CHAPTER ONE

INTRODUCTION

1.1 Background Information

Heavy Metals can be introduced to the environment through natural and anthropogenic sources. Some of the natural sources are soil and rock weathering, earthquake and flood, while man-made activities includes urbanization, industrialization, auto-mobile mechanic emission works, cassava mills, leachates from open dumpsites, crude oil spillage (spill site due to artisanal refineries), application of fertilizers in agriculture, the use of herbicides and pesticides, mining activities and disposal of untreated waste water among others (Olufemi *et al.*,2021; Ikezam *et al.,* 2021; Opara *et al.,* 2020; Otele and Ogidi, 2019; Ibraham *et al.,* 2019; Ejiogu *et al.*, 2017; United Nations Environment Programme 2011.

The rate of increase of heavy metals in the environment (soil and water resources) due to human activities are becoming worrisome in the recent time. Heavy metals generated through anthropogenic activities are one of the major sources of soil and water pollution (Singh and Kalanhand 2011). Heavy metals are those elements with an atomic number greater than 20 and atomic density above $5gcm^{-3}$ (Sarmistha and Apaala, 2021). Heavy metals cannot be destroyed through biological degradation as in the case of other pollutants, heavy metals are formed naturally in the earth crust but are enhanced by anthropogenic activities. They have toxic effect on living organisms in the soil when the permissible concentration levels exceed the tolerable limits (Garba *et al.,* 2013).

Heavy metals are easily assimilated and bio-accumulated in the protoplasm of aquatic organisms (Egborge, 1994). Heavy metals such as Copper (Cu), Iron (Fe), Nickel (Ni), Manganese (Mn), Zinc (Zn), and Chromium (Cr), are essential elements. Essential elements are required by living organisms for growth, metabolism and development of different organs while Cadmium (Cd), Mercury (Hg), Lead (Pb) and Arsenic are non- essential elements; are not required by plants even in trace amount for any of the metabolic process, as they are highly toxic even at low

concentration (Sarmistha and Apaala 2021*).* Soil has been recognized as a sink for many pollutants, excessive accumulation of heavy metal in soil can lead to high heavy metal uptake by plants, thus affecting food quality. The intake of heavy metal contaminated food by humans endanger human health thus causes health issues such as gastro-intestinal disorder, cancer, Immune system dysfunctions, birth defects, nervous system disorder, skin lessons, kidney dysfunction, growth retardation (Singh and Kalanhand, 2011, Olufemi *et al.,* 2021).

Water, after air is one of the most elementary needs of man required for life (Khalifa and Bidaise, 2018; Nwankwoala and Ememu, 2018). Human livelihood depends on availability of water for domestic, fishing, irrigation and industrial purposes among others. Water used for domestic purposes could be obtained from groundwater, rivers and lakes. Fishes and aquatic invertebrate take up heavy metals and bio-accumulate them, this can have effects on the aquatic species and others across the food chain and other users such as human (Olufemi *et al.*, 2021).

Heavy metals decrease the enzymatic and microbiological activities of soil. The toxicity of chromium restricts the uptake of nutrient in soil by forming insoluble compounds (Chigonum *et al.,* 2019). The presence of Cr negatively affects the growth of plants by impairing their essential metabolic processes (Shanker *et al.,* 2009). Due to the high solubility in water and soil Chromium (IV) is regarded as a hazardous ion, which contaminates ground water and can be transfered through the food chain (Joutey *et al.,* 2015; Kumar *et al.,* 2019). Chromium (VI) has been reported to cause detrimental effects on soil microbial cell metabolism at high concentration (shun-hong *et al.,* 2009). As soil and water are important to humans, plant and aquatic organisms, there is a need to protect them against heavy metals contamination.

1.2 Statement of Problem

Due to industrialization, population growth and urbanization in Yenagoa and environs, anthropogenic activities are on increase daily, which could probably introduce contaminants into the soil and water resources. These are the reasons for this current study.

1.3 Aim and Objectives

Aim

The aim of this study is to assess the sources of heavy metals and their impacts on soil and water resources of Yenagoa and its environs.

Objectives

The objectives are to:

1. evaluate the extent of heavy metal contamination in soils across various environmental settings (dumpsites, mechanic workshops, cassava mills, and crude oil spill sites).
2. assess the impact of these contaminated sites on groundwater quality and public health risks.
3. investigate the level of contamination in surface water bodies adjacent to the impacted sites.
4. compare seasonal variations in pollutant concentrations and identify critical pollution hotspots.

1.4 Justification of Study

Soil is an essential component of the environment which serves as a source of nutrient to plants, water filtration and storage. Water is important to humans for continuous living, it's used for domestic, fishing and industrial purposes among others. Despite the importance of soil and water to humans, they still neglect environmental activities that can introduce and increase heavy metal concentrations like Arsenic, Chromium, Lead, Zinc, Manganese, Iron, and others that can contaminate soil and water resources and cause cancer, immune system dysfunction, birth damage, and other health issues. This research provides the possible sources of heavy metals to the soil and water resources in the study area and the levels of concentrations.

1.5 Scope of the Work

This study investigates heavy metals concentration level in soil and water (surface and groundwater) in automobile workshop, crude oil spill site, dumpsites and cassava mill in Yenagoa and environs. To compare the heavy metal concentration in water and soil with various standards to know the level of contamination and existing literature for comparison.

1.6 Limitation

The major limitation in this study was to assess the crude oil spill sites (artisanal refinery). Most of the illegal oil bunkers and the community dwellers suspected that we had a motive to implicate them by reporting them to the government.

1.7 Location of the Study Area

The study area is located in Yenagoa metropolis and part of Ogbia Local Government Area of Bayelsa State, Southern Nigeria. The study area is situated within latitudes 4°48' 56.5”N and 5° 5' 42.72”N and longitudes 6°7' 54.165”E and 6°25' 50.592”E. The study area is bounded on the North by Mbiama Town in Ahoada West Local Government Area of River State, on the South by Ikoli Creek, on the West by Epie Creek and on the East by Kolo Creek. There are networks of aoads linking the various parts of the study area, the elevation of the area is 4m to 15m above sea level. Figure 1.1 shows the location map of the study area.

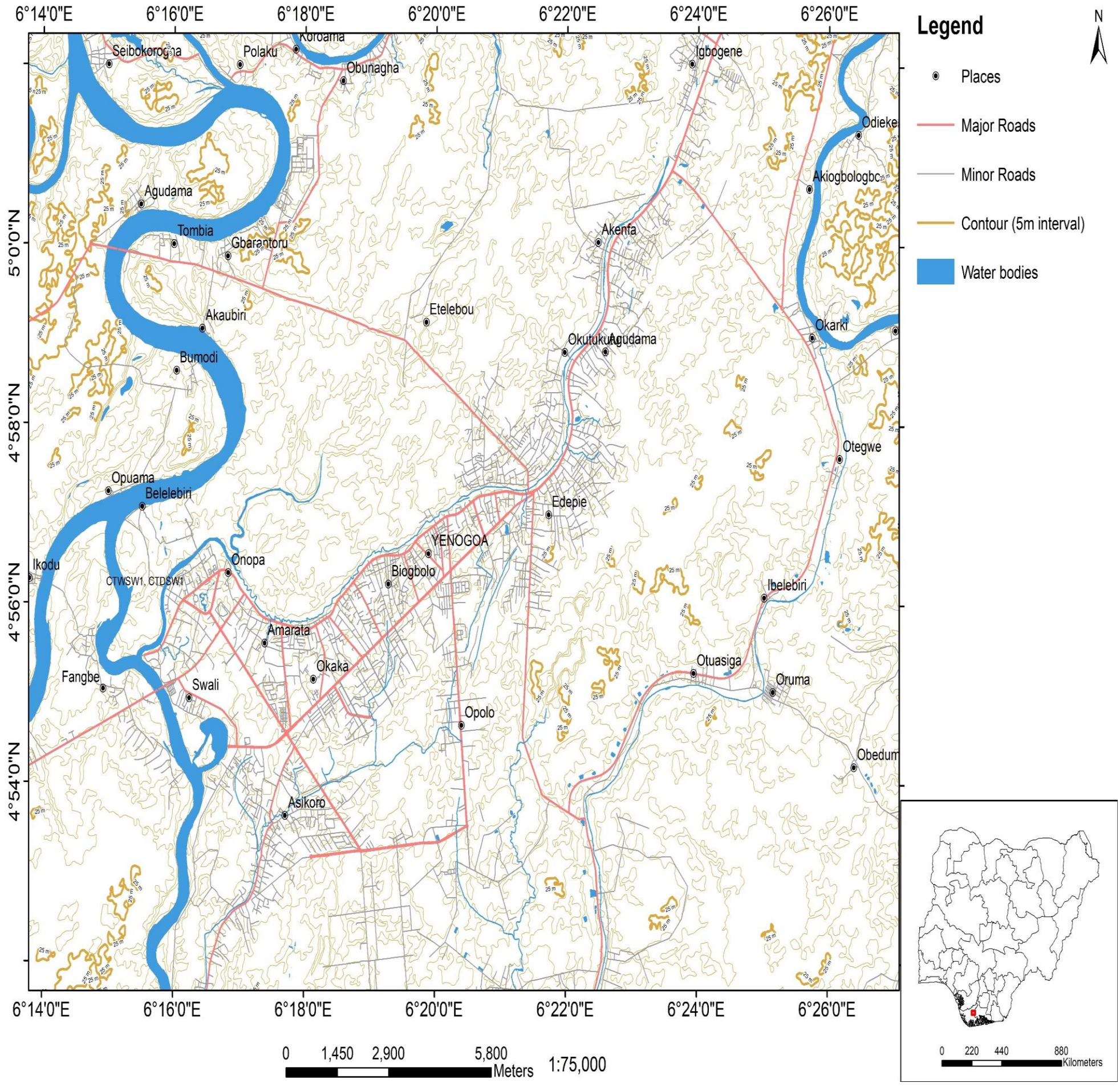

Figure 1. 1: Location Map of the Study Areas

1.8 Accessibility

The study area is accessible within Yenagoa and Ogbia Local Government Area of Bayelsa State Southern, Nigeria. There are networks of roads linking the various part of the study area.

1.9 Climatic Condition of the Study Area

The study area which lies within the tropical rainforest zone of Nigeria. The area has a heavy rainfall record with short period of dry season; the dry season runs through the months of November to March while the rainy season begins in April and ends in October. The area lies in the heaviest rainfall area in the country (Niger Delta Budget Monitory Group, 2022).

The study area received about 241.57millimeters (9.51) inches of precipitation annually in 2022, the wettest month being July and dryest January (The Global Historical Weather and Climate Data, 2022). The greatest amount of precipitation occur in September with the mean monthly temperature ranging from 25^0C to 31^0C. The hottest months are December to April, the temperature difference between the wet season and the dry season is about 2^0C. The lowest average temperature in the year occurs in July, relative humidity is high in the area through the year and decreases slightly in the dry season (Niger Delta Budget Monitoring Group, (2022).

CHAPTER TWO

LITERATURE REVIEW

2.1 Regional Geology of the Study Area

The study area is situated in the central Niger Delta sedimentary basin which is one of the largest sedimentary basins in Africa. The Niger Delta Basin was formed along a failed arm of a triple junction system (aulacogen) interrupted by episodic transgressions during Late Cretaceous time that originally developed during breakup of the South American and African Plates in the late Jurassic (Burke, 1972). Is an extensional rift basin, located in the Gulf of Guinea on the passive continental margin near the Western Coast of Nigeria. It is a prolific complex basin (Tuttle *et al.,* 1999) that covers a subarerial area of about 75, 000km^2, a total area of 300.000km^2, sediment fill of 500,000km^3, the sediment fill has a depth between 9-12km. (Fatoke, 2010). The Niger Delta basin continued to prograde during Middle Cretaceous time into a depocenter, located above the collapsed continental margin at the site of the triple junction, Sediment supply was mainly along drainage systems that followed two failed rift arms. Sediment progradation was interrupted by episodic transgressions during Late Cretaceous time. During the Tertiary, sediment supply was mainly from the north and east, through the Niger, Benue and Cross Rivers. Cross and Benue Rivers provided substantial amounts of volcanic detritus from the Cameroon volcanic zone beginning in the Miocene. The Niger Delta Basin prograded into the Gulf of Guinea at a steadily increasing rate in response to the evolution of these drainage areas and continued basement subsidence. Regression rates increased in the Eocene, with an increasing volume of sediments accumulated since the Oligocene (Owoyemi, 2004).

The sedimentary fill of the Niger Delta is divided into three lithostratigraphic units from the oldest to the youngest, Akata Formation (Paleoceone) pro-delta, the Agbada Formation (Eocene) delta-front and the Benin Formation (Miocene to Recent) the delta –top (Short and Stauble,1967). The Benin formation comprises of lacustrine and fluvial deposits whose

thicknesses are variable but basically exceeds 1970meters (Asseez, 1989). The Benin Formation consists coarse to medium sands, silts, gravel and clayey intercalations (Amajor, 1991).

2.2 The Litho-Stratigraghic Units of Niger Delta

2.2.1 Akata Formation

This formation is at the base of the delta, is of deep marine origin pro- delta facies, age ranges from Paleocene to Recent (Evamy *et.al.*, 1978; Short and Stauble, 1967). It consists of thick shale, sand and minor amount of clay and silt (Tuttle *et al.*, 1999). The Akata Formation was formed during lowstands, when terrestrial organic matter and clays were transported to deep water areas characterize by low energy condition and energy deficiency (Stacher, 1995). The Formation is estimated up to 7,000 meters thick (Doust and Omatsola, 1990), and underlies the whole delta. Marine planktonic foraminifera makes up to 50% of microfauna assemblage and indicate shallow marine shelf deposition (Doust and Omatsola, 1989). Turbidity currents likely deposited deep sea fan sands within the upper Akata Formation during development of the delta (Burke, 1972).

2.2.2 Agbada Formation

The Agbada Formation occurs throughout Niger Delta clastic wedge and has a maximum thickness of about 3,962.4meters. The lithologies consist of alternating sands, silts and shales, arranged within ten to hundred feet successions defined by progressive upward changes in grain size and bed thickness. The Agbada Formation is fluviomarine, and is generally interpreted to have formed in fluvial-deltaic environs, the formation ranges in age from Eocene to Pleistocene (Kogbe, 1989). In the lower Agbada Formation shale and sandstone beds were deposited in equal proportions, the upper portion is mostly sand with minor shale inter-beds (Tuttle *et al.*, 1999).

2.2.3 Benin Formation

This Benin Formation is of continental deposit of Miocene to Recent alluvial or upper Coastal Plain Sands, up to 1820m thick (Avbovbo, 1987). The Formation extends from the west Niger Delta area and to the south, beyond the present coastline. The top of the formation is the recent

subaerially-exposed delta top surface. Shallow parts of the formation are composed entirely of non-marine sand deposits (Doust and Omatsola, 1989). The Formation comprises coarse to medium grained sands, silts, gravel and clayey intercalations (Amajor, 1991). Table 2.1 shows the Stratigraphic Column of the Niger Delta.

Table 2.1: Stratigraphic Column of the Niger Delta (Allen, 1965)

Geologic Unit	Lithology	Age
Alluvial (General) Fresh Water Backswamp Meader Belt Mangrove and Salt Water Backswamps Active Abandoned Beach Ridges Sombreiro-Warri Deltaic Plain	Gravel, Sand Clay, Silt Sand, Clay, Some silt and gravel Medium-fine sands, clay and some silt Sand, Clay and some Silt Sand, Clay and some Silt	Quaternary
Benin Formation (Coastal Plain Sand)	Coarse to medium sand with subordinate silt and clay lenses	Miocene
Agbada Formation	Mixture of sand clay and silt	Eocene
Akata Formation	Clay	Paleocene

2.3 Local Geology

The study area is located within the lower delta plain, believed to have been formed during the Holocene of the Quaternary Period by the accumulation of sedimentary deposits. The study area is of geological units of alluvium and Mangrove Swamp (Figure 2.1). The lithologic units consist of sand, clay, silt and gravel. The study area is situated within the lower floodplain of the Niger Delta. The terrain is poorly drained, with a gentle slope to the Gulf of Guinea in a southwestern direction. It has elevation of 4m to 15m above sea level. The main features of the drainage in the study area include meandering of the distributaries of the River Niger which makes the area prone to flooding (Koinyan *et al.*, 2013).

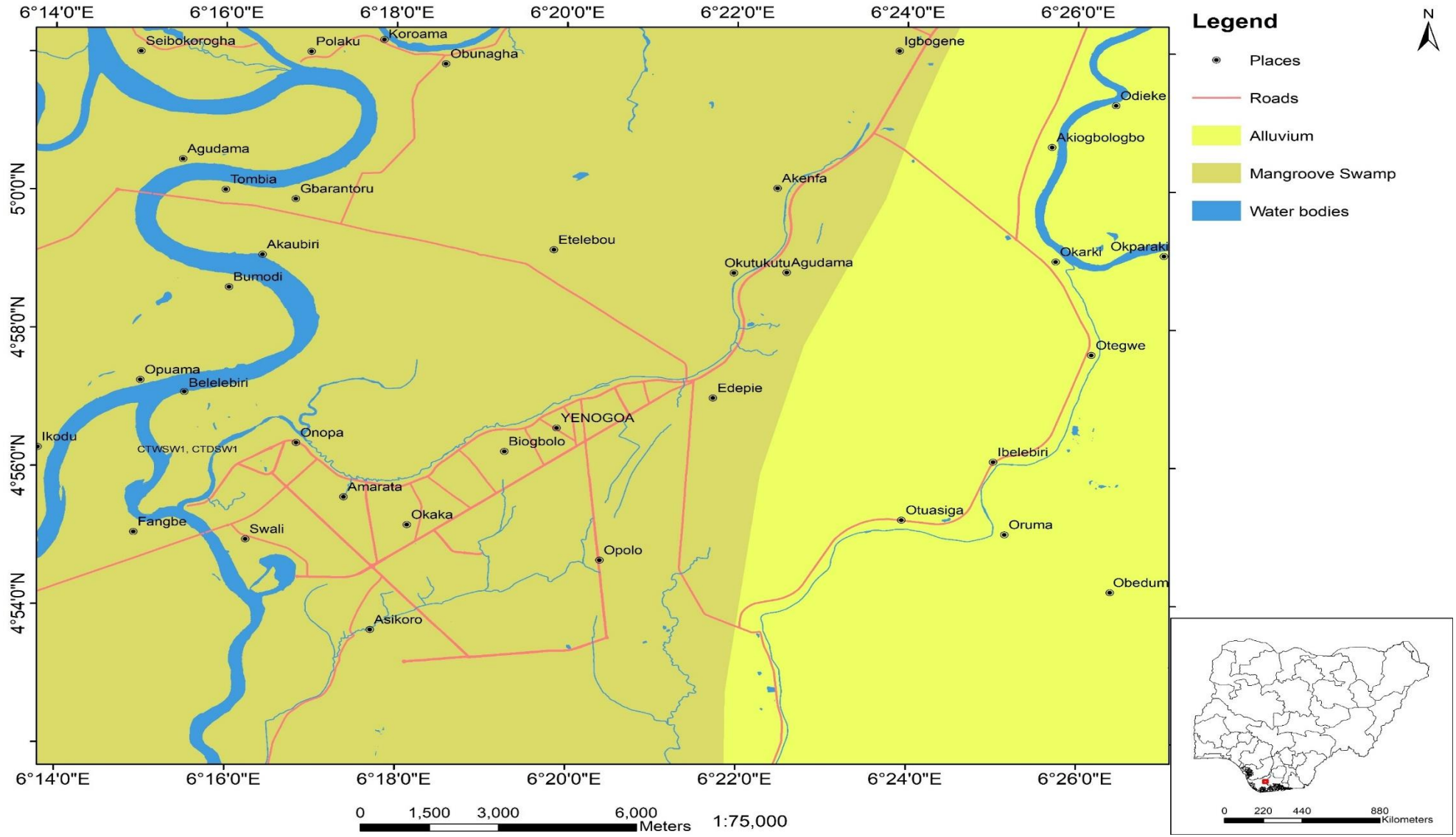

Figure 2. 1: Geological Map of the study area

2.4 Hydrogeology of the Study Area

The hydrogeology of the study area has been described by several researchers such as; Etu-Efeotor; (1981) Amadi, *et al.,* (1989); Etu-Efeotor and Akpokodje (1990), Edet (1993); and Udom *et.al.,* (1998).The Benin Formation is the water-bearing zone of the area where the wells and boreholes tap water from the overlaying Benin Formation (Coastal Plain Sands). The Benin Formation is highly permeable, prolific, and productive. The upper section of the formation is overlain by Quaternary deposits (40-150m) thick and generally consists of rapidly alternating sequences of sands and silty clay which later become increasingly prominent seawards (Etu-Efeotor and Akpokodje, 1990). Generally, multi-aquifer systems have been identified in the Delta based on strata logs (Etu-Efeotor, 1981). Most of the aquifers are confined except for the first. The average borehole depth in Yenagoa is 20–50 meters (Acra and Udom, 2006). Boreholes in the area draw water from 200m or more. Most groundwater in Yenagoa is high in iron, according to Acra and Udom (2006). Its static water level is 0-1m during the rainy season and 1-3m during the dry season. Infiltration through the highly permeable Benin Formation sands recharges aquifers from rainfall.

Oborie, *et,al.,* (2023) in "Geoelectrical delineation of aquifers in Yenagoa and Ogbia areas of Bayelsa State, Nigeria" examine the region's hydrogeology. They employed Vertical Electrical Sounding (VES) with Schlumberger electrodes to assess subsurface resistivity to identify aquifers and to decipher were suitable for groundwater supply and storage. Figures 2.2–2.4 depict a stratified underlying structure of clay aquitards and sandy aquifers. The sandy layers, with higher resistivity, were the main aquifer zones with significant groundwater potential, while the clay layers limited or separated them. Scattered aquifer thicknesses and depths showed a complex Niger Delta depositional environment. These findings suggest the research region has large groundwater reserves that feed local people with water. In conclusion, Yenagoa and Ogbia's aquifer systems are hydrogeologically significant. The results also demonstrate

geoelectrical resistivity's ability to map aquifers and reveal underlying hydrogeology. For sustainable water management, aquifer zones provide a steady supply of groundwater. Hydrogeological research and careful aquifer management are needed to ensure Bayelsa State's water security.

The study "Correlation of Borehole Lithology Using Vertical Electrical Sounding (VES) Method for Groundwater Exploration in Part of Otuoke, Bayelsa State, Nigeria" by Adejumo, *et.al.,* (2021) examined its hydrogeological characteristics using borehole lithology and geoelectrical resistivity data. Both the Schlumberger electrode configuration and Vertical Electrical Sounding (VES) were utilised to duduse subsurface lithological structures and link them to borehole data. By properly identifying aquifers and understanding their hydrogeological conditions, the study improved groundwater exploration. A strong correlation was found between borehole lithology and resistivity. The research identified clay aquitards and limiting beds and sandy aquifers (Figure 2.5) and observed sandy aquifers with higher resistivity at varying depths and thicknesses, indicating a complex hydrogeological environment. Vertical Electrical Sounding (VES) with Schlumberger electrodes detected underlying lithological formations and correlated them with borehole data. The study improved groundwater exploration via better aquifer delineation and hydrogeological understanding. The borehole lithology and resistivity measurements were significantly related. Clay layers as aquitards or limiting beds and sandy layers as aquifers were discovered of importance (Figure 2.5). Different depths, thicknesses, and resistivity values of sandy aquifers suggested a heterogeneous hydrogeological environment.

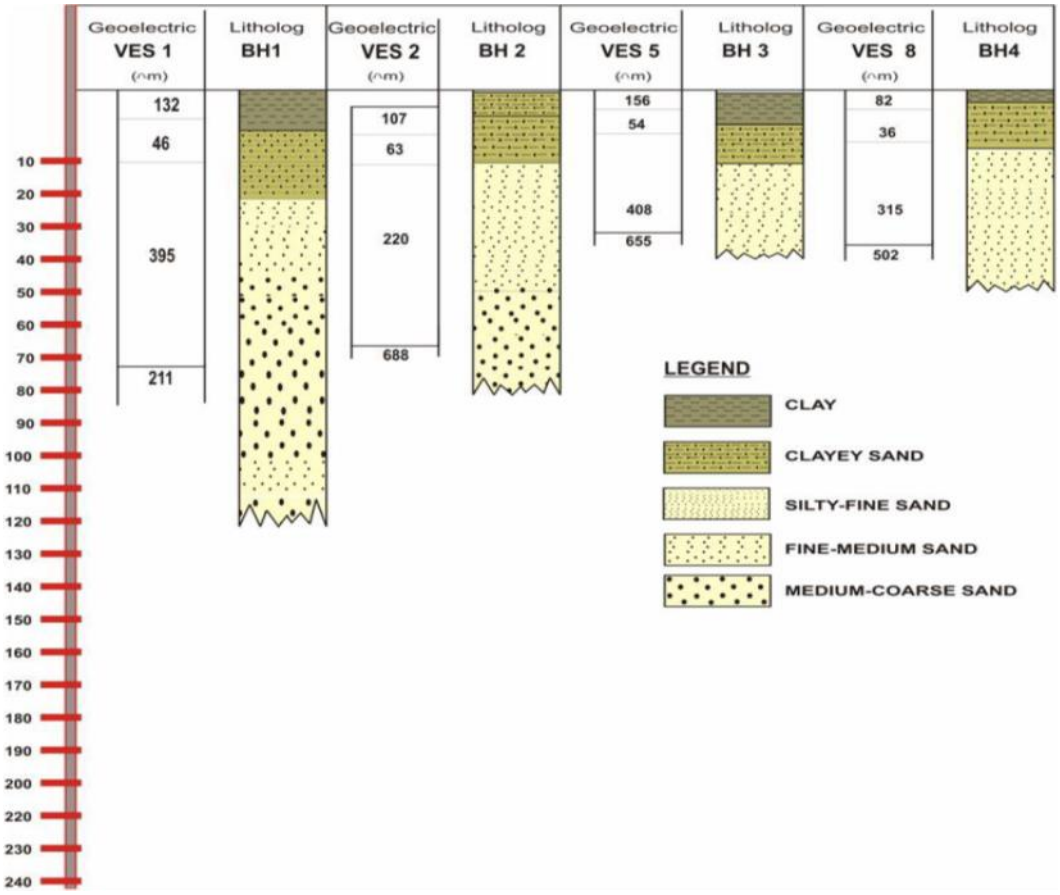

Figure2.2: Correlation of geoelectric sections and lithologic logs of existing boreholes in Yenagoa (Oborie *et al.*, 2013)

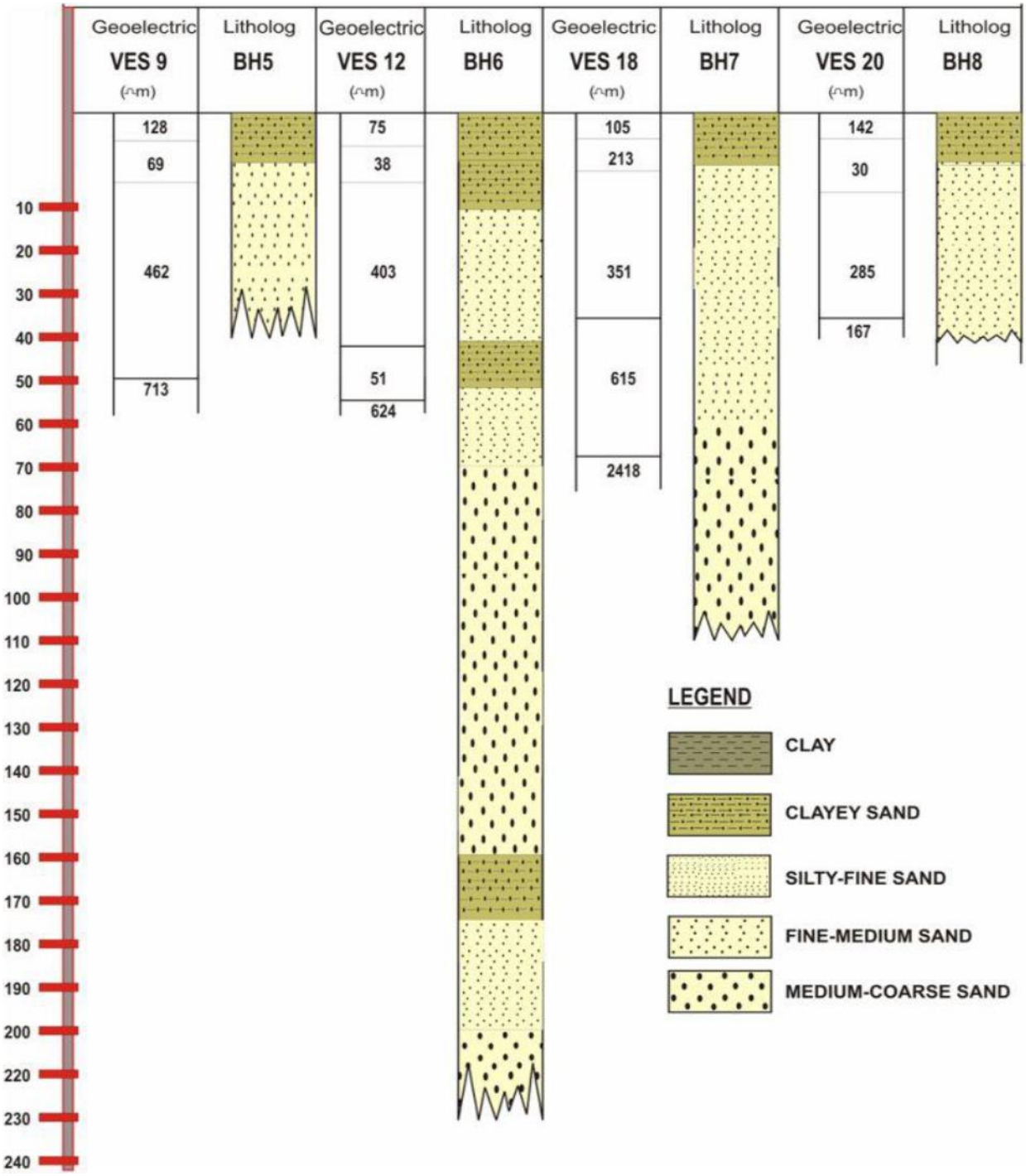

Figure 2. 3: Correlation of geoelectric sections and lithologic logs of existing boreholes in Yenagoa (Oborie et al.,2013)

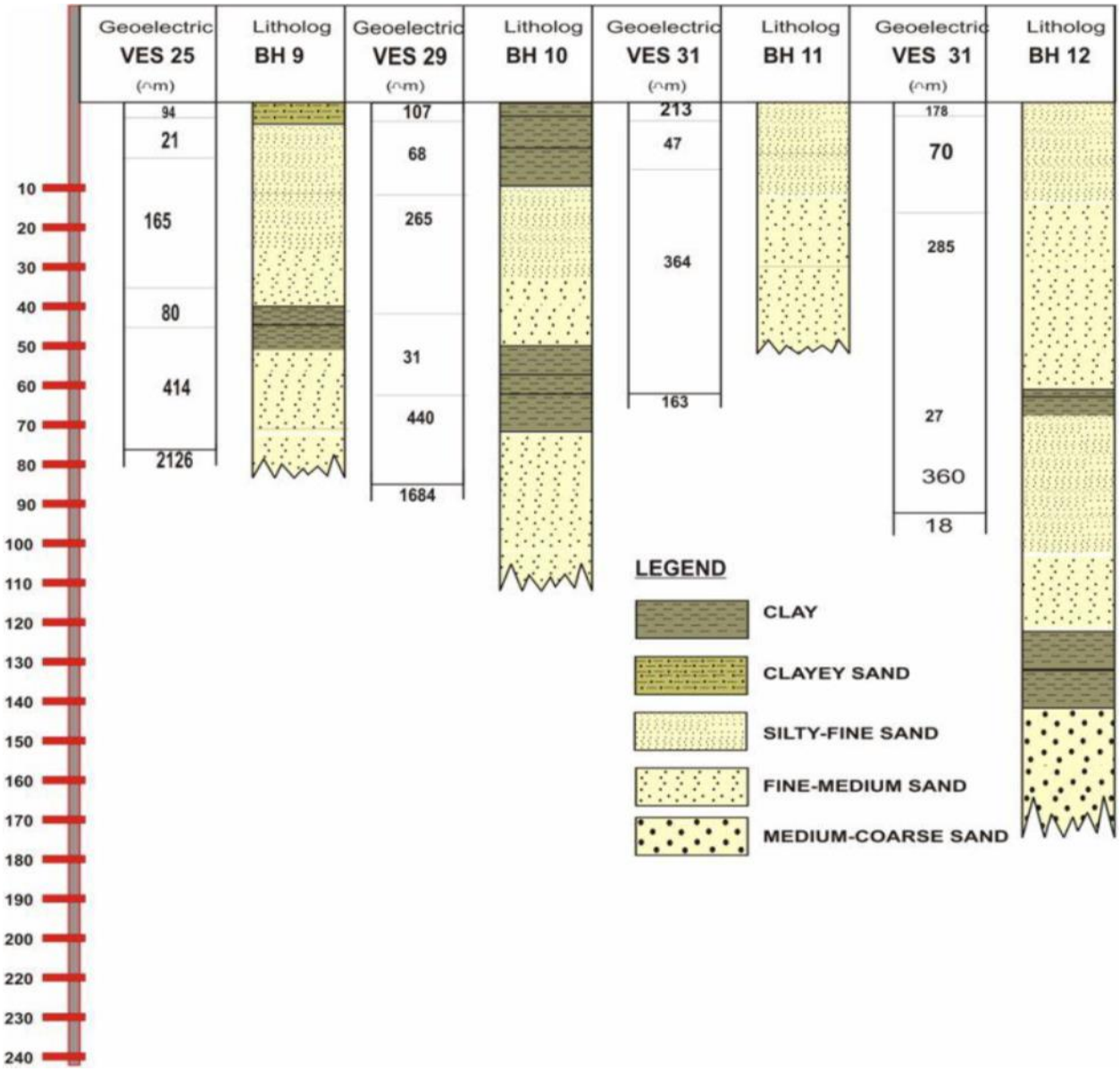

Figure 2.4: Correlation of geoelectric sections and lithologic logs of existing boreholes in Ogbia (Oborie *et al.*, 2013)

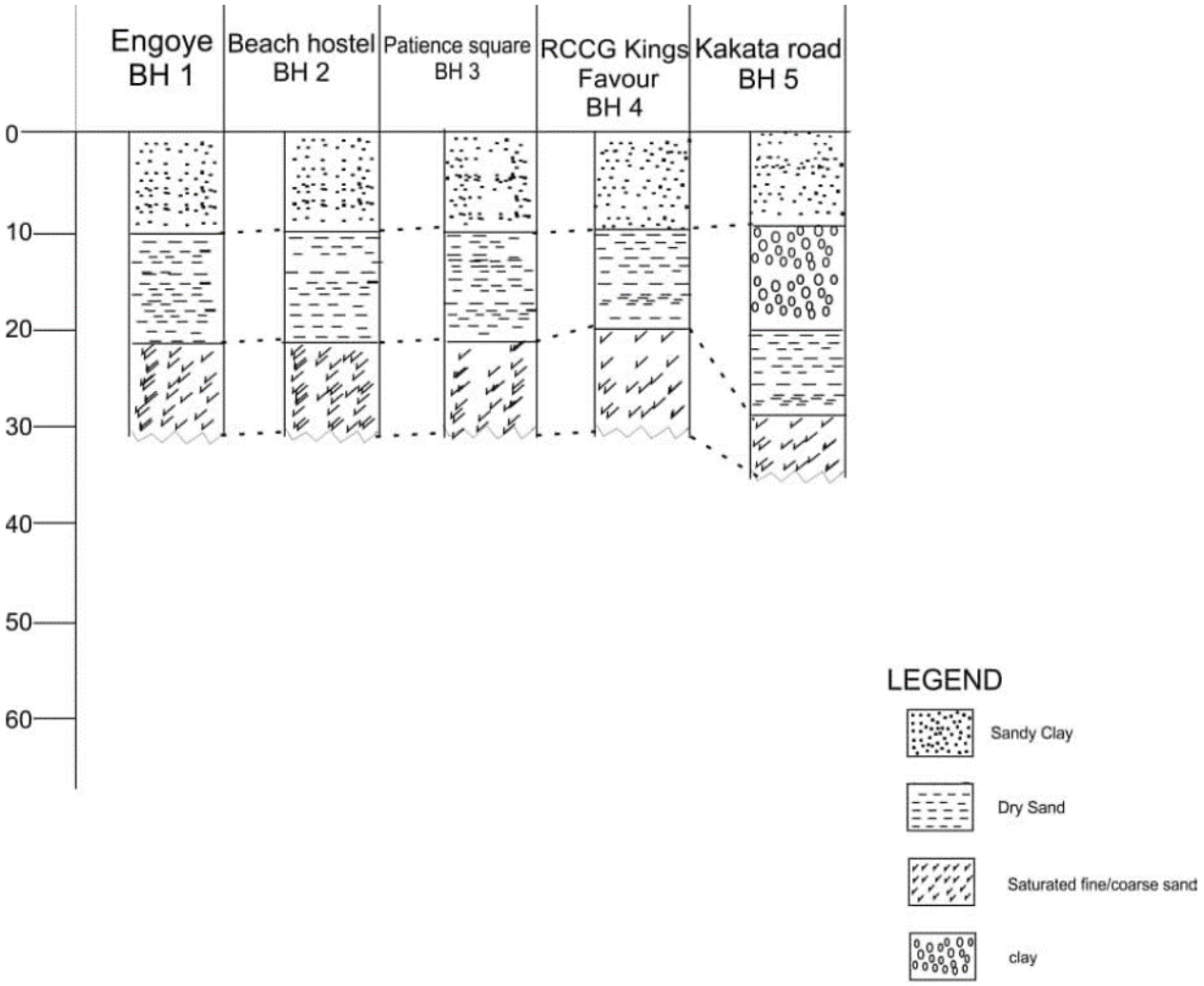

Figure 2.5: Lithologic logs of boreholes in Otuoke, Ogbia (Adejumo *et al.*, 2021).

2.5 Review of Related Research Work from Anthropogenic Activities

2.5.1 Review of Related Research Works from Dumpsites

Ikoko *et al.,* (2020) investigated the contamination and pollution levels of five heavy metals namely Cr, Fe, Mn, Ni, and Pb in spent sand filter media (SFM) in a dumpsite at Ovom Yenagoa to determine level of contamination, pollution, and potential migration in the environment. The results showed low heavy metal concentrations compared to those at 1 m depth, indicating that metal ions were mobile, possibly as a result of leaching and chemical reactions.The amounts of heavy metals were below the World Health Organization (WHO) and national standards for soil quality permissible limits.

In southeastern Nigeria', Ejiogu *et,al.,* (2017) conducted a study on the geochemical and bacteriological analysis of water resources susceptible to contamination from solid waste dumpsites. The findings showed that both groundwater and surface water samples revealed levels of lead (Pb), potassium (K+), nitrate (NO_3-), iron (Fe^{2+}), and other elements that were above the acceptable limit (WHO, 2010). They concluded that there may have been anthropogenic pollution from the neighboring dumpsite due to the high content of potassium Fe^{2+} K+, NO_3-, and Pb as well as the high prevalence of bacteria in the research area's water resources.

In a study done by Amos-Tantua *et al.,* (2014) on the concentration of heavy metals and physiochemical characteristics in soil of a municipal waste dumpsite in Yenagoa, it was discovered that the levels of Pb, Cr, and Cd were all well below the maximum tolerable limits for agricultural soil established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). The findings revealed that the composition of the municipal wastes produced in Yenagoa and its surroundings, is consistent with the low amounts of heavy metals found in the investigated soil samples. The findings also demonstrated that the soil is safe for agricultural and recreational purpose and is not contaminated by any pollutants. Therefore, they

advised that the dump site and the control region, which both have sufficient soil nutrients and low metal concentrations, be gradually turned into agricultural land with no remediationrequired.

Makuleke and Ngole-Jeme, (2020) carried out a study to evaluate heavy metal concentrations in soils and plants around the closed Lumberstewart landfill in Bulawayo, Zimbabwe, to determine the pollution potential of a closed landfill and the risks they present to plants growing in this environment and surrounding communities. Soil samples and Datura stramonium were collected at depths of 0–30 cm, 30–60 cm, and 60–90 cm around the landfill and at a control site and characterized for various properties and concentrations of Cd, Cu, Cr, Fe, Ni, and Zn. soils were sandy, mostly acidic (5.01 < pH < 7.65) with low organic matter content (<2%) and cation exchange capacity (<15 meq/100 g). properties varied with depth around the landfill. Heavy metals concentrations in the soils and *Datura stramonium* followed the order Fe > Zn > Cu > Cr > Ni > Cd with samples from around the landfill having higher concentrations than samples from the control site. Soil heavy metal enrichment was highest at a depth of 30–60 cm. Pollution load index (PLI) values indicated that all sites around the landfill were polluted (PLI > 1). Heavy metal transfer coefficient in *Datura stramonium* ranged between 0.0 and 209 with <60% of the variation observed in heavy metal transfer coefficient in *Datura stramonium* explained by the extent of heavy metal enrichment in the soils. More than 20 years after closure of the landfill, there are indications that leachate migration may still be going on around the landfill. Monitoring of environments around closed landfills needs to be ongoing to mitigate negative impacts on humans and the environment.

Eguakun and Alagoa (2020) did a research on heavy metal pollution index and safety concerns of borehole water located proximally to dump sites in Yenagoa, Bayelsa State. Nine (9) Boreholes (3/area) located proximally to each of the dumpsites were sampled for heavy metals using 50 ml empty plastic bottles. Samples were collected in triplicates and twenty-seven (27) plastic bottle samples were collected. Water samples were taken to the Institute of Pollution Studies (IPS) laboratory Port Harcourt and analyzed for Iron (Fe), Chromium (Cr), Cadmium

(Cd), Lead (Pb) and Nickel (Ni). The electro spectrophotometric method was used to detect and determine heavy metal prevalence. Data were analyzed for means, standard deviation and analyses of variance (ANOVA) with the aid of SPSS version 20 software. Heavy metal pollution index (HPI) was also conducted for the borehole water from the sampled locations. Results reveal that Fe content in the sampled ranged from 0.28mg/l - 0.38mg (Tombia>Opolo>Greenvilla). Cr values ranged between 0.004mg/l – 0.02mg/l (Tombia=Opolo>Greenvilla). Cd concentration ranged 0.036mg/l -0.50mg/l. Pb concentration ranged between 0.035mg/l – 0.18mg/l and Pb concentration ranged between 0.036mg/l – 0.18mg/l. All parameters exceeded the WHO limit for safe drinking water except Cr which was below limit. Heavy metal pollution index (HPI) reveals that: Tombia (461.23), Greenvilla (127.84) and Opolo (50.40). Tombia and Greenvilla exceeded the threshold value of 100. Based on the findings from this research, only borehole water from Opolo was below the threshold (50.40). Therefore, the consumption or use of water from Tombia and Greenvilla for cooking or drinking is hazardous and portends grave danger as it can result in organ or systemic damage to humans.

Omo-irabo *et al., (*2018) conducted a study on assessment of heavy metals contamination of soil around dumpsite in Agbor area Delta State, Nigeria. The heavy metal concentration in the collected soil sample was found in the following order: Fe>Zn>Ni>Cu>Pb>Cr>Cd. The presence of heavy metals in soil sample indicates that there is appreciable contamination of the soil by leaching migration from an open dumping site. However, these pollutants species will continuously migrate and attenuate through the soil strata and after certain period of time they might contaminate the groundwater system if there is no action to be taken to prevent this phenomenon.

Ukpong *et al.,* (2013) did a study on evaluation of heavy metals content in soils and plants around waste dumpsites in Uyo metropolis, Akwa Ibom. Heavy metals were assessed in five randomly chosen dump sites. Twenty (20) soil samples were drawn at the depth of 0-15cm and

15-30cm on each of the two sampling points of the five randomly chosen locations and six samples from three locations away from the dumpsites. The results of the analysis carried out showed that the level of heavy metals were generally higher at surface soils than subsurface soils, with mean values of 1059.2mg/kg and 695.8mg/kg for iron (Fe) surface and subsurface, respectively against control value of 665.3mg/kg. The mean value for lead (Pb) was 99.1mg/kg and 95.2mg/kg for surface and subsurface, respectively, against control soil of 15.8mg/kg and 13.6mg/kg for surface and subsurface soils, respectively. Nickel (Ni) was 308.5mg/kg and 5.9mg.kg for surface and subsurface, respectively, and a mean value of 1.13mg/kg (surface) and 0.9 (subsurface) for control. Chromium (Cr) was 2.2mg/kg and 2.1mg/kg for surface and subsurface, respectively. The level of Cr in the samples from control site was 0.3mg/kg for surface and subsurface soil. This indicates a higher concentration of heavy metals at the surface soils than subsurface and a high concentration at waste dumpsites than control sites. Assessments of some physicochemical properties of these metals were also carried out. The results show that the soils around the dumpsites were acidic with mean pH of 6.1. Organic matter had a mean value of 4.4%, available phosphorus was 23.3mg/kg, clay was 6.8% and effective cation exchange capacity (ECEC) was 10.6%.

Chessed *et al.,* (2018) carried out a study to examine the concentration of heavy metals such as Iron (Fe), Lead (Pb), Copper (Cu), Chromium (Cr), and Cadmium (Cd) in soil near dumpsites of Jimeta and Ngurore, Yola North Local Government Areas (LGAs), Adamawa State, North-Eastern Nigeria. Soil samples from 0-20 cm layer depth were collected in triplicates and analyzed using atomic absorption spectrophotometer (AAS). Results reveal that Fe, Pb, Cu and Chromium were detected, while Cadmium was found to be below the limit of detection. The mean concentration of the exchangeable cation in mg/kg in soil at Jimeta sites were: Fe (31.4 mg/kg) >Pb (0.92 mg/kg) > Cu (0.34 mg/kg) > Cr (0.11 mg/kg) >Cd (below limit of detection), while the mean concentration of the heavy metals in soil at Ngurore sites were: Fe (32 mg/kg) >Pb (0.83 mg/kg) > Cu (0.28 mg/kg) > Cr (0.07 mg/kg) >Cd (below limit of detection),

respectively. Iron (Fe) was the most abundant element in both sites, followed by Pb. Heavy metal concentrations in soil followed the order of Fe>Pb>Cu>Cr>Cd, respectively. The paired T-test analyses for concentration of Cr, Fe, and Pb in soil near the two dumpsites show that there were statistically significant differences in the concentration levels of Cr, Fe, and Pb, while Cu showed no statistically significant difference between the two dumpsites. However, all the metals detected were below the permissible limit of WHO international standard with the exception of Pb whose concentration was above maximum permissible concentration (MPC). Persistent heavy metals accumulation in soils near these dumpsites may lead to increase uptake by vegetables grown near the dumpsites and this may pose a threat to their quality and safety and ultimately human health. The need to replace open dumpsites with well-designed landfills is advised.

Nyiramigisha *et al.,* (2021) did research on assessment of the levels of heavy metals (Mn, Cr, Pb, Cd, and Fe) in soil and crops around two dumpsite and control in Surakarta Central Java, Indonesia. The level of each metal was detected low in the control site compared to the dumpsites which proved that there had been an anthropogenic contribution of heavy metal through the disposal of waste contained or made of heavy metals. The crops in the two sites and control had Cr, Cd, and Pb occurring below the detection limit. All the concentrations of metals studied in soil and crops were found to be lower than the maximum permissible limit of heavy metal in soil and crops stated by the World Health Organization (WHO) which implies that the crops are presently safe for human consumption. The higher concentration of metals in the dumpsite and their crops more than the control site shows that there is gradual pollution of heavy metals in the crops and implies that there is a need to avoid consuming crops grown on these sites and discourage the use of the sites for any form of farming activities.

Ediene and Umoetok (2017) carried out research to investigate the levels of heavy metals in soils at the municipal dumpsite in Calabar, Cross River State, Nigeria. Composite soil samples were collected from five different landscape positions along a toposequence (crest, upper slope,

middle slope, lower slope and valley/swamp) at the dumpsite in Calabar. The control sample was taken from an adjacent plot. The control soil was slightly acidic (5.6) while soil from the dumpsite were slightly acidic (6.7 -7.4) to slightly alkaline in reaction. In all the dumpsite locations the levels of Mercury (0.4-1.0 mg/kg), Chromium (0.66 - 200 mg/kg), Nickel (26 - 748.6 mg/kg), Lead (118 - 4548 mg/kg), and Zinc (1248 -2864 mg/kg) were above the permissible limits in soil whereas iron and copper concentrations were within soil limits. Generally, the values of Mercury (Hg), Cadmium (Cd), Chromium (Cr), iron (Fe), Nickel (Ni), Lead (Pb), Zinc (Zn) and Copper (Cu) observed for the dumpsite were higher than the control soil. The metal contamination/pollution index assessment revealed that the soils in the dumpsite were excessively polluted with impending negative effect on plants, animal, humans and the environment at large. Suggestion was made that necessary actions be put in place to sort at source, recycle and reuse wastes materials to minimize the quantity of these toxic metals in the environment. This will aid in reducing the impact of these metals which by virtue of their variable valences can exhibit multifarious effects on soil properties depending on their concentration levels and the length of exposure of the soil to such contaminants.

Karkarna and Matazu (2021) did a study to assess the level of metals contamination around municipal solid waste dumpsites in Kano metropolis, Nigeria. Forty-two (42) soil samples were collected from seven municipal solid waste dumpsites (Durumin Zungura, Murtala Muhammad Specialist Hospital, Sharada, Kaura Goje, Tudun wada, Dorayi and Gwale). Analysis for the concentration of these heavy metals; Zn, Pb, Cd, Cr and Ni was conducted by the use of Flame Atomic Absorption Spectrophotometer. The mean concentration of heavy metals in the soils sample were Zn (0.009 mg/kg), Pb (1.02 mg/kg), Cd (0.007 mg/kg), Cr (0.15 mg/kg) and Ni (0.15 mg/kg) for surface soils (0-15cm) while the mean values for sub-surface soils (15-30cm) were Zn (0.10 mg/kg), Pb (0.27 mg/kg), Cd(0.008 mg/kg), Cr (0.15 mg/kg) and Ni (0.17 mg/kg). The maximum concentrations of the five heavy metals in both sample and control sites were below DPR (2002) standard. Based on the result of soil contamination around the dumpsites in

Kano metropolis, it indicated that all seven dumpsites were in the class of low contamination. The contamination/Pollution Index values of all the studied heavy metals (Zn, Pb, Cr, Cd and Ni) were in the class slightly contaminated by heavy metals. It is recommended that the government should consider a basement treatment for dumpsites before use. This will provide sorption surfaces for pollutants and prevent groundwater contamination.

Olorunfemi *et al., (*2020) carried out a study on geochemical assessment of heavy metal impact on soil around Ewu-Elepe dumpsite off Ijede road in Ginti Estate, Ikorodu Local Government Area of Lagos State, Nigeria. The concentrations of certain heavy metals in the topsoils around the Ewu-Elepe dumpsite and its environs were determined with a view to ascertaining the level of metal pollution in the soils of the dumpsite vicinity. Thirty-two (32) soil samples were randomly collected within the dumpsite vicinity, and one control sample was collected from a distance of about 9.0 km from the dumpsite. The samples were prepared according to standard procedures and analyzed for some heavy metals (Ni, Mn, Co, Cd, Cu, Pb, and Zn) using the Atomic Absorption Spectrophotometer at the Geochemistry Laboratory of the Department of Geology, Obafemi Awolowo University, Ile-Ife. The results obtained showed that the mean concentrations of Ni (12.00 ppm), Mn (525.60 ppm), Co (5.64 ppm), Cu (44.59 ppm), and Zn (105.28 ppm) were within the acceptable limits for agricultural soil while those of Cd (1.40 ppm) and Pb (33.74 ppm) exceeded the limits. Geo-accumulation index and contamination factor revealed that the soils around the dumpsite were moderately contaminated with Cd and slightly contaminated with Pb. The overall decreasing order of heavy metal concentration in the dumpsite soil is Cd > Pb > Zn > Cu > Mn > Co > Ni. The study concluded that the soils around the Ewu-Elepe dumpsite were contaminated with Cd and Pb and as such should be discouraged in its usage for agricultural related purposes as these highly toxic trace elements can be absorbed by plants. A well-engineered landfill that takes into consideration the local geology and the topography of the area should be designed so as to prevent infiltration of leachates into the soil and shallow groundwater systems.

Adegboye *et al.,* (2021) conducted a study on evaluation of heavy metals in soils from different dumpsites in Ilesha, Osun State. The results of the findings reveals that soil sample from sample A had 0.09±0.006, 0.28±0.06, 1.98±0.04, 0.19±0.008 and 0.02±0.006 of cadmium, lead, cobalt, chromium and nickel. Sample B soil sample had cadmium, lead, cobalt, and chromium and nickel concentrations of 0.02±0.006, 1.56±0.24, 1.81±0.01, 0.15±0.01 and 0.01±0.006 respectively. Soil sample collected from Sample C had 0.09±0.006, 0.68±0.08, 1.10±0.07, 0.22±0.08 and 0.02±0.006. The study showed that all the dumpsites soil samples collected contained Cadmium, Lead, Cobalt, Chromium and Nickel but are within permissible standards by WHO and SON, the dumpsites are not considered a health hazard. They advised that a standard environmental sanitary dumpsite be built as soon as possible, with recycling of garbage encouraged surrounding the dumpsites.

Wokoma and Friday (2019) did a study on heavy metal concentrations in dumpsite soil and its associated environment in Rumuolumeni, Port Harcourt, Rivers State, Nigeria. Some heavy metal concentrations (Zn, Cu, Cd, Pb, Cr and Fe) in soil of waste dumpsite and its associated environment were undertaken in this study. Soil samples were collected from the dumpsite (station 1), Staff Quarters of Ignatius Ajuru University of Education Port Harcourt (station 2) and Fence of Eagle Cement Company (station 3) for a period of four months. Mean concentrations of heavy metal obtained were 3.761±1.525mg/kg, 1.223±0.828mg/kg, 0.160±0.293mg/kg, 0.126±0.085mg/kg, 3.481±0.133mg/kg and 248.548±13.800mg/kg for Zn, Cu, Cd, Pb, Cr and Fe respectively with Fe having the highest concentration of 248.548±13.800mg/kg and Pb having the lowest concentration of 0.160±0.293mg/kg. The order of heavy metal concentration is Fe > Zn > Cr > Cu > Cd>Pb. Highest concentration of heavy metals across the stations was obtained in dumpsite soil (station 1) followed by Eagle Cement Fence (station 3). The result shows that plants planted close to dumpsite, surface and groundwater of nearby environments will be contaminated with heavy metal and will not be usable for human consumption and other

categories of water usage. They recommended that waste from the dump site can be reduced, reused and recycled.

Nkop *et al.,* (2016) undergoes a study on comparative study of heavy metals in the soil around waste dump sites within University of Uyo. Heavy metals determined were Fe, Pb, Cd, Zn and Ni, the research was focused on the investigation of soil contamination (Fe, Pb, Cd, Zn, Ni) in dumpsite soil and accumulation in plant growing in the environment within University of Uyo. A total of six (16) soil samples were collected from three dumpsites in which three were control and nine (9) plants samples were also collected at the three different dumpsite. Soil samples were randomly collected by depth profile (0-5cm). Concentrations of the metals in the dumpsite soil and plant were found to be in higher concentrations compared to control. However, continuous exposure to these metals might bring about bioaccumulation and thus harmful health effects on the population. Suggestion was made that the dumpsites should be eradicated from the University of Uyo environment and phytoremediation of soil should be established as a matter of urgency.

Ojiego *et al., (*2022) undertook a study on the concentrations of some heavy metals (Cd, Cr, Cu, Pb, Mn, Ni and Zn) in soil samples from Kuje and Kwali solid waste dumpsites, Abuja, Nigeria. A total thirty (30) samples (12 from each dumpsite and 3 each from control sites: 2 km way) were randomly collected using soil auger (0-45 cm depth). The concentrations of metals were in the orders: Al > Zn > Cr > Mn > Ni > Cu > Pb > Cd and Al > Zn > Mn > Cu > Cr > Ni > Pb > Cd for Kuje and Kwali solid waste dumpsites, receptively. The control soil samples had significantly lower ($p>0.05$) metal contents. All the metals except Cd, Cr, Mn, Ni, and Zn were above the permissible limits stipulated by NESREA for Nigerian soils. Kuje dumpsites were highly contaminated by Ni (87.29), Cr (33.18), Pb (31.94) Cd (18.70), and Zn (8.72), unlike in Kwali dumpsite with very high pollution index only for Ni (44.70) and Pb (23.50). Strong positive correlations were recorded between Cr/Al, Mn/Cd, Zn/Al and Zn/Cu for Kuje dumpsite and Cr/Al, Cu/Al, Ni/Cu and Zn/Pb for Kwali dumpsite, indicating common accumulation by

concerned metals in soil. This study suggest soil around Kuje and Kwali dumpsites are heavily polluted by Ni, Cr, Pb, Cd and Zn. Proper waste management and application of ecofriendly remediation actions are recommended to reclaim the polluted dumpsites.

Nnaji, and Chukwu (2020) carried out a study on ecological risk assessment of heavy metals in soils from dumpsites within Umuahia, Nigeria. The average metal pollution indices obtained in this study indicated that the soils in the dumpsites are unpolluted except cadmium in Dumpsites 4 and 5. Degree of contamination values also indicated low degrees of contamination but enrichment factors for Pb, Cd and Cr indicated significant enrichments in three Dumpsites. Geo-accumulation indices (Igeo) for lead at Dumpsites 2 and 1 and for chromium at Dumpsite 5 indicated moderate pollution while values of ecological risk and potential ecological risk indices indicated low ecological risk. However, continuous disposal of waste in these dumpsites may lead to high ecological risks of heavy metal contamination in future. The edible plants grown near the dumpsites showed traces of heavy metal which leached into the soil from the dumpsites and the consumption of the leaves of the plants may cause health problems for humans since the recommended maximum limits for cadmium was exceeded. Cultivation of vegetables near dumpsites should be discouraged by public health authorities and adequate plans should be made to create modern waste management facilities.

Beinabaj *et al.* (2023) did a study on Concentration of heavy metals in leachate, soil, and plants in Tehran in the Kahrizak region of Tehran, heavy metals in the leachate of two landfills and the soil and plants near them, the amount of pollution caused by the leachate in the environment around the landfills in Tehran was investigated. This study was conducted in three stations, three indexes including bioavailability Pollution Index (PI), Nemerow Pollution Index (PINemerow) and Bioavailability Factor (BF) were used to interpret the results. The results showed that the concentration of total metals in the old landfill leachate and new landfill leachate were only 12% different and was 24.13 mg/L on average. In the new landfill leachate, iron had the highest concentration among metals, which was 22.94 and 17.01 mg/L in two samples. In the old landfill

leachate, the concentration of manganese was 15.71 mg/L, which was the highest among the studied metals. The concentration of heavy metals in the soil of the old landfill was 24.6% lower than the concentration of metals in the soil of the new landfill. In all samples, the highest metal concentration in the soil was related to manganese, which was 33.65–34.14 mg/L. Cadmium had the lowest concentration in soil compared to other metals. The concentration of total metals in the studied plants was 29–60 ppm. The PInemerow for studied stations was 0.1711, 0.1708, and 0.1463. The highest PI in the case of lead was observed at the second station, equal to 0.54. The highest BF in case of Atriplex Undulata was more than 6 and related to cadmium, while the highest BF in case of Atriplex Cinearea was more than 3.5 related to cadmium. This study showed that the soil and plants of the landfill were contaminated with heavy metals under the influence of leachate, and the ability of plants to uptake and accumulate metals can be used to manage soil pollution near the landfill.

Usman *et al., (*2019) conducted research on heavy metals contamination in solid waste compost at Kumshe and Bakasi in Maiduguri, Nigeria. A total of twelve (12) soil samples for the two solid waste dumpsites were collected at the depth of 30 cm using soil auger for laboratory analysis. The soil samples for dry and wet seasons were analysed for pH, zinc, iron, copper, cadmium, chromium, lead, arsenic and manganese. The soil pH was measured using Turbo pH/mV/temp meter. The soil samples were digested using acid digestion method with polytetraflouroethylene (PTFE) Teflon bomb in a mixture of concentrated nitric acid (HNO_3), concentrated hydrochloric acid (HCl) and 27.5% hydrogen peroxide (H_2O_2). The digested soil samples were analysed for the heavy metals using the Multi-wave Plasma Atomic Emission Spectrophotometer (MP-AES 4200). The mean pH values of the soil samples analyzed for dumpsite A and B ranged from 6.88-8.17 and all the samples fell within FAO standard limit. The mean concentrations of Zn, Fe, Cu and Pb for dumpsite A and B ranged from 404-1181 mg/Kg, 3138-11803 mg/Kg, 18-97 mg/Kg and 12.75-136 mg/Kg for dry and wet season respectively. While the mean concentrations of As, Cd, Cr and Mn ranged from 97-131 mg/Kg, 0.5-2.95

mg/Kg, 28.45-72.85 mg/Kg and 238-665 mg/Kg for dry and wet season, respectively. The mean concentration of Zn, Fe, Pb, As and Mn for the two dump sites were above FAO standard limit for soil quality in both seasons, while Cd, Cu and Cr were within the FAO standard limit. All the indices revealed that the study area was seriously affected by different heavy metals and the use of solid waste compost as organic manure may accumulate the metals to a harmful level as can be introduced into the food chain.

Ibe *et al.,* (2017) carried out a study on investigation of the concentration of heavy metals in soils and edible plant leaves grown in an abandoned dumpsite along Akachi Road in Owerri municipality Imo State, Nigeria. The soil samples were collected at each plot using a soil auger at the depth of 0-10 cm. Leaves of dominant edible plant species were selected and collected from each sample plot. The samples were dried in an oven with forced air at 40 °C, milled to fine powder, then digested with 10 ml concentrated HNO_3 and 5 ml concentrated $HClO_4$ and were analyzed for Cr, Cu, Fe, Mn, Al, and Zn, using an H183200 MultiParameter Bench Photometer. Results showed that metals in the sampled soils included (in order of quantity) Cr: 150-280 >Fe: 116.50-203 >Cu: 12.4-18.8 >Mn: 0-20 >Al: 0.08-0.16 >Zn: 0-1.4 mg kg. Moreover, levels of metals in the edible plant leaves are in the order of: Zn>Fe>Cu>Al>Mn>Cr. Zn content, in particular, was higher than FAO/WHO recommended limits. Still, application of Pollution Load Index and ecological risk models showed that the area is unpolluted and safe for use. Daily Metal Intake estimates indicated that zinc is mostly consumed from the plant species. The trends in Transfer Factor (TF) for the heavy metal in vegetable samples studied were in order: Zn>Al>Cu>Mn>Fe>Cr. Therefore, abandoned solid waste dumpsites contained significant concentrations of heavy metals which are later absorbed and accumulated by plants growing on such sites.

Omaka *et al., (*2020) conducted a study on assessment of heavy metals; lead (Pb), cadmium (Cd) and mercury (Hg) concentration in Amaenyi Dumpsite Awka. Findings of this study showed that the dumpsite of Amaenyi Awka contains heavy metals such as cadmium, mercury and lead. The

concentrations of heavy metals in the samples were observed to be very high in concentration as compared to W.H.O approve limit. This implies that the waste dump area is not safe for humans as well as some crop cultivation as this may interfere with some physiological functioning of the plant. It recommended that designated places should be used as dumpsites and indiscriminate marking of dumpsites be discouraged. Dumpsites should be treated before use especially for cultivation, and people living around these dumpsites should stop farming on or around them as well as designated places should be used as dumpsites.

Wunzani *et al., (*2020) undertake a study on **a**ssessment of heavy metal contamination in soil from selected solid waste dumpsites in Kafanchan metropolis of Kaduna State, Nigeria. The soil samples were determined and compared with control soil using standard analytical methods. The results showed that Heavy metals (Zn, Mn, Cu, Ni, Cd & Pb) mean- concentration (mg/kg) from the solid waste dumpsites were 1095.4, 843.7, 124.0 32.7, 1.5 & 312.0 respectively. While, the concentrations obtained from the control site for, Zn, Mn, Cu, Ni, Cd & Pb were 674.8, 941.7, 16.4, 39.4, 0.8 and 119.8 respectively. The trend of the heavy metals' pollution status from the solid waste dumpsites, were Cu > Pb > Cd > Zn > Mn > Ni. Analysis of variance (ANOVA at P > 0.05) showed that, there was no significant difference in the concentrations of Mn, Cu & Cd, while, the concentrations of Zn, Ni and Pb were significantly different. The solid waste increases the concentration of the heavy metals in the soil within the dumpsites. The concentration varies between the dumpsites which was suggested to be as a result of the heterogeneous nature of solid waste. The trace and heavy metals concentration was high and might leach out to contaminate both the surface and ground water. Also, the use of these dumpsites as farmland could lead to transfer of heavy metals to ecosystem that might be detrimental to human health.

Verla *et al.*, (2017) did research on Pollution assessment models of surface soils in Port Harcourt City, Rivers State, Nigeria, in four locations: Oil mill Market, Trans Amadi for the industrial road area and GRA Diobu and Borokiri for the residential areas and a control was taken from Federal Land Resource Umuahia. A total of twenty-five (25) composite soil samples were

analyzed for physicochemical parameters and heavy metals by means of a 969 Unicam AAS model series. The data obtained were then subjected to index models. Results showed iron (Fe) to be most abundant metal, ranging from 10.44 to 19.54 mg/kg, then Ni (8.03 to 13.6mg/kg), Cd (3.96 to 5.41 mg/kg), Pb (1.36 to 7.64 mg/kg), Zn (0.09 to 7.24 mg/kg), Cu (0.16 to 0.32) and As (0.07 to 0.11 mg/kg). All metal concentrations were below permissible limits set by National Environmental Standard and Regulation Agency (NESRA). Contamination factor (Cf) and Igeo revealed moderate to heavy contamination by Cd and Zn. Anthropogenicity revealed that increasing metals in the environment are largely from anthropogenic inputs. The Pollution Index revealed that soils were unpolluted (PLI < 1) with the heavy metals. Furthermore, the sodium absorption ratio showed that the soils are less sodic and could be good soils for plant growth. All four sites showed a linear relationship between anthropogenicity and geoaccumulation indexes, and so both indices furnish basically the same information. However, pollution from these metals in the study area should be under routine check for possible pollution in the near future, as some metals showed elevated concentrations above background values.

Piyada and Suksaman (2013) conducted a study on assessment of heavy metal distribution in soil and groundwater surrounding municipal solid waste dumpsite in Nai Muang Sub-district Administrative Organization, Amphur Phichai, Uttaradit, Thailand. The study determined heavy metals in the soil and groundwater at dumpsite surrounding areas and assessed the heavy metal contents and distributions. The results obtained indicated the following ranges for the metal in the dumpsite soil: 0.51-0.98 mg/kg of Cd, 1.22-8.78 mg/kg of Pb, 8.33-22.40 mg/kg of Cu, 25.14-75.75 mg/kg of Zn and 869.04-948.83 mg/kg of Fe. The heavy metal content at surrounding soil ranged between 0.13-0.73 mg/kg of Cd, 1.22-12.69 mg/kg of Pb, 2.27-17.35 mg/kg of Cu, 11.16-34.15 mg/kg of Zn and 782.47-938.28 mg/kg of Fe. These values were found to be below the critical permissible concentration of soil quality standard of World Health Organization / Food and Agriculture Organization of the United Nations (WHO/FAO (2001). The results indicated that the groundwater in the area of study is suitable for domestic purposes,

but it is not suitable for drinking purposes. It suggested that necessary actions should be taken to ensure that future activities should not pose environmental contamination and risks to human health.

Renshaw *et al., (2021*) carried a study on assessment of heavy metals leached from electronic waste dumpsites in Ibadan City, Oyo State Nigeria. pH values and heavy metals levels from soils and leachates collected from three waste Dump sites in Ibadan were assessed. Atomic Absorption Spectrometry (AAS) was used for determining Cobalt (Co), Lead (Pb), Arsenic (As), Selenium (Se), Nickel (Ni), Cadmium (Cd), Mercury (Hg) and Chromium (Cr). Results of heavy metal concentrations of leachates at the three locations A were (mg/l): Co 0.06 ± 0.02, Pb 0.14± 0.8, Ni 0.10 ± 0.04, Cd 0.02 ± 0.01, Hg 0.03 ± 0.02, Cr 0.20 ± 0.05 location B Pb 0,13 ± 0.06, Cd 0.01 ± 0.00 and location C Pb 0.11 ± 0.06, Cd 0.02 ± 0.01. Heavy metal concentrations in leachates at location A was in the order Cr > Pb > Ni > Co > Hg > Cd while As and Se were below detectable limits in the three locations. Heavy metal concentrations in the topsoil of the three sampling locations were as follows: Location A: Co > Pb > Se > Ni > Hg > Cd, Location B: Co > Pb > Se > Cd > Hg and Location C: Pb > Ni > Cd. Heavy metal concentrations in the subsoil of the three locations showed this sequence: Location A: Co > Hg > Pb > Se > Ni > As > Cr > Cd. Location B: Co > Hg > Pb > Se > Cr > Ni > Cd > As. Location C: Co > Pb > Cd > Ni > Cr. Conclusively, the concentration of cobalt (Co) was the highest among all metals analyzed followed by lead (Pb). This suggested that the dumpsites have capacity to impact the environment negatively a concern for public health. pH values of leachates at locations A, B and C were 7.61±2.5 ,6.00± 2.00 and 8.13± 2.8 respectively. As for the pH values of leachates, the topsoils and sub-soils of dumpsites A and C were alkaline while those of dumpsite B was acidic and traceable to mixed solid wastes typical of e-waste and biodegradables. It is therefore recommended that proper e-wastes management should be strengthened through legislation, capacity building and enhanced budget allocation.

Iyebor *et al.,* (2020) carried out a study on "Assessment of Heavy Metals Concentrations in four (4) Dumpsites Soils in Benin City, Edo State, Nigeria." The dump sites were located in Iguosa, Oluku, Otofure 1 and Otofure 2 communities, near Benin City, Edo State, Nigeria. The heavy metals analysed were Pb, Cd, Cr, Ni, Fe, Zn, Cu and Mn. Sampling of soils at 0 – 15 cm depth was done in all the dump sites. Atomic Absorption Spectrophotometry (AAS) was used to analyze heavy metal concentrations in soils and the results obtained were Pb (24.66 – 57.89 mg/kg), Cd (3.49 – 7.02 mg/kg), Cr (4.66 – 7.58 mg/kg), Ni(12.20 – 19.84 mg/kg), Fe (8580.56 – 11072 mg/kg), Cu (4.59 – 8.12 mg/kg), Zn (91.52 – 208.42 mg/kg) and Mn(173.96 – 235.67 mg/kg). The Analysis of Variance (ANOVA) showed no significant ($p<0.05$) difference among the metals except Cadmium ($p<0.05$). Degree of soil contamination was in this order Iguosa>Oluku>Otofure. Soil metal concentrations obtained from the analysis indicated that Cd concentrations were above the permissible limit of National Environmental Standards and Regulatory Agency (NESREA, 2011).

Kuok and Zhu (2022) did research on "The Levels of Heavy Metals in the Soil of Illegal Open Dumpsites in Malaysia". This study aimed to understand the soil impacts of illegal dumpsites in Malaysia through quantifying the heavy metals in the soil of two dumpsites, one receiving construction waste and the other receiving municipal solid waste. Five (5) soil samples were collected from each dumpsite, and sampling was repeated in the second week to examine the temporal changes in the levels of heavy metals. All sampling was conducted in triplicates. The soil samples were sieved, dried, and digested with aqua regia at 70 °C, after which the digested mixtures were filtered. The filtrates were diluted and tested with an Atomic Absorption Spectrophotometer for heavy metals. The soil heavy metal concentration ranges were as follows: Al (24.67-142.20 mg/kg), Cd (< 0.01-0.083 mg/kg), Cu (0.10-14.99 mg/kg), Fe (11.20-241.77 mg/kg), Mn (0.09-22.60 mg/kg), Ni (0.02- 0.77 mg/kg), and Zn (0.14-35.03 mg/kg). All the heavy metals have been detected at all the sampling points except that the Cd levels at some sampling points were below the detection limit. The levels of heavy metals varied spatially and

temporally, though higher Cd, Cu, Fe, Mn, Ni, and Zn were detected consistently at two sampling points of the dumpsite receiving municipal waste. This could be linked to the electrical and electronic waste at the dumpsite. The levels of heavy metals in the soil did not constitute soil contamination. However, it suggested that it is important to control illegal dumping activities to reduce the associated health and safety concerns, such as infestation of vermin, fire, physical hazards, and odor.

Akintan *et al., (*2019). Conducted a study on heavy metals loads in soil, farmlands and plant crops at open dumpsite in Owokoro Road, Ado Eketi, Eketi State. The study evaluates concentrations of selected heavy metals in the soils of Ilokun dumpsite and adjourning farmlands, and to determine levels of heavy metals uptake as well in various parts of Carica papaya plant collected from the dumpsite. Twenty-two soil samples were collected within the dumpsites and farmlands at depths of 0-20 cm and 20-40 cm. Evaluations of heavy metals (Ni, Zn, Cd, Cr, Pb and Cu) in soil samples and in different parts of Carica papaya plants were carried out using atomic absorption spectrophotometer. The study revealed higher concentration of Pb in the dumpsite than the farmlands. Mean concentrations of Cd in the dumpsites; 2.98±1.93 (0-20 cm) and 3.22±2.14 (20-40 cm) were higher than their corresponding depth in farmlands (1.93±1.28 (0-20cm) and 1.94±1.59 (20 – 40 cm). The study established a strong correlation for Ni/Pb (0.948) at depth of 0.20cm; Cu/Cd (0.985) and Pb/Cd (0.918) at depth of 20-40cm. Heavy metal uptake was highest in the plant parts compared to the dumpsites and farmlands. The result showed that translocation factor arrangement is Cu > Zn > Cd> Cr> Pb> Ni and Cu had the highest translocation factor of 4.698. Based on the results, the various heavy metal could be classified as slight contaminants (Pb, Cr and Ni), moderate contaminants (Cu and Cd) and severe contaminants (Zn). Although concentrations of heavy metals in the farmlands were below the Department of Petroleum Resources and World Health Organization allowable limits, monitoring the concentration profile

of these heavy metals concentrations in the area is recommended to prevent detrimental effects on the environment.

Valentine and Victor (2021) conducted research on identification of heavy metals source within four major cities Abakaliki, Ebonyi; Owerri, Imo; Nnewi, Anambra; and Aba, Abia in selected active dumpsites southeastern Nigeria using statistical tools. The dumpsites were Enyimba Dumpsite Aba (dumpsite-1), Okpuno-Egbu Dumpsite Nnewi (dumpsite-2), Rice Mill Dumpsite Abakaliki (dumpsite-3) and Nekede Dumpsite Owerri (dumpsite-4) in Abia, Anambra, Ebonyi and Imo State respectively. After standard sampling, elemental analysis was carried out using an energy dispersive x-ray Fluorescence Spectrometer; Chromium (Cr), Manganese (Mn), Cobalt (Co), Iron (Fe), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Lead (Pb) and Cadmium (Cd) were quantified and results showed they were present in high concentrations above control and standard values set by the National Environmental Standards and Regulations Enforcement Agency (NESREA) and the Food and Agriculture Organization of the United Nations (FAO) / World Health Organization (WHO). Metals investigated exhibited variable correlations among themselves suggesting potential multi-element contamination, while soil organic matter (OM) and pH displayed both significant positive and negative influence on the metal availability in the studied soils. Test of significance of the observed correlation were positive and significant ($r > 0.9$ at $p < 0.05/0.01$) for Cr/Co, Cr/Fe, Mn/Co, Co/Fe, Cu/Zn, Zn/Pb, Cu/As, Cu/Pb, Zn/As, As/Pb in dumpsite-1; in dumpsite-2, only Ni/Cu; in dumpsite-3, Fe/OM and Cd/OM while in dumpsite-4,Co/Fe, Cu/As, Cu/Pb, Zn/Cd, Ni/OM, and As/Pb. Hierarchical cluster analysis (HCA) and Principal component analysis (PCA) extracted two to three components/groups based on square Euclidean distance and eigenvalues > 1, confirming sources to be from organic pigments in plastics, scrap metals and incinerated biodegradable wastes. This study concludes that statistical methods can provide a scientific basis for monitoring heavy metals accumulation in dumpsite soils.

Otabor *et al.,* (2018) did a study on "Assessment of the Levels of Heavy Metal Contamination in Soils Around Selected Municipal Solid Waste Dumpsites in Benin City, Nigeria using Pollution Indices". Contamination levels assessment of heavy metals such as Cu, Pb, Mn, Ni, Zn, Cd and Cr in soils around municipal solid waste dumpsites in Benin City, Edo State, Nigeria was carried out. The aforementioned metals were analytically determined with Atomic Absorption Spectrophotometer. The mean concentration levels of heavy metals in the studied dumpsites ranged from 7.63± 0.06 to 37.27 ± 0.06 mg/kg for Cu, 1.23 ± 0.21 to 8.30 ±0.01mg/kg for Pb, 1.30 ± 0.26 to 9.27 ± 0.31mg/kg for Mn, 1.00± 0.00 to 5.13 ±0.06 mg/kg for Ni, 5.00 ± 0.17 to 37.93 ± 0.87 mg/kg for Zn, 1.00 ± 0.00 to 6.79 ± 0.02 mg/kg for Cd, and 0.91± 0.01 to 5.60 ± 0.36 mg/kg for Cr. Zn was found to be more abundant and was closely followed by Cu while Cr was least abundant in the studied sites. The contamination and pollution index (C/PI) of the analyzed heavy metals showed that only Cd was in the pollution ranges with high-risk degree while other analyzed heavy metals were in the contamination ranges with low-risk degree as indicated by the C/PI and the potential ecological risk index respectively. The pollution load index (PLI) ranges and mean levels were in the following order: Dumpsite II (1.41 – 6.1) averaging 3.41 > dumpsite I (1.85 – 3.82) averaging 2.76 > dumpsite III (1.08 – 2.92) with an average of 1.95, which represents the number of times the metal content in the soil exceeds the average natural background concentration.

