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A STUDY ON PHYSICOCHEMICAL, MICROBIOLOGICAL AND BIOCHEMICAL PROPERTIES OF WETLAND SOILS IN EKET, AKWA IBOM STATE, NIGERIA.

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ABSTRACT: *The physicochemical, microbiological and biochemical characteristics of wetland soils in the Eket Local Government Area were studied between March 2019 to February 2021. Soil samples were collected at depths of 0-15cm and 15-30cm and analyzed for physicochemical, Microbiological and Biochemical properties. Laboratory data obtained were subjected to statistical analysis. The results showed that sand particles dominated the particle size distribution, of the entire wetland soils, while silt and clay were very low. Chemical analysis revealed that the mean pH obtained was 6.2 ± 0.2, 6.45 ± 0.07, and 6.60 ± 0.14 for Ntak Inyang, Etebi, and Ekpene Obo wetland soils respectively. Similarly, the highest organic matter was obtained in Ekpene Obo (6.96 ± 0.74%) followed by Ntak Inyang (6.58 ± 2.69%), while Etebi had the least (4.89 ± 1.77%). The highest total nitrogen was obtained in Ekpene Obo (0.17 ± 0.02%), followed by Ntak Inyang (0.16 ± 0.07%) and Etebi having the least with (0.12 ± 0.04%). Ntak Inyang wetland soils had the highest biomass carbon (1.58 ± 00 μg^{-1}) followed by Etebi (1.37 ± 0.44 μg^{-1}), and Ekpene Obo the least (1.01 ± 00 μg^{-1}). The highest biomass of Nitrogen was obtained in soils of Ekpene Obo (0.4 ± 0.01 μg^{-1}) followed by Ntak Inyang (0.02 ± 0.02 μg^{-1}) while soils of Etebi had the least (0.03 ± 0.01 μg^{-1}). The Pearson correlation matrix showed that moisture content had a strong and negative relationship with* ***bulk density (r = -0.69), while base saturation correlates positively with total nitrogen (r=0.681). Urease had a strong, and positive relationship with catalase (r=0.734), whereas bacteria relate negatively with total N (r=-0.801), and B.S (r=-0.781), but positively with catalase (r=-0.698).*** *The negative correlation observed in most of the soil properties is a result of the low decomposition of organic matter in wetland soils, because anaerobic bacteria operate at a much slower energy level than aerobic bacteria, decomposition proceeds much more slowly in anaerobic and oxygen-limited environments such as wetlands.*

KEYWORDS: Physicochemical, microbiological, properties, wetland soils.

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INTRODUCTION

Wetlands are ecologically as well as economically important systems due to their high productivity, their nutrient cycling capacities and their prominent contribution to global greenhouse gas emissions. Being on the transmission between terrestrial and aquatic ecosystems, wetlands are buffers for terrestrial runoff thereby preventing eutrophication of inland as well as coastal waters (Edwards, 1990)

Wetlands are endowed with specific structural and functional attributes performing major ecological roles in the biosphere (Edwards, 1990). They have been recognized as peat bogs, green and sedge marches, flood plains consisting of recent alluvial deposits bordering rivers, inland valleys, shadows ponds, mudflats, and littoral areas of large bodies of water which can be grouped into naturally occurring and anthropogenic wetlands (Gopel et al., 1982; Eshiet, 1992).

The proximity of oxic-anoxic conditions, often created by wetland plant roots, facilitates the simultaneous activity of aerobic as well as anaerobic microbial communities. The input of nutrients and fast recycling due to active aerobes and anaerobes makes these systems highly productive and therefore attractive for humans as well as many other organisms. Wetlands soils in Nigeria constitute vast, under-exploited and sometimes undiscovered ecologies (Eshiet, 1994). Changes in land use as well as altered hydrological due to climate change and anthropogenic activities will lead to the disturbance and loss of these habitats. This is true of wetland soils in Eket receiving industrial wastes and effluents from Mobil Producing Nigeria Unlimited, the second largest oil and Gas Company in Nigeria after Shell Petroleum Development Company (Udotong et al., 2008). Several studies carried out on selected wetlands in Nigeria have considerable agricultural potential (Eshiet et al., 1988; Eshiet, 1994). However, the diversity and functioning of microbial communities in wetland systems is highly underexploited in comparison to soils and aquatic ecosystems. This research was therefore designed to study the microbiological, enzymatic and physicochemical properties of the wetland soil of Eket, Nigeria.

MATERIALS AND METHODS

Study Area

The study area comprises wetland sites distributed along Ntak Inyang, Etebi and Ekpene Obo in Eket Local Government Area. The land types of the sampling locations can be described as being nearly level to gently undulating slope of 0-3; which provides a very stable physiographic environment for relatively uniform parent materials. The vegetation of sampling locations comprises grasses, ferns, oil and raffia palms (Peters, 1989)

Sample Collection

Soil samples were collected at two depths (0-15 and 15-30cm) from three locations–Ntak Inyang (NI), Etebi (ET), and Ekpene Obo (EO). The soil samples were collected in the month of March into labelled sterile polythene bags and taken in ice-packed coolers to the laboratory for microbial and enzymatic properties. Other samples were collected into labelled polythene bags for physical and chemical analysis.

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Table 1: The Study sites

Location	Lat.	Long.
Ntak Inyang (NI)	7 º 57¹	4º 41¹
Etebi (ET)	7 º 56¹	4º 43¹
Ekpene Obo (EO)	7 º 54¹	4º 39¹

Physico-chemical properties of the soil

The physico-chemical properties of the soil were determined by using standard methods as by Sparls (1996). Particle size was done by Bouyocos (1951). Hydrometer method, Soil pH was done using 1:2.5 soil-to-water ratio on a digital pH meter, model (EQ-610). Organic Carbon was determined by dichromate-wet oxidation method by Walkley – Black (1934). Total Nitrogen was estimated by macro–Kjeldahl procedure (Jackson, 1962). Available phosphorus was estimated using the Bray-P-1 method as described by Bray and Kurtz (1945). Exchangeable Bases, Ca, Mg, Na and K were extracted using NH_4OAC, Ca and Mg were determined using EDTA titration methods, while K and Na were determined by flame photometer. Exchangeable acidity in the soil was extracted with 1M KCl and determined by titration method by 0.05N NaOH, as described by Mclean (1965). Effective Cation exchange capacity was obtained by summation of exchangeable bases and exchangeable acidity. Percentage base saturation was calculated as % Base Saturation = $\frac{Ca+Mg+K+Na}{ECEC}$ x 100

Bulk density was determined using the method for non-Stoney soils as described by Anderson and Ingram (1993).

