation of Fe and Mn into redoximorphic concretions and depletions (12). Oxides of these metals and organic matter influence physicochemical properties of soils as well as heavy metal distribution in soils (13).

Owerri is the capital city of Imo State, Nigeria and has seen unprecedented population, economic and industrial growth in recent years resulting in the accumulation of heavy metal-laden wastes. Remarkably, there are no sanitary landfills and inhabitants resort to open dump waste disposal systems into two major rivers that criss-cross the municipality. Absolute poverty characteristic of a greater percentage of the populace force inhabitants to extend economic activities in the watershed, leading to alterations that influence ecosystem balance. A study was conducted in temporal variability of heavy metals in arable soils of the area contaminated with heavy metals (14) but none on pedogensis of emerging habitats of the wetlands proximal to the city. However, such studies are important since an aquatic environment is very dynamic (15,16) and knowledge gained therefore improve eco-technical data necessary for restoration and sustenance of the vital ecosystem. The major objective of this survey study was to investigate soil formation processes as well as quality of an urban wetland soils.

MATERIALS AND METHODS

The study area is Nekede; Owerri Southeastern Nigeria is about 10km away from owerri metropolitan town. It lies between latitudes 5o 10’ 55.51’’ and 5o 25’10.12’’N and longitudes

6o 45’25.11’’ and 70 05’ 06.21’’ E. Soils originate from Coastal Plain Sands, and are on a lowland geomorphology. The area has a mean annual rainfall of 2500 mm and mean annual temperature ranging from 27 to 29 oC. It has an anthropogenically- depleted rainforest. Main socioeconomic activities in the area include proliferation of cottage industries, automobile servicing, engineering, constructions, riverside vegetable and arable farming, fishing, hunting, sand mining and devastation for fuelwood.

Field studies were conducted in 2010, and involved use of a transect technique in aligning soil profile pits for soil sampling purpose. The transect was drawn to link 3 geomorphic surfaces, namely terrestrializing (profile1) transitional (profile 2) and paludifying (profile 3). Soil temperature was measured by Type K- thermocouples ungrounded and Iconel (International Nickel Co, Toronto, and On Canada) sheathed. Five soil samples per horizon collected from the bottommost horizon were upwards and sampling was done based on the degree of profile pit differentiation. Soil samples were air-dried, gently crushed and passed through 2-mm sieve. A total of 60 soil samples were used for the study.

All analyses were performed on the < 2-mm soil fraction using standard techniques. Particle size distribution was determined by hydrometer method (17), pH in a 1:2.5 soil KCl ratio (18), organic carbon by combustion (19). In the determination of dithionite-citrate – bicarbonate iron and manganese, fresh 50-mg soil samples were used and placed in 50-ml plastic centrifuge tubes. Five milliliters of deionized water and 5 ml of 0.5 M citrate and 0.2 M Na-bicarbonate stock were added to each tube. Tubes were shaken for 30 minutes and centrifuged at 3000 rpm (1086xg) for 20 minutes. The supernatant was decanted into 50-ml flasks. This process was done thrice on the same soil samples and the extracted Fe and Mn were analyzed according to the procedure of Jackson et al. (20). Samples were analyzed in a Hewlett–Packard (Palo Alto, CA) 8453 uv visible spectrophotometer.

In the measurement of oxalate Fe and Mn, 50 mg of ground soil was weighted into 50-mL centrifuge tubes. Ten millilitres of 0.2 M Foex were added to each tube in the absence of light. Tubes were shaken for 150 minutes and centrifuged at 2086 g for 30 minutes. The resulting supernatant was decanted, dilute (to 50 mL) and analyzed colourimetrically for Fe and Mn.

Digestion of soil samples for heavy metals was carried out with mixture of concentrated HClO3 and HNO3 at a ratio of 2.1 and heavy metals were extracted using 0.5M HCl (21). The heavy metals concentrations in supernatants were determined using Atomic Absorption Spectrophotometer Alpha 4 Model.

Statistical analyses were performed using the Pearson correlation procedure and the generalized linear model. Again, mean values of some properties were calculated and reported.