Bongoua-Devisme *et al., (*2018) carried out a study on "Assessment of Heavy Metal Contamination Degree of Municipal Open-air Dumpsite on Surrounding Soils: Case study of Dumpsite of Southeast Region of Ivory Coast at Bonoua". Analyses of the vertical and lateral distributions of heavy metals in soil samples collected from the solid waste disposal site of M'Ploussoue Park in Bonoua indicated that there are high levels of heavy metals (Cr, Pb, Cd, Zn, Ni) in the top soil layers as well as in the soil at the bottom of the slope, with contents that exceed permissible limits Canadian Council of Ministers of the Environment updated 2007 (CCME) in agricultural and industrial soils, suggesting a high pollution potential. Examination

of the metal distribution in the soil profiles indicates the accumulation of metals in the surface soil layers as a result of human activities, urbanization or atmospheric deposition. The heavy metals in surface soil layers can migrate to plants, groundwater and surface water resources. Furthermore, our study also show that the heavy metal enrichment of soil located under the dumpsite is probably due to migration and the infiltration of the dumpsite leachate. The vertical and lateral distributions of metals in M'ploussoue Park in Bonoua can pose potential ecological risks if these elevated concentrations of metals migrate into soil, plants and groundwater, which would lead to adverse effects on plants, animals and humans. It appears that in a wet tropical climate, the open dumpsite has a significant impact on soil and on the soil quality in surrounding areas, likely due to the dumpsite leachate produced. It is thus recommended to prevent soil contamination via dumpsite leachates. Finally, it is necessary to study this dumping site and determine the exact boundaries of the contamination area and the risk to people living there. To limit heavy metal migration in plants, groundwater and surface water resources, it appears necessary to develop proper remediation techniques.

Gaobotse *et al.,* (2018) did a study on "Assessment of the Concentration of Heavy Metals Associated with Landfill Leachate in Gamodubu Soils in the Kweneng District, Botswana". This study investigates the amount of four heavy metals (Cr, Co, Cu and Pb) in Gamodubu soils that are associated with leachate from a landfill in that area. Soil samples were collected from five randomly selected points around the Gamodubu landfill. A control site was established 1000m away from the landfill i.e. free from landfill leachate. Water samples were collected in a control natural pond away from the landfill and a leachate pond within the landfill. Total recovery concentrations for Cr, Co, Cu and Pb were determined using microwave digestion with nitric acid. The findings showed no evidence of heavy metal concentration in Gamodubu soils as these metals were detected at negligible amounts. The presence of these metals in the soil was greater than their presence in water. Concentrations of all metals (except Pb) in the control water sample

were within the chemical requirements of drinking water as set by the Botswana Bureau of Standards.

Emori *et al*., (2015*)* did a study on "Assessment of Heavy Metals Contamination in Leachate Under Waste Dumpsites and Automobile Workshops in Calabar, Nigeria". For all locations, Cadmium, chromium, iron and lead showed values above the guide values by the standard of World Health Organization (World Health Organisation, 1996) and Nigerian Industrial Standard (Standards Organisation of Nigeria, 2007) for drinking water while only the dumpsite recorded value above the recommended limit for manganese. Generally, the Calabar Municipality Dumpsite showed higher heavy metals concentration levels while University of Calabar (Unical) showed the least. Except for copper, lead and zinc, some metals showed higher concentrations in the 1.0 m depth than the 0.5 m depth suggesting the risk of groundwater contamination as the contaminants are washed down the soil profile. The correlation matrix was applied to identify and quantify the relationship between couple of investigated heavy metals. The results revealed that there is significant correlation between the metals. It suggested that regular monitoring of heavy metals in soils, groundwater, leachates and crops should be encouraged since the detrimental effects of heavy metal pollution manifest many years after exposure.

Mustapha and Muhammad (2020) conducted a study "To Determine the Level of Pollution, by Selected Metals Cr, Cu, Fe, Pb and Zn in Soil Samples Collected from the Bank of River Yobe, Nigeria" where bank of the river is used as dumping site while the other part is used as farmlands. The samples were collected from four (4) different locations and were analyzed for soil nutrients, heavy metals and pollution indices. The nutrient concentrations in this study showed that the soil samples had low (< 100 kg/ Acre) levels of nitrogen. Also phosphorous levels in sites P1 and P3 were found to be low in concentrations while medium (100-200 kg/ Acre) levels were registered in sites P2 and P4. High (> 200 kg/Acre) level of potassium level was recorded in the sampling sites. The concentrations of Cr, Cu, Fe and Pb in the soil samples were found to be above the WHO permissible limits. The contamination factor and

geoaccumulation index in all the sampling sites indicated low to moderately contamination level. The findings of this research work proved that the samples collected were polluted by the metals under study. Furthermore, the results revealed that sampling points that are close to the dumpsite are almost always having the highest concentrations level of contaminants. Therefore, the study concludes that ongoing human activities such as waste dumping along the riverbanks have significant negative implications on the environment and may contaminate food crops grown around the vicinity.

Issa *et al., (*2022) carried out a study on "Index Model Approach of Heavy Metals Pollution Assessment in Soil Quality of some Selected Solid Waste Dumpsites in Warri and Environs, Delta State, Nigeria". The study evaluated the potential ecological risk (PERI), pollution load index (PLI) and Geo-Accumulation Index (Igeo) of soil pollution by heavy metal around the solid waste dumpsites in Warri and Environs. The concentrations of Pb, Cu, Ni, Cr Zn, Cd, Fe and Mn were monitored using Atomic Absorption Spectrophotometer (Unican 929) for 12 months in the selected dumpsites. The spatial variation of Pb, Ni, Cr and Zn showed no significant difference across the sampling location when subjected to one-way Analysis of Variance (ANOVA) while evaluation of PLI revealed a value of less than one in all the sample locations which indicated no pollution. PERI was evaluated with a value of ER < 30 across the sampling locations which indicates slight pollution and Igeo result showed that the soil at all the study areas is practically uncontaminated by heavy metal. The concentrations of heavy metals in the soil within the vicinities of the dumpsites were within the Department of Petroleum Resources (DPR 2002) stipulated levels.

Sanusi *et al.,* (2017) did a study on "Assessment of Heavy Metals Contamination of Soil and Water Around Abandoned Pb-Zn Mines in Yelu, Alkaleri Local Government Area of Bauchi State, Nigeria". Results of the Atomic Absorption Spectrophotometric (AAS) analysis of samples of the soils revealed that for heavy metals, the concentrations in the soils are above background levels and permissible limits recommended for soils in some countries as indicated

by the following mean concentration ranges (mg/kg): Cu, 42.01-111.60; Pb, 65.80 –291; Zn, 185.56-373; Cd, 12.62-20.70, and Fe, 0.583-0.781 with a variation pattern in the order: Zn>Pb>Cu>Cd>Fe. The contamination of Cu, Pb and Zn were high while Cd and Fe in the soil samples were low. Zn, Cu and Pb concentrations exceeded the Dutch target values (Zn: 50 mg/kg, Cu: 30 mg/kg, and Pb: 85mg/kg) in all the sampling sites. The results of the analysis of the water samples were Pb (16.63±2.63), Cu (6.049.16±0.22), Zn (9.66±4.59), Cd (0.0012±0.06) and Fe (0.189±0.450) in mg/l respectively. The Pb, Zn and Cu concentration in water were higher than WHO standards which indicated significant contamination of the water, while the values for Fe and Cd were below permissible limit. The results from the study indicated that the mining had a direct impact on the concentrations of the heavy metals determined, hence, the level of contamination of soil and water (with the exception of borehole water) samples around the abandoned Zn-Pb mines.

Tommy *et al., (*2021) did a study on "Assessment of Heavy Metals in Soils and Plant Samples Around Some Dumpsites in Uyo, Akwa Ibom State, Nigeria". The study examined the concentration of heavy metals (Cr, Cd, Ni, Cu, Pb) in soils and fluted pumpkin (Telfairia occidentalis)) growing wildly around some dumpsites in Uyo, Nigeria. Soil (0 – 30cm) and plant samples were collected at distances of 0 – 20m, 20 – 40m, 40 – 60m, 60 – 80m, 80 – 100m for two seasons (wet and dry) and analyzed for metal contents. Cu had the highest mean concentration (17.06mgkg-1), (9.39mgkg-1) in the soil and plant, respectively. Mean concentration of soil and plant samples at dumpsite soil were significantly ($p<0.05$) higher than control samples for both wet and dry season. Metal accumulation in soil and plant samples is sequentially arranged as Cu > Pb > Cr > Cd > Ni (0.31) and Cu > Pb > Cd > Cr > Ni respectively for both wet and dry seasons. Value recorded for all metals was higher than the allowable limit for soil and the two most toxic heavy metals (Pb and Cd) was higher in the plant samples than the WHO/FAO recommended values and the transfer factors of these two metals were also high. Indeed, the consumption of vegetables grown on such site; could be dangerous and can poison

human and animal health status. They suggested that heavy metal concentrations at dumpsites need to be properly addressed by regulating waste disposal and management processes. Improved remediation techniques such as bioremediation that have shown potential for their ability to degrade and detoxify certain contaminants should be recommended and practiced by farmers to reduce harmful effects of heavy metal uptake by plants.

Abiaziem *et al.,* (2022) carried out a study "Ecological and Human Health Risk Assessment of Heavy Metals Contamination of Soil in E-Waste Dumpsite in Atan, Ogun State, Nigeria" determining the level of heavy metals in e-waste dumpsite and evaluated the ecological and human health risk of soil contaminated with heavy metals in Atan e-waste dumpsite. The results of the analysis revealed that the concentrations of Cd ranged from 64.20 to 207.99 mg/kg, Cr; 414.83 to 470.47 mg/kg, Pb; 1036.89 to7362.36 mg/kg, Cu; 2963.8 to 3993.78 mg/kg, As from 149.12 to 250.03 mg/kg, and Zn; 21034.74 to 25119.61 mg/kg. The mean concentrations occurred in the order of; Zn > Pb > Cu > Cr > As > Cd. Zn had the highest concentration of 2098.45 mg/kg while Cd had the lowest concentration, 64.20 mg/kg. The values of all the metals determined in the soil were higher than the control and the tolerable limits recommended by World Health Organization. The ecological risk index of all the metals in the e-wastes soil indicated a high risk. Hence, heavy metals in soil around e-wastes dumpsites in Atan, Ogun State present serious health risk whilst urgent measures are required.

Ugbomei *et al., (*2018) conducted a study to determine the level of some heavy metals pollution in soil collected from within and around three different waste dumpsites in Sapele town. Five (5) heavy metals; Cadmium (Cd), Nickel (Ni), lead (Pb), Iron (Fe) and Zinc (Zn) were determined using Atomic Absorption Spectrophotometer (AAS). The concentration of heavy metal recorded in the soil samples from the study area ranges from 4.67± 0.10 to 17.16 ± 0.03 mg/kg for Cd, 5.33 ± 0.05 to 10.02 ± 0.03 mg/kg for Ni, 27.51 ± 0.07 to 56.06 ± 0.03 mg/kg for Pb, 866.11 ± 0.06 to 1346.79 ± 0.16 mg/kg for Fe and 87.86 ± 0.09 to 163.05 ± 0.02 mg/kg for Zn respectively. The concentration of cadmium and iron recorded in the soil samples were above the

maximum permissible limit reported by WHO (1996) and FEPA (1991). The level of Zn recorded in the soils were above the maximum permissible limit set by WHO (1996) but were found below the safe limit reported by FEPA (1991) and E.U (2002). The concentration recorded for lead and nickel were below these safe limits. The concentration of heavy metals in the soil samples was in the order; Fe> Zn> Pb>Cd>Ni. The contamination factor (Cf), Geo accumulation index (Igeo), Pollution load index (PLI) and Potential ecological risk (Eri and Ri) indices were calculated, and the results indicate that the sites were heavily contaminated with Cd and moderately contaminated with Fe and Zn. The results also revealed the control site to be moderately contaminated with Fe which could be as a result of natural occurrences.

Anietie and Labunmi (2015) conducted a study on "Surface Soil Pollution by Heavy Metals in Two Refuse Dumpsites in Akure Metropolis". Soil samples were collected randomly from nine different points of about 1m part at depth of about 0-30cm and analyzed for heavy metals and pH. The metals analyzed include Zn, Fe, Co, Cu, Ni, As, Ba, Pb, Cr and Cd using Atomic Absorption Spectrophotometer (AAS) with HF/Aqua regia wet digestion method. The pH of the soils ranged between 7.49 and 8.66. The results revealed heavy metal presence and implicated wastes as the major sources of heavy metals in the soils of the dumpsites. All the metals were detected in all the soil samples except arsenic that was not detected in three points at site A. Fe had the highest concentrations, while Ni had the least concentration in both sites. The trend in concentration was Fe > Zn >Pb> Cu> Cd> Co> Cr >As>Ba>Ni in site A, While the trend in concentration was Fe> Cr> Zn> Cu >Pb>Cd> Co> As > Ba> Ni in site B. The mean metal concentrations were compared with Department of Petroleum Resources (DPR) Standard values for soils in Nigeria, all the metals except Cr and Cu are below the DPR target values while Cd and arsenic are above the DPR intervention values for the two sites. Suggestions were made for immediate remediation.

Nwoke and Edori (2020) under went a study on "Assessment of Heavy Metals Contamination in Soil from Farmlands within a Dumpsite in Rumuagholu for a Period of Three months, Rivers

State, Nigeria". The soil samples were analyzed using atomic absorption spectrophotometer. The results obtained showed that the mean values of the metals were Pb (1.71±0.75 mg/Kg), Cd (0.21±0.19mg/Kg), Cr (2.59±0.59mg/Kg), Cu (1.75±0.34 mg/Kg) and Ni (2.06±0.62 mg/Kg). The results also showed that the concentrations of all the metals were below the DPR target and intervention values. Contamination factor analysis of the results of the heavy metals showed that the soils are not contaminated with any of the metals in all the stations examined except Cd at station 1, which showed signs of slight pollution. Pollution load index (PLI), contamination degree (CD) and modified contamination degree (mCD) analysis of the heavy metals in the soil at the different farm stations showed that the soils were not contaminated. Geochemical index (I-geo) analysis showed non contamination of the soils with heavy metals. The observed concentrations of heavy metals in the soil of the dumpsite farms showed that although waste is being discharged at the dumpsite, it might not have contributed much to the levels of the heavy metals.

Abd El Mohsen and Mohamed Abd El, (2020) assessed soil quality at a municipal solid waste dumpsite in Hurghada Red Sea, Egypt, which includes the old dumpsite and new dumpsite. These dumpsites were filled with the following wastes: paints, plastic, electric, metal, textile, wood, food, cosmetic, packing, machinery, agricultural, chemical, and automotive remains. Soil samples were randomly collected from the two waste dumpsites and two dry drainage patterns, located away from the waste dumpsites, at a depth of 50cm. The soil physicochemical properties, such as pH, electrical conductivity, total organic matter, and TDS in addition to grain size distribution were determined. Also, an assessment of heavy metal pollutants was conducted using contamination factor ratios (CF), and geoaccumulation index This study revealed that the heavy metals in soil followed the order of Fe>Al>Ba> Zn>Pb> Cu> Co> Cr>Ni>Cd. The distribution pattern of heavy metals in both drainage pattern samples exhibited decreasing concentrations of these metals than those found in the nearby two dumpsites. The heavy metals concentrations of soils in municipal solid waste dumpsite exceeded the background value of soils

from the earth's crust except for Fe and Al. The characteristics study of soil samples from the dumpsites showed that the solid waste dump had changed the soil characteristics, which were higher limits at certain places only. Contaminations in soil samples were classified using geoaccumulation index and contamination factor to make sure that heavy metal pollution levels of soils collected from dumpsites are greater than those from drainage pattern samples. (Igeo) methods.

Salamatou *et al.,* (2015) did a study on "Impact of Solid Waste Disposal System on Soil in Maradi City (Niger Republic)". A total of sixty-eight (68) composite soil samples were collected from three types of dumpsites and analyze for Zinc (Zn), Lead (Pb), Cadmium (Cd) and pH. A significant difference was found among the different dumpsites and their controls. This could indicate the beginning of contamination as further demonstrated by the calculated pollution index. The pH of these sites was mainly alkaline, indicator of active landfill/dumpsite. No significant difference was found between landfill site, official dumpsite and informal dumpsite. The result from this study showed that the management of waste disposal sites is insufficient in terms of heavy metal contamination prevention. The inadequate use of soils from dumpsite as compost could contaminate crops and create health and environmental issues. The municipality must sensitize the population about how to dispose of their wastes and the consequences of such activities and also improve the waste management system.

Iyama and Edori (2020) carried study to determine the variations of some heavy metals in soil sample between Mile 3 (M3) and Mile 4 (M4), all in Diobu, Port Harcourt, Nigeria, which are both primarily business and residential areas when compared to the control represented by the Rivers State University (RSU), Port Harcourt. The Azuka Index (AI) was used to determine the Safety Factor Index. The levels and distribution of seven heavy metals (Fe, Pb, Cu, Cd, Cr, Ni, As) in soil (0–25 cm depth) from the area using Atomic Absorption Spectrometer (AAS, Perkin Elmer 2380) were assessed. The results showed that in M3, Fe (1418.303), Cd (2.692), Pb (7.646), Ni (7.412) and M4, Fe (1162.011), Cd (1.436), Pb (7.372), Ni (5.384) were above

WHO/FAO/FEPA recommended permissible limits for soils. High percentage variations occurred between the study stations and the controls, M3/RSU for Fe, Cd, Cr, Ni, As and M4/ RSU for Cd, Cr, Ni, As, respectively. Though, the results of the ANOVA showed p-value of 0.2845 (α=0.05) meaning no significant difference within the M3, M4 and RSU stations was also corroborated by the t-test result for M3/ RSU control and M4/ RSU control which were 1.013 and 1.037 respectively at 0.05 significant levels. The mile 3 study station was observed to have more anthropogenic inputs which also showed in the variations from the Mile 4 results. The above results showed that only Cu in the Mile 4 study station certified a safe range while all the heavy metals exceeded safe limits especially Cd, As and Ni. The concentration distribution trend for the heavy metals studied were M3 (Fe>Cr>Cu>Pb>Ni>As>Cd); M4 (Fe>Pb>Cr>Cu>Ni>As>Cd); RSU (Fe>Cu>Pb>Cr>Ni>As>Cd). The increasing concentration of these heavy metals in the soils of these areas stands a threat to health of the inhabitants; hence must be monitored and adequate measures taken by appropriate authorities of government.

Olabisi *et al.*, (2021) did a study on Heavy metals concentration in underground water and tts environmental health effects in Solous Dumpsite, Igando, Lagos. Water samples from 12 different locations within a distance range of 0.07 - 0.72 km were collected while structured questionnaire was administered to 120 respondents to find out their perceptions about the environment and possible ill-health effect of water. The physicochemical parameters were measured, and heavy metals concentration of the water samples were determined using Flame Atomic Absorption Spectrometer. The water samples contained heavy metals concentrations: Lead (Pb) (0.08-1.20 mg/L), Cadmium (Cd) (0.03-0.08 mg/L), Iron (Fe) (1.4-12.3 mg/L), Nickel (Ni) (0.08-0.19 mg/L), Zinc (Zn) (0.05-0.13 mg/L) and Manganese (Mn) (0.01-0.04 mg/L) respectively. It was revealed that age, educational qualification and year of living in the community explain a significant variance in the perception of the respondents on effect of heavy metal contamination. Furthermore, over 75% of the respondents were not sure of any prior ailment linked to heavy metal contamination, all water samples analyzed were contaminated with

heavy metals with heavy metals and respondents were ignorant of the danger. They suggested that there is a need for proper provision of safe alternative water supply to the communities in the neighborhood of dumpsite for domestic use and raising awareness on environmental impact of heavy metal toxicity in drinking water to avert serious health challenges.

Akintola *et al., (*2018) carried out a study on the assessment of heavy metal status in groundwater around a dumpsite in Ibadan, southwestern Nigeria. Twenty-five (25) composite groundwater samples were collected within and at some distances from the vicinity of the dumpsite at different axes (downslope and upslope) locations. Water samples were analyzed for heavy metal (Zn, Cu, Pb, Fe, Ni, Cr, Co, Mn, As, and Ni) concentrations using ICP-AES instrumentation techniques. Data was analysed using descriptive statistics, graphics, and contamination indices (contamination factor and degree of contamination). Water samples from downslope locations revealed high metal concentrations in comparison to upslope locations. Heavy metal concentrations showed reductions with increased distances from the waste dumpsite. The Contamination Factors (CF) of heavy metal concentration in water were Fe (1.04), Zn (1.14), Cu (1.07), Pb (1.07), Cd (0.95), Ni (0.99) and Co (0.87); and the Degree of Contamination (Cd) in water was 8.0, indicating groundwater in the study area was moderately contaminated. The study showed that toxic heavy metals from waste materials in the dumpsite had contaminated the groundwater. It concluded that residents in this location may in future be exposed to greater risk; hence, redesigning the dumpsite construction to a sanitary landfill with clay or plastic liners and adopting clean-up technology for heavy metals are recommended.

Thomas *et al.,* (2019) carried out a study on "Heavy Metal Contamination Assessment of Groundwater Quality in Oti Landfill Site in Kumasi, Ghana". The sampling technique and sample treatment were done based on the standard methods for the examination of water and Wastewater. The results suggested that the mean concentration of Pb, Fe, Cd, and Cr was above the acceptable limits of the World Health Organisation (2011) for drinking water except for Zn and Cu. The heavy pollution index indicates contamination, while hazard index values at sites

BH1 and W4 were greater than one, suggesting adverse health effects. However, the heavy metal pollution index values were less than the critical limit of 100 for drinking water. Multivariate analysis predicted that lithogenic and anthropogenic factors were the possible sources of water pollution of heavy metal in the Oti community. Thus, multivariate statistical techniques could be a beneficial tool for the evaluation of possible sources of heavy metal contamination. The high levels of heavy metals found in the Oti community suggested considerable pollution of water by leachate percolation from the landfill site. It's recommended that findings of the study, which can be used in areas under similar environmental conditions, can offer a valuable benchmark for the design of suitable approaches to manage groundwater resources by both local and national policymakers.

Karkarna and Matazu (2021) did a study on "Assessment of Heavy Metal Contamination in Surface and Sub-surface Soils from Dumpsites in Kano Metropolis, Nigeria. Forty-two (42) soil samples were collected from seven municipal solid waste dumpsites (Durumin Zungura, Murtala Muhammad Specialist Hospital, Sharada, Kaura Goje, Tudun wada, Dorayi and Gwale). Analysis for the concentration of these heavy metals; Zn, Pb, Cd, Cr and Ni was conducted by the use of Flame Atomic Absorption Spectrophotometer (FAAS).The mean concentration of heavy metals in the soils sample were Zn (0.009 mg/kg), Pb (1.02 mg/kg), Cd (0.007 mg/kg), Cr (0.15 mg/kg) and Ni (0.15 mg/kg) for surface soils (0-15cm) while the mean values for sub-surface soils (15-30cm) were Zn (0.10 mg/kg), Pb (0.27 mg/kg), Cd(0.008 mg/kg), Cr (0.15 mg/kg) and Ni (0.17 mg/kg). The maximum concentrations of the five (5) heavy metals in both sample and control sites were below WHO (2007) and DPR (2002) standard. Based on the resulst of soil contamination around the dumpsites in Kano metropolis, it indicated that all seven dumpsites were in the class of low contamination. The Contamination/Pollution Index values of all the studied heavy metals (Zn, Pb, Cr, Cd and Ni) were in the class slightly contaminated by heavy metals. It is recommended that the government should consider a basement treatment for

dumpsites before use. This will provide sorption surfaces for pollutants and prevent groundwater contamination.

Okumoko and Izeze, (2020) carried out research on "Heavy Metal Contamination of Groundwater an Effect of dumpsite Leachate Percolation in Selected dumpsites of Osubi, Western Niger-Delta. Ten (10) stations (wells) around abattoir dumpsite in Osubi, Delta State were chosen to collect and assess copper, lead, manganese, cadmium and iron contamination in groundwater using methods as pollution load index (PLI) and geo-accumulation index (I-geo). Cadmium and lead had the lowest concentration as they were not detected, whereas iron had the highest concentration ranging from not detected to 45.45mg/kg with 13.48492 as average, manganese ranging from 0.03 to 0.77 with 0.192 s average and copper with 0.2 in only well 6. Methods as enrichment factor (EF), Pearson's correlation coefficient (PCC), one-way Anova, and cluster analysis (CA) were used to evaluate the relationships between the growing heavy metal concentrations. Geo-accumulation index indicated that well 4, 5 and 6 were the most polluted with respect to manganese with values ranging from - 1.90689 at the least to 2.35989 at the most, iron with values ranging from -7.67243 at the least to 2.155711 at the most and copper, with value 5.058894 at the most. Enrichment factor results indicated that copper in well 6 was the most enriched relative to iron with value as high as110.7492. The one-way Anova and cluster dendogram indicated that most of the heavy were closely related in concentration and growth as only two clusters were represented. All methods used indicated that the study unpolluted to moderately polluted and pollution was anthropogenic and not geogenic.

Angaye *et al.,* (2016) did a research on study assessing the impacts of scrap metal dumping on soil, water and vegetation at Etegwe, Biogbolo, Okutukutu and Swali in Yenagoa Metropolis. Soil, groundwater and vegetation samples were randomly collected from scrap metal dumpsites in Yenagoa Metropolis. The samples were similarly analyzed for heavy metals using standard analytical methods. Results of soil quality for surface (0-15cm) and subsoil (15-30cm) were 12.27 – 74.27 and 6.21 – 52.13 mg/kg respectively (iron), 7.24 – 35.73 and 11.41 – 33.57 mg/kg

(copper), 14.23 – 47.17 and 12.11 – 36.22 mg/kg (manganese), 11.07 – 49.38 and 17.42 – 35.72 mg/kg (zinc), 24.43 – 47.67 and 17.11 – 32.38 mg/kg (aluminum), 11.48 – 35.77 and 9.53 – 31.22 mg/kg for nickel. For water quality, the pH ranged from 4.62 – 6.33. While the level of iron, copper, manganese, zinc, aluminum and nickel ranged from 3.27 – 9.73, 0.0152 – 0.071, 0.0023 – 0.0023, 0.0022 – 0.523, 0.0023 -0.0023 and 0.005 – 0.005 mg/l, respectively. On the other hand, concentrations of manganese, aluminum and nickel recorded were below detection limit. For vegetation, Iron, copper and zinc ranged from 0.338 – 3.027 mg/kg, 0.0152 – 0.1071 mg/kg and 0.0023 – 0.223 mg/kg, respectively. While manganese, aluminum and nickel were not detected. Based on the findings of this research, it is recommended that scrap metal dumping in Yenagoa Metropolis should be subjected to periodic monitoring.

2.5.2 Review of Related Research Work from Auto-Mechanic Activities

Opara *et al.,* (2010) carried out an assessment on the impact of auto-mechanic activities on groundwater in Mile 2 Diobu. The outcome of the research showed that the groundwater within the auto mechanic workshops was slightly acidic as the pH of the water samples investigated ranged from 6.0 – 6.2. All the other parameters analyzed were within the WHO permissible limit. It concluded that the auto- mechanic activities carried out in the area has not insignificantly impacted on the groundwater resources.

Orodu and Leizou, (2017) carried out research to determine the concentration level of heavy metal cadmium and nickel in soil of Auto Mechanic Village in Yenagoa, cadmium and nickel showne a lower concentration below the limit set by Department of Petroleum Resources for Agricultural, Residential, Commercial and Industrial standard, indicating that the source of these heavy metals were natural. These metals do not pose a threat to the soil dwelling fauna and human health. They suggested that Mechanic Village and its Environs are likely to face the threat of heavy metals in years to come with the present level of heavy metals.

Adelekan and Abegunde (2011) carried out investigation on heavy metals contamination of soil and groundwater at automobile mechanic villages in Ibadan. The result of the study showed high

values of Pb, Cu and Cr in the soil samples on all locations at the auto- mechanic villages when compared to established guidelines for evidence of high value of nickel (Ni) in the soil was found.It was also observed that in Pb had the highest concentration values in the soil samples which is above the permissible limit for soil, while Cd had the least concentration value. The groundwater samples met the WHO (1993, 1996 and 2004) guidelines values set for Pb, Cd, Cr and Ni but copper (Cu) exceeded the limit.

Chidi (2019) investigated concentration of toxic heavy metals in soil within a reclaimed section of the Orji mechanic village in Imo State. The result showed that at the reclaimed section of the Orji Mechanic village in Owerri North Nigeria the soil is contaminated by Pb, Cd and arsenic. The activities at the mechanic village in the area is significantly affected by the accumulation of heavy metals.

Ibrahim *et al., (*2019) studied heavy metal contamination of soil and groundwater at automobile mechanic workshops in Borno State, by assessing the level of some selected heavy metals chromium (Cr), Zinc (Zn), lead (Pb), Manganese (Mn), Nickel (Ni) and cadmium (Cd). The result showed that automobile mechanic workshops of the sample areas: Daija and Kenken wards were highly polluted with heavy metals Cr, Pb, Zn Mn, Cd and Cu which were confirmed with indices of Contamination factors (CF), Geo-accumulation index (I-geo), Quantification of Contamination (Qoc) and Pollution Load Index (PLI). Pollution has significant negative impact on the environment that also has a direct relationship with well waters around the mechanic workshops.

Vincent *at al.,* (2022) carried out a study to assess the heavy metals content in soil and groundwater within the vicinity of automobile mechanic workshops in Yola and Jjimeta Towns, Adamawa State, Nigeria using standard methods. Heavy metals were determined using AAS model 210 VGP while pH was determined by electronic JENWAY glass electrode pH meter (Model 3510). Data obtained revealed that, the pH of the soil and ground water samples ranged from 7.52 to 5.19. From the study conducted, it can be seen that the level of heavy metals found

in the soil is in the order of Zn>Ni>Fe>Pb>Cd. While heavy metals found in the groundwater of automobile mechanic locations are in the order Ni>Fe>Zn>Cd>Pb. The levels of metals found in the present study were generally below the Department of Petroleum of Petroleum Resources (2002) target values for metals in soils.

Bariweni *et al., (*2018) did a study by using I-geo and enrichment factor to ascertain the current pollution status and contributory source of heavy metals around soils of auto-mechanic workshop clusters in Yenagoa Metropolis, Bayelsa State, Nigeria. Three upper soil layers (0 to 15 cm, 15 to 30 cm and 30 to 45 cm) were sampled over three distant extremes (0 meter, 50 meters and 100 meters) and analyzed. Values of i-geo showed that Zn (2.23) showed moderate to highly polluted geogenically while Pb (0.76), Cu (0.79), Cd (0.77), Co (0.63), Cr (0.65), Ni (0.83), Hg (0.48), Mn (0.94) and Fe (-0.13) showed unpolluted to moderately polluted geogenically around soils of auto-mechanic workshop clusters in the Yenagoa Metropolis. Enrichment factor has shown that Zn (1.47) was not introduced through anthropogenic but geogenic sources while Pb (11.54), Cu (10.18), Cd (13.54), Co (4.02), Cr (15.35), Ni (13.48), Hg (8.89) and Mn (4.16) were respectively through anthropogenically. Fe (1.00) was the normalizer. They concluded that progressive contamination scenario observed in soils of the auto-mechanic workshop clusters in this work were mainly attributable to anthropogenic activities arising from unprofessional ways artisans adopted in disposal of heavy metal-bearing wastes onto soils of the study area.

Odoh *et al., (*2011) did a study on "Assessment of Trace Metals Pollution in Auto-Mechanic workshop in Some Selected Local Government Area of Benue State", Nigeria. The determination of Cd, Co, Cu, Mn, Ni, Pb and Zn in soils within motor parks were carried out with Flame Atomic Absorption Spectrophotometric technique. The method developed by the United State Environmental Protection Agency for (total sobbed) heavy metals in soils, sediments and sledges was used in the preparation of the soil samples for the determination of total metal content in this study. The ranges and mean concentrations (μg/g) of metals in auto-

mechanical workshop soils were 5.00 - 5.93 (5.47 ± 0.29), 2.07 - 2.93 (2.44 ± 0.28), 204.33 - 273.83 (240.29 ± 23.04), 402.00 - 486.67 (436.91 ± 35.53), 17.87 - 22.23 (19.23 ± 1.02), 513.00 - 582.00 (567.52 ± 19.35) and 106.67 -138.33 (119.02 ± 8.77) for Cd, Co, Cu, Mn, Ni, Pb and Zn, respectively. The enrichment factors obtained for Cd, Co, Cu, Mn, Ni, Pb and Zn in auto-mechanical workshops were 19.54, 1.80, 29.63, 3.03, 1.80, 172.50 and 12.45 respectively. The inter-element correlation was found among metals in the soils of auto-mechanical workshops using Pearson's correlation co-efficient. There were positive correlations among the metals determined. Metals such as Pb, Cd, Cu and Zn show high degree of contamination, while Co, Mn and Ni show low degree of contamination in the study sites.

Aloysius *et al., (*2013) carried out a study on "Evaluation of Heavy Metals in Soils around Auto Mechanic Workshop Clusters in Gboko and Makurdi, Central Nigeria". The concentration levels of selected heavy metals (Cd, Cu, Mn, Ni, Pb and Zn) in soils around two major auto mechanic workshop clusters were investigated to ascertain the possible environmental impact of these clusters. Results of the Atomic Absorption Spectrophotometric (AAS) analysis of samples of the soils revealed that for the majority of heavy metals, the concentrations in the soils are above background levels and permissible limits recommended for soils in some countries as indicated by the following ranges (mg/kg): Cu, 254-1,348; Pb, 283 - 665; Zn, 295-553; Mn, 58.8-272.; Ni, 18.0 - 41; and Cd, 10.50-12.7, with a variation pattern in the order: Cu>Pd>Zn>Mn>Ni>Cd. The order of accumulation of metals in the Auto-mechanic workshop locations is: Gboko>Apir. Factors which appear to significantly influence the mobility of metals in the soils were the pH, cation exchange capacity (CEC), organic matter (OM) content and texture of the soils. Contamination factors for Pb and Cu in the areas under investigation ranged from considerable to very high contamination, while Zn, Mn and Cd had minimal to moderate enrichment and Ni demonstrated moderate to considerable enrichment. Geo-accumulation index values for the metals in the soils also showed that the environment surrounding the workshops is highly

polluted with Pb and Cu, and to a lesser degree with Ni. Both Cd and Mn showed moderate pollution status while the soil remain unpolluted with Zn.

Osayande *et al.,* (2022) conducted a research on six (6) samples were taken from locations close to the selected auto repair shops (Experimental sites) and locations far enough away from the shops to have no effect on the samples (Control sites).The levels of cadmium (Cd), lead (Pb) and mercury (Hg) were ascertained with the aid of Atomic Absorption Spectrophotometer (AAS). It was established that heavy metals were generally higher in soil due to the activities of automobile workshops than the areas far away, but lead (Pb) values were higher than mercury (Hg) and cadmium (Cd) values. The mean values of Hg, Pb and Cd are 3.07, 91.03 and 5.63 mg/kg respectively, in soils under the impacts of automobile workshops and 0.03, 60.25 and 1.79 mg/kg, respectively in soils far away from the automobile workshop. At the 0.05 confidence level, there was a statistically significant difference in heavy metal levels between the experimental and control sites. The sediments maintained fairly uniform pH value across the topsoil. The lowest pH value is 6.94 with a prime value of 7.40 as against the control sample's values of 6.98 and 7.5. The EC ranges from 238.0 to 330.8μS/cm as against those of the control 90.3-149 μS/cm. This clearly shows that the contaminated site poses more electrical conductivity than the control site. Potassium (K), ranges from 15-16.2mg/kg against that of the control samples which range from 16.12-16.62mg/kg. The concentration of K is well below the WHO permissible limit of 200mg/kg. Ca ranges from 3.80-21.02mg/kg while Na ranges from 0.98-1.88mg/kg as against the control sample of 19.5-30.66mg/kg and 1.22-1.86mg/kg. The Ca and Na content in the analyzed soil samples are within WHO stipulated limits of 75 and 200 mg/kg. It is pertinent that mechanic villages should be in industrial areas away from residential areas, sensitization must be carried out on environmental pollution and waste management while bioremediation of polluted soil using plants should be encouraged.

Sawyerr *et al., (*2019) conducted a study to assess the extent of heavy-metal contamination of soils within battery technicians' workshops within Ilorin metropolis, Kwara State, Nigeria. A

total of twenty-five (25) composite soil samples were collected from six selected battery charger workshop within Ilorin metropolis and analyzed for the presence of heavy metals using Atomic Absorption Spectrophotometer. Results reveal significant positive relationship between Mn and Fe (r=0.511**, p<0.001), Mn and Cu (r=0.565**, p<0.001), Fe and Cr (r=0.895**, p<0.001), Fe and Cu (r=0.823**, p<0.001) and between Cr and Cu (r=830**, p<0.001). The result also show significant negative relationship between Mn and Cr (r=-0.679**, p<0.001), Pb and Cu (r=-0.468*, p<0.05) respectively. The pollution status of heavy metals in soils was evaluated using quantitative indices (pollution index–PI). The result show that Zn was moderately contaminated while other heavy metals (Pb, Cd, Cr and Cu) had very slight contamination (pollution index<0.1). Ilorin Metropolis soils of Kwara State were found to have moderate to very slight contamination respectively. Large variations in Pollution index (PI) values of Zn revealed that soil in those areas of the city, which are influenced by anthropogenic activities, have moderate concentrations of Zn resulting in "considerable risk". The findings of this study recommend comprehensive continuous annual monitoring and auditing and further studies on the level of these heavy metals in the near future to ascertain long-term effects of anthropogenic impact is forestalled to protect the men and the environment. It should also involve larger coverage with studies on ground water around such locations. Furthermore, continuous metals speciation should be carried out so that the form and extent of metal bioavailability can be evaluated further.

Amukali *et al., (*2018) carried out a study on distributional patterns of heavy metal contamination indices in soils within and around auto-mechanic workshop clusters in Yenagoa Metropolis, Nigeria. Soil samples were taken and analyzed from three soil layers (0 to 15 cm, 15 to 30 cm and 30 –to 45 cm), over three distances (0 meter, 50 meters and 100 meters) from the auto-mechanic workshop clusters. Pb (5.85), Cd (5.63), Ni (4.62), Hg (4.52) and Cu (3.99) all showed evidence of considerable contamination; Cr (2.4) and Mn (2.22) showed moderate contamination while Zn (0.73), Co (1.630 and Fe (0.82) implied evidence of low contamination.

Overall degree of contamination (32.42) implied very high degree of contamination while Pollution Load Index (681.22) implied progressive deterioration of soils of auto-mechanic workshop clusters in the study area. It was noticed that levels Pb, Cu, Cd, Co, Cr, Ni, Mg and Hg encountered in this study showed evidence of anthropogenic input into soils of auto-mechanic workshop clusters, as against values of Zn and Fe which showed evidence of geogenic input. The progressive contamination scenario observed in soils of the auto-mechanic workshop clusters in this work were mainly attributable to anthropogenic activities arising from unprofessional ways artisans adopted in disposal of heavy metal-bearing wastes onto soils of the study area.

Magaji *et al.*, (2023) did a research on determination of selected soil physical parameters in automobile repair workshops of Damaturu Metropolis, Yobe State, Nigeria. Soil samples were collected from the sampled automobile repair workshops in Damaturu Metropolis at the depths of 0-5, 5-10, 10-15, 15-20 and 20-25cm. A simple random sampling technique was employed for the study. Data analysis was carried out using mean ($\bar{x}$), standard deviation (σ) and analysis of variance (ANOVA). The concentration of physical parameters such as soil pH, electrical conductivity (EC), soil moisture content, bulk density and total organic carbon were also analyzed. The concentration of soil pH values ranged from 6.41+ 0.16 – 8.03+ 0.38, Electrical conductivity ranged from 9.7+ 5.3 – 124.4+ 15.7 μS/cm, moisture content ranged from 0.60+ 0.07 – 4.16+ 2.56 %, bulk density ranged from 0.60 + 0.01 – 0.74 + 0.03gc-3 and lastly total organic carbon ranged from 0.12 + 0.07 – 12.83 + 0.16%. The result further revealed that significant differences ($P<0.05$) were observed in the selected soil physical parameters. The results indicated that soil qualities varied between slightly contaminated to highly polluted status. In order to control issues related to soil contaminations, the study recommended that the automobile repair workshops in the study area should be encouraged to practice accurate collection and disposal of used engine oils.

Boisa and Falodun, (2017) carried out a study on human soil ingestion exposure assessment of selected toxic metals for soils contaminated by auto-mechanic spills, crude Oil and mining

wastes. This study was designed to compare the risks resulting from soils contaminated by toxic metals from crude oil, auto-mechanic spills and lead mining. Nine (9) archive composite surface soil samples previously collected from cities and towns in Rivers, Bayelsa and Ebonyi state impacted by crude oil, auto-mechanic spills and lead mining wastes were used for the investigation. Dried soil samples (<250um) were digested with aqua regia and the resulting digests analysed for As, Cd, Mn, Pb and Zn. Human soil ingestion exposure assessment was conducted using pseudo-total concentrations of the individual metals. The pseudo-total concentration ranges for As, Cd, Mn, Pb and Zn in all three different contaminated matrices were 24.9 – 55.7 mg/kg, 7.4 – 18.4 mg/kg, 400 – 4938 mg/kg, 77 – 7451 mg/kg, and 109 – 2220 mg/kg, respectively. Among the three different contaminated matrices investigated the mine wastes contaminated surface soils indicated the highest mean pseudo-total concentrations for all five toxic metals of interest in this study. Calculation of potential daily intake doses of As and Pb from topsoil around mining sites indicated levels above the tolerable daily intake (TDI) values set for the toxic metals. This study highlights relatively low levels of toxic metals in surface soils contaminated by crude oil. Data obtained from this study suggest that of the three industries investigated Pb mining indicated the highest concentration of all the toxic metals investigated in surrounding surface soils. This study has also highlighted auto-mechanic service operations as a potential point source of toxic metals, especially Pb.

Opara *et al.*, *(*2020) did a study on Geo-environmental assessment of activities of auto–mechanics workshops at Alaoji Aba and Elekahia Port Harcourt, Niger Delta, Nigeria. The main objective of the study is to determine the extent of soil contamination arising from anthropogenic activities within mechanic villages (MVs). Geochemical analysis of soil samples from the study area revealed that the concentrations of the trace metals ranged from <1 mg/kg for chromium (Cr) to 1,925 mg/kg for lead (Pb). Soil analysis for polycyclic aromatic hydrocarbon (PAH) and total petroleum hydrocarbon (TPH) across the area revealed concentrations ranging from <0.02 to 1.80 mg/Kg and from <1.00 to 38,327 mg/kg respectively. Elevated levels of heavy metals

and TPH were observed at MV in Alaoji Aba when compared to MV in Elekahia Port Harcourt, and the control sites. This could be attributed to contamination due to the presence of these auto-mechanics in the area for over thirty years. The concentration of Pb and Cd recorded in some sample points were above USEPA (United State Environmental Protection Agency,) and the National Environmental Standards and Regulations Enforcement Agency (NESREA) permissible limits. Results of PAH analysis showed the presence of naphthalene, phenanthrene, pyrene, fluorene, benzo(a)anthracene, acenaphthene, methylnaphthalene. Risk assessment analysis showed significant geo-accumulation values for Cd and Pb indicating heavy contamination. The monomial risk factor of the heavy metals in the MVs are in the order Cd >Pb>Cr, while potential ecological risk index analysis showed values indicating very high risk, considerable risk and a moderate risk to the area under study as well as the surrounding environment. These results suggest that the soils from the MVs which represent the mechanic workshops at Alaoji Aba and Elekahia Port Harcourt are considered to be of pollution concern due to elevated Pb and Cd levels. Hence, there is a serious need to regularly monitor the activities of auto-mechanics in the study area.

Edori and Edori (2012) did a study on effect of auto-mechanic works on Lead and Iron content in two mechanic villages in Port Harcourt, Rivers State Nigeria. Forty (40) soil samples were collected from two mechanic workshops (villages), Mile 2, Anyama and Mile 3, zone C and a control, River State University of Science and Technology (RUST) to examine the pH, conductivity and the concentrations of lead (Pb) and iron (Fe). The pH at the topsoil samples (0-15cm) were formed to be higher than those of the lower soil samples (15-30cm). pH values ranged from 7.3- 8.4. The values observed for conductivity also followed the same pattern as the pH with the top-soil samples(0-15cm) having higher conductivity values than those of the lower soil samples (15-30cm) and were within the range of 7.70 × 10 - 6.60 × 102 μS/cm. The values of the pH and conductivity were higher in the mechanic workshops than the control. The concentration of Pb was very low at UST (control), which were 4.09mg/kg for the topsoil and

3.44mg/kg when compared to those observed at the mechanic workshops which were within the range of 205.50mg/kg 1551.25mg/kg. The value of Pb was highest at Mile 3 zone C 1 (155.25mg/kg) and lowest at Mile 3 zone C 2 (205.50mg/kg). Iron (Fe) concentration was lowest at UST (control), being 1412.50mg/kg (topsoil) and 2325.00 mg/kg (lower soil) and was highest at the Mile 2, Anyama 1 workshop which was 13162.50 mg/kg (topsoil) and 13050.10 mg/kg (lower soil). The work showed that the contribution of heavy metals into the soil through anthropogenic activities at the workshops is alarming.

Nebo *et al., (*2018) conducted a research to ascertain the level of contamination of the soil and groundwater around Elekahia Mechanic Workshop Area in Port Harcourt Metropolis. Soil samples were collected from the study area (including the control) at the depths of 1m, 2m and 3m. A total of six soil samples were collected from the workshop and control located 50m away from the workshop at depths of 1m, 2m and 3m. Groundwater samples were collected from 2(two) boreholes within the workshop and a borehole outside the workshop area as control. Results of groundwater and soil samples were compared to the World Health Organization (WHO)and Department of Petroleum Resources (DPR) standard for drinking water and soil respectively. Results of the analytical studies of the physicochemical parameters and heavy metals on the soil and groundwater resource from the Mechanic village, Elekahia show that the activities of the workshop do not really pose a great risk to contamination of groundwater and the subsurface soil. However, the low pH observed suggests the treatment of the water before consumption. The tendency for concentration and bioaccumulation of these contaminants over time is high and therefore continuous monitoring of the site is important in order to ascertain pollution status and the effects on humans.

Adebayo *et al.,(*2017) did a research on delineation of heavy metals in soils from Auto-Mechanic Workshops within Okitipupa, Ondo State, Nigeria. Soil samples were collected from selected automobile workshops (four) in the study area at the depths of 0-15cm, 30-45cm, 45-60cm, 60-75cm and 75-100cm. A total of twenty-four (24) soil samples were collected in four different

locations in the ancient town of Okitipupa. Six control samples were also collected in farmland about 3km away from auto mechanic activities. The soils were analysed for heavy metals levels. Ten heavy metals (Cd, Zn, Cu, Cr, Pb, Fe, Mn, Co, Ni and Mg) were analysed using AAS techniques. The heavy metal concentration for the ten metals determined in soil was in the order: Fe > Mg > Zn >Mn> Cu >Pb> Ni > Cr > Cd > Co. Heavy metals concentrations (mg/Kg) Ranging from 0.01±0.00 to 112.00±0.00 in all the sites. Site C is about ten years older than others and recorded the highest concentrations of heavy metals in all the sites. Comparing the results of the study area with the control shows that the study area is moderately contaminated; the value obtained was below the DPR permissible limit for soil. It is therefore recommended that a separate portion of land be set apart for automobile workshops in Okitipupa.

Naluba and Adah, (2023) carried out a study to determine the impact of Auto-mechanic Workshops on soil properties and heavy metals in Woji Area of Obio/Akpor Local Government Area Port Harcourt, River State. The experimental research design was used for this research. Data was sourced from both primary and secondary sources. However, it relied on primary data generated through laboratory analysis of soil samples collected using soil auger and at depths 0-30cm from five randomly selected sites and one control. Standard field and laboratory methods employed in data collection and analysis. Three specific objectives and two hypotheses guided the study. Data for the hypothesis was tested using the Analysis of Variance (ANOVA) statistical techniques and the two sample t-test. Findings revealed that pH level in soil of the area ranged from 5.2 to 7.1 and a mean occurrence of 6.02 as against 6.2 for the control. Soil temperatures ranged from 25.70C to 27.40C with a mean of 26.660C as against 26.80C for the control. The soil in the area is dominated with sandy particles (87.14%); silt (11.58%) and clay (1.84%). The hypothesis was rejected, and this means that there is significant variation in the occurrence of the heavy metals across the five experimental sites. The mean value for the iron (Fe) for the five experimental sites was 32.78Mg/kg, Nickel (Ni) 23.65mg/kg, Copper (Cu) 14.17mg/kg, Lead (Pb) 20.62mg/kg, Magnesium (Mg) 11.32mg/kg, Cadmium (Cd) 9.14mg/kg and Zinc (Zn)

42.28mg/kg. Zinc (Zn) had the highest mean value (42.28mg/kg) while Cadmium (Cd) had the lowest mean figure of 9.14mg/kg. In the control, Iron (Fe)was 9.6mg/kg, Nickel (Ni) 4.5mg/kg, Copper (Cu) 1.6mg/kg, Lead (Pb) 9.47mg/kg, Magnesium (Mg) 33.2mg/kg, Cadmium (Cd) 3.48mg/kg and Zinc (Zn) 12.4mg/kg. Based on these findings, the study recommended the following: proper siting and monitoring of mechanic workshop activities; the use of ecofriendly method (phytoremediation) to remediate the heavy metals, regular evaluation of the soil to guide against excessive contamination by auto-mechanic workshop activities in the area.

Nwankwoala and Ememu (2018) conducted a study to assess the soil and ground water quality in Okpoko and Environs in Anambra State. Fifteen (15) soil and groundwater samples were collected and analyzed for physico-chemical, heavy metals and hydrocarbon content. Soils were sampled at 15cm and 30 cm depth. Heavy metals in soil and groundwater were analyzed using Atomic Absorption Spectrometer. Grain size analysis shows that topsoils (0-15 cm) and sub-soils (15-30 cm) in the area are predominantly sands (>70%), and soil classification scheme based on SAR (<13), pH (<8.5) and EC (>4 μS/cm) shows that the soils are saline. Apart from Ni, all the other metals show concentrations that decrease with depth. Total Petroleum Hydrocarbons (TPH) ranges from 109.43 to 2112.64 mg/kg and 105.57 to 1747.82 mg/kg in topsoil and sub-soils in the area. The average TPH content is 654.01 ± 582.12 and 568.27 ± 502.11 mg/kg in topsoil and sub-soils respectively, and 54.43 and 16.63 mg/kg at control site. The total hydrocarbon content (TOC) is higher in the vicinity of the fuel filling and service station than at the control site which is an indication of anthropogenic influences. The TPH content generally decreases with depth and is lower at control than at the vicinity of the fuel filling and service station. Apart from Fe and Mn, all other metal concentration exceeds those of the control. The metal concentrations were within DPR regulatory limits for safe agricultural soils. Assessment of anthropogenic influences on the soil quality in the area with the control site as baseline was accomplished using soil quality models including: Contamination Index (CI), Pollution Load Index (PLI), Modified Contamination Degree (mCD), Geo-accumulation Index (Igeo), and

Nemerov Integrated Pollution Index (NIPI) which shows that the soils are heavily polluted from the activities at the fuel filling and service stations in the area. Regular soil and groundwater assessment is recommended to monitor the contamination potential in the area.

Lucky *et al., (*2024) did a research to analyze the presence and dispersion of hydrocarbons in dumpsites at mechanic workshops in Port Harcourt, Rivers State, Nigeria. Soil samples were collected from within 15-25 cm soil depth from three mechanic workshops in Port Harcourt, situated at Elekahia, Rumeme and Eleme Local Governments. The total petroleum (TPH) and Polycyclic aromatic hydrocarbons (PAHs) concentrations in the soil samples were determined using standard methods. Total TPH concentration in mechanic workshop dumpsites ranged from 9508.18 ppm to 10342.41 ppm, while in the control the concentration was 424.41 ppm. Total PAH concentration in mechanic workshop dumpsites ranged from 312.45 ppm to 1654.08 ppm, while in the control the concentration was 157.89 ppm. All the dumpsites had high levels of PAHs, which were several folds more than in the control. Results revealed that soil at mechanic workshop dumpsites were highly contaminated with hydrocarbons, exceeding the allowable limit of 50 mg/kg by the Department of Petroleum Resources (DPR). Remediation of the soil is recommended, as well as proper management of waste, where relocation of the dumpsite is not possible.

2.5.3 Review of Related Research Works from Cassava Mill

Iwegbue et al., (2013) conducted a study on heavy metal contamination in soils near a cassava processing mill in the Delta State sub-urban areas of Abraka, Eku, and Obieruku. The study found that, with the exception of some sites, the concentration of metals was generally below the limit set by the Department of Petroleum Resources (DPR) for soil. In order to prevent excessive metal contamination of both surface and groundwater, soil around cassava processing mills should be of concern.

Chidozie and Chukwuebuke (2022) carried out investigation on assessment on environmental degradation due to cassava processing in four locations in Nsukka Nigeria, Ogurugu Road,

Justina Eze Street, Agbami Nsukka Road and Nguru Road Nkpnnano. The result showed that the soil, wastewater and sludge from around cassava processing mill in Nsukka were characterized by high concentration of hydrogen cyanide, acidic pH and elevated heavy metal content. Pollution indices indicate that the soils in the vicinity of the cassava mills have been significantly contaminated with heavy metals, especially arsenic and chromium.

Adamu *et al.,* (2021) investigated heavy metals on cassava processing plant and the environmental effects in some sites at Lafia, Obi, Keana and Wamba, Local Government areas of Nassarawa State. The report showed that heavy metals concentrations were present in the vicinity of the cassava mill. Lead (Pb) identified in all the samples in the four Local Government were above the WHO and US standards. Nickel, Copper, Cadmium, Zinc and Manganese were also identified in traceable quantity. The mineral contents of Magnesium, Sodium and Potassium are significantly lower in all the locations due to high in Cyanide concentration. The hydrogen cyanide concentration reduces the mineral contents and increases the acidity which is detrimental to the soil. Heavy metal pollution is of very serious public health concern due to its persistence, toxicity and non-biodegradability in the environment.

Fawole and Ibikunle, (2019) did a study on assessment of effect of cassava wastewater on geotechnical properties of soil Eruwa, Ibarapa East Local Government Areas of Oyo State, Nigeria. Cassava wastewater chemical composition analysis was done as well. Chemical analysis of the effluent gives 4.5mg/L of cyanide and trace quantity of heavy metals especially zinc, lead, manganese, and copper which has highest concentration of 0.2mg/100g of the metals. Grain size analysis shows that the percentage passing No. 200BS sieve is 12.83%, 20.04% 14.83% 24.37% for samples 1.2.3 and 4 respectively. The liquid limit range between 23.18% and 28.39%, plastic limit range between 13.57% and 17.63%, plasticity index was between 9.61% and 12.63% and shrinkage limit range between 4.3% and 7.1%. the maximum dry density range between 2.01g/cm3 and 2.18g/cm3 for BS, 2.11g/cm3 and 2.32g/cm3 for WAS and 2.09g/cm3 and 2.26g/cm3 for AASHTO respectively. Also their optimum water contents ranging between

8.50% and 11,20% for BS, 6.20% and 10.22% for WAS, 7.12% and 12.33% for AASHTO, respectively while California bearing ratio (soaked) is between 51.92% and 66.77%. The result indicate that cassava wastewater affects geotechnical properties of soil especially Atterberg limits with the value of plasticity index lesser than 10% specified by Federal Ministry of Works, Nigeria (1997) thereby renders the contaminated soil material suitable for sub-grade, sub-base and base materials.

Chinyere *et al.,* (2016) carried out a study on seasonal impact of cassava mill effluents (CME) on dumping on soil physicochemical parameters and selected enzyme activities in Isuikwuato Area, Abia State, Nigeria. A total of eight (8) milling sites were sampled using standard methodologies. Sample collection from each site was from discharge spot of effluent, four and eight meters away from discharge spots along the flow route of effluents. Topsoil samples (0-30cm depth) subsoil samples (31-60cm depth) and bottom soil samples (61-90cm depth) were collected from each sampling spot while control samples were from spots within each sampling site uncontaminated with cassava mill effluent (CME). Cassava mill effluent (CME) dumping significantly increased ($P<0.05$) the temperatures of top and subsoils in both seasons. Similarly, CME impacted soil samples had higher ($P<0.05$) pH values (alkaline) than corresponding soil samples in both seasons. Both the cation exchange capacities (CEC) and exchangeable acidities (EA) of the dumpsite soil samples remained unchanged ($P>0.05$) from control soil values. There was also an increase in the test soil samples in organic carbon in both seasons. Similarly, CME dumpsite soils alkaline phosphatase and urease activities were significantly high ($P<0.05$) relative to control soil samples in contrasts to test soil acid phosphatase, lipase and dehydrogenase which were significantly ($P<0.05$) reduced. However significantly high levels of cyanide ions were obtained from cassava mill effluents dumpsite soils. This suggests a possible cause of low soil enzyme activities obtained in this work and the need to detoxify cassava mill effluents before dumping.

Eze and Onyilide, (2015) did a study on "Microbiological and Physicochemical Characteristics of Soil receiving Cassava Effluent in Elele, Rivers State, Nigeria". A total of twenty-four (24) samples were collected and analysed microbiologically for total aerobic bacterial plate count, coliform count, *Escherichia* coli count and fungal count using pour plate technique. The media used were nutrient agar, "MacConkey agar, eosin methylene blue agar, "Sabouraud dextrose agar. The T-test was used to test for significant difference. The mean total aerobic plate count of contaminated soil ranged from 5.76 ± 0.05 log10cfu/g to 5.60 ± 0.11 log10cfu/g, coliform count of contaminated soil ranged from 4.71 ± 0.07 log10cfu/g to 4.56 ± 0.08 log10cfu/g, Escherichia coli count of contaminated soil ranged from 2.56 ± 0.06 log10cfu/g to 2.39 ± 0.11 log10cfu/g, fungal count of contaminated soil ranged from 3.65 ± 0.09 log10cfu/g to 3.47 ± 0.09 log10cfu/g. The control sample has the following values for total aerobic plate count 5.84 ± 0.07 log10cfu/g, Coliform count of 4.28 ± 0.11 log10cfu/g, fungal count of 3.19 ± 0.16 log10cfu/g and Escherichia coli count of 2.14 ± 0.12 log10cfu/g. Microorganisms isolated were: Klebsiella species, Staphylococcus aureus, Escherichia coli, Pseudomonas species, Enterobacter species, Bacillus species, Proteus species, Aspergillus species, Rhizopus species and Penicillium species. Soil contaminated with cassava effluent caused some physicochemical changes in the samples collected which were: Cyanide content 3.0 mg/kg, conductivity 33.4uS/cm, phosphate 0.52 mg/kg, nitrate 0.35 mg/kg, sulphate 13.0 mg/kg, calcium 167.0 mg/kg, pH 6.3 mg/kg, magnesium 89.0 mg/kg, potassium 4.0 mg/kg and sodium 92.0 mg/kg. They suggested that cassava effluent should therefore be treated before discharge into the environment to prevent possible pollution.

Akinyele *et al., (*2019) conducted a study on impacts of heavy metals concentration on soil in auto-mechanic workshops and cassava mill in Ibadan, Nigeria. The study revealed that auto-mechanic workshops and cassava processing areas were polluted with lead, cadmium, zinc, copper, and nickel. It concluded that the level of high heavy metals has negative impacts on the

water resources and soil and the elevated level of heavy metals in the soil also poses health risk on human and the immediate environment.

Okunade and Adekalu (2014) did a research on "Characterization of Cassava-waste Effluents Contaminated Soils in Ile-Ife". Analyses were found to have great variation in terms of pH (5.5-6.2), electrical conductivity EC (0.62-0.86 mmhos/cm) and were quite high for Location IV and V when compared to that of other locations, heavy metal ions with high concentrations values were above acceptable limits (0.74, 5.66, 0.38, and 3.12 ppm for Zn, Fe, Cu and Mn respectively) apart from the environment being odorous and the soil of high coloured pigmentation. The percentage organic matter (OM) ranged from 0.33-0.45% while the organic carbon (OC) ranged from 0.24-0.32%. It is therefore recommended that cassava waste effluent, which is a major source of pollution in the cassava processing areas and with deleterious effects on the flora and fauna, be properly treated before being discharged to the adjourning environment.

Obueh and Odesiri-Eruteyan (2016) conducted a study to examine the effects of cassava processing wastes on the soil environment of a local cassava mill in Ekiadolor, Ovia Northeast Local Government Area of Edo State, Nigeria. Microbial, physicochemical and mineral compositions of fresh cassava effluent, cassava effluent from waste pit, soil around the cassava mill (soil 1) and soil samples 100 m away from the mill (the control, soil 2) were determined. Soil 2 had the highest microbial count of 3.52× 105 cfu/ml. The microbial species isolated included *Klebsiella aerogenes, Bacillus subtilis, Lactobacillus plantarum, Staphylococcus aureus, Lactobacillus delbrueckii, Fusarium solani, Aspergillus niger and Saccharomyces cerevisiae*. The occurrence of the isolated microorganisms was lowest in soil 1 with 37.5%. Fresh cassava effluent was the most acidic with pH 3.2 and cassava effluent from waste pit had the highest cyanide content of 53.52 mg/l. The mineral contents (Ca, Mg, Na and K) of fresh cassava effluent, effluent from waste pit and soil 1 were significantly lower ($p<0.05$) than the control. The heavy metals (Fe, Zn, Mn, Al, Pb and Cu) were significantly higher in soil 1 when

compared with soil 2. Nitrate and phosphate contents were high in all the samples except the control. The continuous disposal of the cassava processing waste in the soil environment around the mill and into a waste pit has reduced the soil quality leading to environmental degradation.

Odoabuchi *et al., (*2020) carried out a study on effect of cassava mill effluent on microbial properties of garden soil – Eziobodo, Imo State Nigeria. Two (2) soil samples were collected; one from a farmland polluted with cassava effluent and, another as an unpolluted sample – free from cassava effluent pollution. Results showed that unpolluted soil sample was normal, while the results of the polluted soil sample showed extinct or absence of normal garden soil microbial fauna with the presence of Staphylococcus aureus which are more harmful than good wherever they are found. However, the presumptive identification of fungi in the polluted soil sample showed presence of *Candida sp*. The results of the bacteriological count showed absence of coliform bacteria, and the triple sugar iron and various biochemical reactions showed the absence of bacteria such as *Bacillus sp* which possess nitrogenise and is able to fix atmospheric nitrogen. Such genus of bacteria could stimulate plant growth by colonizing plant tissues – external or internal and providing fixed nitrogen to the host plant. Also various species of Bacillus have the ability to increase plant nutrients in soil. Bacillus forms positive interactions (symbiotic) involving bacteria and fungi to stimulate growth in plants. Many strains are capable of inhibiting pathogenic growth or activity directly and indirectly in soil. Enlightenment campaign, detoxifying cassava effluent in accordance with regulatory Standard, appropriate method(s) of environmentally friendly disposal of both solid and cassava wastewater are recommended for safe and healthy environment.

Okoli, *et al.,(*2018). Conducted a research on long-term impact of cassava mill effluent on some chemical and biological properties of soil in Iho-Dimeze, Ikeduru in Imo State Southeastern Nigeria. Soil samples collected were analysed for chemical and biological properties and data generated were subjected to t-test analysis to assess the impact of cassava effluent on some selected soil chemical properties and biological properties. The results of the chemical properties

indicated that the polluted site had higher organic matter (mean=25.97 g kg-1) relative to the control site (mean= 15.42 g kg-1). Total nitrogen was higher in the polluted site (mean = 1.29 g kg-1) relative to the control site (mean = 0.74 g kg-1). Available phosphorus was higher in the polluted site (mean = 13.5 mg kg-1) relative to the control site (mean = 8.67 mg kg-1). Total exchangeable bases (TEB) was higher in the polluted site (mean= 6.7 cmolckg-1) relative to the control site (mean=4.05 cmolc kg-1). Effective cation exchange capacity (ECEC) was higher in the polluted site (mean = 8.25 cmolckg-1) relative to the control site (mean=4.78 cmolckg-1) whereas the pH was lower in the polluted site (mean=5.71) relative to the control site (mean=6.8). The results of the biological properties showed that the Total Fungal Count was higher in the polluted site (mean=1.12 x 105 CFU g-1) relative to the control (mean=0.33 x 105 CFUg-1) whereas Total Heterotrophic Bacterial Count was lower in the polluted site (mean=2.29 x105 CFUg-1) relative to the control (mean=5.72 x 105 CFUg-1). The t-test analysis result revealed that cassava effluent had a significant positive impact on organic matter, total nitrogen, available phosphorus, ECEC and total fungal population whereas it had a significant negative impact on soil pH and total bacterial population.

Etienajirhevwe and Agbini, (2021) did a study on effects of cassava processing mill effluents on the surrounding soil using heavy metals, conductivity and pH at Erho – Abraka in Ethiope East Local Government Area of Delta State, Nigeria. Results of analyses showed the presence of heavy metals to range as follows: Fe (72.21 – 133.01mg/kg), Cu (0.479 – 0.24mg/kg), Mn (2.06 – 3.11mg/kg), Cr (0.001 – 0.003mg/kg), Zn (1.071 – 1.730mg/kg) and Cd recorded 0.001mg/kg for all locations. The pH was found in the range of 4.00 – 4.84 while the conductivity ranges from 198.4 – 260.7μS/cm. The results were found to be higher than the control samples which suggested pollution which was attributed to the nature of activities in the study sites. The cassava mill effluents decrease soil pH while it led to higher level of electrical conductivity. The result of the analysis of heavy metals showed elevated level of heavy metals in the soil. The pH and EC of

the soil revealed that cassava mill effluent had detectable changes in the availability of the metals tested for.

Adewumi *et al.*, (2016) carried out a study to determine the impacts of indiscriminate disposal of processed cassava wastewater into the environment by determining the physicochemical characteristics of the wastewater and soil characteristics within the vicinity of starch processing industry (Matna Foods Industry) at Ogbese, Akure in Ondo State, Nigeria. The cassava wastewater quality was tested in accordance with the standard methods for the examination of water and wastewater while soil samples were analyzed using Atomic Absorption Spectrometer. The result of cassava wastewater showed that the effluent is acidic with pH of 3.8 and high conductivity of 6500μΩ. The cyanide content is also very high with 0.17mg/l as compared to 0.05mg/l recommended by WHO. The total solid, total dissolved solid and total suspended solid are also in high range of 20619, 17048 and 3571 mg/l respectively. Hardness is 812mg/l, chloride 2516mg/l and nitrate 470mg/l. The dissolved oxygen was not detected while COD and BOD were also on the high side with values of 560 and 1410mg/l respectively. The results of soil analysis indicate that the cyanide concentration is high at the surface but reduces with depth. The pH is also in acidic range. However, Magnesium, Sodium, Sulphate, Zinc, Chromium, Vanadium, Europium and Rubidium were not detected in the soil samples. The percentage of Calcium, Potassium, Copper, Manganese and Titanium were small and vary between 0.07 and 6.37ppm. Three unlined aerobic ponds provided for the treatment of cassava wastewater reduce the pollution strength of the wastewater, but the untreated wastewater interferes with the surrounding soil during conveyance to the pond as well as pond environment. It is recommended that the wastewater conveyance and ponds should be well designed to prevent interference with the surrounding soil.

Izonfuo *at el.*, (2013) did a study on soil contamination from cassava wastewater discharges in a rural community in the Niger Delta, Nigeria. It concluded from the results of this study that cassava wastewater alters the physico-chemical characteristics of soils. All the parameters

assessed had higher values in the topsoil than the subsoil downstream the processing plant except Na, Mg, exchangeable acidity and available Phosphorus, which had higher values in the subsoil than the topsoil, and for % N which remained unchanged. The results obtained downstream the processing plant were observed to be reversed upstream the plant except for pH, %N, Mg and CEC, which maintained the same trend both upstream and downstream the processing plant. The pH of the soils in the area, which was generally acidic, were slightly decreased in acidity. This may have distorted the activities of soil bacteria which can trigger off a number of reactions, which may deleteriously impact the physico-chemical characteristics of the soil. Results from correlation analyses reveal that soil pH influences the CN (r = 0.18), K (r = 0.17), Ca (r = 0.47) Mg (r = 0.13), Na (r = 0.03), P (r=0.08), N (r=0.40), organic carbon (r=0.08) and organic matter (r=0.06). Results from correlation analysis also reveal that electrical conductivity of the soil is related to the Ca (r = 0.2) and Mg (r = 0.1) levels. The trends observed suggest varying degrees of binding of CN and Na (r = 0.15); K (r = 0.19); Ca (r = 0.06) and Mg (r = 0.18), which invariably influenced electrical conductivity. Major cause for concern is the high cyanide levels in the soil, which were found to be higher than the safe levels for agriculture and other purposes. They suggest that there is a need for enlightenment on the deleterious effects of indiscriminate dumping of untreated cassava wastewater on arable lands. They also recommended that all cassava wastewaters be subjected to some form of treatment before they are discharged to surroundings where large scale cassava processing activities take place.

Izah *et al.*, (2017) conducted a study on "Assessment of Pollution Load Indices of Heavy Metals in Cassava Mill Effluents Contaminated Soil in Ndemili Umusadege, Utagba-Uno communities in Ndokwa-West Local Government Area of Delta State". Secondary data from cassava mill effluents soil were used for the study. The data were classified based on seasons. The pollution load was calculated following standard protocol. Nine pollution indices were considered including Contamination factor (CF), Degree of contamination (CD), Pollution load index (PLI), Pollution index (PI), Sum of pollution index (SPI), Pollution index/ Contamination Index

(PI/CI), Metal pollution Index (MPI), Average Pollution Index (API) and Nemerow integrated pollution index (NIPI). In few instance that some heavy metals were not detected, 50% of mean detected individual metals were considered for the location that the metals were not detected. Geometric (BGM) and median mean (BMM) were considered for the background scenarios except for API and PI/CI in which median mean was used. The pollution load resulting from these heavy metals viz: Fe, Cr, Zn, Cu, Co, Ni, Mn, Pb and Cd revealed that CF and CD had low to moderate contamination level in both seasons apart from Pb that had considerable pollution in one of the locations for wet season, PLI were within no pollution to moderate pollution, PI were also within no pollution to low pollution level and NIPI were within warning line of pollution to low level of pollution for dry season ,and warning line of pollution to high pollution in wet season. MPI, PI/CI and API showed slight pollution. The findings of this study also showed that cassava processing by smallholder in rural communities in the Niger Delta is slightly contributing to heavy metals pollution is receiving soil which varies according to seasons. Furthermore, age and heavy metal content in the cassava tuber and quantity of cassava processed in each mill and other anthropogenic activities could account for difference in pollution among the various locations, while runoff resulting from rainfall could account for the seasonal influence.

Aweto, (2013), carried out a research to "Evaluate the Impacts of Cassava Mill Effluent (CME) on Groundwater around Eku in Delta State". A 2D electrical resistivity survey, geochemical analysis and groundwater modelling was adopted for this study. The zones impacted by CME imaged by the inverted resistivity structure were distinguished by low resistivity ranging between 0.46 – 21.05 Ωm. Geochemical analysis of CME indicated high concentrations of Total Dissolved Solids (TDS), Electrical Conductivity (EC), CN, and heavy metal components and have the capability to contaminate surrounding groundwater. The groundwater model showed flow in the Southeast – Northwest (SE – NW) direction with a velocity of 54.24 m/year. The pH value, the concentration of CN, TDS, EC, and heavy metals in groundwater samples, when

compared with the WHO drinking standard, revealed that groundwater in only one hand dug well about 20 m away from a cassava mill indicated a significant degree of contamination. A pattern of decreasing CN concentration with distance from the mill was observed in groundwater; areas with CN concentration greater than 0.2 mg/l after 1 year was 30 m away from the cassava mill but extended to about 75 m after 5 years.

2.5.4 Review of Related research Works from Crude Oil Spill Sites

Nnamdi *et al.,* (2021) carried out research on empirical characterization of heavy metals in crude oil spill sites in Emohua Local Government Area in River State. Surface and subsurface soil, groundwater and surface water samples were analyzed in three oil spill sited in the study area, the result shown that the concentration of lead (Pb) in site A in surface soil was higher than the permissible limit set by Department of Petroleum Resources (DPR) 530mg/kg) and United State Environmental Agency (USEPA 400mg/kg) but site B and C concentration level Pb were below the limit stipulated by DPR and USEPA. The concentration of most of the heavy metals in surface soil, subsurface soil and groundwater were within the acceptable limit of DPR.

Olu *et al.,* (2019) investigated the concentrate of heavy metals (Cd, Pb, Fe, Al and V) in surface water and sediment and their sediment enrichment factor were determined in Soku oil Field Area of Rivers State, Nigeria. All recorded values were above permissible limits for both water and sediment with the exception of Al in water. Heavy metals concentrations were generally high in the dry season depicting heavy metal pollution and suggestive of high dilutions by heavy rain fall in the wet season. Higher concentrations of heavy metals in the sediments against the surface water were indicative of overtime pollution of the river and confirmation of the sediment as a sink for heavy metals. Enrichment factors calculated showed a high Cd and Pb pollution of the environment which is a potential threat to aquatic and human life. Presence of soluble hydroxides of Al act as respiratory toxicant for fish.

Extensive investigation of oil contamination in Ogoni land River State was carried out by the United Nations Environment Programme (UNEP) 2010 and the assessment was done at the

request of the Nigerian government. During the assessment, drinking water samples were taken in wells and sediments and surface water samples were collected from streams, ponds and wetlands in and around Ogoniland from April to November. The study shown extensive pollution of Rivers, Creeks and groundwater. the oil spill also causes extensive damage to mangroves. (United Nations Environment Programme 2011).

Ogwugwa *et al.*, (2018) carried out study on Ogoni land in five communities: Akpajo - Eleme, Okuluebi- Eleme, Kites, Tai, Nwikara – Agu and Gbe in Goni land to investigate heavy metals, indices and its environmental effects. The analysis revealed that three major heavy metals (Arsenic, Barium and Cobalt) were found in five sediments samples collected from these communities mentioned above. The concentration of heavy metals obtained from the samples exceeded the tolerable limits of Standard Organization of Nigeria (SON 2007). The source of these heavy metals in the sediments could be attributed to petroleum hydrocarbon in Ogoniland.

Amadi *et al.*, (2016) investigated physioco- chemical and bacteriological parameters of surface soil and water resources in Eastern Niger Delta, in Port-Harcourt, Aba and Owerri. The results show that heavy metal pollution in the soil and water range from slightly polluted to very highly polluted. The pH of the groundwater falls below the acceptable limit of 6.50 – 8.50 stipulated by Nigeria Standard for drinking water quality (NSDWQ, 2007). The low pH, wide range in the concentration of Electrical conductivity (EC), Total Dissolved Solid (TDS), Chloride, E- Coli, Total Coliform and heavy metals in the soil and water resources in the area are attributed to oil spillage, gas flaring and industrial effluent.

Otele and Ogidi, (2019), investigated crude oil spillage and its effects on soil degradation in Libeled community Ogbia Local Government Area of Bayelsa State,.The results showed that the generation of organic nutrient required by plant are rule out which render the soil unproductive by destroying the soil fertility not only quality of the soil also plant are affected and living beings that rely on these plants resulting from direct release on land and through percolation and run-off

into ground and surface water. Findings also reveal that there was high level of contamination of total petroleum hydrocarbon.

Nwankwoala *et al.*, (2017), carried out study on the impact of artisanal refining activities on soil and water quality in part of Okrika and Ogu - Bolo area of River State. The results of the study showed that water within the study area is not suitable for drinking as well as for other domestic purposes due to high concentration of Fe and Zn. The study also reveals that there are negative effects of bunkering and artisan refining on the aquifer, and the contaminants are flowing at a very faster rate into the aquifer as a result of the elevation. The physicochemical analysis on soil and water revealed poor water and soil. Also the soil samples recorded high levels of crude content from 1meter with concentration reducing with depth up to 3 meters. The following recommendations were made: Water quality assessment should be carried out regularly to determine any future pollution of the water due to the activities in the area, appropriate water treatment of borehole should be done and artisanal refining activities in the area should be discouraged to avoid further contamination in the area.

Ikezam *et al.*, (2021). Carried out research on assessment of the physicochemical parameters and heavy metals concentration across artisanal refining sites in the core Niger Delta Region (Bayelsa Rivers and Delta. Soil samples were collected from both the artisanal refining sites and control sites. It was revealed that soil quality for both the control sites and artisanal refining sites fell below the WHO permissible limits, however, the soil from control sites were less polluted than soils from artisanal refining sites. Also, Rivers state had the most polluted soil followed by Bayelsa and Delta States. The one sample t test shown that, the pollutants detected in soil at artisanal refining sites were statistically different from the WHO permissible limits at $p<0.05$. Similarly, the pollutants detected at the artisanal refining sites were significantly higher than the one found in the control sites at $p<0.05$. The detected soil pollutants are detrimental to agriculture, and man. The study thus recommends environmental remediation and legalization on improvement in artisanal refining process in the Region.

John *et al.,* (2016). Carried out research on the effects of heavy metal contamination on soil by non-conventional refining plants in Bodo community in the Southern part of Gokana Local Government Area of Rivers State, Southern Nigeria. Two soil samples were collected at 18 m intervals between Plants A and B and at 24 m intervals between Plant B and C. Control sample was collected 2 km away from unimpacted soil. The result of the analysis showed that polynuclear aromatic hydrocarbon (PAH) recorded maximum concentration of 6899.4942 ppm at station C at the depth of 0-15 cm. Furthermore, the concentration of heavy metals investigated are below critical levels as proposed by FEPA (1991).

Tunde and Igiogbe, (2021), investigated the impact of locally refined petroleum products on the water quality of Ekehuan River in Edo State, Nigeria to determine the water quality status, using the limits set by Nigerian standard and WHO guidelines for drinking water quality. Water samples were collected from three stations—station I was located in the oil-impacted Ekehuan River, which is a tributary of Ovia River, while stations II and III were located along the stretch of Ovia River at Gelegele community as control stations. The water samples were analyzed for water and air temperatures, pH, conductivity, TDS, DO, BOD, COD, sodium, calcium, potassium, chloride, some selected heavy metals and total hydrocarbon concentration (THC). At the oil-impacted station I, DO and water temperature were significantly lower, while THC was significantly higher ($p < 0.05$) compared to the other stations. Statistically, the heavy metals and other parameters investigated in the water did not show any significant difference ($p > 0.05$) across the stations. However, the levels of cadmium, nickel and lead at all stations were much higher than the Nigerian standard and WHO guidelines for drinking water quality. These findings are indicative that the water quality at station I is compromised and not fit for consumption.

Aigberua *et al.,* (2017) did a study on "Assessment of Some Selected Heavy Metals and their Pollution Indices in an Oil Spill Contaminated Soil in Rumuolukwu Community, Eneka, Obio/Akpor Local Government Area, Rivers State, Niger Delta region of Nigeria". This study

investigated concentrations of heavy metals (Ni, Pb, Cr and V) and assessed their pollution risk in the environment using contaminant factor ecological risk factor. Ex-situ analysis was carried out for 6 months i.e. 3 months wet and dry seasons each. The samples were collected at different depth using soil auger. The samples were processed and analyzed using flame atomic absorption spectrophotometer. Results ranged from 0.16 – 3.02 mg/kg Ni, 0.20 – 8.14 mg/kg Pb, 0.18 – 7.88 mg/kg Cr and 0.01 – 0.20 mg/kg V for oil spill contaminated soil. The concentration of heavy metals (Ni, Pb, Cr and V) was higher than the control samples, but below Department of Petroleum Resource Nigeria Limit. Ecological risk factor showed that the contamination level is low at various depth, however instance of moderately and considerable contamination was observed at 45 – 60 cm and 15 – 30 cm depth for Pb during the wet season. Also, contamination factor showed moderate contamination. Although in few instances Pb and Ni contamination factors were very high. The concentration in oil spill environment is higher during the wet season compared to dry season. Heavy metal mean distribution was in the order: Pb>Cr>Ni>V. A decreasing degree of contamination was observed during the dry season. They recommended that concerned stakeholders should routine monitoring and checks on their numerous pipelines right of way to serve as a stop gap measure for repetitive future occurrence.

