Interrelationship between Soil Properties and Earthworm Abundance in the Ecological Belts of Western Niger Delta, Nigeria

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Abstract: The study examined the interrelationship between soil properties and earthworm abundance in ecological belts of Western Niger Delta, Nigeria. Eight 20m x 20m quadrat were delimited in the natural vegetation in each of the rainforest (RF), mangrove (M), fresh water swamp (FWS) and guinea savanna (GS) ecological belts to collect soil samples. Three quadrats of 1m x 1m were delineated to collect earthworm species. Earthworm species and soil samples were collected from the topsoil (0-15cm) and subsoil (15-30cm) and were taken to laboratory for further analysis. Descriptive statistics and inferential statistics were used for data analysis. Findings showed that in the topsoil, the silt content was highest in FWS (17.37±4.8%). The bulk density, total porosity and water holding capacity were slightly varied among the four ecological zones. In the subsoil, the mean soil moisture was significantly highest in the M (31.13±3.2%) and the silt content was highest in the RF. The soil moisture, sand, silt and clay were significantly varied among the ecological zones in both topsoil and subsoil. Findings revealed that soil pH was acidic in all the ecological zones. A total of 19 earthworm species were found with 58.5% individual species recorded in the topsoil and 41.5% recorded in the subsoil. The total population of *Eudrilius eugeniae* was predominantly highest in both topsoil (38.4%) and subsoil (27.1%). Significant relationships existed between earthworm abundance and soil physical properties ($R=0.895$, $p<0.05$), soil nutrients ($R=0.850$, $p<0.05$) and heavy metals ($R=0.859$, $p<0.05$) in the topsoil while only soil nutrients ($R=0.759$, $p<0.05$) and soil heavy metals ($R=0.592$, $p<0.05$) in the subsoil. The study recommended that soil nutrients should be improved in guinea savanna for the survival of earthworm abundance.

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1. Introduction

Earthworm abundance is related to high levels of soil fertility (Bernier and Ponge, 1998); as the duo is assumed to be influencing each other. It is revealed that there exist special interrelationships which express themselves to some degree by the total productivity of the soils because soil properties and ecosystem productivity seem to depend so much on earthworm fauna and vice versa. Understanding the influence of soil organisms on soil organic matter dynamics is important for the development of sustainable agro-ecosystems (Fonte et al., 2009). The beneficial effects of soil organic matter on soil productivity through the supply of plant nutrients, enhancement of cation exchange capacities, and improvements in soil and water retention are well established (Woomer and Swift, 1994). In addition, soil organic matter supports various soil biological processes by acting as a substrate for decomposer organisms and ecosystem engineers, such as earthworms. They play a role in both acceleration of decomposition and mineralization processes (C loss) and in carbon storage or protection from decomposition (C accumulation) in stable aggregates (Brown *et al*., 2000). Aggregation is a complex procedure that includes environmental factors, soil management factors, plant influences, and soil properties such as mineral composition, texture, SOC-concentration, pedogenic processes, microbial activities, exchangeable ions, and moisture availability (Kay, 1998). Cortez et al. (2000) reported that the presence of earthworms whatever the ecological category, increased the quantity of inorganic N in the soil. This was caused by enhanced mineralization of N forms, both of a ^{15}N-labelled residue and that of the soil organic matter. Earthworms can impact plant growth by promoting N-availability (Li et al., 2002; Ortiz-Ceballos, et al., 2007). The earthworm gut provides ideal conditions for N_2O producing microorganisms by providing abundant substrate, an anaerobic environment, suitable pH and high moisture content (Drake and Horn, 2007).

It is observed that earthworms have gained widespread awareness due to their influence on a diverse array of soil processes including aggregation, residue decomposition, nutrient mineralization, aeration, water infiltration rates, improve plant available moisture by increasing field capacity

(Stockdill and Cossens, 1966; Lee, 1985; Fonte et al., 2008) and benefit pasture production (van Groenigen et al, 2014). Thus, earthworms help maintain and enhance the physical condition and function of soils and their contribution to soil services, such as the flow of water, nutrients and gases, is influenced by earthworm abundance and diversity (Schon et al., 2017). The ability of earthworms to build soil aggregates and associated micropores (Six et al., 2002; Zangerle et al, 2011) and affect soil functioning by various mechanisms has earned them recognition as ecosystem engineers (Jones et al, 1994; Lavelle et al, 1997; Fonte et al, 2008). In addition, Greenwood and McKenzie (2001) have reported that earthworm benefits soil structure and reduce the impacts of detrimental agricultural practices by physically modifying the soil. This has generated interest in determining the factors that govern their abundance and community composition (Fonte et al., 2008). Despite these functions, a number of controls on earthworm growth and survival have been put forth which include tillage, fertilization, soil C inputs and soil texture (Marchan and Scheu, 2005). Studies have also revealed that intensive agricultural practices have resulted in the degradation of many soils, with some soils showing decreases in soil organic matter and loss of soil structure (Schipper et al., 2010).

Previous studies have reported many ways that earthworm abundance has been influencing and improving soil physical and chemical properties but none have considered varying ecological belts at a stretch in which the present study is filling the gap. Thus, the study investigated the interrelationship between soil properties and earthworm abundance in the ecological belts of Western Niger Delta, Nigeria.

2. Material and Methods

The study area is the Western Niger Delta Region of Nigeria. It is located between longitude 4^o 15' 0"E and 7^o 0' 0"E and latitude 5^o 0' 0"N and 7^o 30' 0"N. The Western Niger Delta Region comprises Ondo, Edo and Delta States (Figure 1). The study area involved the four ecological zones namely guinea savanna, rainforest, fresh water swamp and mangrove in the Western Niger Delta Region. The study area is located in the tropics and therefore experiences humid tropical climate (Adejuwon, 2012). It has distinct dry and wet seasons. Between 8 and 10 months in the year, the climate of the region is dominated by tropical maritime (mT) air mass while the remaining 2 to 4 months of the year are under the influence of the dry tropical continental (cT) air mass (Adejuwon, 2012). The annual temperature range is small as low as 3^{0}C. Mean monthly temperature is 26-28^{0}C (Adejuwon, 2012). Rainfall is between 1800mm and 3000mm per year (Ologunorisa and Adejuwon, 2003; Emaziye, et al., 2012). Relative humidity is about 85% and the relief of study area comprises of coastal plain. It is generally low lying without remarkable hills, consisting of unconsolidated sediments of quaternary age. Some hills can be found northwards within the Aniocha LGA in Delta State and northern parts of Ondo State. Thus, the relief of the region includes coastal lowland, the Esan Plateau, Orle valley, the dissected uplands of Akoko-Edo and Akure-Owo axis (Adejuwon, 2012). The soil types are made up of ferrosols predominantly dominated by sandy and little clay composition (Imoroa, 2000; Okoh, 2013). Geologically, the study area is underlain by the Coastal Plain sands having its place from the Pleistocenic Formation (Nwakoala and Warmate, 2014). The drainage of the study area is made up of River Niger that discharges into the sea through its several distributaries such as the Forcados, Escravos and Warri rivers and creeks such as the Bomadi Creeks, amongst others (Aweto, 2001; Okoh, 2013). Rivers Jamieson and Ethiope rise from the north and northeast respectively and subsequently join and form the Benin River, which eventually discharges into the sea in the West (Emaziye et al., 2012). Also importantly, River Osse in Ondo State which also discharges into the Atlantic Ocean. The study area comprises natural vegetation of lowland rainforest with patches of swamp vegetation. The forest was a major source of timber and the notable timber producing species include *Antiaris toxicaria, Milicia excelsa, Ceiba pentandra*, *Piptadeniastrum africanum*, *Pentaclethra macrophylla, Chrysophyllum albidum* and *Irvingia gabonenesi*s (Okoh, 2013). The types of occupation of the residents in the study locations include farming, fishing and industrial jobs.

