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Environmental evaluation studies of soil condition in a thermal desorption and incinerator plant site in Ogale, Niger Delta, Nigeria

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ABSTRACT

Environmental evaluation assesses a perceived polluted or impacted environment to establish the state of contamination. The treatment plant comprises of thermal desorption unit and an incinerator used for the treatment of drill cuttings, contaminated soil and water. Studies involved field boring and collection of 8 soil samples within and around; and two control samples outside and away from the plant site; analysis for physico-chemical, heavy metal, organo-pollutants and microbial concentrations over the wet and dry seasons using the APHA (4500-H+ B) APHA 311B methods and use of atomic adsorption spectrophotometer. Organo - chemical species depicted a Total organic content ranging from 0.72 – 11.85(mg/kg) with a mean of 4.46(mg/kg) in the 0 – 15cm soil samples and 0.72 – 7.94(mg/kg) averaging 2.53(mg/kg) in the 15 – 30cm depth samples and 0.72 – 7.94(mg/kg) with average of 2.53(mg/kg) in the dry season and 0.283 - 0.858(mg/kg) with a mean of 0.551(mg/kg), in the top soil samples and 0.244 - 0.614 with a mean of 0.404 in the bottom soil samples in the wet season. The total hydrocarbon content varies from 0.53 – 2.36(mg/kg) with average of 1.11(mg/kg) in the top soil samples and 0.27 – 1.94(mg/kg) with average of 0.87(mg/kg) in the bottom soil samples during the dry season. The composition of the total hydrocarbon content in top soil samples during the wet season range from 0.68 - 2.68(mg/kg) with a mean of 1.151(mg/kg). The results of the bottom soil samples show a range of 0.53 – 2.4(mg/kg) with a 2.4 mean of 1.016(mg/kg) in the wet season. The total petroleum hydrocarbon (TPH) ranges from 0.08 – 1.03(mg/kg) with average of 0.47(mg/kg) in the top soil samples and 0.05 – 0.79(mg/kg) with average value of 0.364(mg/kg) in the bottom samples during the dry season. The top soil samples during the wet season had TPH values ranging from 0.24 - 0.99(mg/kg) with average 0.565(mg/kg) while the bottom soil samples recorded 0.29 - 0.73(mg/kg) with average of 0.488(mg/kg) during the wet season. Polynuclear Aromatic Hydrocarbon (PAH) and BTEX were not detected throughout the study periods. Results show that there is no anthropogenic contamination.

Keywords: Environmental evaluation, nutrient ions, heavy metals, organo-compounds, soil microbes

1. INTRODUCTION

Soil is a living system and represents a vital resource life. It is a valuable natural resource and provides habitat for a wide range of organisms, influences species distribution of plants, controls water flow and chemical substances between the atmosphere and the earth; and acts as a source and storehouse for gases like oxygen and carbon dioxide in the atmosphere. As a natural resource, it supports plant and or crop growth and guarantees food security and its significance is epitomized designation in the United Nations agenda 2030 as sustainable development goal 6. Soil is worthy of sustainable management for the present and future generations. Its quality and or degradation largely affect land use for agricultural practices and human health in the built environment. Declining soil quality poses a threat to agricultural productivity, economic growth and healthy environment (Tesfahunegn, 2014). As geochemical reservoirs, soil ecosystems serve as primary receptor of anthropogenic contaminations in the energy production, processing and transportation of petroleum hydrocarbons through various discharges and or releases. It also constitutes one of the sinks of weathered and transported materials against the natural background elemental compositions in the media. The accumulation of chemical compounds such as hydrocarbons is significant due to their bioavalability in the food web (Abija and Abam, 2018). Contamination with total petroleum hydrocarbons (TPH) is currently one of the major environmental problems (Guarino et al. 2017). Marinescu et al. (2010) observed that pollution caused by crude oil by spills in the petroleum energy life cycle is one of the most prevalent problems in the environment receiving worldwide attention. Oil spillage also has a negative impact on the environment and society (Lim et al. 2016), the hydrocarbons affecting the soil minerals, organic, heavy metal and other chemical contents, physical and biological properties, plants as well as pH change, carbonate amounts and increasing salt content in the soils (Chukwumati and Asiegbu, 2022; Alao et al. 2025). Crude oil in soils also reduces its permeability due to entrapment of the crude oil film within the pore spaces of the soil (Zabbarov et al. 2019) and soil acidity is also enhanced by crude oil. The Total petroleum hydrocarbon is the major constituent in unrefined petroleum oil that has severe adverse effects on soil properties, qualities, and biota (Medjor et al. 2017). Soil contamination also offers a pathway to groundwater contamination through the vadose zone where contaminants are partitioned into partitioned into vapor (in soil gas), residual (adsorbed onto soil and organic matter), aqueous (dissolved in groundwater), and free product (immobile and immiscible liquid phase hydrocarbons). Crude oil contamination of soils alters their chemical, physical and biological properties of a soil thereby degrading its fertility. The soils and its properties are affected to a great extent by hydrocarbon contamination (Asadi et al. 2017, Abija, 2021).

Crude oil contamination of soil poses adverse environmental effects on soil, forests and water bodies in host communities in the Niger Delta area of Nigeria (Worgu 2000, Udoh and Chukwu, 2014). Decline in soil quality has tremendous challenge causes loss of agricultural productivity, poor economic growth and environmental degradation (Tesfahunegn, 2014). Wanga et al. (2017) held that absorption of petroleum hydrocarbons in soil surface h affects permeability and porosity due to its inherent low density, higher viscosity and lower emulsifying ability of petroleum, changes the composition and structure of soil organic matter and impacts on the C/N, C/P, salinity, pH, Eh and conductivity of soil (Wang et al. 2017), increase the heavy metals (nickel and vanadium) in the media due heavy metals in oil mixtures (Saadat et al, 2014) and high concentrations of salt in oilfield output water can also damage the soil environment (Efsun et al, 2015); and inhibits microorganisms in natural environment are quite abundant in healthy and clean soil. Microorganisms which can resist the oil pollution stress are not developed, while in contaminated soil, have to adapt to the crude oil by producing certain enzymes and gradually form a dominant population with symbiotic or synergy effect (Okafor, 2023). A number of studies have shown that the hydrocarbon pollution can change the microbial population, the composition of the community structure and the enzyme system in soil, given priority to the inhibitory action (Uzoije and Agunwamba et al, 2009). Crude oil impedes crop growth through reduction of germination rate and fertility and decline the resistance to pests and diseases (Osibemhe et al. 2025). It reacts with inorganic nitrogen and phosphorus, limiting the nitrification and removal of phosphoric acid (Liao et al, 2015) and its contamination of natural media (soil and groundwater) poses health risk to through the carcinogenic, mutagenic, teratogenic and other toxic effects of polycyclic aromatic hydrocarbons and the BTEX which be assimilated by humans, animals and crops. It can also cause atmospheric pollution due to release of the low boiling point and light weight hydrocarbons through evaporation (Wanga et al. 2017). Groundwater also forming the major and perhaps the only source of potable water due to contaminated surface and rain water, its pollution means poses health risk in the area. Attention on soil and groundwater contamination in the Niger Delta from hydrocarbon exploration and production assumed prominence following wide protest by host communities. Research has shown that hydrocarbons are persistent in the media with short- and long-term effects in temporal scales of decades (Kingston, 2002). The degradation caused is very significant in coastal environments (Khana et al. 2018). Oil spillage in the region has persisted as long as the life span of the oil and gas facilities imposing its adverse impacts on the soil, surface and groundwater, sediments and the atmosphere. These impacts and the associated environmental degradation have led to huge social unrest over the past decades culminating in the commissioning of the United Nations Environmental Programme to carry out environmental assessment of Ogoniland by Nigeria's Federal Government (UNEP, 2011) aimed at providing systematic scientific data base which was hitherto lacking. Extensive release of oil and gas products in the land areas, sediments and swampland in in Ogoniland was reported to have caused soil and groundwater contamination (UNEP, 2011), most of the contamination arising from crude oil although contamination by refined product was also found at several locations. UNEP's recommendations formed the basis for a regional cleanup programme for restoration of the contaminated soil and water in the study area. Oil and gas facilities and associated products release major environmental contaminants and their environmental impacts in the Niger Delta area have been adequately documented in several studies, including the 2011 report of the United Nations Environment Programme. Therefore, the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria 1991 of the Department of Petroleum Resources (DPR), revised in 2002 provides that every 3 years, environmental evaluation studies be carried out on operational oil and gas facilities to provide information on how to improve the quality of environmental management and or modification systems (EGASPIN, 2002).

Environmental evaluation study (EES) aims to establish the level of contamination in an already 'polluted' or 'impacted' environment to enable the government know how 'good' or 'bad' (i.e. state of the environment) the recipient environment is, so as to decide and design strategies for protection and restoration (EGASPIN, 2002). The EGASPIN, (2002) stipulates that EES be carried out every 3 years on operational oil and gas facilities to provide information to improve the quality of decision making with reference to environmental management as well as to change and modification. EES is also a regulatory requirement on all oil and gas facilities before any certification and or decommissioning and studies concentrates on the biophysical environmental components that included air, ambient noise, meteorology, vegetation, wild life and biodiversity, soil, geology, surface and ground water, sediment, aquatic organisms and fisheries where applicable. Assessment of environmental status of contaminants in soils within oil/gas facilities assures knowledge of the health of the soil micro-ecosystem and offers insight into the potential health risks and hazards inherent in the bioavailability of soil contaminants. The assessment found there is no continuous clay layer across Ogoniland, exposing the groundwater in Ogoniland (and beyond) to hydrocarbons spilled on the surface. In 49 cases, UNEP observed hydrocarbons in soil at depths of at least 5 m. This finding has major implications for the type of remediation required. At two-thirds of the contaminated land sites close to oil industry facilities which were assessed in detail, the soil contamination exceeds Nigerian national standards, as set out in the Environmental Guidelines and Standards for the Petroleum Industries in Nigeria (EGASPIN) (UNEP, 2011). The basic principles of soil sampling in the context of the monitoring of environmental contamination are expected to cover a wide range of aspects depending upon the cause of the contamination, which can vary from a gradual deposition of contaminants over a large span of time to release of shock loads from accidents/explosions leading to soil contamination. This may require designing of separate sampling plans for the monitoring of environmental contaminants for different sites. An environmental evaluation studies of the thermal desorption waste treatment facility was carried out evaluation is carried out over a two-season sampling campaign which commenced with the dry season and concluded in the wet season in 2021 as commissioned assessment in compliance with regulatory requirements to establish the baseline environmental status of the soil around the thermal desorption facility.