Ghorban*i et al.*, (2020) did a study on "Assessment of the Potential Hazard to Human Health from Exposure to Heavy Metals in Surface Soil in Iran, Khuzestan Province, Ahvaz Oil Field". Sixty-six (66) soil samples were collected, mean levels of As, Cd, Co, Cr, Cu, Ni, Pb, V, and Zn were 5.9, 0.4, 7.1, 36.5, 41.2, 39.8, 67.4, 31.5, and 77.6 mg/kg, respectively. Contents of all studied heavy metals, with the exception of Co, Cr, and V, were several times higher than that of baselines. Correlation coefficients and principal component analysis (PCA) identified two main groups as sources of heavy metals in the surface soil of Ahvaz Oil-Field. Metals such as Co, Cr, and V were observed to originate from natural sources and As, Cd, Cu, Ni, Pb, and Zn originated from anthropogenic sources such as petroleum leakage and the pollution caused by drilling mud from oil wells. Pb and Zn were of significantly high mean enrichment value, and Co, Cu, Cd,

and As had high enrichment in surface soil. Pb, Cr, V, Zn, Co, Cu, Ni, and As had a low potential ecological risk (PER) whereas Cd had a moderate (PER). The risk of carcinogenic and non-carcinogenic diseases was detected to be higher in children than in adults. The carcinogenic risk (Cr) calculation was more than 1 × 10-6 for children and adults. Additionally, the CR of Cr for both children and adults indicated risk under control conditions.

Oyeleke and Okpaeaocha (2016) carried out a study on "Assessment of Some Heavy Metals in Groundwater in the Vicinity of Nigrian National Petroleum Corporation (NNPC) Oil Depot along Abeokuta Road, Ibadan, Nigeria". The study reveals high concentration of lead (Pb) in all the groundwater sample which were above World Health Organization (WHO) and Nigeria Industrial Standard (NIS) tolerable limits for drinking water and other heavy metals investigated copper (Cu), Cadmium (Cd), chromium (Cr) and zinc (Zn) were far below the standards set by WHO and NIS. This shows that groundwater such as hand dug wells which are only sources of water supplies are definitely not safe for agricultural purposes, and domestic uses or human consumption for the people living in the vicinity of the oil depot. This suggest that the sources of Pb pollution could be attributed from the anthropogenic activities such as loading and offloading of petroleum products. They recommended that prompt clean-up and remediation such as phyto-remediation should be carried out by appropriate environmental managements for proper uptake of lead Pbd metal which has grossly contaminated the groundwater and the anthropogenic activities around the oil depot should be controlled by relevant authorities to minimize the risks associated with the released of hazardous elements through oil spilling and leakages as well as washing of storage tanks in the area.

Umunnakwe and Aharanwa (2016) carried out research on the impact of oil spillage on the soil quality of Idu-Ekpeye Community in Ahoada west Local Government Area of River State. The results of questionnaires showed that the spill affected the soil and drop in plant yield compelling the local farmers to abandon their occupation to seek other occupations. The activities affected the health of the people as 42.10% of respondents reported fever, 21.33% suffered from various

respiratory ailments such as bronchitis. Asthma. Cough and 21.05% suffered from various gastrointestinal disorder. The results from analyzed parameters showed that Ph mean values of 6.15 at the spilled site were acidic which affected plant yield and nutrient availability. The results further indicated that conductivity, iron, cadmium, THC, TOC, oil grease were above the standard limits. The analysis showed that the level of the physicochemical variables of the soil at the spilled site cannot sustain plant yield and agricultural practice.

Wang *et al., (*2013) carried out a study on effects of crude oil contamination during oil exploration on soil physical and chemical properties in marshes of the Momoge National Nature Reserve in Jilin Province, China. The concentration of total petroleum hydrocarbon in the marsh soil near the oil wells is significantly higher than those in the adjacent control marsh. Soil water contents in oil contaminated marshes are negatively correlated with soil temperature and are significantly lower than those in the control site, especially in fall. Crude oil contamination significantly increases the soil PH up to 8.0 and reduces available phosphorous concentrations in the soil. The concentration of total organic carbon is significantly different among sampling sites. Therefore, crude oil contamination could potentially be alkalinize marsh soils, adversely affect soil fertility and physical and chemical properties and cause deterioration of the marshes in the study area. Suggestion was made that phyto-remediation *calamagrostis angustifolia* has the potential to simultaneously restore and remediate the petroleum hydrocarbon contaminated wetlands, so developing an effective restoration program in the Momoge wetlands is necessary.

Yang and Gang (2018) investigated the effects of oil pollution on water soil moisture characteristics in Northern Shaaanxi province in Yanan city in China, loessial soil in Northern Shaanxi was used as the research object to determine wettability, capillary water rise and situarated hydraulic conductivity of soils under five different pollution gradients (0%, 0,5%, 1%, 2% and 4%). The results showed that when the soil is polluted by oil, the wettability of the soil will change, resulting in a certain degree of water repellence. In the same rising period uncontaminated soil capillary water rose significantly higher than the oil contaminated soil, and

the higher degree of pollution, the smaller the capillary water rises. Oil pollution made soil saturated hydraulic conductivity decrease with the increase of pollution concentration, although saturated hydraulic conductivity decreases, but for loessial it was within an order of magnitude.

Olobaniyi and Omo-Irabor (2016) did a study on effects of crude oil production activities on the chemistry of soil and groundwater in oil production facilities located in the following communities Uzere, Igbide, Koko, Ologbo, Ozoro, Sepele and Afiesere within Western Niger Delta. Sample collected were analyzed for pH, Total Organic Carbon (TOC), Total Petroleum Hydrocarbon (TPH), Vanadium (V), Nickel (Ni) and Iron (Fe) by standards procedures. The results indicates a general conformity of groundwater physic- chemistry to international standards for chemical portability, the results of the soil sample showed in some cases elevated values of TPH (mean; 266.07mg/kg) and Ni (mean: 8.89 mg/kg) which suggest a negative impact on the soil in the vicinity of oil production facilities, the occurrence of high concentration of TPH in soil could lead to death of plant s as a result of oxygen deficiency. Ni is slightly enhanced in comparison with the control site while Fe has a massively greater value in the eight sites as a result of the ferruginous nature of the soil in the study area. Vi was below detection limit for both soil and water samples. Ground water indicated low contamination of hydrocarbon from measured dissolved oxygen (DO) values.

Onwugbuta *et al., (*2022) carried out a study to evaluate the concentration of heavy metals in soils and *Manihot esculenta* in some selected communities in Niger Delta: Umuechem land in Etche Local Government Area, Ebocha in Ogba/Egbema/Ndoni Local Government Area and a control site Ndashi in Etche Local Government Area in Rivers State respectively and Ofuoma, Ughelli North Local Government Area of Delta State. The three communities under study have petroleum flow stations apart from Ndashi community which serves as control site has none. Heavy metals were analyzed following standard methods using Perkin-Elmer model 403 Atomic Absorption Spectrophotometer. Data revealed that the levels of heavy metals in soil samples from the selected stations vary significantly ($P<0.05$). Heavy metals such as Cd were above

permissible limit (WHO), Cu, Ni and Pb were all below detectable limit, while Cr was below detectable limit in the dry season and below permissible limit in the wet season. The study further revealed that heavy metals such as Cd, Cu, Ni and Pb in *Manihot esculenta* were all above permissible limit (WHO) while Cr was above permissible limit in all stations except in the control station (Ndashi) in the wet season and below detectable limit in the dry season. This study established that there should be constant monitoring of anthropogenic activities in the study area.

Kieri *et al., (*2021) carried out a study to determine heavy metals pollution in sediment of Silver River along the northern axis through Fonibiri, Opuama and ended at Akamabobou in the southern axis in Southern Ijaw Local Government Area of Bayelsa State, Atomic Absorption Spectrophotometer was used to ascertain the concentration level. The result indicated the presence of heavy metals at different concentrations. The concentrations of the heavy metals showed that Fe>Mn>Zn>Cu>Ni>Cr>Pb>Cd>Hg. The mean concentrations of the measured metals in mg/Kg were Cd (2.638±0.900), Pb (6.004±1.368), Cr (6.228±1.752), Ni (6.570±1.102), Cu (8.754±2.386), Zn (15.320±3.486), Fe (219.593±22.641), Mn (54.172±51.645) and Hg (0.006±0.005). All the concentrations of the heavy metals examined when compared with those of average value of heavy metals in shale showed that all the metals were lower than their corresponding world average values except Cd. Contamination factor index analysis of the sediment heavy metals burden showed that the sediment was polluted with Cd, contaminated with Cu, Zn and Cr and uncontaminated with Pb, Fe, Mn, Hg, and Ni. The obtained values are yet to implicate anthropogenic input sources of heavy metals into the river. They suggested that frantic effort should be put in place to curb input sources into the river.

Udoetok *et al., (*2011) carried out a study on associated petroleum hydrocarbons and heavy metals of an oil spilled site in the Niger Delta, Nigeria. Soil samples were collected from an oil polluted site in the Idu – Ekpeye in Ahoada West Local Government Area of Rivers State, southern region of Nigeria, and were analyzed for petroleum hydrocarbons and heavy metals,

which may have been introduced to the soil as a result of the oil spillage that was incidence at the site. The total extractable hydrocarbon content (THC) of 1.13×105±2.91×104 mg/kg of the affected soil revealed a high level of petroleum hydrocarbon contamination that far exceeds compliance limits. The gas chromatographic analyses conducted on the samples showed significant contamination in the n-C12 - n-C17 range, especially the n-C13 and n-C17 fractions, and pristane being more abundant than phytane. It also showed a significant concentration of the polycyclic aromatic hydrocarbons (PAHs) with naphthalene which may actually be oxidized before many saturates which are the most prone to biodegradation and attenuation, while indeno 1, 2, 3 cd pyrene was the most abundant. The results also depicted a substantial concentration of the benzene, toluene, ethyl benzene and xylene (BTEX) fractions with 1, 3, dichlorobenzene as the most abundant fraction while o-xylene had the least concentration. Heavy metals were detected in varying concentration in polluted soils. Zinc had the highest concentration of 9.84 ± 0.93mg/kg while Arsenic had the least concentration of 0.12±0.04mg/kg. These results suggest that at the time of sample collection, the spilled oil was still fresh on site. That pristane was more abundant than phytane inferred an oxic depositional environment of a probable non-waxy, marine derived organic matter and a phytoplankton input for the spilled oil.

2.6 Effects of Heavy Metals on Surface, Subsurface Water and Soil

Chinemelu and Okeke (2019) carried out research on "Evaluation of Heavy Metal Pollution in Soils of Warri and Environs, Southwestern Nigeria, Using Contamination Indexes". The mean concentrations of heavy metals obtained in all the samples in the study area showed an increasing order of As>Cd>Pb>Ni>Cr>Zn>Cu>Fe. Evaluation of the extent of pollution in all soil samples using calculated geoaccumulation index, contamination factor and enrichment factor values, calculated from the observed concentrations of heavy metals showed that the soils of the study area were unpolluted. Hierarchical cluster analysis (HCA) was employed in order to further investigate the sources of heavy metal at all sampled sites in the study area, and it revealed that the heavy metals in all the sampled media had a common origin and were

associated with anthropogenic activities in the study area. Generally, the present study showed that there was no substantial accumulation of the heavy metals in soils of Warri and environs. The results of this study show that the surface soils in Warri and environs are affected by anthropogenic activities such as the use of fertilizers, atmospheric depositions from gas flaring, etc., but their concentrations do not pose a significant environmental threat.

Chinemelu and Nwankwor (2019) did investigation on seasonal variations of heavy metals in groundwater of Warri and environs, Southwestern Nigeria. The concentrations of a suite of heavy metal in the groundwater of Warri and environs were determined using Atomic Absorption Spectrophotometer in order to assess its suitability for drinking. Forty (40) groundwater samples were randomly collected in both rainy and dry seasons. The results showed that the mean concentrations of heavy metals (mg/kg) obtained in all the groundwater samples during the rainy season were in the order: As (0.0034) <Ni (0.0035) <Cd (0.0038) <Pb (0.0047) <Cu (0.0054) <Cr (0.0056) <Fe (0.0101) <Zn (0.0116). The mean heavy metal concentrations reported for the dry season were in the order: Cr (0.0056) <As (0.0084) <Cd (0.0115) <Ni (0.0126) <Cu (0.0162) <Fe (0.0195) <Pb (0.0200) <Zn (0.0240). The result showed that the mean concentrations of heavy metals determined during the dry season were slightly higher than those obtained during the rainy season. The result shows that the mean concentrations of Pb, Cd, and Cr in some groundwater samples were above the permissible limit of international standards for drinking water. Pearson's correlation of heavy metals in the groundwater samples showed no significant correlation was observed among all the metals in groundwater in the dry season, whereas that of the rainy season showed strong relationships among metals suggesting a similar distribution pattern and a combination of natural and anthropogenic sources.

Aghoghovwia *et al.,* (2018) carried out investigation on level of heavy metals in surface water quality off lower Nun River at Gbarantoru and Tombia communities in Yenagoa Local Government Area of Bayelsa State. The results showed that the heavy metal concentrations were within the standard for drinking water except for cadmium and lead which exceeded as specified

by World Health Organization (WHO), European Union and Standard Organization of Nigeria (SON). The bioaccumulation of Cadmium and Lead in the body of aquatic organisms such as fisheries over a long period of time, depicts possible health risk to individuals that consume fisheries from the area and drink the water.

David and Minati (2018) studied the level and health risk assessment of heavy metals in soil, water and vegetable of Dares Salaam, Tanzania. The results showed that Pb and Fe contents in irrigation water were higher than the Agricultural Water Standards in soil. All the heavy metals levels were above the set standards for Agricultural soil, while in vegetables the mean concentrations of Zn and Pb were higher than the set standard of WHO/FAO.

Mash *et al.*, (2017) carried out bacteriological study of the surface water of Ikoroma, Tombia in Nun River and Swali in Ikole River in Bayelsa State. The report showed that the Total Cultivable heterotrophic Bacterial (TCHB), Total Coliforms (TC) and Fecal Coliform (FC) were above the permissible limit of safe water within the Yenagoa Metropolis contains high microbial load which is not safe for consumption. All the heavy metals iron (Fe), Lead (Pb), Chromium (Cr) Nickel (Ni) and Manganese were within the acceptable limit set by WHO, Total Hydrocarbon (THC), Turbidity and Biological Oxygen Demand (BOD) were higher than the acceptable limit of drinking water.

Saheed *et al*., (2021) conducted study on heavy metals contamination and associated risks in shallow groundwater sources in part of Ibadan metropolis, Southwest Nigeria, in three different residential areas. The heavy metals analyzed were Lead (Pb), Cadmium (Cd), Zinc (Zn), Iron (Fe), and Manganese (Mn). The concentration level of Pb, Cd, Fe, and Zn for all the groundwater samples were above the recommended standard, however, the levels of Mn and Total Dissolve Solid (TDS) are within the safe limits set by World Health Organization (2015). The results of contamination factor (CF) showed that groundwater samples from all the investigated residential areas could be classified between not contaminated (< 1) to moderately contaminated ($1 \leq CF < 3$). However, two water samples were considerably contaminated. Integrated pollution indices

indicated that groundwater within the study area lie in the range of “unpolluted” to “slightly polluted” class. The results of Enrichment Factor (EF) and Quantification of Contamination (QoC) of analyzed metals in water samples indicate geogenic and anthropogenic inputs. The contribution of study of studied metals to the incidence of posing non-carcinogenic health risk through the oral intake route was identified in the three residential areas with the order of trace metals impacts Cd > Pb > Zn > Fe > Mn. The hazard index as a result ingested heavy metals for the three population classes surpasses the acceptable range in the order > 1 for Pb and Cd in adult, child, and infant, representing a possible health risk. Cadmium impacted more on the evaluation of cancer risk (CR) than (Pb) for the three categories of peoples in the studied residential locations.

Anyanwu and Onyele, (2018) carried out study on the occurrence and concentrations of heavy metals in a rural spring (Iyinna Spring) in South- Eastern Nigeria, at Umuariagha Community Ikwuano Local Government Area Area of Abia State. Eight (8) heavy metals were assessed (Mn, Cu, Pb, Fe, Zn, Cd, Cr and Ni) to determine the suitability for human consumption. The analysis showed that manganese, chromium, lead, iron and cadmium exceeded tolerable limits of Nigeria Standard for Drinking (SON, 2007) WHO (2017) in various percentages of the samples and could basically be attributed to geogenic source exacerbated by seasonal and anthropogenic influences. The values of lead, iron and cadmium were higher and pose serious health risk to the consumers of the spring water over time. Rural springs hitherto considered safe due to little or no anthropogenic influences have been found to be unsafe due to geogenic contamination. The spring is therefore not safe for drinking but can be used for other domestic purposes.

Adegoke e*t al.,* (2009) carried out research on evaluation of heavy metals status of water and soil at Isogloss in warm Spring, Ondo State, Nigeria. The heavy metals determined were Cu, Cd, Zn, As and Cr with the results reealing that the mean concentration level of heavy metals in soil and water resources in the study area were within the standard values obtained in Nigeria and some

developed countries. This indicates low contamination of soil and water in the study area from anthropogenic activities.

Saeed *et al*., (2014) investigated heavy metal concentration in water and sediment in Tembi River, Iran. The results revealed that water and sediments are contaminated by heavy metals, therefore it is used for fishing and other purposes.

Aliyu *et al., (2015*) carried out study on heavy metal pollution on surface water sources in Kaduna Metropolis. The study revealed that the concentration of most heavy metals was higher than the World Health Organization (WHO) standard (1997). They concluded that the water from the River Kaduna along Kakuri-Makera drain is polluted with heavy metals and may cause serious ecological and health hazards. Through bioaccumulation in fish and other agricultural produce which are consumed by most of the people of the metropolis. The river pollution was likely as a result of urban, municipal, industrial effluents and other anthropogenic sources.

Imasuen and Egai, (2012) investigated the concentration and environmental implication of heavy metals in surface water such as Cu^{2+}, Fe, $Pb^{2+,}$ Ni^{2+}, Cd^{6+}, Zn^{2+}, Mn^{2+} and V^{2+} in Aguobiri community Southern Ijaw Local Government Area Bayelsa State, with the aim of determine the environmental status and suitability of the water in the area for drinking and domestic purposes. The result of the analysis of the samples was compared with standard stipulated by WHO (2006), SON (2007), FEPA (1991) and DPR (1991) and it showed that Lead (Pb^{2+}), Iron (Fe^{2+}), Nickel (Ni^{2+}), Cadmium (Cd^{2+}) and Total Hydrocarbon Content (TPC) were above the permissible limit. It concluded that the high concentration of heavy metal and THC content was as a result of artisanal refineries.

Obua *et al., (*2019) carried out research on "Geoenvironmental Implications of Heavy Metals Distribution in Parts of Lagos Lagoon, Southern Nigeria". The study investigated the level of heavy metals in surface waters and sediments in the Lagos Lagoon, Lagos State. Water and sediment samples were collected in sterile plastic containers respectively from eight (8) sampling locations inclusive of a control. The samples were treated and digested and analyzed using the

Atomic Absorption Spectrophotometer (AAS). The t-test, single factor ANOVA, post-hoc means plot and Principal Components Analysis (PCA) were used to analyze data. Cu, Zn, Cd, Mn, Ni,Cr and Fe varied as follows: 1.97-5.60 (3.07) mg/L in water columns and 9.9-527.35 ppm in sediments, 1.58 – 6.99 (3.03) mg/L in water columns and 37.69 – 875.64 ppm, 0.18–0.93 (0.62) mg/L and 0.37–11.46 ppm, 4.48–11.28 (8.51) mg/L and 184.95–547.45 ppm, 9.83-20.50 (14.54) mg/L and 46.30–551.00 ppm, 4.93–44.70 (23.39) mg/L and 105.17-227.77 ppm and 31.60–86.17 (1.08) mg/L and 454.27-768.23 ppm respectively. The pH, electrical conductivity, water temperature, salinity, total dissolved solids and dissolved oxygen varied as follows:7.85- 8.39 (8.05), 15.60-28.20 (21.89µS/cm) and 28.00-30.00 (29.130C), 8.10-14.50 (11.280/00), 9.36 – 16.92 (13.49mg/L) and 4.40 – 7.00 (5.78mg/L) in water samples, respectively. The results were compared with WHO (2003) and NESRA (2011s) standards and were found to be above the limits. Results indicate lithological origin for the heavy metal presence and possible transportation of heavy metal species from the industries and domestic wastes and deposition in sediments of the proximal Lagos Lagoon.

Uzoekwe and Aigberua, (2019) did a study on heavy metal distribution and assessment of ecological risk in surface waters and sediment within the flow stations in Kolo Creek in Ogbia Local Government Area, Nigeria. Water and sediment sample were randomly collected from seven spatially varying locations A to G, across the stretch of water course. Locations A and G represented 500 metres up and downstream of crude oil flow station at Imiringi community respectively, while Points B to F reflected samples around the midstream locations where oil activities are most concentrated. Each field location was sampled in triplicate to ensure data repeatability. Samples were collected in the dry season month of November 2017. The heavy metal loading status of Kolo creek surface water and sediments were determined using the atomic absorption spectrophotometer – GBC Avanta PM A6600 model. Surface water metals ranged from <0.001 to 0.007 mg/l, <0.001 to 0.023 mg/l and 0.807 to 3.450 mg/l for lead (Pb), nickel (Ni) and iron (Fe) respectively, while cadmium (Cd) was reportedly below measurable

detection limit. Apart from iron, with concentrations exceeding DPR limit of 1.0 mg/l at locations B, C, F and G, all other metals were within regulatory limit. Sediment metal concentrations ranged from 0.120 to 0.480 mg/kg, 1.180 to 7.303 mg/kg, 3.150 to 8.803 mg/kg and 1,619.55 to 4,183.60 mg/kg for Cd, Pb, Ni and Fe respectively. All sediment metals were reportedly within DPR limit of 0.8, 85 and 35 mg/kg for Cd, Pb and Ni respectively. Heavy metal pollution indices such as degree of contamination (CD), pollution load index (PLI) and index of geoaccumulation (Igeo) were used to further evaluate the potential risk of residual metals. Test metals were qualified as tending from non-contamination to moderate/considerable contamination. Sample locations of potential cadmium and lead hazard were identified as locations A and B, for water and sediment respectively. Consequently, the results of positive contamination factor and negative geoaccumulation index in surface waters and sediment proved that lead and cadmium micro pollutants are from anthropogenic sources.

Mohammed and Olowolafe, (2020) assessed the distribution of heavy metals, soil enzymes, and evaluate the functional relationship in irrigated land around Getsi river alley which passed through Bompai Industrial Area, Kano, Northwestern Nigeria. The study area was divided into two locations as contaminated and control; each location one square kilometre was demarcated and divided into 25 small square (grid). A Sample was collected in each grid from 0 – 15 cm depth using point composite sampling technique. The properties investigated were heavy metals, enzymes, pH, and soil temperature. The results were subjected to statistical analyses to undertake one-way analysis of variance, and a t-test of means at α value of <0.05, also correlation, and regression at a $P<0.05$ significant level. The results revealed that there is a gradual accumulation of all heavy metals and the concentration is higher in the contaminated than control locations. The soil is potentially polluted with Cd and is clean from Cr, Fe, Mn, Zn, Pb, and Cu. High values of heavy metals were discovered in the dry season than the wet season due to rainfall which enhanced the dissolution, leaching, and runoff of heavy metals which is capable of removing the metals from the subsurface. High pH and temperature in the contaminated location

influenced the toxicity and microbial activity respectively, resulting in high enzymatic activity in the contaminated location. Favorable environmental conditions in the wet season led to the higher activity of in the enzymes than the dry season. The findings also revealed that phosphatase and urease were negatively correlated with Cd and Ni. Inversely, dehydrogenase was negatively correlated with Ni and Zn. It was concluded that the determination of heavy metals and enzymes reflects the microbial activities in soils and is considered as soil quality indicators.

Agbalagba *et al., (*2011) carried out a study on physico-chemical properties and hydrochemical processes of groundwater from commercial boreholes in Yenagoa, Bayelsa State, Nigeria. Eight (8) commercial borehole water samples were analyzed for various physico-chemical parameters using standard methods. The results obtained showed that the water samples quality compared favorably with WHO (1998) standard for drinking water. Although the values for pH (5.20±0.14, 6.10±0.10, 6.20±0.10, 6.20±0.20 in well 2, 5, 6, and 7 respectively), electrical conductivity (EC) of 520.00±5.50 mS/cm in well 7, biochemical oxygen demand (BOD) of 9.55±0.26 mg/L in well 3, Ca (9.25±0.10, 8.25±0.03 and 7.90±0.10 mg/L in wells 2, 3, and 7 respectively) and all values obtained for Fe exceeded the WHO permissible limits for safe drinking water. The concentration of heavy metals; lead, copper, chromium, cadmium and arsenic (major sources of ground water pollution) were below detectable limit except at wells 5, 6, and 7 where lead values of 0.03±0.001, 0.008±0.00, 0.04±0.00 mg/L respectively were obtained. The hydrochemical analysis shows that ionic exchange and silicate weathering were the major prevailing hydrochemical processes in the groundwater. All the results obtained were however not significantly different from other reported values within the Niger Delta region. The higher concentrations of some of the parameters (pH, Ec, BOD, Fe^{2+}, Ca^{2+}) and the present of lead in some samples, are indications of some levels of pollution in the boreholes/ground water. The authour recommended that appropriate treatment measures should be taken before the consumption of these waters by the populace to avoid long-term accumulative health problems.

Ogunlowo and Sakwe (2013) conducted a study to evaluate the levels of lead and iron in the domestic water supply system at Ekeki Housing Estate Yenegoa Local Government and Otuoke Community in Ogbia local government in Bayelsa State, Nigeria. "AAS version 5.0 Model was used to analyze Iron and Lead after acid digestion. Results obtained were compared with WHO (2016) standard, and statistical inferences were drawn using ANOVA and spearman correlation matrix. All water sampled presented values of lead between (0.02-0.64) mg/L expect for location I3 and I4, which conformed to 0.01mg/L, while Iron values ranged from (0.01-5.3) mg/L. Most of the results obtained exceeded the WHO (2016) standard of 0.01 mg/L for lead and 0.03mg/L respectively. The research findings had shown that most treatment processes adopted were not suitable for treatment of the contaminants, hence the need to review treatment processes, distribution and monitoring of the source.

Amolo *et al., (*2022) carried out a study on "Assessment of Heavy Metals Concentration in Surface Water from Kolo Creek along Ogbia Axis, Bayelsa State, Nigeria". Water samples collected from Ogbia axis of Kolo Creek at Imiringi, Emeyal and Otabagi were analyzed for heavy metals concentrations. The results showed that lead varied from 0.729±0.10 - 1.034±0.11 mg/L, copper varied from 0.611±0.03 - 1.136±0.12 mg/L, cadmium varied from undetected - 0.0012±0.00 mg/L, mercury was undetected in all the stations, nickel varied from 0.069±0.01 - 2.413±0.16 mg/L. Other metal variation include from 0.711±0.11 - 1.360±0.22 mg/L, iron varied from 1.321±0.21 - 2.348±0.41 mg/L and zinc varied from 1.344±0.13 - 2.461±0.42 mg/L. Evaluation of the pollution indices indicated that the water has either been contaminated or polluted by individual heavy metals, except mercury. Findings revealed that the water is not fit for human consumption, adequate measures should be put in place by the different governments (local, state or federal) to preserve this water body from complete deterioration, since it is a mojor source of water supply for the Ogbia tribe of Bayelsa State, Nigeria.

Ngah and Nwankwoala (2013) conducted a study on iron (Fe^{2+}) occurrence and distribution in groundwater sources in different geomorphologic zones of Eastern Niger Delta. The study sites

were chosen from the five (5) geomorphologic units that make up the area. Iron is a major chemical issue in groundwater from the area as nearly all the analysis revealed some value for iron. Iron concentration was mapped with a view to relating the high occurrence to depth of boreholes. However there is no definite relationship between the depth of boreholes and iron content. Their relationship is rather haphazard and probably related to the geologic history of the Niger Delta region. For instance, the boreholes with highest concentration of iron in the area of 10mg/l are located at Idama (Saltwater Swamp) and Umuoji (Coastal Plain Sands) and are 100m and 81m deep respectively. Ahoada (Coastal Plain Sands) has 0.04 from a borehole 65m deep. The deep wells at Onne (264m) have iron concentration of 0.06mg/l, Joinkrama (Freshwater Swamp) has 6.2mg/l from a borehole 176m deep. Toru-Ndoro (freshwater swamp) has 6.2mg/l from 176m-deep borehole while Forupa (Freshwater Swamp) has 0.3mg/l from a borehole of 215m. The high iron concentration appears to be more prevalent in the boreholes drilled in Freshwater Swamps/Backswamp/Meander Belt region as well as the mangrove swamps and coastal ridges. Here, the values range from 0.4 – 10mg/l. It was less than 0.4mg/l in 50% of the samples, 0.4mg/l – 1.0mg/lin 22% of the samples and >1.0mg/l in 20% of the samples. The highest value of 10.0mg/l occurs at Rumuokachi and Umuoji while the groundwater from Harry's Town has 8.0mg/l. WHO (2008) recommended a range of 0.1mg/l – 0.3mg/l as highest desirable and maximum permissible limits respectively. The implication therefore is that most water boreholes in the study area deliver water with iron in objectionable concentration. Most of the water in its natural state is not fit for human consumption.

Aminu *et al., (*2023) carried out a study on "Assessment of Seasonal Variation in Heavy Metal Status of a Lotic Ecosystem in Federal Capital Territory, Abuja, North Central Nigeria". The concentrations of Cu, Zn, Fe, Cd, Co, Cr, and Mn and their seasonal variations in water samples from the Wupa River, Abuja, Nigeria, were studied using the Atomic Absorption Spectrophotometric method to determine the suitability of the water for domestic usage and identify potential sources of contamination. Sixty (60) samples were collected during both dry

and wet seasons. The respective metal concentrations (in mg/dm^3) in the dry and wet seasons were as follows: Cu (0.023 ± 0.022, 0.023 ± 0.026), Zn (0.104 ± 0.039, 0.158 ± 0.085), Fe (0.350 ± 0.097, 0.3630.103), Cd (not detectable), Co (not detectable), Cr (0.003 ± 0.003, 0.004 ± 0.004), and Mn (0.120 ± 0.132, 0.110 ± 0.099). Among these metals, Cu, Zn, Cr, and Mn occurred in concentrations below the tolerable limits recommended by Nigeria Standard for Drinking Water Quality and WHO, whereas Fe exceeded these limits, while Cd and Co were not detectable. The calculated heavy metal pollution index values (68.22 in the dry season and 63.78 in the wet season) were lower than the critical value (100), indicating low pollution levels in both seasons. The metal index values for both seasons (1.50 for the dry season and 1.55 for the wet season) suggest that the water from the Wupa River was slightly affected by heavy metals. No significant differences in metal concentrations existed between the dry and wet seasons. A strong positive correlation occurred between Zn and Fe only during the wet season. Water from the river was polluted with Fe and unsuitable for domestic use. Potential sources of contamination include agricultural areas, industrial effluents, and domestic waste in the wet season, and industrial and domestic sewage in the dry season. They suggested that to make the river water safe for use, it should be treated and regularly monitored for metal contents, and sources of contamination should be managed appropriately.

Nwankwoala and Omemu, (2019) carried out a baseline monitoring of elemental contamination levels in soil samples in Elebele Community, Bayelsa State, Nigeria. The metals studied were detected in all the sites. Generally the concentrations of the metals were highest at the topsoils. This is expected since the top soil is the point of contact. The metal levels in all the sites were significantly higher than the levels observed in the control sites. It’s concluded that sources of heavy metals in soils like inorganic fertilizers and pesticides need to be controlled.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials Used on the Field for Water and Soil Sampling

The following materials were used in this study on the field for soil and water samples collection. Global Positioning System (GPS); Hand Auger; Polyethylene Bags; Clean one litter plastic containers; Masking tape; Camera; Notebooks, and pen. Also, the materials used in the laboratory analysis were: separating glass funnels; Pipette, Mechanical shaker, Cuvette; conical flask; Filter paper; Whatman No.1; Oven, Conductivity/TDS Meter; volumetric flask; Reagents: n- Hexane;Hydrazine Sulphate; Hexamethylene Tetramine; Potassium Chloride (KCl) and Atomic Absorption Spectrometer $21D^{+}$.

3.2 Research Design

This project was designed to be carried out in these phases; collection of samples during rainy and dry seasons, data analysis and data interpretation as shown in the flow chart (Figure 3.1).

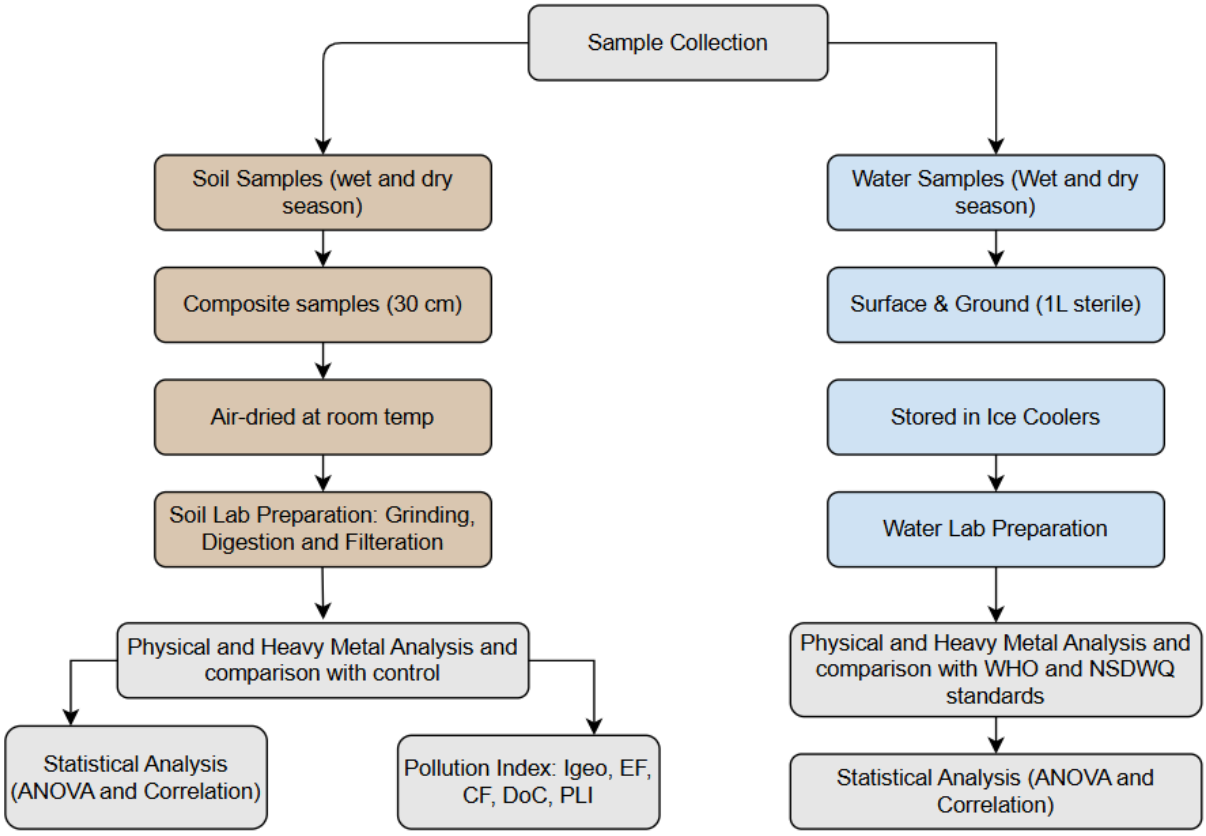

Figure 3.1: Flow chart

3.3 Surface, Groundwater and Soil Sampling

A total of one hundred and twelve (112) samples were collected randomly per season. Seventy-seven (77) soil samples and thirty-five (35) surface and groundwater samples were collected during the rainy and dry seasons from July 2023 and December 2023 as shown in Figure 3.2 to 3.5. Surface and groundwater samples were collected in sterile one-litter plastic containers, borehole water samples were collected after 5 minutes of pumping, and both samples were carefully corked immediately after sampling. Before laboratory analysis, the water samples were stored in an ice-packed cooler to prevent significant chemical composition, chemical absorption, and ion interference. The sample locations' elevation and geo-graphical coordinates (longitudes and latitudes) were measured using GPS. Photographs were taken in the field as shown in plates 3.1 to 3.4. Composite soil samples of 30cm depth were collected per location using a hand auger and packed in polyethylene bags. The soil and water samples were labelled with masking tape and transported to the laboratory for heavy metal analysis using an Atomic Absorption Spectrophotometer $21D^{+}$ (AAS) with cathode-containing heavy metal lamps. Figures 3.2-3.5 shows maps of samples collected from Dumpsites, Mechanic workshops, Cassava mills and crude oil spill sites.

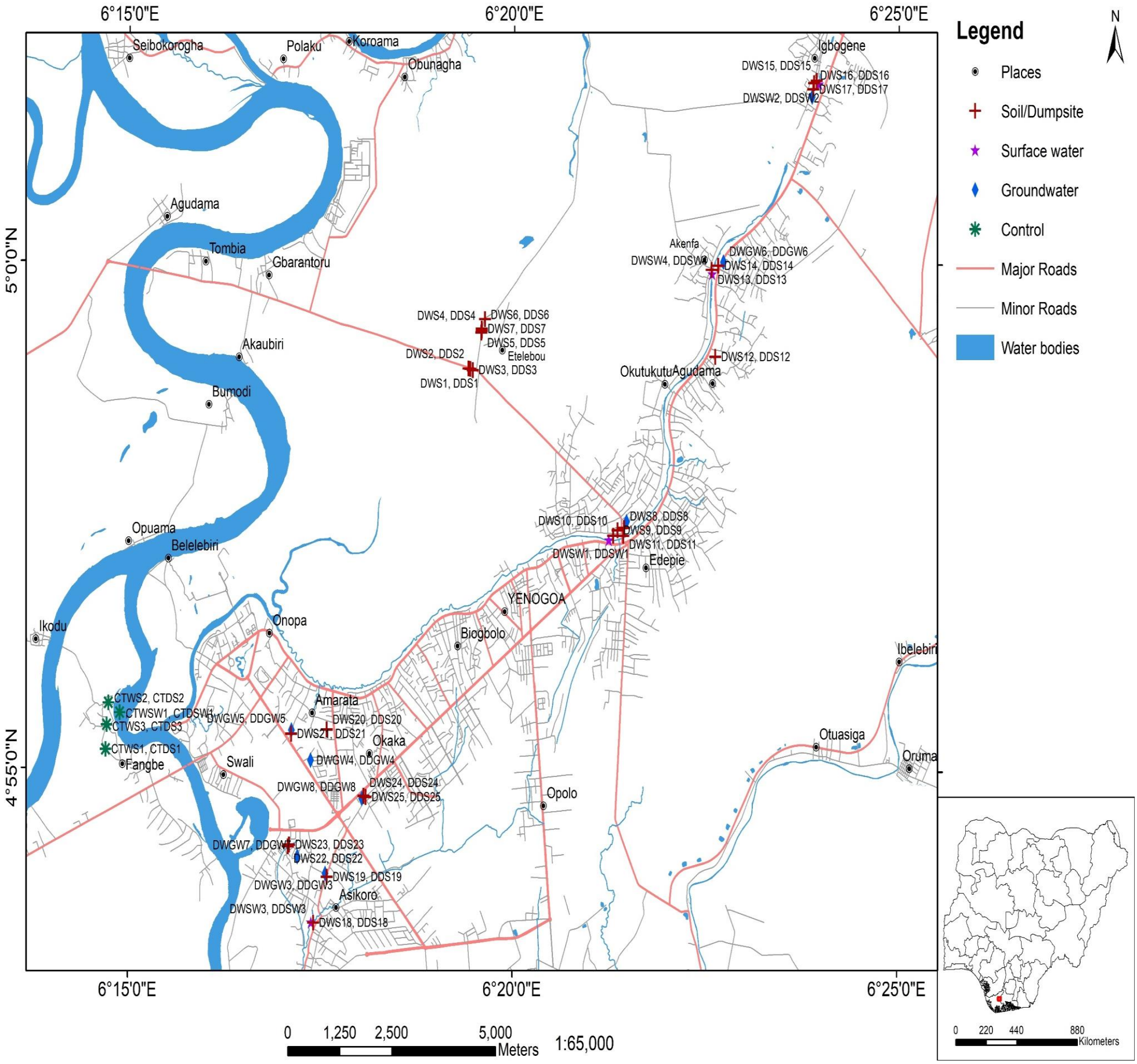

Figure 3. 2: Map of sample collected from Dumpsites within the study area

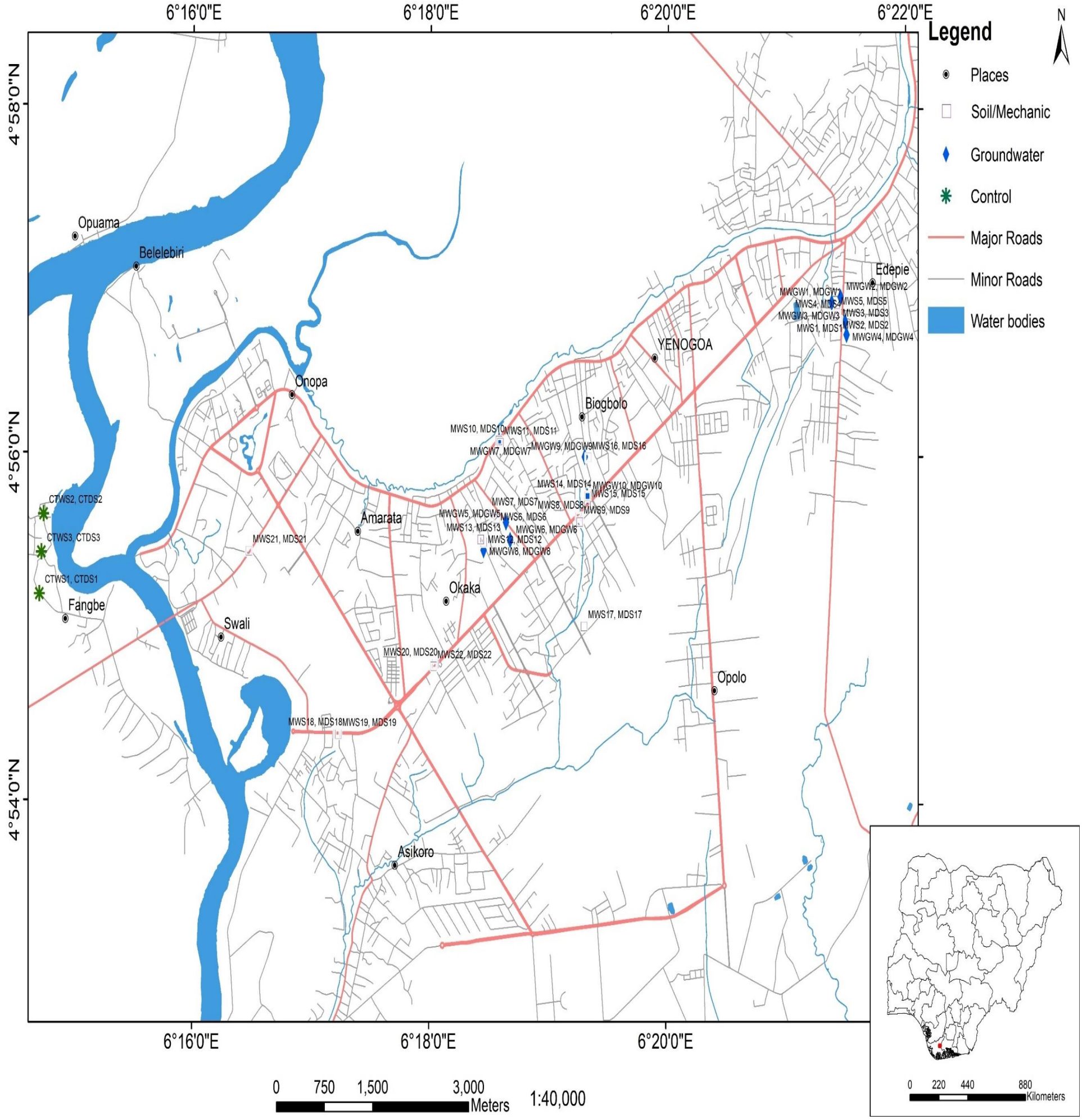

Figure 3.3: Map of sample collected from Mechanic workshop within the study area

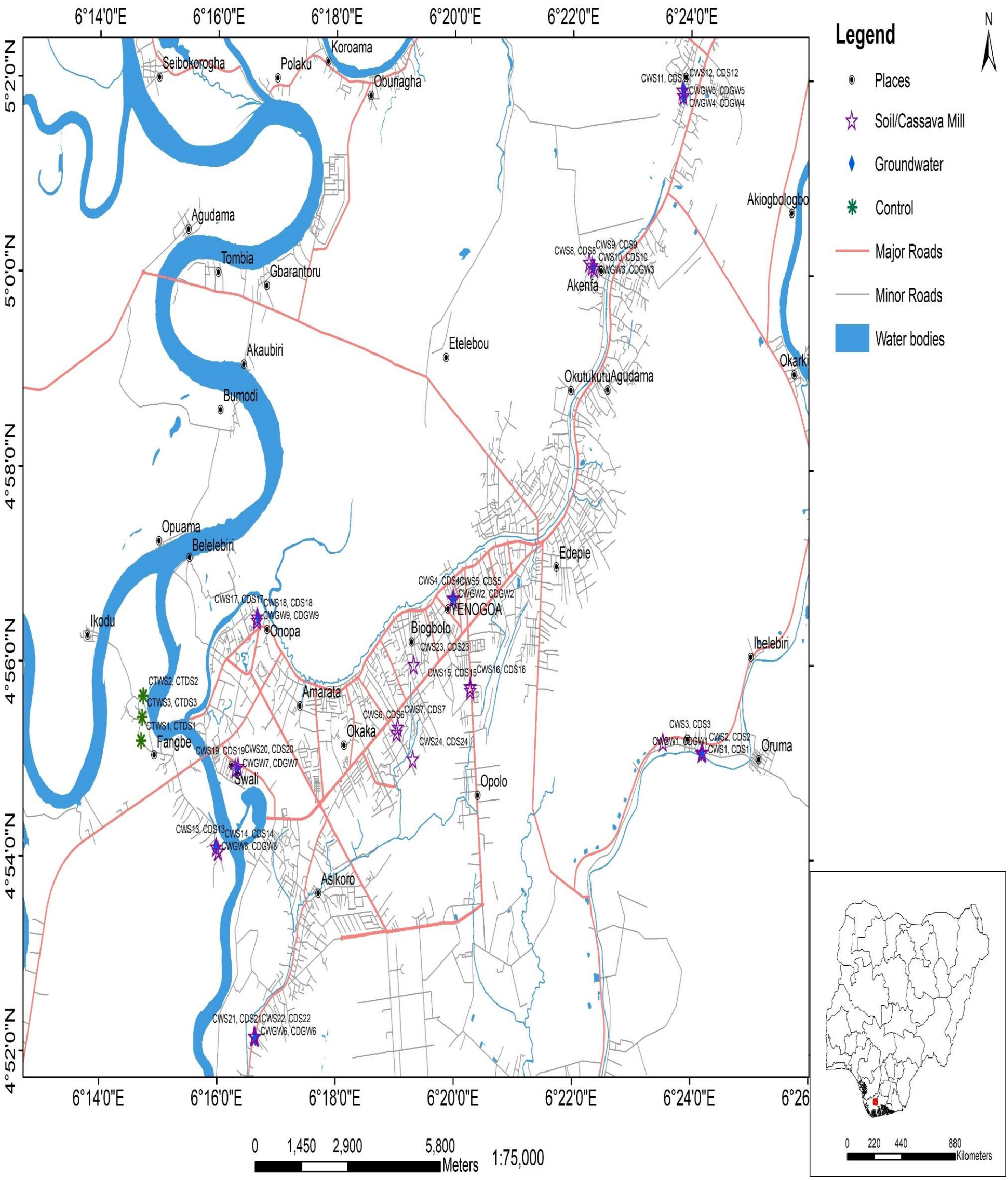

Figure 3.4: Map of sample collected from Cassava mills within the study area

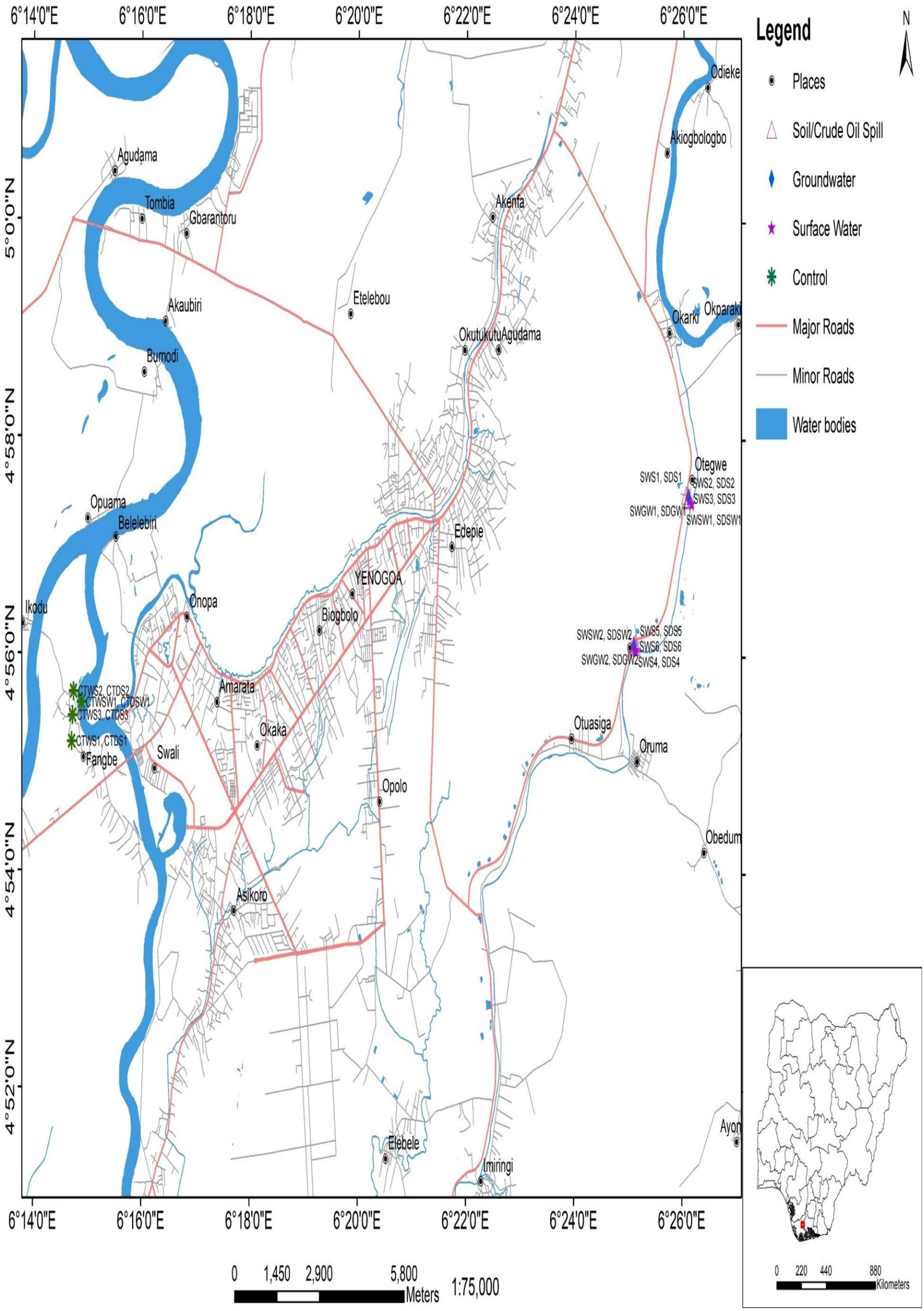

Figure 3.5: Map of sample collected from Crude oil spill sites within the study area

Plate 3.1: Soil sample collected from dumpsite within the study area at Swali

Plate 3. 2: Soil sample collected from Mechanic workshop in the study area at Mechanic Village Imiringi Road

Plate 3. 3: Soil sample collected from Cassava Mill within the study area at Akenfa 1

Plate 3.4: Soil sample collected from another Dumpsite within the study area at Etelebu Tombia Amassoma Road

3.4 Laboratory Analysis of Samples

The analysis of both the water and soil samples were carried out by Martlet Environmental Research Laboratory Limited, Benin City, Nigeria. The analysis were carried out using the Spectronics $21D^{+}$ Atomic Absorption Spectrophotometer (AAS). They were carried out immediately the samples arrived to avoid delays which could affect the accuracy of the analysis.

3.5 Water Samples Analysed

3.5.1 Determination of Total Hydrocarbons

Procedure

50ml of the water sample was measured into 150ml separating funnel, 10ml of n-Hexane was added, and shaken for 2 minutes manually, and the stopper was removed and allowed to settle for 20minutes. The water layer was drained off and n-Hexane layer was collected and read at 460nm in a Spectronic 21D+ Spectrophotometer. The n-Hexane was used as the blank. THC Standard Stock 1000ppm and Pipette 1.18ml of Forcados Blend Crude Oil was made to 1 litre with n-Hexane from this prepare 0, 10,20, 40,60,80 and 100ppm was used as working standards.

3.5.2 Determination of Conductivity/Total Dissolved Solids

Procedure

0.1M Potassium chloride (KCl) was dissolved in 74.55g of KCl in 900ml of water, the volume of the solution was made up to 1litre. The instrument was switched on and allowed to stabilize for 10 minutes. Conductivity was calibrated by pressing the meter-CND2000 board and immersing the probe in the Potassium chloride (KCl) solution. Calibration of Total Dissolved Solids (TDS) was also done by pressing TDS and immersing the Probe in the KCl solution. The probe was rinsed with distilled water and immersed in the sample solution. EC/TDS reading were taken by pressing CND and TDS respectively. The meter recorded the Conductivity and TDS directly in μs/cm and mg/l respectively.

3.5.3 Determination of Suspended Solids in Water by Gravimetry

Procedure

The Whatman Filter Paper No.1 was dried at 50^0C to constant weight double (1g) Filter, through the weighed paper, 100ml of water sample was dried in the same oven to constant weight a 50oC. The filter paper was weighed with its content double (2g) and the reading were taken.

3.5.4 Determination of Turbidity

Procedure

1g of Hydrazine Sulphate and 10g of Hexamethylene Tetramine were dissolved in water separately and were diluted to 100ml, 5ml of each solution were mixed in a 100ml flask, and kept for 24 hours at room temperature. The solution was diluted to the 100ml mark and mixed properly. 25ml of water was poured into the cuvette and recording was done at zero in the spectrophotometer at 450 nm**.** 25ml of the water sample was poured into another cuvette and reading was done in the meter, the working standards were read similarly.

3.5.5 Determination of Heavy Metals by Atomic Absorption Spectrophotometer (AAS) for the Water Samples

Procedure

Atomic Absorption Spectrometry was used for the determination of heavy metals such as Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Zinc (Zn), Mercury (Hg) and Cyanide (CN) in the water. The water samples were read directly in the AAS without dissolving it with reagents and the source of radiation was a hallow lamp, which contains a cathode constructed with the same metals as that being analysed. The wavelength characteristics of the metal was emitted, and a different lamp was required for each metal. The light from the lamp was directed through a flame and onto monochromator, which selected the preferred analytical wavelength. The light monochromator was detected by a photomultiplier tube and converted to an electrical signal. The sample was aspirated in the flame where the solution was evaporated and the metal –containing compounds were volatilized and

dissociated into ground state atoms. The ground state atoms absorbed the radiation from the hallow lamp and excited to higher energy levels. Some atoms were also thermally excited but their fraction was so small that it caused no error in the analysis. An acetylene-air flame was used. Table 3.1 shows some heavy metals with their wavelengths and currents of their lamps.

3.6 Soil Samples Analysed

Double acid extraction method was adopted to extract the heavy metals from the soil samples through digestion. The soil Samples were air dried at room temperature, and then loosened using a ceramic pestle and mortar, after which they were sieved using a 2 mm mesh sieve in order to remove coarse materials and other debris. Afterward, 5g of the dried fine soil and sediment samples were ground and blended with an agate mortar until a fine powder which could pass through a 0.15 mm polyeth-ylene sieve was obtained. Then about 2g of this powder was taken, and transferred into a 250cm^3 acid washed conical flask, this was digested with 1ml of perchloric acid ($HClO^4$) and 3ml of nitric acid (HNO^3) for 10 minutes at room temperature. The digested mixture was heated on a hot plate in a fume cupboard at 40^0C until the digestion was completed. After the mixture had been cooled at room temperature, it was filtered using Whitman No.1 filter paper into a 50 ml flask. The filtrate was then stored in polythene bottles ready for analysis. The same procedures were carried out for the blank samples. The sample solution, the standard, and the blanks were aspirated respectively into the air-acetylene flame of Atomic Absorption Spectrophotometer (AAS) for heavy metal analyses using different heavy metals cathode lamps.

Table 3. 1: Some Heavy Metals with their Wavelengths and Currents of their Lamps

Lamp Name/Element	Wavelength (nm)	Lamp Current (mA)
Cadmium (Cd)	228.8	8
Chromium (Cr)	357.8	10
Copper (Cu)	324.8	5
Iron (Fe)	248.3	15
Lead (Pb)	217.0	10
Manganese (Mn)	279.5	12
Nickel (Ni)	232.0	15
Zinc (Zn)	213.9	10
Cyanide (CN)	420.0	4
Mercury (Hg)	578.2	5

3.6.1 Determination of Soil pH and Electrical Conductivity

The soils were spread out on a sheet of polythene and 25g were weighed out, small portions were taken from different parts of the heap. The sample was then placed in a 100ml beaker and 25ml of distilled water was added to the beaker containing the soil sample. The contents of the beaker were well stirred and left to stand for approximately 6 hours with occasional stirring using a glass rod. Where the electrode used was not the dual type, the level of Potassium Chloride (KCl) solution was checked in the calomel electrode, and the presence of solid KCl was ensured. The buffer solutions were made up according to directions. The electrodes were then immersed in pH7 buffer, and the needle was set to figure after checking the zero point. The buffer was removed, the electrode was rinsed, and buffer of pH4 substituted. It was read at 4.00 without adjustment. The soil sample was then stirred and placed under the electrodes, the beaker gently rotated to stir the contents and the meter switched to ‘read’. Reading was taken at steady state. The electrodes were rinsed between each test. Very little creep occurred in the samples after the first and reading was taken about 1 minute after inserting the electrodes. The batch was repeated after finishing the first set of reading.

3.7 Statistical Analysis of Data

The data obtained from this study were analyzed using descriptive statistics, correlation and Analysis of Variance (ANOVA), the univariate relationship among heavy metal was done using correlation and differences in heavy metal between the sites were compared using ANOVA. The Statistical Packages for Social Sciences (SPSS version 25.0) was used to enhance data analysis and statistical significance was established at 0.05 level of significance. The p-value<0.05 was considered significant.

3.8 Pollution Indexes

The extent of heavy metal pollution in the soil samples was quantitatively assessed using the Pollution Intensity Indices (PII), Geoaccumulation index (Igeo), Contamination Factor (CF), enrichment factor (EF), Degree of Contamination (DoC) and Pollution Load Index (PLI). These indices are methods widely used for the assessment of the impacts of anthropogenic activities on soils and they generally involve calculating the contamination factors for the heavy metal concentrations against uncontaminated background levels (Lin *et al.*,2016)..

3.8.1 The Geoaccumulation Index (Igeo):

Geo-accumulation Index was introduced by Muller (1969). This approach involves comparing the current concentration of heavy metal in a system to pre-industrial concentrations. The method has been commonly used to evaluate heavy metal contamination in soils and sediments.

Geoaccumulation index is expressed as follows:

$$Igeo = \log2 (Cn /1.5Bn) \quad \ldots\ldots\ldots (1)$$

Where I_{geo} is geo-accumulation index; Cn is the measured concentration of the element in question measured at a certain site, Bn is the geochemical background value of the element in the soil (Muller, 1969). The constant 1.5, is incorporated in the relationship to account or possible variation in background data due to lithogenic effect. The geoaccumulation index has been subdivided into seven grades: Igeo < 0 = unpolluted; 0-1 = unpolluted to mod-erately polluted; 1-2 = moderately polluted; 2 -3 = moderately to heavily pollsuted; 3-4, heavily polluted; 4-5 =

heavily to ex-tremely polluted; > 5 = extremely polluted. There threshold values are shown in table 3.2.

Table 3. 2: Ranges of grades of Geoaccumulation Index

Class	Value	Soil or sediment quality
0	$I_{geo} \leq 0$	Uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 < I_{geo} < 5$	Heavily to extremely contaminated
6	$5 < I_{geo}$	Extremely contaminated

Muller (1969)

3.8.2 Enrichment Factor (EF)

The Enrichment Factor (EF) of any given metal in a given soil sample is a measure of differentiating between metals that originate from natural sources and those that originate from anthropogenic activities. It is based on the principle of standardization of a measured metal against a reference metal and a reference metal is often the one characterized by low occurrence viability (Sam *et al.,* 2015). Examples of reference metals are Aluminium, Iron and Silicon (Sutherland *et al.,* 2000; Zhang *et al.,* 2009). For this study, Iron was used as the reference metal in this study. Enrichment Factor (EF) is determined by the following relationship;

EFx=Xs/Es(ref)Xc/Ec(ref)·····(2)

Where EFx = Enrichment Factor for an element X, Xs = Concentration of element of interest in a given soil sample, Es(ref) = Concentration of the reference element used for normalization of a given soil sample, Xc = Concentration of the element in the crust and Ec (ref) = Concentration of the reference element used for normalization in the crust (Taylor and McLennan,1985; Atiemo *et al.,* 2011).

Categories for Enrichment factors are as follows: EF <3, minor enrichment, EF between 3-5, moderate enrichment; EF 5-10, moderately severe enrichment; EF between 25 and 50, very

severe enrichment; EF > 50, extremely severe enrichment (Zalewska *et al.*,2015). Values of EF lower than 1.5 (García *et al.*, 2008) or <2 (Abreu *et al.*, 2016) indicate that the metal is entirely from crustal materials or natural processes, while EF values higher than 1.5 or 2 suggest an increasing portion of the anthropogenic sources (Abreu *et al.*, 2016) as shown in Table 3.3.

Table 3. 3: Categories for Contamination Factor (CF), Degree of Contamination (DoC) and Pollution Load Index (PLI).

Enrichment Factor	Category
EF < 3	Minor enrichment
EF between 3-5	Moderate enrichment
EF between 5-10	Moderately severe enrichment
EF between 25-50	Very severe enrichment
EF > 50	Extremely severe enrichment
Enrichment Factor (EF)	Source Indication
EF < 1.5	Metal is entirely from crustal materials or natural processes
EF < 2	Metal is entirely from crustal materials or natural processes
EF > 1.5	Increasing portion of anthropogenic sources
EF > 2	Increasing portion of anthropogenic sources

Source: Zalewska *et al.*, 2015, Garcia *et al.*, 2008, Abreu *et al.*, 2016

3.8.3 Contamination Factor (CF)

Contamination Factor is one of the statistical tools that was used in assessing the extent of contamination of heavy metals in a given soil sample. Contamination factor is defined according to the following relationship;

$CF=Ci\ 0{-}1Cin\cdots\cdots\cdots\cdots\cdots\cdots\cdots(3)$

Where CF = Contamination factor of the element of interest, Ci0-1 = Concentration of the element in the given sample of interest and Cin = background concentration, which is usually denoted by the continental crust average (Taylor *et al.,* 1985; *Atiemo et al.,* 2011) (Table 3.4).

3.8.4 Degree of Contamination (DOC)

According to Sam *et al.,* (2015), the sum of the contamination factors of all the elements in a given soil sample gives the degree of contamination and this is shown by the mathematical relationship;

$Cdeg=\Sigma CF\ldots\ldots\ldots\ldots\ldots...$ (4)

Where $Cdeg$ implied the degree of contamination and ΣCF indicate the sum of contamination factors of all heavy metals of interest (Table 3.4).

3.8.5 The Pollution Load Index (PLI)

Pollution Load Index was developed by Thomilson *et al.,* (1980) and it is used to provide a simple but comparative means for addressing the pollution quality of a given soil. It is mathematically expressed with the following equation.

$PLI=n\sqrt{CF1x\ CF2\ x\ CF3\ \cdots\cdots\ CFn}\ \cdots\cdots\cdots\cdots(3)$

Where CF implies the concentration factor of a given element of interest and n implies the number of elements being studied (Table 3.4).

Table 3. 4: Categories for Contamination Factor (CF), Degree of Contamination (DoC) and Pollution Load Index (PLI).

S/No.	Categories for CF	Definition
1	$CF < 1$	Implies low contamination
2	$2 \leq CF \geq 3$	Implies moderate contamination
3	$3 < CF \leq 6$	Implies considerate contamination
4	$CF > 6$	Implies very high contamination
S/No.	**Categories for DoC**	**Definition**
1	Cdeg< 8	Implies low degree of contamination
2	$8 \leq Cdeg \geq 16$	Implies moderate degree of contamination
3	$16 < Cdeg \geq 32$	Implies considerable degree of contamination
4	Cdeg> 32	Implies very high degree of contamination
S/No.	**Categories for PLI**	**Definition**
1	$PLI < 1$	Implies perfection
2	$PLI = 1$	Implies that only baseline levels of pollutants present
3	$PLI > 1$	Implies progressive deterioration of site

Source: Thomilson *et al.,* (1980)

CHAPTER FOUR

PRESENTATION OF RESULTS AND DISCUSSION

This chapter presents a complete examination of the physicochemical parameters of water and soil samples taken from a variety of environmental settings. These settings include, dumpsites, mechanic workshops, cassava mills, and places where crude oil spills have occurred. Detailed information regarding the sampling locations may be found in Tables 4.1 and 4. 2, which provide specific geographic information for the location samples that were collected. Tables 4.3– 4.6 present the results of water samples taken from boreholes located in the vicinity of dumpsites, mechanic workshops, cassava mills, and crude oil spill sites. These results demonstrate fluctuations in heavy metals, organic and inorganic compounds, and other pollutants that occur during the wet season. The results of the dry season are presented in Tables 4.7–4.10, and they demonstrate that the various environmental situations have their own unique contamination profiles. Tables 4.11–4.18 present the results of soil sample tests conducted during the wet and dry seasons. Tables 4.11 and 4.15; 4.12 and 4.16; 4.13 and 4.17; and 4.14 and 4.18, respectively give the findings of an investigation of the soils surrounding dumpsites, mechanic workshops, cassava mills, and crude oil spill sites during both seasons. This section gives insights into the sources, seasonal trends, and potential ecological and health implications of pollution throughout the study sites by combining the data from Tables 4.1 through 4.18. These tables contain information obtained from the study sites.