Determination of microbial biomass Carbon

Soil microbial biomass C was estimated by extracting 20g field moist soil samples in 0.5M k_2SO_4

(1:4 w/v) known as the Chloroform-fumigation – extracting method described by Brookes et al. (1985) and Vance et al (1987). Duplicate soil samples from each wetland were placed in a 50ml flat-bottomed flask, samples designated for fumigation were placed in the vacuum desiccator and fumigated by exposing the soil to Chloroform vapour for 24hrs, the desiccators were sealed, placed in a laboratory hood, after the $CHCl_2$ was evacuated, allowing the Chloroform to boil approximately for 30secs after $CHCl_2$ was removed by vacuum extraction, the soil was transferred to a 250 ml beaker where 120ml 0.5M K_2SO_4 was added. At the same time, the unfumigated soil samples were placed on a Conical flask and were treated in the same way. The flasks were shaken for 30 mins on a reciprocal shaker and the supernatant was filtered through a Whatman No 42 filter paper. Filtrates were kept at 4ºC. Microbial biomass C was estimated in 8ml aliquots of K_2SO_4 extracts after oxidation with 0.4 $NK_2Cr_2O_7$ at 150ºC for 30 minutes and back-titration with ferrous ammonium sulphate. Microbial biomass C was calculated by measuring the difference in extractable organic C between the fumigated and unfumigated soils, which are simply fumigated as Equation 1 (Variance et al., (1987):

Biomass C= 2.64 x E_c ---------- (1)

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Where: E_c refers to the difference in extractable organic C, between the fumigated and unfumigated treatments. 2.54 is the proportionality factor for biomass C released by fumigation extraction.

Determination of Microbial Biomass Nitrogen

The Kjedahl digestion-distillation extraction method was used to determine the total N in the K_2SO_4 with 10ml 95% H_2SO_4, 15ml of extract was digested after the addition of 0.4ml of 0.2M $CUSO_4$ to promote organic matter breakdown. The mixture was digested at 380ºC for 3hr until all the organic compounds were decomposed. The solution was brought to a volume of 250ml with deionized water. A 50ml subsample was steam-distilled in a strong alkaline solution (10M NaOH) and the distillate was collected in a biotic-acid-mixed indicator solution; the solution was then back-titrated (Anderson and Ingram 1999) N was calculated using the Equation 2

Biomass N = F_n/0.54 ---------- (2) where Fn= Total N from fumigated soil - Total N from unfumigated soil.

Determination of Enzyme Activity

Determination of Urease activity

Urease activity was determined as described by Pancholy and Rice (1973). Briefly, one militre toluene was thoroughly mixed with a 10g field moist sample in a 100 ml Erlenmeyer flask. After 15 mins, 20 ml phosphate buffer (pH 6.5), and 20 ml of 10% urea solution were added to the flask. The reactants were incubated at 37C for 24hrs followed by shaking for 15 mins with 30ml KCl solution. The contents were filtered with Whatman No. 41 filter paper and the filtrate was made up to 100ml with deionized water. Aliquots of five millilitres were analysed for NH_4-N content calorimetrically at 587nm. Urease activity was expressed as mgNH_4-Ng soil.

Determination of catalase

Catalase activity was measured according to the method of Dragon-Bullah (2000). The reaction mixtures consisted of three grams of wet soil samples added to a 250 ml flask, then 40ml of distilled water, five millilitres of 3% hydrogen peroxide (H_2O_2), 10ml phosphate buffer (pH 6.8), and 7ml of 0.1N $KMnO_4$ were poured into the flask and shaken for 30 mins., in an end to end shaker. After shaking, 10ml 3N H_2SO_4 was added to terminate the reaction. The residual potassium tetraoxomagnate (vii) was measured colorimetrically at 480nm and the result was recorded as Mg H_2O_2/g soil.

Microbial Analysis

Serial dilution

Seven sterile test tubes were set up, in the test tube rack and 9ml of sterile distilled water dispersed into them as diluent or dilutions blank 1g of the soil sample was added to the first test factor of 10^{-}. The process was repeated for all other tubes until a dilution factor of 10^{-6} was attained. 1ml of aliquot from 10^{-6} dilution was then aseptically transferred into sterile petri dishes and the microbial load was determined by the pour plate technique (Collins and Lyne, 1976; Halligan and Micance, 1976).

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Determination of Microbial Load (or Viable Plate Count or Total Plate Count).

Microbial load = No of colonies x the reciprocate of the Dilution factor (CFU/g)

= No of colonies x ¼ (CFU/g)

Enumeration of Heterotrophic Bacteria

The medium of choice was nutrient agar (NA) for enumeration of bacterial population. For fungi, the medium was SDA. One milli-litre of the liquor from 10^{-6} dilution was aseptically transferred into sterile petri dishes and the molten medium was poured up to 10-15cm. The plates were swirled appropriately and allowed to sit on the bench. All plates were incubated in an incubator for 24 hours while fungi plates were incubated at room temp. 28ºC for at least 72 hours.

Statistical Analysis

Collected laboratory data were subjected to statistical analysis using mean, standard deviation, coefficient of variability, correlation analysis and analysis of variance. Analysis of Variance (ANOVA) was used to compare treatment means among wetland types while correlation analysis was used to determine the relationship between soil's physical, chemical and microbial properties. Significance was tested probability level of 5%.

RESULTS AND DISCUSSIONS

Physical properties of the soils

Particle Size Distribution

Table 1 shows the particle size distribution of the soils. The highest sand (830.0 ± 42.43 g) was obtained in Etebi followed by Ntak Inyang (780.0 ± 113.14 g) while Ekpene Obo had the least (706.0 ± 26.46). The highest silt content was obtained in Ekpene Obo (134.0 ± 11.31 g) followed by Ntak Inyang (70.0 ± 42.43 g) while Etebi had the least (45.0 ± 7.07 g). Also, the soil of Ekpene Obo had the highest clay particle of 160.0 ± 14.14 g closely followed by the soil of Ntak Inyang with 150.0 ± 70.71 g while the least was obtained in the soil of Etebi (125.0 ± 35.36 g). Generally, sand particles dominated the particle size distribution of the entire soil while silt and clay were very low in terms of fertility status. This is because almost all the physicochemical properties that determine soil performance (water and nutrient retention and release, swelling and shrinking, cation exchange, cohesion) are surface phenomena. The magnitude of these processes is determined by the surface area available which in turn is determined by the texture of the soil.

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Table 2: Physical properties of the soils

Location	SN	Sand (g)	Silt (g)	Clay (g)	Textural class	BD (g/cm^3)	Moisture content (%)
Ntak Inyang	0-15	700	100	200	SCL	1.88	10.00
	15-30	860	40	100	LS	1.97	14.28
	Mean	780.0	70.00	150.0	SCL	1.67	8.58
	SD	113.14	42.43	70.71		0.11	4.50
	CV	14.38	60.61	47.14		6.59	52.45
Etebi	0-15	800	50	150	SL	1.88	10.00
	15-30	860	40	100	LS	1.97	14.28
	Mean	830.0	45.0	125.0	SL	1.93	12.14
	SD	42.43	7.07	35.36		0.06	3.03
	CV	5.11	15.71	28.29		3.11	24.96
Ekpene Obo	0-15	724	126	150	SL	1.5	18.75
	15-30	688	142	170	SL	1.88	15
	Mean	706.0	134.0	160.0	SL	1.69	16.88
	SD	25.46	11.31	14.14		0.27	2.65
	CV	3.70	8.44	8.84		15.98	15.70

Different textural fractions impart certain unique properties to the soil. The coarse fraction (sands) because of their large size and therefore small specific surface, contribute very little to the water and nutrient holding capacity of the soil. Sand fraction does not only contribute little to soil nutrient and water holding capacity of the soils; it also influences the distribution of the soil properties negatively or positively as the case may be. Sand particles dominated the particle size distribution of the entire soil. The low content of silt and clay particles also suggests that the soils are not well sorted and this may have a serious effect on the structural stability of the soils. The distribution of particle size with depth revealed that sand, silt and clay particles were slightly higher in 0-15cm than 15-30cm in all the three wetland soils except Ekpene Obo implying slight variations in textural characteristics of wetland soil depths.