1.1. Thermal desorption and Incineration plant and process

Thermal desorption techniques of contaminated soil remediation use temperature in a desorber to volatize the contaminants, separate them from the soil or sludge and thereafter collect and destroy them in off-gas treatment systems. Heat is applied to hydrocarbon-contaminated soil and water to vaporize the contaminants, essentially "driving off" the hydrocarbons. This technique uses heat transfer to increase contaminant volatility to enhance its removal from the soil matrix, sludge or cake. The volatilized contaminants are then either collected or thermally destroyed. A thermal desorption unit or system has (1) a desorber and (2) off-gas treatment system. In the low temperature thermal desorption (LTTD) unit, contaminated soil with volatile or semi volatile organic compounds are heated to 200^0 – 500^0C in a rotating kiln causing desorption of the contaminants into gaseous phase (Ola and Ojuri, 2008, Rim-Rukeh and Nkwokoma, 2022). The end product is a clean treated soil which may be used as daily over at landfill or re-used as clean backfill material. The volatilized contaminants are converted to a combustion afterburner where they are destroyed or to a cooling unit where condensation recovers them in a liquid form. Most LTTD units are mobile truck mounted systems equipped with a combustion afterburner and are capable of treating 20 – 50 tons per hour. The advantages of the LTTD units include fast, low cost, effective remediation and reliable systems. In the incineration unit, the contaminated media is heated to very high temperatures as high as ≥ 1500^0C (EPA, 1999) to achieve oxidation of the organic contaminants and completely destroys these volatilized hydrocarbons by burning them in the presence of oxygen, often used in conjunction with thermal desorption to achieve complete remediation of contaminated soil and water. Incinerators are equipped with a kiln using fluidized bed combustion technology. The unit cost of incineration is relative higher than LTTDUs hence they are often reserved for hazardous waste treatment for which few alternatives are available. Incinerators are advantageous because they possess high potential for destruction and removal efficiency and applicable to a wide range of contaminants.

1.2. Study Area

1.2.1. Climate and Geomorphology

The study area (figure 1) is located in Ogale in Eleme in Rivers State, Nigeria georeferenced 295780E and 534011N with a total area of 7.44m^2. It is a coastal plain, poorly developed with fresh forest vegetation (Abija et al. 2018) with elevations varying from 0m (zero) at the coast to 470m at the boundary with the Lower Benue trough. Abam, (2016) reported that the network of rivers and creeks which drain the hinterland, transports both water and sediments to the Atlantic Ocean characteristic of the Niger Delta basin. The climate is tropical equatorial with sunshine being high throughout the year and maximum between January and May while minimum occurs in July and September. Temperatures range, on average, between 26 and 27 ℃ during the dry months of February to March and about 24 ℃ during wet months of June and September. Daily temperatures oscillate between 31. 7 ℃ and 23 ℃ in dry season highest average values of humidity reach 90 in August as against an average minimum of 74 % in February. Rainfall is most intense (>3500 mm) between April and October, the values being 5 - 7 times higher than in November to March (500 mm) (Ofoma et al., 2005, Abija, 2018). Tse and Eshiemomo, (2016) noted that several authors including Short and Stable (1967) have research on the geology of the Niger Delta. The project site is underlain by the surficial recent deposits overlying the Benin Formation which is predominantly coarse-grained sandy soils with a few shale intercalations.

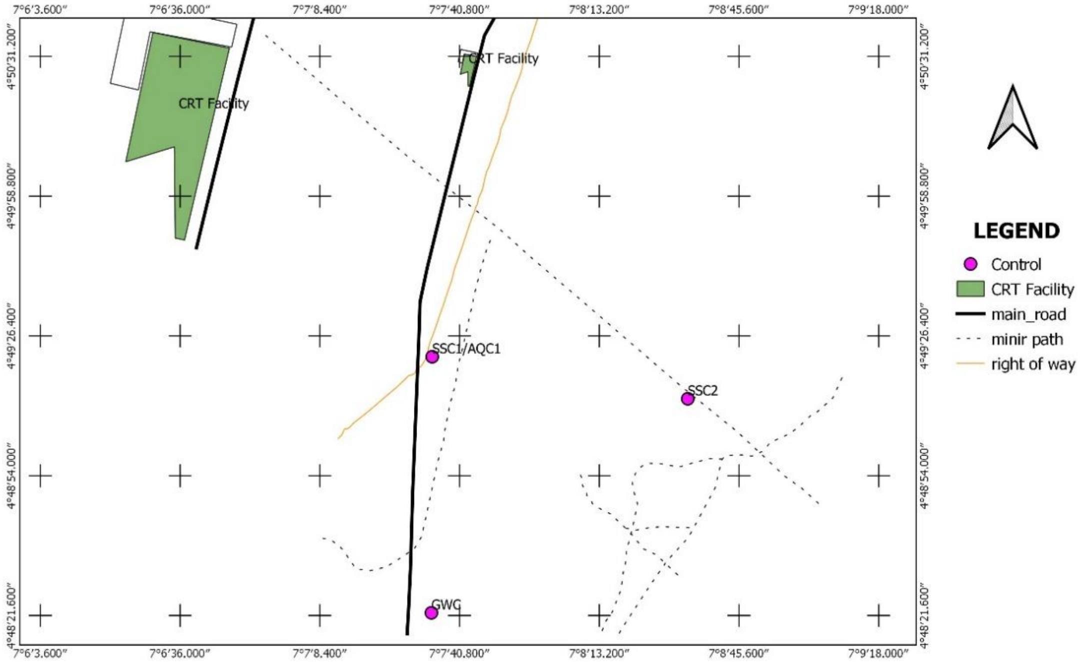

Figure 1: Map of the study location showing the waste treatment facility

1.3. Geotectonic and Geohydrologic Setting

The basin is one of the largest regressive deltas estimated to cover an area of 300,000 km^2 with a sediment volume of 500,000km^3 (Hospers, 1965) and a sediment thickness of over 10km in the basin depocenter (Onojake et al., 2015; Kaplan et al., 1994). The Niger Delta basin has been reported to evolve through triple junction rifting, opening of the continent and extension of the equatorial fracture zones into the Gulf of Guinea during the Cretaceous (Abija et al. 2018, Abija, 2019). The stratigraphic sequences of the basin are subdivided into three units namely Akata, Agbada and Benin Formations each of which range from Tertiary to Recent (Short and Stauble, 1967). The oldest and basal unit overlying the continent is the Akata shale Formation which is Paleocene to Holocene in age and the hydrocarbon source rock of the basin. It is overlain by intervening paralic sandstone/shale layers of the Agbada Formation, the sandstones forming the hydrocarbon reservoirs. The Agbada formation is overlain by Oligocene to Pleistocene continental sands, sandstones and gravels of the Benin Formation. These friable sands and gravels are of fresh water origin and have excellent aquifer properties with occasional intercalation of shales. A southwestward progradation during basin evolution formed depobelts that represent the most active portions of the delta at each stage of its evolution (Doust and Omatsola, 1990; Kulke, 1995). Recoverable hydrocarbons are estimated at about 34.5 billion barrels of oil and 93.8 trillion cubic feet (Tutle et al., 1999) of gas (14.9 billion barrels of oil equivalent) per unit volume of basin-fill (Oni et al., 2014). The onshore portion of the Niger Delta Province is delineated (Turtle et al., 1999) by the geology of southern Nigeria and southwestern Cameroon. The Benin flank, an East-North East trending hinge line south of the West Africa basement massif marks the boundary towards the northwest while Cretaceous outcrops of the Abakaliki High form the northeastern boundary. The Calabar flank, a hinge line bordering the (Onojake et al., 2015) adjacent Precambrian, forms the East-South-East limit of the basin. Offshore, the basin is bounded by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern-most (Turtle et al., 1999) West African transform-fault passive margin) to the west, and the two-kilometer sediment thickness contour or the 4000m bathymetric contour in areas where sediment thickness is greater than two kilometers to the south and southwest. This forms the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System. Geohydrologically, it is controlled by freshwater rivers intricately linked with creeks that serve as receptacles for sediments from the hinterlands of the Niger River system. The water table is very close to the ground surface and varies from 0 to 4meters while the hydraulic conductivities of the sands vary from 3.82×10^{-3} to 9.0×10^{-2}cm/sec which indicates a potentially productive aquifer (Etu-Efeotor, and Akpokodje, 1990). The Benin Formation forms the regional aquifer of the Niger Delta basin and it grade into various types of quaternary alluvial deposits comprising mainly of recent deltaic sands on the surface (Etu-Efeotor, and Akpokodje, 1990; Abam, 2016).