Table 4.1: Locations for Water Samples

S/No	Location	Latitude	Longitude	Environment	Wet Season	Dry Season
1	Tombia Junction Market (BH)	4.955526	6.356472	Dumpsite	DWGW1	DDGW1
2	Igbogene (BH)	5.029389	6.398333	Dumpsite	DWGW2	DDGW2
3	Azikoro (BH)	4.899472	6.292889	Dumpsite	DWGW3	DDGW3
4	Amarata (BH1)	4.922667	6.285528	Dumpsite	DWGW4	DDGW4
5	Amarata (BH2)	4.923028	6.285515	Dumpsite	DWGW5	DDGW5
6	Akenfa 1 (BH)	4.999222	6.377167	Dumpsite	DWGW6	DDGW6
7	Kingdom RD Swali (BH)	4.903778	6.285167	Dumpsite	DWGW7	DDGW7
8	Okaka Estate	4.911833	6.300778	Dumpsite	DWGW8	DDGW8
9	Tombia Junction Market Epie creek	4.955472	6.356083	Dumpsite	DWSW1	DDSW1
10	Igbogene Epie Creek	5.029194	6.398639	Dumpsite	DWSW2	DDSW2
11	Azikoro canal	4.891389	6.289833	Dumpsite	DWSW3	DDSW3
12	Akenfa 1 Epie Creek	4.999139	6.376222	Dumpsite	DWSW4	DDSW4
13	Mechanic Village Imiringi Rd (BH1)	4.947083	6.357083	Mechanic	MWGW1	MDGW1
14	Mechanic Village Imiringi Rd (BH2)	4.947306	6.357278	Mechanic	MWGW2	MDGW2
15	Mechanic Village Imiringi Rd (BH3)	4.946222	6.358389	Mechanic	MWGW3	MDGW3
16	Mechanic Village Imiringi Rd (BH4)	4.946667	6.358583	Mechanic	MWGW4	MDGW4
17	Kpansia Nikton RD (BH 1)	4.926361	6.310639	Mechanic	MWGW5	MDGW5
18	Kpansia Nikton RD (BH 2)	4.927645	6.310944	Mechanic	MWGW6	MDGW6
19	Kpansia Milford Okilo Rd (BH)	4.934667	6.309778	Mechanic	MWGW7	MDGW7
20	Yenizue-Epie Septex Rd (BH)	4.924917	6.307667	Mechanic	MWGW8	MDGW8
21	Yenizue-Gene Erepa Rd (BH)	4.933139	6.321833	Mechanic	MWGW9	MDGW9
22	Yenizue-Gene Otiotio RD (BH)	4.929361	6.322194	Mechanic	MWGW10	MDGW10
23	Otuasega (BH)	4.91836	6.40325	Cassava Mill	CWGW1	CDGW1
24	Opolo Big Brother Rd (BH)	4.94453	6.33308	Cassava Mill	CWGW2	CDGW2
25	Akenfa 1, Opp. Glory Drive First Bridge (BH)	5.00136	6.37244	Cassava Mill	CWGW3	CDGW3
26	Igbogene (BH1)	5.03061	6.39786	Cassava Mill	CWGW4	CDGW4
27	Igbogene (BH2)	5.03175	6.39781	Cassava Mill	CWGW5	CDGW5
28	Agbura (BH)	4.86917	6.27764	Cassava Mill	CWGW6	CDGW6
29	Swali (BH)	4.91538	6.27231	Cassava Mill	CWGW7	CDGW7
30	Ogu (BH)	4.90186	6.26647	Cassava Mill	CWGW8	CDGW8
31	Onopa (BH)	4.94099	6.27808	Cassava Mill	CWGW9	CDGW9
32	Agba (Otuegwe) BH	4.95783	6.43511	Crude Spill	SWGW1	SDGW1
33	Ibelebiri BH	4.93497	6.41842	Crude Spill	SWGW2	SDGW2
34	Agba (Otuegwe) Kolo creek	4.95744	6.43594	Crude Spill	SWSW1	SDSW1
35	Ibelebiri (Kolo creek	4.93461	6.41856	Crude Spill	SWSW2	SDSW2
36	Famgbe Control (River)	4.925417	6.246861	Control	CTWSW1	CTDSW1

Table 4.2: Locations for Soil Samples

S/No	Location	Latitude	Longitude	Environment	Wet Season	Dry Season
1	Famgbe control 1	4.91975	6.24522	Control	CTWS1	CTDS1
2	Famgbe control 2	4.92644	6.24681	Control	CTWS2	CTDS2
3	Famgbe control Riverbank 3	4.92544	6.24694	Control	CTWS3	CTDS3
4	Etelebu Tombia/Amasssoma Rd Old dumpsite 1	4.98253	6.32431	Dumpsite	DWS1	DDS1
5	Etelebu Tombia/Amasssoma Rd Old dumpsite 2	4.98256	6.32403	Dumpsite	DWS2	DDS2
6	Etelebu Tombia/Amasssoma Rd Old dumpsite 3	4.98258	6.32461	Dumpsite	DWS3	DDS3
7	Etelebu off Tombia/Amasssoma Rd New dumpsite 1	4.98883	6.32647	Dumpsite	DWS4	DDS4
8	Etelebu New dumpsite 2	4.98864	6.32655	Dumpsite	DWS5	DDS5
9	Etelebu New dumpsite 3	4.99075	6.32717	Dumpsite	DWS6	DDS6
10	Etelebu New dumpsite 4	4.98894	6.32658	Dumpsite	DWS7	DDS7
11	Tombia junction market 1	4.95625	6.35656	Dumpsite	DWS8	DDS8
12	Tombia junction market 2	4.95613	6.35603	Dumpsite	DWS9	DDS9
13	Tombia Junction market 3	4.95492	6.35522	Dumpsite	DWS10	DDS10
14	Tombia Junction market 4	4.95547	6.35639	Dumpsite	DWS11	DDS11
15	Akenfa 1(1)	4.98472	6.37708	Dumpsite	DWS12	DDS12
16	Akenfa 1, Epie creek 2	4.99914	6.37625	Dumpsite	DWS13	DDS13
17	Akenfa 1(3)	4.99931	6.37711	Dumpsite	DWS14	DDS14
18	Igbogene Epie creek 1	5.02939	6.39864	Dumpsite	DWS15	DDS15
19	Igbogene 2	5.02969	6.398548	Dumpsite	DWS16	DDS16
20	Igbogene 3	5.02936	6.39847	Dumpsite	DWS17	DDS17
21	Azikoro 1	4.89142	6.29011	Dumpsite	DWS18	DDS18
22	Azikoro 2	4.89917	6.29308	Dumpsite	DWS19	DDS19
23	Amarata 1	4.92314	6.29313	Dumpsite	DWS20	DDS20
24	Amarata 2	4.92242	6.28542	Dumpsite	DWS21	DDS21
25	Swali 1	4.90389	6.28492	Dumpsite	DWS22	DDS22
26	Swali 2	4.90394	6.28511	Dumpsite	DWS23	DDS23
27	Okaka 1	4.91228	6.30117	Dumpsite	DWS24	DDS24
28	Okaka 2	4.91211	6.30161	Dumpsite	DWS25	DDS25
29	Mech Village Imiringi Rd 1	4.94675	6.35686	Mechanic	MWS1	MDS1
30	Mech Village Imiringi Rd 2	4.94628	6.35747	Mechanic	MWS2	MDS2
31	Mech Village Imiringi Rd 3	4.94636	6.3575	Mechanic	MWS3	MDS3
32	Mech Village Imiringi Rd 4	4.94681	6.35689	Mechanic	MWS4	MDS4
33	Mech Village Imiringi Rd 5	4.94708	6.35725	Mechanic	MWS5	MDS5
34	Kpansia Nikton Rd 1	4.92669	6.30953	Mechanic	MWS6	MDS6
35	Kpansia Nikton Rd 2	4.92675	6.31083	Mechanic	MWS7	MDS7
36	Kpansia JJWAKS 1	4.92739	6.32185	Mechanic	MWS8	MDS8
37	Kpansia JJWAKS 2	4.92753	6.32064	Mechanic	MWS9	MDS9
38	Kpansia Melford Okilo Rd 1	4.93467	6.30978	Mechanic	MWS10	MDS10
39	Kpansia Melford Okilo Rd 2	4.93446	6.30997	Mechanic	MWS11	MDS11
40	Yenezue - Epie Saptex Rd 1	4.92492	6.30767	Mechanic	MWS12	MDS12
41	Yenezue - Epie Saptex Rd 2	4.92517	6.30725	Mechanic	MWS13	MDS13
42	Yenezue -gene Otiotio Rd 1	4.92942	6.32225	Mechanic	MWS14	MDS14

S/No	Location	Latitude	Longitude	Environment	Wet Season	Dry Season
43	Yenezue- gene Otiotio Rd 2	4.92850	6.32222	Mechanic	MWS15	MDS15
44	Yenezue – gene Erepa Rd 1	4.93308	6.32203	Mechanic	MWS16	MDS16
45	Yenezue – gene Erepa Rd 2	4.91689	6.32181	Mechanic	MWS17	MDS17
46	Oxbow lake Rd Swali 1	4.90647	6.28708	Mechanic	MWS18	MDS18
47	Oxbow lake Rd Swali 2	4.90642	6.28731	Mechanic	MWS19	MDS19
48	Ekeki Opposite Aridolf	4.91322	6.30089	Mechanic	MWS20	MDS20
49	UBA/Swali Road	4.92394	6.27467	Mechanic	MWS21	MDS21
50	Ekeki Opposite Aridolf	4.91297	6.30067	Mechanic	MWS22	MDS22
51	Otuasega 1	4.91825	6.40331	Cassava Mill	CWS1	CDS1
52	Otuasega 2	4.91842	6.40356	Cassava Mill	CWS2	CDS2
53	Otuasega 3	4.92014	6.39236	Cassava Mill	CWS3	CDS3
54	Big Brother Rd Opolo 1	4.94447	6.33314	Cassava Mill	CWS4	CDS4
55	Big Brother Rd Opolo 2	4.94439	6.33314	Cassava Mill	CWS5	CDS5
56	Kpansia market Rd 1	4.92147	6.31725	Cassava Mill	CWS6	CDS6
57	Kpansia market Rd 2	4.92236	6.31758	Cassava Mill	CWS7	CDS7
58	Akenfa 1, location Rd	5.00108	6.37269	Cassava Mill	CWS8	CDS8
59	Akenfa 1, Glory drive	5.00211	6.37128	Cassava Mill	CWS9	CDS9
60	Akenfa 1, location Rd First bridge	5.00153	6.37206	Cassava Mill	CWS10	CDS10
61	Igbogene 1	5.03072	6.39772	Cassava Mill	CWS11	CDS11
62	Igbogene 2	5.03164	6.39752	Cassava Mill	CWS12	CDS12
63	Ogu 1	4.90167	6.26644	Cassava Mill	CWS13	CDS13
64	Ogu 2	4.90092	6.26706	Cassava Mill	CWS14	CDS14
65	Elebele/Opolo Rd 1 Kpansia (2)	4.92872	6.33803	Cassava Mill	CWS15	CDS15
66	Elebele/Opolo Rd, (2)	4.92931	6.33797	Cassava Mill	CWS16	CDS16
67	Onopa 1	4.94108	6.27786	Cassava Mill	CWS17	CDS17
68	Onopa 2	4.94047	6.2778	Cassava Mill	CWS18	CDS18
69	Swali 1	4.91514	6.27181	Cassava Mill	CWS19	CDS19
70	Swali 2	4.91542	6.27258	Cassava Mill	CWS20	CDS20
71	Agbura 1	4.86931	6.27728	Cassava Mill	CWS21	CDS21
72	Agbura 2	4.86933	6.27753	Cassava Mill	CWS22	CDS22
73	Yenizue – gene 1	4.93308	6.32203	Cassava Mill	CWS23	CDS23
74	Yenizue – gene 2	4.91689	6.32181	Cassava Mill	CWS24	CDS24
75	Agba (Otuegwe) 1	4.95817	6.43447	Crude Spill	SWS1	SDS1
76	Agba (Otuegwe) 2	4.95756	6.43535	Crude Spill	SWS2	SDS2
77	Agba (Otuegwe) 3	4.95767	6.43525	Crude Spill	SWS3	SDS3
78	Ibelebiri 1	4.93511	6.41825	Crude Spill	SWS4	SDS4
79	Ibelebiri 2	4.93542	6.41883	Crude Spill	SWS5	SDS5
80	Ibelebiri 3	4.93492	6.41875	Crude Spill	SWS6	SDS6

Table 4.3: Physicochemical Parameters of Groundwater and Surface Water Samples from Dumpsites Collected in the Wet Season

Sample	Fe (mg/l)	Mn (mg/l)	Zn mg/l	Cu (mg/l)	Cr (mg/l)	Cd (mg/l)	Ni (mg/l)	Pb (mg/l)	THC (mg/l)	CN (mg/l)	V mg/l	Hg (mg/l)	P^H	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)
DWGW1	0.458	0.24	0.27	0.081	0.073	0.037	0.035	0.043	0	0	0	0	6.4	195	65	2.1	0.5
DWGW2	0.411	0.81	0.251	0.084	0.044	0.045	0	0.079	0	0	0	0	6	200	100	0.9	1
DWGW3	0.513	0.401	4.31	0.51	0.074	0.042	0	0.045	0	0	0	0	6.8	207	230	0.8	0.4
DWGW4	0.643	0.071	0.362	0.556	0.068	0.014	0	0.007	0	0	0	0	6.9	201	172	1.9	0.9
DWGW5	0.453	0.152	0.648	0.264	0.075	0.024	0	0.015	0	0	0	0	6.3	149	105	2	0.6
DWGW6	0.811	0.274	0.821	1	0.054	0.092	0	0.025	0	0	0	0	5.9	230	207	2.3	0.8
DWGW7	0.517	0.047	2.36	2.341	0.365	0.004	0	0.042	0	0	0	0	5.2	200	85	1.2	0.6
DWGW8	0.741	0.064	3.014	0.069	0.201	0.007	0	0.005	0	0	0	0	6.4	171	73	1	0.5
DWSW1	0.341	0.41	6.21	2.43	1.36	0.046	0.037	0.058	0	0	0	0	6.1	217	108	4.2	2.9
DWSW2	0.57	0.51	5.52	0.025	0.211	0.039	0.003	0.064	0	0	0	0	6.2	110	97	5.1	2.4
DWSW3	0.464	0.511	5.2	1.43	0.062	0.13	0	0.132	0	0	0	0	5.6	151	100	5.1	5.2
DWSW4	0.093	0.646	7.176	1.321	0.156	0.251	0	0.066	0	0	0	0	5.1	140	120	5.4	4
CTWSW1	0.577	0.25	0.311	0.343	0	0	0	0	0	0	0	0	6.3	124	63	1.5	3.0
NSDWQ 2007	0.3	0.2	3	1	NS	0.003	0.02	0.01	NS	0.01	NS	0.001	6.5-8.5	1000	500	5	NS
WHO 2011	0.3	0.1	0.01	1	NS	0.003	0.02	0.01	NS	NS	NS	0.001	6.5-8.5	1000	500	5	NS

*NS – Not stated

Table 4.4: Physicochemical Parameters of Groundwater Samples from Mechanic Workshops Collected in the Wet Season

Sample	Fe (mg/l)	Mn (mg/l)	Zn mg/l	Cu (mg/l)	Cr (mg/l)	Cd (mg/l)	Ni (mg/l)	Pb (mg/l)	THC (mg/l)	CN (mg/l)	V mg/l	Hg (mg/l)	pH	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)
MWGW1	0.235	0.119	0.436	0.092	0.058	0.035	0.023	0.045	0.321	0	0	0	6.3	408	203	0.2	0.6
MWGW2	0.416	0.145	0.361	0.118	0.067	0.038	0.03	0.053	0.141	0	0	0	6.4	257	128	3.7	5.3
MWGW3	0.217	0.055	0.455	0.321	0.055	0.024	0	0.036	0.115	0	0	0	6	300	201	2.4	0.8
MWGW4	0.403	0.136	0.415	0.253	0.043	0.031	0	0.025	0.12	0	0	0	5.9	240	100	3	0.1
MWGW5	0.301	0.063	1.024	0.031	0.006	0.001	0	0.011	0.004	0	0	0	6.5	215	112	0.8	0.9
MWGW6	0.225	0.081	1.131	0.011	0.022	0.001	0	0.023	0.132	0	0	0	6.5	230	200	0.4	0.6
MWGW7	0.002	0.061	0.314	0.051	0.034	0.005	0	0.043	0.022	0	0	0	6.9	415	152	2.2	0.8
MWGW8	0.006	0.089	0.243	0.066	0.041	0.024	0	0.024	0.011	0	0	0	6.3	693	346	0.3	0.7
MWGW9	0.235	0.046	0.136	0.034	0.013	0.004	0	0.042	0.007	0	0	0	6.9	250	200	0.6	0.9

MWGW10	0.35	0.143	0.424	0.024	0.035	0.002	0	0.031	0.004	0	0	0	6.5	234	123	1.4	0.8

Table 4.5: Physicochemical Parameters of Groundwater Samples from Cassava Mills Collected in the Wet Season

Sample	Fe (mg/l)	Mn (mg/l)	Zn mg/l	Cu (mg/l)	Cr (mg/l)	Cd (mg/l)	Ni (mg/l)	Pb (mg/l)	THC (mg/l)	CN (mg/l)	V mg/l	Hg (mg/l)	pH	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)
CWGW1	0.411	0.02	0.414	0.341	0.046	0.003	0	0.016	0	0	0	0	6.5	570	203	0.1	0.7
CWGW2	0.289	0.101	0.544	0.15	0.063	0.034	0	0.052	0	0.01	0	0	6.1	480	239	0.2	0.5
CWGW3	0.6	0.014	0.153	0.335	0.03	0.016	0	0.032	0	0	0	0	6.1	343	223	0.2	0.3
CWGW4	0.5	0.02	0.13	0.083	0.044	0.022	0	0.053	0	0	0	0	6.5	350	200	0.1	0.4
CWGW5	0.4	0.051	0.364	0.165	0.063	0.03	0	0.009	0	0	0	0	6.4	500	235	0.4	0.1
CWGW6	0.7	0.036	0.243	0.075	0.08	0.024	0	0.053	0	0	0	0	6.2	450	300	0.1	0.5
CWGW7	0.351	0.085	0.155	0.41	0.043	0.013	0	0.041	0	0	0	0	6.9	493	215	0.2	0.6
CWGW8	0.526	0.038	0.314	0.145	0.04	0.03	0	0.007	0	0	0	0	6.3	432	230	0.5	0.3
CWGW9	0.453	0.044	0.41	0.302	0.055	0.014	0	0.005	0	0	0	0	6.4	525	150	0.3	0.4
NSDWQ 2007	0.3	0.2	3	1	NS	0.003	0.02	0.01	NS	0.01	NS	0.001	6.5-8.5	1000	500	5	NS
WHO 2011	0.3	0.1	0.01	1	NS	0.003	0.02	0.01	NS	NS	NS	0.001	6.5-8.5	1000	500	5	NS

*NS – Not stated

Table 4.6: Physicochemical Parameters of Groundwater and Surface Water Samples from Crude Oil Spill Sites Collected in the Wet Season

Sample	Fe (mg/l)	Mn (mg/l)	Zn mg/l	Cu (mg/l)	Cr (mg/l)	Cd (mg/l)	Ni (mg/l)	Pb (mg/l)	THC (mg/l)	CN (mg/l)	V mg/l	Hg (mg/l)	pH	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)
SWGW1	0.015	0.22	0.13	0.16	0.121	0.072	0.07	0.133	0.173	0	0.061	0	6.1	108	112	0.2	0.6
SWGW2	0.076	0.038	0.254	2.34	0.085	0.074	0.064	0.102	0.263	0	0.051	0	5.3	100	121	0.4	0.4
SWSW1	3.41	0.341	5.021	3.13	0.164	0.254	0.102	1.552	12.05	0	00.13	0	5.9	84	30	3.2	3.6
SWSW2	3.001	0.346	0.004	1.64	0.11	0.12	0.182	1.31	11.62	0	0.084	0	5.1	80	57	2.1	5
CTWSW1	0.577	0.25	0.311	0.343	0	0	0	0	0	0	0	0	6.3	124	63	1.5	3

Table 4.7: Physicochemical parameters of groundwater samples from Mechanic workshops collected in the dry season

Sample	Fe (mg/l)	Mn (mg/l)	Zn mg/l	Cu (mg/l)	Cr (mg/l)	Cd (mg/l)	Ni (mg/l)	Pb (mg/l)	THC (mg/l)	CN (mg/l)	V mg/l	Hg (mg/l)	pH	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)
MDGW1	0.317	0.117	0.177	0.051	0.044	0.005	0.004	0.032	0.143	0	0	0	5	424	215	0.2	0.3
MDGW2	0.625	0.123	0.187	0.013	0.05	0.031	0.007	0.036	0.042	0	0	0	5.3	273	136	3.9	3.2
MDGW3	0.414	0.042	0.163	0.123	0.042	0.005	0	0.012	0.014	0	0	0	5.1	325	211	3.4	0.3
MDGW4	0.511	0.124	0.352	0.13	0.005	0.01	0	0.016	0.03	0	0	0	5.3	251	117	3.4	0.1
MDGW5	0.342	0.018	0.041	0.014	0.005	0.001	0	0.003	0.001	0	0	0	5.9	225	120	0.9	0.5
MDGW6	0.353	0.009	0.061	0.017	0.042	0.001	0	0.013	0.052	0	0	0	6.1	240	235	0.7	0.4
MDGW7	0.452	0.041	0.077	0.021	0.026	0.002	0	0.05	0.005	0	0	0	6.4	435	189	2.7	0.2
MDGW8	0.057	0.087	0.102	0.066	0.021	0.02	0	0.015	0.001	0	0	0	5.8	720	385	0.4	0.5
MDGW9	0.332	0.008	0.124	0.02	0.027	0.003	0	0.026	0.003	0	0	0	6.1	265	204	0.8	0.5
MDGW10	0.441	0.114	0.134	0.016	0.024	0.001	0	0.007	0.002	0	0	0	6.2	250	131	1.6	0.4

Table 4.8: Physicochemical parameters of groundwater samples from Cassava mills collected in the dry season

Sample	Fe (mg/l)	Mn (mg/l)	Zn mg/l	Cu (mg/l)	Cr (mg/l)	Cd (mg/l)	Ni (mg/l)	Pb (mg/l)	THC (mg/l)	CN (mg/l)	V mg/l	Hg (mg/l)	pH	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)
CDGW1	0.468	0.024	0.234	0.012	0.044	0.002	0	0.01	0	0	0	0	5.6	621	206	0.1	0.3
CDGW2	0.317	0.104	0.164	0.08	0.045	0.028	0	0.037	0	0.001	0	0	5.8	500	248	0.02	0.3
CDGW3	0.655	0.005	0.045	0.053	0.002	0.014	0	0.024	0	0	0	0	5.3	459	230	0.1	0.2
CDGW4	0.63	0.003	0.154	0.062	0.014	0.021	0	0.042	0	0	0	0	6	425	217	0.01	0.1
CDGW5	0.473	0.004	0.045	0.077	0.051	0.013	0	0.005	0	0	0	0	5.9	625	247	0.2	0.01
CDGW6	0.771	0.044	0.054	0.033	0.046	0.002	0	0.045	0	0	0	0	6	475	311	0.01	0.2
CDGW7	0.421	0.084	0.074	0.055	0.042	0.02	0	0.034	0	0	0	0	5.7	498	226	0.1	0.2
CDGW8	0.654	0.005	0.246	0.071	0.034	0.011	0	0.004	0	0	0	0	5.9	447	244	0.2	0.01
CDGW9	0.503	0.026	0.214	0.091	0.045	0.001	0	0.003	0	0	0	0	6.1	535	162	0.01	0.2

Table 4.9: Physicochemical parameters of groundwater and surface water samples from Crude oil spill sites collected in the dry season

Sample	Fe (mg/l)	Mn (mg/l)	Zn mg/l	Cu (mg/l)	Cr (mg/l)	Cd (mg/l)	Ni (mg/l)	Pb (mg/l)	THC (mg/l)	CN (mg/l)	V mg/l	Hg (mg/l)	pH	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	TSS (mg/L)
SDGW1	0.425	0.125	0.046	0.043	0.055	0.025	0.006	0.054	0.054	0	0.005	0	5.9	120	119	0.1	0.1
SDGW2	0.546	0.025	0.155	0.122	0.064	0.028	0.001	0.013	0.146	0	0.002	0	5.1	115	129	0.01	0.2
SDSW1	4.11	0.288	3.331	0.193	0.093	0.068	0.063	0.074	9.44	0	0.051	0	5	96	40	2.9	3
SDSW2	3.88	0.217	2.287	0.174	0.08	0.061	0.057	0.066	10.23	0	0.045	0	4.9	89	65	2	4.3
CTDSW1	0.541	0.21	0.41	0.165	0	0	0	0	0	0	0	0	6	130	73	2.1	3.2

Table 4.10: Physicochemical Parameters of Soil Samples from Dumpsites Collected in the Wet Season

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
DWS1	161.2	84.5	138.6	36.3	12.01	0.529	0.127	2.52	0.033	0	0	0	5.3	864
DWS2	215.3	112.9	185.1	48.5	16.02	0.707	0.17	3.366	0.044	0	0	0	6.3	578
DWS3	130.7	91.3	125.4	40.6	13.03	0.438	0.113	2.11	0.031	0	0	0	5.8	588
DWS4	352.1	184.7	302.8	79.4	26.21	1.156	0.227	5.504	0.072	0	0	0	6.6	267
DWS5	275.5	144.5	236.9	62.1	20.51	0.904	0.217	4.307	0.056	0	0	0	7.3	468
DWS6	174	91.2	149.6	39.2	12.95	0.571	0.137	2.72	0.036	0	0	0	7.5	755
DWS7	216.3	131.1	156.4	53.3	17.38	0.604	0.118	4.102	0.048	0	0	0	7.1	315
DWS8	230.2	120.7	197.9	51.9	17.13	0.756	0.181	3.599	0.047	0	0	0	7.3	536
DWS9	160.3	113	151.6	43.4	15.15	0.502	0.167	3.436	0.051	0	0	0	6.9	418
DWS10	180.1	101.3	174.5	28.6	12.18	0.614	0.136	2.51	0.031	0	0	0	6.8	501
DWS11	23	104.2	19.8	8.2	3.71	0.156	0.018	0.36	0.005	0	0	0	6.9	491
DWS12	29.5	25.3	18.5	10.9	3.6	0.107	0.017	0.327	0.01	0	0	0	6.3	365
DWS13	31.6	21.4	12	12.1	2.41	0.132	0.016	0.103	0.009	0	0	0	6.9	503
DWS14	27.4	16.1	15	9.9	3.51	0.171	0.014	0.231	0.004	0	0	0	6.1	431
DWS15	15.4	9.7	14	3.1	2.45	0.116	0.012	0.231	0.007	0	0	0	6.9	402
DWS16	12.6	15	11.3	1.52	2.41	0.101	0.01	0.12	0.009	0	0	0	6.6	350
DWS17	16.1	14.5	23.7	3.6	1.51	0.129	0.013	0.252	0.003	0	0	0	6	501
DWS18	20.3	18	30.3	5.9	2.53	0.116	0.024	0.55	0.005	0	0	0	6.1	440
DWS19	8	30.3	11	2.2	3.15	0.112	0.015	0.131	0.003	0	0	0	6.8	403
DWS20	15.4	29.6	10.5	4.4	3.01	0.12	0.013	0.131	0.005	0	0	0	6.4	307

DWS21	10.1	15.4	12.3	6	2.52	0.123	0.001	0.234	0.002	0	0	0	7	408
DWS22	12.6	101.8	9.15	1.4	3.41	0.126	0.005	0.136	0.001	0	0	0	6.8	269
DWS23	11.7	73.6	8.5	2.61	1.161	0.001	0.077	0.31	0.003	0	0	0	7.1	450
DWS24	12.9	14.3	4.1	3.8	2.51	0.123	0.038	2.121	0.031	0	0	0	6.5	278
DWS25	14.3	32	13.6	1.35	0.129	0.013	0.253	0.214	0.023	0	0	0	6.8	310
CTWS1	31.2	13.4	26.8	7	2.3	0.102	0.024	0.481	0.006	0	0	0	6.7	279
CTWS2	25.4	7.5	13.7	5.7	1.9	0.128	0.019	0.394	0.005	0	0	0	7.2	518
CTWS3	38	12	32.7	3.1	2.83	0.214	0.029	0.594	0.006	0	0	0	7.3	265

Table 4.11: Physicochemical Parameters of Soil Samples from Mechanic Workshops Collected in the Wet Season

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
MWS1	333.6	175.5	386.8	75.2	24.28	1.095	0.263	5.215	0.068	1.02	0	0	7.4	269
MWS2	133.2	69.8	114.5	30	9.91	0.493	0.105	2.082	0.027	1.97	0	0	7.3	157
MWS3	450.2	236.1	387.1	101.5	33.51	1.478	0.355	7.038	0.092	2.9	0	0	7.7	243
MWS4	124	16.2	15	28.4	2.48	0.119	0.026	0.521	0.007	1.58	0	0	7.2	348
MWS5	59.1	23.6	21.7	7.5	2.52	0.183	0.013	0.208	0.003	0.004	0	0	7.4	532
MWS6	241	126.4	207.2	54.3	17.94	0.791	0.19	3.767	0.049	0.058	0	0	7.6	524
MWS7	204	85	116.5	38	12.68	0.435	0.016	1.43	0.052	0.02	0	0	7.8	502
MWS8	44.1	120.6	20.7	5.4	1.8	0.191	0.019	0.377	0.006	0.003	0	0	7.5	258
MWS9	33.3	8.9	11.5	3	0.99	0.011	0.083	0.208	0.004	0.001	0	0	7.3	396
MWS10	21	17.5	28.7	6.4	1.603	0.144	0.036	0.703	0.027	0.002	0	0	7.6	534
MWS11	6.45	19.4	29.5	10.2	10.69	0.148	0.011	0.206	0.009	0.001	0	0	6.9	406
MWS12	35.3	19.6	18.4	7.5	0.059	0.018	0.013	0.108	0.006	0.003	0	0	7.3	678
MWS13	27	13.6	23	8.4	0.719	0.132	0.018	1.631	0.014	0.002	0	0	7.4	536
MWS14	32.6	24	7.3	18.9	1.364	0.143	0.12	2.138	0.01	0.004	0	0	7.5	513
MWS15	33.2	12.8	20	13.3	4.352	0.101	0.037	1.135	0.009	0.001	0	0	7.3	418
MWS16	41.1	14	81.3	30.1	1.53	0.241	0.143	2.014	0.03	0.002	0	0	7.6	462
MWS17	38.8	8.5	46.4	21.5	1.34	0.151	0.125	1.343	0.021	0.001	0	0	7.3	369
MWS18	33	13.4	32	43	0.361	0.023	0.058	2.561	0.031	0.004	0	0	7.1	248
MWS19	30.3	7	16.8	13.8	0.786	0.048	0.018	1.038	0.106	0.001	0	0	7.4	365
MWS20	35.4	11.6	38.1	31.5	1.561	0.483	0.164	1.784	0.026	0.001	0	0	7.1	479

MWS21	28.6	14.8	10	5.3	0.014	0.01	0.027	1.094	0.021	0.001	0	0	7.5	502
MWS22	24.3	10.4	14.2	7	0.017	0.071	0.042	0.915	0.007	0.002	0	0	7.3	479
CTWS1	31.2	13.4	26.8	7	2.3	0.102	0.024	0.481	0.006	0	0	0	6.7	279
CTWS2	25.4	7.5	13.7	5.7	1.9	0.128	0.019	0.394	0.005	0	0	0	7.2	518
CTWS3	38	12	32.7	3.1	2.83	0.214	0.029	0.594	0.006	0	0	0	7.3	265

Table 4.12: Physicochemical Parameters of Soil Samples from Cassava Mills Collected in the Wet Season

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
CWS1	223	116.9	191.7	50.3	16.6	0.732	0.176	3.486	0.046	0.087	0	0	7.8	562
CWS2	153	80.2	131.5	34.5	11.28	0.502	0.121	2.392	0.031	0.073	0	0	7.6	531
CWS3	86.1	30	73.4	24.6	7.12	0.379	0.068	1.41	0.023	0.045	0	0	7.8	1276
CWS4	188.3	98.7	161.9	42.4	14.02	0.618	0.148	2.944	0.039	0.074	0	0	7.3	650
CWS5	151	48	134	30.6	16.04	0.326	0.121	1.832	0.027	0.053	0	0	7.1	625
CWS6	123.7	64.8	106.3	27.9	9.21	0.406	0.097	1.943	0.025	0.066	0	0	7.5	3563
CWS7	115.4	53.1	101	23.7	7	0.415	0.071	1.483	0.009	0.051	0	0	7	3148
CWS8	141	86	129.3	28.3	8.3	0.269	0.101	2.132	0.02	0.038	0	0	7.4	734
CWS9	138.1	57.3	100.3	20.9	12.5	0.51	0.044	1.843	0.006	0.068	0	0	7.5	658
CWS10	103.1	37.4	98.6	37	11	0.608	0.03	0.984	0.007	0.026	0	0	7.4	816
CWS11	73	28.3	71.4	19.8	8.7	0.206	0.009	1.078	0.008	0.019	0	0	7.5	573
CWS12	60.2	21.7	39.2	14.6	6	0.189	0.004	0.016	0.005	0.028	0	0	6.9	532
CWS13	32.3	39.5	102.1	30	10.5	0.354	0.087	0.873	0.008	0.065	0	0	7.2	598
CWS14	25.6	26.3	86.7	24.8	8.21	0.307	0.003	0.54	0.006	0.064	0	0	7.4	523
CWS15	27.3	40	99.6	27	11	0.209	0.008	1.034	0.003	0.007	0	0	7.5	1532
CWS16	27	27.8	86.3	24.6	24.6	0.243	0.006	1.008	0.005	0.06	0	0	7.3	415
CWS17	106	62.1	105.1	32.1	9	0.162	0.015	0.348	0.004	0.024	0	0	7.1	521
CWS18	99.7	49.6	112	21.6	3.2	0.201	0.011	0.572	0.007	0.031	0	0	7	633
CWS19	29.9	90.7	120.6	5	1.66	0.132	0.012	0.402	0.003	0.059	0	0	7.4	604
CWS20	38.4	74.9	97.3	4.2	1.4	0.118	0.009	0.35	0.002	0.043	0	0	7.3	521
CWS21	101.3	50	63	30.1	7.8	0.359	0.004	0.463	0.008	0.052	0	0	7.2	598
CWS22	86.7	68.5	51.8	21.6	5	0.106	0.002	1.032	0.006	0.038	0	0	7.4	430
CWS23	30.4	11.7	9.9	4.2	1.4	0.188	0.015	0.193	0.002	0.018	0	0	7.1	451

CWS24	50	18.6	13.2	12.8	0.92	0.132	0.009	0.294	0.005	0.012	0	0	7	395
CTWS1	31.2	13.4	26.8	7	2.3	0.102	0.024	0.481	0.006	0	0	0	6.7	279
CTWS2	25.4	7.5	13.7	5.7	1.9	0.128	0.019	0.394	0.005	0	0	0	7.2	518
CTWS3	38	12	32.7	3.1	2.83	0.214	0.029	0.594	0.006	0	0	0	7.3	265

Table 4.13: Physicochemical Parameters of soil Samples from Crude Oil Spill Sites Collected in the Wet Season

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
SWS1	516.3	270.8	444	116.4	38.43	1.695	0.407	8.071	0.106	10.75	0	0	6	97
SWS2	487.9	255.9	419.5	110	36.32	1.602	0.384	7.627	0.108	8.54	0	0	6.2	124
SWS3	359.6	233.2	391	101	31.3	1.45	0.352	7.039	0.094	8.03	0	0	5.9	74
SWS4	457.3	239.9	393.2	103.1	34.04	1.501	0.36	7.149	0.094	8.1	0	0	5.6	152
SWS5	319	209.6	315	99.2	31.02	1.34	0.316	6.018	0.078	7.93	0	0	5.9	123
SWS6	301.6	200.4	304.2	81.8	26.43	1.301	0.116	4.607	0.071	7.08	0	0	6	108
CTWS1	31.2	13.4	26.8	7	2.3	0.102	0.024	0.481	0.006	0	0	0	6.7	279
CTWS2	25.4	7.5	13.7	5.7	1.9	0.128	0.019	0.394	0.005	0	0	0	7.2	518
CTWS3	38	12	32.7	3.1	2.83	0.214	0.029	0.594	0.006	0	0	0	7.3	265

Table 4.14: Physicochemical Parameters of Soil Samples from Dumpsites Collected in the Dry Season

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
DDS1	171.3	91.3	142.9	43.5	14.03	0.642	0.459	5.732	0.557	0	0	0	3.5	1250
DDS2	248.4	130.4	241.3	55.7	18.01	0.918	0.27	5.423	0.436	0	0	0	5.4	803
DDS3	139.8	97.2	131.5	48.5	16.05	0.459	0.456	4.215	0.335	0	0	0	5	925
DDS4	363.5	197.3	333.7	84.7	31.03	2.364	0.458	7.525	0.284	0	0	0	5.9	470
DDS5	289.7	156.4	247.4	71.3	27.64	1.501	0.548	6.504	0.368	0	0	0	6.5	609
DDS6	189.5	123.6	168.5	49.5	22.46	2.052	1.042	7.051	0.525	0	0	0	6.8	916
DDS7	246.1	143.1	164.5	59.6	23.16	1.106	0.743	5.415	0.459	0	0	0	6.4	478
DDS8	240.4	142.3	213.5	64.4	22.15	1.347	0.814	6.266	0.742	0	0	0	5.7	736
DDS9	171.3	125.4	163.4	49.6	19.17	1.004	0.763	5.235	0.561	0	0	0	5.8	626
DDS10	189.5	121.4	183.7	37.5	19.25	1.013	0.634	4.31	0.734	0	0	0	6	698
DDS11	29	136.4	23.5	19.5	4.51	0.654	0.724	1.344	0.514	0	0	0	6.1	627
DDS12	35.8	38.1	39.2	15.7	6.34	0.702	0.816	0.726	0.654	0	0	0	5.7	506
DDS13	39.3	29.6	28	17.2	7.53	0.734	0.625	0.643	0.546	0	0	0	5.4	699
DDS14	33.4	25.6	21.3	14.5	2.35	0.971	0.714	0.541	0.604	0	0	0	5.2	579
DDS15	20.4	15.5	28.6	6.5	5.13	0.726	0.762	0.652	0.734	0	0	0	6.2	518
DDS16	21.2	23.2	23.3	5.3	4.43	0.804	0.715	0.525	0.821	0	0	0	6	447
DDS17	22.5	28.1	31.5	6.7	2.46	0.903	0.513	0.612	0.502	0	0	0	5.5	628
DDS18	27.2	22.4	39.2	10.4	4.5	0.613	0.521	1.005	0.604	0	0	0	5.7	534
DDS19	12.3	39.1	18.2	4.3	2.52	0.713	0.512	1.132	0.502	0	0	0	6.1	515
DDS20	18.2	35.2	19.3	6.4	3.4	0.174	0.451	0.163	0.534	0	0	0	5.8	423
DDS21	16.3	19.2	19.4	8.4	3.3	0.634	0.501	0.634	0.503	0	0	0	6.3	566
DDS22	15.4	121.5	14.5	2.4	2.16	0.626	0.514	0.536	0.421	0	0	0	6	397
DDS23	17.6	82.4	13.7	2.08	2.2	0.502	0.607	0.501	0.603	0	0	0	6.2	578
DDS24	18.6	19.5	7.4	4.6	1.4	1.23	0.635	3.124	0.525	0	0	0	5.7	365
DDS25	20.5	37.4	19.2	2.41	0.921	0.615	0.645	1.214	0.621	0	0	0	5.9	447
CTDS1	32.4	15.3	27.7	8.5	4.1	0.164	0.065	0.495	0.019	0	0	0	5.5	314
CTDS2	27.2	8.4	14.3	6.4	2.05	0.218	0.059	0.695	0.076	0	0	0	6.4	568
CTDS3	39.5	12.8	33.9	3.4	2.97	0.154	0.069	0.767	0.009	0	0	0	6.6	295

Table 4.15: Physicochemical Parameters of Soil Samples from Mechanic Workshops Collected in the Dry Season

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
MDS1	339.7	186.4	399.7	81.3	29.38	2.704	0.643	7.312	0.608	1.84	0	0	7	387
MDS2	147.4	73.6	124.6	41	13.2	0.934	0.406	3.032	0.701	2.14	0	0	7	237
MDS3	468.7	248.7	398.4	122.6	41.31	2.053	0.675	8.334	0.923	3.4	0	0	7.3	315
MDS4	136.2	21.1	19.2	34.3	4.56	1.145	0.72	1.021	0.501	2.2	0	0	6.9	489
MDS5	64.4	29.7	30.5	8.2	3.42	0.802	0.514	1.503	0.632	1.34	0	0	7.1	627
MDS6	255	135.5	224.1	61.5	21.43	1.431	0.904	4.452	0.446	0.817	0	0	7.1	617
MDS7	214.5	93.2	127.6	40.5	16.71	0.936	0.614	3.302	0.752	0.72	0	0	7.2	608
MDS8	47.5	230.3	35.5	7.5	3.4	0.551	0.513	1.344	0.058	0.603	0	0	7	368
MDS9	45.4	15.6	23.6	5.4	1.76	0.721	0.089	0.805	0.077	0.084	0	0	6.8	394
MDS10	28.6	22.5	39.4	9.1	1.951	0.645	0.651	1.504	0.097	0.076	0	0	7	687
MDS11	8.05	29.6	45.6	22.5	24.06	0.84	0.051	0.602	0.095	0.083	0	0	6.9	573
MDS12	37.5	29.5	27.5	9.7	0.098	0.085	0.063	1.008	0.063	0.095	0	0	6.7	816
MDS13	27	13.6	23	8.4	0.719	0.533	0.814	2.441	0.073	0.087	0	0	6.8	804
MDS14	36.5	28.6	9.3	28.4	1.674	0.551	0.174	2.562	0.062	0.061	0	0	6.9	723
MDS15	39.6	22.6	24.1	18.5	4.655	0.403	0.073	2.045	0.089	0.052	0	0	6.5	636
MDS16	43.2	17.4	9.5	37.5	1.75	0.554	0.56	2.654	0.055	0.102	0	0	7	675
MDS17	39.8	9.7	56.5	28.6	1.652	0.551	0.626	2.533	0.071	0.051	0	0	6.6	516
MDS18	43.5	19.5	37.5	53.1	0.664	0.443	0.098	3.631	0.055	0.044	0	0	6.3	408
MDS19	34.4	8.4	25.6	17.8	1.068	0.845	0.086	3.053	0.506	0.073	0	0	5.4	501
MDS20	38.6	15.7	45.4	34.6	1.766	0.853	0.643	2.755	0.066	0.051	0	0	6.9	426
MDS21	37.8	28.6	19.5	7.5	1.414	0.753	0.657	3.004	0.053	0.061	0	0	6.3	528
MDS22	28.5	14.5	19.6	9.2	0.717	0.876	0.745	1.017	0.087	0.072	0	0	6	524
CTDS1	32.4	15.3	27.7	8.5	4.1	0.164	0.065	0.495	0.019	0	0	0	5.5	314
CTDS2	27.2	8.4	14.3	6.4	2.05	0.218	0.059	0.695	0.076	0	0	0	6.4	568
CTDS3	39.5	12.8	33.9	3.4	2.97	0.154	0.069	0.767	0.009	0	0	0	6.6	295

Table 4.16: Physicochemical Parameters of Soil Samples from Cassava Mills Collected in the Dry Deason

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
CDS1	236	125.6	197.9	55.4	24.64	0.964	0.767	5.466	0.086	0.587	0	0	7.1	768
CDS2	175.4	86.3	143.6	38.7	15.35	0.755	0.446	3.565	0.056	0.757	0	0	6.9	739
CDS3	89.5	37.4	76.6	30.5	9.55	0.779	0.088	2.615	0.057	1.545	0	0	7.5	2374
CDS4	255.5	105.8	174.5	47.6	18.04	0.863	0.468	3.654	0.059	0.476	0	0	6.9	789
CDS5	164.1	56.6	147	35.6	19.06	0.625	0.523	2.324	0.067	0.536	0	0	6.4	773
CDS6	135.7	70.8	126.5	35.6	14.53	0.736	0.667	3.53	0.058	0.656	0	0	6.8	5121
CDS7	127.4	59.5	117.6	28.7	9.3	0.645	0.076	2.586	0.079	0.553	0	0	6.4	5110
CDS8	154.5	96.3	137.5	32.5	14.6	0.766	0.511	3.435	0.053	0.648	0	0	7	997
CDS9	145.3	64.5	114.1	32.5	19.7	0.851	0.069	3.543	0.076	0.568	0	0	6.9	734
CDS10	133.6	47.2	108.5	45.5	13.5	0.788	0.097	2.351	0.077	0.536	0	0	7	1011
CDS11	96.3	35.7	83.5	26.5	14.5	0.206	0.079	3.458	0.208	0.419	0	0	6.8	728
CDS12	69.5	32.5	43.4	21.5	8.2	0.889	0.064	1.313	0.055	0.328	0	0	6.3	720
CDS13	44.4	44.3	123.4	38.4	15.6	0.655	0.088	0.876	0.078	0.565	0	0	6.5	763
CDS14	31.7	35.5	98.7	32.8	10.16	0.657	0.103	1.456	0.086	0.574	0	0	6.9	687
CDS15	34.5	49.7	114.3	38.5	18.3	0.513	0.058	3.137	0.046	0.157	0	0	7	1748
CDS16	36.2	35.5	99.5	36.8	32.7	0.645	0.079	2.435	0.065	0.66	0	0	6.8	652
CDS17	123.3	74.4	115.4	42.5	14.6	0.765	0.065	1.568	0.057	0.553	0	0	6.4	893
CDS18	115.7	54.7	123.3	29.8	5.6	0.631	0.074	2.352	0.087	0.425	0	0	6.2	821
CDS19	35.9	105.8	136.4	7.4	2.77	0.545	0.065	0.754	0.055	0.555	0	0	7	798
CDS20	54.6	98.8	128.6	10.3	2.56	0.765	0.159	1.436	0.076	0.665	0	0	6.7	677
CDS21	119.5	62.3	69.4	38.5	10.9	0.869	0.055	1.567	0.068	0.056	0	0	6.8	703
CDS22	114.7	71.5	63.8	28.6	7.2	0.576	0.065	3.044	0.056	0.535	0	0	6.8	515
CDS23	39.5	19.7	14.06	7.5	1.55	0.788	0.155	1.543	0.054	0.413	0	0	6.6	623
CDS24	59.6	25.5	18.6	20.5	1.94	0.646	0.109	1.054	0.076	0.346	0	0	6.4	593
CTDS1	32.4	15.3	27.7	8.5	4.1	0.164	0.065	0.495	0.019	0	0	0	5.5	314
CTDS2	27.2	8.4	14.3	6.4	2.05	0.218	0.059	0.695	0.076	0	0	0	6.4	568
CTDS3	39.5	12.8	33.9	3.4	2.97	0.154	0.069	0.767	0.009	0	0	0	6.6	295

Table 4.17: Physicochemical Parameters of Soil Samples from Crude Oil Spill sites Collected in the Dry Deason

Sample	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu mg/kg	Cr mg/kg	Cd mg/kg	Ni mg/kg	Pb mg/kg	V mg/kg	THC mg/kg	C N- mg/kg	Hg mg/kg	pH	EC (µS/cm)
SDS1	568.5	278.8	457.3	126.5	45.63	2.755	0.708	15.354	0.716	15.78	0	0	4.2	143
SDS2	546.4	268.5	425.7	120.1	43.25	1.852	0.655	10.546	0.538	12.56	0	0	4	183
SDS3	365.8	246.1	421.5	117.6	39.54	2.24	0.554	9.436	0.604	9.55	0	0	4.1	106
SDS4	468.6	325.7	406.4	119.5	40.54	1.755	0.561	11.541	0.705	13.5	0	0	4.1	230
SDS5	347.5	226.4	326.6	105.7	41.07	1.551	0.456	8.457	0.563	10.66	0	0	4	139
SDS6	334.8	216.6	328.1	85.8	32.36	2.401	0.616	7.516	0.701	11.85	0	0	4.4	140
CTDS1	32.4	15.3	27.7	8.5	4.1	0.164	0.065	0.495	0.019	0	0	0	5.5	314
CTDS2	27.2	8.4	14.3	6.4	2.05	0.218	0.059	0.695	0.076	0	0	0	6.4	568
CTDS3	39.5	12.8	33.9	3.4	2.97	0.154	0.069	0.767	0.009	0	0	0	6.6	295

4.1 Heavy Metals

Heavy metals are significant environmental pollutants due to their persistence, bioaccumulative nature, and toxicity at elevated levels. This section examines the concentrations of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), nickel (Ni), lead (Pb), mercury (Hg), and vanadium (V) across various sampling locations, including dumpsites, mechanic workshops, cassava mills, and crude oil spill sites. The data, presented in water and soil sample analyses (Tables 4.1 – 4.18), highlight seasonal variations and potential ecological and human health risks. These results provide critical insights into the extent of heavy metal contamination and its environmental implications within the study area.

4.1.1 Heavy Metals in Soils

4.1.1.1 Heavy Metals in Soils Around Dumpsites

In areas like dumpsites, where various forms of wastes are dumped, these metals can originate from discarded industrial materials, electronic waste, paints, batteries, and other sources (Oladejo and Otene, 2018).

4.1.1.1.1 Iron (Fe^{2+})

Iron (Fe) is one of the most abundant elements in the Earth's crust and can be found in both natural and anthropogenic environments. In areas designated as dumpsites, where various types of waste are disposed, iron can originate from discarded materials like metals, electronics, and organic waste decomposition processes. The study of iron concentrations in these environments provides insight into pollution levels, potential soil degradation, and the impact on local ecosystems. In the wet season, seventy-seven (77) soil samples were collected from various dumpsites to evaluate the presence of iron, an element that can significantly influence soil chemistry and environmental health due to its potential for contamination from waste materials. According to Table 4.10, the iron concentration in these soil samples varied widely, with levels ranging from as low as 8 mg/kg to as high as 352.1 mg/kg. Notably, some locations exhibited particularly high iron levels; for instance, DWS4 (Etelebu off Tombia/Amasssoma Rd New

Dumpsite 1) recorded an iron concentration of 352.1 mg/kg, suggesting that this site might be experiencing substantial pollution from iron-rich waste or that the natural iron content in the soil is being mobilized by water infiltration. A visual comparison with a control site, as depicted in Figure 4.1, shows that the majority of dumpsite samples had elevated iron levels compared to the control, with some samples demonstrating concentrations far above what would be considered background levels for the area. During the dry season, soil samples were again collected to examine iron concentrations within the study area. As detailed in Table 4.14, the iron levels in these samples ranged from 12.3 mg/kg to 363.5 mg/kg. The highest iron concentration was observed at DDS4 (Etelebu New Dumpsite 1), reaching 363.5 mg/kg, which could indicate significant waste input or a concentration effect due to reduced water content in the soil. Figure 4.1, which also includes the dry season data, shows that while there are still high iron concentrations at some sites, the variability in iron levels appears to be less pronounced than during the wet season, likely due to the aforementioned concentration effect. As can be seen in Figure 4.1, a comparison between the wet and dry seasons demonstrates that the dry season is characterized by a modest rise in the concentration of iron. This rise can be linked to the concentration effect, which occurs when water evaporates and leaves behind increased concentrations of iron in the soil. In the wet season, there is a risk of iron and other contaminants leaching into groundwater, potentially affecting water quality. Conversely, in the dry season, the reduced dilution by water may have resulted in concentrated pollutants within the soil, posing different environmental challenges. The results from both seasons, presented in Tables 4.10 and 4.14, highlight the importance of continuous monitoring and the implementation of waste management strategies to minimize the environmental impact of pollutants like iron.

4.1.1.1.2 Manganese (Mn^{2+})

Manganese, which can be found in steel production waste, batteries, and fertilizer, was analyzed in soil samples from dumpsites during the wet season. Table 4.10 shows manganese concentrations ranging from 9.7 mg/kg to 184.7 mg/kg. The highest level was observed at DWS4

(Etelebu off Tombia/Amasssoma Rd New Dumpsite 1) with 184.7 mg/kg, indicating significant contamination. Figure 4.2 compares these concentrations with a control site, revealing that manganese levels are higher at dumpsites than in control areas except at location DWS15, which might be due to the leaching of manganese from waste materials into the soil.

There was a wide range of manganese concentrations during the dry season, ranging from 15.5 mg/kg to 197.3 mg/kg (Table 4.14). The highest concentration was again at DDS4 (Etelebu New dumpsite 1), suggesting persistent pollution. The mean concentration across the samples is 80.06 mg/kg (Table 4.20), indicating that manganese remains a concern even with reduced moisture. Figure 4.2 shows a slight decrease in manganese concentration during the wet season due to dilution by rainfall. However, the high levels at specific sites like Etelebu remain a concern, highlighting the need for remediation strategies.

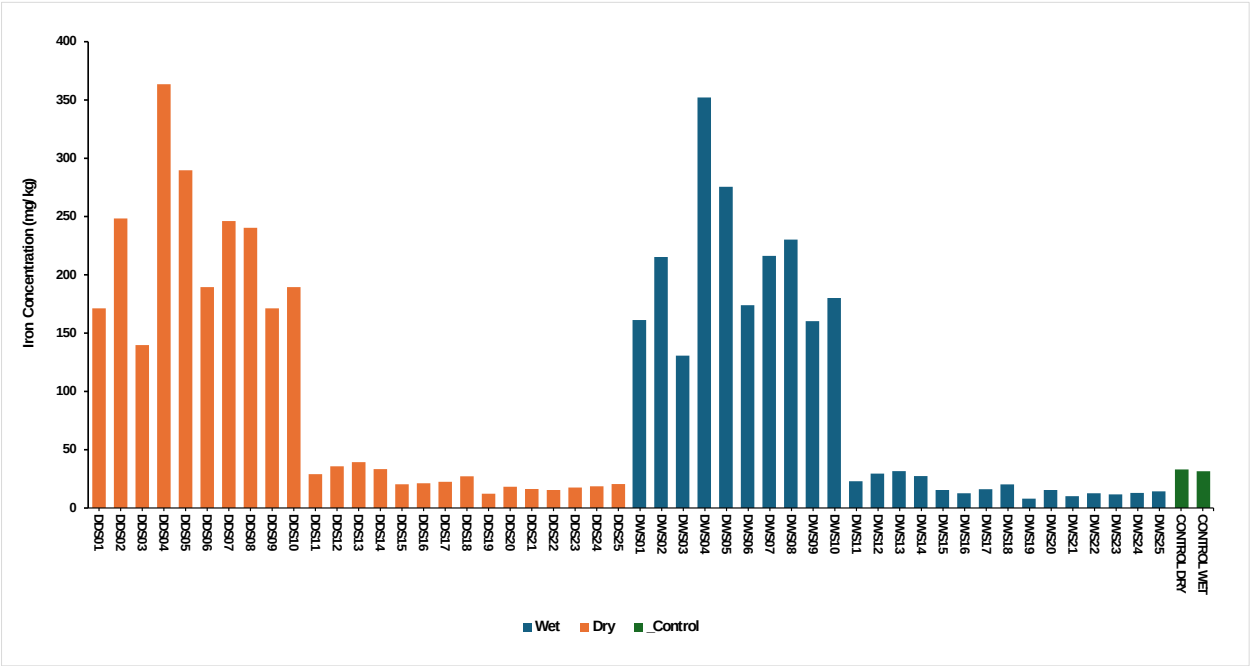

Figure 4.1: Iron concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

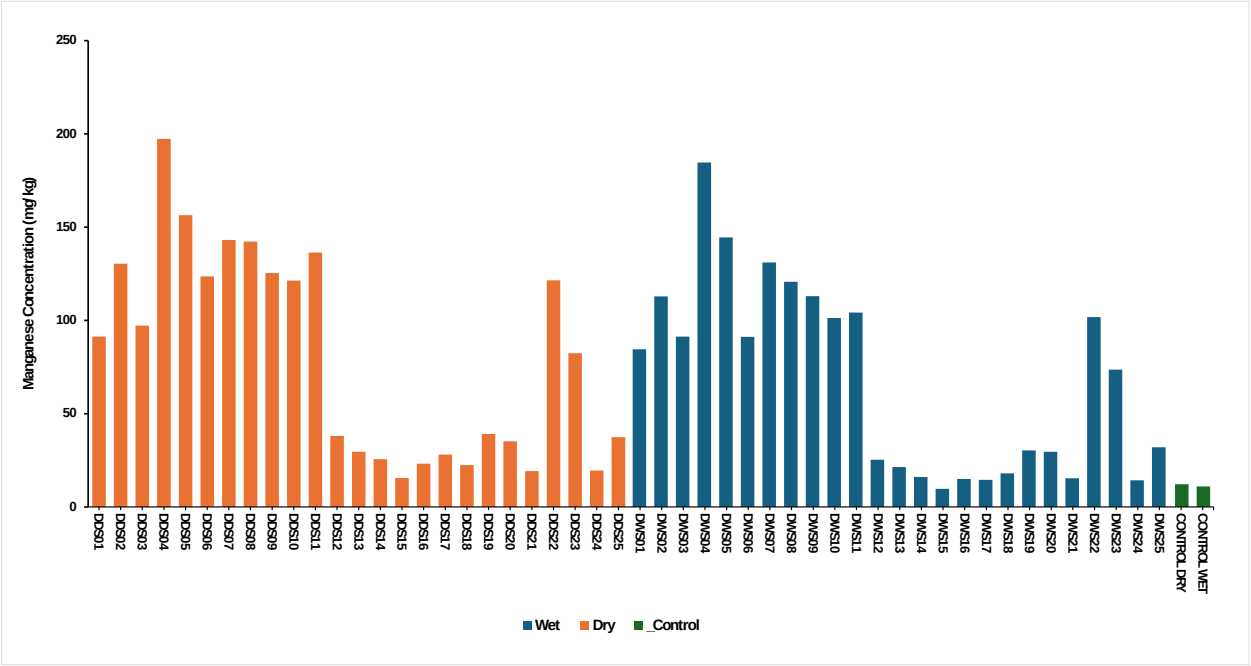

Figure 4.2: Manganese concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

4.1.1.1.3 Zinc (Zn^{2+})

Zinc, often found in galvanized materials, batteries, and industrial waste, varied from 4.1 mg/kg at DWS24 (Okaka 1) to 302.8 mg/kg at DWS4 (Etelebu off Tombia/Amasssoma Rd New dumpsite 1) in the wet season (Table 4.11). The lowest concentration at Okaka 2 suggests less industrial or waste-related zinc input in this area. Figure 4.3 illustrates that zinc levels at dumpsites are significantly higher than the control, indicating substantial environmental impact from waste disposal. During the dry season, zinc levels ranged from 7.4 mg/kg at DDS24 (Okaka 2) to 333.7 mg/kg at DDS4 (Etelebu New dumpsite 1) (Table 4.15). The mean concentration was 93.47 mg/kg (Table 4.19), showing an increase due to the concentration effect caused by less water in the soil. The consistently low concentration at Okaka 2 suggests that zinc pollution might affect this site less. The seasonal comparison shown in Figure 4.3 demonstrates that zinc concentrations change over time, with larger levels occurring during the dry season because of the concentration effect. This highlights the importance of diligent waste management to effectively prevent zinc pollution.

4.1.1.1.4 Copper (Cu^{2+})

Copper, which can come from electrical wiring, electronic waste, and agricultural chemicals, was found in concentrations ranging from 1.35 mg/kg at DWS25 (Okaka 2) to 79.4 mg/kg at DWS4 (Etelebu off Tombia/Amasssoma Rd New Dumpsite 1) in the wet season (Table 4.11). The lowest concentration at Okaka 2 might reflect less copper contamination from waste. Figure 4.4 compares these levels with the control, showing that copper concentrations are notably higher at dumpsites. In the dry season, copper concentrations varied from 2.08 mg/kg at DDS23 (Swali 2) to 84.7 mg/kg at DDS4 (Etelebu New dumpsite 1) (Table 4.15). The mean concentration was 27.63 mg/kg (Table 4.19), indicating that copper, though less prevalent than zinc or manganese, still poses an environmental concern. Swali 2, with the lowest concentration, might be less affected by copper pollution sources. Figure 4.4 shows that copper levels remain relatively between seasons, suggesting that this metal is less affected by dilution effects.

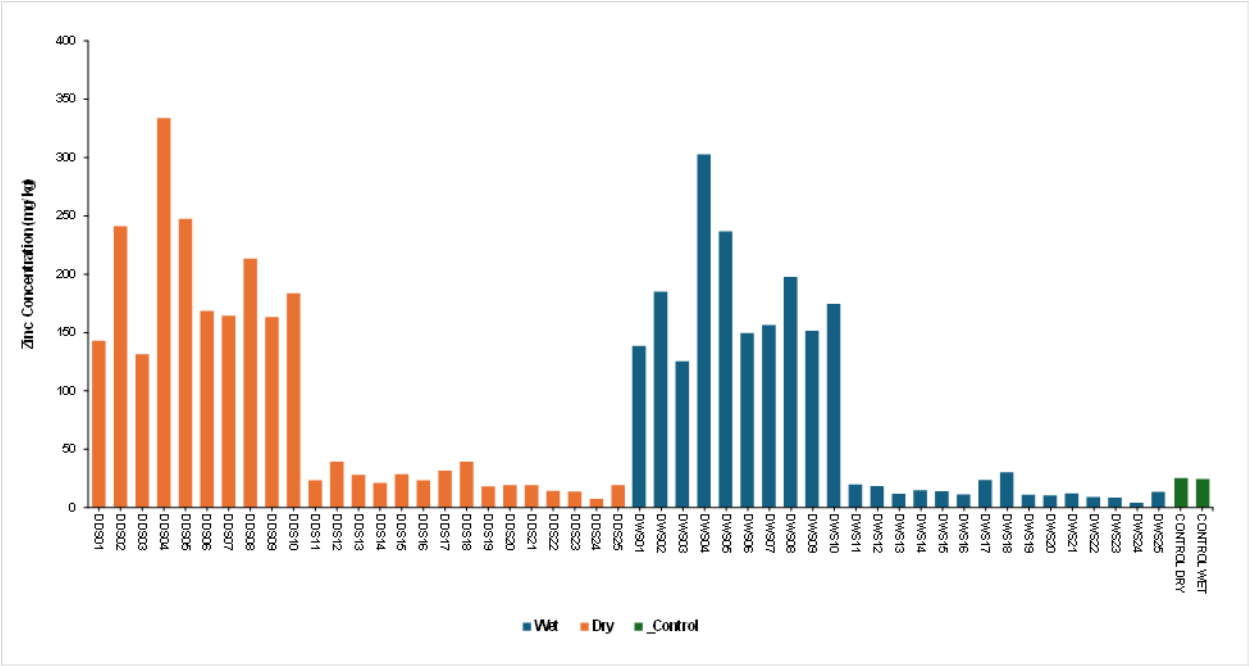

Figure 4.3: Zinc concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

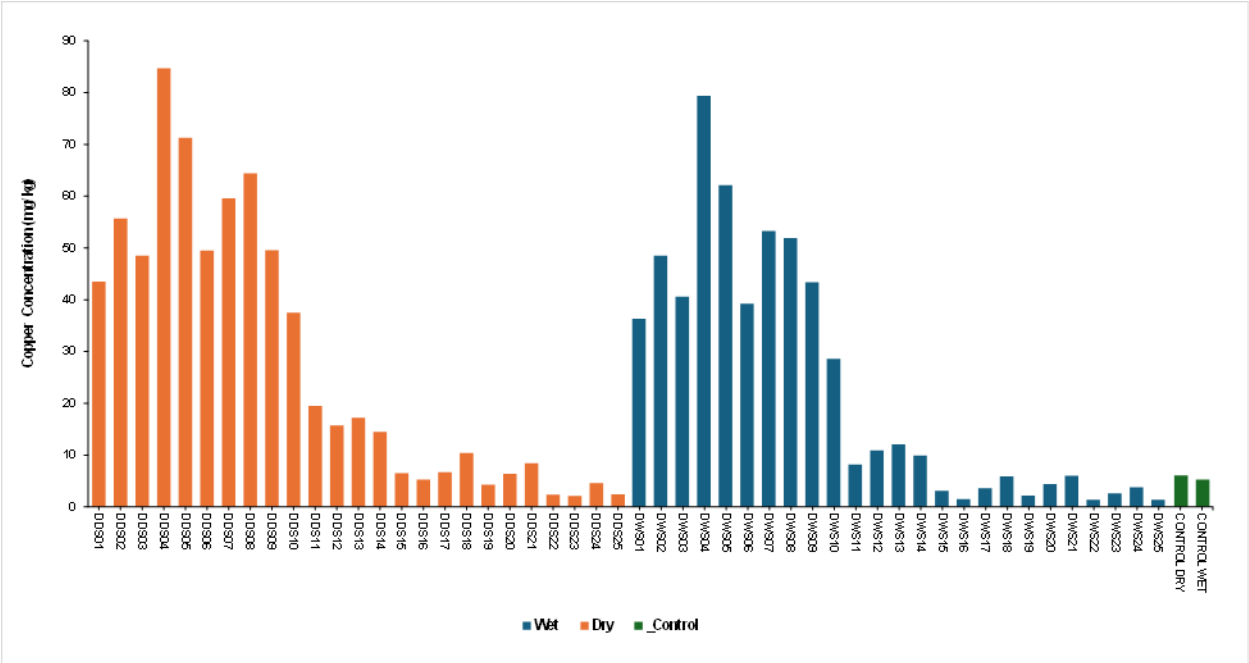

Figure 4.4: Copper concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

4.1.1.1.5 Chromium (Cr^{6+})

Chromium, which can come from industrial processes like tanning, electroplating, and stainless-steel production, was found in concentrations ranging from 0.129 mg/kg at DWS25 (Okaka 2) to 26.21 mg/kg at DWS4 (Etelebu off Tombia/Amasssoma Rd New Dumpsite 1) during the wet season (Table 4.11). The lowest concentration at Okaka 2 suggests minimal chromium pollution in this area, possibly due to less industrial activity or waste disposal containing chromium. Figure 4.5 compares these levels with a control site, showing that chromium concentrations at dumpsites are significantly higher, indicating substantial environmental impact.

Chromium concentrations in soil samples varied from 0.921 mg/kg at DDS25 (Okaka 2) to 31.03 mg/kg at DDS4 (Etelebu New Dumpsite 1) throughout the dry season, as shown in Table 4.15. The average concentration was 10.64 mg/kg, as shown in Table 4.19. This indicates that chromium, despite being present in lesser quantities than other metals, is still a cause for concern because it has the potential to be hazardous. Okaka 2 continued to have the lowest chromium concentration, suggesting a consistent pattern of lower pollution at this site. Figure 4.5 shows that chromium levels do not fluctuate significantly between the wet and dry seasons, suggesting that this metal is less affected by dilution effects. However, the high levels at specific sites like Etelebu remain a concern, highlighting the need for targeted remediation efforts.

4.1.1.1.6 Cadmium (Cd^{2+})

Cadmium, found in industrial waste, fertilizers, and batteries, varied from 0.001 mg/kg at DWS23 (Swali 2) to 1.156 mg/kg at DWS4 (Etelebu off Tombia/Amasssoma Rd New dumpsite 1) (Table 4.11) with a mean of 0.34 mg/kg in the wet season. The lowest concentration at Swali 2 might indicate less cadmium pollution from industrial sources. Figure 4.6 compares these concentrations with the control, highlighting elevated cadmium levels at dumpsite locations.

During the dry season, cadmium concentrations ranged from 0.174 mg/kg at DDS20 (Amarata 1) to 2.364 mg/kg at DDS4 (Etelebu New dumpsite 1) (Table 4.15). The mean cadmium concentration was 0.92 mg/kg (Table 4.19), showing an increase due to reduced water content.

Amarata 1, with the lowest concentration, suggests this site might be less affected by cadmium pollution. Figure 4.6 shows a slight increase in cadmium concentration during the dry season when compared to the concentration in wet season, likely due to the dilution effect. Cadmium is of particular concern due to its high toxicity and potential for bioaccumulation.

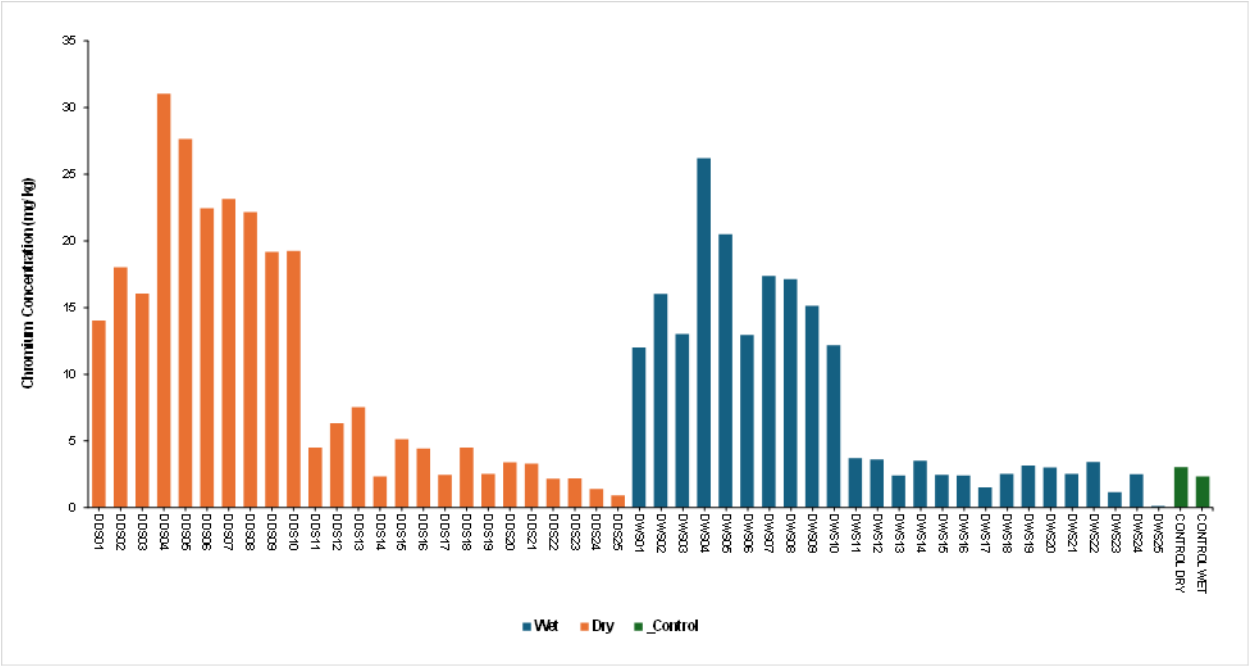

Figure 4.5: Chromium concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

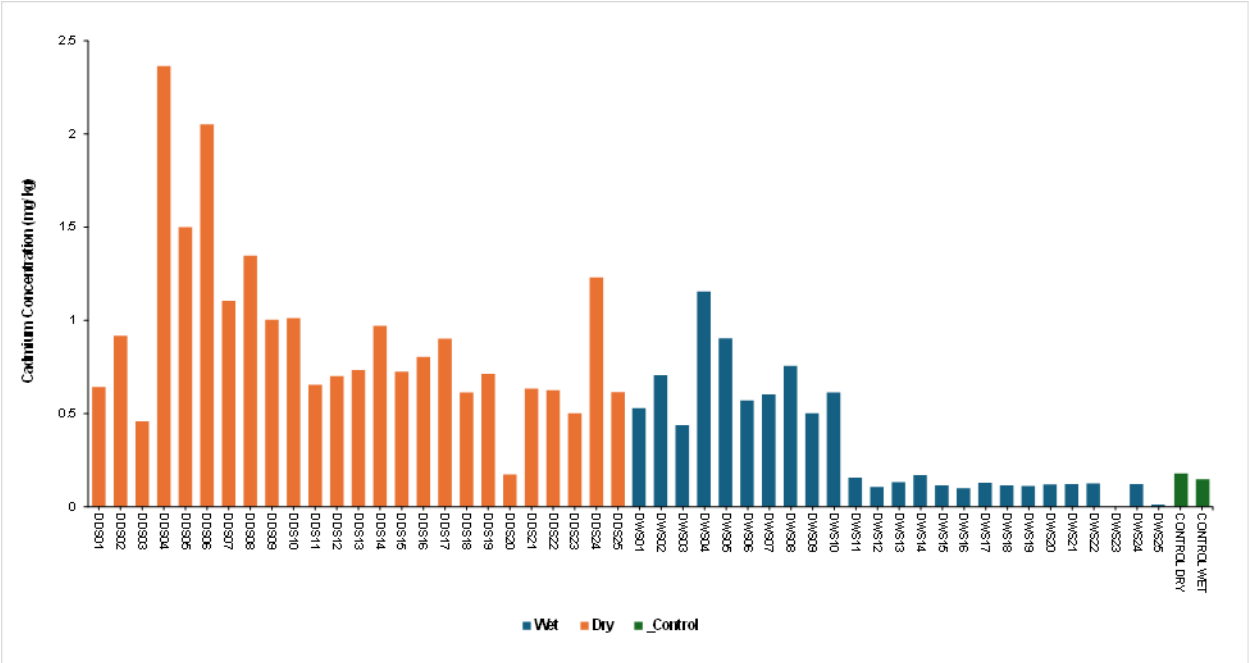

Figure 4.6: Cadmium concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

4.1.1.1.7 Nickel (Ni^{2+})

Nickel, found in various industrial wastes, batteries, and alloys, varied from 0.001 mg/kg at DWS23 (Swali 2) to 0.253 mg/kg at DWS4 (Etelebu off Tombia/Amasssoma Rd New Dumpsite 1) with a mean of 0.08 mg/kg in the wet season (Table 4.11). The lowest concentration at Swali 2 might indicate less nickel contamination from waste materials. Figure 4.7 compares these levels with a control site, revealing that nickel concentrations at dumpsites are generally higher than at control sites. Nickel concentrations varied from 0.27 mg/kg at DDS2 (Etelebu Tombia/Amasssoma Rd Old Dumpsite 2) to 1.042 mg/kg at DDS6 (Etelebu New Dumpsite 3) during the dry season (Table 4.15). The mean concentration was found to be 0.62 mg/kg (Table 4.19), indicating a modest increase for mean concentration. Considering that Etelebu Tombia/Amasssoma Rd Old Dumpsite 2 and Amarata 1 had the lowest concentrations, it is possible that these locations have a lower level of nickel pollution than other locations. Figure 4.7, which shows a comparison for both seasons revealed a slight increase in nickel concentrations during the dry season, likely due to dilution. This indicates that nickel pollution should be managed carefully to prevent its accumulation in the environment.

4.1.1.1.8 Lead (Pb^{2+})

Lead, which is highly toxic and can originate from paints, batteries, and automotive waste, had concentrations ranging from 0.103 mg/kg at DWS13 (Akenfa 1, Epie Creek 2) to 5.504 mg/kg at DWS4 (Etelebu off Tombia/Amasssoma Rd New Dumpsite 1) with a mean concentration of 1.59 mg/kg in the wet season (Table 4.11). The lowest concentration at Akenfa 1, Epie creek 2 might suggest less lead contamination in this particular area. Figure 4.8 illustrates that lead levels at dumpsites are significantly higher than at control sites. The dry season result shows lead concentrations ranging from 0.163 mg/kg at DDS20 (Amarata 1) to 7.525 mg/kg at DDS4 (Etelebu New Dumpsite 1) (Table 4.15). The mean concentration was 2.84 mg/kg (Table 4.19), indicating an increase due to the concentration effect. Amarata 1, with the lowest concentration, suggests that this site might be relatively less polluted by lead. Comparing both seasons, Figure

4.8 demonstrates that lead concentrations tend to rise slightly during the dry season. This highlights the significance of effectively managing lead contamination.

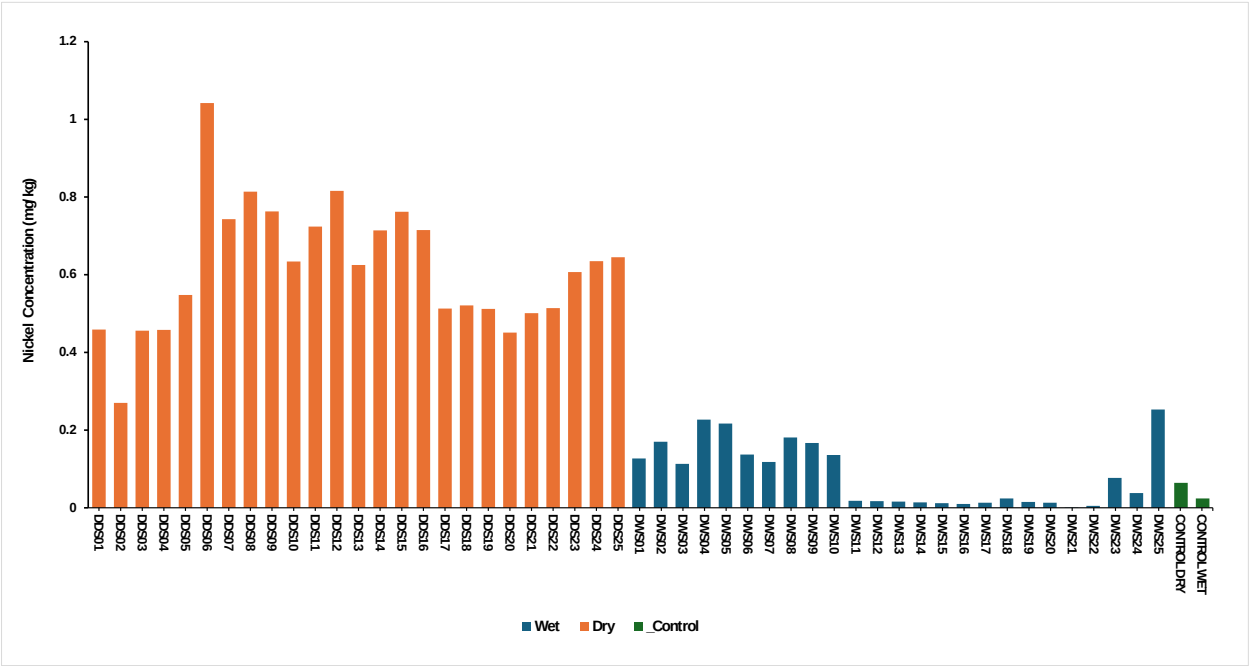

Figure 4. 7: Nickel concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

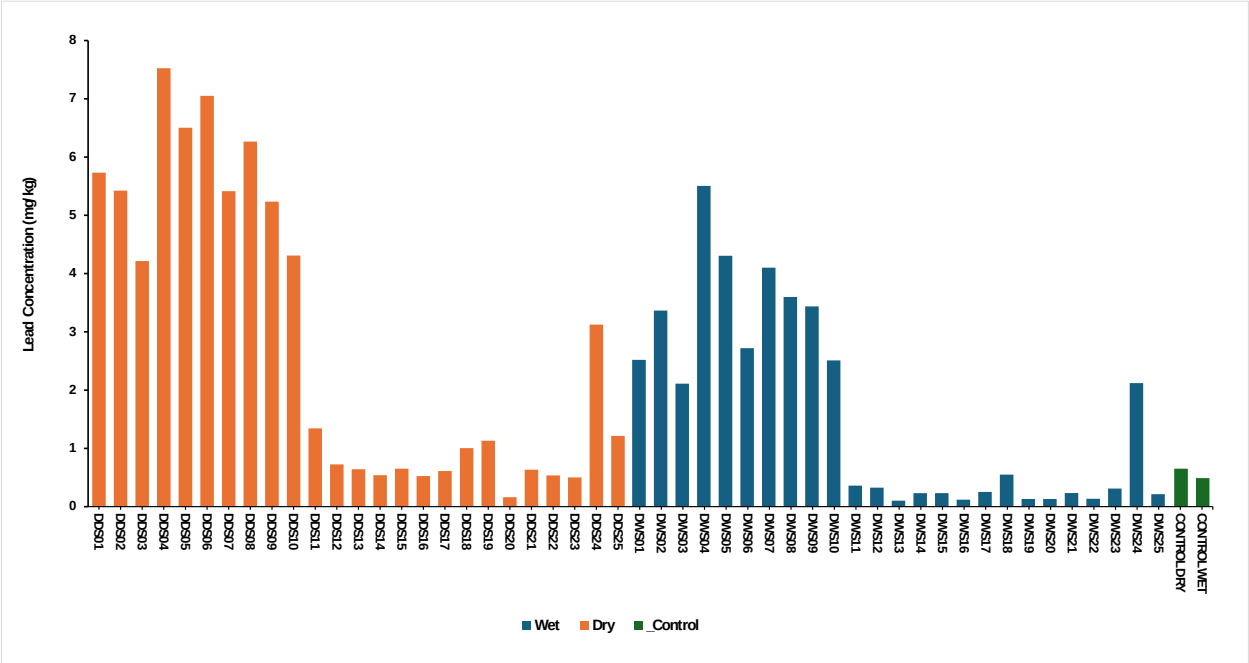

Figure 4. 8: Lead concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

4.1.1.1.9 Vanadium (V^{2+})

Vanadium, which can be found in oil and petroleum products, ranged from 0.001 mg/kg at DWS23 (Swali 2) to 0.072 mg/kg at DWS4 (Etelebu off Tombia/Amasssoma Rd New dumpsite 1) with a mean of 0.02 mg/kg in the wet season (Table 4.11). The lowest concentration at Swali 2 suggests minimal vanadium pollution in this area, possibly due to less oil-related waste. Figure 4.9 compares these levels with the control, indicating elevated vanadium levels at dumpsite locations.

In the dry season, vanadium concentrations varied from 0.284 mg/kg at DDS4 (Etelebu New dumpsite 1) to 0.821 mg/kg at DDS16 (Igbogene 2) (Table 4.15). The mean vanadium concentration was 0.55 mg/kg (Table 4.19), showing an increase due to reduced water content in the soil. Etelebu New dumpsite 1 had the lowest concentration, suggesting that this site might be less affected by vanadium pollution compared to others. Figure 9 reveals a slight increase in vanadium concentration during the dry season when compared to the wet season, likely due to the concentration effect. Vanadium, though less commonly discussed, is still of concern due to its potential toxicity and environmental impact.

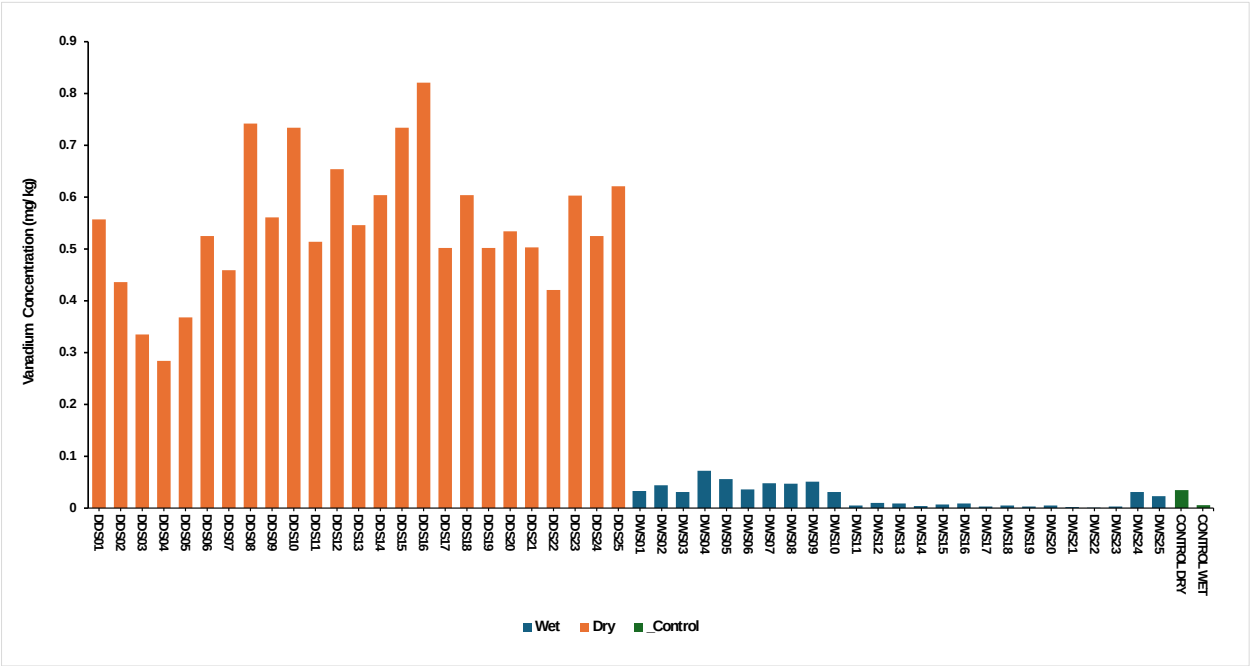

Figure 4. 9: Vanadium concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

4.1.1.2 Heavy Metals in Soils Around Mechanic Workshops

Soil contamination in mechanic workshops is a significant environmental concern due to the extensive use of metals and oils, which can lead to the accumulation of heavy metals like iron, manganese, nickel, etc.

4.1.1.2.1 Iron (Fe^{2}+)

The iron (Fe) content in soils from mechanic workshops exhibits significant variability across the sampled locations, reflecting both site-specific activities and environmental factors. During the wet season, iron concentrations ranged from a minimum of 6.45 mg/kg at MWS11 (Kpansia Melford Okilo Rd. 2) to a maximum of 450.2 mg/kg at MWS3 (Mechanic Village Imiringi) (Table 4.12). The mean concentration during this season was notably high, around 91.34mg/kg (Table 4.19), reflecting the extensive deposition of metal particles and iron-based residues associated with vehicle repairs and maintenance.In the dry season, the pattern remained consistent, with values ranging from 8.05 mg/kg at MDS11 to 468.7 mg/kg at MDS3 with a mean of 98.27 mg/kg (Table 4.16). The highest concentration recorded at MDS3 could be attributed to prolonged and intensive mechanic operations at that site, coupled with poor waste management practices. Seasonal variations are also evident as shown in Figure 4.10. For example, site MWS03 showed a significant increase in iron concentration from the wet season (450.2 mg/kg) to the dry season (468.7 mg/kg). This increase could be attributed to concentration effects from lack of rainfall in the dry season or different operational activities during these periods.

4.1.1.2.2 Manganese (Mn^{2+})

The manganese (Mn) content in soils from mechanic workshops also exhibits significant variability, akin to the pattern observed with iron. This variability reflects the impact of mechanic activities and environmental conditions at different sampling locations. During the wet season, manganese concentrations in the soil samples from mechanic workshops varied widely, with the lowest concentration recorded at 7 mg/kg at MWS19 (Oxbow Lake Rd. Swali) and the

highest at 236.1 mg/kg at MWS03 (Mechanic Village Imiringi) (Table 4.12). The mean concentration for this season was approximately 47.67 mg/kg (Table 4.20), indicating a substantial presence of manganese, likely due to the use of manganese-containing alloys in automotive parts and the subsequent degradation or disposal of these materials.In the dry season, manganese levels showed a similar range, from 8.4 mg/kg at MDS19 (Table 4.16) to 248.7 mg/kg at MDS03 (Table 4.16). The mean concentration during this period was slightly higher at 58.83 mg/kg (Table 4.19). The elevated levels at MDS03 might be due to the accumulation of manganese from the continuous mechanical operations and possibly less leaching of manganese into groundwater due to the absence of significant rainfall, which would otherwise dilute soil concentrations.Seasonal variation (Figure 4.11) as depicted by higher concentration of manganese at MWS03 during the dry season, which then decreases in the wet season to 248.7 mg/kg, suggests that rainwater might play a role in redistributing manganese within the soil profile. This could involve either washing manganese deeper into the soil or moving it into nearby water bodies, thereby reducing its concentration at the surface. Conversely, during the dry season, the lack of rainfall minimizes the leaching effect, potentially leading to a slight increase in the mean manganese concentration across the sites.