A quadrat of 80m x 100m was delimited in natural (virgin) vegetation in the four ecological zones of the Western Niger Delta (Shen, 2011). This quadrat was sub-divided into quadrats of 20m x 20m from which eight (8) quadrats were randomly selected for data collection on soil samples in each ecological belt. Furthermore, three quadrats of 1m x 1m were delineated in each sampled 20m x 20m quadrats and were bulked together to have a total composition of earthworm species in each quadrat (Owa, et al., 2003). The sample plots were delimited with pegs and tagged with red coloured ribbon for easy identification of the boundaries. The sampling methods adopted for this study were stratified and simple random sampling techniques. Earthworm samples were collected at the soil depth of 0-15cm and 15-30cm, Earthworm populations were collected by digging and hand-sorting (Oboh, et al., 2007; Salehi et al., 2013). Digging is the simplest, as it requires only a spade and perhaps a quadrat for density calculations to detect both near surface (epigeic) earthworms and horizontal burrowing (endogeic) species (Butt and Grigoropoulou, 2010). Collected earthworm samples were identified adopting the methods of Segun (1998) and Owa *et al*. (2003). Earthworm composition was determined by counting the individual earthworm in the field and preserved in 4% formalin before bringing them to the laboratory (Julka, 1988). The earthworms were processed and separated according to species in the laboratory. In the laboratory, the earthworms were washed in the running water and drying them with a paper towel in the open air for three minutes (Baretta et al., 2007; Fonte, 2009). All the earthworms were then oven dried at 60°C for 24 hours. Earthworm biomass was computed as stated in Salehi et al. (2013).

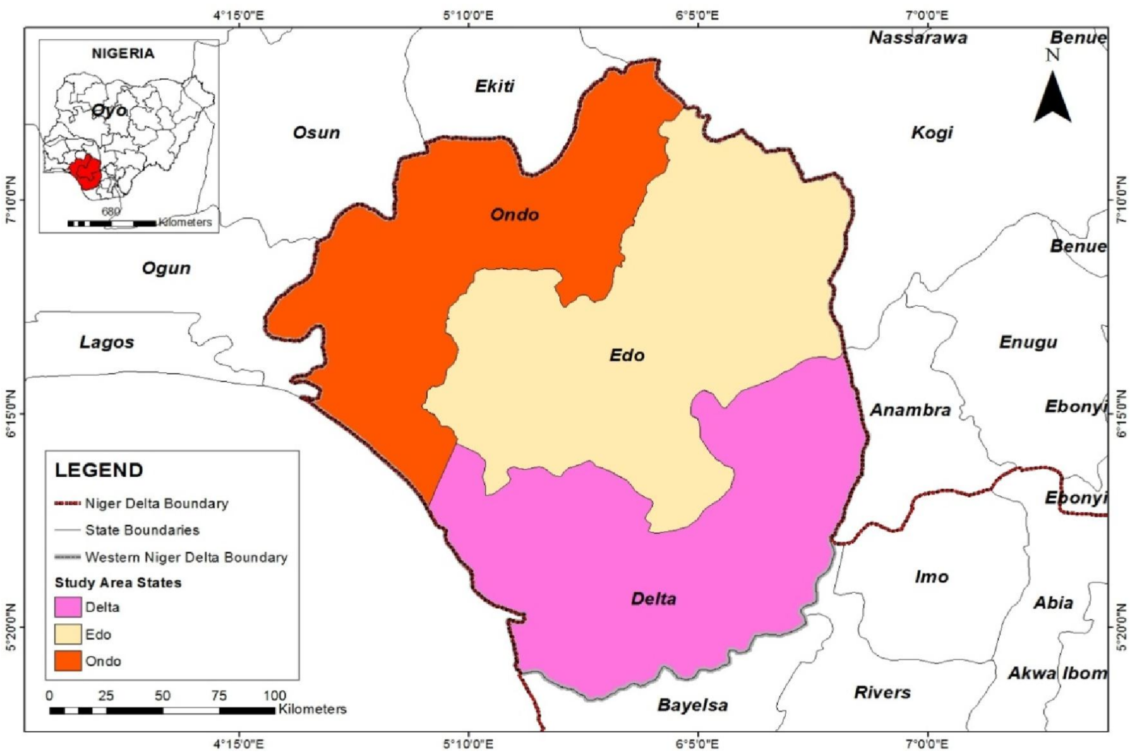

Figure 1: Western Niger Delta

$$LN\ (biomass) = [2.2853 \times LN\ (length)] - 11.9047$$

Length of individual earthworm was measured to the nearest millimeter using a meter rule (Oboh *et al*., 2007). Earthworm population density was computed by dividing the total number of individual earthworm in all quadrats by sampling area (0.0001 ha). Earthworm Soil Impact Index (SIINDEX) was computed using density and biomass of the earthworm. This is because SIINDEX is a function of density and biomass (Owa *et al*., 2003). SIINDEX is defined as the square root of the product of the earthworm density (in million worms/ha) and earthworm biomass (gm^{-2}). SIINDEX helps to determine the rate at which leaf litter breaks down and re-injection into the soil (Owa *et al*., 2003). Forests with SIINDEX less than 0.2 should be regarded as endangered, because their earthworm functions are too low to accomplish significant leaf-litter breakdown and recycling (Owa, et al; 2001).