2. MATERIALS AND METHODS

2.1. Field Sampling

An environmental evaluation studies of the thermal desorption and incineration waste treatment facility was carried out over a two-season sampling campaign which commenced during the dry season and concluded in the wet season of 2021. Field investigations were carried out on 22nd March 2021 and September 6, 2021. Sampling activities commenced with a pre-assessment HSE briefing of the facility accompanied by detailed field sampling. Soil samples were collected by auger boring to a total depth of 30cm for which the top soil samples were taken after boring 15cm and boring discontinued to take the sample before re-injecting the auger bit into the hole to continue boring to the terminal depth of 30cm and the bottom samples collected. All soil samples were taken, appropriately packaged and sealed in foil packs and stored in ice chest boxes. Eight samples were collected within and around the facility and two control samples outside the facility but within the community totaling ten samples in all. All field investigation activities and sampling complied with standard environmental ethics of practices and guidelines such the EGASPIN 2002 and Nigeria's Federal Ministry of Environment, Nigeria and were carried out under the supervision of the Nigerian Upstream Petroleum Regulatory Commission's (NUPRC) representative. Samples were later transmitted to the laboratory for analysis.

2.2. Laboratory Analysis

The pH was determined in the laboratory by preparation of a suspension that approximates 1.5 soil-solution ratios was used. The equilibration period was 2 hours while the suspension was stirred at 30 minutes' intervals. The American Public Health Association APHA (4500-H+ B) was used.

The soil is saline; therefore, it flocculates easily after plunging. Consequently, only the 40 seconds hydrometer reading could be accurately taken. The percentage sand and silt + clay was determined using the hydrometer of Day (1953). Soil texture was established by using the texture triangle. Organic Carbon was determined by the wet digestion method of Walkley and Black (1934) using acidified $K_2Cr_2O_7$ and Ferrous Ammonium Sulphate. Van Bemelem's factor of 1.72 was used in converting organic carbon to organic matter. The extraction solution for Phosphorus analysis was a mixture of 0.03 N NH_4F and 0.025 N HCl (Bray-1 solution). Molybdo-phosphoric acid technique was used in developing the blue colour while the P concentration was determined calorimetrically with spectronic 20. Standard P solution was used to calibrate the spectronic 20. Exchangeable Bases and (Na, K, Mg and Ca) were analyzed by preparing a soil extract with 1N-neautral solution (pH 7.0) of ammonium acetate. Following shaking for 2 hours, the suspension was felted, and Na & K content of the filtrate were determined by flame photometer while Mg and Ca were determined with atomic absorption spectrophotometer (ASS). An approximately 1.2.5 soil water paste was made, vigorously shaken and then filtered under suction for measurement of the electrical conductivity (EC). The EC of the filtrate was determined using APHA 2510 B. Chlorine con ten t was determined by preparing a 1.2.5 soil water suspension was shaken for 1 hour. The suspension was filtered under suction. The chloride content was determined by titration with 0.1N $AgNO_3$ solution, using potassium chromate as internal indicator. Sulphate Sulphur (SO_4^- S) was extracted with potassium phosphate monobasic [KH_2PO_4] solution. The sulphur content was determined gravimetrically by the barium chloride method (Black, 1965). The extractable heavy metal content of the soil was determined, first by extracting with a mixture of Perchloric and dilutes HNO_3 solution. The metal content of the filtrates was determined by APHA 3111B. Standard solution of each of the metals determined were used in calibration and analysis was also carried out with the atomic absorption spectrophotometer (ASS). All the laboratory analytical methods complied with standard environmental practices and statistical analysis was carried out in all the data set.

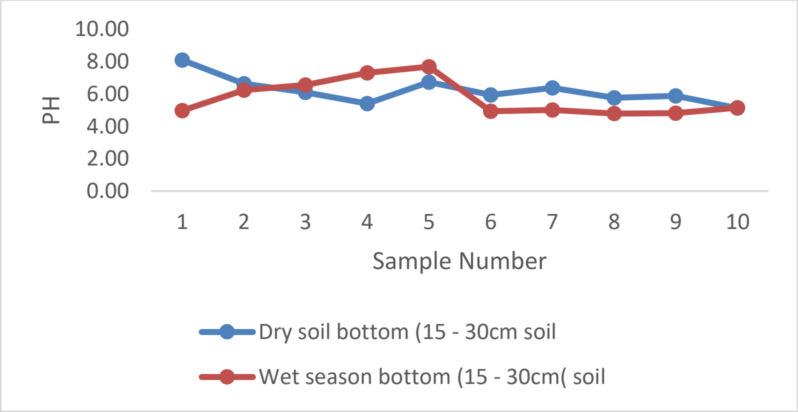

Figure 2a: Typical seasonal variation diagram of PH in the bottom soil samples of the study area.

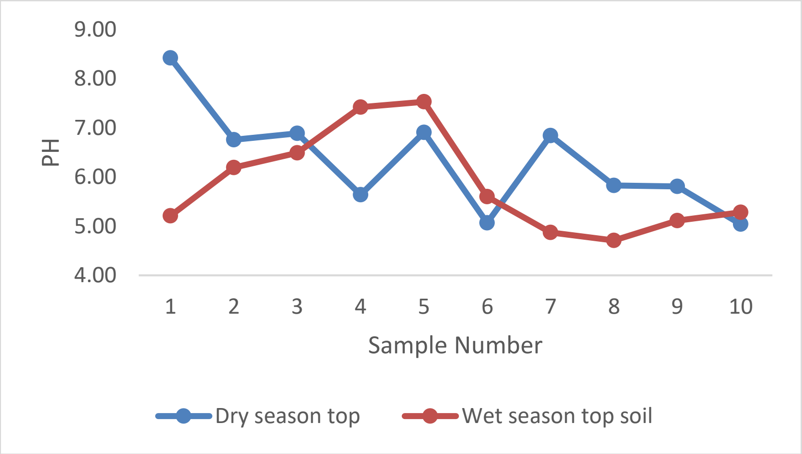

Figure 2b: Typical seasonal variation diagram of PH in the top soil samples of the study

3. RESULTS AND DISCUSSION

Textural and Physical Characteristics

The results are presented in tables 1 – 4 for the dry season and 4 – 8 for the wet season. The dry season top soils (0-15cm) samples recorded moisture content ranging from 10.42% – 22.7% with a mean of 14.38% and standard deviation of 3.38, coefficient of variation of 0.24, kurtosis of 3.46 and skewness of 1.61. The data indicated values of 2.42 for the 95% and 3.47 for the 99% confidence intervals (table 1). During the wet season, the top soils indicated a moisture content varying from 7.87 – 18.33% with average of 13.8%; standard deviation of 3.15, coefficient of variation of 0.075, kurtosis of-0.605 and skewness of 0.224. The 95% and 99% confidence intervals for the means were 0.518 and 0.74 respectively. The bottom soil samples indicated a moisture content of 7.85 – 9.33% averaging 8.60% with a standard deviation of 0.57, coefficient of variation of 0.02, kurtosis of -1.93, skewness of -0.05, 95% and 99% confidence interval of 0.41 and 0.59 during the dry season. In the wet season, the moisture content ranged from 7.87 – 9.33 averaging 8.603% with a standard deviation of 0.57, coefficient of variation of 0.066, kurtosis of -1.932, skewness of -0.045 and 95% and 99% confidence intervals of 0.41

and 0.589 respectively. The porosity values of the top soil samples (figure 3a) were 17.63 – 21.87% with an average of 19.75% and standard deviation of 1.57, coefficient of variation of 0.079, kurtosis of -0.61, skewness of 0.22 and 95% and 99% confidence intervals of 1.12 and 1.61 respectively during the dry season. On the other hand, during the wet season, the top soil porosity (figure 3b) varied from 17.63 - 21.87 with an average of 19.752, standard deviation of 1.57, coefficient of variation of 0.079, kurtosis, -1.256, skewness of -0.109 and 95% and 99% confidence interval of 1.12 and 1.615. The bottom soils indicated porosity of 15.76 - 21.43, with an average of 18.351, standard deviation of 1.60, coefficient of variation of 0.087, kurtosis, 0.547, skewness of 0.589 and 95% and 99% confidence interval of 1.146 and 1.647 during the wet season. The particle size classification and soil type showed a clay content of 7.87 – 34.9%, averaging 21.64% with a standard deviation of 9.97, coefficient of variation 0.46, kurtosis of -1.93, skewness of -0.09 and 95% and 99% confidence intervals of 7.13 and 10,3 respectively in top soil during the dry season. The wet season data showed a rage of 7.87% and 34.9% with average of 21.639%, standard deviation of 9.97, coefficient of variation of 0.46, kurtosis of -1.93, skewness of -0.088, 95% and 99% confidence intervals of 7.13 and 10.25. The bottom soils indicated the clay content vary from 14.74% and 33.84% with an average value of 23.05%, a standard deviation of 7.50, coefficient of variation of 0.33, kurtosis of -1.874, skewness of 0.203 and 95% and 99% confidence intervals of 5.36 and 7.71 during the wet season. Other soil size fractions depict the silt contents of 19.77% and 40.66% with average of 28.88%, standard deviation of 7.30 in the top soils while the bottom soils show a range of 15.2 and 41.16%, average of 28.019% and standard deviation of 6.88. The sand content in the top soil varies from 35.72% and 60.13% averaging 49.481% with a standard deviation of 8.23 while the bottom samples recorded a range of values of 33.28% and 65.74% with average of 48.93 and standard deviation of 9.79. The top soils are characteristically acidic to alkaline with pH (figure 2a) range of 4.71 – 7.53 averaging 5.84 with a standard deviation of 1.02, coefficient of variation of 0.15, kurtosis of -0.83, positively skewed with a value of 0.76. The pH of the bottom samples (figure 2b) varies from 4.79 – 7.69 with average value of 5.75, standard deviation of 1.11, coefficient of variation of 0.17, kurtosis of -0.93, skewness of 0.87 and 95% and 99% confidence intervals of 0.79 and 1.14 respectively during the dry season. The top soil's temperature data recorded a range of 27.44^{0}C and 30.74^{0}C with average of 28.95^{0}C, standard deviation of 1.09, coefficient of variation of 0.16, kurtosis of -0.88, skewness of 0.19, 95% and 99% confidence intervals of 0.78 and 1.11 during the dry season.