The textural characteristics of these soils reflect the parent materials which the soils are derived from. The distribution of the particle size also suggests that these soils may have unstable surface layers that are susceptible to the erosion force of runoff. The coarse texture of these soils with low-activity clay suggests low soil water holding capacity and nutrient availability (Ogban and Ekerete, 2001), hence, influencing the structural stability of the primary aggregates which in turn affect the nutrient holding capacity of the soil and leaching of the basic cations. Texturally, there were variations among the soils of these three wetlands. Soils of Ntak Inyang had Sandy Clay Loam texture (SCL) at the surface and Loamy sand Texture (LS) at the subsurface and SCL overall. A Sandy Loam texture (SL) was obtained at the surface of Etebi soil and Loamy Sand (LS) at the subsurface while soils of Ekpene Obo had a Sandy Loam (SL) texture at the surface and subsurface horizon.

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Bulk Density

Bulk density of the soils is presented in Table 1. It ranged from 1.59-1.74 with a mean of 1.67 ± 0.11gcm^{-3} in Ntak Inyang, 1.88-1.97 with a mean of 1.93 ± 0.06 gcm^{-3} in Etebi soil and between 1.5 and 1.88 with mean of 1.69 ± 0.27 gcm^{-3} in Ekpene Obo. In terms of magnitude, the mean bulk density of the soils was in the order Etebi > Epene Obo> Ntak Inyang. The bulk density of the three soils was moderately high. This implies the movement of water in these soils is high and root penetration may be easy too and these soils may have physical supporting ability foremost plants.

Bulk density gives an indication of how compacted or loose the soil is. High bulk density indicates compact condition while low bulk density indicates looseness. Root growth is enhanced when the soil is less compacted. Hence, compact soil mechanically impedes root elongation or extension. Some degree of compaction is however required in the soil to ensure adequate anchorage for the roots. According to Onofiok (2002), bulk density values for field soils range from 1.20 gcm^{-3} for clay soils to 1.50 gcm^{-3} for coarse or medium-textured soils. Hence, bulk density was slightly higher in 0-15cm than 15-30cm depth in the entire wetland soils except Ekpene Obo suggesting higher structural stability in Ntak Inyang and Etebi than Ekpene Obo.

Moisture content

Table 1 shows the moisture content of the soils. Values obtained ranged from 11.76-5.4% with a mean of 8.58 ±4.50% in Ntak Inyang; it ranged from 10.0-14.28% with a mean of 12.14 ±3.03% in Etebi and between 19.75 and 15.0 with mean of 16.88 ±2.65% in Ekpene Obo. The highest moisture content was obtained in the soil of Ekpene Obo followed by Etebi while Ntak Inyang had the least. However, there was no significant difference in moisture content of the three wetland soils ($P<0.05$)

This indicates that the level of water in wetland soils varies from one location to another. However, values obtained in these soils are generally high suggesting that plants may not easily experience water stress in these soils even with a few days of depth. The moisture content of the soils did not follow any definite pattern. In Ntak Inyang and Ekpene Obo, the highest was obtained at 0-15cm whereas in Etebi, 15-30cm recorded the highest.

Chemical properties of the soil

Soil pH

Mean pH obtained were 6.5±0.21, 6.45±0.07 and 6.60 ± 0.14 for Intak Inyang, Etebi and Ekpene Obo wetland soils (Table 2) and the means were not significantly different at $P>0.05$. However, pH varied greatly between the depths considered. Values obtained at 0-15cm were lower than values obtained at 15-30cm in the entire locations suggesting that acidity of wetland soil is higher at the surface than subsurface. This could be attributed to the leaching of basic cations from the A horizon and subsequent accumulation at the B horizon thereby rendering the surface with more acidic ions like H^+ and Al^{+3} which then results in low pH at the surface compared to the subsurface soil.

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Electrical conductivity

The highest value was obtained in Ekpene Obo soil (0.019 ± 0.001 ds/cm) followed by Etebi (0.002 ± 0.001 ds/cm) while Ntak Inyang had the least (0.044 ± 0.02 ds/cm). Comparatively, the difference was not significant (P>0.05). The electrical conductivity of the three soils was lower than 2ds/cm reported by FAO (1990) for classifying soils as saline. The electrical conductivity of the soils was constantly distributed with depth except in Ekpene Obo.

Table 3: Chemical properties of the soils

Location	Depth	pH	ECs/cm	OM %	TN %	P Mg/kg	Ca	Mg	Na	K Cmol/kg	EA	ECEC	BS %
Ntak Inyang	0-15	6.4	0.019	8.48	0.212	8.4	9.6	3.2	0.05	0.08	1.6	14.5	89.17
	15-30	6.1	0.017	4.68	0.117	5.13	6.0	2.0	0.05	0.08	1.76	9.8	82.2
	Mean	6.25	0.018	6.58	0.16445	6.77	7.8	2.6	0.05	0.08	1.68	12.15	85.69
	SD	0.21	0.00	2.69	0.07	2.31	2.55	0.85	0.0	0.0	0.11	3.32	4.93
	CV	3.36	7.86	40.84	40.84	34.12	32.69	32.69	0.0	0.0	6.55	27.33	5.75
Etebi	0-15	6.4	0.019	3.63	0.09	1	4	1.3	0.04	0.09	2.24	7.67	70.79
	15-30	6.5	0.02	6.14	0.153	1.4	5.6	1.9	0.05	0.07	2.56	10.18	74.85
	Mean	6.45	0.01995	4.89	0.12	1.2	1.6	1.6	0.05	0.08	2.4	8.93	72.82
	SD	0.07	0.00	1.77	0.04	0.28	0.42	0.42	0.01	0.01	0.23	1.77	2.87
	CV	1.09	3.63	36.33	36.66	23.33	26.25	26.25	20.00	12.50	9.58	19.82	3.94
Ekpene Obo	0-15	6.5	0.03	6.43	0.16	1.87	12.4	4.13	0.05	0.09	2.24	18.91	88.15
	15-30	6.7	0.058	7.48	0.19	1.2	12.8	4.3	0.05	0.09	2.08	19.32	89.23
	Mean	6.6	0.044	6.96	0.17	1.54	4.22	0.05	0.05	0.09	2.16	19.12	88.69
	SD	0.14	0.02	0.74	0.02	0.47	0.12	0	0	0	0.11	0.29	0.76
	CV	2.12	45.00	10.68	11	30.52	2.84	0.0	0.00	0.00	5.09	1.52	0.86

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Organic matter

Mean organic matter of 6.58 ± 2.69, 4.89 ± 1.77 and 6.96 ± 0.74% were obtained in Ntak Inyang, Etebi and Ekpene Obo wetland soils respectively. The result shows that the highest organic matter was obtained in Ekpene Obo followed by Ntak Inyang while Etebi had the least but the difference was not significant (P>0.05). The organic matter obtained was higher than the 2% reported by Onfoiok (2002) classifying it as low. This suggests that these soils may have the ability to adequately supply essential nutrients for crops.