Five soil samples were collected from each 20m x 20m quadrat using soil auger at the depth of 0-15cm (topsoil) and 15-30cm (subsoil). The soil samples in each depth were bulked together into a plastic container and a composite soil sample was taken in each quadrat from topsoil and subsoil. Thus, 8 soil samples were collected from each 20m x 20m quadrat the depth of 0-15cm (topsoil) and 15-30cm (subsoil) in the ecological zone. Composite soil samples were collected into well-labelled polythene bags and brought into the laboratory. The soil samples were air-dried and carefully sieved with 2mm diameter mesh in order to separate the soil from stones. Thereafter, the soil samples were taken to the laboratory for analysis to determine the levels of the physical and chemical properties of soils in the ecological belts. Soil particle size composition was analyzed using the hydrometer method of (Bouyoucos, 1926), bulk density and total porosity were determined using core method (Ichikogu, 2012) and water holding capacity as described in Dutta and Agrawwal (2002). Soil temperature were measured with soil thermometer *in situ* (Ochsner, 2008) while soil moisture was measured using gravimetric method (Su et al., 2014). Exchangeable bases which included Calcium (Ca), Potassium (K), and Sodium (Na) were determined using flame photometry, and Magnesium (Mg) using atomic absorption spectrophotometer. Cation Exchange Capacity (CEC) was determined using the summation method (Chapman, 1965) and total Nitrogen (N) was determined using Kjeldahl method. Available Phosphorus (P) was determined using spectophotometric method (Ogbonna and Okeke, 2011). Soil pH was determined using saturated paste extract while organic carbon was determined by Walkey and Black's rapid titration method (Walkey and Black, 1934).

Descriptive statistics were used to describe the mean values of the earthworm parameters and soil properties. Inferential statistics which include analysis of variance (ANOVA) was used to determine the significant variations in earthworm parameters and soil properties across the ecological zones in the study area (Cornish, 2006). Also, simple regression analysis and Pearson's product moment correlation statistics were used to establish relationships between earthworm abundance and soil properties in the ecological belts at 0.05 significant levels (Campbell & Campbell, 2008).

3. Results

Soil Properties across the Ecological Zones

The physical properties of soil in the topsoil and subsoil are shown in Tables 1 and 4.2 respectively. In the topsoil, soil moisture was highest in the mangrove (30.00%) and the lowest was observed in guinea savanna (12.50%). Temperature was slightly varied among the four ecological zones but temperature was higher in guinea savanna with a mean temperature of 27.37 ^{o}C. Among the soil particles size distribution (sand, silt and clay), sand recorded the highest. Sand content was highest in mangrove (87.20%) and the lowest was observed in the freshwater swamp (62.35%). Considering silt content, fresh water swamp recorded 17.37% as the highest among the ecological zones, rainforest recorded 13.90% while mangrove recorded 7.40% and guinea savanna recorded 8.97%. The bulk density slightly varied in the four ecological zones, but guinea savanna recorded the highest with mean value of 1.48 g/cm^3 and the least was observed in mangrove recording 1.44 g/cm^3. The porosity and water holding capacity varied slightly among the ecological zones. However, soil porosity was highest in mangrove. This may be attributed to the high sand content which might have enabled wider pore space within the soil. The water holding capacity was highest in the rainforest with the mean value of 44.81%.

Table 1: Soil Physical Properties at the Topsoil and Subsoil

Soil Depth	Soil Properties	Rainforest	Mangrove	Guinea Savanna	Fresh Water Swamp	F Value
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	
Topsoil (0-15cm)	Soil Moisture (%)	13.75±5.2	30.00±0.1	12.50±3.8	21.25±3.5	38.89*
	Temperature (^{o}C)	27.25±0.5	26.75±0.7	27.37±0.5	27.25±0.5	2.06
	Sand (%)	78.47±4.9	87.20±4.6	80.60±2.1	62.35±7.0	36.10*
	Silt (%)	13.90±4.6	7.40±3.7	8.97±1.5	17.37±4.8	11.05*
	Clay (%)	7.63±2.7	5.40±3.1	10.43±1.0	20.38±3.9	14.87*
	Bulk Density (g/cm^3)	1.46±0.1	1.44±0.8	1.48±0.1	1.47±0.1	0.27
	Total Porosity (%)	45.00±3.7	45.25±3.3	43.38±2.0	44.37±2.6	0.64
	Water Holding Capacity (%)	44.81±0.8	44.13±1.4	44.38±1.3	44.07±1.9	0.48
Subsoil (0-15cm)	Soil Moisture (%)	15.50±1.3	31.13±3.2	12.75±3.6	25.13±3.4	36.87*
	Temperature (^{o}C)	27.38±0.2	26.88±0.6	27.56±0.4	27.44±0.3	2.66
	Sand (%)	76.73±7.5	84.70±4.2	84.60±2.6	65.23±9.5	15.33*
	Silt (%)	15.40±7.3	8.40±4.7	6.98±2.7	14.63±4.5	5.71*
	Clay (%)	7.87±1.5	6.90±1.9	8.42±1.7	20.14±4.6	30.46*
	Bulk Density (g/cm^3)	1.46±0.2	1.42±0.1	1.44±0.1	1.48±0.5	1.47
	Total Porosity (%)	44.25±1.5	47.00±2.8	46.00±3.3	44.00±2.1	2.63
	Water Holding Capacity (%)	44.68±0.8	44.25±1.3	44.25±0.8	43.98±1.3	0.58

*Variation is significant at $p<0.05$ (N=32); N=8 (For mean values)

In subsoil, the mean soil moisture was highest in the mangrove (31.13%) while the least was observed in guinea savanna (12.75%). The soil temperature was highest in guinea savanna (27.56 ^{o}C) and lowest was found in the mangrove (26.88 ^{o}C). Similarly, the sand content was predominantly higher in the subsoil among the particle size composition. The highest sand content was found in mangrove (84.70%) and the lowest sand content was recorded fresh water swamp (70.22%). Meanwhile, the silt content was highest in the rainforest (15.40%) and the least was recorded in guinea savanna (6.98%). The clay content was highest in fresh water swamp (20.14%) and the least was recorded in mangrove (6.90%). The bulk density was highest in the freshwater swamp (1.48 g/cm^3) and the lowest was found in mangrove (1.42 g/cm^3). The total porosity was slightly higher in the mangrove (47.00%) than other ecological zones while the water holding capacity was highest in the rainforest (44.68%). The soil moisture and soil temperature were higher in the subsoil than the topsoil across the ecological zones. Soil moisture, sand, silt and clay were significantly varied among the ecological zones in both topsoil and subsoil at $p<0.05$ significant levels.