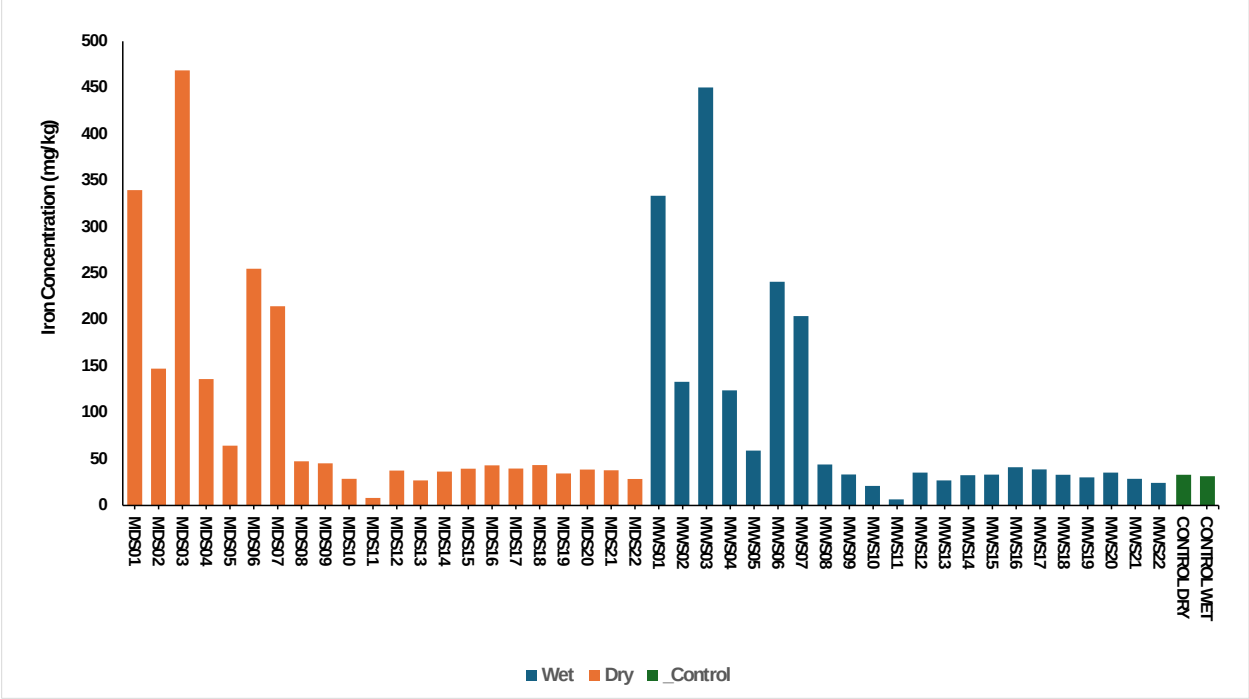

Figure 4.10: Iron concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

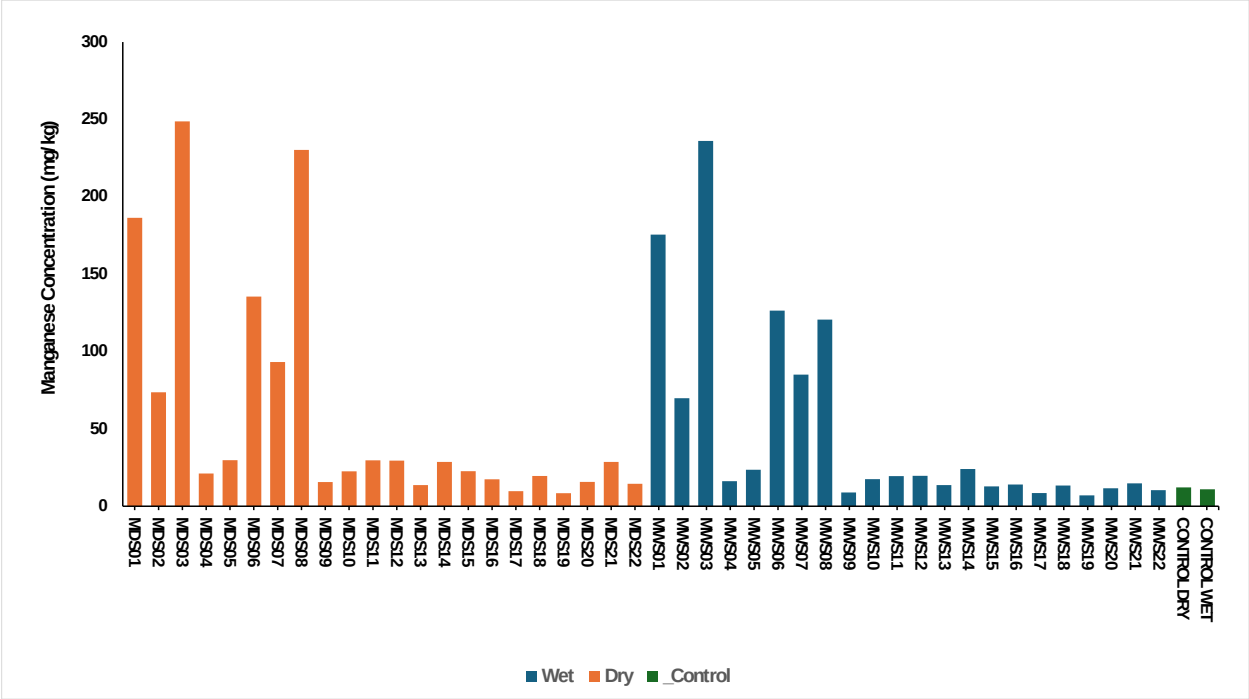

Figure 4.11: Manganese concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

4.1.1.2.1 Zinc (Zn^{2+})

During the wet season, as detailed in Table 4.12, the soil around mechanic workshops exhibited a broad range of zinc concentrations, with the lowest being 7.3 mg/kg at MWS14 (Yenezue-gene Otiotio Rd.) and reaching a high of 387.1 mg/kg at MWS03 (Mechanic Village Imiringi). This variability underscores the significant contamination from zinc, likely originating from zinc-coated parts, zinc-based lubricants, and other automotive materials. The mean concentration for this season was approximately 74.85 mg/kg (Table 4.20), reflecting the extensive presence of zinc in the soil environment. Zinc levels in soil samples taken from mechanic workshops during the dry season ranged from 9.3 mg/kg at MDS14 (Yenezue-gene Otiotio Rd.) to a maximum of 399.7 mg/kg at MDS01 (Mechanic Village Imiringi Rd. 1) as presented in Table 4.16. The mean concentration for this period was slightly higher at 80.26 mg/kg (Table 4.19), indicating an accumulation of zinc due to the lack of significant rainfall, which would otherwise dilute or leach the metal from the soil. This increase can be attributed to continuous mechanical operations and the absence of water movement. The seasonal variation in zinc concentration, as depicted in Figure 4.12, highlights the role of rainfall in soil zinc distribution. A reduction in surface concentration results from the redistribution of zinc within the soil profile during the wet season, which may cause it to be washed deeper into the soil or into adjacent water bodies. In Figure 4.12, the impact of leaching is demonstrated by a decrease in zinc content at MWS03 from the wet to the dry season. The lack of rainfall during the dry season, on the other hand, reduces this leaching impact and permits a modest rise in zinc concentration because of accumulation from continuous mechanical activity.

4.1.1.2.1 Copper (Cu^{2+})

Copper concentrations in the soil during the wet season, as presented in Table 4.12, ranged from 3 mg/kg at MWS09 (Kpansia JJWAKS 2) to 101.5 mg/kg at MWS03 (Mechanic Village Imiringi Rd. 2) with a mean of 25.46 mg/kg (Table 4.20). This range suggests that copper, commonly used in electrical components and as an alloy in automotive parts, is being introduced

into the soil at varying rates across different mechanic workshop sites. Copper levels during the dry season ranged from 5.4 mg/kg at MDS09 to 122.6 mg/kg at MDS03, with the mean concentration rising to 31.24 mg/kg (Table 4.19), as indicated in Table 4.16. Less copper leaching from the soil and its buildup from ongoing mechanical operations may be the cause of this higher mean concentration during the dry season (Figure 4.13). Seasonal variations in copper concentration, as illustrated in Figure 4.13, reveal how environmental conditions affect copper levels in the soil. At MWS03, copper concentration decreased from 101.5 mg/kg in the wet season to 122.6 mg/kg in the dry season, indicating a similar pattern of redistribution and accumulation. During the wet season, copper at MWS03 was likely dispersed by water, reducing its concentration at the surface.

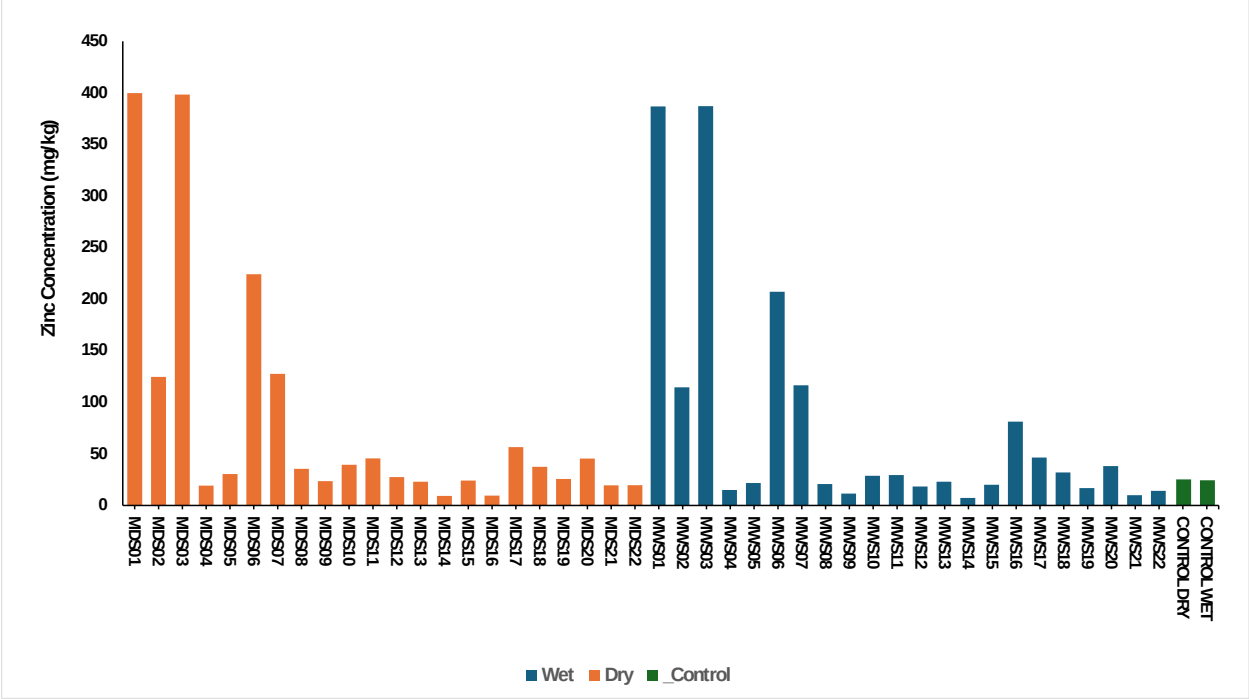

Figure 4.12: Zinc concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

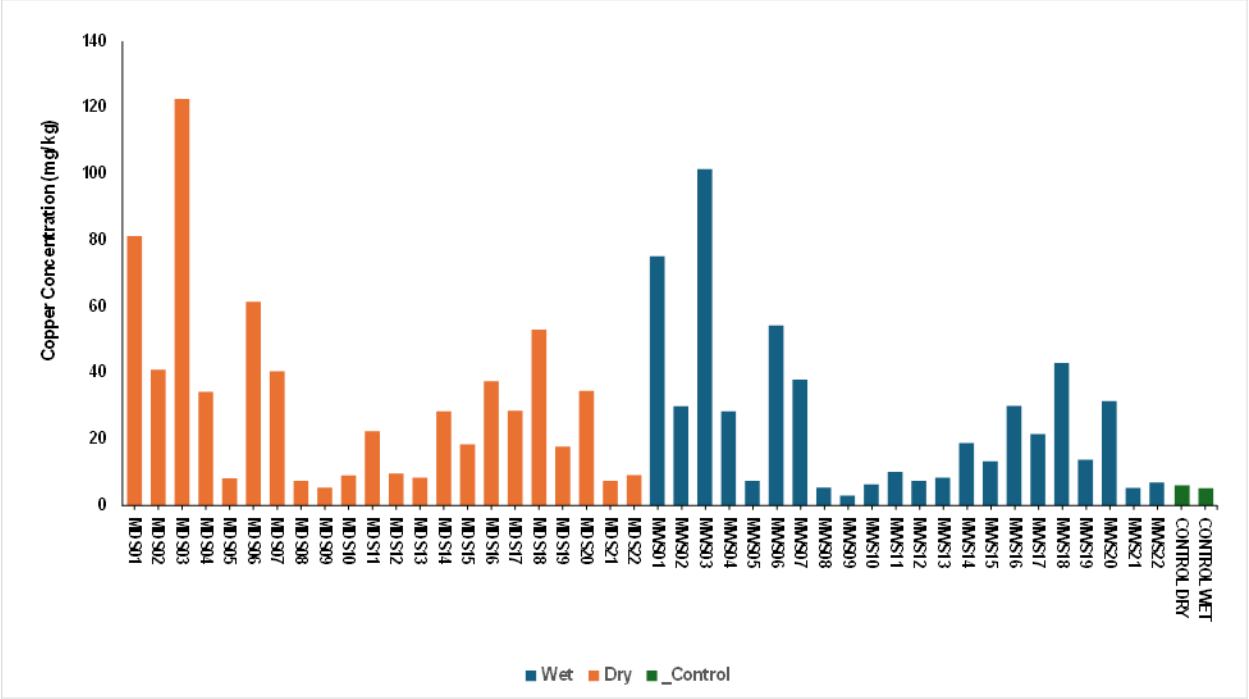

Figure 4. 13: Copper concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

4.1.1.2.2 Chromium (Cr^{6+})

During the wet season, as detailed in Table 4.12, the soil around mechanic workshops exhibited a range of chromium concentrations from 0.014 mg/kg at MWS21 (UBA Swali Rd.) to a high of 33.51 mg/kg at MWS03 (Mechanic Village Imiringi Rd. 2), with a mean concentration of approximately 5.93 mg/kg (Table 4.20). This variability suggests that the use of chromium-containing materials, such as brake linings and chrome-plated parts, contributes significantly to soil contamination. In the dry season, as per Table 4.16, chromium levels in the soil samples ranged from 0.098 mg/kg at MDS12 (Yenizue-Epie Septex Rd. 1) to 41.31 mg/kg at MDS03 (Mechanic Village Imiringi Rd. 2), with the mean slightly higher at 8.06 mg/kg (Table 4.19). This increase in mean concentration can be attributed to the accumulation of chromium due to less leaching from rainfall, highlighting the persistence of chromium contamination.The seasonal variation in chromium concentration, as depicted in Figure 4.14, shows a decrease in chromium levels at MWS03 from the wet season to the dry season, indicating that rainfall redistributes chromium within the soil profile or into nearby water bodies, reducing its concentration at the surface. However, the dry season sees an increase in chromium concentration at MDS03, suggesting that without significant rainfall, chromium accumulates in the soil, likely due to continuous exposure from mechanic activities.

4.1.1.2.3 Cadmium (Cd^{2+})

Cadmium concentrations in the soil during the wet season, as outlined in Table 4.11, ranged from 0.01 mg/kg at MWS09 (Kpansia JWAKS 2) to 1.478 mg/kg at MWS03 (Mechanic Village Imiringi Rd. 2), with a mean of 0.30 mg/kg (Table 4.20). This indicates a wide distribution of cadmium, possibly from cadmium-containing alloys or batteries used in automotive applications. Cadmium levels throughout the dry season varied from 0.085 mg/kg at MDS12 (Yenezue- Epie Saptex Rd. 1) to 2.704 mg/kg at MDS01 (Mechanic Village Imiringi Rd. 1), with the mean rising to 0.87 mg/kg (Table 4.19), according to Table 4.16. The higher mean concentration in the dry season suggests that without significant rainfall, cadmium accumulates in the soil, potentially

due to less leaching and continuous exposure to cadmium sources. The seasonal changes in cadmium concentration, as illustrated in Figure 4.15, show a clear trend of cadmium accumulation during the dry season. Cadmium levels increased from 0.01 mg/kg in the wet season to 2.704 mg/kg in the dry season, highlighting the role of rainfall in redistributing cadmium within the soil or into nearby water bodies, reducing its concentration at the surface during the wet season.

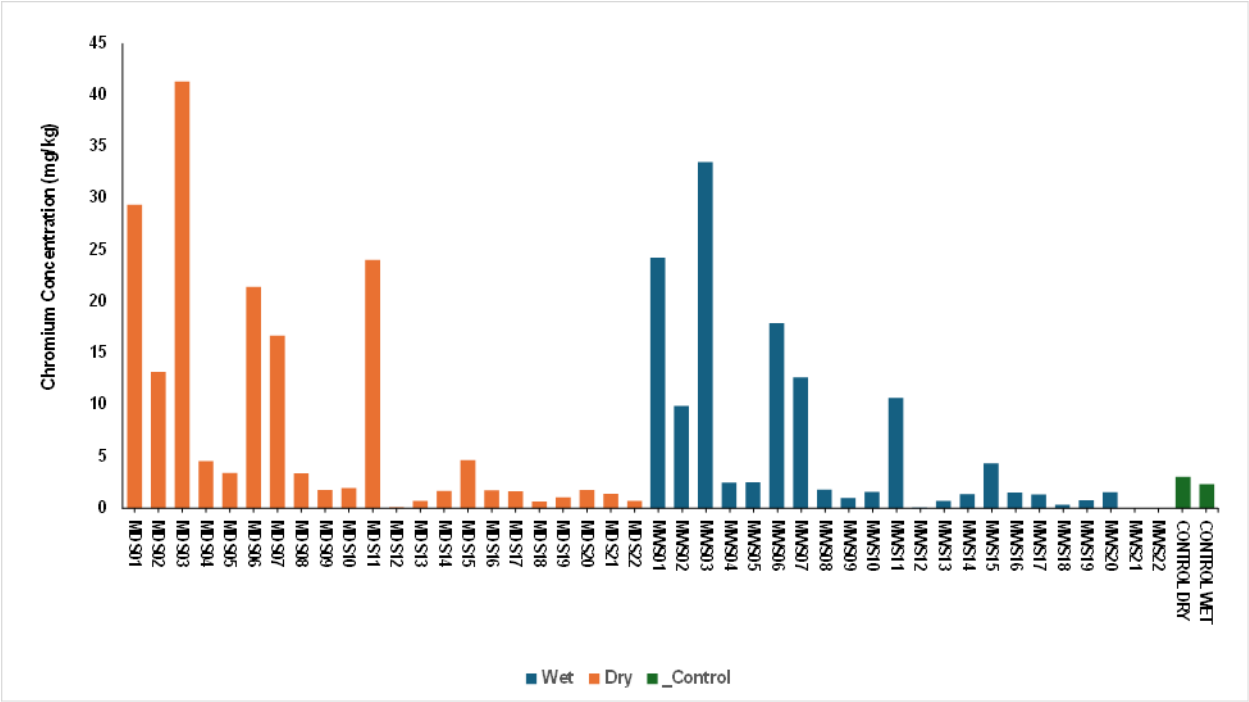

Figure 4.14: Chromium concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

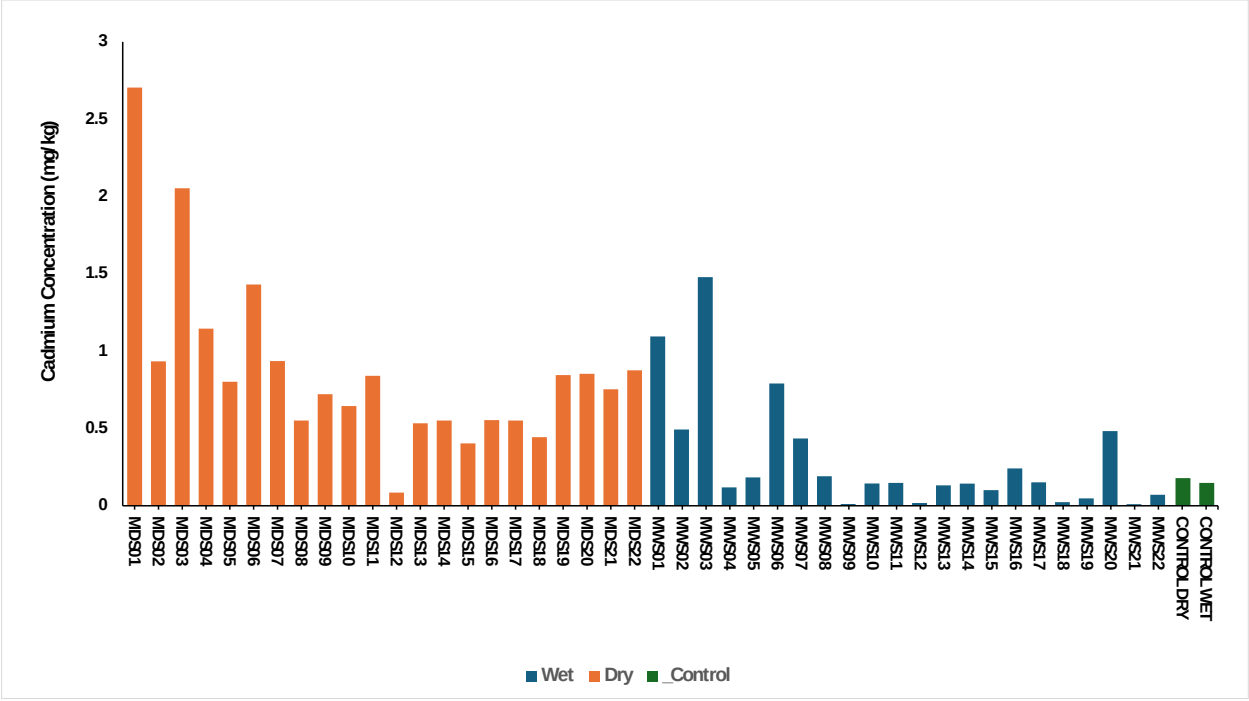

Figure 4.15: Cadmium concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

4.1.1.2.4 Nickel (Ni^{2+})

During the wet season, as detailed in Table 4.12, nickel concentrations varied from 0.011 mg/kg at MWS11 (Kpansia Melford Okilo Rd. 2) to 0.355 mg/kg at MWS03 (Mechanic Village Imiringi Rd. 3) with a mean of 0.09 mg/kg (Table 4.20). This range suggests that nickel alloys used in automotive parts contribute to soil contamination. In the dry season, as per Table 4.16, nickel levels ranged from 0.051 mg/kg at MDS11 (Kpansia Melford Okilo Rd. 2) to 0.904 mg/kg at MDS06 (Kpansia Nikton Rd. 1), with the mean concentration increasing to 0.47 mg/kg (Table 4.19). The slight increase in mean nickel concentration indicates the persistence of nickel contamination, likely due to less leaching and continuous exposure to nickel sources. The seasonal variation in nickel concentration, as depicted in Figure 4.16, shows a slight increase in mean concentration during the dry season, with MDS06 having the highest concentration at 0.904 mg/kg. This suggests that rainfall plays a role in dispersing nickel within the soil or into nearby water bodies, reducing its concentration at the surface during the wet season, while the dry season allows for accumulation.

4.1.1.2.5 Lead (Pb^{2+})

Lead levels in the soil during the wet season, as detailed in Table 4.12, ranged from 0.108 mg/kg at MWS04 (Mechanic Village Imiringi Rd. 4) to 7.038 mg/kg at MWS03 (Mechanic Village Imiringi Rd. 3), with a mean of 1.71 mg/kg (Table 4.20). This variability reflects the impact of lead-based products like old paint, solder, and batteries used in mechanic workshops. According to Table 4.16, lead concentrations during the dry season ranged from 0.602 mg/kg at MDS11 (Kpansia Melford Okilo Rd. 2) to 8.334 mg/kg in MDS03 (Mechanic Village Imiringi Rd. 3), with the mean rising to 2.72 mg/kg (Table 4.19). Due to less leaching to dilute its presence, lead-based compounds may accumulate in the soil during the dry season, increasing the concentration of lead.

The seasonal changes in lead concentration, as illustrated in Figure 4.17, show a clear trend of lead accumulation during the dry season. At MDS03, lead levels increased from 7.038 mg/kg in

the wet season to 8.334 mg/kg in the dry season, indicating that rainfall redistributes lead within the soil profile or into nearby water bodies, reducing its concentration at the surface during the wet season.

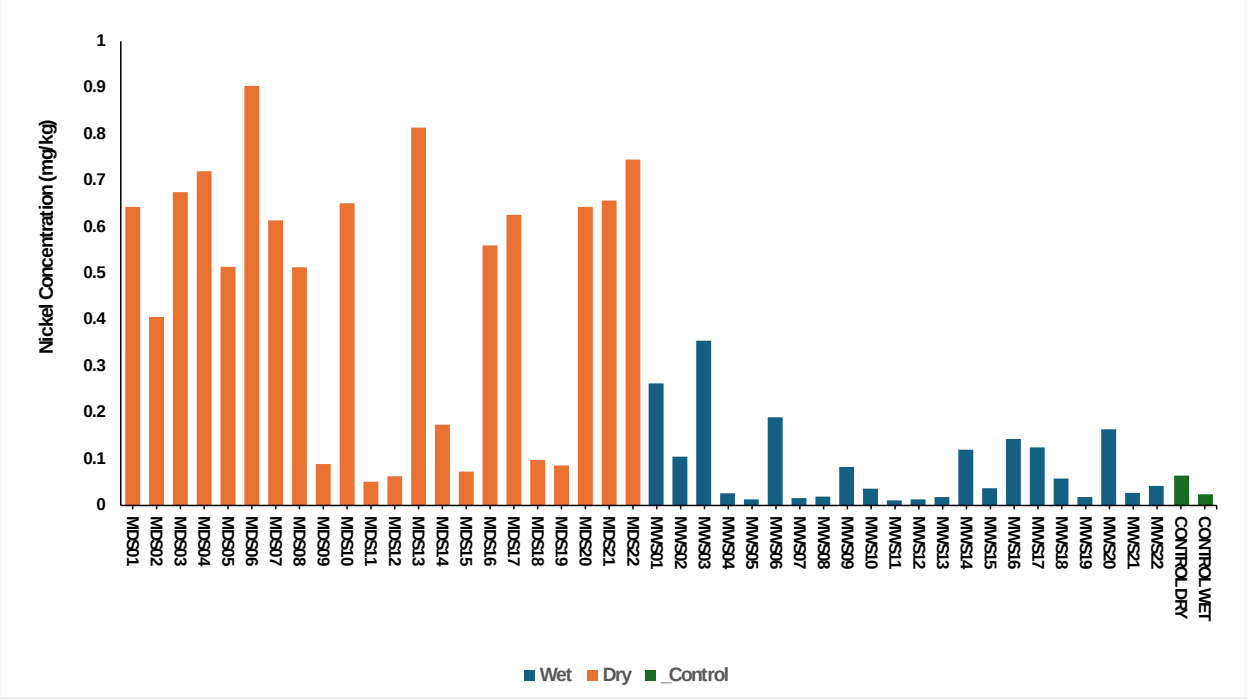

Figure 4.16: Nickel concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

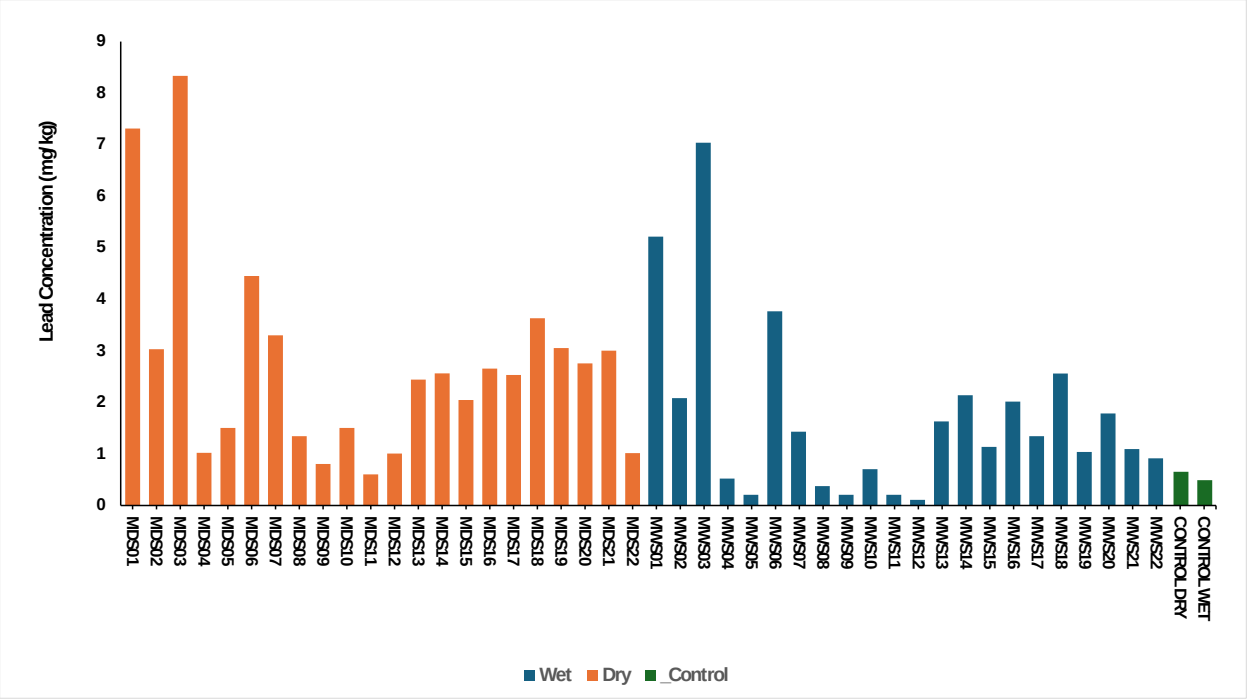

Figure 4.17: Lead concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

4.1.1.2.6 Vanadium (V^{2+})

During the wet season, as per Table 4.12, vanadium concentrations ranged from 0.003 mg/kg at MWS05 (Mechanic Village Imiringi Rd. 5) to 0.106 mg/kg at MWS19 (Oxbow Lake Swali 2), with a mean of 0.03 mg/kg (Table 4.20). This indicates the presence of vanadium, possibly from fuel and oils used in mechanic workshops. In the dry season, as per Table 4.16, vanadium levels ranged from 0.053 mg/kg at MDS21 (UBA/Swali Rd.) to 0.923 mg/kg at MDS03 (Mechanic Village Imiringi Rd. 3), with the mean increasing to 0.28 mg/kg (Table 4.19). The significant increase in vanadium concentration during the dry season suggests accumulation due to less leaching and continuous exposure to vanadium sources. The seasonal variation in vanadium concentration, as depicted in Figure 4.18, shows a significant increase in mean concentration during the dry season, with the highest value at MDS03. This trend indicates that rainfall plays a role in redistributing vanadium within the soil or into nearby water bodies, reducing its concentration at the surface during the wet season, while the dry season allows for accumulation.

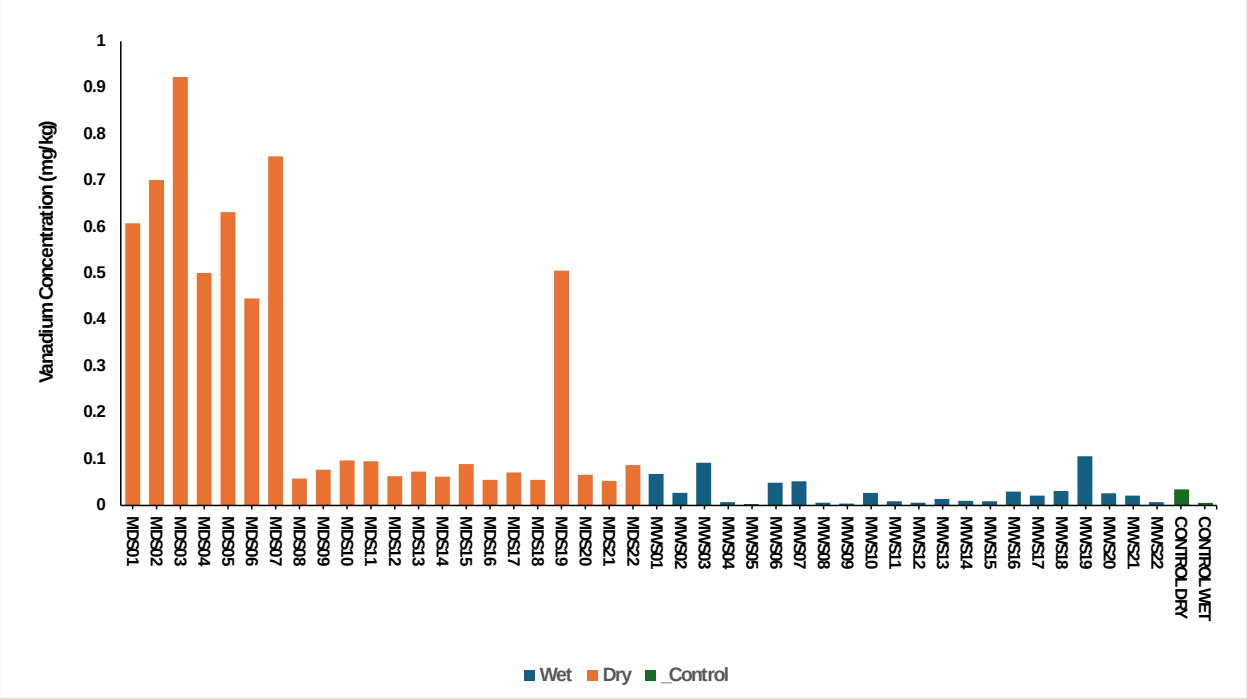

Figure 4. 18: Vanadium concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

4.1.1.3 Heavy Metals in Soils Around Cassava Mills

Heavy metal pollution of soil may originate from cassava mills, which process cassava and dispose of trash. Waste products such as cassava peelings, processing wastes, and the usage of metal containers or equipment during processing are all ways that these metals might get into the soil. These metals' presence in soil can have a big impact on plant development, soil health, and perhaps contaminating nearby water supplies.

4.1.1.3.1 Iron (Fe^{2+})

According to Table 4.13, the soil showed a broad spectrum of iron concentrations, ranging from 25.6 mg/kg at CWS14 (Ogu 2) to 223 mg/kg at CWS01 (Otuasega 1) with a mean of 92.10 mg/kg. This variability suggests that different sites experience varying levels of iron pollution, potentially due to the nature of waste disposal practices or the natural iron content in the soil being mobilized by water infiltration. Figure 4.19 visually compares these samples with a control site, revealing that the majority of cassava mill sites had elevated iron levels compared to the control, with some samples demonstrating concentrations well above what would be considered background levels for the area. The iron levels in these samples throughout the dry season varied from 31.7 mg/kg at CDS14 (Ogu 2) to 255.5 mg/kg at CDS04 (Big brother Rd. Opolo 1) with a mean of 108.02 mg/kg, as shown in Table 4.17. The highest iron concentration was found at CDS04, suggesting either a concentration effect brought on by the soil's decreased water content or a considerable waste intake. Figure 4.19 also includes dry season data, showing that while there are still high iron concentrations at some sites, the variability appears to be less pronounced than during the wet season, likely due to the concentration effect. Comparing the wet and dry seasons, as depicted in Figure 4.19, there is a noticeable increase in iron concentration during the dry season at several cassava mill sites. For instance, at CWS01 (Otuasega 1), iron concentration increased from 223 mg/kg in the wet season to 255.5 mg/kg in the dry season, indicating a concentration effect due to the absence of significant rainfall. Similarly, at CWS23 (Yenezue –

gene 1), iron levels rose from 25.6 mg/kg in the wet season to 39.5 mg/kg in the dry season. In the wet season, there is a risk of heavy metals like iron leaching into groundwater, potentially affecting water quality, whereas in the dry season, the reduced dilution by water can result in concentrated pollutants within the soil, posing different environmental challenges.

4.1.1.3.2 Manganese (Mn^{2+})

To assess manganese concentrations, soil samples were collected from different cassava mill locations during the wet season. According to Table 4.13, manganese levels had a mean of 53.42 mg/kg and varied from 11.7 mg/kg at CWS23 (Yenezue – gene 1) to 116.9 mg/kg at CWS01 (Otuasega 1). This range suggests a high manganese content, most likely as a result of the breakdown of organic waste or the usage of equipment that contains manganese. Figure 4.20 shows a visual comparison with a control site, where most cassava mill sites had elevated manganese levels, suggesting pollution from mill activities. Manganese concentrations in soil samples taken during the dry season ranged from 19.7 mg/kg at CDS11 (Igbogene 1) to 105.8 mg/kg at CDS19 (Swali 1), with a mean of 62.33 mg/kg, as shown in Table 4.17. The highest manganese concentration at CDS19 indicates a significant manganese input from equipment wear or waste from cassava processing. Figure 4.20 also includes dry season data, indicating that while manganese levels remain high at some sites, the variability might be reduced due to the concentration effect. Figure 4.20 shows a slight increase in manganese concentration during the dry season at a number of sites when comparing the wet and dry seasons. Manganese levels at CWS01 (Otuasega), for instance, rose from 116.9 mg/kg during the wet season to 105.8 mg/kg during the dry season at CDS19. This pattern implies that the concentration of manganese in the soil is made possible by the lack of heavy rainfall, possibly as a result of reduced leaching and ongoing exposure to manganese sources.

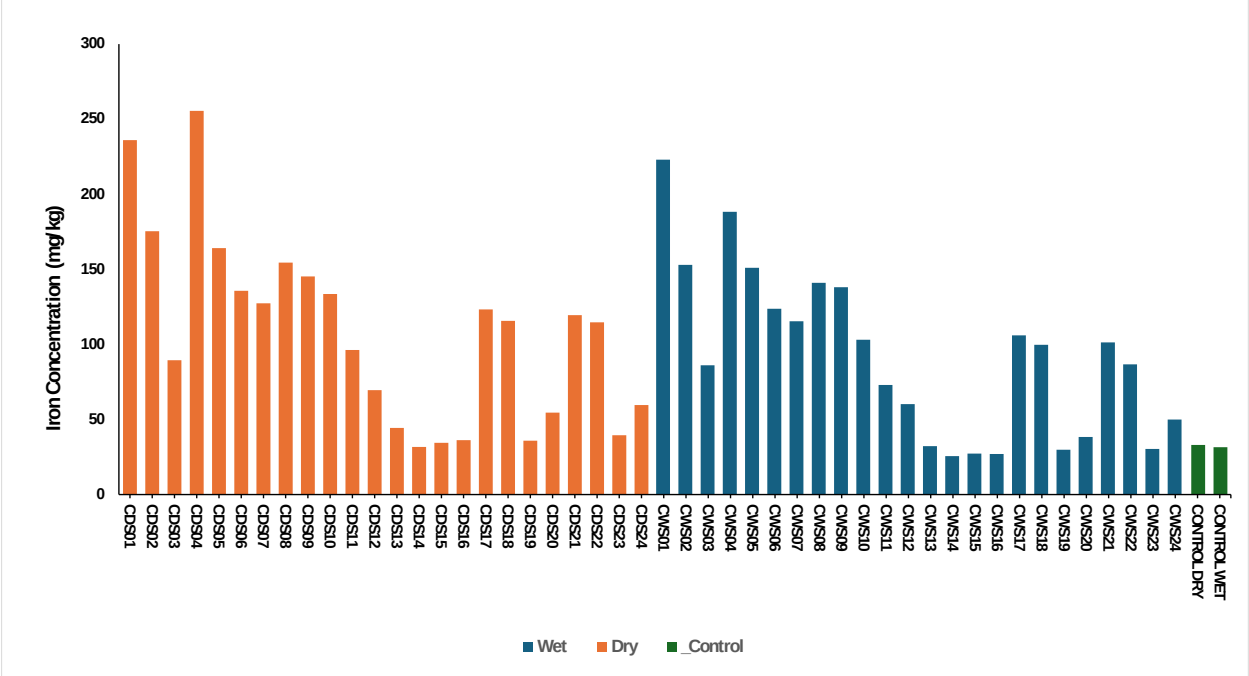

Figure 4.19: Iron concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

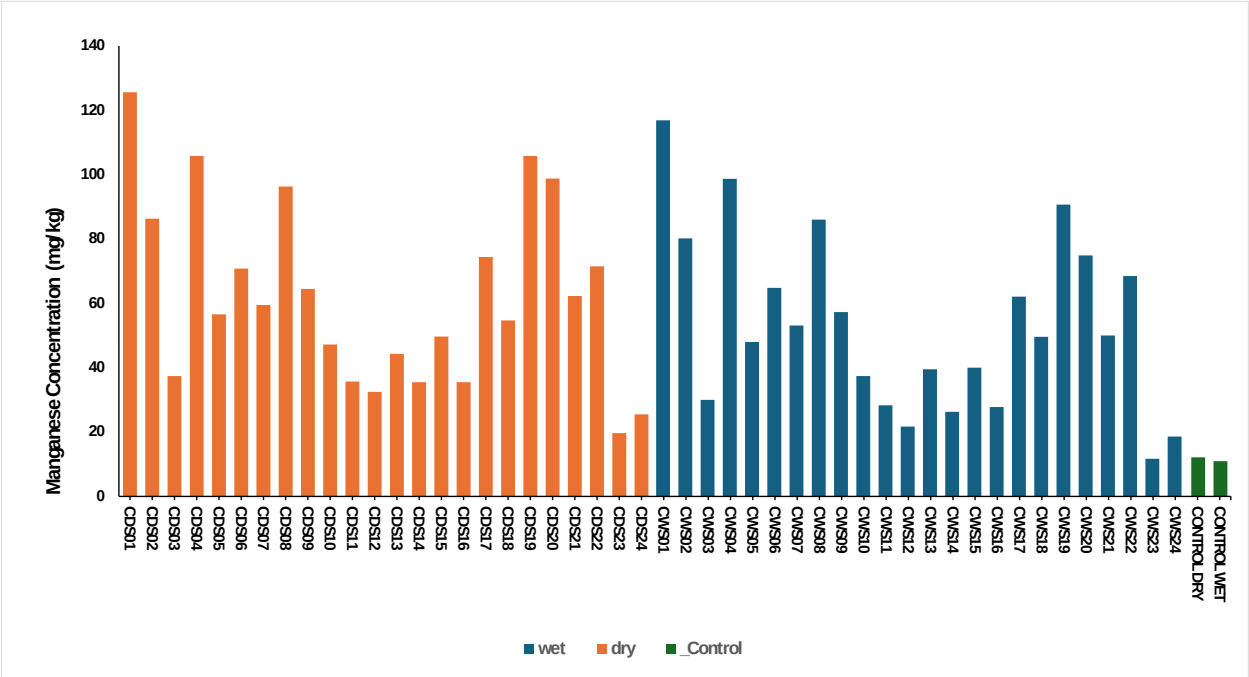

Figure 4.20: Manganese concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

4.1.1.3.3 Zinc (Zn^{2+})

Samples of soil were taken from several cassava mill locations during the wet season in order to measure the levels of zinc. According to Table 4.13, zinc levels varied from 9.9 mg/kg at CWS23 (Yenizue-gene 1) to 191.7 mg/kg at CWS01 (Otuasega 1). The mean concentration was roughly 95.26 mg/kg (Table 4.20). This variation reflects the possibility of zinc pollution from compounds based on zinc that are used to prepare cassava. Figure 4.21 visually depicts these concentrations, showing that most of the cassava mill sites had elevated zinc levels compared to the control, with some sites demonstrating concentrations well above background levels. Zinc levels varied from 14.06 mg/kg at CDS23 (Yenizue-gene 1) to 197.9 mg/kg at CDS01 (Otuasega 1) during the dry season, according to Table 4.17. The mean concentration increased marginally to 107.34 mg/kg (Table 4.19). The highest concentration of zinc at CDS01 points to a substantial contribution from equipment or waste deterioration. Figure 4.21 also shows dry season data, revealing an increase in mean zinc concentration, likely due to less leaching and accumulation from cassava mill activities.

The mean zinc concentration rises throughout the dry season when comparing the wet and dry seasons, as seen in Figure 4.21. Zinc levels, for example, rose from 191.7 mg/kg during the wet season to 197.9 mg/kg during the dry season at CWS01 suggesting that decreased water movement had an impact on zinc accumulation in the soil. This emphasizes how important it is to manage garbage specifically in order to reduce zinc pollution.

4.1.1.3.4 Copper (Cu^{2+})

Copper concentrations in the soil during the wet season, as shown in Table 4.13, ranged from 4.2 mg/kg at CWS23 (Yenezue – gene 1) to 50.3 mg/kg at CWS01 (Otuasega 1), with a mean of 24.69 mg/kg (Table 4.20). This indicates copper contamination, possibly from copper-based equipment or waste materials. Figure 4.22 visually compares these samples with a control site, highlighting that copper levels are significantly elevated at cassava mill sites. In the dry season, Table 4.17 shows copper levels ranging from 7.4 mg/kg at CDS19 (Swali 1) to 55.4 mg/kg at

CDS01 (Otuasega 1), with the mean concentration increasing to 31.76 mg/kg (Table 4.19). The highest copper concentration at CDS01 reflects substantial copper input from mill operations. Figure 4.22 includes dry season data, indicating that copper concentrations remain high, potentially due to less leaching and continuous exposure to copper sources. The seasonal variation in copper concentration, as depicted in Figure 4.22, shows an increase in mean concentration during the dry season. For example, at CWS01, copper levels increased from 50.3 mg/kg in the wet season to 55.4 mg/kg in the dry season, suggesting that the absence of rainfall allows for copper accumulation in the soil. This highlights the need for effective waste management to control copper pollution.

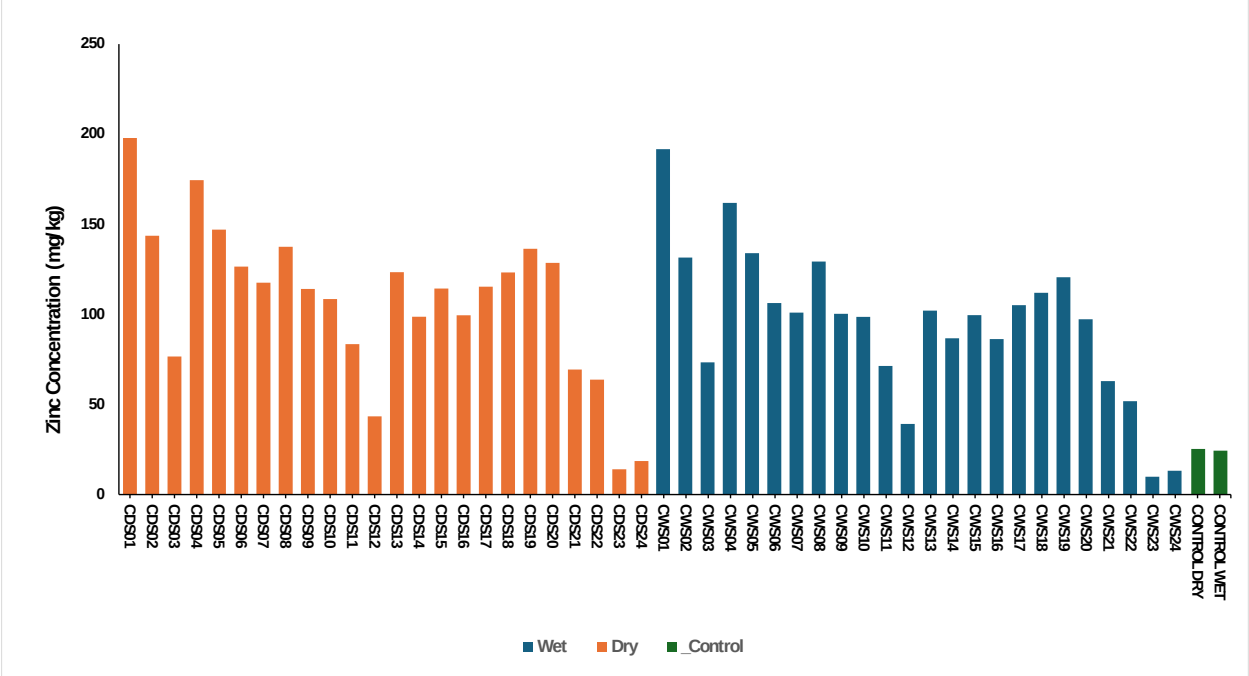

Figure 4. 21: Zinc concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

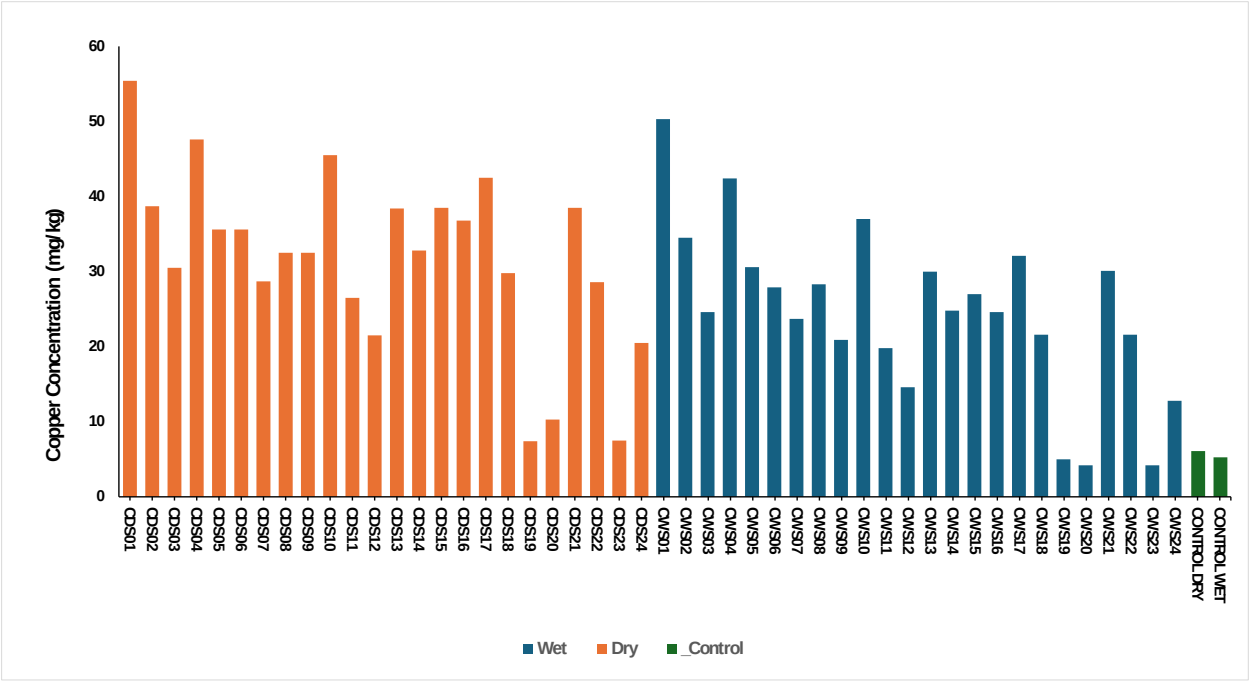

Figure 4. 22: Copper concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

4.1.1.3.5 Chromium (Cr^{6+})

During the wet season, as detailed in Table 4.13, chromium concentrations in the soil around cassava mill sites varied from 0.92 mg/kg at CWS24 (Yenezue – gene 2) to 24.6 mg/kg at CWS01 (Otuasega 1), with a mean of 8.85 mg/kg (Table 4.20). This range suggests chromium contamination from various sources, including waste disposal. Figure 4.23 compares these samples with a control site, showing elevated chromium levels at many mill sites. Chromium levels during the dry season range from 1.55 mg/kg at CDS23 (Yenizue-gene 1) to 32.7 mg/kg at CDS16 (Elebele/Opolo Rd, (2)), with the mean rising to 12.70 mg/kg (Table 4.19). This information is shown in Table 4.17. Significant waste input or equipment degradation is suggested by the greatest chromium concentration at CDS16. Figure 4.23 also includes dry season data, indicating that chromium concentrations can be higher due to less leaching and continuous exposure to chromium sources. Figure 4.23 shows that the mean chromium concentration increases throughout the dry season when compared to the wet season. For example, chromium levels at CWS01 rose from 24.6 mg/kg during the wet season to 32.7 mg/kg during the dry season at CDS16. This trend suggests that the absence of significant rainfall allows for chromium accumulation in the soil, highlighting the need for waste management practices to mitigate chromium pollution.

4.1.1.3.6 Cadmium (Cd^{2+})

Cadmium concentrations during the wet season, as outlined in Table 4.13, ranged from 0.106 mg/kg at CWS22 (Agbura 2) to 0.732 mg/kg at CWS01 (Otuasega 1), with a mean of 0.32 mg/kg (Table 4.20). This indicates cadmium contamination, potentially from cadmium-containing materials used in cassava processing. Figure 4.24 shows that cadmium levels at cassava mill sites are significantly elevated compared to the control.

Cadmium levels fluctuate between 0.206 mg/kg at CDS11 (Igbogene 1) and 0.964 mg/kg at CDS01 (Otuasega 1) during the dry season, with the mean rising to 0.71 mg/kg (Table 4.19).

Significant cadmium input from mill activities is suggested by the greatest cadmium concentration at CDS01. Figure 4.24 includes dry season data, indicating that cadmium concentrations can increase due to less leaching and continuous exposure to cadmium sources. The seasonal variation in cadmium concentration, as depicted in Figure 4.24, shows an increase in mean concentration during the dry season. For example, at CWS01, cadmium levels increased from 0.732 mg/kg in the wet season to 0.964 mg/kg in the dry season, suggesting that the absence of rainfall allows for cadmium accumulation in the soil. This underscores the need for targeted waste management to mitigate cadmium pollution.

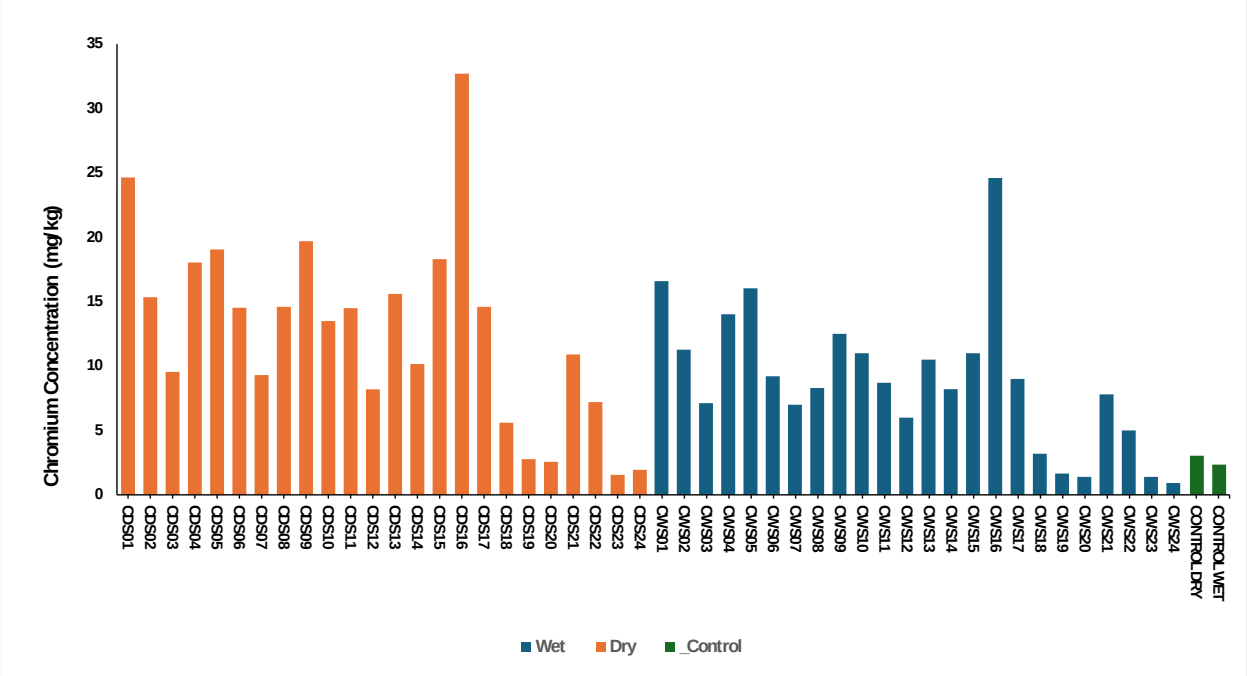

Figure 4.23: Chromium concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

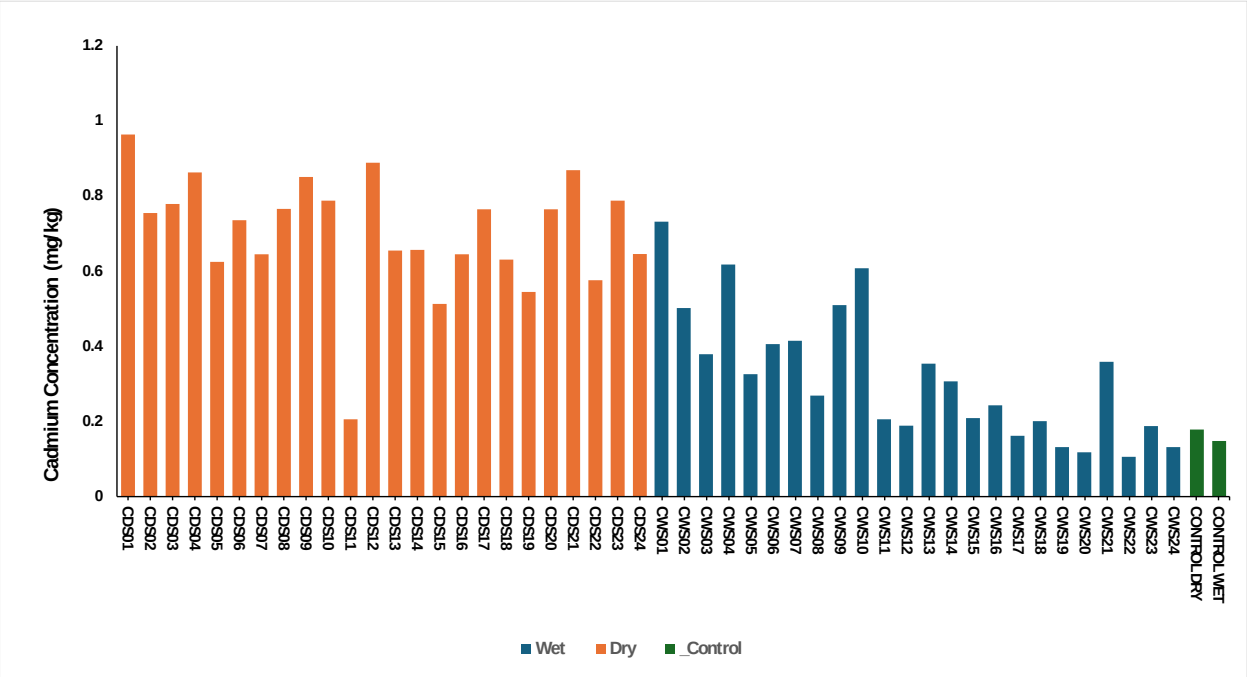

Figure 4.24: Cadmium concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

4.1.1.3.7 Nickel (Ni^{2+})

Nickel concentrations in the soil during the wet season, as detailed in Table 4.13, ranged from 0.002 mg/kg at CWS12 (Igbogene 2) to 0.176 mg/kg at CWS01 (Otuasega 1), with a mean of 0.05 mg/kg (Table 4.20). This variability reflects nickel pollution from nickel-based materials used in cassava processing. Figure 4.25 visually compares these samples with a control site, showing elevated nickel levels at many mill sites. In the dry season, Table 4.17 indicates nickel levels ranging from 0.055 mg/kg at CDS21 (Agbura 1) to 0.767 mg/kg at CDS01 (Otuasega 1), with the mean concentration increasing to 0.21 mg/kg (Table 4.19). The highest nickel concentration at CDS01 suggests significant nickel input from mill operations. Figure 4.25 includes dry season data, revealing an increase in mean nickel concentration, likely due to less leaching and accumulation from cassava mill activities. The seasonal variation in nickel concentration, as depicted in Figure 4.25, shows an increase in mean concentration during the dry season. For instance, at CWS01, nickel levels increased from 0.176 mg/kg in the wet season to 0.767 mg/kg in the dry season, indicating the effect of reduced water movement on nickel accumulation in the soil. This underscores the need for targeted waste management to mitigate nickel pollution.

4.1.1.3.8 Lead (Pb^{2+})

During the wet season, lead concentrations in the soil around cassava mill sites, as outlined in Table 4.13, varied from 0.016 mg/kg at CWS12 (Igbogene 2) to 3.486 mg/kg at CWS01 (Otuasega 1), with a mean of 1.19 mg/kg (Table 4.20). This range suggests lead contamination, possibly from lead-based products or waste materials. Figure 4.26 shows that lead levels at cassava mill sites are significantly elevated compared to the control. Lead levels during the dry season range from 0.754 mg/kg at CDS19 (Swali 1) to 5.466 mg/kg at CDS01 (Otuasega 1), with the mean concentration rising to 2.46 mg/kg (Table 4.19). This information is shown in Table 4.17. The highest lead concentration at CDS01 indicates substantial lead input from mill operations. Figure 4.26 includes dry season data, indicating that lead concentrations can increase due to less leaching and continuous exposure to lead sources. Figure 4.26 illustrates the seasonal variation in lead concentration, which indicates that the mean concentration rises during the dry season. For instance, lead levels at CWS01 rose from 3.486 mg/kg during the wet season to 5.466 mg/kg during the dry season, indicating that lead buildup in the soil is made possible by the lack of rainfall. This underscores the need for targeted waste management to mitigate lead pollution.

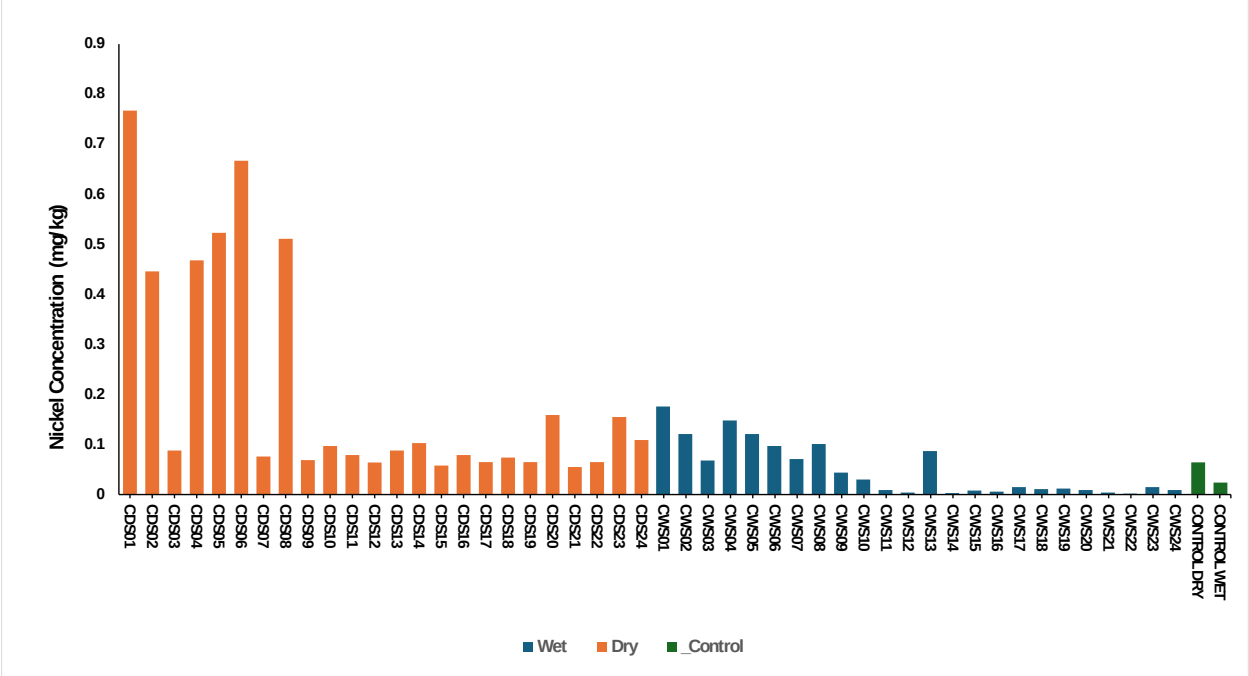

Figure 4. 25: Nickel concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

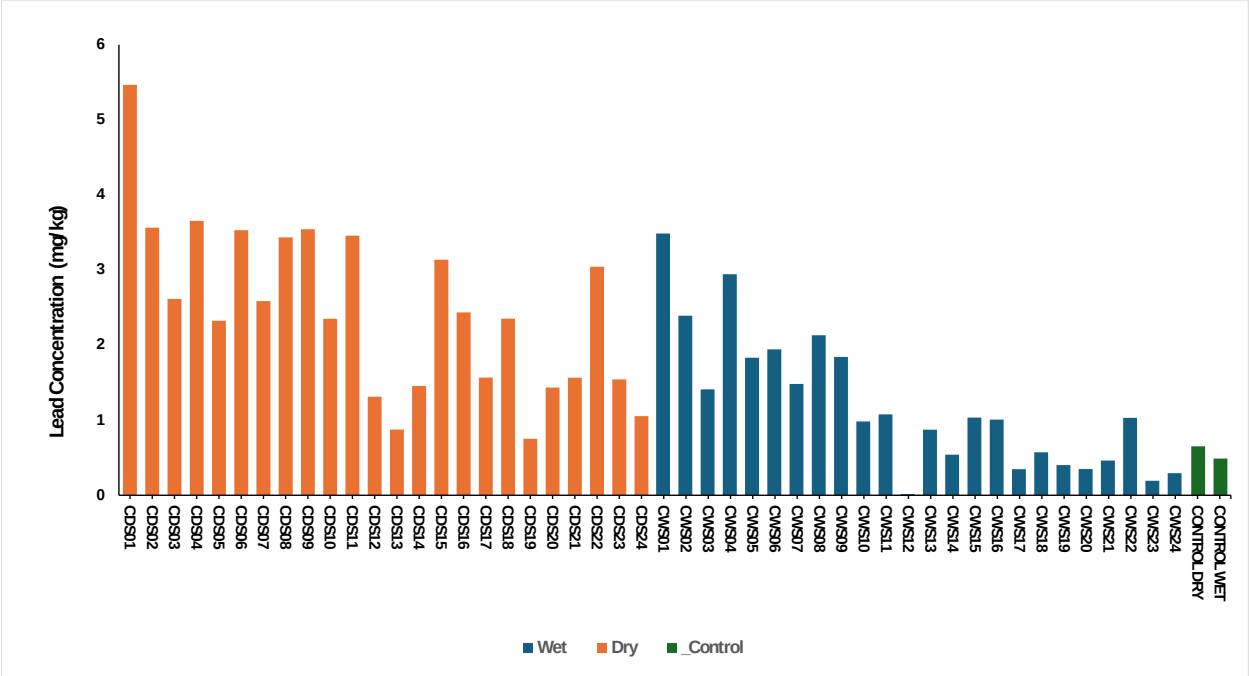

Figure 4. 26: Lead concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

4.1.1.3.8 Vanadium (V^{2+})

The levels of vanadium throughout the wet season varied from 0.002 mg/kg at CWS24 (Yenizue – gene 2) to 0.046 mg/kg at CWS01 (Otuasega 1), with a mean of 0.01 mg/kg (Table 4.20). These levels are displayed in Table 4.13. This indicates vanadium contamination, potentially from fuel and oils used in cassava processing. Figure 4.27 visually compares these samples with a control site, showing elevated vanadium levels at many mill sites. In the dry season, Table 4.17 indicates vanadium levels ranging from 0.046 mg/kg at CDS15 (Elebele/Opolo Rd 1 Kpansia (2)) to 0.208 mg/kg at CDS11 (Igbogene 1), with the mean concentration increasing to 0.07 mg/kg (Table 4.19). The highest vanadium concentration at CDS11 suggests substantial vanadium input from mill operations. Figure 4.27 includes dry season data, indicating that vanadium concentrations increase could be due to less leaching and continuous exposure to vanadium sources. The seasonal variation in vanadium concentration, as depicted in Figure 4.27, shows an increase in mean concentration during the dry season indicating the effect of reduced water movement on vanadium accumulation in the soil. This underscores the need for targeted waste management to mitigate vanadium pollution.

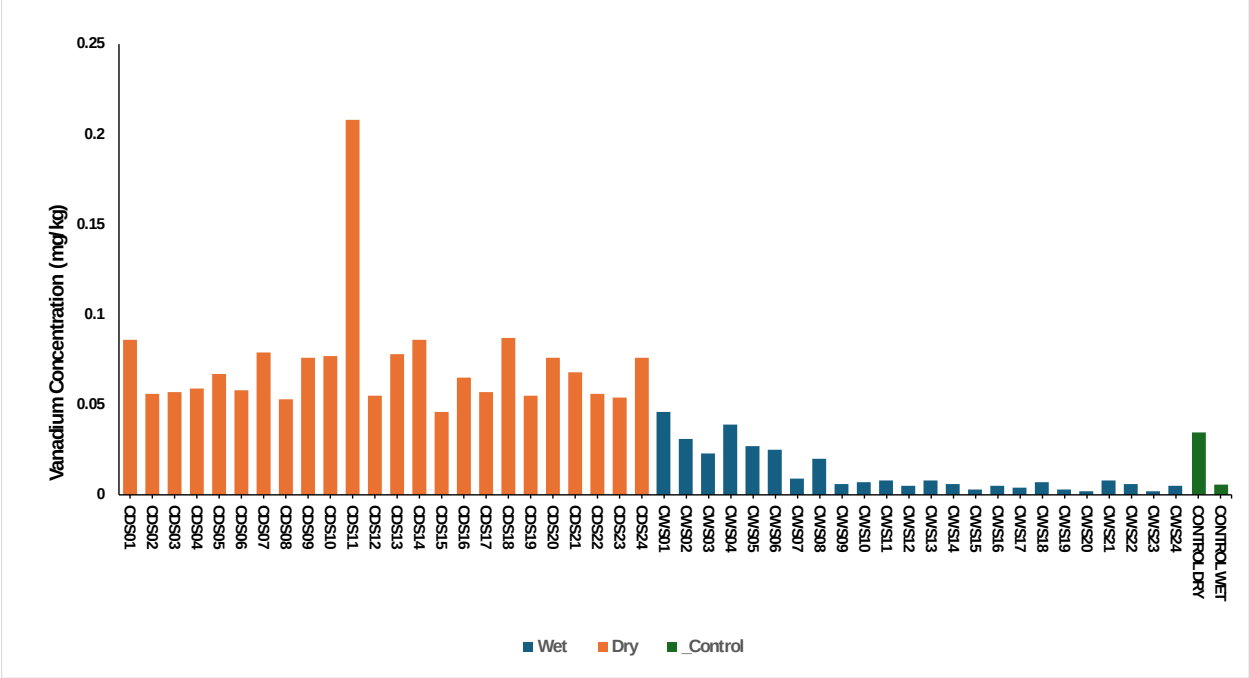

Figure 4. 27: Vanadium concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

4.1.1.4 Heavy Metals in Soils Around Crude Oil Spill Sites

The presence of certain heavy metals in petroleum products and related industrial processes might result in the introduction of these metals into the environment through crude oil spills. By examining the quantities of these heavy metals in soil samples taken during the dry and wet seasons near crude oil spill sites, our investigation sheds light on the environmental impact and pollution levels at these sites.

4.1.1.4.1 Iron ($Fe^{2}+$)

To assess iron concentrations, soil samples were taken during the wet season from the vicinity of crude oil spill locations. With a mean concentration of 406.95 mg/kg, iron levels varied from 301.6 mg/kg at SWS6 (Ibelebiri 3) to 516.3 mg/kg at SWS1 (Agba (Otuege) 1), as shown in Table 4.14. This variability suggests substantial iron contamination, likely due to the presence of iron-rich materials in the oil or associated equipment. Figure 4.28 visually compares these samples with a control site, revealing that most spill sites had elevated iron levels compared to the control, with some samples demonstrating concentrations well above background levels. In the dry season, Table 4.18 shows iron levels ranging from 334.8 mg/kg at SDS6 (Ibelebiri 3) to 568.5 mg/kg at SDS1 (Agba (Otuege) 1), with the mean concentration slightly higher at 438.6 mg/kg (Table 4.19). The highest iron concentration at SDS1 suggests significant iron input from the spill or equipment degradation. Figure 4.28 also includes dry season data, indicating that iron concentrations remain high, potentially due to less leaching and continuous exposure to iron sources. Figure 4.28 shows that when comparing the wet and dry seasons, the mean iron content rises during the dry season. At SWS1 (Agba (Otuege) 1), for example, iron levels rose from 516.3 mg/kg during the wet season to 568.5 mg/kg during the dry season, demonstrating the impact of decreased water movement on soil iron buildup. This underscores the need for targeted waste management and remediation efforts to mitigate iron pollution from oil spills.

4.1.1.4.2 Manganese (Mn^{2+})

During the wet season, soil samples from areas around crude oil spill sites were analyzed for manganese concentrations. As outlined in Table 4.14, manganese levels ranged from 200.4 mg/kg at SWS6 (Ibelebiri 3) to 270.8 mg/kg at SWS1 (Agba (Otuege) 1), with a mean concentration of 234.97 mg/kg (Table 4.20). This range suggests manganese contamination, possibly from manganese-based additives in the oil or associated equipment. Figure 4.29 visually compares these samples with a control site, highlighting that manganese levels are significantly elevated at spill sites. Manganese levels during the dry season range from 216.6 mg/kg at SDS6 (Ibelebiri 3) to 325.7 mg/kg at SDS4 (Ibelebiri 1), according to Table 4.18, with the mean concentration rising to 260.35 mg/kg (Table 4.19). Significant manganese input from the spill or equipment deterioration is suggested by the greatest manganese content at SDS4. Figure 4.29 includes dry season data, indicating that manganese concentrations can increase due to less leaching and continuous exposure to manganese sources.

Figure 4.29 illustrates the seasonal change in manganese content, which indicates that the mean concentration rises during the dry season. Manganese levels, for instance, rose from 270.8 mg/kg during the wet season to 325.7 mg/kg during the dry season in SWS1 (Agba (Otuege) 1), indicating that the lack of rainfall permits manganese buildup in the soil. This emphasizes the necessity of efficient waste management and remediation techniques to reduce oil spill-related manganese pollution.

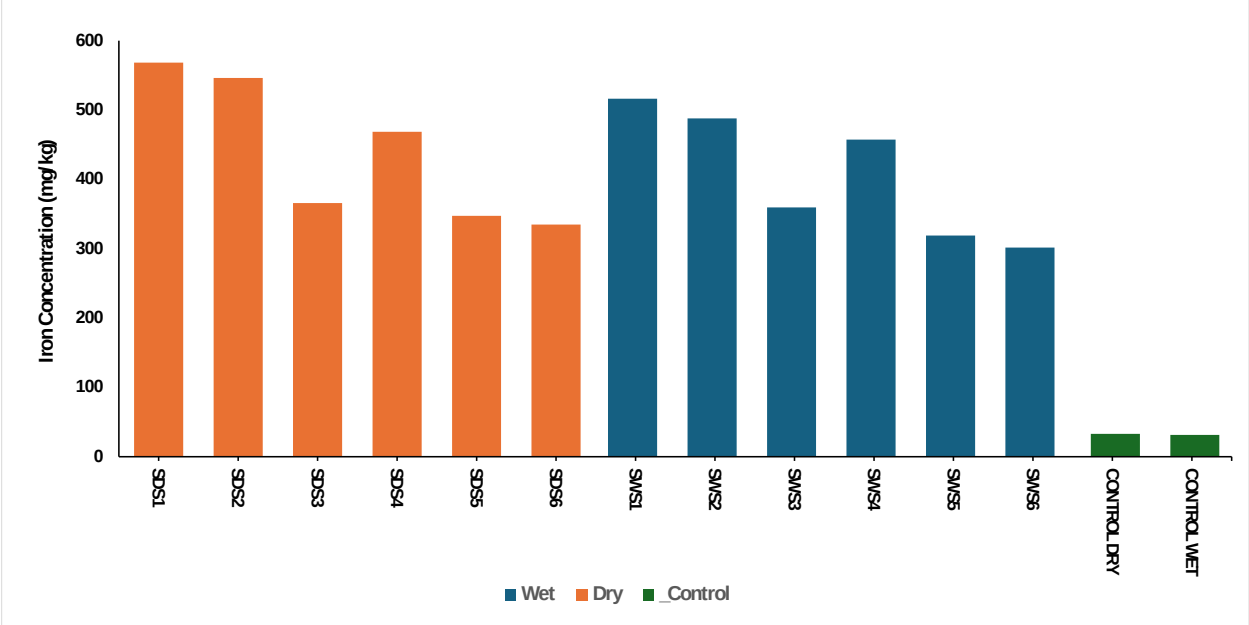

Figure 4. 28: Iron concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

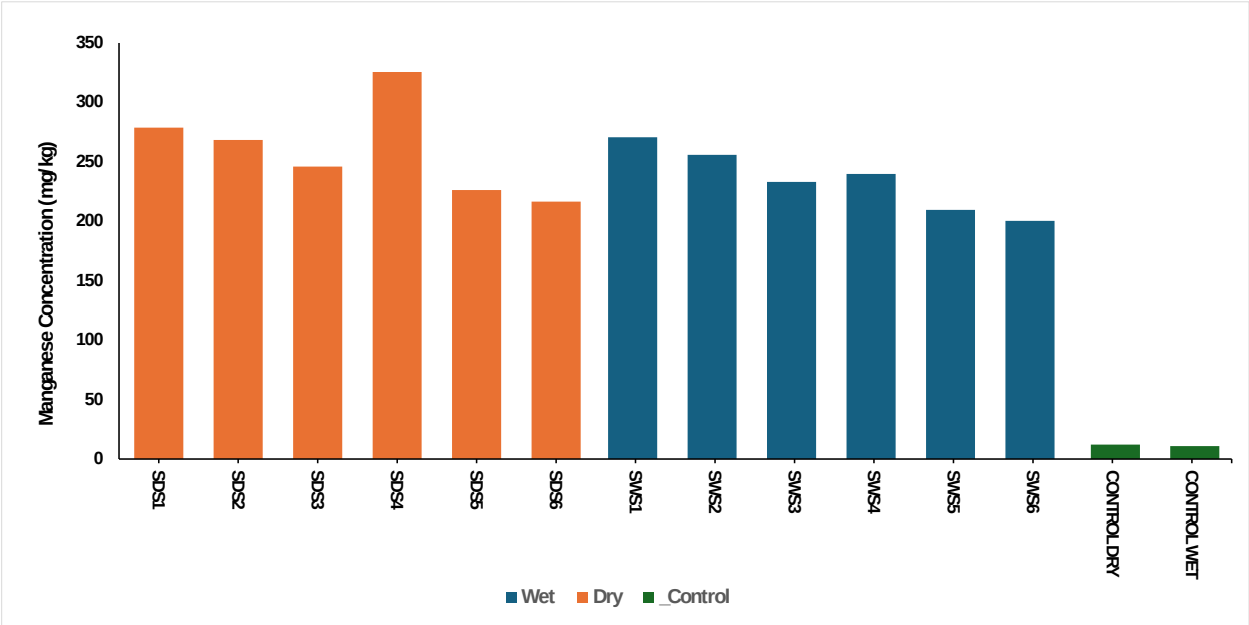

Figure 4. 29: Manganese concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

4.1.1.4.3 Zinc (Zn^{2+})

Zinc concentrations were measured in soil samples collected from the vicinity of crude oil spill locations during the wet season. With a mean concentration of 377.82 mg/kg (Table 4.20), zinc levels range from 304.2 mg/kg at SWS6 (Ibelebiri 3) to 444 mg/kg at SWS1 (Agba (Otuege) 1). This suggests a high level of zinc contamination, most likely brought on by the employment of zinc-based equipment or components in oil processing. Figure 4.30 visually depicts these concentrations, showing that most spill sites had elevated zinc levels compared to the control. Zinc levels during the dry season range from 326.6 mg/kg at SDS5 (Ibelebiri 2) to 457.3 mg/kg at SDS1 (Agba (Otuege) 1), according to Table 4.18, with the mean concentration rising marginally to 394.27 mg/kg (Table 4.19). Significant zinc intake from the spill or equipment deterioration is suggested by the greatest zinc concentration at SDS1. Figure 4.30 also shows dry season data, revealing an increase in mean zinc concentration, likely due to less leaching and accumulation from oil spill activities. Comparing the wet and dry seasons, as depicted in Figure 4.30, there is an increase in mean zinc concentration during the dry season. For instance, at SWS1 (Agba (Otuege) 1), zinc levels increased from 444 mg/kg in the wet season to 457.3 mg/kg in the dry season, indicating the effect of reduced water movement on zinc accumulation in the soil. This underscores the need for targeted waste management and remediation efforts to mitigate zinc pollution from oil spills.