RESULTS AND DISCUSSION

Soil profile characteristics of the study site are shown in Table 1, indicating greater redness in transitional soil samples (Profile 2) while terrestrializing (Profile 1) and paludifying (Profile 3) pits were yellow. Soil colour in the site was influenced greatly by drainage characteristics (degree of hydration) in addition to organic matter and fluvial materials from which soils are derived. Soils from profile pit 2 were sandier possibly due to past fluvial depositions when the river was wider and more erosive at the upper course coupled with sandy parent materials (Coastal Plain Sands) of the Oligocene-Miocene geologic era. Silt and clay contents are highest in Profiles 3 and 1 in keeping with lowland characteristics as these particle sizes are lighter and are easily moved in suspension to lowland geomorphic surfaces. While profile 1 is derived from a cut –off from the main river valley, Profile 3 was genetically developed from annual inundations of the past fluvial activities. Soil pH values are higher in the terrestrializing and paludifying soils while the transitional profile pit exhibited higher acidity. This is similar to the findings of (22) that soils of a transitional zone of a marsh land seasonally flooded with brackish water maintained acidic nature of Ultisols. Highest values of organic carbon are recorded in paludifying soils followed by terrestrializing soils and least in the transitional zone, and this could be due to mineralization rate which is related to oxidation status and soil temperature. Least average temperature value is recorded in paludifying followed by terrestrializing soils, and thus governs mineralization rate as well as activity of prevailing soil microbes. Paludifying soils are closer to the river and lush vegetation of the river banks resulting to a microclimatic condition while the temperature of the terrestrializing soils is probably influenced by high moisture status of the out-off depression which are formerly part of the river course. Generally, soil temperature fluctuations are greatest in the epipedsons but stabilized with a downward movement into the soil profile pits.

Table 1. SOIL PROFIT CHARACTERISTICS (MEAN VALUES)

HORIZON	DEPTH (CM)	COLOUR MATRIX (MOIST)	sand	SILT	CLAY	SCR	pH (in Kcl)	OC(g/kg-1)	Temp.
Profile 1 Terrestrializing (30 meters away from the river)									
A1	0-6	10yr5/8 (YB)	70	18	12	1.5	44	23	15.2
A2	6-12	2.5yr5/6 (LOB)	67	15	18	0.8	46	18	11.6
A3	12-50	2.5yr5/4 (LOB)	70	18	12	1.5	4.7	26	11.4
BSS1	50-89	2.5yr6/6 (OY)	72	20	8	2.5	5.6	16	12.45
Mean			69.75	17.75	12.50	1.57	4.83	20.7	12.45
Profile 2 transitional (20 metres away from the river)									
A1	0-4	10yr4/8 (DYB)	75	10	15	0.6	4.2	24	16.8
A2	4-18	10yr4/4 (DYB)	76	10	14	0.7	4.5	16	15.0
BSS1	18-46	10yr 5/4 (YB)	78	11	11	1.0	4.8	19	14.8
BSS2	46-176	10yr 5/2 (OY)	80	10	10	1.0	5.5	11	14.7
Mean			77.25	10.25	12.50	0.8	4.75	17.5	15.32
Profile 3 Paludifying (10 metres away from the river)									
A1	0-3	2.50yr4/2 (DGB))	60	22	18	1.2	4.5	27	13.2
BSS1	3-16	2.5yr4/4 (OB)	60	23	17	1.3	4.6	32	10.6
BSS2	16-47	2.5yr5/2 (DB)	58	25	17	1.4	4.8	18	10.3
BSS3	47-70	2.5yr4/4 (OB)	61	23	16	1.4	5.8	9	10.3
Mean			59.75	23.25	17.00	1.3	4.92	21.5	11.10

YB= yellowish brown, LOB= light olive brown, OY= olive tallow, DYB= dark yellowish brown, GB= grayish brown, DGB= dark grayish brown. OB = olive brown, DB- dark brown, OC= organic carbon, Temp= temperature and SCR= silt- clay ratio.

Iron and manganese mineralogy of soils of the paludifying and terrestrializing land units were classified as typic endoquepts while transitional soils were classified as fluvaquentic endoaquepts are given in Table 2. Values of the dithionite-citrate bicarbonate iron (FeDCB) representing the crystalline plus amorphous Fe forms are higher than those of oxalate or amorphous iron (Feox). The dominance of FeDCB over Feox may have been due to the age of these soils or the age of the sediments in which soils are derived. The same trend in iron was observed in manganese and the oxides of both elements had higher concentration in the surface soils (10). The Feox /FeDCB values are higher in terrestrializing (profile 1) and paludifying (profile 3) soils when compared with result of soils from transitional zone (profile 2) suggesting rapid redox process in the horizons of the former wetter soils. Lepidocrocite formation is likely in some horizons of this study site especially in terrestrializing and paludifying pits due to values of Feox/FeDCB ratios since (23) postulated that ratios ≤ 0.2 are indicative of this mineral.