Soil Chemical Properties

The analyses of soil chemical properties across the ecological zones at both the topsoil and subsoil are presented in Table 2. In the topsoil, the soil pH was acidic across the ecological zones but more acidic in the freshwater swamp (4.45) and less acidic in mangrove (5.50). The organic C was 5.57% in the freshwater swamp; 3.84% in mangrove, 3.05% in the rainforest and 1.80% in the guinea savanna. Similarly, total N was highest in the freshwater swamp (0.41%) and the least was found in guinea savanna with mean value of 0.16%. Available P in the topsoil was 23.40 mg/kg in the freshwater swamp which was the highest of all the ecological zones, 16.80 mg/kg in the rainforest, 11.55 mg/kg in the mangrove and 8.55 mg/kg in guinea savanna. The exchangeable Ca was highest in the mangrove (3.87 Cmol/kg) while the lowest was observed in both rainforest and fresh water swamp having 1.07 Cmol/kg. Exchangeable Mg ranged from 0.43 Cmol/kg in the freshwater swamp to 1.27 Cmol/kg in the mangrove. Exchangeable K was highest in guinea savanna with a mean value of 0.48 Cmol/kg and the lowest was observed in the rainforest with a mean value of 0.27 Cmol/kg. Furthermore, exchangeable Na was highest in the mangrove (0.31 Cmol/kg) while the lowest was found in guinea savanna (0.24 Cmol/kg). The mean CEC for rainforest in the topsoil was 4.78 Cmol/kg in the rainforest, 6.55 Cmol/kg in mangrove, 3.85 Cmol/kg guinea savanna and 11.03 Cmol/kg in the freshwater swamp. The exchangeable acidity in the topsoil was highest in the freshwater swamp (8.82 Cmol/kg) and lowest in mangrove (0.72 Cmol/kg). Considering the heavy metals in the topsoil, mean Pb was highest in the rainforest (9.09 mg/kg) while mangrove, guinea savanna and freshwater swamp had 7.84 mg/kg, 7.49 mg/kg, and 8.06 mg/kg respectively. It was discovered that mean Mn was high across the ecological zones but this was highest in the freshwater swamp (295.87 mg/kg) and the least was observed in mangrove (251.50 mg/kg). Mean Fe was highest in the rainforest (504 mg/kg) and the lowest was found in the guinea savanna (103.96 mg/kg). Mean Cu had the least concentration in the entire study area compared to all trace elements investigated in this study. Meanwhile the mean Cu was highest in the rainforest (0.83 mg/kg) and lowest in the freshwater swamp (0.15 mg/kg). Mean Zn concentration across the entire study area was similar to Pb and Fe concentrations in the study area whereby the highest concentration of Zn was found in the rainforest with a mean value of 13.07 mg/kg and the lowest was found in guinea savanna with a mean value of 5.97 mg/kg.

In the subsoil, the mean soil pH observed in the entire study area was acidic and it followed similar trend with the topsoil whereby freshwater swamp has the highest level of acidity (4.47) and the least was found in mangrove (5.50). Both organic C and total N were higher in the topsoil than the subsoil and follow the same trend as freshwater had the highest mean organic C (4.57%) and total N (0.42%) while guinea savanna had the lowest organic C (1.41%) and total N (0.12%). Similar to topsoil, the available P was highest in the freshwater swamp with a mean value of 27.01 mg/kg and the lowest was found in guinea savanna (7.38 mg/kg). Available P was higher in the topsoil across the ecological zones except in the mangrove where it was slightly higher in the subsoil. Exchangeable Ca was highest in mangrove (4.18 Cmol/kg) and least was found in guinea savanna (7.38 mg/kg) while mean exchangeable Mg was highest in the mangrove (1.26 Cmol/kg) and lowest in the freshwater swamp (0.41 Cmol/kg). The exchangeable K was 0.51 Cmol/kg, 0.44 Cmol/kg, 0.34 Cmol/kg and 0.26 Cmol/kg in guinea savanna, freshwater swamp, mangrove and rainforest respectively. Mean Na concentration in subsoil was slightly varied from the topsoil and except mangrove, Na concentration was higher in the topsoil than the subsoil. Moreover, the mean CEC was highest in the freshwater swamp (9.27 Cmol/kg) and the least was observed in guinea savanna (3.53 Cmol.kg). The exchange acidity was also highest in freshwater swamp (7.25 Cmol/kg) and least in mangrove (0.97Cmol/kg). The concentration of Pb was highest in the rainforest (9.46 mg/kg) and the lowest concentration was found in the mangrove with a mean value of 7.02 mg/kg. The concentrations of Mn and Fe were highest in the freshwater swamp with mean values of 283.00 mg/kg and 295.00 mg/kg respectively. However, Mn concentration was lowest in rainforest (240.00 mg/kg) while the lowest concentration of Fe was observed in guinea savanna (125.16 mg/kg). The concentrations of Cu and Zn in the subsoil were observed to be highest in mangrove with mean values of 0.57 mg/kg and 9.94 mg/kg respectively. All chemical properties were significantly varied among the ecological zones except Na and Pb in topsoil and only Na in subsoil.

Table 2: Soil Chemical Properties at the Topsoil and Subsoil across the Ecological Zones