The bottom soil's temperature ranges from 27.27^{0}C – 30.91^{0}C with average of 28.82^{0}C, standard deviation of 0.99, coefficient of variation of 0.21, kurtosis of -0.15, skewness of 0.12 and 95% and 99% confidence intervals of 0.71 and 1.01 respectively. Top soil's temperature varies from 27.44 and 30.74 with average of 28.95, standard deviation of 1.09, coefficient of variation 0.04, kurtosis of -0.88, skewness of 0.185 and 95% and 99% confidence interval values of 0.78 and 1.12 during the wet season. The temperature of the bottom soil's ranges from 27.27 and 30.51 with average value of 28.82 with standard deviation of 0.99, coefficient of variation of 0.034, kurtosis of -0.61 and skewness of 0.12 during the wet season. The results of measured electrical conductivity in the top soil (0 – 15cm) during the dry season shows a range of 35 - 536(μS/cm) averaging of 124.4(μS/cm) with a standard deviation of 148.97, coefficient of variation of 0.11, kurtosis of 8.46, skewness of 2.83 and 95% and 995 confidence intervals of 106.6 and 156.1 respectively.

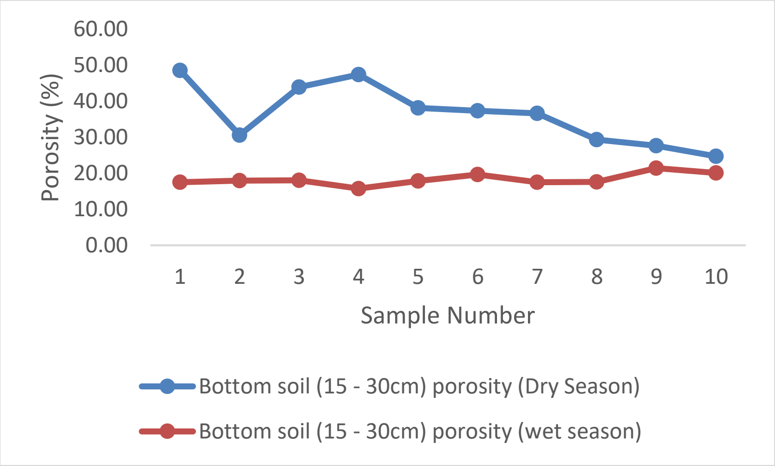

Figure 3a: Typical seasonal variation diagram of porosity in the top soil samples of the study

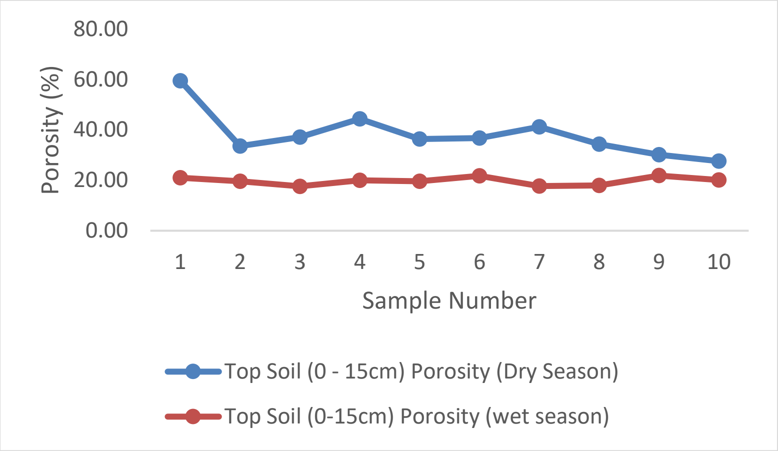

Figure 3b: Typical seasonal variation diagram of porosity in the bottom soil samples of the study

Table 1: Dry season Statistical summary of physico-chemical parameters

Parameter	Min.		Max.		Mean		Std. Dev.		Coefficient of Variation		95% confidence interval		99% confidence interval		Kurtosis		Skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
TEXTURE																		
Moisture Content (%)	10.42	9.33	22.47	18.33	14.38	13.8	3.38	3.15	0.24	0.23	2.42	2.25	3.47	3.23	3.46	-1.28	1.61	0.17
Porosity (%)	27.61	24.72	59.55	48.57	38.09	36.43	8.95	8.33	0.23	0.24	6.41	5.96	9.2	8.57	3.46	-1.28	1.61	0.17
Clay (%)	5.41	4.7	34.9	36.98	23.9	24.42	10.3	11.6	0.24	0.23	7.36	8.27	0.57	11.88	-0.88	-0.29	-0.26	-1.0
Silt (%)	17.94	15.52	53.97	48.61	31.81	32.62	10.9	10.1	0.23	0.21	7.85	7.23	11.28	10.39	0.55	-0.45	0.62	-0.04
Sand (%)	12.86	12.86	63.11	63.11	44.2	44.24	15.4	15.4	0.20	0.21	11.04	11.04	15.86	15.87	-0.37		-0.82	
PHYSICAL TEST																		
PH	5.04	5.13	8.42	8.1	6.32	6.21	1.04	0.83	0.16	0.13	0.74	0.59	1.07	0.85	0.39	2.35	0.65	1.22
EC (µS/cm)	94	102	886	783	210.4	217	247	212	1.17	0.97	176.	152	253.	218	8.01	6.92	2.79	2.57
Temp (^{0})	28.8	28.72	30.28	30.11	29.6	29.5	0.45	0.37	-0.02	0.013	0.32	0.26	0.47	0.38	1.7	-0.63	-0.3	-0.7
NUTRIENT ANIONS																		
Nitrate (mg/kg)	2.39	2.49	5.98	6.05	3.778	3.69	1.08	1.12	0.28	0.30	0.77	0.80	1.11	1.15	0.48	0.61	0.8	0.95
Ammonia (As Nitrogen) (mg/kg)	0.25	0.22	0.62	0.66	0.447	0.43	0.12	0.11	0.27	0.34	0.08	0.10	0.12	0.15	-1.2	-1.3	-0.3	0.13
Phosphate (mg/kg)	4.78	6.11	23.78	20.6	12.1	12.6	6.19	4.1	0.51	0.3	4.42	2.9	6.36	4.17	-0.3	0.75	0.7	0.56
Sulphate (mg/kg)	4.16	3.49	15.64	14.33	8.53	8.05	3.53	3.88	0.41	0.48	2.52	2.78	3.63	3.99	0.3	-0.87	0.9	6.65
Chloride (mg/kg)	5.78	5.78	10.8	18.4	8	8.94	1.72	3.72	0.22	0.41	1.23	2.66	1.76	3.82	-0.24	5.1	0.79	2.119
NUTRIENT CATIONS																		
Magnesium (mg/kg)	0.96	1.06	6.21	5.43	2.26	1.97	1.64	1.28	0.22	0.23	1.18	0.92	1.69	1.32	3.47	7.33	2.0	2.63
Potassium (mg/kg)	9.39	10.12	11.48	11.63	11.02	11.02	0.61	0.48	0.19	0.20	0.43	0.34	0.62	0.49	7.21	-0.76	-2.54	-0.58
Sodium (mg/kg)	1.56	3.49	10.39	9.90	5.12	4.99	2.19	2.13	0.20	0.21	1.56	1.52	2.25	2.18	3.42	2.63	1.93	1.84

Table 2: Dry Season Statistical summary of Heavy Metals

Parameter	Min.		Max.		Mean		Std. Dev.		95% confidence interval		99% confidence interval		Kurtosis		Skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
Copper (mg/kg)	0.88	0.85	1.48	1.45	1.22	1.168	0.21	0.2	0.15	0.13	0.22	0.18	-1.27	-0.44	-0.137	-0.10
Chromium (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (mg/kg)	0.54	0.62	1.13	1.12	0.89	0.93	0.20	0.17	0.15	0.12	0.21	0.17	-1.11	-1.29	-0.41	-0.23
Nickel (mg/kg)	0.62	0.56	1.81	1.4	1.10	0.99	0.31	0.28	0.22	0.19	0.32	0.22	3.24	-0.97	1.18	-0.19
Arsenic (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron (mg/kg)	28.27	29.65	131.1	122.1	68.76	63.99	28.6	25.75	20.5	18.42	29.4	26.46	1.93	2.51	0.87	1.06
Mercury (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead (mg/kg)	1.02	2.33	5.75	5.81	3.44	3.26	1.69	1.14	1.21	0.82	1.74	1.17	-1.45	1.84	0.25	1.61
Zinc (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Manganese (mg/kg)	9.47	8.69	13.3	14.6	11.38	11.23	1.23	1.84	0.88	1.32	1.27	1.89	-0.72	-0.22	0.27	0.76