4.1.1.4.4 Copper (Cu^{2+})

Copper concentrations in the soil during the wet season, as shown in Table 4.14, ranged from 81.8 mg/kg at SWS6 (Ibelebiri 3) to 116.4 mg/kg at SWS1 (Agba (Otuege) 1), with a mean of 101.92 mg/kg (Table 4.20). This indicates copper contamination, possibly from copper-based additives or equipment used in oil extraction or processing. Figure 4.31 visually compares these samples with a control site, highlighting that copper levels are significantly elevated at spill sites. The mean concentration of copper during the dry season rises to 112.53 mg/kg (Table 4.19), with levels ranging from 85.8 mg/kg at SDS6 (Ibelebiri 3) to 126.5 mg/kg at SDS1 (Agba (Otuege)

1). Significant copper input from the spill or equipment deterioration is reflected in the greatest copper concentration at SDS1. Figure 4.31 includes dry season data, indicating that copper concentrations remain high, potentially due to less leaching and continuous exposure to copper sources. The seasonal variation in copper concentration, as depicted in Figure 4.31, shows an increase in mean concentration during the dry season. For example, at SWS1 (Agba (Otuege) 1), copper levels increased from 116.4 mg/kg in the wet season to 126.5 mg/kg in the dry season, suggesting that the absence of rainfall allows for copper accumulation in the soil.

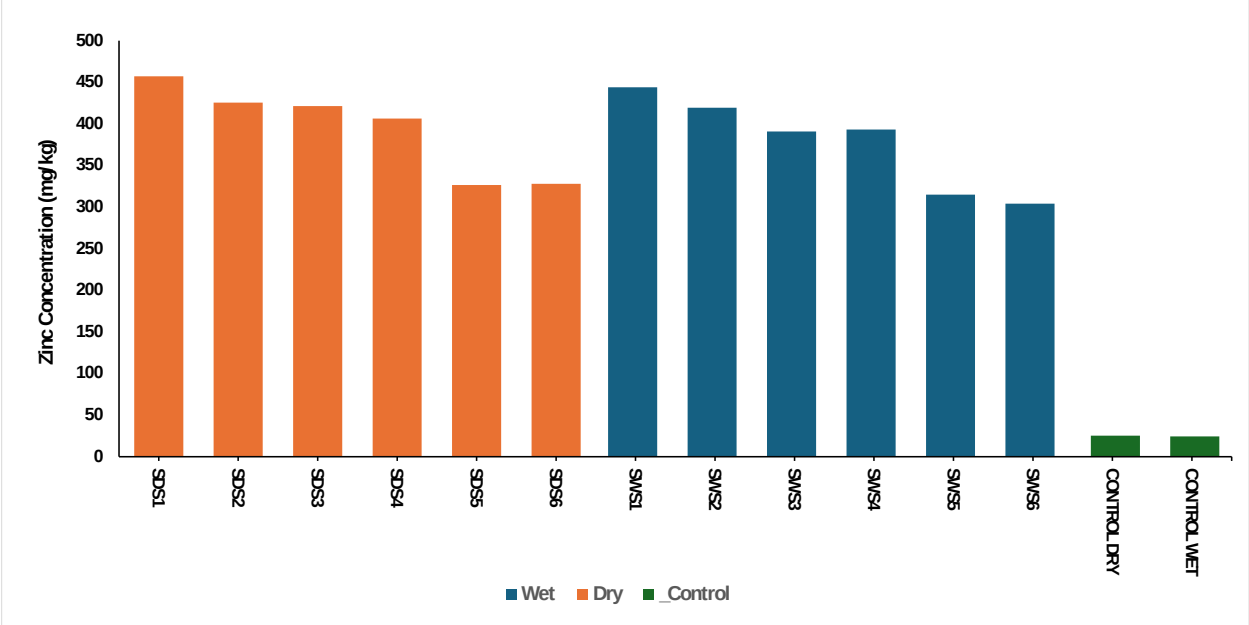

Figure 4. 30: Zinc concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

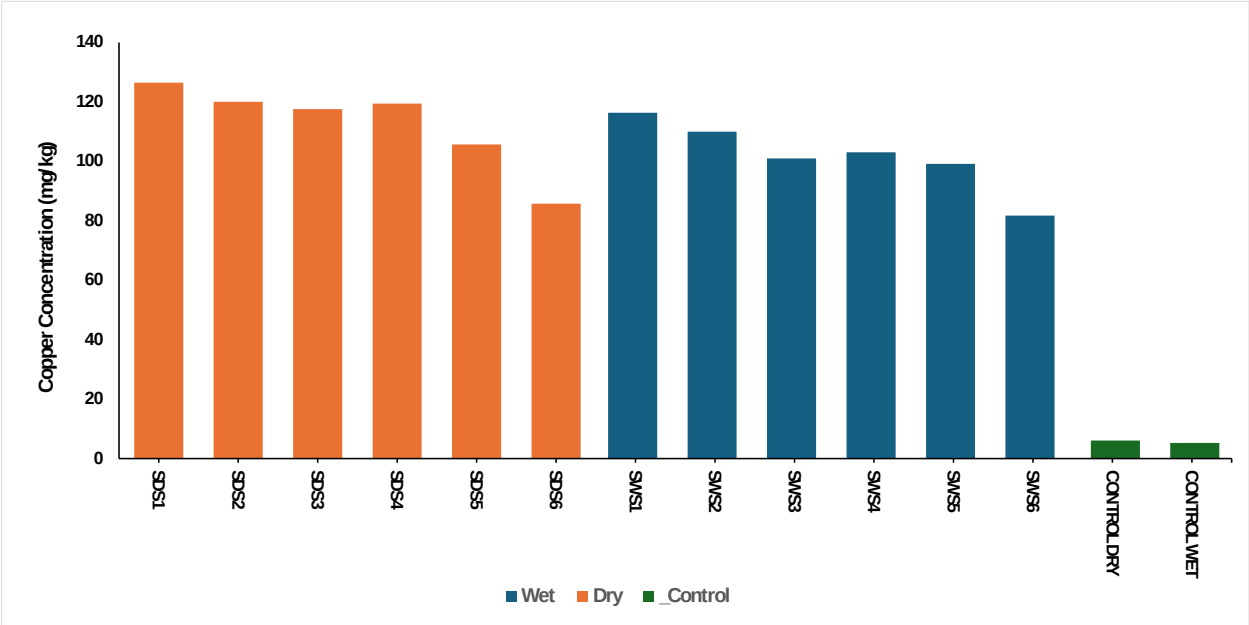

Figure 4. 31: Copper concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

4.1.1.4.5 Chromium (Cr^{6+})

Chromium concentrations in the soil surrounding crude oil spill sites during the wet season ranged from 26.43 mg/kg at SWS6 (Ibelebiri 3) to 38.43 mg/kg at SWS1 (Agba (Otuege) 1), with a mean of 32.92 mg/kg (Table 4.20), as shown in Table 4.14. This range points to chromium contamination from a number of sources, such as oil additives or waste disposal. Figure 4.32 compares these samples with a control site, showing elevated chromium levels at many spill sites. The mean chromium levels throughout the dry season are 40.40 mg/kg (Table 4.19), with a range of 32.36 mg/kg at SDS6 (Ibelebiri 3) to 45.63 mg/kg at SDS1 (Agba (Otuege) 1). Significant waste input or equipment degradation is suggested by the greatest chromium content at SDS1. Figure 4.32 also includes dry season data, indicating that chromium concentrations can be higher due to less leaching and continuous exposure to chromium sources. Figure 4.32 shows that the mean chromium concentration increases throughout the dry season when compared to the wet season. For example, chromium levels in SWS1 (Agba (Otuege) 1) rose from 38.43 mg/kg during the wet season to 45.63 mg/kg during the dry season. This pattern implies that chromium can build up in the soil when there is little to no rainfall, underscoring the necessity of proper waste management practices.

4.1.1.4.6 Cadmium (Cd^{2+})

Cadmium concentrations during the wet season, as outlined in Table 4.13, ranged from 1.301 mg/kg at SWS6 (Ibelebiri 3) to 1.695 mg/kg at SWS1 (Agba (Otuege) 1), with a mean of 1.48 mg/kg (Table 4.20). This indicates cadmium contamination, potentially from cadmium-containing materials used in oil processing or equipment. Figure 4.33 shows that cadmium levels at spill sites are significantly elevated compared to the control. Cadmium concentrations during the dry season range from 1.551 mg/kg at SDS5 (Ibelebiri 2) to 2.755 mg/kg at SDS1 (Agba (Otuege) 1), with the mean rising to 2.09 mg/kg (Table 4.19). Significant cadmium input from the spill or equipment deterioration is suggested by the greatest cadmium levels at SDS1. Figure 4.33 includes dry season data, indicating that cadmium concentrations can increase due to less

leaching and continuous exposure to cadmium sources. The seasonal variation in cadmium concentration, as depicted in Figure 4.33, shows an increase in mean concentration during the dry season. For example, at SWS1 (Agba (Otuege) 1), cadmium levels increased from 1.695 mg/kg in the wet season to 2.755 mg/kg in the dry season, suggesting that the absence of rainfall allows for cadmium accumulation in the soil.

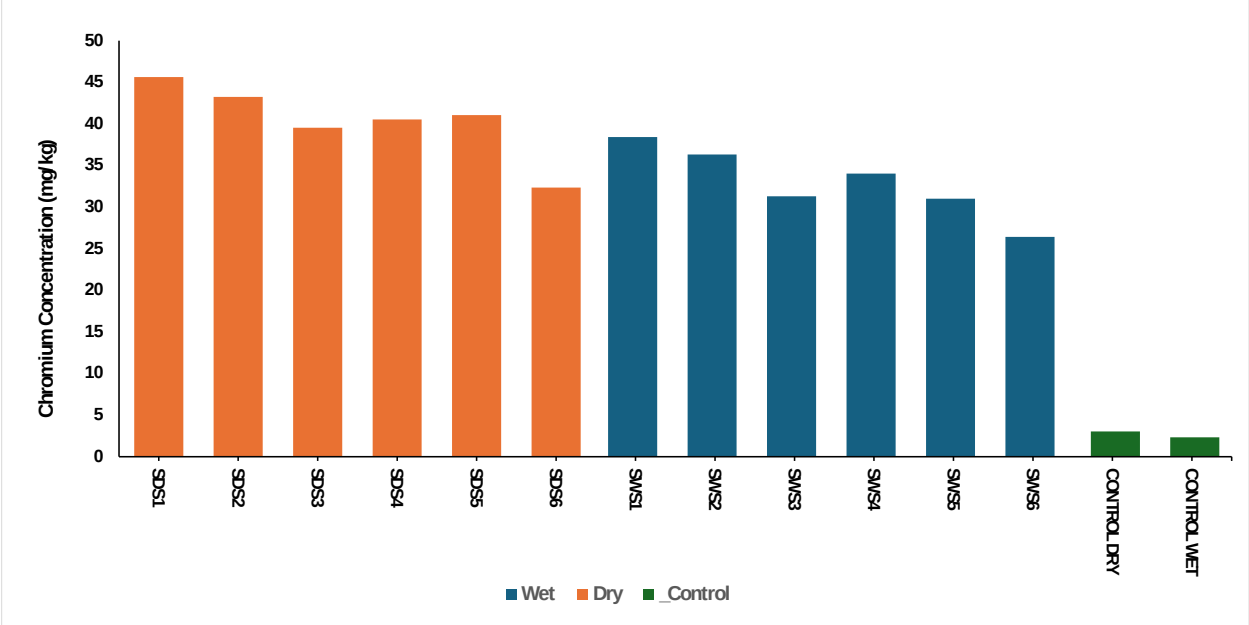

Figure 4. 32: Chromium concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

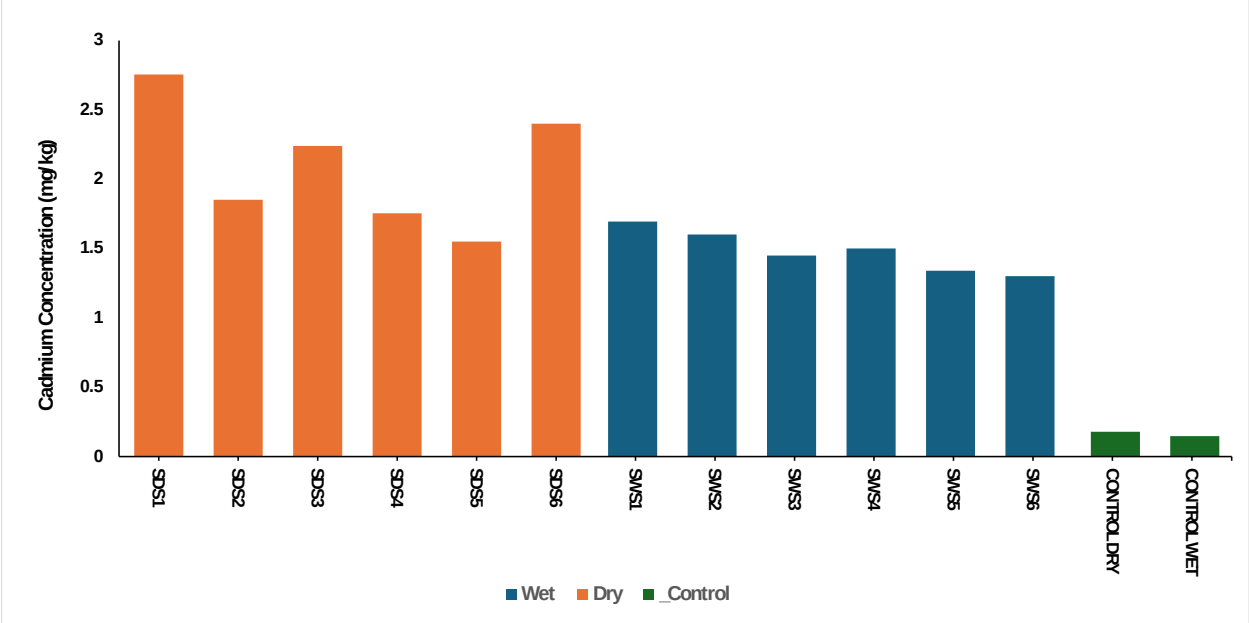

Figure 4. 33: Cadmium concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

4.1.1.4.7 Nickel (Ni^{2+})

Nickel concentrations in the soil during the wet season, as detailed in Table 4.14, ranged from 0.116 mg/kg at SWS6 (Ibelebiri 3) to 0.407 mg/kg at SWS1 (Agba (Otuege) 1), with a mean of 0.32 mg/kg (Table 4.20). This variability reflects nickel pollution from nickel-based materials used in oil extraction or processing. Figure 4.34 visually compares these samples with a control site, showing elevated nickel levels at many spill sites. The mean concentration of nickel increased to 0.59 mg/kg during the dry season, with levels ranging from 0.456 mg/kg at SDS2 (Agba (Otuege) 2) to 0.708 mg/kg at SDS1 (Agba (Otuege) 1) (Table 4.18). The consistent shows of maximum nickel concentration in both seasons at SDS1 suggests significant nickel input from spill or equipment degradation around the area. Figure 4.34 includes dry season data, revealing an increase in mean nickel concentration, likely due to accumulation from oil spill activities. Figure 4.34 illustrates the seasonal variation in nickel content, which indicates an increase in mean concentration during the dry season. For example, nickel levels at SWS1 increased from 0.407 mg/kg during the rainy season to 0.708 mg/kg during the dry season, suggesting that lack of dissolution impacted the increase of nickel concentration in soil during the dry season.

4.1.1.4.8 Lead (Pb^{2+})

Lead levels in the soil surrounding crude oil spill sites during the wet season ranged from 4.607 mg/kg at SWS6 (Ibelebiri 3) to 8.071 mg/kg at SWS1 (Agba (Otuege) 1), with a mean of 6.75 mg/kg (Table 4.20). These results are shown in Table 4.14. This range points to the possibility of lead contamination from waste materials or products containing lead. Figure 4.35 shows that lead levels at spill sites are significantly elevated compared to the control. During the dry season, the mean concentration of lead increased to 10.48 mg/kg (Table 4.19), with levels ranging from 7.516 mg/kg at SDS6 (Ibelebiri 3) to 15.354 mg/kg at SDS1 (Agba (Otuege) 1). Significant lead input from the spill or equipment deterioration is indicated by the greatest lead concentration at SDS1. Figure 4.35 includes dry season data, indicating that lead concentrations can increase due

to less leaching and continuous exposure to lead sources. Figure 4.35 illustrates how lead content varies seasonally, with the mean concentration rising during the dry season. Lead values in SWS1, for instance, rose from 8.071 mg/kg during the wet season to 15.354 mg/kg during the dry season, indicating that the lack of rainfall permits lead buildup in the soil. This emphasizes the necessity of focused waste management and cleanup initiatives to reduce lead contamination from oil spills.

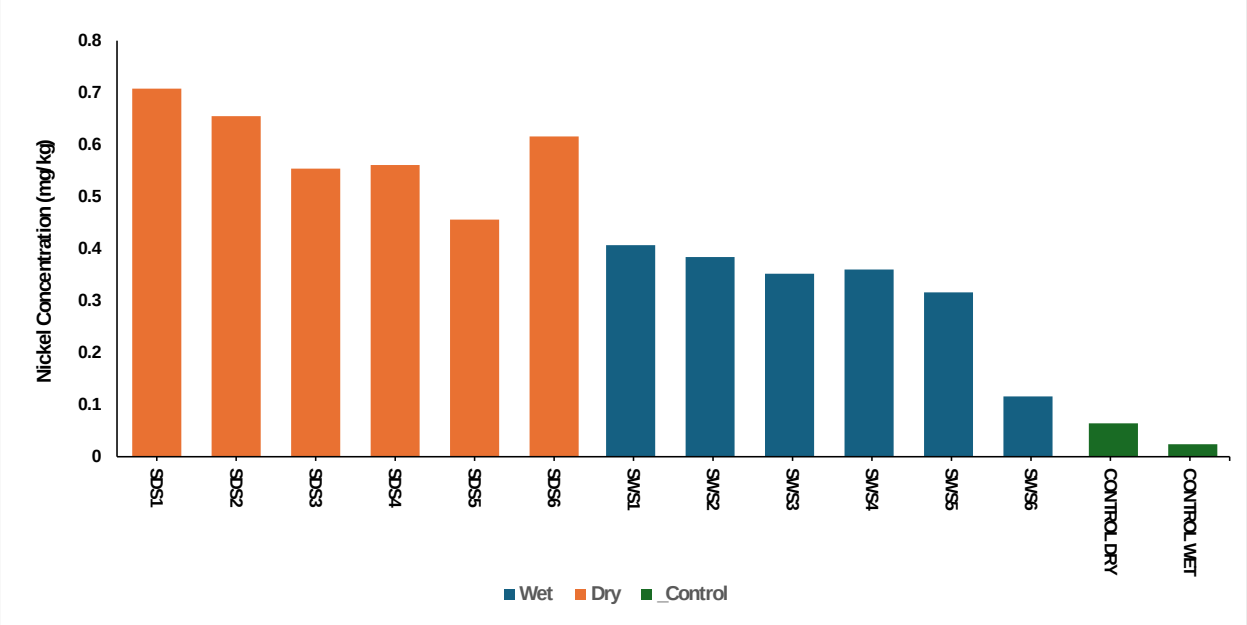

Figure 4.34: Nickel concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

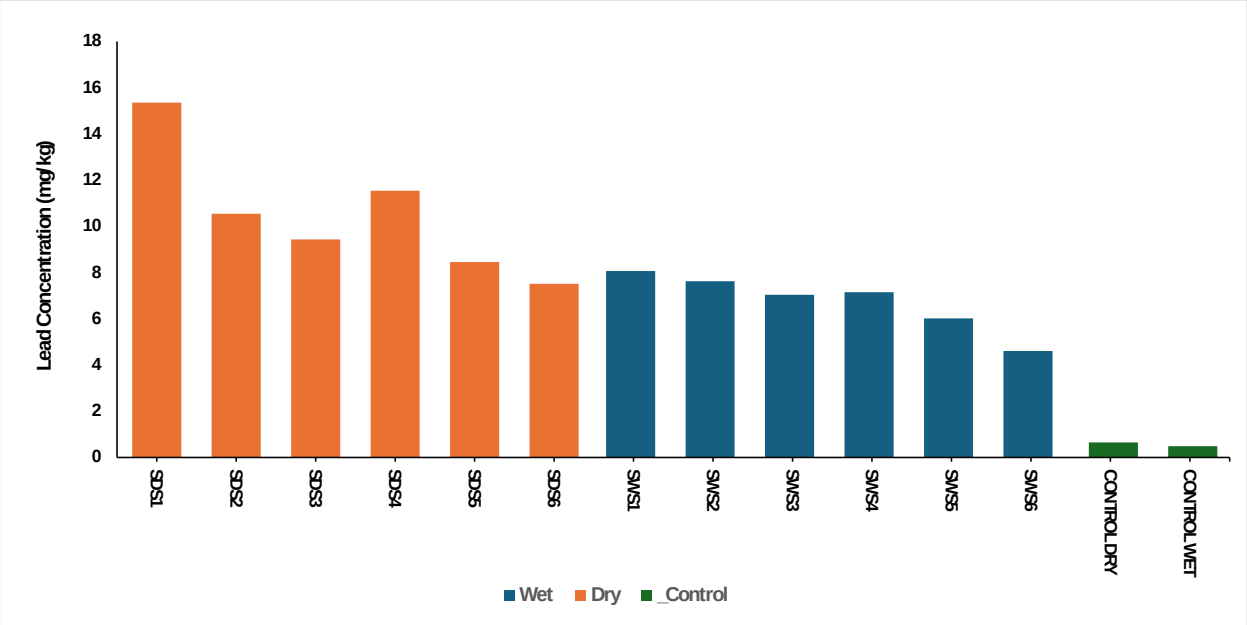

Figure 4.35: Lead concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

4.1.1.4.9 Vanadium (V^{2+})

Vanadium concentrations during the wet season, as shown in Table 4.14, ranged from 0.071 mg/kg at SWS6 (Ibelebiri 3) to 0.108 mg/kg at SWS2 (Agba (Otuege) 2), with a mean of 0.09 mg/kg (Table 4.20). This indicates vanadium contamination, potentially from fuel and oils used in oil extraction. Figure 4.36 visually compares these samples with a control site, showing elevated vanadium levels at many spill sites. Vanadium levels during the dry season range from 0.538 mg/kg at SDS2 (Agba (Otuege) 2) to 0.716 mg/kg at SDS1 (Agba (Otuege) 1), according to Table 4.18, with the mean concentration falling to 0.64 mg/kg (Table 4.19). Significant vanadium input from the spill or equipment deterioration is suggested by the very high vanadium content at SDS1. Figure 4.36 includes dry season data, indicating that vanadium concentrations can decrease due to less leaching and continuous exposure to vanadium sources. Figure 4.36 illustrates the seasonal variation in vanadium concentration, which reveals that during the wet season, there is a modest drop in the mean concentration of vanadium. Vanadium levels, for example, dropped from 0.716 mg/kg during the dry season to 0.106 mg/kg during the wet season in SWS1, which is an indication of the effect that reduced water movement has on the accumulation of vanadium in the soil. Consequently, this highlights the importance of implementing targeted waste management and cleanup activities in order to reduce the amount of vanadium contamination caused by oil spills.

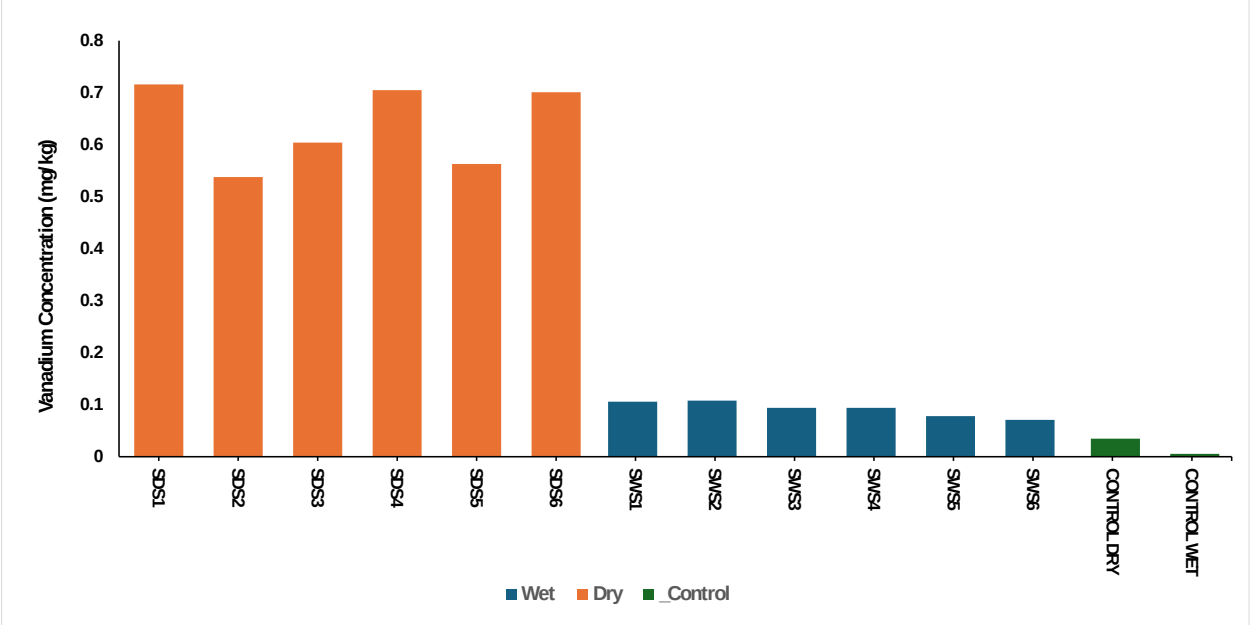

Figure 4.36: Vanadium concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

4.1.2 Heavy Metals in Groundwater

4.1.2.1 Heavy Metals in Groundwater Around Dumpsites

The presence of heavy metals like iron, manganese, zinc, copper, chromium, cadmium, nickel, lead, and vanadium is a major cause for worry at locations where trash is disposed of, such as dumpsites. The leaching of these metals from waste items, runoff from contaminated soil, and the direct discharge of industrial effluents are all potential entry points for these metals into water systems. Significant information regarding pollution levels, potential health risks, and the influence on aquatic ecosystems can be obtained by the examination of heavy metal concentrations in water that is located in close proximity to dumpsites. Figures 4.37- 4.44 shows groundwater samples collected around dumpsite during dry and wet seasons compared with World Health Organization (WHO) and Nigeria Standard of Drinking Water Quality (NSDWQ).

4.1.2.1.1 Iron (Fe^{2+})

During the wet season, iron concentrations in groundwater samples around dumpsites (Table 4.3) ranged from 0.411 mg/L DWGW2 (Igbogene) to 0.811 mg/L DWGW6 (Akenfa 1), with a mean concentration of 0.568 ± 0.146 mg/L (Table 4.30). As shown in Figure 4.37, all sampling locations exceeded the WHO and NSDWQ permissible limit of 0.3 mg/L for drinking water. The highest concentration was recorded at Akenfa 1 (DWGW6), while the lowest was observed at Igbogene BH (DWGW2). Six out of eight sampling locations showed concentrations that exceeded the permissible limit indicating significant iron contamination in the groundwater during the wet season. In the dry season, iron concentrations in dumpsite groundwater (Table 4.7) ranged from 0.311 mg/L (DDGW2) to 0.721 mg/L (DDGW6), with a mean concentration of 0.488 ± 0.143 mg/L (Table 4.31). Figure 4.37 illustrates that all sampling points continued to exceed regulatory standards during the dry season. Similar to the wet season, Akenfa 1 (DDGW6) maintained the highest iron concentration, while Igbogene (DDGW2) recorded the lowest. The dry season data showed that five out of eight locations had iron concentrations that exceeded the permissible limit of 0.3 mg/L by more than 1.5 times.Seasonal variation analysis

reveals that mean iron concentrations were higher during the wet season (0.568 mg/L) compared to the dry season (0.488 mg/L) around dumpsites. As evident in Figure 4.37, while exceedances of standards occurred in both seasons, there was a moderate decrease in iron concentrations during the dry season, with a mean difference of 0.080 mg/L between seasons. This seasonal variation suggests that iron mobility in groundwater around dumpsites is influenced by rainfall patterns, though concentrations remained above permissible limits throughout both seasons.

4.1.2.1.2 Manganese (Mn^{2+})

Manganese levels in groundwater samples near dumpsites (Table 4.3) varied from 0.047 mg/L DWGW7 (Kingdom Road Swali) to 0.81 mg/L DWGW2 ((Igbogene) during the rainy season, with an average of 0.257 ± 0.255 mg/L (Table 4.30). Figure 4.38 illustrates that four of the eight sampling sites had manganese levels above the NSDWQ 2007 allowable limit of 0.2 mg/L while five of the eight samples had manganese values above WHO 2011 allowable limits of 0.1 mg/L. The highest concentration was recorded at Igbogene (DWGW2), while the lowest was observed at Kingdom RD Swali (DWGW7). With a mean value of 0.071 ± 0.052 mg/L (Table 4.31), manganese concentrations in dumpsite groundwater (Table 4.7) during the dry season varied from 0.015 mg/L DDGW1(Tombia Junction Market) to 0.157 mg/L DDGW6 (Akenfa 1). All the sample locations were below NSDWQ limit while three of the eight samples were above WHO limit during the dry season, as shown in Figure 4.38. The maximum manganese concentration was maintained at Akenfa 1 (DDGW6), while the lowest was reported at Tombia Junction Market (DDGW1). The mean manganese concentrations surrounding dumpsites were substantially greater during the wet season (0.257 mg/L) than during the dry season (0.071 mg/L), according to seasonal variation study. With a mean difference of 0.186 mg/L across seasons, manganese concentrations significantly decreased during the dry season, as seen in Figure 4.38. This significant seasonal variation indicates that rainfall and related leaching processes have a significant impact on manganese mobility and concentration in groundwater

surrounding dumpsites. Increasing manganese mobilization from waste materials during times of increasing rainfall is indicated by the greater rainy season concentrations.

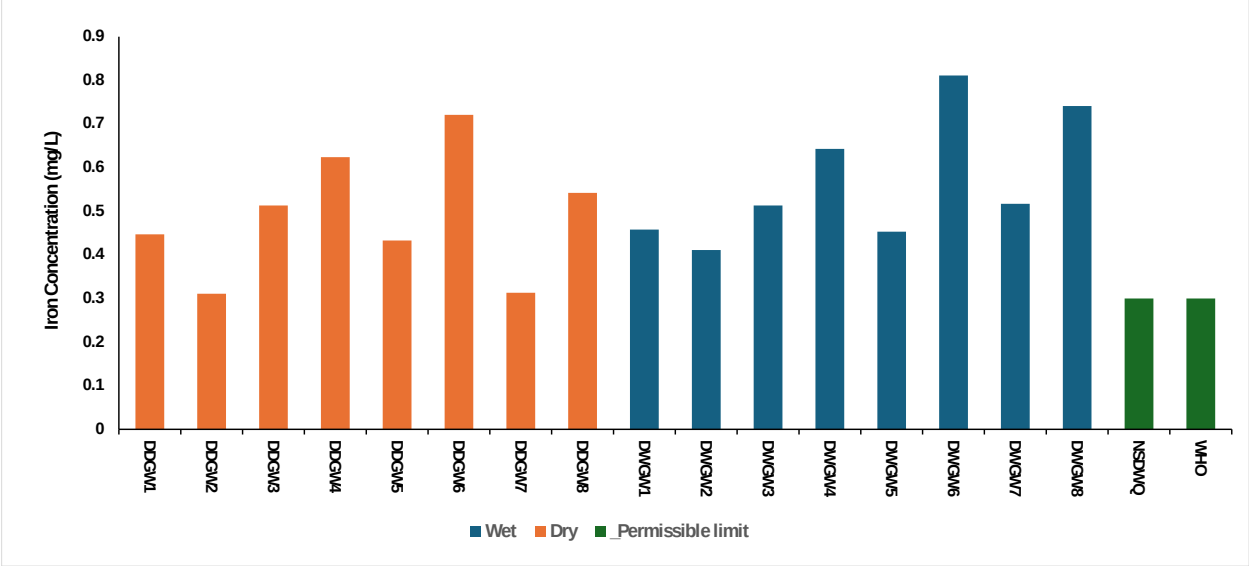

Figure 4.37: Iron concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

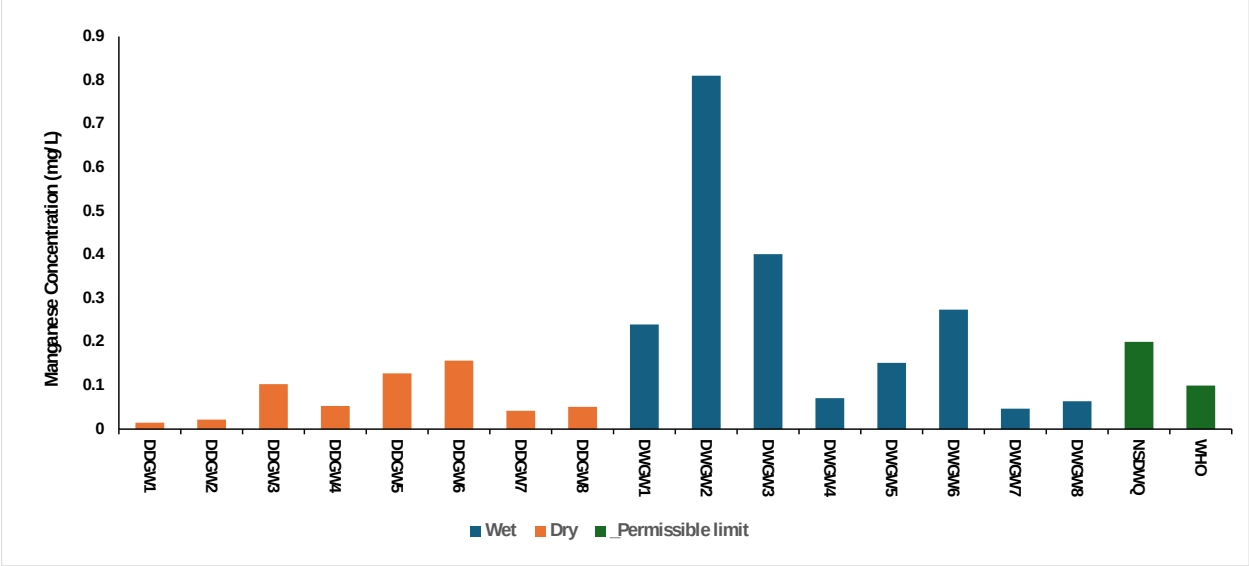

Figure 4. 38: Manganese concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

4.1.2.1.3 Zinc (Zn^{2+})

Groundwater samples near dumpsites (Table 4.3) had zinc concentrations ranging from 0.251 mg/L DWGW2 (Igbogene) to 4.31 mg/L DWGW3 (Azikoro) during the wet season. The mean value was 1.505 ± 1.430 mg/L (Table 4.30). No sampling sites went beyond the 3.0 mg/L drinking water permitted level set by the NSDWQ 2007 whereas all the samples were above 0.01 mg/L set by WHO 2011, as seen in Figure 4.39. The highest concentration was recorded at Azikoro (DWGW3), while the lowest was observed at Igbogene (DWGW2). With a mean value of 0.568 ± 0.664 mg/L (Table 4.31), zinc concentrations in dumpsite groundwater (Table 4.7) during the dry season varied from 0.033 mg/L DDGW1(Tombia Junction Market) to 2.04 mg/L DDGW8 (Okaka Estate). Zinc concentrations when compared to NSDWQ and WHO were the same with observations in the wet season as shown in Figure 4.39. DDGW8 maintained the highest zinc concentration, while DDGW1 recorded the lowest. The mean zinc concentrations surrounding dumpsites were significantly greater during the wet season (1.505 mg/L) than during the dry season (0.568 mg/L), according to seasonal variation study. Zinc concentrations significantly decreased during the dry season, as seen in Figure 4.39 although concentrations stayed within safe bounds for all seasons, this seasonal variation implies that rainfall patterns have an impact on zinc mobility in groundwater surrounding dumpsites.

4.1.2.1.4 Copper (Cu^{2+})

Copper levels in groundwater samples near dumpsites (Table 4.3) during the wet season varied from 0.069 mg/L DWGW8 (Okaka Estate) to 2.341 mg/L DWGW7 (Kingdom RD Swali), with an average of 0.613 ± 0.768 mg/L (Table 4.30). One sampling site had drinking water levels over the WHO 2011 and NSDWQ 2007 allowable limits of 1.0 mg/L, as seen in Figure 4.40. The highest concentration was recorded at Kingdom RD Swali (DWGW7), while the lowest was observed at Okaka Estate (DWGW8). Three locations showed concentrations that exceeded the permissible limit. Copper levels in dumpsite groundwater (Table 4.7) during the dry season varied from 0.012 mg/L DDGW1 (Tombia Junction Market) to 0.253 mg/L DDGW4 (Amarata),

with an average of 0.090 ± 0.074 mg/L (Table 4.31). During the dry season, all sampling points stayed below the regulatory standards, as shown in Figure 4.40. Amarata (DDGW4) maintained the highest copper concentration, while Tombia Junction Market (DDGW1) recorded the lowest. The dry season data showed that none of the locations had copper concentrations exceeding the permissible limit of 1.0 mg/L. According to seasonal variation study, mean copper concentrations surrounding dumpsites were substantially greater during the wet season (0.613 mg/L) than during the dry season (0.090 mg/L). Copper concentrations decreased significantly during the dry season, as seen in Figure 4.40, with a mean difference of 0.523 mg/L between seasons. It is clear from this significant seasonal variation that rainfall patterns and related leaching processes have a significant impact on the mobility of copper in groundwater from dumpsites.

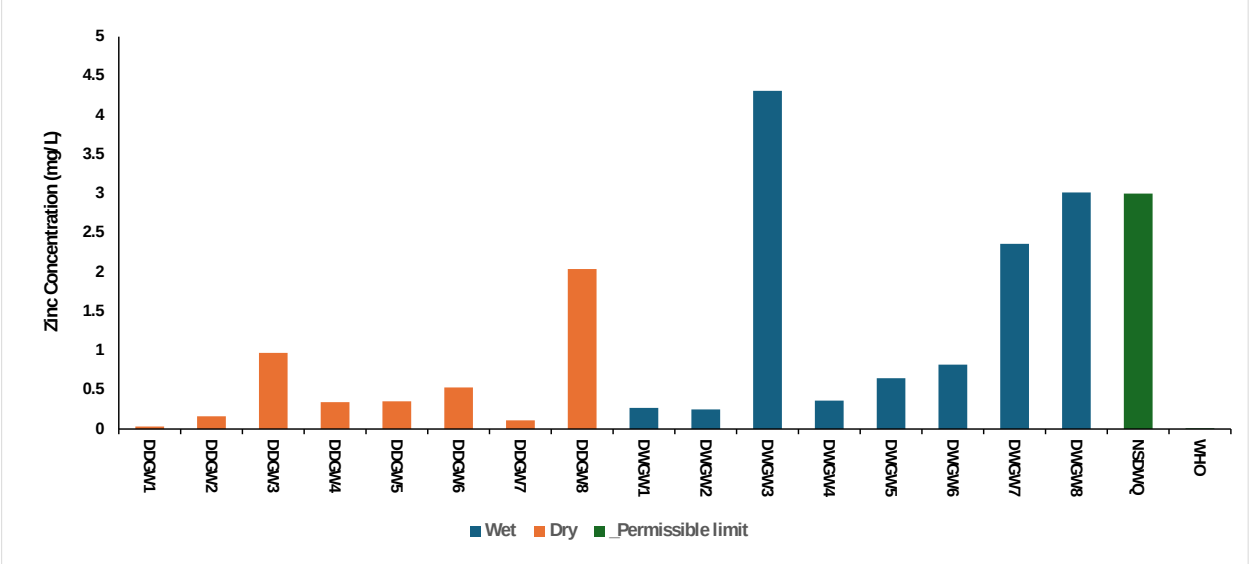

Figure 4. 39: Zinc concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

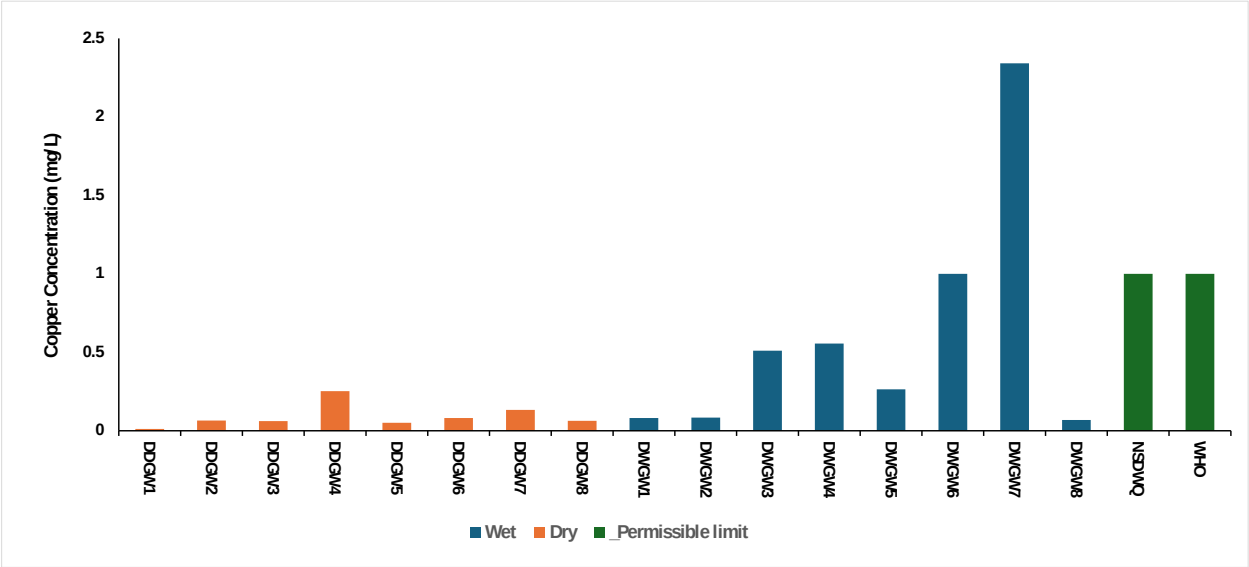

Figure 4.40: Copper concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

4.1.2.1.5 Chromium (Cr^{6+})

Chromium levels in groundwater samples near dumpsites (Table 4.3) during the rainy season varied from 0.044 mg/L DWGW2 (Igbogene) to 0.365 mg/L DWGW7 (Kingdom Road Swali) with an average of 0.119 ± 0.111 mg/L (Table 4.30). Figure 4.41 illustrates that the concentration was lowest at Igbogene (DWGW2) and highest at Kingdom Road Swali (DWGW7). Chromium levels in dumpsite groundwater (Table 4.7) during the dry season varied from 0.001 mg/L DDGW7 (Kingdom Road Swali) to 0.063 mg/L DDGW3 (Azikoro), with an average of 0.029 ± 0.023 mg/L (Table 4.31). Azikoro (DDGW3) had the highest chromium concentration, while Kingdom Road Swali (DDGW7) had the lowest, as seen in Figure 4.41. The mean chromium concentrations surrounding dumpsites were considerably greater during the wet season (0.119 mg/L) than during the dry season (0.029 mg/L), according to seasonal variation analysis. With a mean difference of 0.090 mg/L across seasons, chromium concentrations significantly decreased during the dry season, as seen in Figure 4.41. This significant seasonal variation indicates that rainfall patterns have a significant impact on the mobility of chromium in groundwater surrounding dumpsites.

4.1.2.1.6 Cadmium (Cd^{2+})

During the wet season, cadmium concentrations in groundwater samples around dumpsites (Table 4.3) ranged from 0.004 mg/L DWGW7 (Kingdom Road Swali) to 0.092 mg/L DWGW6 (Akenfa 1), with a mean concentration of 0.033 ± 0.028 mg/L (Table 4.30). As shown in Figure 4.42, all sampling locations exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.003 mg/L for drinking water. The highest and lowest were recorded at DWGW6 (Akenfa 1) and DWGW7 (Kingdom Road Swali) respectively. In the dry season, cadmium concentrations in dumpsite groundwater (DDGW1-DDGW8, Table 4.7) ranged from 0.001 mg/L DDGW5,8 (Amarata and Okaka Estate) to 0.073 mg/L DDGW6 (Akenfa 1) with a mean concentration of 0.025 ± 0.029 mg/L (Table 4.31). Figure 4.42 illustrates that five sampling points exceeded the regulatory standards during the dry season. Akenfa 1 (DDGW6) maintained the highest cadmium

concentration, while Amarata and Okaka Estate (DDGW5,8) recorded the lowest. The mean cadmium concentrations surrounding dumpsites were somewhat higher during the wet season (0.033 mg/L) than during the dry season (0.025 mg/L), according to seasonal variation study. As evident in Figure 4.42, there was a moderate decrease in cadmium concentrations during the dry season, with a mean difference of 0.008 mg/L between seasons. This indicates that cadmium contamination persists across seasons with slightly enhanced mobility during the wet season.

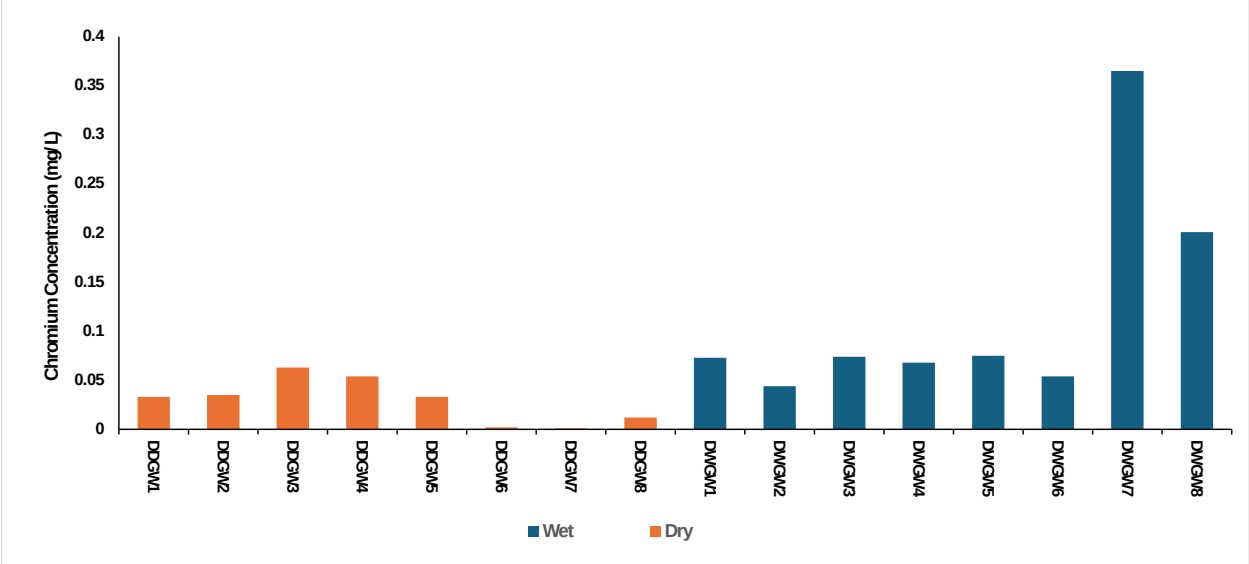

Figure 4. 41: Chromium concentration in groundwater samples collected around dumpsites during the wet and dry seasons

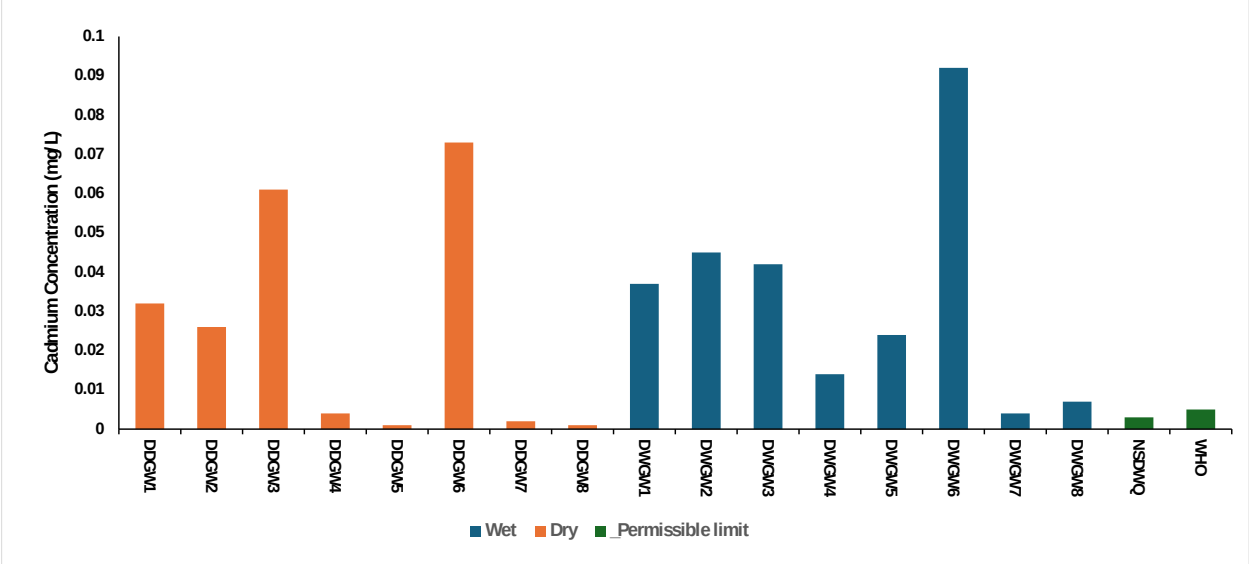

Figure 4. 42: Cadmium concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

4.1.2.1.7 Nickel (Ni^{2+})

In groundwater samples near dumpsites during the rainy season, nickel concentrations varied from 0.000 mg/L DWGW2-8 (Igbogene, Azikoro, Amarata 1&2, Akenfa 1, Kingdom Road Swali and Okaka Estate) to 0.035 mg/L DWGW1 (Tombia Junction Market), with a mean concentration of 0.004 ± 0.012 mg/L (Table 4.30). As shown in Figure 4.43, only one sampling location exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.02 mg/L for drinking water. The highest concentration was recorded at Tombia Junction Market (DWGW1), while no detectable concentrations were observed at seven locations. Nickel levels in dumpsite groundwater (7) varied from 0.000 mg/L (DDGW3-8) to 0.032 mg/L DDGW1 (Tombia Junction Market) throughout the dry season, with an average of 0.004 ± 0.011 mg/L (Table 4.31). Only one sampling point during the dry season exceeded the regulation criteria, as shown in Figure 4.43. Tombia Junction Market (DDGW1) maintained the highest nickel concentration, while no detectable concentrations were found at six locations. The mean nickel contents surrounding dumpsites stayed constant during the wet and dry seasons (0.004 mg/L), according to seasonal variation research. As seen in Figure 4.43, there was no discernible seasonal change in nickel concentrations, indicating that seasonal variations in rainfall do not significantly affect nickel pollution in groundwater surrounding dumpsites.

4.1.2.1.8 Lead (Pb^{2+})

During the wet season, lead concentrations in groundwater samples around dumpsites (Table 4.3) ranged from 0.005 mg/L DWGW8 (Okaka Estate) to 0.079 mg/L DWGW2 (Igbogene), with a mean concentration of 0.033 ± 0.025 mg/L (Table 4.30). As shown in Figure 4.44, six sampling locations exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.01 mg/L for drinking water. The highest concentration was recorded at Igbogene (DWGW2), while the lowest was observed at Okaka Estate (DWGW8). Six out of eight sampling locations showed concentrations that exceeded the permissible limit by more than two times.In the dry season, lead concentrations in dumpsite groundwater (Table 4.7) ranged from 0.001 mg/L DDGW4,5,8

(Amarata1,2 and Okaka Estate) to 0.073 mg/L DDGW2 (Igbogene), with a mean concentration of 0.015 ± 0.024 mg/L (Table 4.31). Figure 4.44 illustrates that three sampling points exceeded the regulatory standards during the dry season. Igbogene (DDGW2) maintained the highest concentration, while Amarata, Amarata and Okaka Estate (DDGW4,5,8) recorded the lowest concentrations. The mean lead concentrations surrounding dumpsites were significantly higher during the wet season (0.033 mg/L) than during the dry season (0.015 mg/L), according to seasonal variation study. With a mean difference of 0.018 mg/L across seasons, lead concentrations significantly decreased during the dry season, as seen in Figure 4.44. This pattern suggests that lead mobility in groundwater is enhanced during the wet season, likely due to increased leaching from waste materials during periods of higher rainfall.

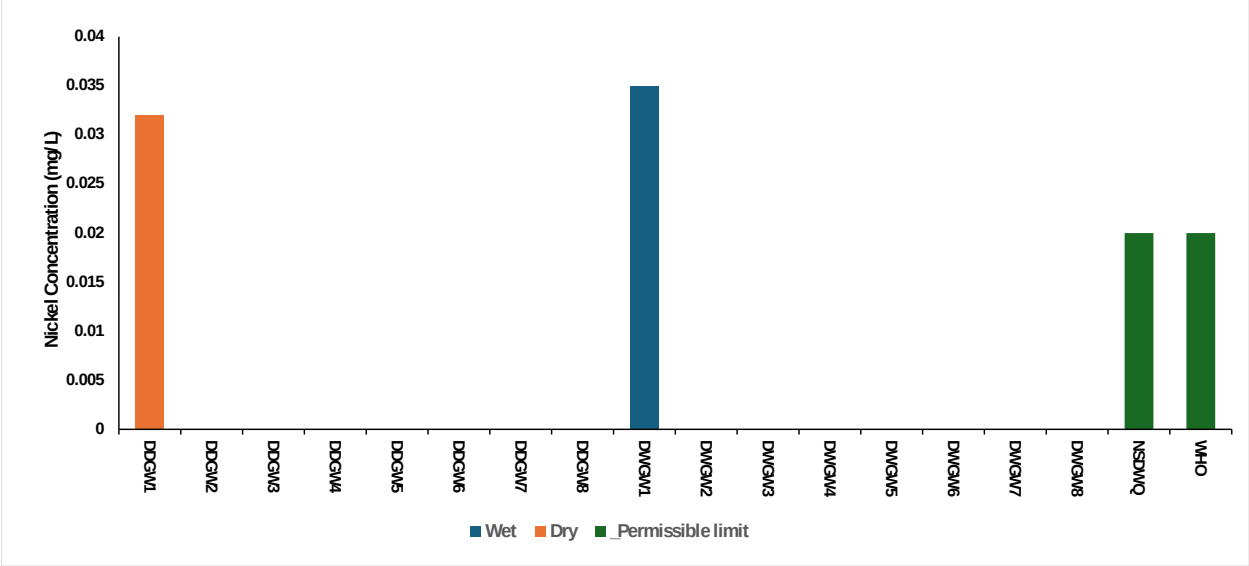

Figure 4. 43: Nickel concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

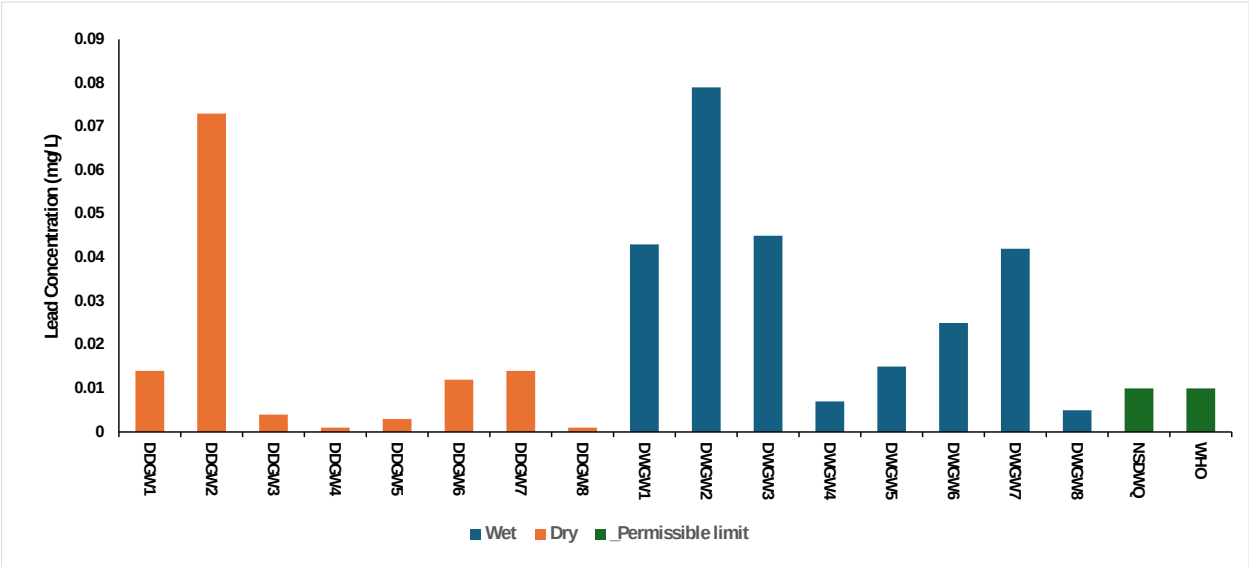

Figure 4. 44: Lead concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

4.1.2.2 Heavy Metals in Groundwater Around Mechanic Workshop

Heavy metals are produced at mechanic shops because of the usage of oils, lubricants, brake pads, and other automotive products, as well as the disposal of these materials. Mechanic shops are places where activities such as vehicle maintenance and repair take place. With the use of this study, the concentrations of these heavy metals in groundwater samples that were obtained during both the wet and dry seasons around mechanic workshops are investigated. The results of this analysis provide insights into the levels of pollution and the environmental impact that these locations experienced. Figures 4.45- 4.50 shows groundwater samples collected around mechanic workshop during dry and wet seasons compared with World Health Organization (WHO) and Nigeria Standard of Drinking Water Quality (NSDWQ).

4.1.2.2.1 Iron (Fe^{2}+)

The mean concentration of iron in groundwater samples near mechanic workshops (Table 4.4) during the rainy season was 0.239 ± 0.144 mg/L, with a range of 0.002 mg/L (MWGW7) to 0.416 mg/L (MWGW2). As shown in Figure 4.45, four sampling locations exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.3 mg/L for drinking water. The highest concentration was recorded at Mechanic Village Imiringi Rd (MWGW2), while the lowest was observed at Kpansia Melford Okilo Road (MWGW7). Iron levels in mechanic workshop groundwater (Table 4.8) varied from 0.057 mg/L (MDGW8) to 0.625 mg/L (MDGW2) during the dry season, with an average of 0.384 ± 0.149 mg/L (Table 4.31). Figure 4.45 illustrates that six sampling points exceeded the regulatory standards during the dry season. Similar to the wet season, Mechanic Village Imiringi Rd (MDGW2) maintained the highest iron concentration, while Kpansia Nikton RD (MDGW8) recorded the lowest. The mean iron concentrations around mechanic workshops were greater during the dry season (0.384 mg/L) than during the wet season (0.239 mg/L), according to seasonal variation study. With a mean difference of 0.145 mg/L across seasons, iron concentrations increased throughout the dry season, as seen in Figure 4.45.

This pattern implies that, perhaps as a result of less dilution effects, iron deposition in the groundwater surrounding mechanic workshops is more noticeable during the dry season.

4.1.2.2.2 Manganese (Mn^{2+})

During the wet season, manganese concentrations in groundwater samples around mechanic workshops (MWGW1-MWGW10, Table 4.4) ranged from 0.046 mg/L (MWGW9) to 0.145 mg/L (MWGW2), with a mean concentration of 0.094 ± 0.039 mg/L (Table 4.30). As shown in Figure 4.46, no sampling locations exceeded the NSDWQ 2007 limit of 0.2 mg/L but four sample locations exceeded the WHO 2011 limit of 0.1 mg/L for drinking water. The highest concentration was recorded at Mechanic Village Imiringi Rd (MWGW2), while the lowest was observed at Yenizue-Gene Erepa Rd (MWGW9). In the dry season, manganese concentrations in mechanic workshop groundwater (MDGW1-MDGW10, Table 4.8) ranged from 0.008 mg/L (MDGW9) to 0.124 mg/L (MDGW2), with a mean concentration of 0.068 ± 0.049 mg/L (Table 4.31). Figure 4.46 illustrates that all sampling points remained below NSDWQ limit while four sample location exceeded the WHO limit during the dry season. Similar to the wet season, Mechanic Village Imiringi Rd (MDGW2) maintained the highest manganese concentration, while Yenizue-Gene Erepa Rd (MDGW9) recorded the lowest. Seasonal variation analysis reveals that mean manganese concentrations were slightly higher during the wet season (0.094 mg/L) compared to the dry season (0.068 mg/L) around mechanic workshops. As evident in Figure 4.46, there was a modest decrease in manganese concentrations during the dry season. This suggests that manganese levels in groundwater around mechanic workshops show minor seasonal variation while remaining within safe limits throughout the year.

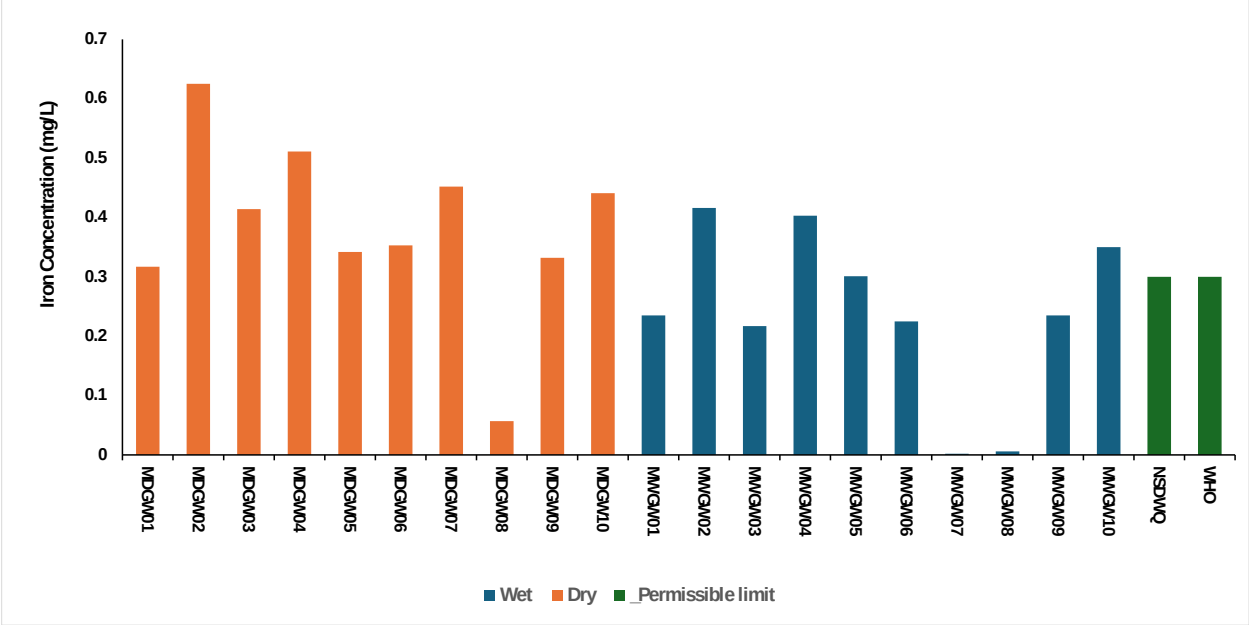

Figure 4. 45: Iron concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

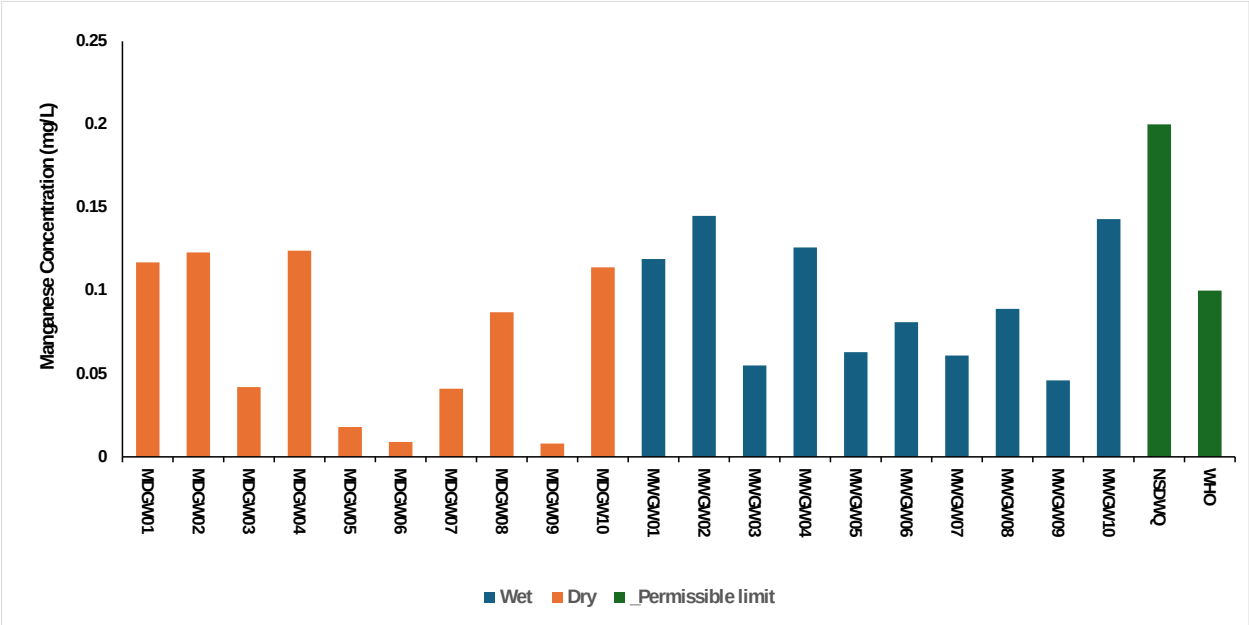

Figure 4. 46: Manganese concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

4.1.2.2.3 Zinc (Zn^{2+})

Groundwater samples near mechanic workshops (Table 4.4) had zinc concentrations ranging from 0.136 mg/L (MWGW4) to 1.131 mg/L (MWGW6) during the rainy season, with a mean of 0.494 mg/L (Table 4.30). As shown in Figure 4.47, no sampling locations exceeded the NSDWQ 2007 limit of 3 mg/L but all the sample exceed the WHO limit of 0.01 mg/L for drinking water. The highest concentration was recorded at Kpansia Nikton RD. BH 2 (MWGW6), while the lowest was observed at Mechanic Village Imiringi Rd. BH4 (MWGW4). Zinc concentrations in groundwater around mechanic workshop (MDGW1-MDGW10, Table 4.8) varied from 0.041 mg/L (MDGW5) to 0.352 mg/L (MDGW4) throughout the dry season, with a mean of 0.142 mg/L (Table 4.31). As seen in Figure 4.47, the comparison with the limit was identical to what was seen during the wet season. Kpansia Nikton Rd BH1 (MWGW5) recorded the highest zinc concentration, while Mechanic Village Imiringi Rd. BH4 (MWGW4) recorded the lowest. The mean zinc concentrations near mechanic workshops were greater during the wet season (0.494 mg/L) than during the dry season (0.142 mg/L), according to seasonal variation study. Zinc concentrations moderately decreased during the dry season, as shown in Figure 4.47. Although concentrations stayed within permissible bounds for both seasons, this seasonal change indicates increased zinc mobility during the wet season.

4.1.2.2.4 Copper (Cu^{2+})

During the wet season, copper concentrations in groundwater samples around mechanic workshops (Table 4.4) ranged from 0.011 mg/L MWGW6 (Kpansia Nikton Road BH2) to 0.321 mg/L MWGW3 (Mechanic Village Imiringi Road BH3), with a mean concentration of 0.1 mg/L (Table 4.30). As shown in Figure 4.48, no sampling location exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 1.0 mg/L for drinking water. The highest concentration was recorded at Mechanic Village Imiringi Rd (MWGW3), while the lowest was observed at Kpansia Nikton Rd BH 2 (MWGW6). In the dry season, copper concentrations in mechanic workshop groundwater (Table 4.8) ranged from 0.013 mg/L MDGW2 (Village Imiringi Road BH2) to 0.13

mg/L MDGW4 (Mechanic Village Imiringi Road BH4), with a mean concentration of 0.047 mg/L (Table 4.31). Figure 4.48 illustrates that all sampling points remained below the regulatory standards during the dry season. Mechanic Village Imiringi Rd BH4 (MDGW4) maintained the highest copper concentration, while Mechanic Village Imiringi Rd BH2 (MDGW2) recorded the lowest. The mean copper concentrations near mechanic workshops were significantly greater during the wet season (0.1 mg/L) than during the dry season (0.047 mg/L), according to seasonal variation study. During the dry season, copper concentrations significantly decreased, as shown in Figure 4.48. Although all sites kept concentrations below the allowable limit during all seasons, this pattern suggests that copper mobility in groundwater surrounding mechanic workshops is increased during the wet season.

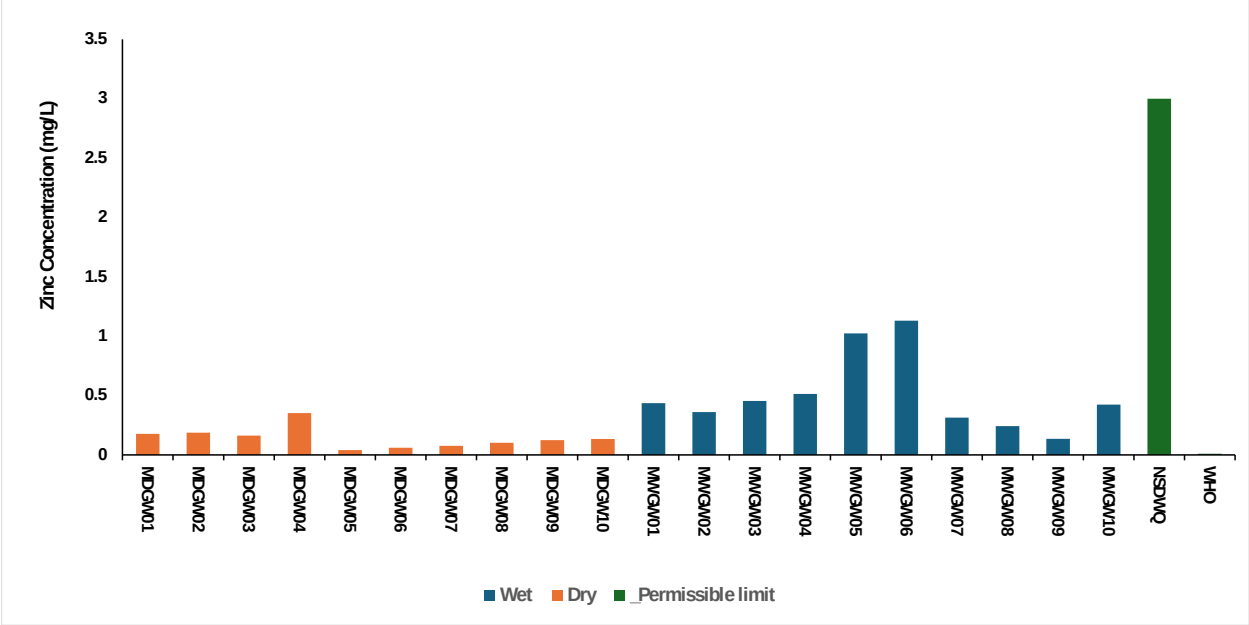

Figure 4.47: Zinc concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

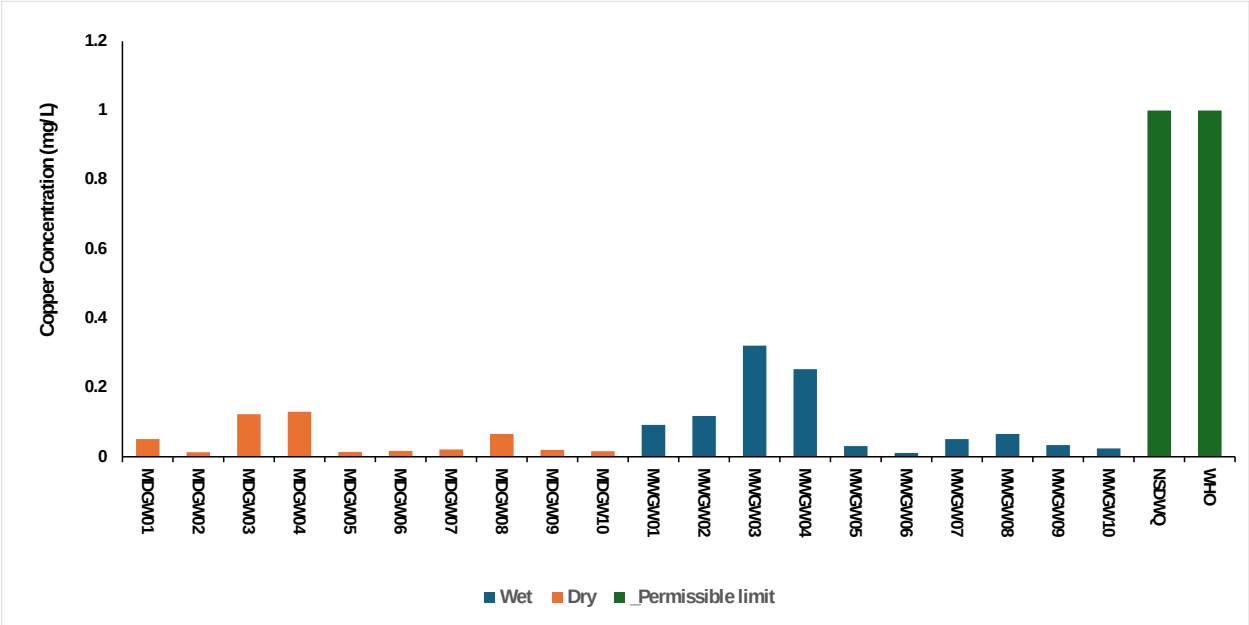

Figure 4.48: Copper concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

4.1.2.2.5 Chromium (Cr^{6+})

Groundwater samples near mechanic workshops (Table 4.4) had chromium values ranging from 0.006 mg/L (MWGW5) to 0.067 mg/L (MWGW2) during the rainy season, with a mean of 0.037 mg/L (Table 4.30). As seen in Figure 4.49, Mechanic Village Imiringi Rd (MWGW2) had the highest concentration and Kpansia Nikton Rd BH1 (MWGW5) recorded the lowest. The mean concentration of chromium throughout the dry season was 0.029 mg/L, with a range of 0.005 mg/L (MDGW5) to 0.05 mg/L (MDGW2) (Table 4.31). Mechanic Village Imiringi Rd (MDGW2) continued to have the greatest chromium concentration, whereas Kpansia Nikton Rd BH1 (MWGW5) had the lowest, much like during the wet season.The seasonal fluctuation that is depicted in Figure 4.49 demonstrates that the mean chromium concentrations were somewhat higher during the wet season (0.037 mg/L) in comparison to the dry season (0.029 mg/L). Based on this pattern, it can be deduced that the mobility of chromium in groundwater in the vicinity of mechanic workshops is marginally increased during the wet season.

4.1.2.2.6 Cadmium (Cd^{2+})

Cadmium levels in groundwater samples near mechanic workshops (Table 4.4) varied from 0.001 mg/L (MWGW6) to 0.038 mg/L (MWGW2) during the rainy season, with a mean of 0.017 mg/L (Table 4.30). As shown in Figure 4.50, all sampling locations exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.003 mg/L for drinking water except in 2 locations (MWGW6 and MWGW10). The highest concentration was recorded at Mechanic Village Imiringi Road (MWGW2), while the lowest was observed at Kpansia Nikton RD. BH 2 (MWGW6).Cadmium levels in the groundwater surrounding the mechanic workshop (MDGW1-MDGW10, Table 4.8) varied from 0.001 mg/L MDGW5 (Kpansia Nikton Road BH1) to 0.031 mg/L MDGW2 (Mechanic Village Imiringi Road) throughout the dry season, with a mean of 0.008 mg/L (Table 4.31). Five sampling points were either equal to or below the NSDWQ and WHO standards throughout the dry season, as shown in Figure 4.50. Mechanic Village Imiringi Road (MDGW2) maintained the highest cadmium concentration. A comparison of the mean

cadmium concentrations during the dry season (0.008 mg/L) and the rainy season (0.017 mg/L) reveals that the wet season shows a greater concentration of cadmium. It may be deduced from this that cadmium pollution is present throughout the year, with increased mobility during the wet season particularly.