Considering the two depths, the highest organic matter was obtained at 15-30cm except at Ntak Inyang soil. Generally, organic matter decreases with depth due to the activities of soil-living organisms which decreases with depth. Exceptions in these wetland soils particularly Etebi and Ekpene Obo could suggest that this theory may not hold in some wetland soils, or on the other hand, the organic matter might have been buried due to erosion.

Total Nitrogen

The Total Nitrogen of these soils reflects organic matter levels in the three wetland soils. The highest was obtained in Ekpene Obo (0.17 ± 0.02%) followed by Ntak Inyang (0.17 ± 0.07%) while Etebi had the least (0.12 ± 0.04%). However, there was no significant difference in the nitrogen content of the soils. Just like organic matter, 15-30cm depth had higher Nitrogen than 0-15cm except in Ntank Inyang. The trend in total nitrogen is similar to the trend in organic matter observed in this study and this is expected because most of the soil's nitrogen exists in organic form.

Phosphorus

Ntak Inyang soil had the highest phosphorus content (6.77 ± 2.31 mg/kg) significantly higher than that of Ekpene Obo (1.54 ± 0.47 mg/kg) and Etebi (1.20 ± 0.28 mg/kg). The high phosphorus content of Ntak Inyang soil compared to Ekpene Obo and Etebi may be attributed to the nature of the basement complex. Ntak Inyang soil is formed from the coastal plain sand materials while soils of Ekpene Obo and Etebi are derived from beach ridge sand. It may therefore suggest that the phosphorus level of wetlands soils varies with land forms or geologic material from which the soil is derived. Available Phosphorus is known to be associated with organic matter (Ibia, 1994; 1997) but the distribution of available Phosphorus in this study did not reflect the distribution of organic matter in the three locations. Available Phosphorus content of the entire locations was lower than the 15mg/kg reported by Enwozor et al. (1990) as the critical value for crop production. Also, available P was higher at 0-15cm depth than at 15-30cm depth except in Etebi. The result is in agreement with Edem (1997) who reported higher available P at the surface than sub-surface soils of selected wetland soils in Akwa Ibom State.

Exchangeable Bases

Exchangeable cations of the soils are presented in Table 3. The highest (12.60 ± 0.28 cmol/kg) mean Ca was obtained in Ekpene Obo followed by Ntak Inyang with 7.80 ± 2.55cmol/kg while Etebi had the least (4.80 ± 1.13 cmol/kg). The highest mean Mg was obtained in Ekpene Obo (4.22 ± 0.12cmol/kg) followed by Ntak Inyang soil (2.60 ± 0.85cmol/kg) while Etebi had the least (1.60 ± 0.42cmol/kg). Similarly, Na was constantly distributed among the three locations each having a concentration of 0.05 cmol/kg while Ekpene Obo had the highest K (0.09 ± 0.0)

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slightly higher than 0.08 cmol/kg obtained in Ntak Inyang and Etebi respectively. There was a significant difference in Ca and Mg contents of the three locations (P<0.05) whereas, Na and K were not significantly different among the three locations (P>0.05). Comparing values of exchangeable basic cations obtained in the study with critical ranges of 10-20 Cmol/kg. Ca, 3-8 Mg, 0.6-1.2 K and 0.7-2.0 Na cited in John (2000), it can be inferred that the Ca level of Ekpene Obo soil is critical while that of Etebi and Ntak Inyang were at deficiency level. Furthermore, soils in Ntak Inyang and Etebi were deficient in Mg while the soil of Ekpene Obo is at a critical level. Generally, Na and K levels of the entire soil were at deficiency levels. Generally, these soils had low contents of exchangeable basic cations. The low content of these basic cations might have resulted from the leaching of basic cations leading to a high content of acidic cations (Al^{+3} $H^{+)}$ as the acidic cations might have brought the basic cations into solution. Values obtained in this study are slightly higher than values obtained by John (2000) in Wetland soils of Akwa Ibom State. The distribution of Ca basic cations of the soils was slightly higher at 0-15cm than at 15 cm except in Etebi.

Exchangeable Acidity (EA)

Exchangeable Acidity is made up of exchangeable Al^{+3} and H^{+}. In the study, the highest EA (2.40 ± 0.23 Cmol/kg) was obtained in Etebi followed by Ekpene Obo (2.16 ± 0.11 Cmol/kg) while Ntak Inyang had the least (1.68 ± 0.11 Cmol/kg). There was a significant difference in the EA of the three soils (P<0.05). The result suggests a higher exchange acidity problem in the soil of Ekpene, Obo and Etebi than Ntak Inyang. However, EA occupied less than 30% of the ECEC in the entire location and this proportion is far less than the 60% reported by Kamprath (1984) cited by Edem (1997) as a detrimental level for crop production. In Ntak Inyang and Etebi, EA was slightly higher in 0-15cm depth than in 15-30cm but the reverse was the case in Ekpene Obo.

Effective Cation Exchangeable Capacity (ECEC)

Soil of Ekpene Obo recorded the highest ECEC (19.12 ± 0.29 Cmol/kg) followed by the soil of Ntak Inyang (12.15 ± 3.322 Cmol/kg) while the soil of Etebi had the least (8.93 ± 1.77 Cmol/kg). The soils of Ntak Inyang and Ekpene Obo have a higher capacity to exchange cations than the soil of Etebi. There was a significant difference in ECEC of the three soils (P<0.005). However, the values are all below 20 Cmol/kg reported by FAO (1996) as an indication of the high suitability of soil for crop production. The distribution of ECEC with depth did not follow any definite pattern. In Ntak Inyang, ECEC was higher in 0-15cm than 15-30cm while 15-30cn recorded the highest in Etebi but constant distribution between the two depths in Ekpene Obo.

Base Saturation (BS)

Soil of Ekpene Obo had the highest base saturation (88.69 ± 0.76%) followed by Ntak Inyang with 85.69 ± 4.93% while Etebi had the lowest (72.82 ± 2.87%) and the difference was statistically significant (P<0.05). Base saturation of these wetland soils was generally high compared to 60% reported by Donahue (1986) as the critical limit for crop production. The high base saturation is an indication that these wetland soils were dominated by basic cations which are vital in soil fertility management. Generally, the fertility status of these wetland soils was very high suggesting that they can support crop proportion even with little or no fertilizer application thereby reducing the cost of farming in these soils. There was no definite pattern in the distribution of base saturation with depth, it was slightly higher in 15-30cm depth than 0-15cm in Ntak Inyang with the reverse in Etebi while they were similar in Ekpene Obo.

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The microbial population of the soil

Microorganisms isolated in the study include total heterotrophic bacteria (THB), total heterotrophic fungi (THF), Salmonella and Shigella and E-Coli, Salmonella, E-Coli. The distribution of these organisms in the soil of the study area is presented in Table 4. Population of THB ranged from 8.0 x 10^{7} – 1.50 x 10^{8} with mean of 1.15 x 10^{8} ± 2.1 x10^{8} cfug^{-1} in Ntak Inyang, it ranged from 3.60E±08 – 6.60 x 10^{8} with mean of 5.1 x 10^{8} ± 2.1 x 10^{8} cfug^{-1} in Etebi and between 1.8 x 10^{8} and 2.20 x 10^{8} cfug^{-1} with mean of 2.0 x 10^{8} ± 2.8 x 10^{7} cfug^{-1} in Ekpene Obo. Comparatively, Etebi had the highest THB followed by Ekpene Obo while Ntak Inyang had the least. THB of the soils did not reflect its organic matter content. The highest organic matter was obtained in Ekpene Obo followed by Ntak Inyang but the highest THB was obtained in Etebi followed by Ekpene Obo. Distribution of THB with depth revealed that 0-15cm had the highest in all the locations suggesting surface soil is higher in biomass population than sub-surface soil. This supports results obtained by Azam et al. (2003) who reported a higher biomass population on the surface than subsurface.