Table 2. Iron and manganese distribution in the studied soils (mean values) Mg kg-1x102(n=60)

	IRON									
ORIGIN	DCB	SE	OX	SE	OX/DCB	DCB	SE	OX	SE	OX/DCB
Profile 1	884	63	235	13	0.27	69	72	67	3.6	0.97
Profile 2	676	73	147	10	0.21	60	96	65	1.0	1.08
Profile 3	624	96	160	16	0.25	18	3	16	2.3	0.88

DCB = dithionite-citrate-bicarbonate, OX=Oxalate, SE= stand and error.

Higher values of heavy metal are recorded in paludifying soils (profile 3). Generally, there were differences in the distribution of individual metal but all the metals studied exceeded permissible limits of 0.10, 0.05, 1.0, 0.01, and 0.002 mg kg-1 for Cr, Pb, Ni, Cd, and Hg (24), respectively. Heavy metal pollution of this wetland is due to the movement of heavy metal sources from the Owerri urban by Otamiri River. The upper course of the river passes through open dumpsite and automobile service stations before settling at the study site. Variation in metal distribution is attributable to pollution sources existing in the catchments area. The proximity of the paludifying soils to the river and the attendant high concentration of these heavy metals suggest that the river deposits a good proportion of the contaminants laden wastes (25) which become part of the soils via pedogenesis. Intrapedal redistribution of these toxic metals may be responsible for higher values of transitional soils compared with terrestrializing soils of the river cut -off. These heavy metals have influence on pedogenetic activities of soils microbes. It was reported (26) that increases cationic chromium significantly decreased active and total fungal mycelia. This reduced the colonizing power of these pioneers in protosoils. It is evident from the distribution of these heavy metals that decline in the proliferation and abundance of stromatolites and stromatolitic –type structures would be higher in paludifying soils. However, the presence of Fe and Mn oxides could buffer such effect as since they act as sinks of heavy metals (27). Again, the soil –plant barrier limits transition of trace elements through food chain although Cd can by-pass it (28).

Table 3. Distributions of selected total heavy metals (mg kg-1) in the study site (n=60)

Heavy metal	Terrestrializing (profile1)			Transitional (profile (2)			Paludifying (profile 3)		
	Max	min	mean	Max	min	mean	Max	min	mean
Cr	13.8	5.2	8.3	14.2	8.8	12.2	22.9	17.6	19.5
Cd	7.9	2.6	5.6	4.9	1.6	2.1	15.6	8.2	12.2
Pd	88.2	42.4	65.8	100.2	76.4	83.6	144.2	108.1	123.6
Ni	0.8	0.1	0.4	2.8	1.0	1.4	7.2	3.8	4.7
Hg	0.002	Trance	0.001	0.08	0.02	0.04	1.6	0.7	1.1

Highly significant relationships exist between studied heavy metals and the following soils properties', Organic matter, pH, Fe oxide, Mn oxide and clay at P=0.001, P=0.01 and P=0.05 levels. Sand content did not significantly influence heavy metals distributions in line with findings of other scholars (29,30) in similar aquatic habitats of Mexico and China . However, statistically significant relationship at p=0.001, p=0.01 and p=0.05 are indicative of positive or negative closeness in terms of adsorption or desorption of these heavy metals with the prevalent characteristics. There is variation in the way metals related to these edaphic properties. Nonetheless, significant positive relationship between Hg and OM (=0.88***) and Hg and OM (r=0.95*) values reported by (31, 32). These close relationships are helpful for prediction purposes and modeling, hence highly demanded in precision agriculture and quality control of the environment.

Table 4. Pearson Correlation Coefficient (r) between some heavy metals and selected soil properties (n=60)

Soil properties	Cr	Cd	Pb	Ni	Hg
pH	0.83**	0.48*	0.46*	0.58*	0.62*
Om	0.91***	0.52**	0.86**	0.72**	0.88***
Feox	0.68***	0.48***	0.77**	0.87**	0.78***
Mnox	0.61***	0.73**	0.72***	0.69***	0.80***
Clay	0.65*	0.45*	0.58*	0.53*	0.68**
Silt	0.16Ns	0.28*	0.21Ns.	0.26Ns	0.31Ns
Sand	-0.12Ns	0.09Ns	-0.13Ns	0.19Ns	0.14Ns

Om = organic matter, Feox= oxalate iron, Mnox= oxalate manganese, ***,P=0.001,**,P=0.01,*,P=0.05,Ns not significant.

CONCLUSIONS

The total heavy metal content of soils of the study site were higher than critical limits. Movement of the river across a highly polluted urban area caused an increase in heavy metal load in soils along the water course, leading to higher concentration of these contaminant metals in the paludifying soils when compared with values in transitional and terrestrializing soils. Soil organic matter, Fe and Mn oxides pH and clay content had significant correlations with heavy metals, suggesting their use for modeling environment quality.

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