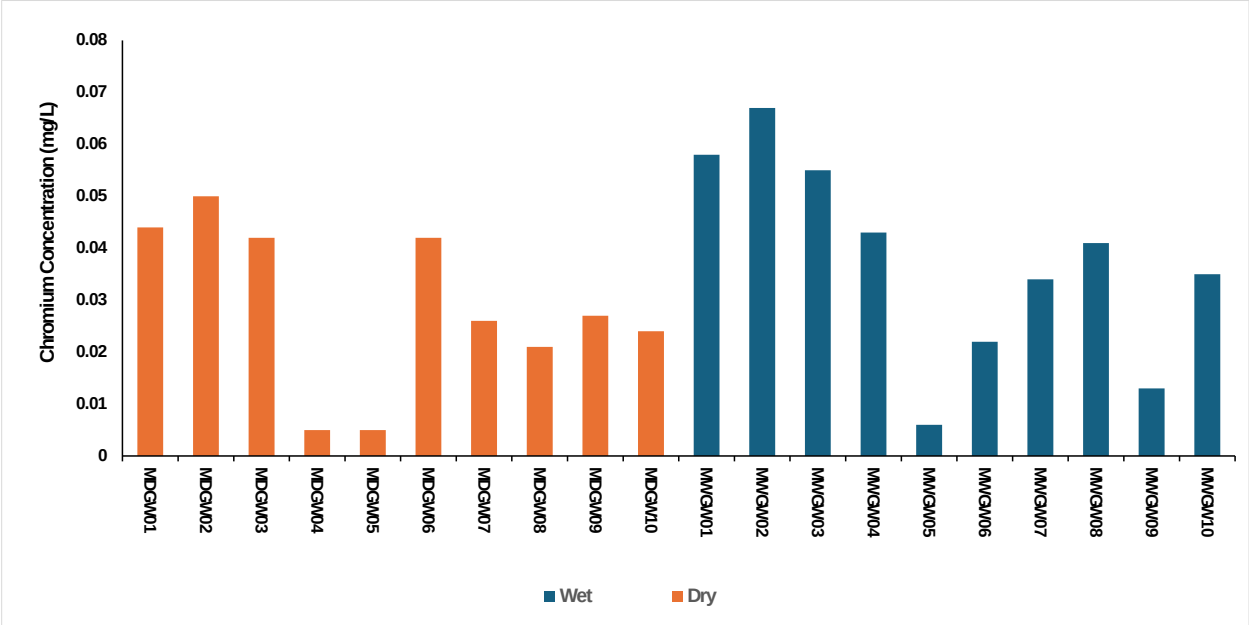

Figure 4.49: Chromium concentration in groundwater samples collected around mechanic workshops during the wet and dry seasons

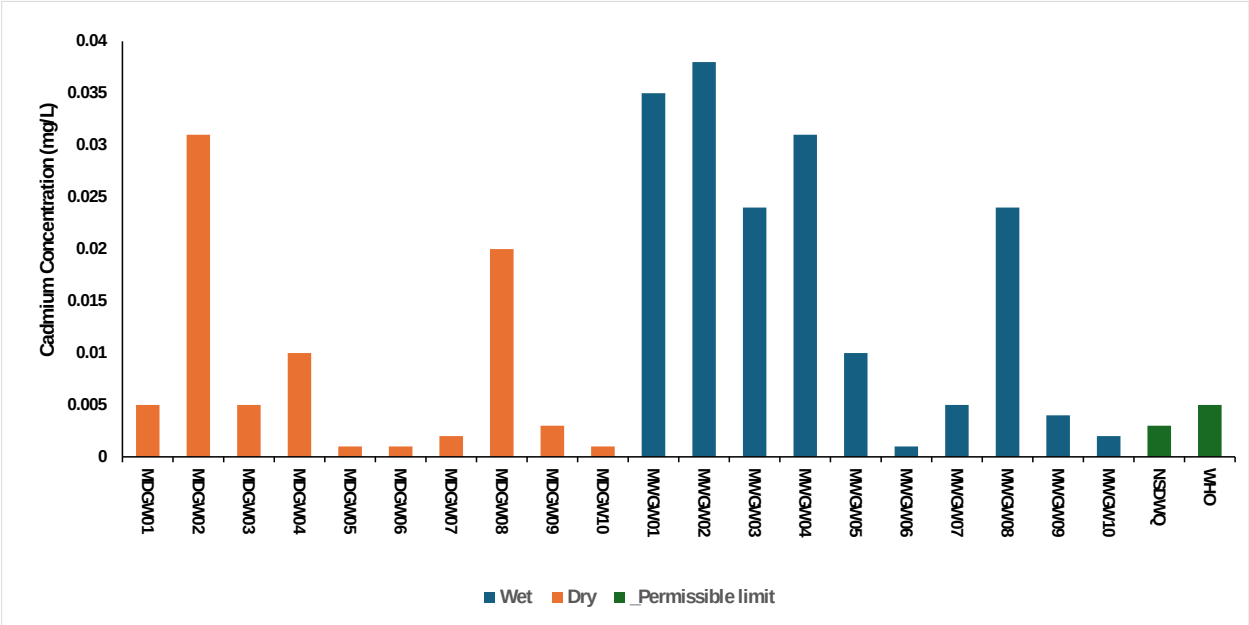

Figure 4. 50: Cadmium concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

4.1.2.2.7 Nickel (Ni^{2+})

In the vicinity of mechanic workshops, nickel concentrations throughout the wet season varied from 0.000 mg/L (MWGW3-10) to 0.03 mg/L MWGW2 (Mechanic Village Imiringi Road BH2), with an average of 0.005 mg/L (Table 4.30). As seen in Figure 4.51, only two sites went beyond the WHO 2011 and NSDWQ 2007 allowable limit of 0.02 mg/L. The highest concentration was recorded at Mechanic Village Imiringi Road (MWGW2). With a mean value of 0.001 mg/L, nickel concentrations in mechanic workshops throughout the dry season varied from 0.000 mg/L (MDGW3–10) to 0.007 mg/L MDGW2 (Mechanic Village Imiringi Road BH2), (Table 4.31). The acceptable range was met by every sampling point. At mean values of 0.005 mg/L (wet) and 0.001 mg/L (dry), seasonal fluctuation was negligible. This suggests that nickel contamination endures throughout the year, with increased mobility during the rainy season.

4.1.2.2.8 Lead (Pb^{2+})

During the wet season, lead concentrations ranged from 0.011 mg/L MWGW5 (Kpansia Nikton Road BH1) to 0.053 mg/L MWGW2 (Mechanic Village Imiringi Road BH2), with a mean concentration of 0.033 mg/L (Table 4.30). Figure 4.52 shows that all sampling locations exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.01 mg/L. The highest concentration was recorded at Mechanic Village Imiringi Road BH2 (MWGW2), while the lowest was observed at Kpansia Nikton Road BH1 (MWGW5). In the dry season, lead concentrations ranged from 0.003 mg/L MDGW5 (Kpansia Nikton Road BH1) to 0.05 mg/L MDGW7 (Kpansia Milford Okilo Road), with a mean concentration of 0.021 ± 0.015 mg/L (Table 4.31). All sampling points except two (MDGW5 & MDGW10) exceeded permissible limit. According to a seasonal variation analysis, the mean lead concentrations were 0.011 mg/L higher during the wet season (0.033 mg/L) than during the dry season (0.021 mg/L). This indicates that lead mobility is increased throughout the rainy season, as most sites surpass allowable limits in both seasons.

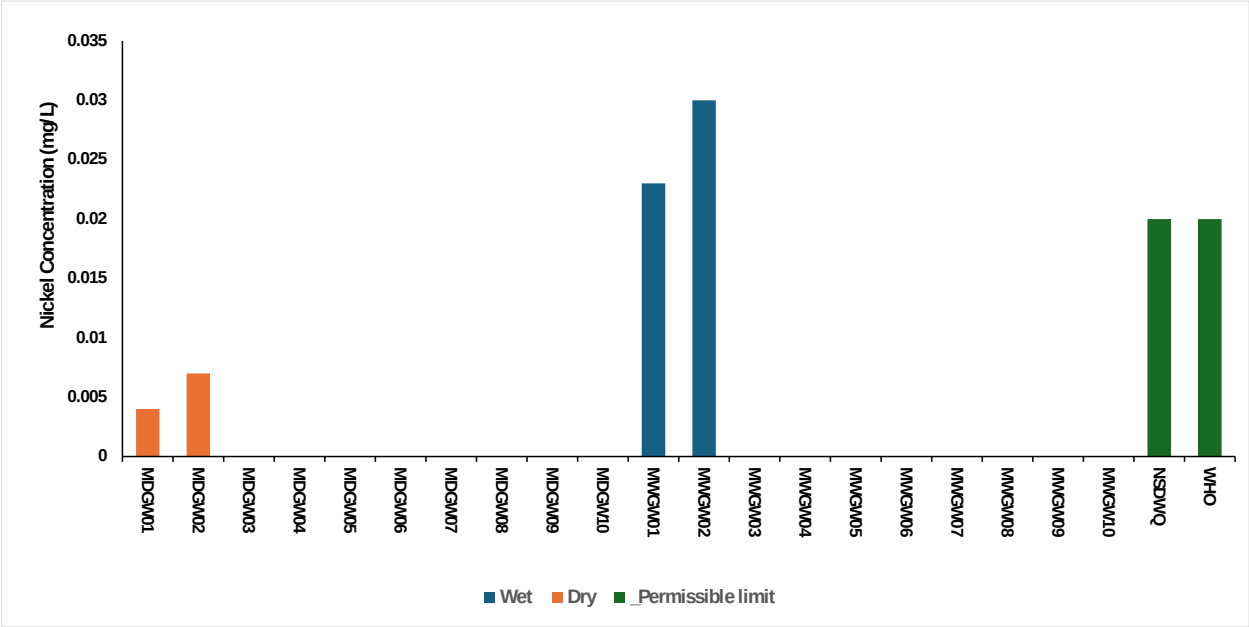

Figure 4. 51: Nickel concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

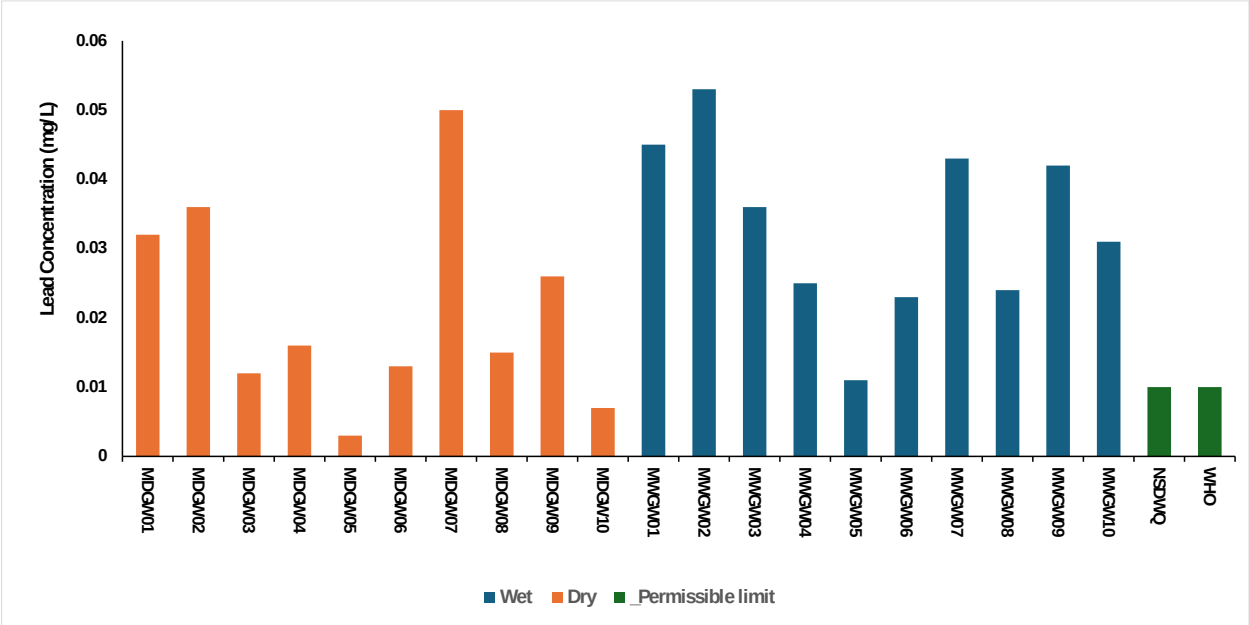

Figure 4. 52: Lead concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

4.1.2.3 Heavy Metals in Groundwater Around Cassava Mills

Heavy metal emissions from cassava mills, which turn cassava roots into a variety of goods like starch and flour, can pollute the environment. Because it can absorb metals from the soil, the cassava plant itself may be the source of these metals, or they may come from industrial operations like the use of metal tools and chemicals. By examining the quantities of heavy metals in groundwater samples taken during the dry and wet seasons near cassava mills, this investigation sheds light on the environmental impact and pollution levels at these locations.

4.1.2.3.1 Iron (Fe^{2}+)

Groundwater samples near cassava mills (CWGW1-CWGW9, Table 4.5) had iron concentrations ranging from 0.289 mg/L (CWGW2) to 0.7 mg/L (CWGW6) during the rainy season. The mean value was 0.47 ± 0.127 mg/L (Table 4.30). All sampling location surpassed the NSDWQ 2007 and WHO 2011 drinking water permitted level of 0.3 mg/L, except one (CWGW2) location recorded within the standards, as illustrated in Figure 4.53. The highest concentration was recorded at Agbura (CWGW6), while the lowest was observed at Opolo Big Brother Road (CWGW2). Iron concentrations (CDGW1-CDGW9, Table 4.9) varied from 0.317 mg/L (CDGW2) to 0.771 mg/L (CDGW6) throughout the dry season, with a mean of 0.544 ± 0.143 mg/L (Table 4.31). Every sampling point exceeded the allowable limit, as seen in Figure 4.53. The highest and lowest amounts were identical to those found during the rainy season.

Analysis of seasonal variation shows that iron exhibited a clear pattern, with concentrations being greater in the dry season (mean: 0.544 mg/L) than in the wet season (mean: 0.47 mg/L). Higher concentrations of dissolved metals as a result of decreased groundwater levels and diminished dilution effects could be the cause of this rise in the dry season. Moderate temporal fluctuation in iron concentrations is indicated by this seasonal variation.

4.1.2.3.2 Manganese (Mn^{2+})

During the wet season, manganese concentrations (CWGW1-CWGW9, Table 4.5) ranged from 0.014 mg/L CWGW3 (Akenfa 1) to 0.101 mg/L CWGW2 (Opolo Big Brother Road), with a

mean concentration of 0.045 ± 0.03 mg/L (Table 4.30). No sampling locations exceeded the NSDWQ 2007 and WHO 2011 permissible limit of 0.2 and 0.1 mg/L respectively for drinking water except at CWGW2 where the water point exceeds 0.1 mg/L limit of WHO 2011 as shown in Figure 4.54. The highest concentration was recorded at Opolo Big Brother Road (CWGW2), while the lowest was observed at Akenfa 1(CWGW3). Manganese levels (CDGW1-CDGW9, Table 4.9) varied from 0.003 mg/L (CDGW4) Igbogene BH1 to 0.104 mg/L (CDGW2) Opolo Big Brother Road throughout the dry season, with an average of 0.033 ± 0.037 mg/L (Table 4.31). Comparison with permissible limit was same as observed in the wet season with only CDGW2 sample above WHO limit of 0.1 mg/L. All other sampling points remained below the regulatory standards. Opolo Big Brother Road (CDGW2) observed the highest concentration, while Igbogene BH1 (CDGW4) recorded the lowest. Manganese exhibited stronger seasonal fluctuations with notably higher concentrations in the wet season (mean: 0.045 mg/L) compared to the dry season (mean: 0.033 mg/L). This decrease during the dry season suggests that manganese mobility is enhanced during periods of increased rainfall, possibly due to the reduction of manganese oxides under the more reducing conditions that develop during wet periods.

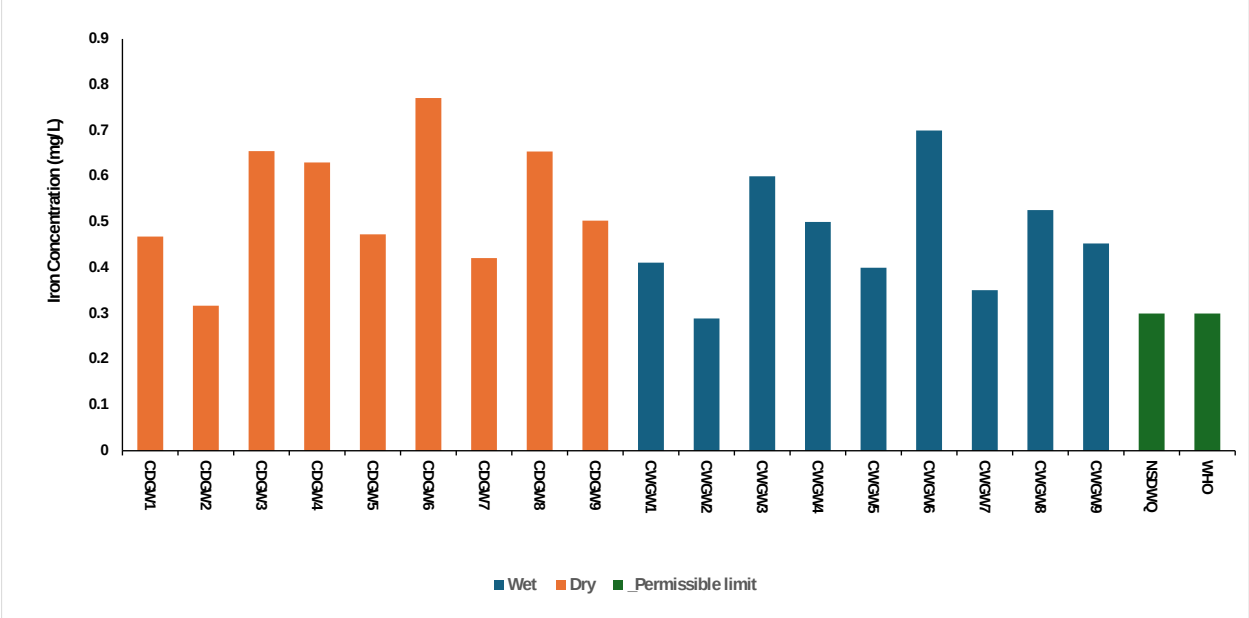

Figure 4. 53: Iron concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

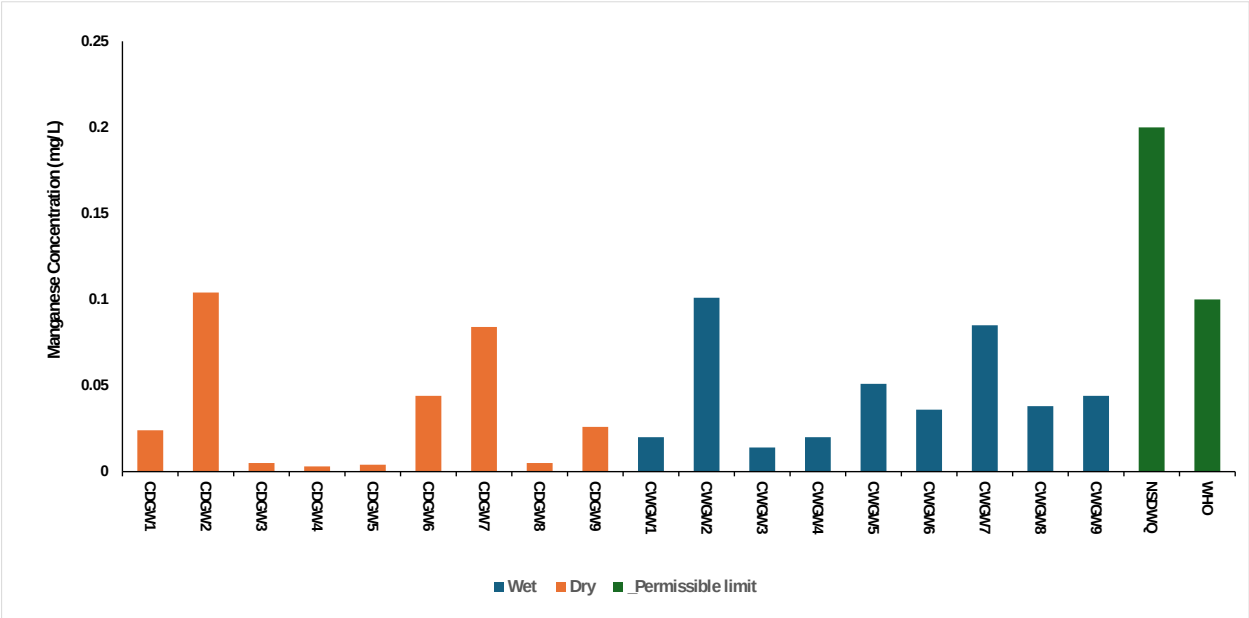

Figure 4. 54: Manganese concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

4.1.2.3.3 Zinc (Zn^{2+})

Zinc levels (CWGW1-CWGW9, Table 4.5) averaged 0.303 ± 0.143 mg/L (Table 4.30) during the wet season, ranging from 0.13 mg/L CWGW4 (Igbogene BH1) to 0.544 mg/L CWGW2 (Opolo Big Brother Road). Figure 4.55 shows that no sampling sites had levels higher than the 3.0 mg/L NSDWQ 2007 permissible limit. However, all the sampling location exceeded the WHO 2011 permissible limit of 0.01 mg/L. The highest concentration was recorded at CWGW2 (Opolo Big Brother Road), while the lowest was observed at Igbogene BH1 (CWGW4). Zinc levels (CDGW1-CDGW8, Table 4.9) varied from 0.045 mg/L CDGW3 (Akenfa 1) to 0.246 mg/L CDGW8 (Ogu) throughout the dry season, with an average of 0.137 ± 0.084 mg/L (Table 4.31). The comparison with the allowable limit was identical to the findings during the rainy season, when every sample exceeded the WHO standard of 0.01 mg/L. The highest concentration was demonstrated at Ogu (CDGW8), while the lowest was observed at Akenfa 1 (CDGW3). Zinc demonstrated pronounced seasonal variations with significantly higher concentrations during the wet season (mean: 0.303 mg/L) compared to the dry season (mean: 0.137 mg/L). The reduction in zinc concentrations during the dry season indicates that zinc mobility is strongly influenced by rainfall patterns. This may be attributed to enhance leaching of zinc from cassava mill waste during periods of higher precipitation.

4.1.2.3.4 Copper (Cu^{2+})

During the wet season, copper concentrations (CWGW1-CWGW9, Table 4.5) ranged from 0.075 mg/L CWGW6 (Agbura) to 0.41 mg/L CWGW7 (Swali), with a mean concentration of 0.223 ± 0.124 mg/L (Table 4.30). Figure 4.56 shows that no sampling locations exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 1.0 mg/L. Swali (CWGW7) recorded the highest concentration, while Agbura (CWGW6) maintained the lowest. Over the course of the dry season, the concentrations of copper (CDGW1-CDGW9, Table 4.9) varied from 0.012 mg/L CDGW1 (Otuasega) to 0.091 mg/L CDGW9 (Onopa), with a mean value of 0.059 ± 0.025 mg/L (Table 4.31). As can be seen in Figure 4.56, all of the sampling locations continued to fall below

the regulatory regulations. Highest concentration was recorded at Otuasega (CDGW1), while Onopa (CDGW9) recorded the lowest. Copper showed marked seasonal differences with elevated concentrations in the wet season (mean: 0.223 mg/L) compared to the dry season (mean: 0.059 mg/L). This decrease during the dry season suggests that copper mobility is significantly enhanced during wet periods, likely due to increased dissolution and transport of copper compounds from cassava processing waste.

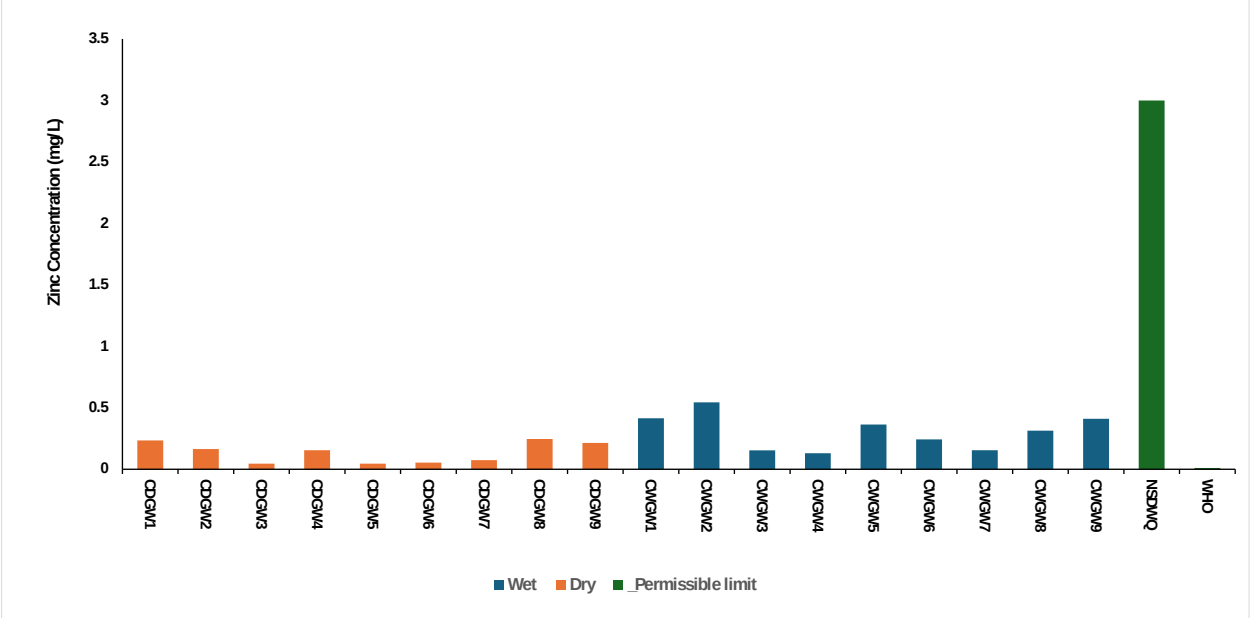

Figure 4. 55: Zinc concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

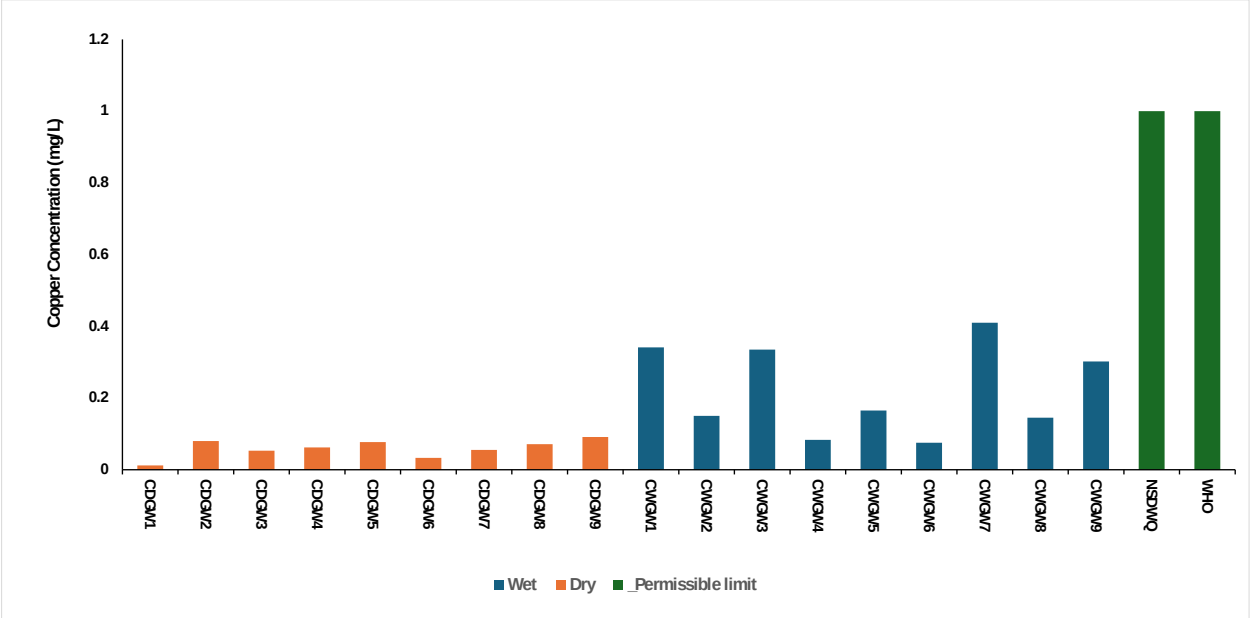

Figure 4. 56: Copper concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

4.1.2.3.5 Chromium (Cr^{6+})

Chromium levels in groundwater samples near cassava mills (CWGW1-CWGW9, Table 4.5) varied from 0.030 mg/L CWGW3(Akenfa1) to 0.080 mg/L CWGW6 (Agbura) throughout the wet season, with an average of 0.052 ± 0.015 mg/L (Table 4.30). All sampling sites had chromium values that were generally higher, as seen in Figure 4.57. Akenfa1 (CWGW3) demonstrated the lowest concentration, while Agbura (CWGW6) recorded the highest. In the dry season, chromium concentrations in cassava mill groundwater (CDGW1-CDGW9, Table 4.9) ranged from 0.002 mg/L CDGW3 (Akenfa1) to 0.051 mg/L CDGW5 (Igbogene), with a mean concentration of 0.036 ± 0.017 mg/L (Table 4.31). Figure 4.57 illustrates a general decrease in chromium concentrations across all sampling points. Igbogene BH2 (CDGW5) recorded the highest concentration, while Akenfa1 (CDGW3) maintained the lowest concentration. Seasonal variation analysis reveals that mean chromium concentrations were notably higher during the wet season (0.052 mg/L) compared to the dry season (0.036 mg/L), representing a slight reduction. This pattern indicates enhanced chromium mobility during the wet season, possibly due to increased leaching from cassava processing waste. The consistency in spatial distribution across seasons is noteworthy, with locations like Otuasega consistently showing lower concentrations in both seasons.

4.1.2.3.6 Cadmium (Cd^{2+})

Groundwater samples near cassava mills (CWGW1-CWGW9, Table 4.5) had cadmium concentrations ranging from 0.003 mg/L CWGW1 (Otuasega) to 0.034 mg/L CWGW2 (Opolo Big Brother Road) during the wet season. The mean value was 0.021 ± 0.010 mg/L (Table 4.30). As shown in Figure 4.58, all sampling locations exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.003 mg/L. The highest concentration was recorded at Opolo Big Brother Road (CWGW2), while the lowest was observed at Otuasega (CWGW1).Cadmium levels in groundwater from cassava mills (CDGW1-CDGW9, Table 4.9) varied from 0.001 mg/L

CDGW9 Onopa to 0.028 mg/L CDGW2 Opolo Big Brother Road throughout the dry season, with an average of 0.012 ± 0.010 mg/L (Table 4.31). Figure 4.58 illustrates that eight out of nine sampling points exceeded the regulatory standards. Opolo Big Brother Road (CDGW2) maintained the highest cadmium concentration, while Onopa recorded the lowest. The mean cadmium contents were slightly lower during the dry season (0.012 mg/L) than during the wet season (0.021 mg/L), according to seasonal variation study. This implies that during the rainy season, cadmium mobility in the groundwater surrounding cassava mills is increased. In both seasons, Opolo Big Brother Road the location consistently displayed the highest quantities, suggesting that this site is a continuous source of contamination.

4.1.2.3.7 Lead (Pb^{2+})

During the wet season, lead concentrations in groundwater samples around cassava mills (Table 4.5) ranged from 0.005 mg/L CWGW9 (Onopa) to 0.053 mg/L (CWGW2, CWGW4, CWGW6) Opolo Big Brother Road, Igbogene and Agbura respectively, with a mean concentration of 0.030 ± 0.021 mg/L (Table 4.30). As shown in Figure 4.59, all sampling locations exceeded the WHO and NSDWQ permissible limit of 0.01 mg/L. The highest concentrations were recorded at Opolo Big Brother Road (CWGW2) and Agbura (CWGW6), while the lowest was observed at Onopa. In the dry season, lead concentrations in cassava mill groundwater (Table 4.9) ranged from 0.003 mg/L CDGW9 (Onopa) to 0.045 mg/L (CDGW6) Agbura, with a mean concentration of 0.023 ± 0.017 mg/L (Table 4.31). Figure 4.59 illustrates that seven sampling points exceeded the regulatory standards. Agbura (CDGW6) recorded the highest lead concentration. Seasonal variation analysis reveals that mean lead concentrations were higher during the wet season (0.030 mg/L) compared to the dry season (0.023 mg/L), representing a slight reduction. This indicates that lead mobility is enhanced during the wet season. The spatial pattern shows consistent elevated concentrations at Igbogene and Agbura locations across both seasons, suggesting persistent sources of lead contamination at these sites.

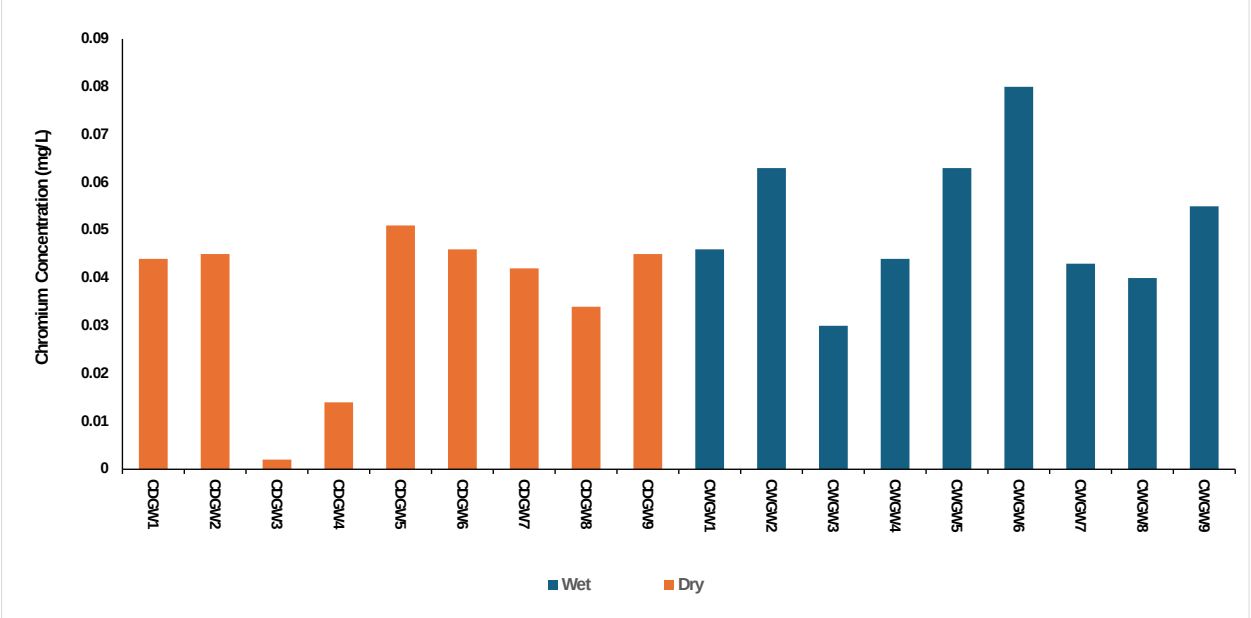

Figure 4.57: Chromium concentration in groundwater samples collected around cassava mills during the wet and dry seasons

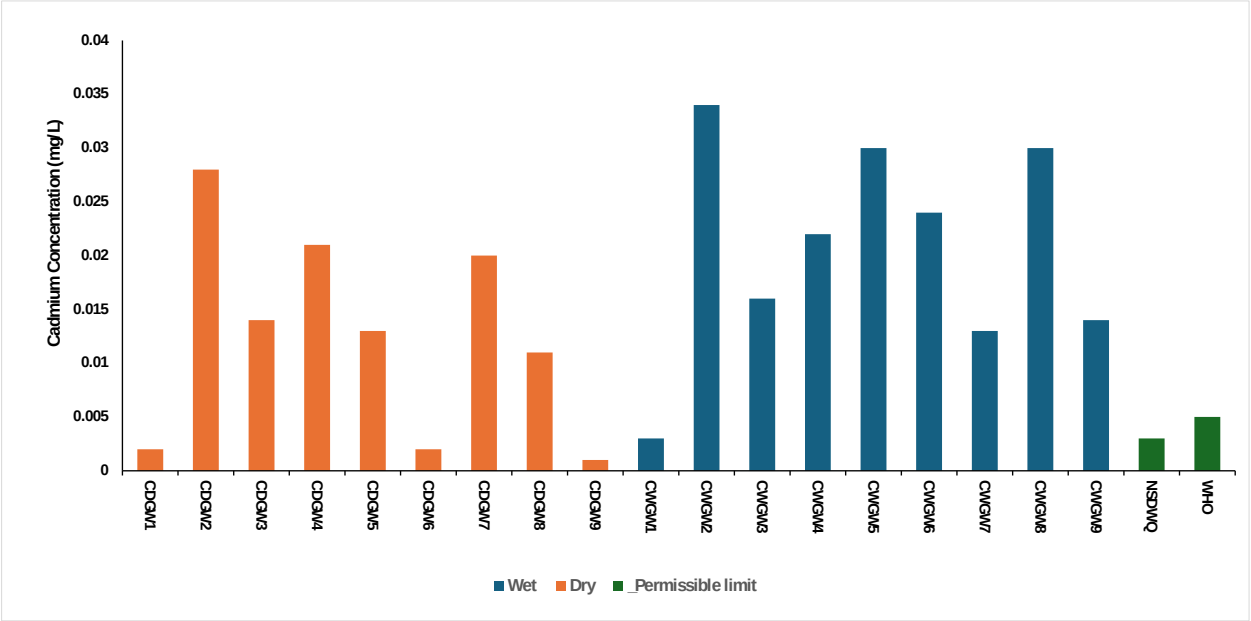

Figure 4.58: Cadmium concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

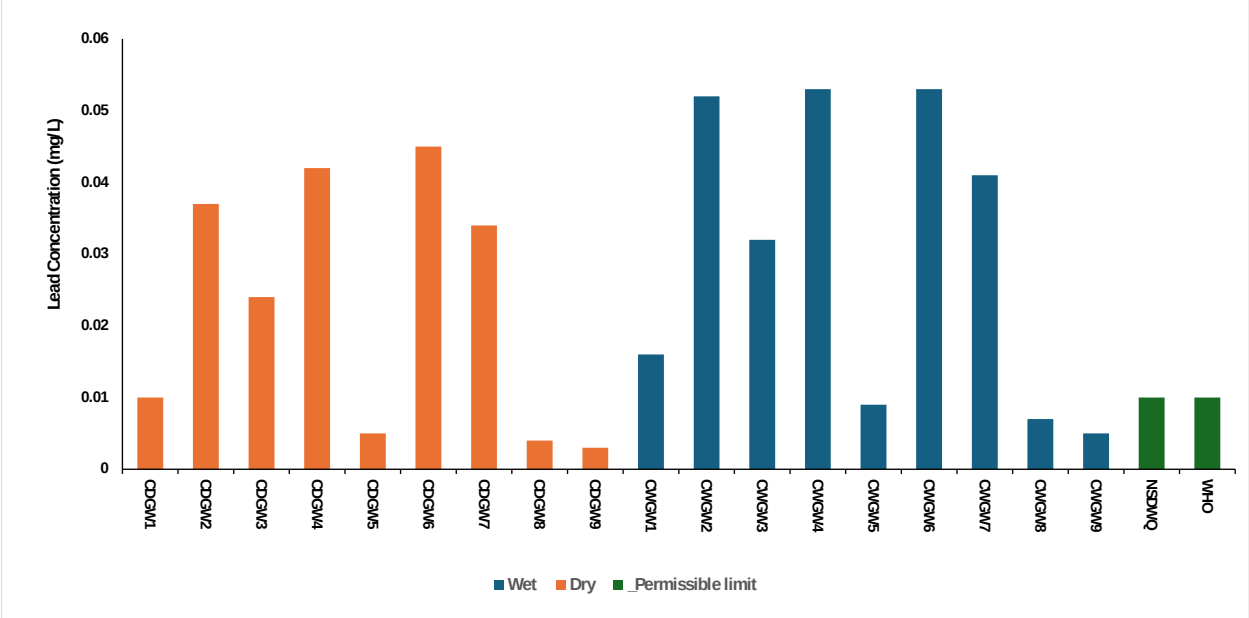

Figure 4. 59: Lead concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

4.1.2.4 Heavy Metals in Groundwater Around Crude Oil Spill Sites

Many contaminants, including heavy metals, are released into the environment as a result of crude oil spills. Groundwater contamination by these metals can affect water quality and endanger local ecosystems as well as human health. By examining the quantities of these heavy metals in groundwater samples taken during the dry and wet seasons near crude oil spill sites, our investigation sheds light on the environmental impact and pollution levels at these sites.

4.1.2.4.1 Iron ($Fe^{2}+$)

Groundwater samples near crude oil spill locations (SWGW1-SWGW2, Table 4.6) had iron concentrations ranging from 0.015 mg/L SWGW1 Agba (Otuegwe) to 0.076 mg/L SWGW2 (Ibelebiri) during the wet season. The mean value was 0.046 ± 0.043 mg/L (Table 4.30). As shown in Figure 4.60, iron concentrations were below the WHO 2011 and NSDWQ 2007 permissible limit of 0.3 mg/L at all sampling locations. The highest concentration was recorded at Ibelebiri (SWBH2), while the lowest was observed at Agba (Otuegwe) (SWGW1). Iron levels (SDGW1-SDGW2, Table 4.10) varied from 0.425 mg/L SDGW1 Agba (Otuegwe) to 0.546 mg/L SDGW2 (Ibelebiri) during the dry season, with an average of 0.486 ± 0.086 mg/L (Table 4.31). Figure 4.60 illustrates that both sampling points exceeded the regulatory standards during the dry season. Ibelebiri (SDGW2) maintained the highest iron concentration, while Agba (Otuegwe) (SDGW1) recorded the lowest. The mean iron concentrations were considerably greater during the dry season (0.486 mg/L) than during the wet season (0.046 mg/L), according to seasonal variation study. This sharp rise calls for more research since it raises the possibility of concentration effects during the dry season.

4.1.2.4.2 Manganese (Mn^{2+})

Manganese levels (SWGW1-SWGW2, Table 4.6) varied from 0.038 mg/L SWGW2 (Ibelebiri) to 0.220 mg/L (SWGW1) Agba (Otuegwe) during the wet season, with an average of 0.129 ± 0.129 mg/L (Table 4.30). As shown in Figure 4.61, one sampling location exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 0.1 and 0.2 mg/L respectively. The highest

concentration was recorded at Agba (Otuegwe) (SWGW1). With a mean value of 0.075 ± 0.071 mg/L (Table 4.31), manganese concentrations (SDGW1-SDGW2, Table 4.10) varied from 0.025 mg/L SDGW2 (Ibelebiri) to 0.125 mg/L SDGW1 Agba (Otuegwe). Figure 4.61 shows that all sampling points remained below NSDWQ permissible limit of 0.2 mg/L whereas location SDGW1 was above WHO permissible limit of 0.1 mg/L during the dry season. Ibelebiri (SDGW2) observed the highest Manganese concentration, while Agba (Otuegwe) (SDGW1) recorded the lowest. The mean manganese concentrations were greater during the wet season (0.129 mg/L) than during the dry season (0.075 mg/L), according to a seasonal variation analysis. This implies that manganese mobility is improved in moist environments.

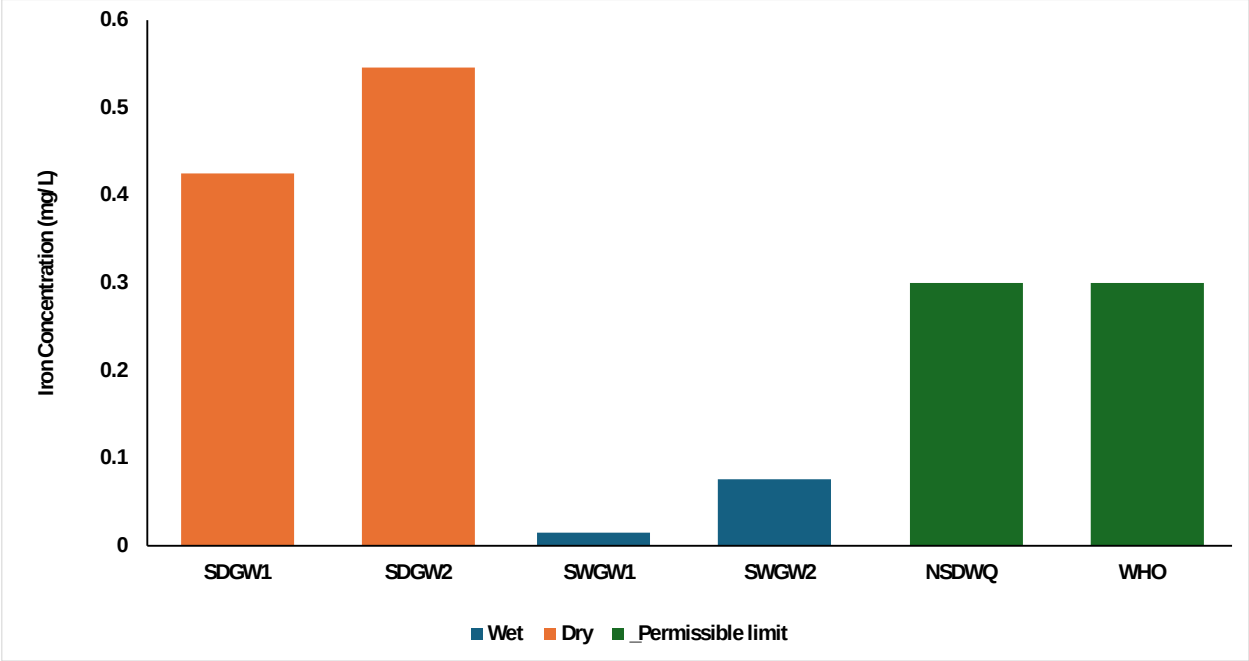

Figure 4.60: Iron concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

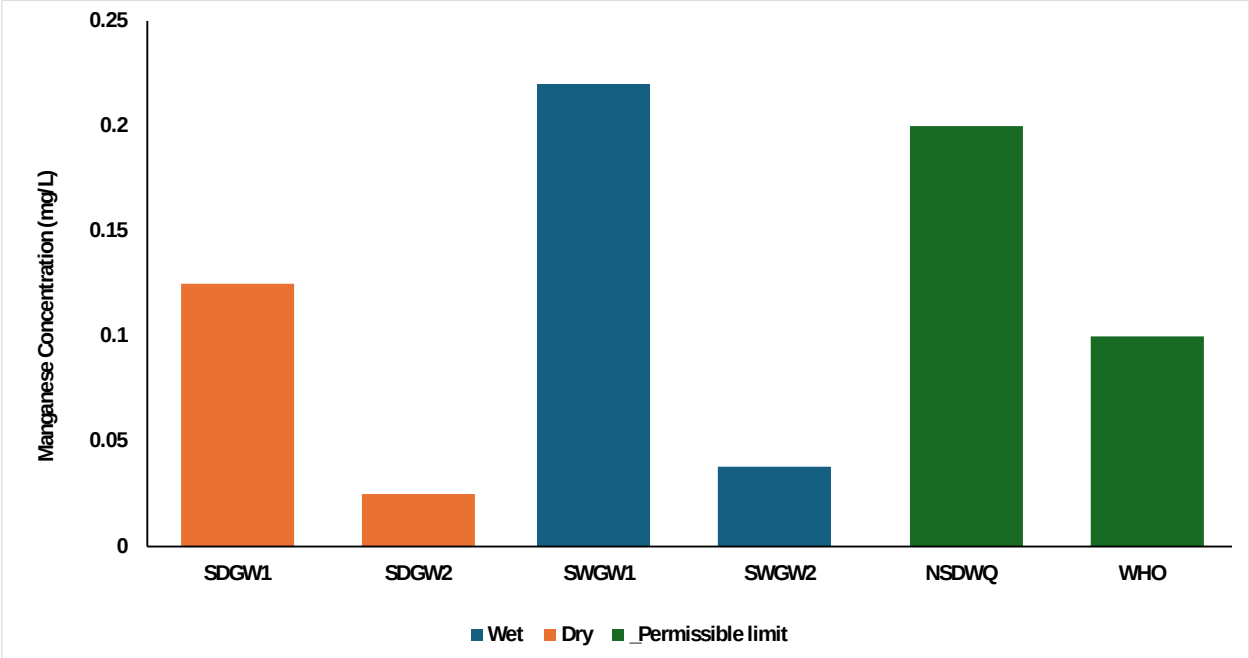

Figure 4. 61: Manganese concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

4.1.2.4.3 Zinc (Zn^{2+})

During the wet season, zinc concentrations (SWGW1-SWGW2, Table 4.6) ranged from 0.130 mg/L at SWGW1 (Otuegwe) to 0.254 mg/L SWGW2 (Ibelebiri), with a mean concentration of 0.192 ± 0.088 mg/L (Table 4.30). As shown in Figure 4.62, all concentrations were well below the NSDWQ 2007 permissible limit of 3 mg/L but both were above the WHO 2011 permissible limit of 0.01mg/L. In the dry season, zinc concentrations (Table 4.10) ranged from 0.046 mg/L at SDGW1 to 0.155 mg/L at SDGW2, with a mean concentration of 0.101 ± 0.077 mg/L (Table 4.31). Comparison with permissible limit was same as was observed in the wet season were all the samples were above WHO limit of 0.01 mg/L. Seasonal variation analysis reveals that mean zinc concentrations were higher during the wet season (0.192 mg/L) compared to the dry season (0.101 mg/L). The seasonal variation indicates high temporal variability. Ibelebiri (SWGW2) consistently showed higher concentrations across both seasons.

4.1.2.4.4 Copper (Cu^{2+})

Copper levels (SWGW1-SWGW2, Table 4.6) varied from 0.160 mg/L at SWGW1(Agba (Otuegwe) to 2.340 mg/L at SWGW2 (Ibelebiri) during the wet season, with an average of 1.250 ± 1.541 mg/L (Table 4.30). As shown in Figure 4.63, one location exceeded the WHO 2011 and NSDWQ 2007 permissible limit of 1.0 mg/L. With a mean value of 0.083 ± 0.056 mg/L (Table 4.31), copper concentrations (SDGW1-SDGW2, Table 4.10) varied from 0.043 mg/L (SDGW1) to 0.122 mg/L (SDGW2). Every sampling location continued to fall short of legal requirements. Mean copper concentrations were significantly greater during the wet season (1.250 mg/L) than during the dry season (0.083 mg/L), according to seasonal variation study. This striking seasonal variation indicates that copper is highly mobile under wet circumstances. The concentrations of Ibelebiri were consistently greater in both seasons.

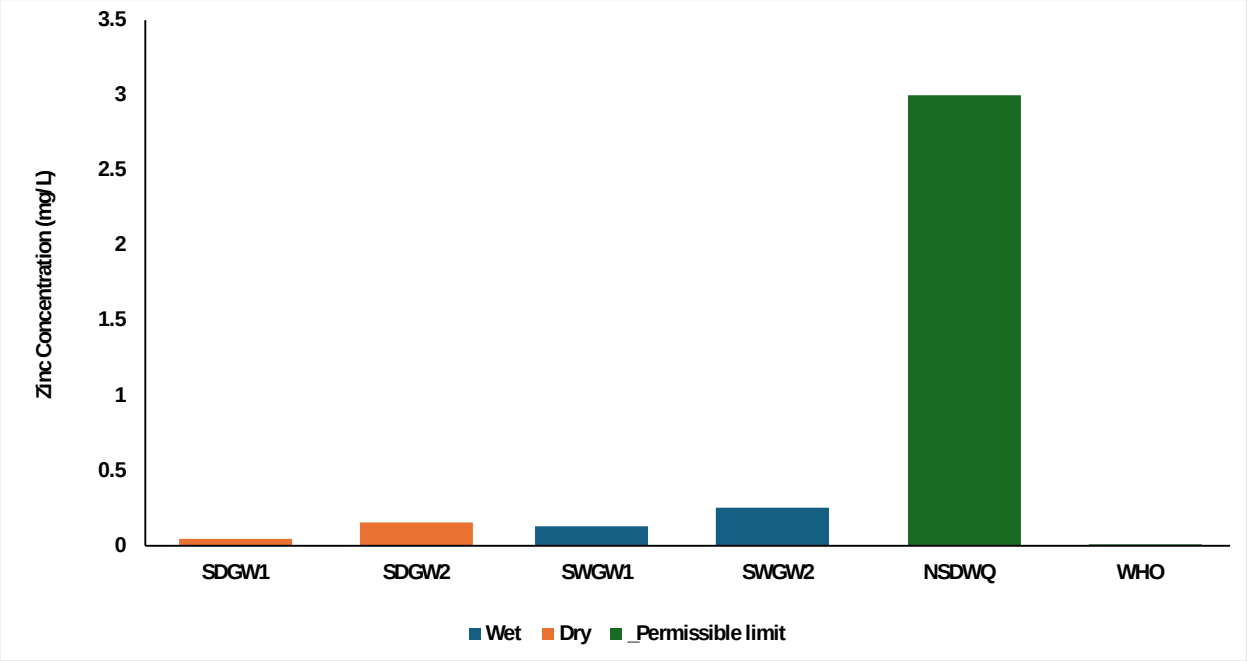

Figure 4.62: Zinc concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

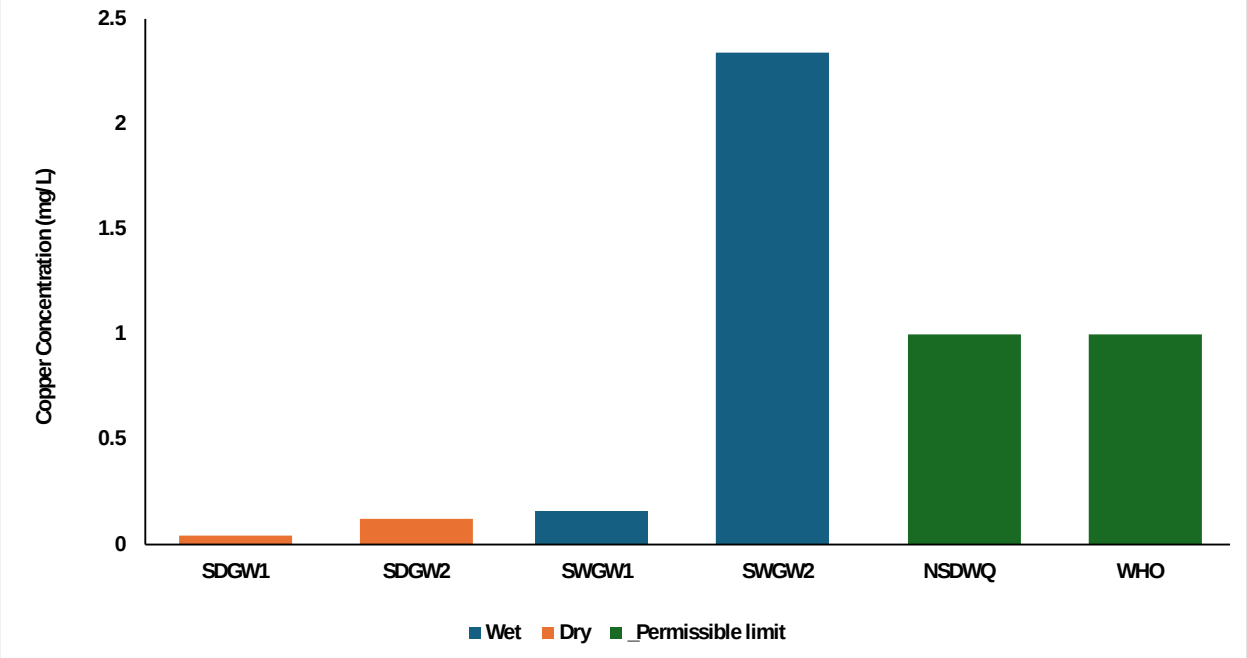

Figure 4. 63: Copper concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

4.1.2.4.5 Chromium (Cr^{6+})

Wet season monitoring revealed chromium concentrations (SWGW1-SWGW2) spanning from 0.085 mg/L at SWGW2 (Ibelebiri) to 0.121 mg/L at SWGW1 (Agba, Otuegwe), averaging 0.103 ± 0.025 mg/L (Tables 6, 30). The distribution pattern shown in Figure 4.64 indicates consistently elevated concentrations across both sampling locations. The highest concentration of chromium was recorded at Agba (Otuegwe). Dry season measurements showed lower chromium levels (SDGW1-SDGW2) ranging between 0.055 at SDGW1 and 0.064 mg/L at SDGW2, with a mean of 0.060 ± 0.006 mg/L (Tables 10, 31). The spatial pattern remained similar, though with reduced concentrations at both sites. The highest concentration was observed at Ibelebiri (SWGW2). The seasonal comparison highlights a significant decrease from wet to dry season, suggesting stronger chromium mobilization during rainfall periods. The consistent relative concentrations between sites across seasons points to stable contamination sources, though with varying intensity based on hydrological conditions.

4.1.2.4.6 Cadmium (Cd^{2+})

Wet season cadmium levels in the study area ranged from 0.072 at SWGW1 (Otuegwe) to 0.074 mg/L at SWGW2 (Ibelebiri), averaging 0.073 ± 0.001 mg/L (Tables 6, 30). Figure 4.65 shows both locations significantly exceeded the WHO 2011 and NSDWQ 2007 limit of 0.003 mg/L. Dry season monitoring found reduced cadmium concentrations between 0.025 at SDGWI to 0.028 at SDGW2 mg/L, with a mean of 0.027 ± 0.002 mg/L (Tables 10, 31). Though lower, values still exceeded regulatory standards. Ibelebiri (SDGW2) showed higher concentrations across both seasons. The substantial reduction from wet to dry season (0.073 to 0.027 mg/L) indicates strong seasonal influence on cadmium mobility. However, the persistent elevation above standards in both seasons signals ongoing contamination requiring attention.

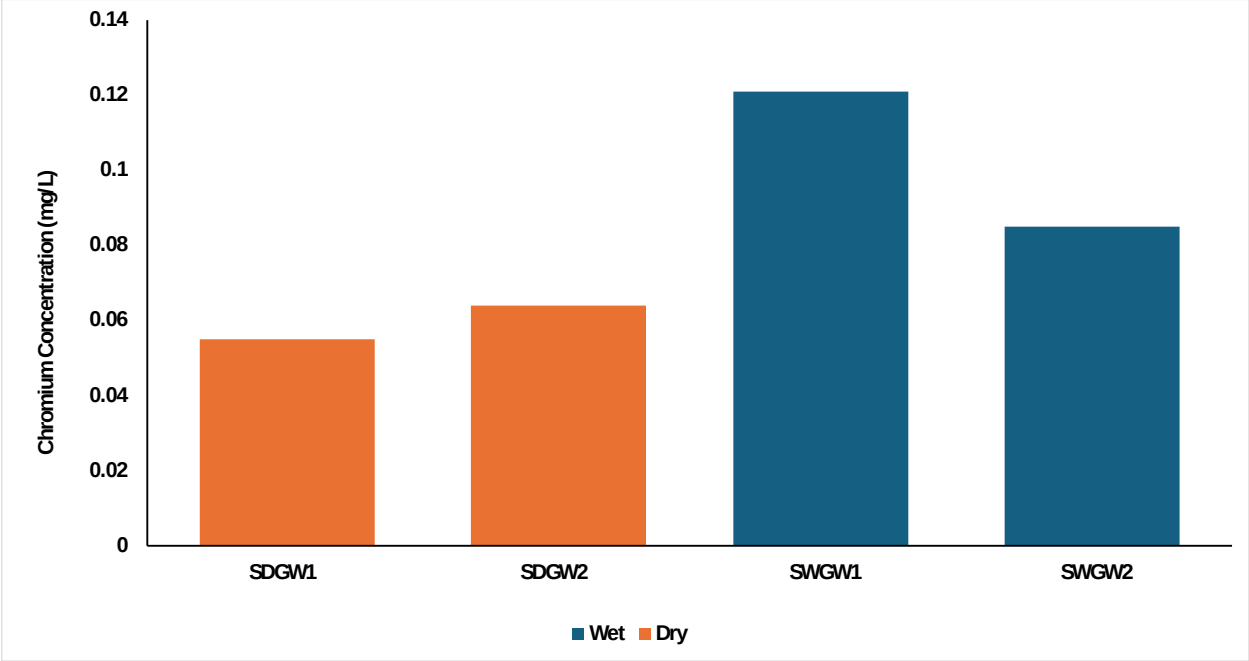

Figure 4. 64: Chromium concentration in groundwater samples collected around crude oil spill site during the wet and dry seasons

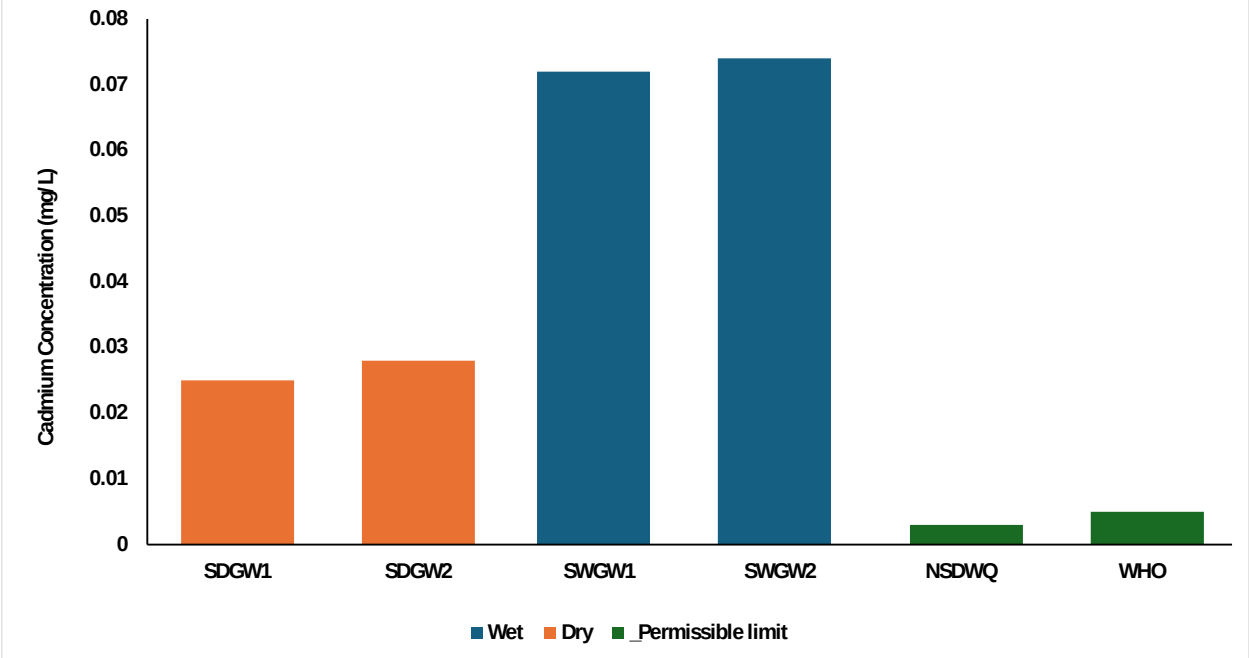

Figure 4. 65: Cadmium concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

4.1.2.4.7 Nickel (Ni^{2+})

Wet season nickel concentrations (SWGW1-SWGW2) fell between 0.064mg/L at SWGW2 (Ibelebiri) and 0.070 mg/L at SWGW1 (Otuegwe), with a mean of 0.067 ± 0.004 mg/L (Tables 6, 30). Figure 4.66 demonstrates both sampling points exceeded the WHO 2011 and NSDWQ 2007 guideline of 0.02 mg/L. Dry season sampling showed markedly lower nickel levels (SDGW1-SDGW2) ranging from 0.001 at SWGW2 to 0.006 mg/L at SWGW1, averaging 0.004 ± 0.004 mg/L (Tables 10, 31). These values fell within acceptable limits. The dramatic decrease from wet to dry season (0.067 to 0.004 mg/L) suggests nickel contamination is heavily influenced by seasonal hydrology. The stark contrast between seasons may indicate different mobilization mechanisms at play. The concentrations of Nickel at SDGW1Agba (Otuegwe) were greater in both seasons.

4.1.2.4.8 Lead (Pb^{2+})

Wet season lead concentrations varied between 0.102mg/L at SWGW2 (Ibelebiri) to 0.133 mg/L at SWGW1 (Otuegwe), averaging 0.118 ± 0.022 mg/L (Tables 6, 30). Figure 4.67 indicates both locations substantially exceeded the WHO/NSDWQ limit of 0.01 mg/L. Dry season measurements showed reduced lead levels ranging from 0.013 mg/L at SDGW2 to 0.054 mg/L at SDGW1, with a mean of 0.034 ± 0.029 mg/L (Tables 10, 31). Though lower, values still exceeded regulatory standards. A reduction was observed from wet to dry season (0.118 to 0.034 mg/L), indicating strong seasonal influence on lead mobility. The persistent elevation above standards, albeit at different magnitudes, suggests continuous contamination. Agba (Otuegwe) showed higher concentrations of (Pb^{2+}) across both seasons.

4.1.2.4.9 Vanadium (V^{2+})

Wet season vanadium levels ranged from 0.051mg/L at SWGW2 (Ibelebiri) to 0.061 mg/L at SWGW1 (Otuegwe), with a mean of 0.056 ± 0.007 mg/L (Tables 6, 30). Figure 4.68 shows relatively consistent concentrations between sampling points.

Dry season monitoring found much lower vanadium concentrations between 0.002mg/L at SDGW2 and 0.005 mg/L at SDGW1, averaging 0.004 ± 0.002 mg/L (Tables 10, 31), representing a marked decrease across all locations. The pronounced reduction from wet to dry season (0.056 to 0.004 mg/L) demonstrates vanadium's high sensitivity to seasonal hydrological changes. This pattern aligns with other metals showing enhanced mobility during wet conditions.

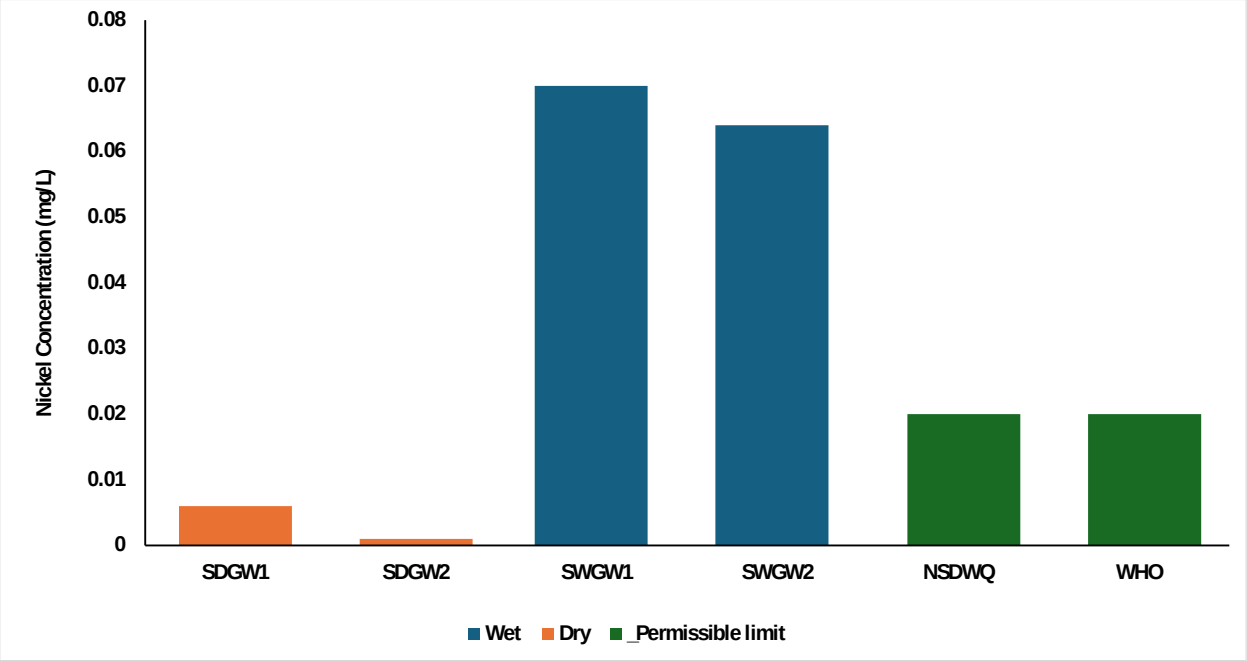

Figure 4. 66: Nickel concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

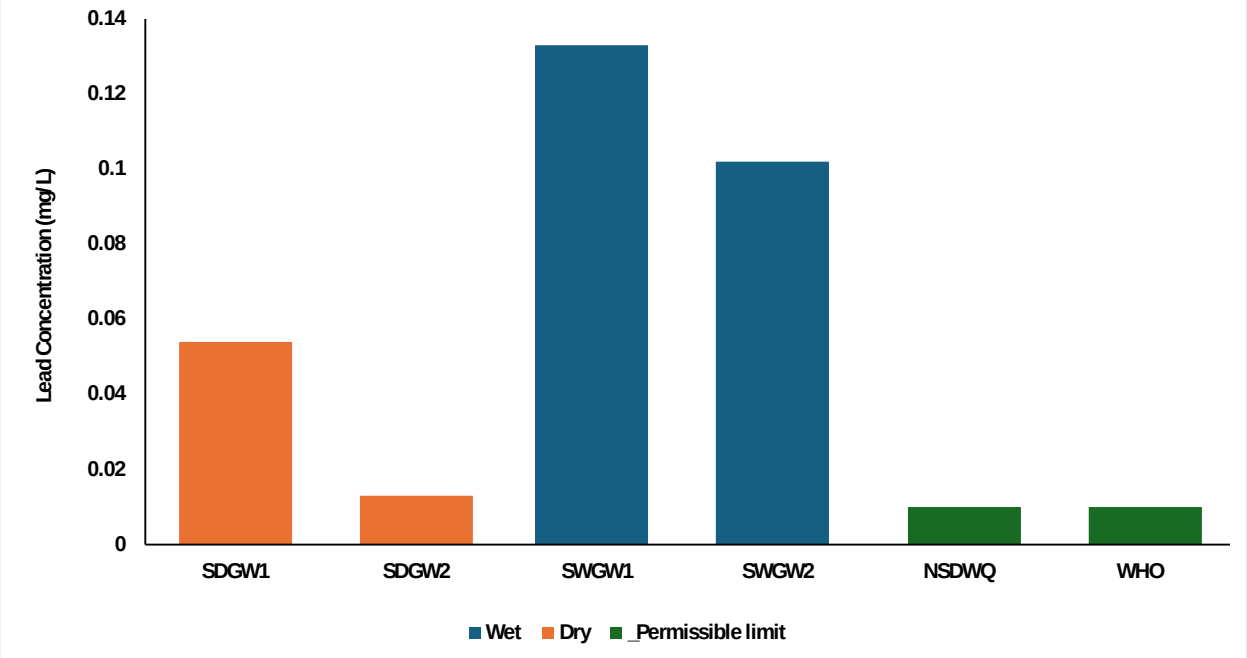

Figure 4. 67: Lead concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

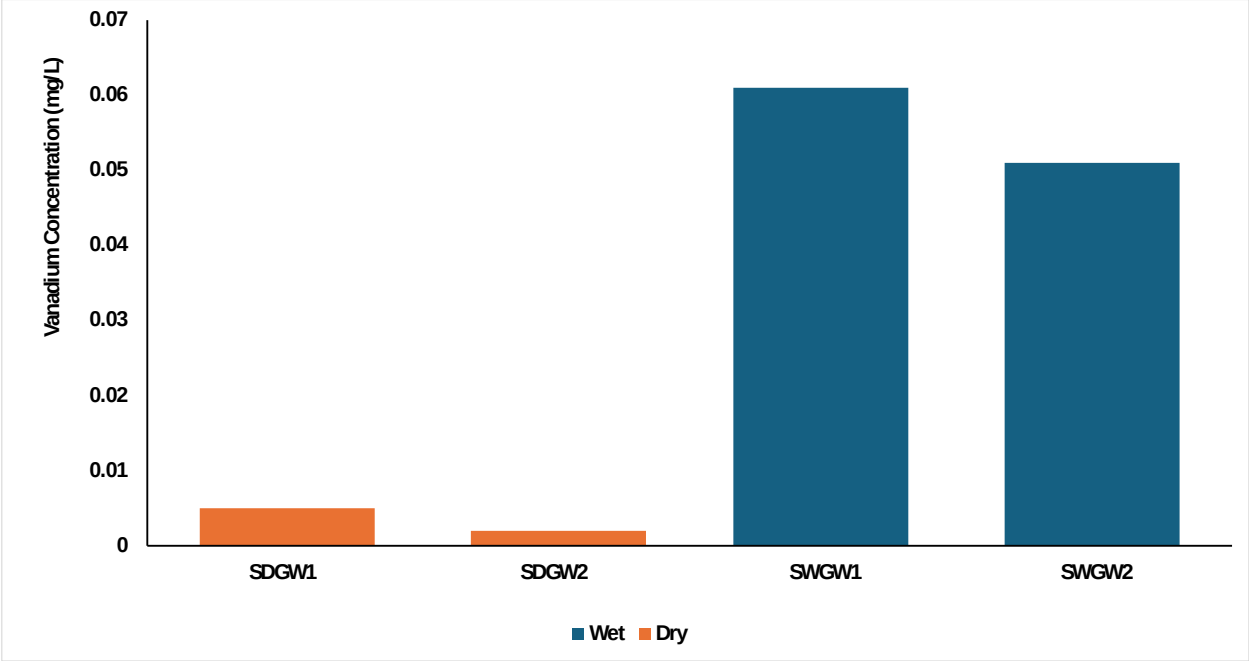

Figure 4. 68: Vanadium concentration in groundwater samples collected around crude oil spill site during the wet and dry seasons

4.1.3 Heavy Metals in Surface Water

4.1.3.1 Heavy Metals in Surface Water Around Dumpsites

Heavy metals are among the many contaminants that dumps, which are used to dispose of different kinds of waste, can leak into the environment. These metals have the potential to contaminate surface water, endangering aquatic life, human health, and water quality. In order to shed light on pollution levels and the environmental effects at dumpsites, this investigation examines the amounts of these heavy metals in surface water samples that were taken during the wet and dry seasons. Figures 4.69 – 4.76 shows concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons are presented on bar charts.

4.1.3.1.1 Iron ($Fe^{2}+$)

The average iron concentration in surface water near dumpsites during the wet season was 0.367 ± 0.205 mg/L, with a range of 0.093 mg/L at DWSW4 (Akenfa 1 Epie Creek) to 0.570 mg/L at DWSW2 (Igbogene Epie Creek). As shown in Table 4.3 and Figure 4.69, the control site (CTWSW1) recorded 0.577 mg/L, suggesting that dumpsite iron levels were generally below background levels. Iron concentrations ranged between 0.074 mg/L at DDSW4 and 0.560 mg/L at DDSW2 during the dry season, averaging 0.352 ± 0.204 mg/L, as shown in Table 4.7 and Figure 4.69. The control site (CTDSW1) showed 0.541 mg/L (Table 4.7), indicating that dumpsite concentrations remained below natural background levels during this period.The mean iron concentrations from the wet to dry season decreased somewhat (from 0.367 to 0.352 mg/L), according to the seasonal comparison shown in Tables 32 and 33. There was little seasonal variation at the control sites (0.577 to 0.541 mg/L), indicating that site-specific causes rather than more general seasonal effects were mostly responsible for the variations seen at dumpsite locations.

4.1.3.1.2 Manganese (Mn^{2+})

Manganese concentrations around dumpsites during the rainy season averaged 0.519 ± 0.097 mg/L, ranging from 0.410 mg/L at DWSW1 (Tombia Junction Market Epie Creek) to 0.646 mg/L at DWSW4 (Akenfa 1 Epie Creek), as indicated in Table 4.3 and Figure 4.70. These values were notably higher than the control site (CTWSW1) concentration of 0.25 mg/L (Table 4.3), indicating significant anthropogenic inputs. Over the course of the dry season, the measurements that were provided in Table 4.7 and visualized in Figure 4.70 revealed a decrease in manganese levels. These levels ranged from 0.021 mg/L at DDSW2 (Igbogene Epie Creek) to 0.515 mg/L at DDSWW4 (Akenfa 1 Epie Creek), with a mean of 0.232 ± 0.211 mg/L. These levels were closer to the control site (CTDSW1) value of 0.21 mg/L. The fact that this is the case shows that manganese is retained in sediments more effectively when moisture levels are lower. The mean manganese concentrations decrease from the wet to the dry season (0.519 to 0.232 mg/L), according to seasonal variation study (Tables 32 and 33). Levels at the control locations remained comparatively constant (0.25 to 0.21 mg/L), suggesting that seasonal variations were more noticeable at the affected sites.

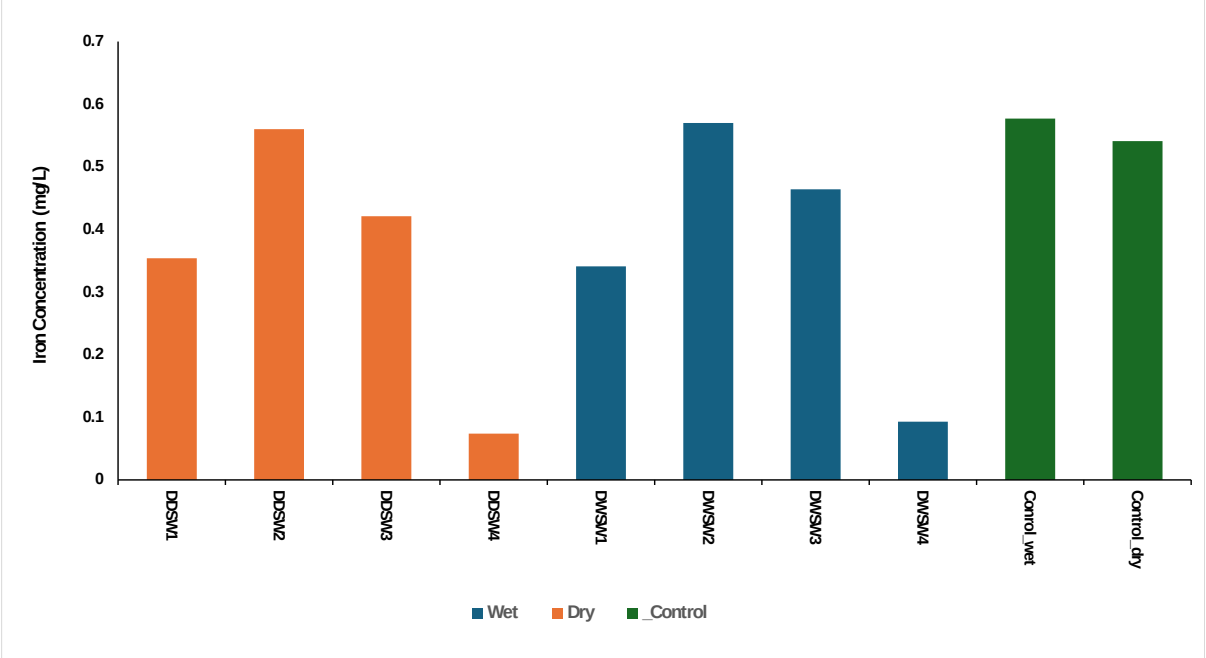

Figure 4.69: Iron concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

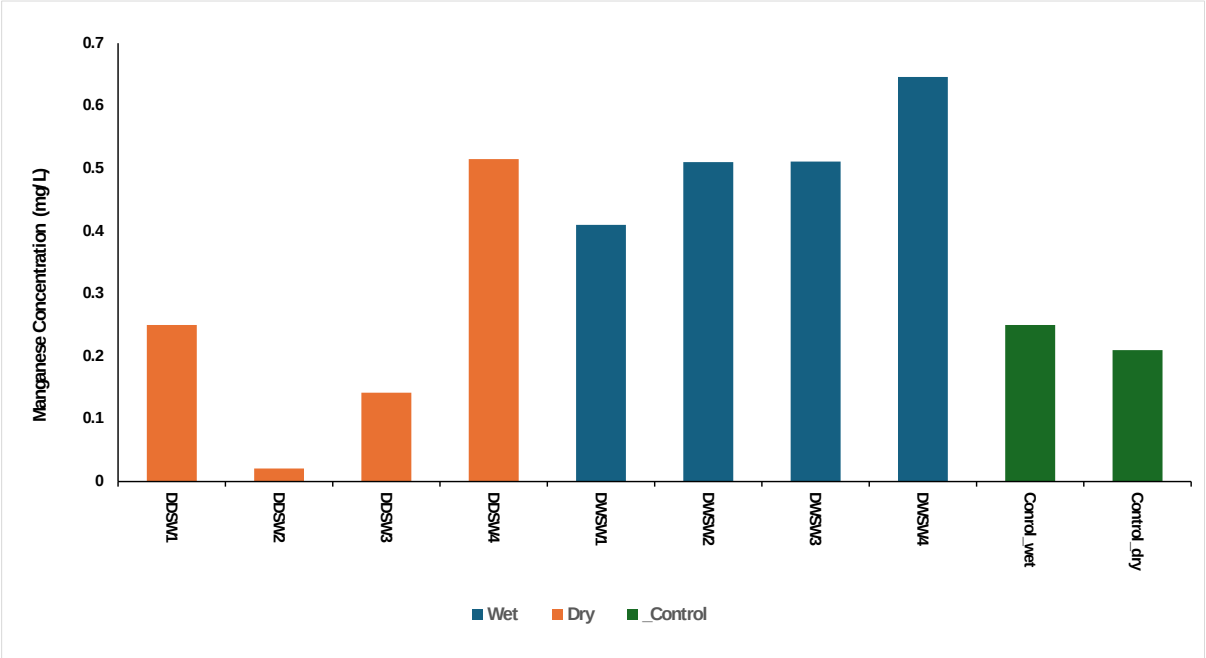

Figure 4. 70: Manganese concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

4.1.3.1.3 Zinc (Zn^{2+})

Zinc concentrations throughout the wet season were exceptionally high, with a mean of 6.027 ± 0.875 mg/L and a range of 5.200 mg/L at Azikoro Canal (DWSW3) to 7.176 mg/L at Akenfa 1 Epie Creek (DWSW4), as shown in Table 4.3 and Figure 4.106. These values substantially exceeded the control site (CTWSW1) value of 0.311 mg/L (Table 4.3), indicating significant contamination at dumpsite locations. Zinc levels are significantly lower during the dry season, ranging from 0.141 at DDSW3 (Azikoro Canal) to 0.311 at DDSW1 (Tombia Junction Market Epie Creek) with a mean of 0.207 ± 0.081 mg/L as shown in Table 4.7 and Figure 4.71. These values are becoming closer to the control site (CTDSW1) value of 0.41 mg/L. This marked reduction is clearly visible in the seasonal comparison shown in Figure 4.71. While control sites maintained reasonably steady levels (0.311 to 0.41 mg/L), the seasonal comparison shown in Tables 32 and 33 demonstrates a considerable decrease from the wet to the dry season (6.027 to 0.207 mg/L).