Population of THF ranged from 4.8 x 10^{5} – 2.2 x 10^{6} with mean of 1.3 x 10^{6} ± 1.2 x 10^{6} cfug^{-1} in Ntak Inyang, it ranged from 1.5 x 10^{5} – 3.7 x 10^{6}, with mean of 1.9 x 10^{6} ± 2.5 x 10^{6} cfug^{-1} in Etebi and between 2.2 x 10^{6} – 6.8 x 10^{8} cfug^{-1} with mean of 4.5 x 10^{6} ± 3.2 x 10^{6} cfug^{-1} in Ekpene Obo. Comparatively, Ekpene Obo had the highest THB followed by Ntak Inyang while Etebi had the least. THF of the soil reflects its organic matter content. The highest organic matter was obtained in Ekpene Obo followed by Ntak Inyang but the highest THB was obtained in Etebi followed by Ekpene Obo suggesting that fungal pupation in the soil varies directly with the level of organic matter in the soil. Distribution of THF with depth showed that, just like THB, 0-15cm had the highest in all the locations. Suggesting surface soil is higher in biomass pollution than sub-surface soil as reported by Azam, Farooq, and Lodhi (2003).

For Salmonella and Shigella (TSSC), values obtained ranged from 4.4 x 10^{5} – 2.2 x 10^{6} with mean of 1.3 x 10^{6} ± 1.2 x 10^{6} cfug^{-1} in Ntak Inyang; from 3.8 x 10^{5} – 2.5 x 10^{6} with mean of 1.4 x 10^{6} ± 1.07 x 10^{6} cfug^{-1} in Ekpene Obo. From the result, the soil in Etebi had the highest TSSC followed by the soil of Ntak Inyang while Ekpene Obo had the least but the difference was not statistically significant (P>0.05). Distribution of TSSC with depth showed that, just like THB, 0-15cm had the highest in all locations. Suggesting surface soil is higher in biomass pollution than sub-surface soil as reported by Azam et al., (2003).

The E coli population of the soil ranged from 8.0 x 10^{7} – 2.4 x 10^{8} with a mean of 1.6 x 10^{8} ± 1.1 x 10^{8} cfug^{-1} in Etebi and between 3.6 x 10^{5} and 6.8 x 10^{6} with a mean of 3.5 x 10^{6} cfug^{-1} in Ekpene Obo. The highest population was obtained in Ntak Inyang followed by Etebi while Ekpene Obo had the least and the difference was significant (P<0.05). Distribution of E-Coli with depth showed that just THB, 0-15cm had the highest in all the locations. Suggesting surface soil is higher in biomass pollution than sub-surface soil as reported by Azam et al. (2003).

Changes in human activity on land disturb the equilibrium between biomass population and soil organic matter (Harris, 2003). The microbial population of these soils were generally high and high content in Ntak Inyang compared to Etebi and Ekpene Obo soils did not reflect the accelerated oxidation of organic matter and the lower inputs of organic materials in these soils. Organic matter has a key influence on the biological properties of the soil. Biomass population

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has a direct influence on soil health and the high biomass population obtained in this study suggests high soil productivity in the entire locations.

The high population density of *Shigella dysenteriae*, *Salmonella* and *E. coli* are strong indicators that the wetlands in Eket are populated with human faeces and other industrial pollutants.

Table 4: Level of heterotrophic organisms in the soils

Locations	Depth	THB ▲	THF Cfu/g ▼	TSSC	E. coli
	0-15	1.50×10^6	2.2×10^6	2.2×10^6	8.0×10^7
Ntak Inyang	15-30	8.0×10^7	4.8×10^5	4.4×10^5	2.4×10^8
	Mean	1.15×10^8	1.3×10^6	1.3×10^6	1.6×10^8
	SD	4.9×10^7	1.2×10^6	1.2×10^6	1.1×10^8
Etebi	0-15	6.6×10^8	3.7×10^6	2.5×10^6	6.6×10^6
	15-30	5.1×10^8	1.5×10^5	3.8×10^5	$6.4x\ 10^6$
	Mean	2.1×10^8	1.9×10^6	1.4×10^6	3.5×10^7
	SD		2.5×10^5	1.4×10^5	4.0×10^7
Ekpene Obo	0-15	2.2×10^8	6.8×10^6	1.8×10^6	6.8×10^6
	15-30	1.8×10^8	2.2×10^6	3.8×10^5	3.6×10^5
	Mean	2.0×10^8	4.5×10^6	1.04×10^6	3.5×10^6
	SD	2.8×10^7	3.2×10^5	1.07×10^6	4.5×10^6

THB: Total Heterotrophic Bacteria, THF: Total Heterotrophic Fungi, TSSC: Salmonella and Shigella

Bacterial Strains Identified

Table 4 shows the occurrence and abundance of bacteria obtained in this study. These values were used in relating these organisms with the biomass levels in the soil. A total of 1168 bacteria were identified distributed within twelve (12) species. Of this population, 39.64% were obtained in Ekpene Obo. In Ntak Inyang, the highest bacteria species found was *Pseudomonas aeruginosa* (17.1%) followed by *Proteus mirabilis* (7.5%) while *Bacillus subtilis* were the least (1.0%) respectively. However, *Proteus rettigerii, Lactobacillus casei* and E-Coli and Coryne-bacterium, monocytogenes were absent in Ntak Inyang Soil. In Etebi, *Klebsiella aerogenes* was the highest bacterium species obtained (12.0%) followed by *Lactobacillus casei* (10.3%) while *Shigella dysenteriae* was the least *(0.3). Species not identified were Pseudomonasa aeruginosa and Staphylococus aureus.* Similarly, *Lactobacillus casei* occupied the highest population in Ekpene Obo (11.3%) followed by *Pseudomonas aeruginosa* (4.8%) while E-Coli was the least (0.6%). Species not found in Ekpene Obo were *Proteus miarabilis, Klebsiella aerugenes, Bacillus subtilis*, *Staphylococus aureus* and *Staphylococcus albus*. In terms of abundance, most abundance bacteria species all together included *Pseudomonas aeruginosa* (21.9%), *Proteus mirabilis* (16.1%), *Klebsiella aerogenes* (13.7), *Proteus rettigerii* (11.4%) and *Lactobacillus casei* (11.3%).