Table 3: Dry season Statistical summary of organo-chemicals

Parameter	Min.		Max.		Mean		Std. Dev.		95% confidence Interval		99% confidence interval		kurtosis		skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
TOC (%)	0.46	0.51	1.13	1.04	0.81	0.76	0.22	0.21	0.15	0.15	0.22	0.22	-0.49	-1.85	0.12	0.36
Oil & Grease (mg/kg)	0.72	0.72	11.85	7.94	4.46	2.53	4.16	2.38	2.97	1.71	4.27	2.45	-1.03	1.92	0.79	1.55
Total Hydrocarbon Content (mg/kg)	0.53	0.27	2.36	1.94	1.11	0.87	0.57	0.49	0.40	0.35	0.58	0.50	1.73	1.62	1.32	1.18
Total Petroleum Hydrocarbon (mg/kg)	0.08	0.05	1.03	0.79	0.47	0.364	0.31	0.26	0.22	0.19	0.32	0.27	-0.41	-0.88	0.53	0.54
Polynuclear Aromatic Hydrocarbon (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BTEX (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 4: Dry season Summary of microbiological Parameters

Parameter	Min.		Max		Mean		Std. Dev.		95% confidence interval		99% confidence interval		Kurtosis		Skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
Total Coliform Count (MPN/100g)	4.0	7.0	210	62	52.83	24.2	79.72	23.93	83.67	29.71	131.22	49.27	4.55	0.59	2.12	1.29
Faecal Coliform (MPN/100g)	4	11	170	47	62.67	29	93.1	25.45	231.26	228.71	533.41	1145.83	N/A	N/A	1.71	N/A
Total Heterotrophic Bacteria Count (x10^6 cfu/g)	0.54	0.5	1.5	1.63	0.98	0.89	0.31	0.35	0.22	0.25	0.32	0.36	-0.93	1.1	0.179	1.1
Total Heterotrophic Fungi Count (x10^5 cfu/g)	0	0	0.51	0.44	3	0.236	0.17	0.12	0.17	0.09	0.18	0.12	70.46	0.99	0.004	-0.17
Total Hydrocarbon Utilizing Bacteria (x10^5 cfu/g)	3.8	3.6	9.6	7.5	6.08	5.6	1.85	1.38	1.32	0.98	1.90	1.42	0.011	-1.68	0.867	0.011
Total Hydrocarbon Utilizing Fungi (x10^2 cfugl)	0	0	2.1	3	0.9	0.87	0.87	1.16	0.62	0.83	0.8	1.19	-1.65	-0.16	0.2	1.13

Table 5: Wet season Statistical summary of physico-chemical parameters

Parameter	Min.		Max.		Mean		Std. Dev.		Coefficient of Variation		95% confidence interval		99% confidence interval		Kurtosis		Skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
TEXTURE																		
Moisture Content (%)	8.56	7.87	10.73	9.33	9.545	8.603	0.73	0.57	0.08	0.07	0.52	0.41	0.75	0.59	-0.61	-1.93	0.22	-0.05
Porosity (%)	17.63	15.76	21.87	21.43	19.752	18.351	1.57	1.60	0.08	0.09	1.13	1.15	1.62	1.65	-1.26	0.55	-0.11	0.59
Clay (%)	7.87	14.74	34.9	33.84	21.639	23.05	9.97	7.50	0.46	0.33	7.13	5.36	10.25	7.71	-1.93	-1.87	-0.09	0.20
Silt (%)	19.77	15.2	40.66	41.16	28.88	28.019	7.31	6.89	0.25	0.25	5.24	4.93	7.51	7.08	-1.36	1.40	0.09	-0.01
Sand (%)	35.72	33.28	60.13	65.74	49.481	48.93	8.23	9.79	0.17	0.20	5.89	7.01	8.46	10.07	-0.32	-0.51	-0.77	0.01
PHYSICAL TEST																		
PH	4.71	4.79	7.53	7.69	5.841	5.746	1.02	1.11	0.18	0.19	0.73	0.79	1.05	1.14	-0.83	-0.95	0.76	0.87
EC (μS/cm)	35	32	536	327	124.4	91.4	148.97	87.82	1.19	0.96	106.56	62.82	153.11	90.25	8.46	7.1	2.83	2.55
Temp (^{0})	27.44	27.27	30.74	30.51	28.95	28.82	1.09	0.99	0.04	0.03	0.78	0.71	1.12	1.02	-0.88	-0.61	0.19	0.12
NUTRIENT ANIONS																		
Nitrate (mg/kg)	1.26	1.76	3.96	3.44	2.566	2.429	0.79	0.56	0.31	0.23	0.56	0.40	0.81	0.57	0.05	-0.74	0.29	0.45
Ammonia (as Nitrogen) (mg/kg)	0.517	0.664	1.495	1.365	0.998	0.963	0.31	0.24	0.31	0.25	0.22	0.17	0.32	0.25	-0.47	-1.1	0.32	0.59
Phosphate (mg/kg)	4.14	4.46	8.69	7.42	5.71	5.694	1.56	1.13	0.28	0.19	1.13	0.81	1.62	1.16	-0.57	-1.46	0.66	0.42
Sulphate (mg/kg)	4.89	5.66	27.05	12.11	9.61	7.43	6.45	1.91	0.67	0.25	4.61	1.33	6.63	1.91	7.5	4.91	2.61	1.98
Chloride (mg/kg)	4.89	5.66	27.05	12.11	9.61	7.43	6.45	1.86	0.67	0.25	4.61	1.33	6.63	1.91	7.5	4.91	2.61	1.98
NUTRIENT CATIONS																		
Magnesium (mg/kg)	0.67	0.83	111.01	12.41	2.54	2.55	3.0	3.48	1.18	1.37	2.15	2.49	3.09	3.58	9.49	9.73	3.05	3.10
Potassium (mg/kg)	12.42	10.95	22.68	25.4	16.87	17.47	3.26	4.28	0.19	0.25	2.33	3.06	3.35	4.39	-0.495	-0.098	0.16	0.331
Sodium (mg/kg)	1.042	1.394	3.222	2.236	1.77	1.68	0.59	0.28	0.33	0.17	0.42	0.19	0.61	0.29	4.28	0.54	1.73	1.26

Table 6: Wet season Statistical summary of Heavy metals

Parameter	Min.		Max.		Mean		Std. Dev.		Coefficient of Variation		95% confidence interval		99% confidence interval		Kurtosis		Skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
Copper (mg/kg)	0.055	0.078	1.523	1.648	0.306	0.302	0.43	0.51	1.42	1.68	0.31	0.39	0.45	0.57	9.25	8.82	2.99.	2.96
Chromium (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium (mg/kg)	0.205	0.197	0.773	0.688	0.475	0.441	0.17	ND	0.35	0.38	0.12	0.12	0.17	0.17	0.02	-1.34	0.03	0.113
Nickel (mg/kg)	24.64	25.63	101.01	96.16	55.59	51.34	22.67	20.41	0.41	0.39	16.22	14.59	23.29	20.97	0.402	1.92	0.786	1.08
Arsenic (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Iron (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mercury (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead (mg/kg)	1.248	1.04	2.32	2.84	1.797	1.748	0.37	0.58	0.21	0.33	0.26	0.42	0.38	0.59	-1.34	-0.536	-0.07	0.621
Zinc (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Manganese (mg/kg)	0.72	0.74	10.53	14.8	2.27	2.36	3.02	4.37	1.33	1.85	2.16	3.12	3.10	4.49	7.96	9.96	2.78	3.15

Table 7: Wet season Statistical summary of Organo-chemicals

Parameter	Min.		Max. Mean				Std. Dev.		Coefficient of variation		95% confidence Interval		99% confidence interval		kurtosis		skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
TOC (%)	0.283	0.244	0.858	0.614	0.551	0.404		0.11		0.28	0.15	0.08	0.21	0.12	-1.64	-0.342	0.19	0.335
Oil & Grease (mg/kg)	1.28	1	4.76	4.35	2.566	2.307	1.24	1.11	0.48	0.48	0.88	0.79	1.27	1.14	-0.19	0.003	1.02	0.805
Total Hydrocarbon Content (mg/kg)	0.68	0.53	2.68	2.4	1.151	1.016	0.58	0.53	0.50	0.53	0.41	0.38	0.59	0.55	6.64	5.81	2.394	2.18
Total Petroleum Hydrocarbon (mg/kg)	0.24	0.29	0.99	0.73	0.565	0.488	0.25	0.31	0.44	0.15	0.26	0.11	0.26	0.16	-0.47	-1.32	0.71	0.48
Polynuclear Aromatic Hydrocarbon (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BTEX (mg/kg)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Table 8: Summary of wet season microbiological parameters

Parameter	Min.		Max		Mean		Std. Dev.		Coefficient of variation		95% confidence interval		99% confidence interval		Kurtosis		Skewness	
	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm	0 – 15cm	15 – 30cm
Total Coliform Count (MPN/100g)	4	7	170	96	38.623	25.29	56.56	32.55	1.46	1.29	47.29	30.11	69.97	45.6	5.235	5.141	2.252	2.26
Faecal Coliform (MPN/100g)	4	4	11	4	6.5	4	3.32	0	0.51	0	5.28	0	9.69	0	-0.05	0	1.09	0
Total Heterotrophic Bacteria Count (x10^6 cfu/g)	0.71	0.65	1.3	1.55	0.988	0.985	0.19	0.25	0.20	0.25	0.14	0.18	0.20	0.25	-1.27	2.56	0.22	1.05
Total Heterotrophic Fungi Count (x10^5 cfu/g)	0	0	0.2	0.22	0.127	0.137	0.06	0.06	0.51	0.45	0.05	0.04	0.07	0.06	0.084	2.12	-0.9	-0.92
Total Hydrocarbon Utilizing Bacteria (x10^5 cfu/g)	3.4	3.9	7.5	7.1	5.24	5.7	1.18	1.11	0.23	0.19	0.84	0.79	1.21	1.14	0.44	-1.18	0.60	-0.25
Total Hydrocarbon Utilizing Fungi (x10^2 cfugl)	0	0	1.9	2.1	1.01	0.93	0.64	0.76	0.64	0.82	0.46	0.54	0.66	0.78	-0.45	-1.06	-0.43	0.42

The bottom soils depicted values ranging from 32 – 327 averaging 91.4 with a standard deviation of 87.81, coefficient of variation of 0.14, kurtosis of 7.1 and skewness of 2.56 during the dry season. Results obtained during wet season depicts the electrical conductivity of the top soil samples to vary from 35 – 536(μS/cm) averaging 124.4(μS/cm) with a standard deviation of 148.97, coefficient of variation of 1.19, kurtosis of 8.46 and skewness of 2.83. The bottom soils data shows a range of 32 and 327(μS/cm) averaging 92.4(μS/cm) with a standard deviation of 87.82, coefficient of variation of 0.96, Kurtosis of 7.1 and Skewness of 2.55.