Soil Depth	Soil Properties	Rainforest	Mangrove	Guinea Savanna	Fresh Water Swamp	F Value
		Mean±SD	Mean±SD	Mean±SD	Mean±SD	
Topsoil (0-15cm)	pH (H_2O)	4.85±0.2	5.51±0.3	4.70±0.2	4.45±0.1	46.68*
	Organic C (%)	3.05±.4	3.84±1.4	1.80±0.6	5.57±1.6	7.11*
	Total N (%)	0.24±0.2	0.31±0.1	0.16±0.6	0.41±0.2	4.28*
	Available P (mg/kg)	16.80±1.9	11.75±2.4	8.55±1.5	23.40±4.1	4.35*
	Ca (Cmol/kg)	1.07±0.8	3.87±0.5	1.22±0.3	1.07±0.4	53.07*
	Mg (Cmol/kg)	0.57±0.3	1.27±0.1	0.47±0.1	0.43±0.1	34.34*
	K (Cmol/kg)	0.27±0.0	0.35±0.2	0.48±0.1	0.47±0.1	5.18*
	Na (Cmol/kg)	0.28±0.1	0.31±0.6	0.24±0.0	0.27±0.9	1.32
	CEC (Cmol/kg)	4.78±2.7	6.55±0.9	3.85±1.0	11.03±3.3	15.76*
	Ex. Acidity (Cmol/kg)	2.60±1.7	0.72±0.3	1.42±0.9	8.82±3.3	25.66*
	Pb (mg/kg)	9.09±1.6	7.84±1.0	7.49±0.9	8.06±3.4	0.92
	Mn (mg/kg)	239.25±18.1	251.5±28.1	265.25±24.9	295.87±64.0	3.26*
	Fe (mg/kg)	504.00±194.3	148.31±64.1	103.96±33.5	380.37±95.1	12.36*
	Cu (mg/kg)	0.83±0.2	0.55±0.1	0.29±0.1	0.15±0.1	9.25*
	Zn (mg/kg)	13.07±8.3	8.54±1.6	5.97±1.0	5.80±0.8	6.39*
Subsoil (15-30cm)	pH (H_2O)	4.93±0.1	5.59±0.2	4.73±0.3	4.47±0.0	5.39*
	Organic C (%)	2.64±2.2	3.46±0.8	1.41±0.5	4.57±2.2	5.20*
	Total N (%)	0.21±0.2	0.29±0.1	0.12±0.0	0.42±0.2	7.08*
	Available P (mg/kg)	14.81±1.2	12.18±2.9	7.38±1.7	27.01±1.5	5.91*
	Ca (Cmol/kg)	1.26±0.6	4.18±0.5	1.20±0.4	0.92±0.3	70.78*
	Mg (Cmol/kg)	0.61±0.3	1.26±0.2	0.46±0.2	0.41±0.2	26.58*
	K (Cmol/kg)	0.26±0.0	0.34±0.1	0.51±0.1	0.44±0.1	7.95*
	Na (Cmol/kg)	0.27±0.0	0.30±0.1	0.25±0.0	0.25±0.1	1.39
	CEC (Cmol/kg)	4.96±3.1	7.10±1.1	3.53±0.5	9.27±1.8	13.35*
	Ex. Acidity (Cmol/kg)	2.52±2.3	0.97±0.5	1.10±0.6	7.25±2.6	24.38*
	Pb (mg/kg)	9.46±1.7	7.02±1.1	7.41±2.0	7.66±1.2	3.93*
	Mn (mg/kg)	240.00±10.7	272.25±14.6	279.00±22.4	283.00±44.2	4.40*
	Fe (mg/kg)	156.45±105.1	167.47±56.8	125.16±38.9	295.00±74.3	8.40*
	Cu (mg/kg)	0.40±0.4	0.57±0.1	0.29±0.1	0.03±1.5	4.72*
	Zn (mg/kg)	8.27±3.3	9.94±2.4	5.53±0.8	0.94±3.6	8.23*

*Variation is significant at p<0.05 (N=32); N=8 (For mean values)

Earthworm species distribution across the ecological zones

The earthworm species population in each ecological zone in the topsoil and subsoil are presented in Table 3 while Table 4 shows the total percentage of individual species of earthworm. A total of 19 species of earthworm were observed in the entire study area and a total of 605 individual species of earthworm of which 354 (58.5%) individual species were found in the topsoil and 251 (41.5%) were found in the subsoil. In the topsoil, of the total population, *Eudrilius eugeniae* was predominantly highest (38.4%), followed by *Hyperiodrilus africanus* (9.6%) and *Lumbricus terrestris* (7.9%) while the population of *Hyperiodrilus oshogbensis* (0.8%), *Iridodrilus preussi* (0.6%) and *Libyodrilus mekoensis* (0.6%) were very low (Table 4). In subsoil, the population of *Eudrilius eugeniae* was also highest (27.1%), followed by *Lumbricus terrestris* (16.7%) and *Ephyriodrilus afroccidents* (8.6%) and while the population of *Iridodrilus preussi* (0.7%), *Iridodrilus tonyii* (0.5%), and *Libyodrilus mekoensis* (0.3%) were very low (Table 4). Of the total number of earthworm species found in the entire study area, 12 was found in freshwater swamp, 9 in mangrove, 7 in guinea savanna and 10 in rainforest. Comparing the earthworm population in each ecological soil with respect to the soil depth, it was revealed that in the topsoil *Eudrilius eugeniae* was highest (105) in the freshwater swamp, *Hyperiodrilus africanus* was highest (13) in the mangrove while, *Lumbricus terrestris* was the highest in the guinea savanna (18) and rainforest (10) (Table 3). It was also observed that in subsoil, *Lumbricus terrestris* was the highest (36) in the freshwater swamp, *Eudrilius eugeniae* was highest in both mangrove (12) and guinea savanna (6) while *Lumbricus terrestris* was highest in the rainforest. Generally, the total population of earthworm species was highest in the freshwater swamp in the topsoil (217 (61.3%)) while mangrove, guinea savanna and rainforest had 43(12.1%), 42 (11.9%) and 52 (14.7%) respectively (Table 3). In subsoil, rainforest had the highest population of earthworm species of 104(41.4%) and followed by freshwater swamp 92 (36.7%) and the lowest was recorded in guinea savanna (21(8.4%)) (Table 3). The mean abundance of earthworm was significantly varied among the ecological zones in topsoil (F=88.353; p<0.05) and subsoil (F=18.270; p<0.05) (Table 4).

Table 3. Earthworm population in topsoil and subsoil across ecological zones

S/N	Earthworm Species	Topsoil				Total	Subsoil				Total	Overall Total
		FS	MS	GS	RF		FS	MS	GS	RF		
1	*Eutoreutus abinsanus*	23	0	4	0	27	6	0	2	0	8	35
2	*Ephyriodrilus afroccidents*	26	0	0	5	31	13	0	0	8	21	52
3	*Eudrilius eugeniae*	105	12	10	9	136	0	12	6	10	28	164
4	*Hyperiodrilus africanus*	16	13	0	5	34	0	6	0	14	20	54
5	*Iridodrilus roseus*	16	0	0	3	19	0	0	0	10	10	29
6	*Ikennodrilus wurea*	15	0	0	0	15	0	0	0	0	0	15
7	*Parapolytoreutus obiensis*	16	0	0	0	16	0	0	0	0	0	16
8	*Hyperiodrilus oshogbensis*	0	3	0	0	3	16	0	0	0	16	19
9	*Keffia penetrabilis*	0	0	0	0	0	6	4	0	0	10	10
10	*Lumbricus terrestris*	0	0	18	10	28	36	4	3	30	73	101
11	*Heliodrilus lagossensis*	0	8	0	4	12	7	8	4	9	28	40
12	*Keffia proxipora*	0	0	0	8	8	8	0	0	11	19	27
13	*Iridodrilus tonyii*	0	3	0	0	3	0	0	0	0	0	3
14	*Libyodrilus mekoensis*	0	2	0	0	2	0	0	0	0	0	2
15	*Libyodrilus violaceus*	0	2	0	8	10	0	0	0	12	12	22
16	*Iridodrilus preussi*	0	0	2	0	2	0	0	2	0	2	4
17	*Iridodrilus vomiensis*	0	0	4	0	4	0	0	2	0	2	6
18	*Keffia variabillis*	0	0	4	0	4	0	0	2	0	2	6
19	*Total*	217	43	42	52	354	92	34	21	104	251	605
	Percentage (%)	61.3	12.1	11.9	14.7	100	36.7	13.5	8.4	41.4	100	