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Table 5: Bacteria species and their abundance in the soils

Species	Ntak Inyang	Etebi	Ekpene Obo	Total
Proteus mirabilis	88 (7.5)	100 (8.6)	0 (0)	188(16.1)
Kleb-siella aerogenes	20 (1.7)	140 (12.0)	0(0)	160 (13.7)
Pseudomonas aeruginosa	200 (17.1)	0 (0)	56 (4.8)	256 (21.9)
Proteus rettigerii	0 (0)	5 (0.4)	128 (11.0)	133 (11.4)
Bacillus subtilis	12 (1.0)	0 (0)	0 (0)	12 (1.0)
Lactobacillus casei	0 (0)	120 (10.3)	12 (1.0)	132 (11.3)
Coryne bacterium Monocytogenes	14 (1.2)	8 (0.7)	24 (2.1)	46 (3.9)
Staphylococcus aureus	41 (3.5)	0 (0)	0 (0)	41 (3.5)
Staphylococus albus	35 (3.0)	11 (0.9)	0 (0)	46 (3.9)
E-Coli	0 (0)	4 (0.3)	7 (0.6)	11 (0.9)
Salmonella typhi	17 (1.5)	31 (2.7)	12 (1.0)	60 (5.1)
Shigella dysenteriae	36 (3.1)	39 (3.3)	8 (0.7)	83 (7.1)
Total	**463**	**458**	**247**	**1168**

Values in bracket are Percentages

Fungal Strains Identified

A total of 604 fungal organisms were identified and were grouped into eleven (11) species (Table 6) out of which 41.23% were obtained in Ntak Inyang soil. 40.56% in Etebi and 18.21% in Ekpene Obo. In Ntak Inyang, *Sacharomyces currerrisicae* (9.9%) followed by *Sacharomyces cerevisae* (9.3%), Botrytis sp (8.6%) and *Sacromyces* spp. (8.1%) while *Aspergillous niger* was least (0.2). However, *Fusarim oxysporum*, *Aspergillus fumigatus* and *Paecilomyces* sp. Were absent in Ntak Inyang Soil. In Etebi, *Sacharomyces Cerevisice* (16.6%) followed by *Sacharomyces* spp. (9.3%), *Aspergillus terreus* and *Paecilomyces* sp (4.6% respectively) while *Sacharomyces cerevisae* had the least (1.0%). Species not found were *Botryti*s sp, *Fusarium oxysporus* and Aspergillus fumigatus. Similarly, *Aspergillus terreus* (7.6%) was followed by *Sacharomyces cerevisiae* (6.6%) while *Paecilomyces* spp. had the least (0.7%). Species not found in Ekpene Obo were Sacromyces spp, Botrytis sp, *Rhodotorula* spp. *Rhodotorula* spp. And *Aspergillus niger*. In terms of magnitude, most abundant fungal species altogether include *Sacharomyces currerrisicae* (27.8%) followed by *Sacromyce*s spp (17.4%), Sacharomyces cerevisae (16.9%) to *Aspergillus terreus* (13.4%) while *Fusarium oxysporum* was the least (0.33%).

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Table 6: Fungal species and their abundance in the soils

Species	Ntak Inyang	Etebi	Ekpene Obo	Total
Sachromycetes spp.	49 (8.1)	56 (9.3)	0 (0)	105 (17.4)
Botrytis sp	52 (8.6)	0 (0)	0(0)	52 (8.6)
Rhodotorula sp	16 (2.6)	8 (1.3)	0(0)	24 (4.0)
Sacharomyces currerrisicae	60 (9.9)	100 (16.6)	8 (1.3)	168 (27.8)
Rhodo sp	8 (1.3)	0 (0)	0(0)	8 (1.3)
Aspergillous niger	1 (0.2)	19 (3.1)	0(0)	20 (3.3)
Sacharomyces cererrisie	56 (9.3)	6 (1.0)	40 (6.6)	102 (16.9)
Aspergillous tereus	7 (1.2)	28 (4.6)	46 (7.6)	81 (13.4)
Fusarium oxysporum	0 (0)	0(0)	0 (0)	0 (0)
Aspergillus fumigatus	0 (0)	0(0)	12 (2.0)	12 (2.0)
Paecilomyces sp	0 (0)	28 (4.6)	4 (0.7)	32 (5.3)
Total	**249 (41.23)**	**245 (40.56)**	**110 (18.21)**	**604**

Values in bracket are Percentages

Biomass Carbon

Biomass carbon level of these wetland soils is presented in Fig. 1. Values obtained in this study ranged from 1.06 – 1.68 μg^{-1} with mean of 1.37.44 ± 0.44 in Ntak Inyang, 1.1 μg^{-1} with mean of 1.1 ± 0.0 μg^{-1} in Etebi and 1.58 ± 0.0 μg^{-1} in Ekpene Obo. In terms of magnitude, the soil of Ntak Inyang had the highest biomass Carbon followed by Etebi while the soil of Ekpene Obo had the least. However, there was no significant ($P>0.05$) difference in the level of biomass carbon of the three wetland soils. The higher biomass carbon in Ekpene Obo and Ntak Inyang may be attributed to the high organic matter accumulation of these soils compared to the soils of Etebi. Values obtained in this study are lower than 10-910 μg^{-1} obtained by Bauhus et al. (1998), and 61-2000 μg^{-1} obtained by Hernot and Robertson (1994) for agricultural soils. This is in line with results obtained by Kara and Bolat (2008) in Turkey. They compared the biomass carbon of forest, pasture and cultivated soils and reported that forest soils had the highest biomass carbon followed by pasture land while cultivated soil had the least. The high biomass carbon in forest soil was attributed to the high organic content of the soil compared to pasture and cultivated soils.

Distribution of biomass carbon with depth revealed that the trend did not follow any definite pattern suggesting fluctuations in organic matter with depth.

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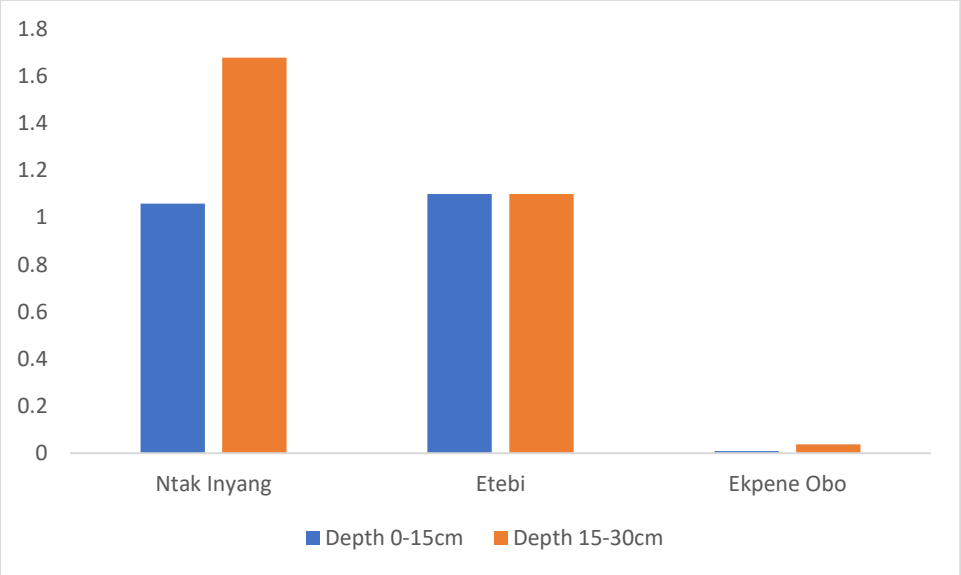