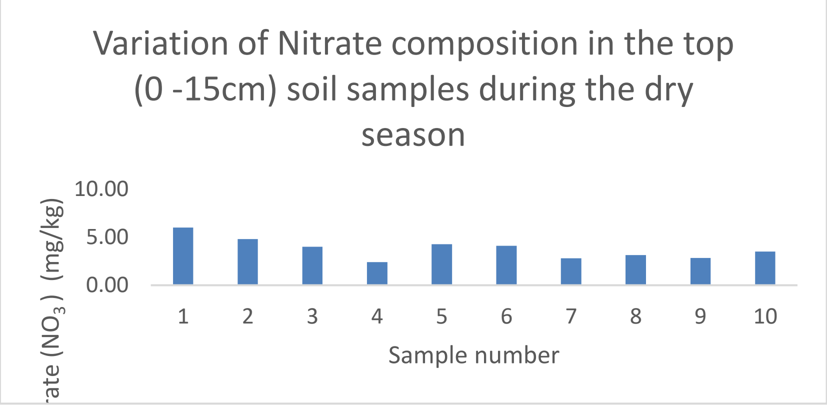

Figure 4a: Typical top soil Nitrate composition histogram (Dry season)

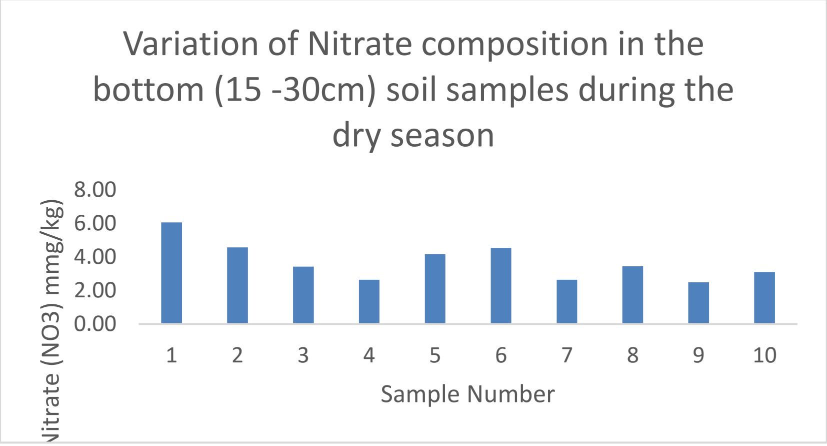

Figure 4b: Typical bottom soil Nitrate composition histogram (wet season)

Nutrient Anions

Nutrient anions analysis indicated Nitrate (NO_3) in the top soil (figure 4a and table 1) to vary from 1.26 – 3.92 (mg/kg) averaging 2.5 (mg/kg) with a standard deviation of 0.78, coefficient of variation of 0.13, kurtosis of 0.054 and skewness of 0.29. The Nitrate (NO_3) composition in the bottom soils (figure 4b and table 4) range from 1.76 – 3.44 with average of 2.43 and standard deviation of 0.55, coefficient of variation of 0.18, kurtosis of -0.74 and skewness of 0.45 during the dry season. The wet season data shows top soil Nitrate composition of ranging from 1.26 and 3.96(mg/kg) with average of 2.566(mg/kg), standard deviation of 0.79, coefficient of variation of 0.31, kurtosis of 0.054 and skewness of 0.29. The results of bottom soils analysis indicated data to vary from 1.76 - 3.44(mg/kg) averaging 2.429(mg/kg) with a standard deviation of 0.56, coefficient of variation of 0.23, kurtosis of -0.74 and skewness of 0.45. Ammonia (as Nitrogen) in the top soils vary from 0.516 – 1.444 with average of 0.998, standard deviation of 0.31, coefficient of variation of 0.21, kurtosis of -0.47 and skewness of 0.32 during the dry season. The bottom soils recorded 0.664 – 1.365 with average of 0.963, standard deviation of 0.24, coefficient of variation of 0.24, kurtosis of -1.07 and skewness of 0.59 during the dry season. Wet season results show Ammonia (as Nitrogen) in the top soil varies from 0.517 - 1.495(mg/kg) with average of 0.998 (mg/kg), standard deviation 0.31, coefficient of variation 0.31, Kurtosis of -0.47 and Skewness of 0.32. The bottom soils however recorded a range of 0.664 - 1.365 with average of 1.365, standard deviation of 0.24, coefficient of variation of 0.25, kurtosis of -1.1 and Skewness of 0.59. Phosphate (PO_4^{3-}) composition in the top soils vary from 6.12 – 10.23(mg/kg) averaging 7.9(mg/kg) with a standard deviation of 1.35, coefficient of variation of 0.16, kurtosis of 0.19 and skewness of 0.89 during the dry season. The bottom soils recorded values ranging from 5.78 – 9.78(mg/kg) with average of 7.9(mg/kg), standard deviation of 0.12, coefficient of variation of 1.40, kurtosis of -1.05 and skewness of -0.07. The results of the wet season analysis depict range of 6.12 - 10.28(mg/kg) with average of 7.9(mg/kg), standard deviation of 1.35, coefficient of variation of 0.17, Kurtosis of 0.19 and Skewness 0.89 in the top soil starting from the ground level to 15cm. The bottom soil samples had a Phosphate (PO_4^{3-}) content varying from 5.78 - 9.78(mg/kg) with average of 7.9(mg/kg), standard deviation of 1.41, coefficient of variation of 0.18, Kurtosis of -1.05 and skewness of -0.07. Sulfate in 0 – 15cm depth in the soils vary from 4.14 - 8.69(mg/kg) with mean of 5.71(mg/kg), standard deviation of 1.57, coefficient of variation of 0.28, Kurtosis of -0.57 and skewness of 0.66. The bottom soils samples showed the Sulfate content to vary from 4.46 – 7.42 with average of 5.694, standard deviation of 1.13, coefficient of variation of 0.15, kurtosis of -1.46 and skewness of 0.42 during the wet season. The soils underlying from 15 – 30c in the site range in their Sulfate content from 5.66 and 12.11(mg/kg) with average of 7.43 (mg/kg), Standard deviation of 1.85, coefficient of variation of 0.25, kurtosis of 4.91 and skewness of 1.98 in the wet season. Chloride in to oils underlying 0 – 15cm of the study area range from 4.89 – 27.05(mg/kg) with average of 9.6(mg/kg), standard deviation of 6.45, coefficient of variation of 0.22, kurtosis of 7.5 and skewness of 2.61 during the dry season while soils underlying 15 – 30cm of the site depicted a range of 5.66 – 12.11(mg/kg) averaging 7.43(mg/kg) with a standard deviation of1.85, coefficient of variation of 0.24, kurtosis of 4.91 and skewness of 1.98 during the dry season. During the wet season, soils underlying from ground level to 15c recorded Chloride content varying from 4.89 - 27.05 with a mean of 9.61, Standard deviation 6.45, coefficient of variation of 0.67, kurtosis of 7.5 and skewness 2.61. Bottom vary from 5.66 - 12.11(mg/kg) with a mean of 7.43(mg/kg), a standard deviation 1.86, coefficient of variation of 0.25, kurtosis of 4.91 and skewness 1.98 during the wet season.