(FS-Freshwater swamp; M-Mangrove; GS-Guinea savanna; RF-Rainforest)

Table 4. Total percentage of earthworm abundance in the topsoil and subsoil across ecological zones

S/N	Earthworm Species	Total Topsoil	Percentage (%)	Total Subsoil	Percentage (%)	Overall Total	Percentage (%)
1	*Eutoreutus abinsanus*	27	7.6	8	3.2	35	5.8
2	*Ephyriodrilus afroccidents*	31	8.8	21	8.4	52	8.6
3	*Eudrilius eugeniae*	136	38.4	28	11.2	164	27.1
4	*Hyperiodrilus africanus*	34	9.6	20	8.0	54	8.9
5	*Iridodrilus roseus*	19	5.4	10	4.0	29	4.8
6	*Ikennodrilus wurea*	15	4.2	0	0	15	2.5
7	*Parapolytoreutus obiensis*	16	4.5	0	0	16	2.6
8	*Hyperiodrilus oshogbensis*	3	0.8	16	6.4	19	3.1
9	*Keffia penetrabilis*	0	0	10	4.0	10	1.7
10	*Lumbricus terrestris*	28	7.9	73	29.1	101	16.7
11	*Heliodrilus lagossensis*	12	3.4	28	11.2	40	6.6
12	*Keffia proxipora*	8	2.3	19	7.6	27	4.5
13	*Iridodrilus tonyii*	3	0.8	0	0	3	0.5
14	*Libyodrilus mekoensis*	2	0.6	0	0	2	0.3
15	*Libyodrilus violaceus*	10	2.8	12	4.8	22	3.6
16	*Iridodrilus preussi*	2	0.6	2	0.8	4	0.7
17	*Iridodrilus vomiensis*	4	1.1	2	0.8	6	1.0
18	*Keffia variabillis*	4	1.1	2	0.8	6	1.0
19	*Total*	354	100	251	100	605	100
	F Value	88.353*		18.270*			

*Variation is significant at P<0.05

Multiple Regression analysis between Soil Properties and Earthworm Abundance in Topsoil and Subsoil

In topsoil, the relationship between physical soil properties and earthworm abundance was significant and high (R=0.895; R^2=0.801, p=0.000); suggesting that 80.1% of the variability of earthworm abundance in topsoil can be explained by the physical properties (Table 5). Significant relationship was recorded between earthworm abundance and soil nutrients

(R=0.850; R^2=0.722; p=0.000) (Table 7) and soil heavy metals (R=0.859; R^2=0.737; p=0.000) (Table 9). Soil nutrients and heavy metals were able to explain 72.2% and 73.7% of the variability of earthworm abundance in the topsoil respectively. In the subsoil, the relationship between earthworm abundance and soil physical properties was not significant but the regression coefficient was moderately high (R=0.632; R^2=0.399; p=0.063) but 39.9% of the variability of earthworm abundance was accounted by the physical properties of soil (Table 11). On the other hand, earthworm abundance had a significant relationship with soil nutrients (R=0.759; R^2=0.577; p=0.010) (Table 13) and soil heavy metals (R=0.592; R^2=0.351; p=0.000) (Table 15). Soil nutrients soil heavy metals can significantly accounted for 57.7% and 35.1% of the variability of the earthworm abundance. The regression model for the relationship between earthworm abundance and physical properties of soil, nutrients and heavy metals in both topsoil and subsoil are expressed in Equations 1, 2, 3, 4, 5, and 6 respectively (Table 6; Table 8; Table 10; Table 12; Table 14; Table 16).

$Y_{\text{Earthworm Abundance (Topsoil)}}$ = 186.554 – 0.151 Soil Moisture- 0.402 Sand + 0.435 Silt + 0.403 Clay – 6.970 Bulk Density – 0.194 Total Porosity - 2.977 Water Holding Capacity + 4.97 ($F_{7,24}$=13.829; p=0.000)………… Equ. 1

$Y_{\text{Earthworm Abundance (Topsoil)}}$ = 18.249 – 2.690 pH + 0.566 Org C + 13.689 Total N -0.010 Av. P – 0.267 Ca – 19.945Mg-0.842K+3.498CEC-2.360Ex.Acidity+6.15 ($F_{9,22}$ =6.346; p=0.001)…………………………………………Equ 2

$Y_{\text{Earthworm Abundance (Topsoil)}}$= -4.991 -0.27 Pb + 0.075 Mn + 0.042 Fe – 9.793 Cu – 1.262 Zn + 5.50 ($F_{5,26}$ =14.579; p=0.000)……………………………………………………………………………………………Equ 3

$Y_{\text{Earthworm Abundance (Subsoil)}}$ = -76.289 + 0.193 Soil Moisture + 0.330 Sand + 0.397 Silt + 1.407 Clay + 21.916 Bulk Density–0.496Total Porosity+0.699Water Holding Capacity+4.92 ($F_{7,24}$=13.829; p=0.063)………………Equ. 4

$Y_{\text{Earthworm Abundance (Subsoil)}}$ = -8.832 + 3.613 pH – 0.114 Org C – 0.138 Total N + 0.119 Av. P – 15.043 Ca – 9.413 Mg-25.997K+12.314CEC–11.505Exchangeable Acidity+4.32 ($F_{9,22}$=3.328; p=0.010)….………………………Equ 5

$Y_{\text{Earthworm Abundance (Subsoil)}}$ = -2.941 + 1.463 Pb – 0.018 Mn + 0.017 Fe – 6.70 Cu + 0.422 Zn + 4.92 ($F_{5,26}$ =2.81; p=0.037)……………………………………………………………………………………………...Equ 6

Table 5. Multiple Regression Model Summary between Physical Soil Properties and Earthworm Abundance in the Topsoil

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.895[a]	.801	.743	4.97460	.801	13.829	7	24	.000

a. Predictors: (Constant), Water Holding Capacity, Bulk Density, Sand, Soil Moisture, Silt, Total Porosity, Clay