Figure 1: Biomass Carbon contents of the soils

Biomass Nitrogen

Level of biomass Nitrogen of the soils is presented in Fig. 2 and values obtained did not reflect that of biomass carbon of the soils. It ranged from 0.02 – 0.4 μg^{-1} with mean of 0.03 ± 0.01 μg^{-1} in Ekpene Obo, 0.02 – 0.04 μg^{-1} with mean of 0.01 ± 0.03 μg^{-1} in Etebi and 0.01-0.04 μg^{-1} with mean of 0.02 ± 0.02 μg^{-1} in Ntak Inyang. The highest biomass of Nitrogen was obtained in the soil of Ekpene Obo which was significantly (P>0.05) higher than Etebi and Ntak Inyang. However, there was no significant (P>0.05) difference in the level of biomass Nitrogen of the soils in Etebi and Ntak Inyang. The higher biomass of Nitrogen in Ekpene Obo soil suggests a higher level of mineralization of organic materials soil than other two areas. This is an indication that the level of mineralization of organic matter in wetland soils varies depending on the microbial and environmental conditions of a particular wetland soil. Values of biomass Nitrogen obtained in this study are lower than 30-132 μg^{-1} reported by Diaz Ravina et al. (1988) for forest soil, 52-125 μg^{-1} reported by Martikainen and Palojarvi (1990) for forest soils 116 μg^{-1} by Tracy and Frank (1998). It is also lower than 129.99, 100.90 and 42.60 μg^{-1} reported by Kara and Bolat (2008) for forest, pasture and cultivated land.

The general comparison of these results shows that microbial carbon and Nitrogen of wetland soils are lower than that of upland soil. Variations in biomass carbon and Nitrogen may be attributed to climatic conditions, differences in land cover vegetation, root activities in the soil, soil types and properties, land use as well as management practices. Distribution of biomass Nitrogen with depth revealed that the trend did not follow any definite pattern suggesting fluctuations in organic matter with depth.

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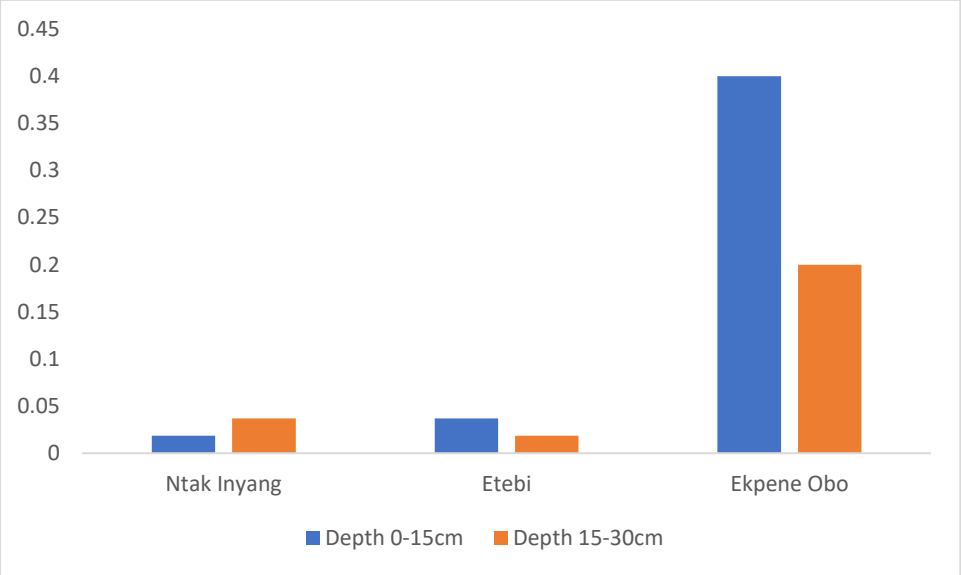

Figure 2: Biomass Nitrogen contents of the soils

Enzymatic activities of the soil

Soil enzymes isolated in the study include catalase (CAT), urease (UR) and cellulase (CEL). The distribution of these enzymes in the soil of the study area is presented in Fig. 3, 4 and 5. The highest CAT was obtained in Etebi (0.62 ± 0.21µg/g) while Ntak Inyang had (0.5 ug/g) and Ekpene Obo (0.30 µg/g) but the difference was not statistically significant (P>0.05). The Catalase of the soil did not reflect its organic matter content. The highest organic matter was obtained in Ekpene Obo followed by Ntak Inyang but the highest CAT was obtained in Ntak Inyang with equal distribution in Etebi and Ekpene Obo. Distribution of CAT with depth revealed that 0-15cm had the highest in all the locations suggesting that surface soil is higher in enzyme activities than sun surface soil. This is also supporting the result obtained by Azam et al. (2003)

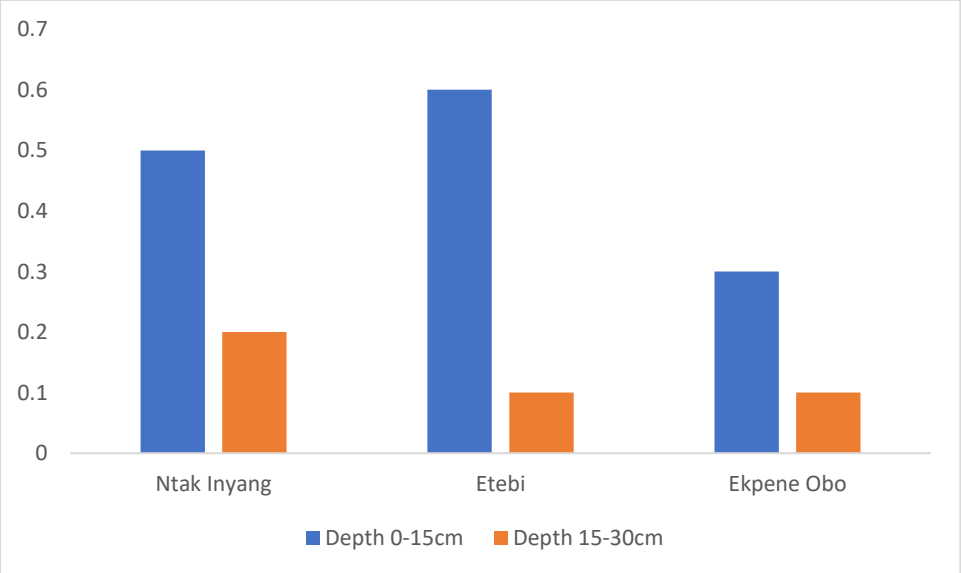

Fig 3: Distribution of Catalase Enzymes in the soil.

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The distribution of Urease (Fig 4) showed that the soil of Ntak Inyang had the highest (0.70 ± 0.07 µg/g) followed by Etebi (0.6 ± 0.35 µg/g) while Ekpene Obo had the least (0.50 ± 0.14 µg/g) but the difference was not statistically different (P > 0.05). The urease activity of the soil did not also reflect its organic matter content. The highest organic matter was obtained in Ekpene Obo followed by Ntak Inyang but the highest UR was obtained in Ntak Inyang followed by Etebi with the least in Ekpene Obo. Distribution of UR with depth revealed that 0-15cm had the highest in all locations suggesting that surface soil is higher in enzyme activity than sub-surface soil still supporting the result obtained by Azam et al. (2003).