Nutrient Cations

Nutrient cations were also analyzed and results show that magnesium in soils from 0 – 15cm depth range from 0.668 – 11.01(mg/kg) averaging 2.54(mg/kg) with a standard deviation of 3.0, coefficient of variation of 1.18, kurtosis of 9.49 and skewness of 9.93 during the dry season. Results of the soil samples underlying 15 – 30cm of the area shows a range of 0.828 – 11.01(mg/kg) with average of 2.55(mg/kg), standard deviation of 3.4, coefficient of variation of 1.34, kurtosis of 9.73 and skewness of 3.10 during the dry season. During the wet season, the magnesium content in the soils underlying 0- 15cm range from 0.67 - 11.01(mg/kg) with a mean of 2.54(mg/kg), standard deviation 3.00, coefficient of variation of 1.18, and kurtosis of 9.49 and skewness of 3.05. Soils underlying the area at depths from 15 – 30cm recorded magnesium content of 0.83 - 12.41(mg/kg) with a mean of 2.55(mg/kg), standard deviation of 3.48, coefficient of variation of 1.37, kurtosis of 9.73, and skewness of 3.10. Potassium content in soils from ground level to 15cm vary from 12.416 – 22.6(mg/kg) with average of 16.87(mg/kg), a standard deviation of 3.25, coefficient of variation of 0.19, kurtosis of -0.495 and skewness of 0.16. The bottom 15 – 30cm soils depicted a compositional range of 10.95 – 25.4(mg/kg) averaging 17.47(mg/kg) with a standard deviation of 4.28, coefficient of variation of 0.24, kurtosis of -0.098 and skewness of 0.331 during the dry season. Conversely, wet season soil underlying from 0 – 15cm, indicated a range of 12.42 - 22.68(mg/kg) with a mean 16.87(mg/kg), standard deviation 3.26, coefficient of variation of 0.19, kurtosis of -0.495 and skewness of 0.16 while those from 15 – 30cm depth recorded a range of 10.95 - 25.4 with a mean 17.47, a standard deviation 4.28, coefficient of variation 0.245, Kurtosis -0.098 and skewness of 0.331. Sodium content in the soils (0 – 15cm) range from 1.042 – 3.222(mg/kg) with average of 1.767(mg/kg), standard deviation of 0.59, coefficient of variation of 0.33, kurtosis of 4.28 and skewness of 1.73 during the dry season. The bottom 15-30cm soils recorded a range of 1.394(mg/kg) – 3.222(mg/kg) averaging 1.682(mg/kg) with a standard deviation of 0.279, coefficient of variation of 0.17, kurtosis of 0.54 and skewness of 1.26. during the wet season, Sodium content in the top soil (0 – 15cm) varied from 1.042 - 3.222 with a mean of 1.77, standard deviation of 0.59, coefficient of variation of 0.33, kurtosis of 4.28 and skewness of 1.73. Soils underlying 15 - 30cm of the site depicted a range of 1.394 – 2.236 (mg/kg) with a mean of 1.68(mg/kg), standard deviation of 0.28, coefficient of variation of 0.17, kurtosis of 0.54 and skewness of 1.26 during the wet season.

Heavy metals

Heavy metals analysis indicated that Copper range from 0.054 – 1.523(mg/kg) with average value of 0.306(mg/kg), a standard deviation of 0.43, coefficient of variation of 1.42, kurtosis of 9.25 and skewness of 2.99 in the top soil (0 – 15cm) samples during the dry season while the composition in the bottom 15 – 30cm range from 0 – 1.648 averaging 0.272 with a standard deviation of 0.49, coefficient of variation of 1.79, kurtosis of 9.61 and skewness of 3.1 during the same dry season. Sampling during the wet season recorded a Copper composition varying from 0.055 - 1.523(mg/kg) with a mean of 0.306(mg/kg), standard deviation of 0.43, coefficient of variation of 1.42, kurtosis of 9.251 and skewness of 2.99 in the top soils (0 – 15cm) soils during the wet season. Similarly, the bottom soil (15 - 30cm) samples have a copper composition varying from 0.078 - 1.648(mg/kg) with a mean of 0.302(mg/kg), standard deviation of 0.51, coefficient of variation of 1.68, kurtosis of 8.82 and skewness of 2.96 during the wet season. Cadmium in the top soil (0 – 15cm) vary from 0.205 – 0.773 with average value of 0.306 with a standard deviation of 0.43, coefficient of variation of 1.42, kurtosis of 9.025 and skewness of 2.99 during the dry season. Results of the bottom soil samples (15 - 30cm) showed a compositional range of 0.187 – 0.688 with a mean 0.441, standard deviation of 0.17, coefficient of variation of 0.38, kurtosis of -1.34 and skewness of 0.113 during the dry season. Cadmium composition in the top soil (0 – 15cm) samples during the wet season indicated a range of 0.205 – 0.773 (mg/kg) with a mean of 0.475(mg/kg), standard deviation of 0.17, coefficient of variation of 0.35, kurtosis of 0.02 and skewness of 0.029. The bottom (15 - 30cm) soil depicted a cadmium composition varying from 0.197 - 0.688(mg/kg) with a mean of 0.441(mg/kg), a standard deviation of 0.17, coefficient of variation of 0.38, kurtosis of -1.338 and skewness of 0.113 during the wet season. Nickel varies from 0.158 – 0.75(mg/kg), averaging 0.344(mg/kg) with a standard deviation of 0.19, coefficient of variation of 0.57, kurtosis of 0.54 and skewness of 0.97 while that of the bottom soil samples range from 0.125 – 0.416(mg/kg) with average of 0.257(mg/kg), a standard deviation of 0.09, coefficient of variation of 0.34, kurtosis of -0.19 and skewness of 0.19 during the dry season. Wet season results indicated a range of 0.158 - 0.75(mg/kg) with a mean of 0.344(mg/kg) standard deviation of 0.19, coefficient of variation 0.57, kurtosis of 0.54 and skewness of 0.97 in soils underlying from 0 – 15cm and soils underlying from 15 - 30cm depth showed a composition that varies from 0.125 - 0.417 with a mean of 0.257, standard deviation of 0.09, coefficient of variation of 0.35, kurtosis of -0.187 and skewness of 0.195. The bottom (15 - 30cm) soils have a Nickel composition that varies from 0.125 - 0.417(mg/kg) with a mean of 0.257(mg/kg), a standard deviation of 0.09, coefficient of variation of 0.35, kurtosis of -0.187 and skewness of 0.195 during the wet season. Iron range in composition from 24.64 – 101.0(mg/kg) with average of 55.59(mg/kg), a standard deviation of 22.7, coefficient of variation of 0.41, kurtosis of 0.40 and skewness of 0.78 in the soil underlying from 0-15c and from 25.63 – 96.16(mg/kg) averaging 50.49(mg/kg) with a standard deviation of 20.9, coefficient of variation of 0.52, kurtosis of 1.67 and skewness of 1.1 in soils underlying from 15 - 30cm depth during the dry season. Results of the wet season sampling period showed that Iron vary from 24.639 - 101.005 with a mean of 55.587, standard deviation of 22.67, coefficient of variation of 0.41, kurtosis of 0.402 and skewness of 0.786 in the top (15 - 30cm) soil samples and 25.628 - 96.159(mg/kg) with a mean of 51.3386(mg/kg), standard deviation of 20.41, coefficient of variation of 0.39, kurtosis of 1.92 and skewness of 1.08 in the bottom (15 - 30cm) soil samples during the wet season. Lead (Pb) vary from 1.248 – 2.32(mg/kg) with average of 1.796(mg/kg), a standard deviation of 0.21, coefficient of variation of 0.24, kurtosis of -1.34 and skewness of -0.072 in the top soil samples and from 1.04 – 2.32(mg/kg) with average of 1.748(mg/kg), a standard deviation of 0.58, coefficient of variation of 0.33, kurtosis of -0.54 and skewness of -0.621 in the 15 – 30cm samples during the dry season. The wet season data depicted a compositional range of 1.248 - 2.32(mg/kg) with a mean of 1.797(mg/kg), standard deviation of 0.37, coefficient of variation of 0.21, kurtosis of -1.342 and skewness of -0.072 in the top (0 – 15cm) soil and a composition ranging from 1.04 - 2.84(mg/kg) with a mean of 1.748(mg/kg), standard deviation of 0.58, coefficient of variation of 0.33, kurtosis -0.536 and skewness of 0.621 in the bottom (15 - 30cm) soil samples during the wet season. Manganese rage from 0.715 – 10.53(mg/kg) with average of 2.272(mg/kg), a standard deviation of 3.02, coefficient of variation of 1.3, kurtosis of 7.96 and skewness of 2.78 in the top soil samples and 0.715 – 14.8(mg/kg) averaging 2.362(mg/kg) with a standard deviation of 4.47, coefficient of variation of 1.85, kurtosis of 9.96 and skewness of 3.15 in the 15 – 30cm depth soil samples during the dry season. During the wet season, manganese varies from 0.715 - 10.532(mg/kg) with a mean of 2.272(mg/kg), a standard deviation of 3.02, coefficient of variation of 1.33, kurtosis of 7.96 and skewness of 2.78 in the 0 – 15cm soil samples and 0.738 - 14.8 with a mean of 2.3623, a standard deviation of 4.37, coefficient of variation of 1.85, kurtosis of 9.96 and skewness of 3.154m in the 15 -30c samples. Chromium, Arsenic, mercury and Zinc were not detected in the soils in both seasons.