Table 6. Coefficients of Regression Model (Physical Soil Properties and Earthworm Abundance) in the Topsoil

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	186.554	64.180		2.907	.008
	Soil Moisture	-.151	.148	-.122	-1.023	.317
	Sand	-.402	.219	-.426	-1.836	.079
	Silt	.435	.260	.242	1.676	.107
	Clay	.403	.443	.214	.910	.372
	Bulk Density	-6.970	18.829	-.060	-.370	.714
	Total Porosity	-.194	.572	-.057	-.340	.737
	Water Holding Capacity	-2.977	.742	-.406	-4.011	.001

a. Dependent Variable: Earthworm Abundance

Table 7. Multiple Regression Model Summary between Soil Nutrients and Earthworm Abundance in the Topsoil

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.850[a]	.722	.608	6.14703	.722	6.346	9	22	.000

a. Predictors: (Constant), Ex Acidity, K, Ca, Available P, Total N, Org C, pH, Mg, CEC

Table 8. Coefficients of Regression Model between Soil Nutrients and Earthworm Abundance in the Topsoil

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	18.249	30.760		.593	.559
	pH	-2.690	6.003	-.118	-.448	.659
	Org C	.566	1.492	.122	.379	.708
	Total N	13.689	17.783	.229	.770	.450
	Available P	-.010	.163	-.010	-.062	.951
	Ca	-.267	8.277	-.036	-.032	.975
	Mg	-19.945	12.055	-.798	-1.654	.112
	K	-.842	12.671	-.013	-.066	.948
	CEC	3.498	7.352	1.262	.476	.639
	Ex Acidity	-2.360	7.216	-.914	-.327	.747

a. Dependent Variable: Earthworm Abundance

Table 9. Multiple Regression Model Summary between Heavy Metals and Earthworm Abundance in the Topsoil

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.859[a]	.737	.687	5.49808	.737	14.579	5	26	.000

a. Predictors: (Constant), Zn, Pb, Fe, Mn, Cu

Table 10. Coefficients of Regression Model between Soil Nutrients and Earthworm Abundance in the Topsoil

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4.991	10.295		-.485	.632
	Pb	-.027	.545	-.005	-.049	.961
	Mn	.075	.026	.324	2.895	.008
	Fe	.042	.007	.608	5.695	.000
	Cu	-9.793	5.988	-.213	-1.636	.114
	Zn	-1.262	.634	-.259	-1.993	.057

a. Dependent Variable: Earthworm Abundance

Table 11. Multiple Regression Model Summary between Physical Soil Properties and Earthworm Abundance in the Subsoil

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.632[a]	.399	.224	4.92368	.399	2.277	7	24	.063

a. Predictors: (Constant), Water Holding Capacity, Silt, Total Porosity, Soil Moisture, Bulk Density, Clay, Sand

Table 12. Coefficients of Regression Model (Physical Soil Properties and Earthworm Abundance) in the Subsoil

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-76.298	92.185		-.828	.416
	Soil Moisture	.193	.140	.292	1.382	.180
	Sand	.330	.535	.605	.617	.543
	Silt	.397	.525	.434	.756	.457
	Clay	1.047	.812	.756	1.289	.210
	Bulk Density	21.916	20.684	.236	1.060	.300
	Total Porosity	-.496	.404	-.239	-1.227	.232
	Water Holding Capacity	.699	.973	.132	.719	.479

a. Dependent Variable: Earthworm Abundance

Table 13. Multiple Regression Model Summary between Soil Nutrients and Earthworm Abundance in the Subsoil

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.759[a]	.577	.403	4.31707	.577	3.328	9	22	.010

a. Predictors: (Constant), Ex Acidity, K, Mg, Available P, pH, Total N, Ca, Org C, CEC

Table 14. Coefficients of Regression Model (Soil Nutrients and Earthworm Abundance) in the Subsoil

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-8.832	18.931		-.467	.645
	pH	3.613	3.863	.296	.935	.360
	Organic C	-.114	2.805	-.040	-.041	.968
	Total N	-.138	32.649	-.004	-.004	.997
	Available P	.119	.118	.252	1.004	.326
	Ca	-15.043	9.521	-3.863	-1.580	.128
	Mg	-9.413	12.141	-.670	-.775	.446
	K	-25.997	11.958	-.644	-2.174	.041
	CEC	12.314	9.377	6.346	1.313	.203
	Ex Acidity	-11.505	9.504	-6.270	-1.210	.239

a. Dependent Variable: Earthworm Abundance

Table 15. Multiple Regression Model Summary between Heavy Metals and Earthworm Abundance in the Subsoil

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.592[a]	.351	.226	4.91669	.351	2.810	5	26	.037

a. Predictors: (Constant), Zn, Mn, Fe, Pb, Cu

Table 16. Coefficients of Regression Model (Heavy Metals and Earthworm Abundance) in the Topsoil

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2.941	10.730		-.274	.786
	Pb	1.463	.557	.458	2.625	.014
	Mn	-.018	.031	-.096	-.574	.571
	Fe	.017	.010	.296	1.787	.086
	Cu	-6.700	5.273	-.348	-1.271	.215
	Zn	.422	.544	.208	.775	.445

a. Dependent Variable: Earthworm Abundance

The correlations between soil properties and earthworm abundance in the topsoil shown in Table 17 revealed that abundance of earthworm was significantly correlated with all soil properties except Pb, K, Na, Temperature, bulk density, total porosity and water holding capacity in the topsoil. However, pH, soil moisture, Ca, Mg, Cu, Zn, and sand correlated negatively with earthworm abundance in the topsoil. The relationships between soil properties and earthworm abundance in the subsoil was significantly correlated with organic C, total N, available P, Pb, K, CEC, Fe, exchangeable acidity, sand and silt at $p<0.05$.