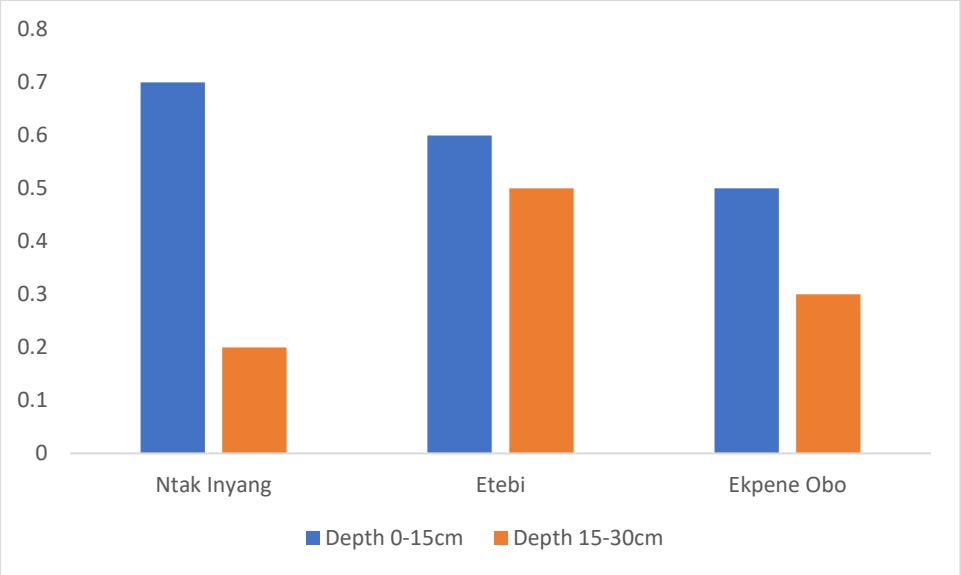

Fig 4 Distribution of Urease Enzymes in the soil

The values of CEL obtained in the study (Fig 5) showed that soil of Ekpene Obo had the highest (1.6 ± 0.21 µg/g) followed by Etebi (0.80 ± 0.14µg/g) while Ntak Inyang had the least (0.4 ± 0.21 µg/g) but the result from Ekpene Obo highest (P>0.05). Distribution of UR with depth revealed that 0-15cm had the highest in all the locations suggesting that surface soil is higher in enzyme pollution than sub-surface soil still supporting the result obtained by Azam et al. (2003).

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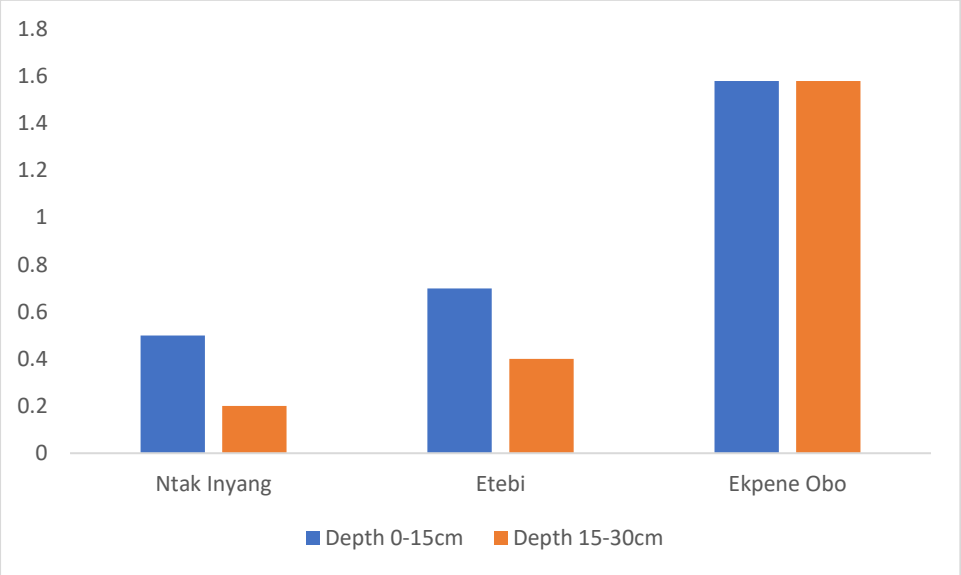

Fig 5: Distribution of Cellulase Enzymes in the soil

Table 7 shows the relationship among the Soil properties including biomass carbon, nitrogen, soil enzyme, bacteria and fungi. Soil moisture content had a highly significant, and negative relationship with a bulk density only (r=-0.690), while base saturation (BS) had a highly significant and positive correlation with total nitrogen (TN) (r=-0.681) Urease (UR) correlated highly and positively with catalase (r=0.734), whereas, microbial biomass C had a significant and negative relationship with Urease (r=-0.804). Bacterial, population relate highly, significantly, and negatively with total nitrogen (r=-0.801) and base saturation (r=-0.781), but relates positively and significantly with catalase. It was also observed that most of the parameters had and negative relationship with each other. This may be because anaerobic bacteria operate at a much lower energy level than aerobic bacteria, decomposition proceeds much more slowly in anaerobic and oxygen-limited environments such as wetlands. In addition to oxygen, organic matter decomposition in wetlands is regulated by other factors, including temperature pH, organic matter quality nutrients, and the availability of other terminal electron acceptors.

Table 7: Pearson correlation matrix among soil physico-chemical properties and soil Biological properties

Properties	BD	Moisture	pH	OM	TN	P	BS	Cat	UR	CEL	BC	BN	BAC	Fungi
BD	1	-.693*	-.223	.108	.011	.418	-.157	.305	-.087	-.473	.286	-.162	.326	-.442
Moisture		1	.126	-.115	.096	-.450	.357	-.629	-.411	.543	.318	-.074	-.251	.265
pH			1	.546	.126	.030	.403	-.006	-.108	.278	-.053	.306	-.220	.371
OM				1	-.517	-.076	.079	.321	.142	.287	-.300	-.250	.255	-.171
TN					1	.511	.681*	-.524	-.363	-.051	.389	-.010	-.801**	-.110
P						1	.488	.316	.050	-.436	-.121	-.253	-.248	-.102
BS							1	-.509	-.525	.280	.227	-.473	-.781*	-.128
Cat								1	.734*	-.401	-.645	.266	.698*	.240
UR									1	-.058	-.804**	.369	.403	.070

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CEL	1	-.201	-.055	-.292	.052
BC		1	-.114	-.165	-.200
BN			1	.275	.666
BAC				1	.217
Fungi				.	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

BD – Bulk density, OM- Organic matter, TN- Total Nitrogen, P- Phosphorus, BS- Base saturation, Bac- Bacteria, BC – Biomass carbon, BN- Biomass Nitrogen. Cat- Catalase, UR- Urease, Cel- Cellulase

CONCLUSION

The three soils had abundant microbial populations but relatively low biomass carbon and nitrogen which did not differ significantly among the three wetland soils. Therefore, there was no possible correlation between biomass carbon and nitrogen in the soils. Diversity of microorganisms is a key parameter for soil structure, fertility and microbial metabolism and these were identified in this study. The metabolic/enzyme activity of microorganisms in soils depends to a great extent on the quantity and nature of soil organic matter rather than the quantity present. The high diversity of species present ensures great potential and soil resilience in the degradation process.

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