Organo-chemicals

Organo - chemical species evaluated depicted a total organic content (TOC) ranging from 0.72 – 11.85(mg/kg) with a mean of 4.46(mg/kg), a standard deviation of 4.16, kurtosis of -1.03 and skewness of 0.79 in the 0 – 15cm (top) soil samples and 0.72 – 7.94(mg/kg) averaging 2.53(mg/kg) with a standard deviation of 2.38, kurtosis of -1.03, skewness of 0.79 and 95% and 99% confidence intervals of 2.97 and 4.27 respectively in the bottom soil samples and 0.72 – 7.94(mg/kg) with average of 2.53(mg/kg), a standard deviation of 2.53, coefficient of variation of 2.38, kurtosis of 1.92, skewness of 1.55 and 95% and 99% confidence intervals of 1.71 and 2.45 respectively in the bottom soil samples during the dry season while that of the top soils during the wet season range from 0.283 - 0.858(mg/kg) with a mean of 0.551(mg/kg), standard deviation of 0.21, coefficient of variation of 0.37, kurtosis of -1.64 and skewness of 0.187 and 0.244 - 0.614 with a mean of 0.404, a standard deviation of 0.11, coefficient of variation of 0.28, kurtosis of -0.342 and skewness of 0.335 in soil beneath 15cm. The total hydrocarbon content (THC) vary from 0.53 – 2.36(mg/kg), averaging 1.11(mg/kg) with a standard deviation of 0.57, kurtosis of 1.73, skewness of 1.32 and 95% and 99% confidence intervals of 0.40 and 0.58 respectively in the top soil samples and 0.27 – 1.94(mg/kg) with average of 0.87(mg/kg), a standard deviation of 0.49, kurtosis of 1.62, skewness of 1.18 and 95% and 99% confidence intervals of 0.35 and 0.50 respectively in the bottom soil samples during the dry season. The composition of the total hydrocarbon content (THC) in top soil samples during the wet season range from 0.68 - 2.68(mg/kg) with a mean of 1.151(mg/kg), a standard deviation of 0.58, coefficient of variation of 0.50, kurtosis of 6.642, skewness of 2.394 and 95% and 99% confidence intervals of 0.41 and 0.59 respectively. The results of the bottom soil samples show a range of 0.53 – 2.4(mg/kg) with a 2.4 mean of 1.016(mg/kg), a standard deviation of 0.53, coefficient of variation of 0.53, kurtosis of 5.807, skewness of and 2.184 and 95% and 99% confidence interval of 0.38 and 0.55 respectively in the bottom soil samples respectively. The total petroleum hydrocarbon (TPH) ranges from 0.08 – 1.03(mg/kg) with average of 0.47(mg/kg) with a standard deviation of 0.31, kurtosis of -0.41, skewness of -0.88 and 95% and 995 confidence intervals of 0.26 and 0.19 respectively in the top soil samples during the dry season. The bottom soil samples had a range of 0.05 – 0.79(mg/kg) with average value of 0.364(mg/kg), a standard deviation of 0.26, kurtosis of -0.41, skewness of 0.54, 95% and 99% confidence intervals of 0.22 and 0.32 respectively during the same dry season. The top soil samples during the wet season had TPH values ranging from 0.24 - 0.99(mg/kg) with average 0.565(mg/kg), a standard deviation of 0.25, coefficient of variation of 0.44, kurtosis of -0.473, skewness of 0.705, 95% confidence interval of 0.18 and 99% confidence interval of 0.26. The counterpart bottom soil samples recorded composition varying from 0.29 - 0.73(mg/kg) with average of 0.488(mg/kg), a standard deviation of 0.15, coefficient of variation of 0.31, kurtosis of -1.32, skewness of 0.481 and 95% and 99% confidence interval of 0.11 and 0.16 respectively during the wet season. Polynuclear Aromatic Hydrocarbon (PAH) and BTEX were not detected throughout the study periods.

Soil Microbiology

The total coliform count varies from 4 – 210 (MPN/100g) with average of 52.83(MPN/100g). Statistical data revel a standard deviation of 79.72, kurtosis of 4.44, skewness of 2.12 and 95% and 995 confidence intervals of 83.67 and 131.22 respectively in the top soil samples. The bottom soil samples depicted a total coliform count of 7 – 62.0 (MPN/100g) with average of 24.2(MPN/100g). The standard deviation of the total coliform count was 23.93 while the kurtosis was 0.59, skewness was 1.29 and 95% and 99% intervals of 29.71 and 49.27 respectively during the dry season. The TCC in the top soil samples during the wet season varies from 4 – 170(MPN/100g) with a mean of 38.623(MPN/100g) while the standard deviation was 56.56 with coefficient of variation of 1.46, kurtosis of 5.235, skewness of 2.252 and 95% and 99% confidence intervals of 47.29 and 69.97. The bottom soil samples showed a range of 7 – 96(MPN/100g) with a mean of 25.29(MPN/100g), a standard deviation of 32.55, coefficient of variation of 1.29, kurtosis of 5.141, skewness of 2.255 and 95% and 99% confidence intervals of 30.11and 45.6 respectively during the wet season. Faecal coliform count ranges from 4 – 170(MPN/100g) averaging 62.67(MPN/100g) with a standard deviation of 93.1, skewness of 1.17, 95% and 99% confidence intervals of 231.26 and 533.41 respectively in the top soil samples and 11 – 47(MPN/100g) with average value of 29(MPN/100g), standard deviation of 25.45 and 95% and 99% confidence intervals of 228.71 and 1145.83 in the bottom soil samples during the dry season. During the wet season, the top soil showed FCC range of 4 – 4(MPN/100g) with a mean of 4(MPN/100g). Statistical data indicated null values for this set of data. The Total Heterotrophic Bacteria Count (THBC) in the top soil samples vary from 0.54 – 1.5(x10^5 cfu/g) with average of 0.98 (x10^5 cfu/g), a standard deviation of 0.31, kurtosis of -0.93, skewness of 0.179 and 95% and 99% confidence interval of 0.22 and 0.32 while the THBC in the bottom soil samples range from 0.5 – 1.63 (x10^5 cfu/g) averaging 0.89 (x10^5 cfu/g) with a standard deviation of 0.25, kurtosis of 1.1, skewness of 1.1, 95% and 99% confidence intervals of 0.25 and 0.36 respectively during the dry season. On the other hand, the THBC in the top soil samples during the wet season vary from 0.71 - 1.3 (x10^5 cfu/g) with a mean of 0.988 (x10^5 cfu/g), a standard deviation of 0.19, coefficient of variation of 0.20, kurtosis of -1.27, skewness of 0.22 and 95% confidence interval of 0.14 and 99% confidence interval of 0.20. The bottom soil samples depicted THBC that varies from 0.65 - 1.55 (x10^5 cfu/g) with a mean of 0.985 (x10^5 cfu/g), standard deviation of 0.25, coefficient of variation 0.25, kurtosis of 2.555, skewness of 1.052, 95% confidence interval 0.18 and 99% confidence interval of 0.26 during the wet season. The Total Heterotrophic Fungi Count (THFC) in the top soil samples during the dry season range from 0 - 0.51(x10^4 cfu/g) with average of 3.0(x10^4 cfu/g), standard deviation of 0.17, kurtosis of 70.46, skewness of 0.004, 95% and 99% confidence intervals of 0.17 and 0.18 respectively. The THFC in the bottom soil samples vary from 0 – 0.44 (x10^5 cfu/g) averaging 0.236(x10^5 cfu/g) with a standard deviation of 0.12, kurtosis of 0.99, skewness of -0.17 and 95% and 99% confidence intervals of 0.09 and 0.12 respectively during the dry season. The (THFC) in the top soil samples during the wet season range from 0 - 0.2 with a mean of 0.127, standard deviation of 0.06, coefficient of variation of 0.51, kurtosis of 0.084, skewness of -0.9, 95% confidence interval of 0.05 and 99% confidence interval of 0.07. On the other hand, the bottom soil samples depicted the THFC to range from 0 - 0.22 with a mean of 0.137, standard deviation of 0.06, coefficient of variation of 0.45, kurtosis of 2.12, skewness of -0.923, 95% confidence interval of 0.04 and 99% confidence interval of 0.06 during the wet season. The total hydrocarbon utilizing bacteria (HUBC) in the top soil during the dry season samples vary 3.8 – 9.6 (x10² cfu/g) with average of 6.08, a standard deviation of 1.85, kurtosis of 0.011, skewness of 0.86, 95% and 99% confidence intervals of 1.32 and 1,90 respectively while that in the bottom soils samples range from 3.6 – 7.5 (x10² cfu/g) averaging 5.6(x10² cfu/g) with a standard deviation of 1.38, kurtosis of -1.68, skewness of 0.011 and 95% and 99% confidence intervals of 0.98 and 1.42 respectively. Top soil samples indicated HUBC varying from 3.4 - 7.5 (x10² cfu/g) with a mean of 5.24 (x10² cfu/g) standard deviation of 1.18, coefficient of variation of 0.23, kurtosis of 0.437 skewness of 0.603, 95% confidence interval of 0.84 and 99% confidence interval of 1.21 during the dry season. The bottom soil samples' HUBC vary from 3.9 - 7.1 (x10² cfu/g) with mean 5.7 (x10² cfu/g), standard deviation of 1.11, coefficient of variation of 0.19, kurtosis of -1.183, skewness of -0.251, 95% confidence interval of 0.79 and 99% confidence interval of 1.14 during the wet season. The total hydrocarbon utilizing fungi (THUF) in the top soil samples during the dry season range from 0 – 0.21 (x10² cfu/g) with average of 0.9 (x10² cfu/g), standard deviation of 0.87, kurtosis of -1.65, skewness of 0.2, and 95% and 99% confidence intervals of 0.62 and 0.8 respectively during the dry season. The bottom soil samples recorded THUF of 0 – 3 averaging 0.87 with a standard deviation of 1.16, kurtosis of -0.16, skewness of 1,13, 95% and 995 confidence intervals of 0.83 and 1.19 respectively during the same dry season. Results for the wet season however indicate the THUF to vary from 0 - 1.9 (x10² cfu/g) with a mean of 1.01 (x10² cfu/g), standard deviation of 0.64, coefficient of variation of 0.63, kurtosis of -0.45, skewness of -0.43 and 95% confidence interval of 0.46 and 99% confidence interval of 0.66 in the top soil samples while the bottom soils depicted a variation from 0 - 2.1 (x10² cfu/g) with a mean of 0.93 (x10² cfu/g) standard deviation of 0.76, coefficient of variation of 0.82, kurtosis of -1.06, skewness of 0.42, 95% confidence interval of 0.54 and 99% confidence interval of 0.78.

4. CONCLUSION

Results depicted most measured parameter values to be close to their mean values during both seasons which are within the limits of regulatory standards. Implicitly, the soil health has not been negatively impacted by the remediation activities of the plant implying that statutory regulatory standards have been adequately complied. The environmental evaluation of the environment has given impetus to the operation of the plant thereby permitting approval by the regulatory agency for compliance having ascertained that there is no contamination of an environment and all operations have conformed with regulatory guidelines.

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Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of interests

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Data and materials availability

All data associated with this study are present in the paper.

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