Table 17. Correlation Matrix between Soil Properties and Earthworm Abundance

Soil Properties	**Earthworm Abundance in Topsoil**	**Earthworm Abundance in Subsoil**
pH	-.564* (0.001)	-.273 (.130)
Soil Moisture	-.457* (0.008)	0.274 (0.128)
Organic C	.557* (0.001)	.453*(.009)
Total N	.486* (0.005)	.458* (0.008)
Available P	.422* (0.016)	.555* (0.001)
Pb	-.011 (0.952)	.471* (0.007)
Ca	-.381* (0.031)	-.347 (0.052)

Soil Properties	Earthworm Abundance in Topsoil	Earthworm Abundance in Subsoil
Mg	-.447* (0.010)	-.270 (0.134)
K	.271 (0.133)	-.354* (0.047)
Na	-.139 (0.448)	-.276 (0.126)
CEC	.666* (0.000)	.368* (0.038)
Temperature	.080 (0.665)	.080 (0.665)
Mn	.494* (0.004)	-.164 (0.370)
Fe	.623* (0.000)	.352* (0.048)
Cu	-.451* (0.010)	.005 (0.998)
Zn	-.397* (0.025)	.072 (0.695)
Ex Acidity	.796* (0.000)	.566* (0.001)
Sand	-.784* (0.000)	-.448* (0.010)
Silt	.632* (0.000)	.416* (0.018)
Clay	.708* (0.000)	.325 (0.070)
Bulk Density	.039 (0.830)	.267 (0.140)
Total Porosity	-.023 (0.899)	-.342 (0.056)
Water Holding Capacity	-.265 (0.142)	.149(0.417)

*Correlation is significant at $p<0.05$ (N=32); p values in brackets

4. Discussions

The soil moisture in both topsoil and subsoil of the mangrove was the highest among the ecological zone and that of guinea savanna was the least. Much soil moisture in the topsoil of mangrove can be attributed to the topsoil that is loosely formed as sandy or clayey types (Hossain and Nuruddin, 2016) as the lighter coloured topsoils are porous and facilitate water percolation and aeration during low tide (Hossain and Nuruddin, 2016). All the ecological zones are predominantly dominated by sand content although, sand contents in the mangrove were higher. The presence of higher sand content in the mangrove can be attributed to the dune ecology of this area which has been considerably disturbed by the removal of sand for building purposes which might have led to increased deposition of wind-blown sand into the mangrove area (Naidu and Raiman, 1982). The bulk density in the four ecological zones was relatively high and this could be attributed to similar higher sand content in the particle size composition. The variation in the total porosity could be attributed to bulk density in which an inverse relationship is maintained between them. Arshad (1996) noted that high bulk density is an indicator of low soil porosity and soil compaction. The higher porosity of the topsoil under rainforest is similar to the findings of Aborisade and Aweto (1990). The slight variation in the water holding capacity can be due to the slight variation in the soil textural composition. Ability of soil to provide plants with adequate water is based primarily on its texture. If a soil contains many macropores, like coarse sand, it loses a lot of water through gravitational drainage (McCauley *et al.,* 2005). In addition and very importantly, the variation in the soil organic matter may cause varying levels of water holding capacity and porosity. The higher mean total N in mangrove contradicted the studies of Reich et al. (2005); and Lovelock et al., (2007) which stated that mangrove soils are found nutrient limited, particularly in N and P. The soil moisture and soil temperature were higher in the subsoil than the topsoil across the ecological zones. It was reported that the soil below the surface are typically waterlogged having little aeration facility which reduces with depth but contain a lot of organic matter (Hossain and Nuruddin, 2016).

Organic C and total N were higher in the freshwater swamp, mangrove and rainforest. The variation in the Organic C and total N could be attributed to different rates of litterfalls in these ecological zones. Guo *et al.* (2004) reported that the rainforest has a greater carbon return through litterfall, which is beneficial to the increase of soil organic matter storage and the maintenance of soil fertility. Boley *et al*. (2009) also affirmed that surface soil nutrient enrichment through litterfall and root turnover increase soil organic matter. The mean organic C and total N were higher in the topsoil than the subsoil in the entire study area. The higher total N in the topsoil in the study area may be due to the progressive build-up of total nitrogen in the topsoil due to litter decomposition (Awotoye *et al*, 2011; Ichikogu, 2012), mineralization (Awotoye *et al*, 2011), external inputs which include nitrogen fixing plants (Fernandes *et al.,* 1997) and atmospheric deposition (Schroth *et al*, 2001). Among the heavy metals investigated, Mn and Fe had higher concentrations in the ecological zones. Adefemi *et al.* (2007) reported that Fe occurs at high concentrations in Nigerian soils. *Eudrilius eugeniae* was predominantly highest among the earthworm species. The result is similar to the findings of Owa et al (2003) whereby *Eudrilius eugeniae* was the highest in the study. The abundance and density of *Lumbricus terrestris* was higher in the subsoil than the topsoil. This may be attributed to their characters as anecic/endogeic species of earthworms that burrow deeply into soil horizon and forming persistent unbranching burrows and to migrate to deeper soil layers with which a state of aestivation to avoid desiccation can be maintained (Edwards and Lofty. 1977; Hale and Host, 2005). In subsoil, rainforest had the highest population of earthworm species and followed by freshwater swamp and the lowest was recorded in guinea savanna. The low abundance in guinea savanna could be attributed to the persistent bush burning activity because of the presence of grasses and this could be detrimental to the survival of invertebrates. This could as well affect the soil nutrient levels especially at the surface and root level. The reason being that the earthworms to move nutrients from soil surface to sub surface have been destroyed (Areola, 1982; Owa et al., 2003).

Higher earthworm population recorded in the topsoil can be attributed to food substances that are being obtained easily in the topsoil. The abundance of earthworms was lowest in the guinea savanna. This may be due to the reduced organic C in this ecological zone. Afterall, Kooch, et al. (2008) reported that the presence and absence of earthworms depended on organic matter and litters. If forest is destroyed; organic matter and litter will be lost. The correlation between the density of earthworms and pH was significant in the topsoil. Similar findings were obtained in the study of Kooch et al (2008). Earthworm's richness is sensitive to pH and in the entire study area, the species richness significantly decreased with the increasing pH (Six et al., 2004). Furthermore, significant relationship between earthworm abundance and Organic C is an indication that carbon stabilization in the soil is much more controlled by earthworm activities. Knowles et al. (2016) reported that in the earthworm gut, organic matter and mineral soil particles form aggregates called castings which are often very stable, and contain a high amount of the originally ingested organic matter. This stable aggregation physically protects the carbon within forming a stabilized pool of carbon in the soil.

5. Conclusion

The study can be concluded that significant relationships existed between earthworm abundance and soil physical properties, soil nutrients and heavy metals in the topsoil while only soil nutrients and soil heavy metals had significant relationship with earthworm abundance in the subsoil. Findings showed that abundance of earthworm was insignificantly correlated with Pb, K, Na, temperature, bulk density, total porosity and water holding capacity in the topsoil while in the subsoil, organic C, total N, available P, Pb, K, CEC, Fe, exchangeable acidity, sand and silt correlated with earthworm abundance. The study recommended that soil nutrients should be improved in guinea savanna for the survival of earthworm abundance and the physical soil properties especially sand, silt, and total porosity in the topsoil should be maintained in the ecological zones because of their major roles in supporting earthworm abundance.

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