4.1.1.2.7 Copper (Cu^{2+})

With a mean of 1.302 ± 0.987 mg/L, the copper concentrations recorded in Table 4.3 and Figure 4.72 during the wet season ranged greatly from 0.025 mg/L DWSW2 (Igbogene Epie Creek) to 2.430 mg/L DWSW1 (Tombia Junction Market Epie creek). In general, these values exceeded the concentration of 0.343 mg/L at the control site (CTWSW1) (Table 4.3). Copper levels during the dry season dropped considerably from 0.012 at DDSW1 (Tombia Junction Market Epie Creek) To 0.257 mg/L at DDSW4 (Akenfa 1 Epie Creek) with a mean of 0.086 ± 0.115 mg/L, below the control site (CTDSW1) value of 0.165 mg/L, as indicated in Table 4.7 and Figure 4.72. Figure 4.107 makes the spatial distribution pattern of this decline quite evident. The mean copper concentrations decreased from the wet to the dry season (1.302 to 0.086 mg/L), according to the seasonal fluctuation analysis shown in Tables 32 and 33. In contrast, control sites exhibited less change (0.343 to 0.165 mg/L).

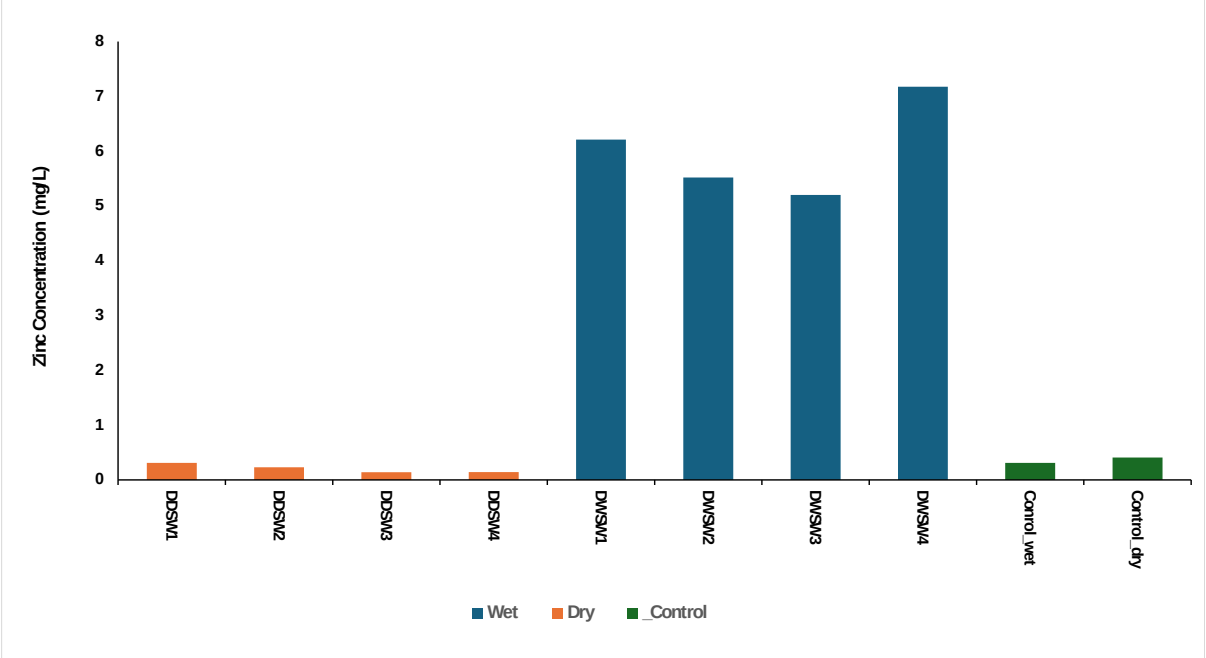

Figure 4.71: Zinc concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

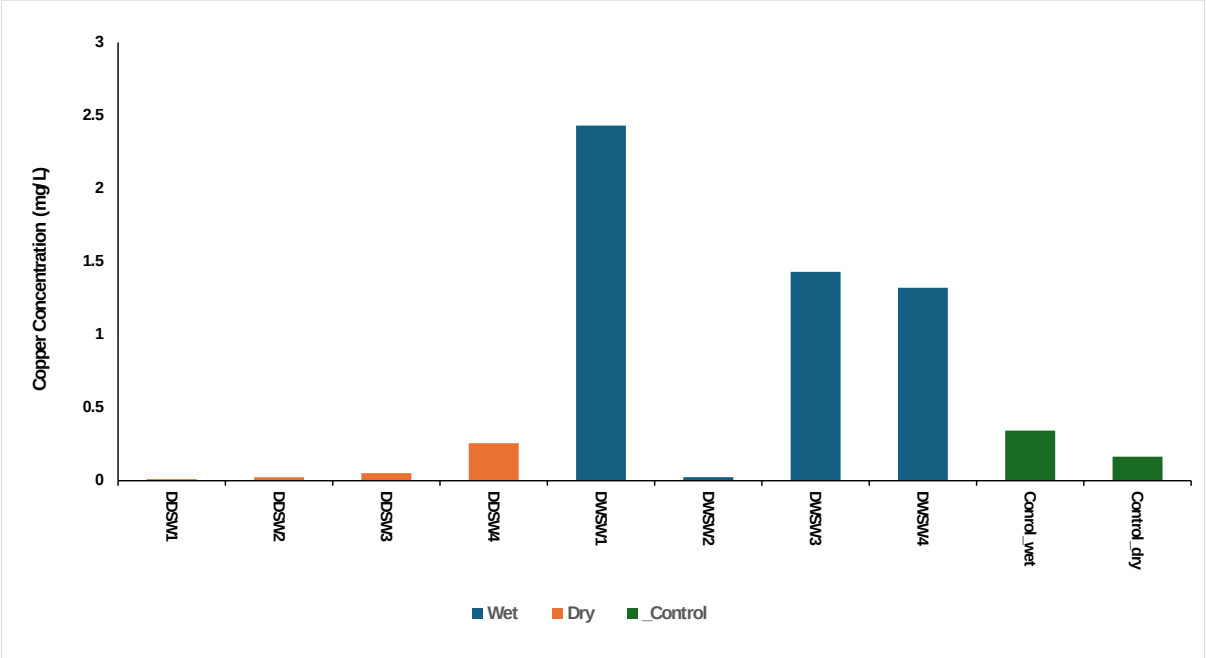

Figure 4. 72: Copper concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons.

4.1.3.1.4 Chromium (Cr^{6+})

As shown in Table 4.3 and Figure 4.73, chromium concentrations during the wet season ranged from 0.062 mg/L at DWSW3 (Azikoro canal) to 1.360 mg/L at DWSW1 (Tombia Junction Market Epie creek), with an average of 0.447 ± 0.612 mg/L. Notably, Table 4.3 indicates that there were large anthropogenic inputs at dumpsites because chromium was not detectable at the control site (CTWSW1).Reduced chromium levels observed in the wet season ranged from 0.054 at DDSW3 (Azikoro canal) to 0.164 mg/L at DDSW2 (Igbogene Epie Creek) with a mean of mean: 0.089 ± 0.051 mg/L as shown in Table 4.7 and Figure 4.73, but they were not detectable at the control site (CTDSW1). Figure 4.73 shows the regional distribution of these reductions.The mean chromium concentrations decreased from the wet to the dry season (from 0.447 to 0.089 mg/L), according to the seasonal comparison shown in Tables 32 and 33. The effect of dumpsite operations on nearby water quality is highlighted by the constant lack of chromium at control locations across both seasons (Tables 3 and 7).

4.1.3.1.5 Cadmium (Cd^{2+})

During the wet season, as shown in Table 4.3 and Figure 4.74, cadmium concentrations around dumpsites ranged from 0.039 mg/L DWSW2 (Igbogene Epie Creek) to 0.251 mg/L DWSW4 (Akenfa 1 Epie Creek), with a mean of 0.117 ± 0.099 mg/L. The control site (CTWSW1) showed non-detectable levels (Table 4.3), indicating significant anthropogenic inputs at dumpsite locations. In the dry season, Table 4.7 and Figure 4.74 illustrate reduced cadmium levels ranging from 0.014 at DDSW3 (Azikoro canal) to 0.136 mg/L at DDSW4 (Akenfa 1 Epie Creek) with a mean of 0.053 ± 0.056 mg/L, while remaining non-detectable at the control site (CTDSW1). The spatial distribution of these reductions is clearly visible in Figure 4.74. The reduction in cadmium concentrations from wet to dry season (Tables 32 and 33) can be attributed to decreased leaching from waste materials during reduced rainfall and lower mobility in drier conditions.

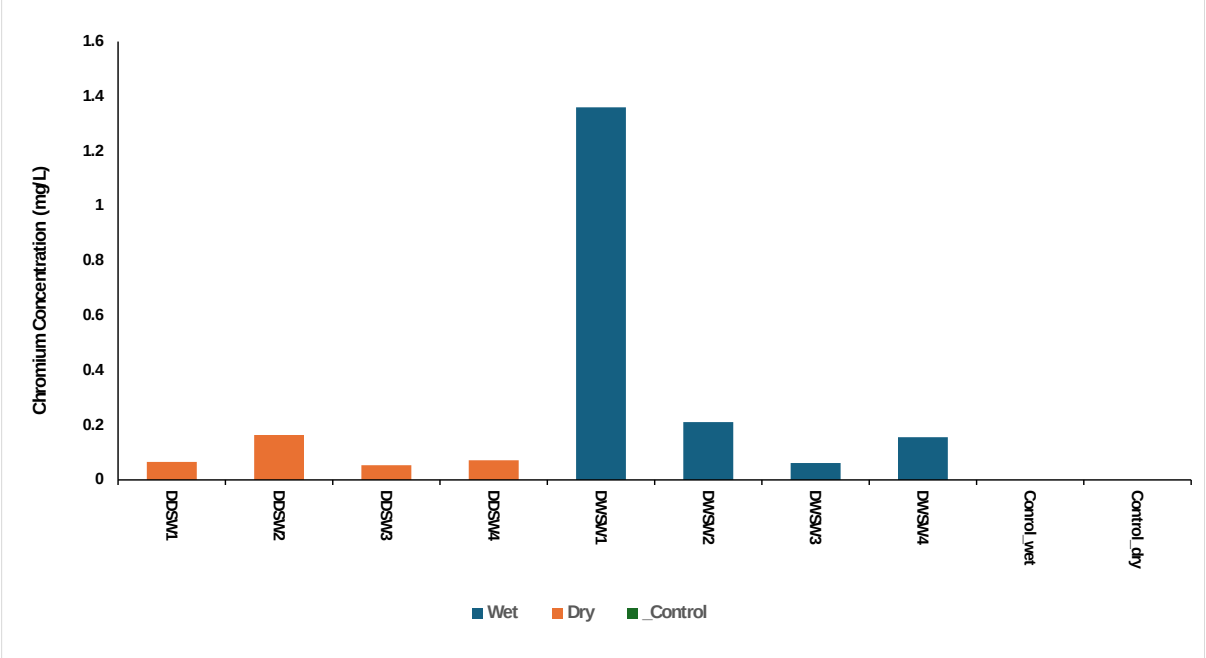

Figure 4. 73: Chromium concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

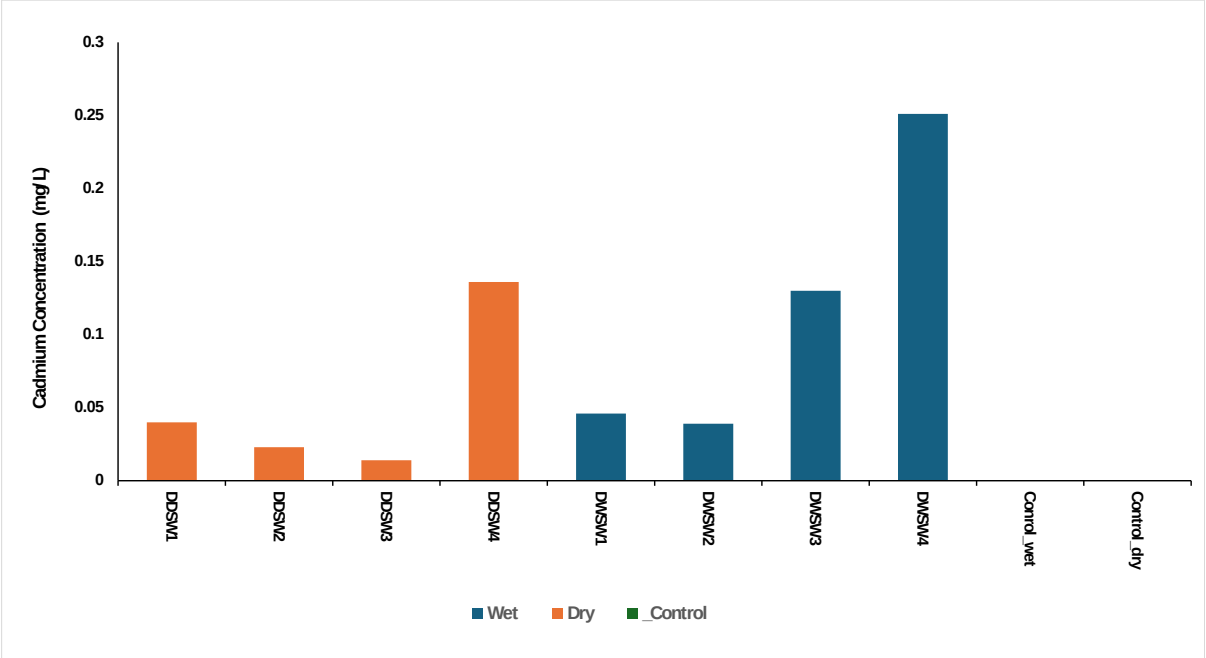

Figure 4. 74: Cadmium concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons.

4.1.3.1.6 Nickel (Ni^{2+})

Nickel concentrations ranged from non-detectable levels to 0.037 mg/L as DWSW1 (Tombia Junction Market Epie creek), during the rainy season, with a mean of 0.010 ± 0.018 mg/L, as shown in Table 4.3 and Figure 4.75. Non-detectable levels were found at the control site (CTWSW1) (Table 4.3), indicating contamination from the dumpsite. Nickel levels in the dry season ranged from non-detectable to 0.034 mg/L at DDSW1 with an average of 0.009 ± 0.017 mg/L, according to the results shown in Table 4.7 and Figure 4.75. During the dry season, non-detectable levels were maintained at the control site (CTDSW1). The minimal reduction in nickel concentrations between seasons (Tables 32 and 33) suggests that nickel mobility is less influenced by seasonal variations, possibly due to its strong binding to organic matter and sediments in the aquatic environment.

4.1.3.1.7 Lead (Pb^{2+})

Lead concentrations throughout the wet season varied from 0.058 mg/L DWSW1 (Tombia Junction Market Epie creek) to 0.132 mg/L DWSW3 (Azikoro canal), with a mean of 0.080 ± 0.035 mg/L, as indicated in Table 4.3 and Figure 4.76. Significant anthropogenic contributions were indicated by non-detectable values at the control site (CTWSW1) (Table 4.3).While the control site (CTDSW1) maintained non-detectable levels, Table 4.7 and Figure 4.76 show lead levels ranging from 0.041 at DDSW2 (Igbogene Epie Creek) to 0.081 mg/L at DDSW3 (Azikoro canal) with a mean of 0.055 ± 0.018 mg/L over the dry season. Figure 4.76 shows the spatial distribution pattern of these changes. The reduction in lead concentrations from wet to dry season (Tables 32 and 33) can be explained by reduced surface runoff and decreased leaching from waste materials, along with increased adsorption to sediments under low-flow conditions.

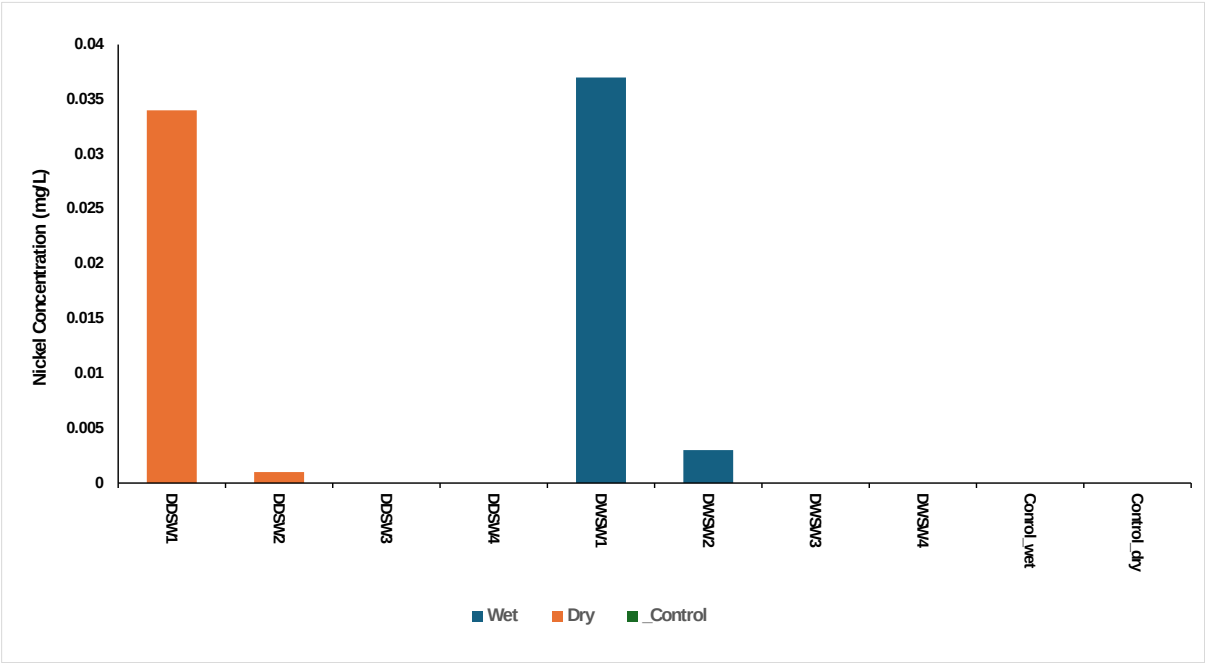

Figure 4. 75: Nickel concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

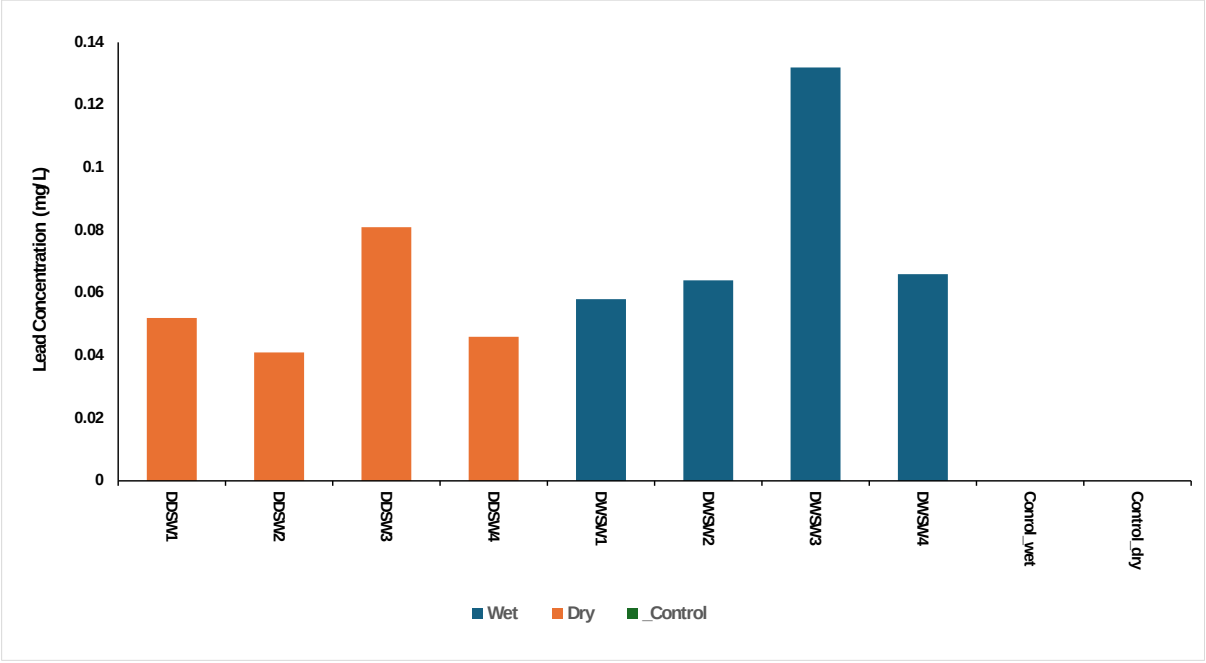

Figure 4. 76: Lead concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

4.1.3.2 Heavy Metals in Surface Water Around Crude Oil Spill Site

Crude oil spills have a major impact on ecosystem health and water quality because they can release a variety of contaminants, including heavy metals, into the environment. Aquatic life, water chemistry, and human health can all be negatively impacted by heavy metal contamination of surface water bodies close to spill locations. This investigation provides information about pollution levels and the environmental impact at crude oil spill sites by examining the amounts of these heavy metals in surface water samples taken during the wet and dry seasons. Figures 4.77-4.85 shows concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons.

4.1.3.2.1 Iron (Fe^{2+})

Iron concentrations at oil spill locations during the wet season varied from 3.001 mg/L at SWSW2 (Kolo Creek at Ibelebiri) to 3.41 mg/L at SWSW1(Kolo Creek at Agba-Otuegwe), with a mean of 3.206 ± 0.289 mg/L, which was substantially higher than the control site (0.577 mg/L), as indicated in Table 4.6 and Figure 4.77. SWSW1 had the highest concentration, which was also more than the control site. Iron levels during the dry season range from 3.88 mg/L to 4.11 mg/L (mean: 3.995 ± 0.163 mg/L), which is significantly higher than the control site (0.541 mg/L), according to Table 4.10 and Figure 4.77. With levels above the control, SDSW1 retained the maximum concentration.

The mean iron concentrations increased from the rainy to the dry season (3.206 to 3.995 mg/L), according to the seasonal comparison. Concentration effects brought on by decreased water volume and higher sediment resuspension during the dry period are responsible for this increase.

4.1.3.2.2 Manganese (Mn^{2+})

As shown in Table 4.6 and Figure 4.78, manganese concentrations during the rainy season were higher than those at the control site (0.25 mg/L), ranging from 0.341 mg/L to 0.346 mg/L with an average of 0.344 ± 0.004 mg/L. The concentration in SWSW2 (Kolo Creek at Ibelebiri) was the highest, with values exceeding the control.

Compared to the control site (0.21 mg/L), manganese levels ranged from 0.217 mg/L to 0.288 mg/L (mean: 0.253 ± 0.05 mg/L) in the dry season observations shown in Table 4.10 and Figure 4.78. With levels higher than control values, SWSW1 (Agba (Otuegwe) Kolo creek) displayed the highest concentration. The mean manganese concentrations drop from the rainy to the dry season (0.344 to 0.253 mg/L), according to the seasonal comparison. Reduced mobility in dry conditions and greater silt absorption account for this decline.

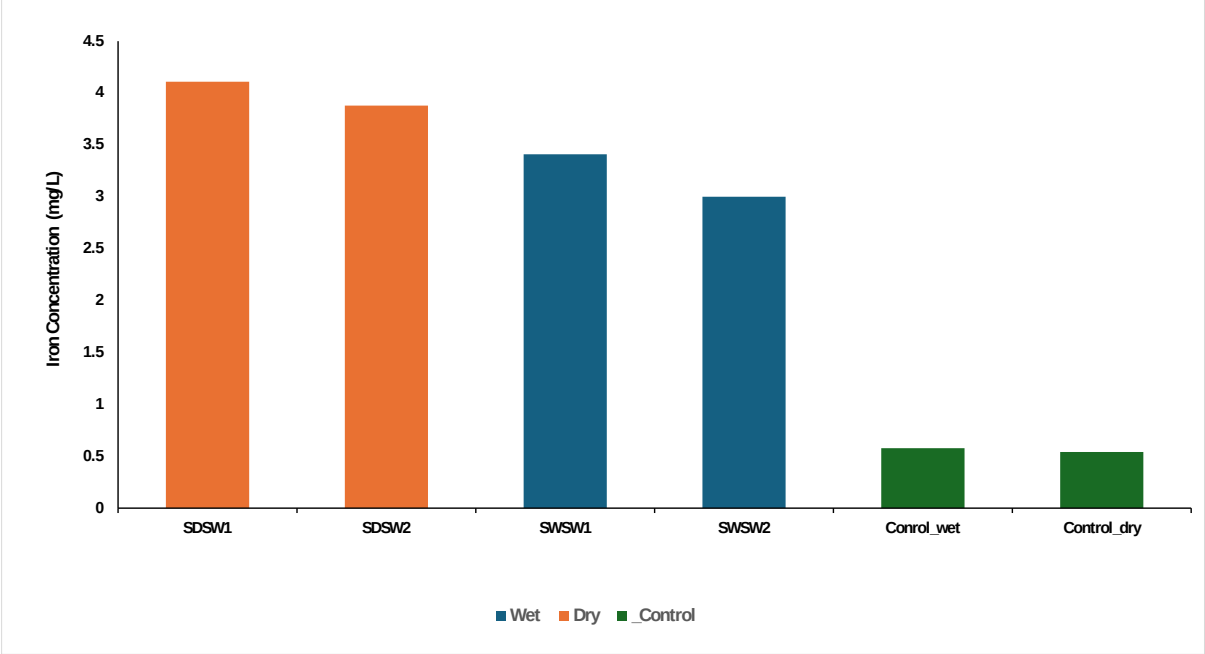

Figure 4. 77: Iron concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

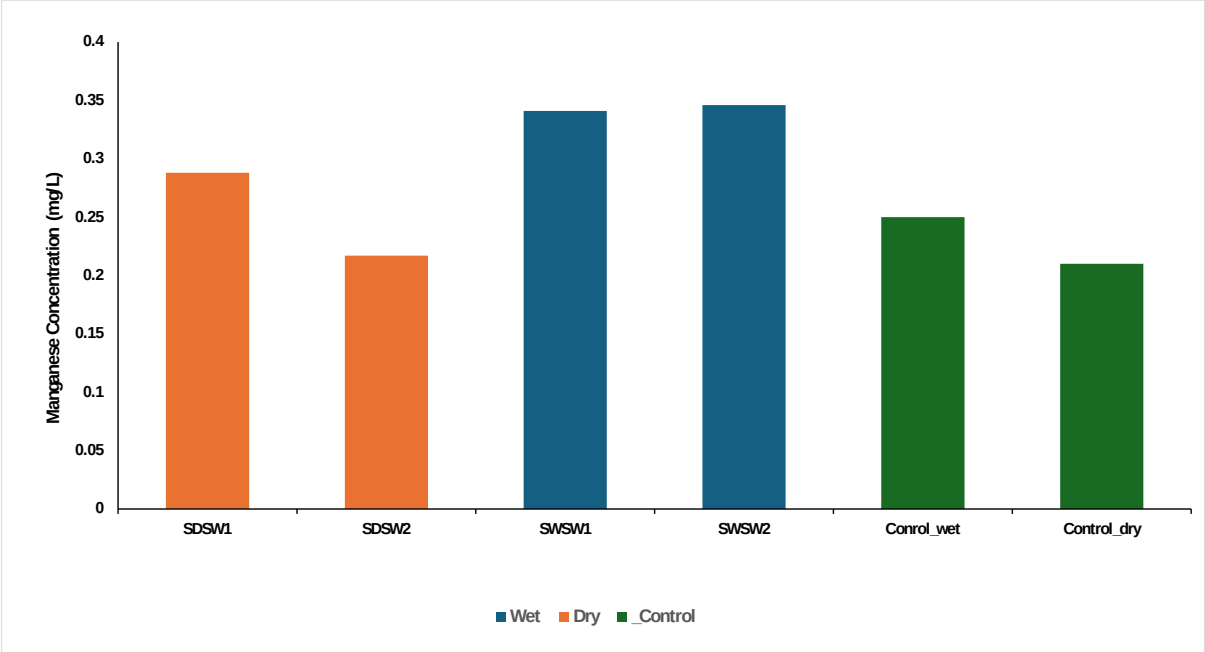

Figure 4. 78: Manganese concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

4.1.3.2.3 Zinc (Zn^{2+})

During the wet season, as shown in Table 4.6 and Figure 4.79, zinc concentrations ranged from 4.0 mg/L to 5.021 mg/L, with a mean of 4.511 ± 0.722 mg/L, substantially higher than the control site (0.311 mg/L). SWSW1 (Agba (Otuegwe) Kolo creek) recorded the highest concentration, exceeding control levels. In the dry season, Table 4.10 and Figure 4.79 reveal zinc levels ranging from 2.287 mg/L to 3.331 mg/L (mean: 2.809 ± 0.738 mg/L), significantly higher than the control site (0.41 mg/L). The spatial distribution remained similar with SWSW1(Agba (Otuegwe) Kolo creek) maintaining levels higher than control values. The seasonal comparison shows a reduction in mean zinc concentrations from wet to dry season (4.511 to 2.809 mg/L). This decrease can be attributed to reduced surface runoff and enhanced sediment retention during the dry period.

4.1.3.2.4 Copper (Cu^{2+})

Copper concentrations during the rainy season were significantly greater than those at the control site (0.343 mg/L), with a mean of 2.385 ± 1.054 mg/L and a range of 1.64 mg/L to 3.13 mg/L, as shown in Table 4.6 and Figure 4.80. The highest concentration was displayed by SWSW1 (Agba- Otuegwe Kolo creek), surpassing control values. According to the data presented in Table 4.10 and Figure 4.80, copper levels during the dry season range from 0.174 mg/L to 0.193 mg/L, with a mean of 0.184 ± 0.013 mg/L. These values are somewhat higher than the control site, which had a concentration of 0.165 mg/L. During the dry season, the disparity between the sites that were affected and those that were under control grew less noticeable. The mean copper concentrations decrease from the rainy to the dry season (from 2.385 to 0.184 mg/L), according to the seasonal comparison. This significant decline is explained by greater adsorption in low-flow situations and decreased mobilization from polluted sediments.

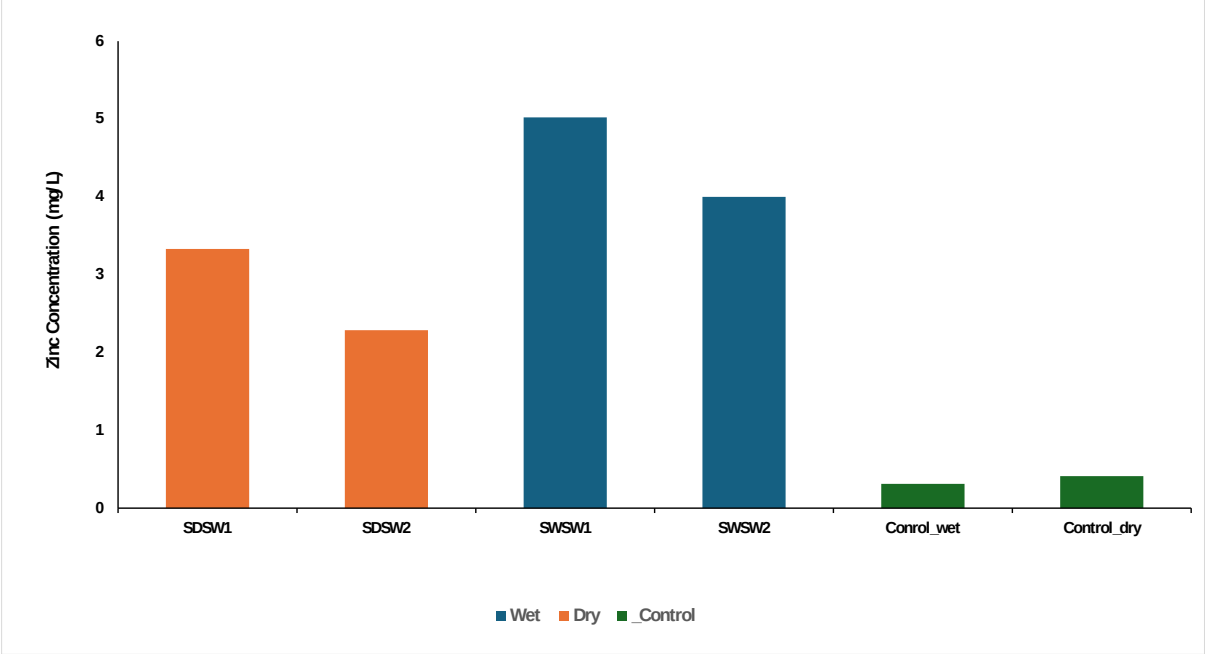

Figure 4. 79: Zinc concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

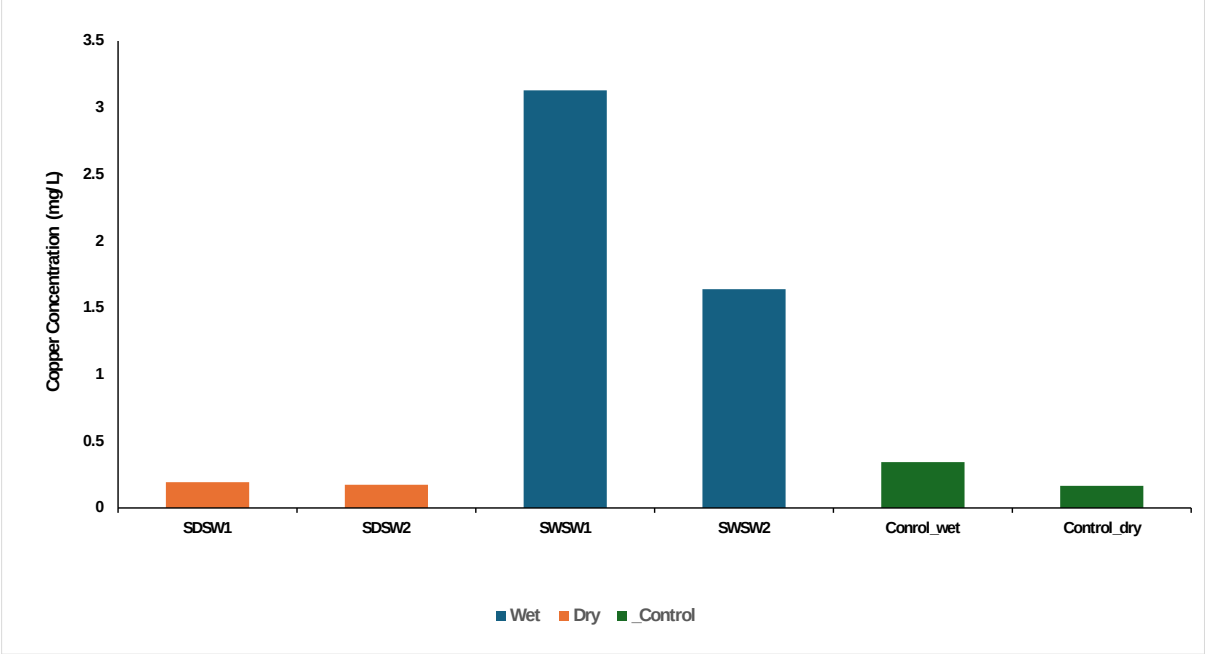

Figure 4. 80: Copper concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

4.1.3.2.5 Chromium (Cr^{6+})

Chromium concentrations during the rainy season were significantly higher than the non-detectable levels at the control location, ranging from 0.11 mg/L to 0.164 mg/L with a mean of 0.137 ± 0.038 mg/L, as indicated in Table 4.6 and Figure 4.81. The maximum concentration was observed by SWSW1 (Agba- Otuegwe Kolo creek). Table 4.10 and Figure 4.81 demonstrate that throughout the dry season, the levels of chromium have been found to range from 0.08 mg/L to 0.093 mg/L (with a mean of 0.087 ± 0.009 mg/L). On the other hand, the control site has maintained levels that are not detectable. The regional distribution remained the same, with SWSW1 (Agba- Otuegwe Kolo creek) exhibiting larger concentrations than the other regions. The seasonal comparison shows a reduction in mean chromium concentrations from wet to dry season (0.137 to 0.087 mg/L). This decrease can be attributed to reduced leaching from contaminated soils and increased sediment retention during the dry period.

4.1.3.2.6 Cadmium (Cd^{2+})

The concentrations of cadmium at oil spill sites throughout the wet season ranged from 0.12 mg/L to 0.254 mg/L, with an average of 0.187 ± 0.095 mg/L. This is significantly higher than the non-detectable levels at the control site, as seen in Table 4.6 and Figure 4.82. The concentration was highest at SWSW1 (Agba-Otuegwe's Kolo Creek). Table 4.10 and Figure 4.82 demonstrate that during the dry season, the amounts of cadmium in the water varied from 0.061 mg/L to 0.068 mg/L (with a mean of 0.065 ± 0.005 mg/L). On the other hand, the control site maintained values that were not detectable. Despite this, SWSW1 remained to have the highest concentration. The mean cadmium concentrations decreased from the wet to the dry season (0.187 to 0.065 mg/L), according to the seasonal comparison, although they remained continuously higher than those at the control site. Although the continuous presence suggests continued contamination from the oil disaster, this decline may be explained by improved adsorption processes during the dry season and lower mobilization from polluted sediments.

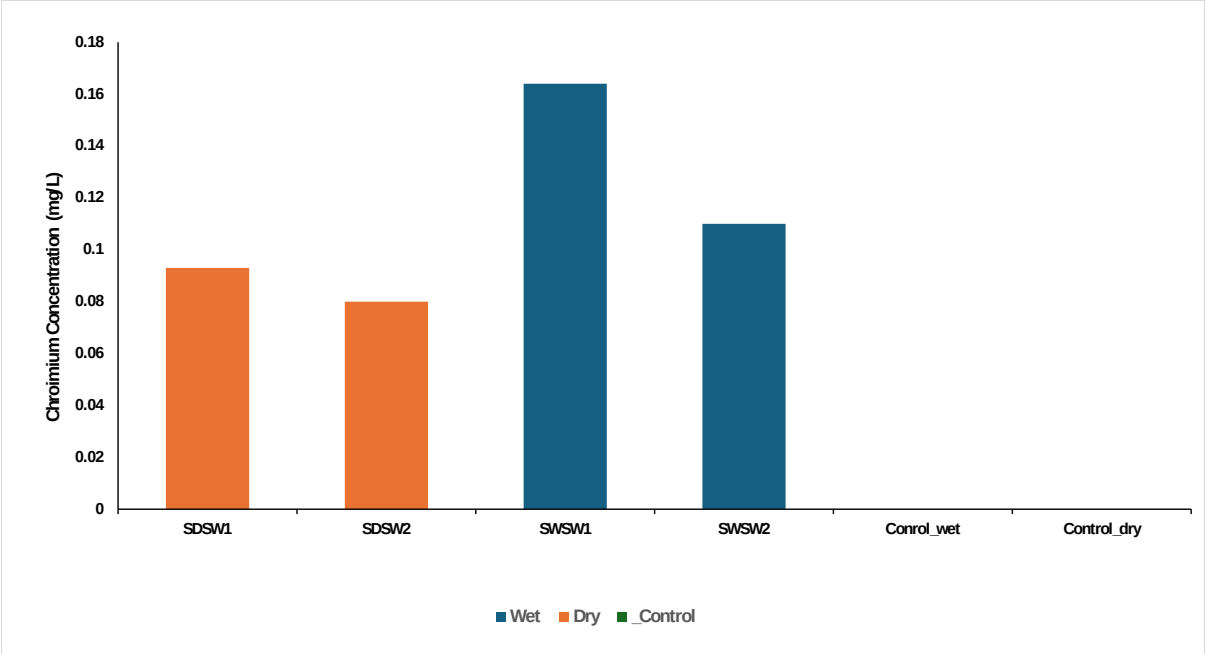

Figure 4. 81: Chromium concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

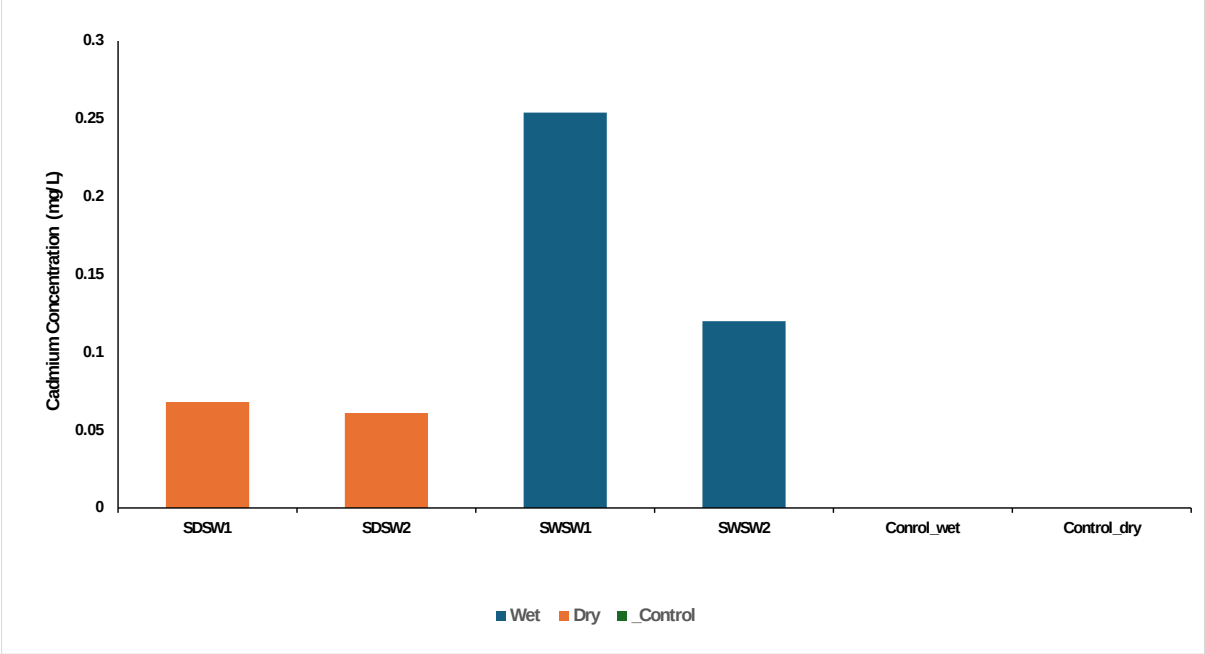

Figure 4. 82: Cadmium concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

4.1.3.2.7 Nickel (Ni^{2+})

Nickel concentrations during the rainy season were much higher than the non-detectable levels at the control location, ranging from 0.102 mg/L to 0.182 mg/L with a mean of 0.142 ± 0.057 mg/L, as shown in Table 4.6 and Figure 4.83. At Ibelebiri, SWSW2 (Kolo Creek) displayed the highest concentration. While the control site maintained non-detectable levels, the dry season measurements shown in Table 4.10 and Figure 4.83 revealed nickel levels ranging from 0.057 mg/L at SDSW2 (Ibelebiri Koko Creek) to 0.063 mg/L at SDSW1 (Agba-Otuegwe's Kolo Creek) with a mean of 0.06 ± 0.004 mg/L. During the dry season, the spatial distribution became more consistent. The seasonal comparison indicates a decrease in mean nickel concentrations from wet to dry season (0.142 to 0.06 mg/L), while maintaining detectable levels compared to the control site. This reduction likely results from decreased surface runoff and reduced leaching from contaminated soils, though the persistent presence suggests continued impact from the oil spill.

4.1.3.2.8 Lead (Pb^{2+})

Lead levels during the rainy season were significantly higher than the non-detectable values at the control site, with a mean of 1.431 ± 0.171 mg/L and a range of 1.31 mg/L to 1.552 mg/L, as indicated in Table 4.6 and Figure 4.84. The maximum concentration was noted by SWSW1 (Agba-Otuegwe's Kolo Creek). Figure 4.84 and Table 4.10 both show that throughout the dry season, lead levels ranged from 0.066 mg/L to 0.074 mg/L, with a mean of 0.07 ± 0.006 mg/L. This indicates that the lead levels were somewhat variable. On the other hand, the control site maintained levels that were not measurable at any other location. When compared to the previous levels, the concentrations of SWSW1 remained marginally higher. While the mean lead concentrations remained higher than at the control location, the seasonal comparison reveals a significant drop from the wet to the dry season (1.431 to 0.07 mg/L). Reduced mobilization from polluted sediments, higher precipitation of lead compounds, and decreased surface runoff during the dry season are all responsible for this significant decline.

4.1.3.2.9 Vanadium (V^{2+})

During the wet season, as presented in Table 4.6 and Figure 4.85, vanadium concentrations ranged from 0.084 mg/L to 0.13 mg/L, with a mean of 0.107 ± 0.033 mg/L, notably higher than the non-detectable levels at the control site. SWSW1 (Agba-Otuegwe's Kolo Creek) showed the highest concentration. During the dry season, the data presented in Table 4.10 and Figure 4.85 demonstrate that the levels of vanadium in the water varied from 0.045 mg/L to 0.051 mg/L, with a mean of 0.048 ± 0.004 mg/L. Conversely, undetectable values were maintained at the control site. SWSW1 had somewhat higher concentrations than the other regions, following a consistent regional pattern.

The seasonal comparison reveals a reduction in mean vanadium concentrations from wet to dry season (0.107 to 0.048 mg/L), while maintaining detectable levels compared to the control site. This reduction can be attributed to decreased weathering of oil-contaminated sediments and reduced mobilization during the dry season, though the continued presence of vanadium indicates persistent contamination from the crude oil spill.

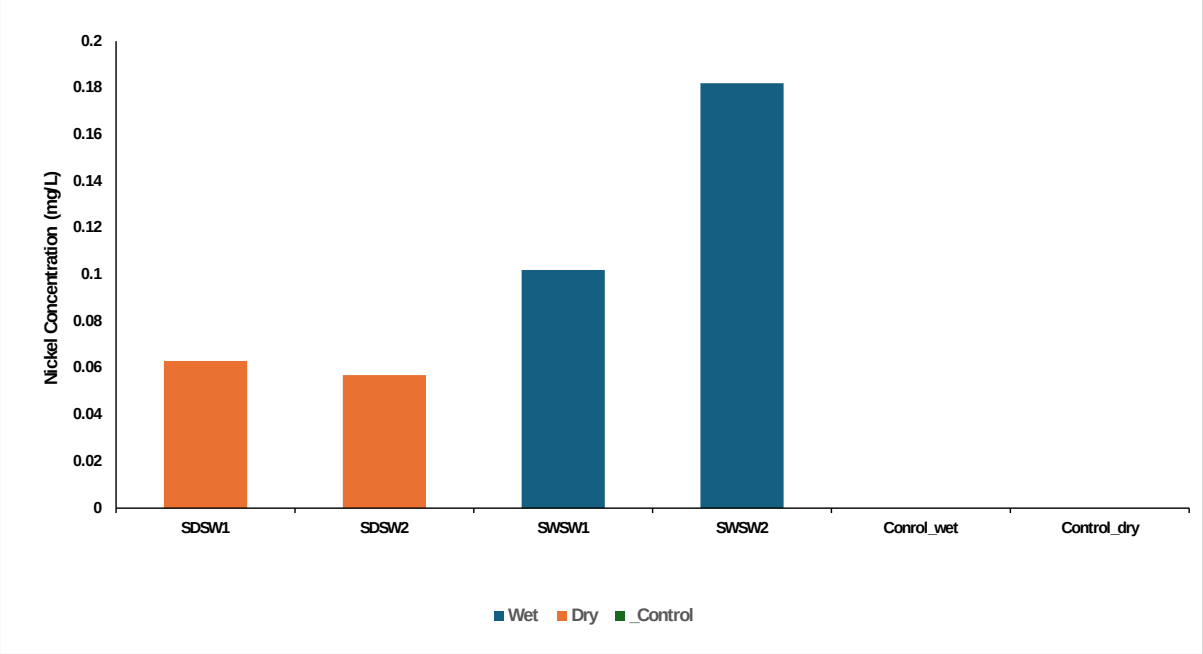

Figure 4. 83: Nickel concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

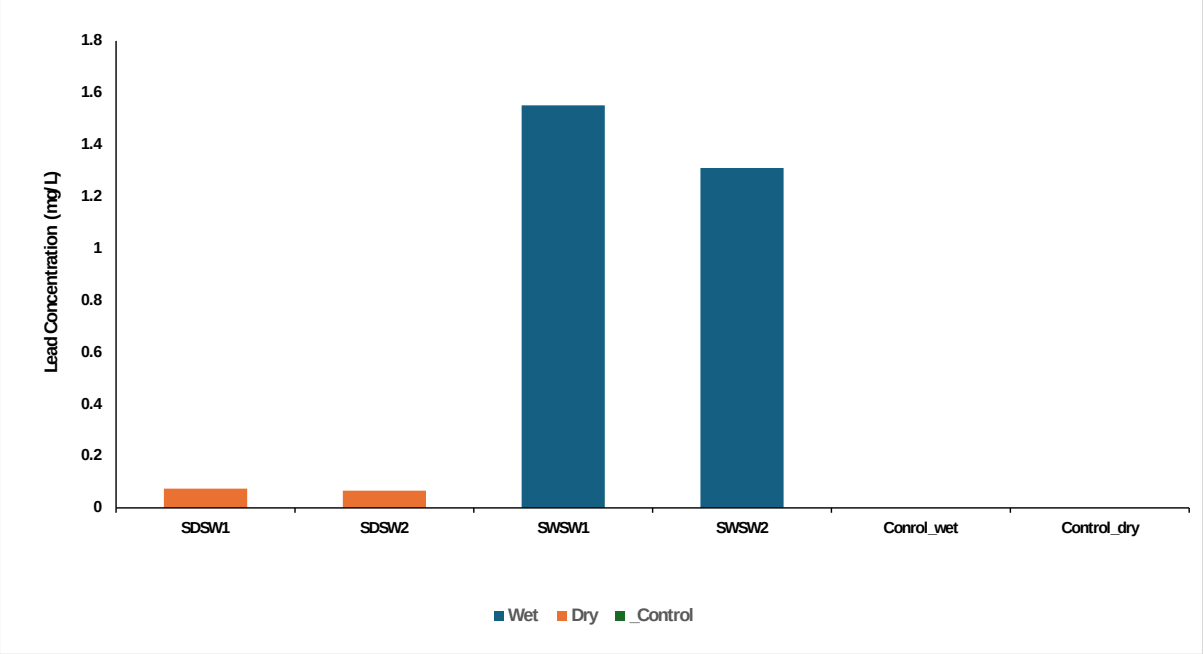

Figure 4. 84: Lead concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

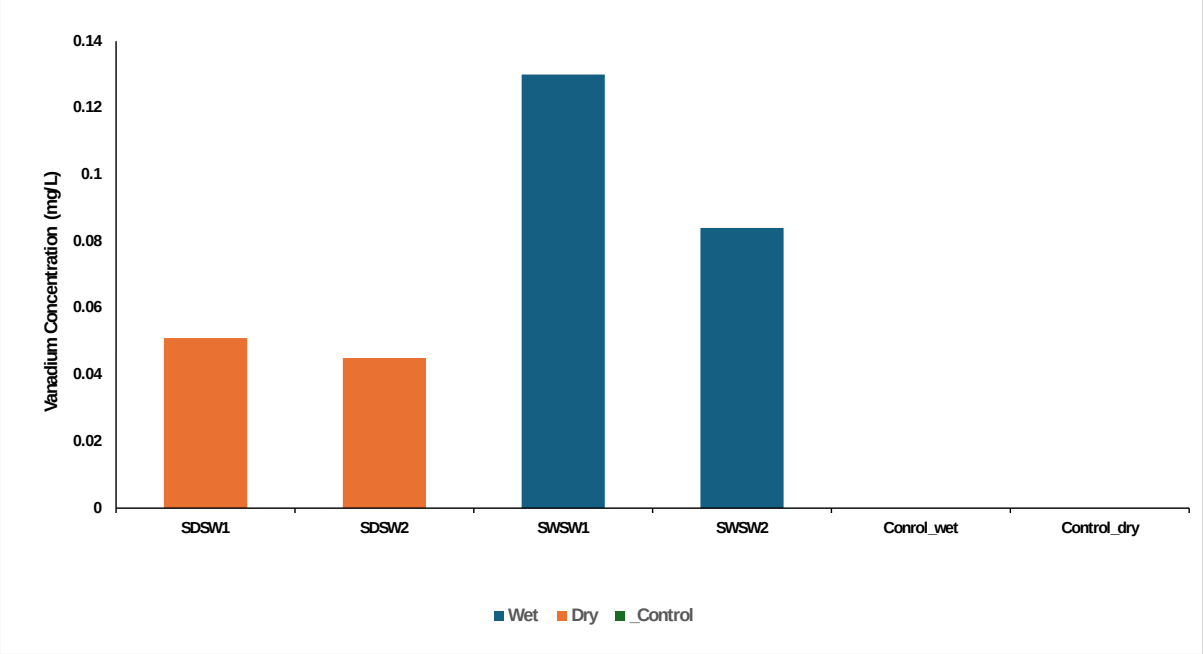

Figure 4. 85: Vanadium concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

4.2 Organic Compounds

To comprehend the scope and effects of human activity in the Niger Delta, it is essential to evaluate organic chemicals in environmental matrices. Cyanide (CN) and total hydrocarbon content (THC) were assessed as important organic characteristics in this study at a variety of polluted sites, such as mechanic shops, dumpsites, cassava processing mills, and crude oil spill sites.The main indicator of petroleum-based contamination is total hydrocarbon content, which is especially important in places where there have been crude oil spills and mechanical workshop operations. Its presence in soil and water samples offers important insights about the persistence and distribution of hydrocarbon pollutants in the environment.

4.2.1 Organic Compounds in Soils

4.2.1.1 Organic Compounds in Soils Around Mechanic Workshops

To evaluate environmental contamination from automotive activities, organic compound analysis of the soils surrounding mechanic workshops is crucial. The main source of organic pollutants in the Niger Delta region's urban and semi-urban mechanic workshops is the leakage of petroleum products, used engine oil, lubricants, and other hydrocarbon-based compounds. In order to determine the degree of contamination and any environmental hazards related to mechanic workshops, this study looks at the Total Hydrocarbon Content (THC), a crucial indication of organic pollution in the soils surrounding these facilities.

4.2.1.1.1 Total Hydrocarbon Content (THC)

THC concentrations at mechanic workshop sites during the wet season ranged from 0.001 to 2.9 mg/kg, with an average of 0.34 ± 0.79 mg/kg. This was greater than the non-detectable values at control sites, as seen in Table 4.12 and Figure 4.86. MWS3, which is situated in the Mechanic Village along Imiringi Road, had the greatest concentration (2.9 mg/kg), followed by MWS2 (1.97 mg/kg) and MWS4 (1.58 mg/kg).THC levels ranged from 0.044 to 3.4 mg/kg (mean: 0.64 ± 0.95 mg/kg) during the dry season, according to Table 4.16 and Figure 4.86, while non-detectable levels were maintained at control sites. MDS3 (3.4 mg/kg), MDS2 (2.14 mg/kg), and

MDS4 (2.2 mg/kg) displayed the maximum concentrations at the same Imiringi Road location, maintaining a comparable spatial distribution. The seasonal comparison shows a huge increase in mean THC concentrations from wet to dry season (0.34 to 0.64 mg/kg), while maintaining consistently higher levels than the control sites. This increase could be attributed to reduced leaching and dilution of hydrocarbons during the dry season, as well as possible accumulation of fresh hydrocarbon contamination from continued mechanical activities. The consistently higher concentrations at the Imiringi Road location suggest intensive mechanical activities and poor waste oil management practices at this site.

4.2.1.2 Organic Compounds in Soils Around Cassava Mills

A range of organic compounds may be released into the environment by cassava mills, which turn cassava roots into different products such cassava flour, starch, and other derivatives. The cassava plant itself, which contains organic elements like proteins, carbohydrates, and cyanogenic glycosides, as well as the waste products and by-products produced during processing, are the sources of these compounds. In order to determine the degree of contamination, evaluate the health of the soil, and estimate the possible effects on nearby ecosystems, it is essential to investigate the organic chemicals found in the soils surrounding cassava mills.

4.2.1.2.1 Total Hydrocarbon Content (THC)

THC concentrations at cassava mill sites during the wet season varied from 0.007 to 0.087 mg/kg, with a mean of 0.05 ± 0.02 mg/kg, as indicated in Table 4.13 and Figure 4.87. These values were greater than the non-detectable levels at control sites. CWS1 (0.087 mg/kg) had the highest concentration in Otuasega, followed by CWS2 (0.073 mg/kg) and CWS4 (0.074 mg/kg). THC levels ranged from 0.056 to 1.545 mg/kg (mean: 0.55 ± 0.27 mg/kg) during the dry season, according to Table 4.17 and Figure 4.87, while non-detectable levels were maintained at control sites. In Otuasega, CDS3 had the highest concentration (1.545 mg/kg), followed by CDS2 (0.757 mg/kg) and CDS1 (0.587 mg/kg). While the mean THC concentrations remained continuously

higher than the control locations, the seasonal comparison shows a significant increase from the wet to the dry season (0.05 to 0.55 mg/kg). Reduced hydrocarbon residue washing away during the dry season and potential accumulation from increased cassava processing activities could be the cause of this notable increase, especially at the Otuasega location where levels were continuously elevated during both seasons.

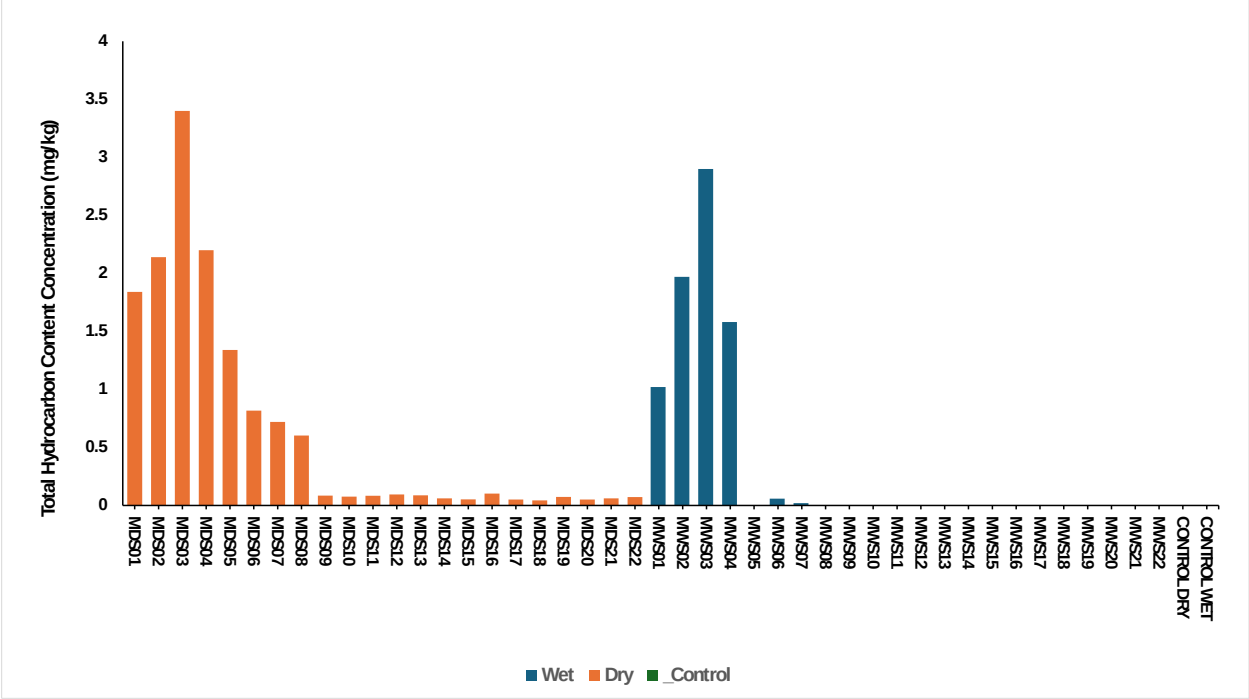

Figure 4. 86: Total hydrocarbon content Concentration in Soil Samples Collected Around Mechanic Workshops Compared with control during the wet and dry seasons

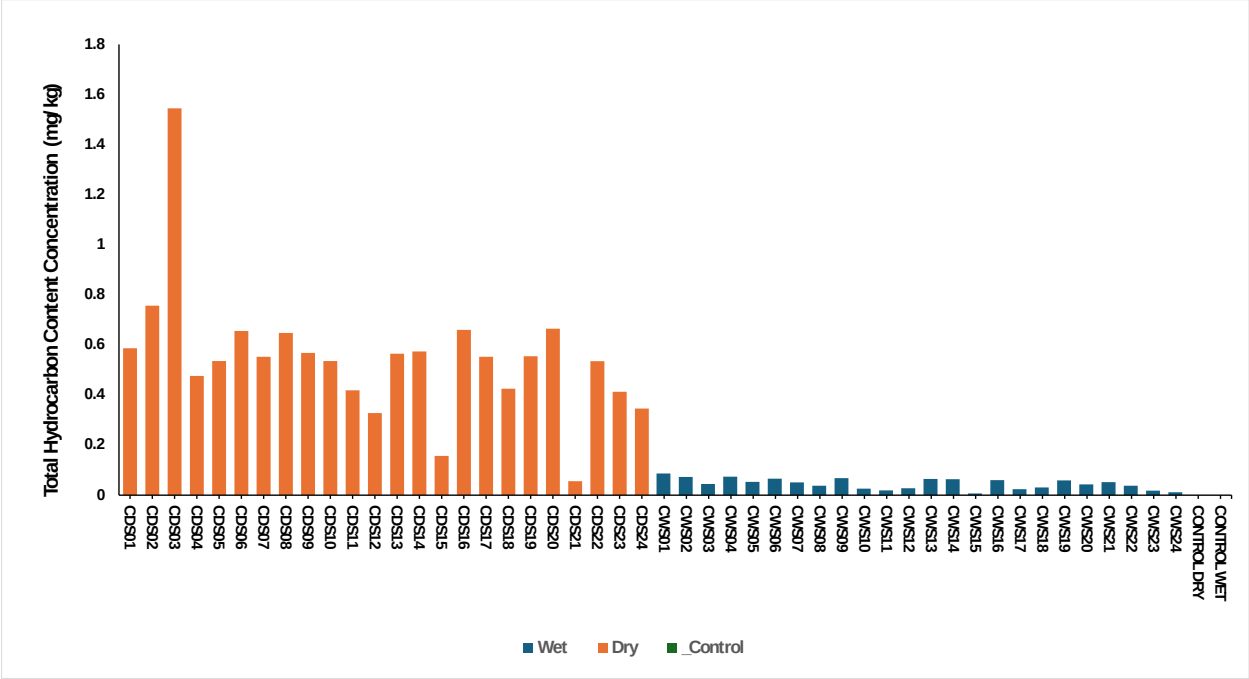

Figure 4. 87: Total hydrocarbon Content Concentration in Soil Samples Collected Around Cassava mills Compared with control during the wet and dry seasons

4.2.1.3 Organic Compounds in Soils Around Crude Oil Spill Sites

The soil at the locations of crude oil spills is greatly impacted by the diverse variety of organic molecules released into the environment. Because of their low volatility and solubility, these substances, which include hydrocarbons like alkanes, polycyclic aromatic hydrocarbons (PAHs), and other petroleum derivatives, can linger in the soil for long periods of time. Assessing the degree of pollution, comprehending the biodegradation processes, and determining the long-term ecological repercussions all depend on the research of organic molecules in the soils surrounding crude oil spill sites.

4.2.1.3.1 Total Hydrocarbon Content (THC)

THC levels in crude oil spill locations during the wet season varied from 7.08 to 10.75 mg/kg, with an average of 8.41 ± 1.24 mg/kg. These levels were significantly higher than the non-detectable values at control sites, as shown in Table 4.14 and Figure 4.88. In Agba-Otuegwe, SWS1 had the highest concentration (10.75 mg/kg), followed by SWS4 at Ibelebiri (8.1 mg/kg).

THC levels in the dry season range from 9.55 to 15.78 mg/kg (mean: 12.32 ± 2.19 mg/kg), according to Table 4.18 and Figure 4.88, but non-detectable levels were maintained at control sites. SDS1 (15.78 mg/kg) in Agba-Otuegwe had the highest concentration, while SDS4 (13.5 mg/kg) in Ibelebiri came in second. The mean THC concentrations increased from the wet to the dry season (8.41 to 12.32 mg/kg), but they remained much higher than in the control sites, according to the seasonal comparison. Reduced hydrocarbon weathering and breakdown during the dry season, along with potential new pollution from ongoing seepage, could be the cause of this rise.

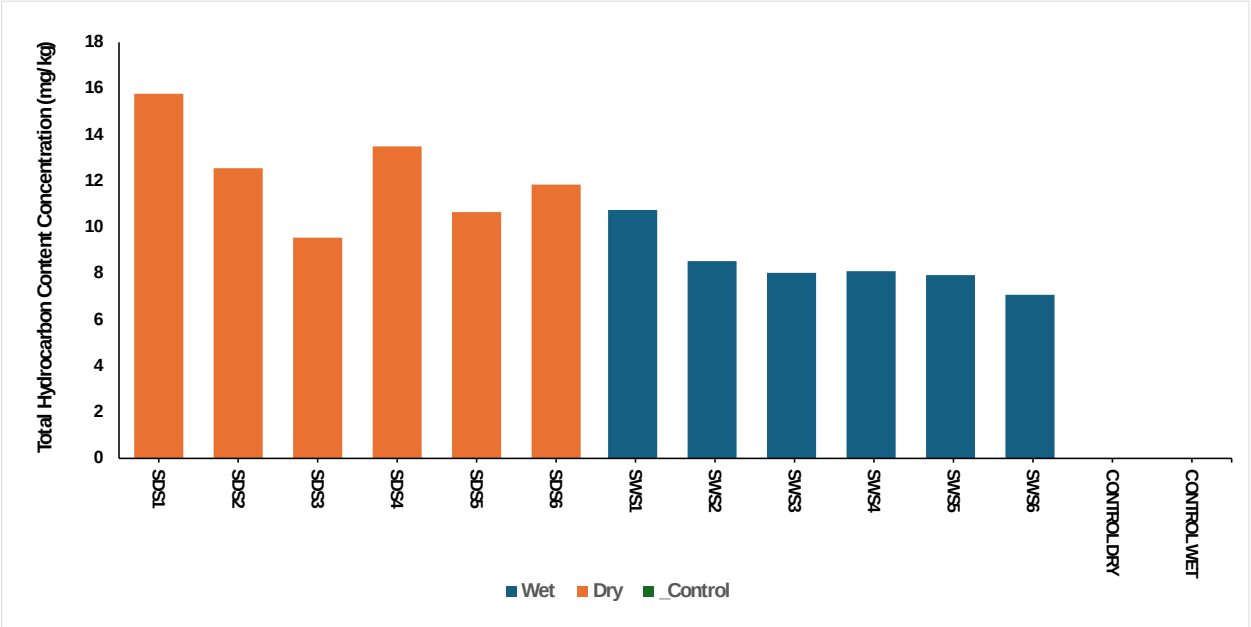

Figure 4. 88: Total hydrocarbon content concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

4.2.2 Organic Compounds in Groundwater

4.2.2.1 Organic Compounds in Groundwater Around Mechanic Workshops

Through operations like car maintenance, oil changes, and the use of different solvents and degreasers, mechanic shops produce a range of organic pollutants. Hydrocarbons are among the organic chemicals that can seep into the soil and contaminate groundwater, endangering both human health and the quality of the water. Finding the kinds and amounts of organic chemicals, as well as their possible sources and effects on nearby water supplies, is the main goal of this investigation

4.2.2.1.1 Total Hydrocarbon Content (THC)

During the wet season, as shown in Table 4.30 and Figure 4.89, THC concentrations in groundwater at mechanic workshop sites ranged from 0.004 to 0.321 mg/L, with a mean of 0.088 ± 0.101 mg/L. The highest concentration was recorded at MWGW1 (0.321 mg/L) at Imiringi Road, followed by MWGW2 (0.141 mg/L) at the same location.Table 4.31 and Figure 4.89 demonstrate that throughout the dry season, the amounts of THC in the water range from 0.001 to 0.143 mg/L, with the mean being 0.029 ± 0.044 mg/L. MDGW1 had the greatest concentration, which was measured to be 0.143 mg/L, followed by MDGW2 with a value of 0.042 mg/L, both of which were found in the Imiringi Road location.While the mean THC concentrations remained continuously higher than the control locations, the seasonal comparison reveals a reduction from the wet to the dry season (0.088 to 0.029 mg/L). This decline might be explained by fewer hydrocarbon pollutants infiltrating during the dry season. The Imiringi Road location's continually higher concentrations point to ongoing groundwater contamination from mechanical activity.

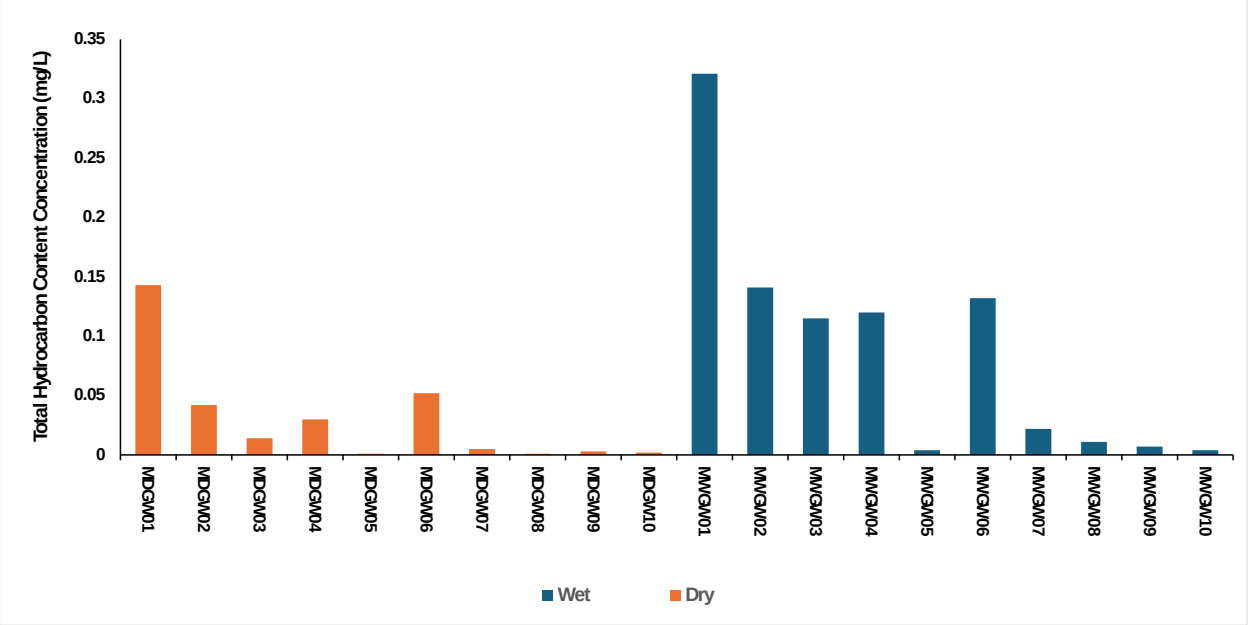

Figure 4. 89: Total Hydrocarbon Content concentration in groundwater samples collected around mechanic workshops during the wet and dry seasons

4.2.2.2 Organic Compounds in Groundwater Around Cassava Mills

By disposing of processing waste, cassava mills, which turn cassava roots into goods like cassava flour and starch, can contaminate groundwater. Groundwater quality may be impacted by organic chemicals that seep into the ground, such as cyanogenic glycosides, which are naturally found in cassava, as well as organic matter from peelings and wastewater. In order to minimize the impact on the environment, waste management techniques will be guided by the insights this investigation seeks to provide regarding the organic compound load in groundwater.

4.2.2.2.1 Cyanide (CN)

Cyanide concentrations in groundwater at cassava mill sites during the wet season ranged from non-detectable to 0.01 mg/L, with a mean of 0.001 ± 0.003 mg/L, as indicated in Table 4.30 and Figure 4.90. The only CWGW2 at Opolo Big Brother Road had detectable levels (0.01 mg/L), which was at the NSDWQ 2007 maximum allowable limit. In the dry season, Table 4.31 and Figure 4.90 reveal cyanide levels ranging from non-detectable to 0.001 mg/L (mean: 0.0001 ± 0.0003 mg/L). Similar to the wet season pattern, only CDGW2 at Opolo Big Brother Road showed detectable levels (0.001 mg/L), which was within the NSDWQ 2007 limit guideline for cyanide in drinking water. The seasonal comparison indicates a decrease in mean cyanide concentrations from wet to dry season (0.001 to 0.0001 mg/L). This decrease could be attributed to reduced leaching of cyanide compounds from cassava processing waste during the dry season. The consistent detection at the Opolo Big Brother Road location, though at very low concentrations as shown in Figure 4.90, suggests minimal but persistent groundwater impact from cassava processing activities.

4.2.2.3 Organic Compounds in Groundwater Around Crude Oil Spill Sites

A complex mixture of organic chemicals, including a variety of hydrocarbons that might contaminate groundwater, can be released into the environment by crude oil spills. Determining the amount and existence of organic compounds, monitoring their movement, and assessing their effects on groundwater resources are the main objectives of this investigation.

4.2.2.3.1 Total Hydrocarbon Content (THC)

THC concentrations in groundwater at crude oil spill locations during the wet season varied from 0.173 to 0.263 mg/L, with a mean of 0.218 ± 0.064 mg/L, as shown in Table 4.30 and Figure 4.91. SWGW2 at Ibelebiri had the highest concentration, at 0.263 mg/L.THC levels ranged from 0.054 to 0.146 mg/L (mean: 0.100 ± 0.065 mg/L) during the dry season, according to Table 4.31 and Figure 4.91. SDGW2 in Ibelebiri had the highest concentration (0.146 mg/L). When comparing the wet and dry seasons, the mean THC concentrations decrease from 0.218 to 0.100 mg/L. Reduced hydrocarbon mobility in the subsurface during the dry season may be the cause of this decline. The continuously elevated levels at Ibelebiri point to ongoing groundwater pollution from the oil disaster.

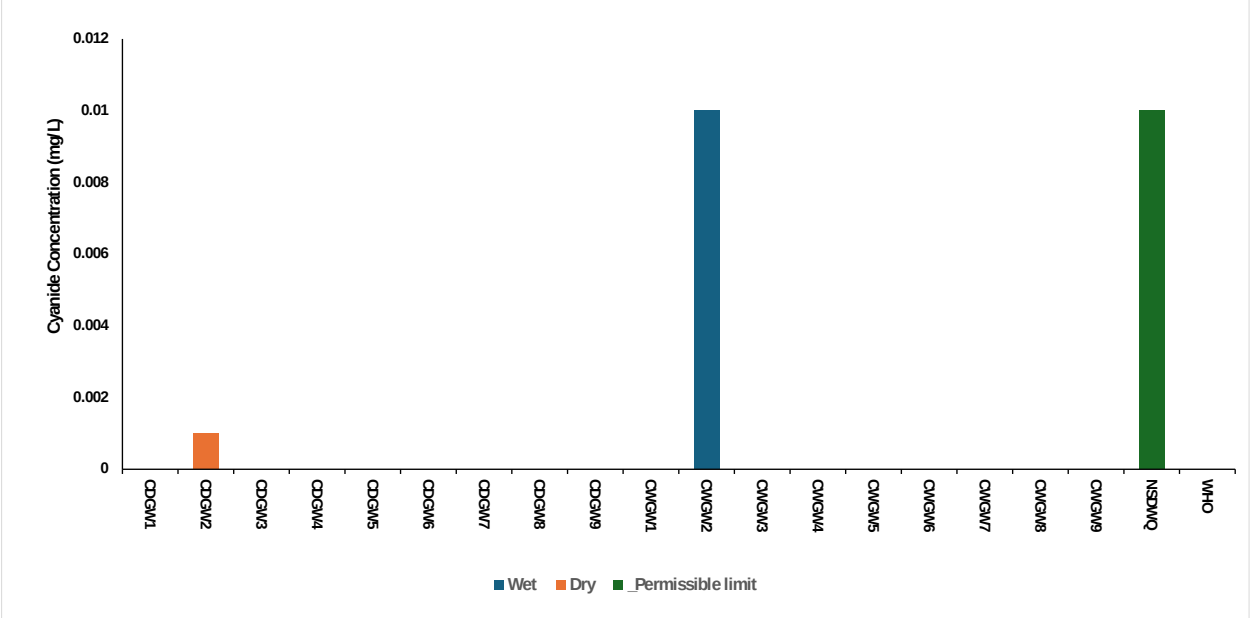

Figure 4. 90: Cyanide concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

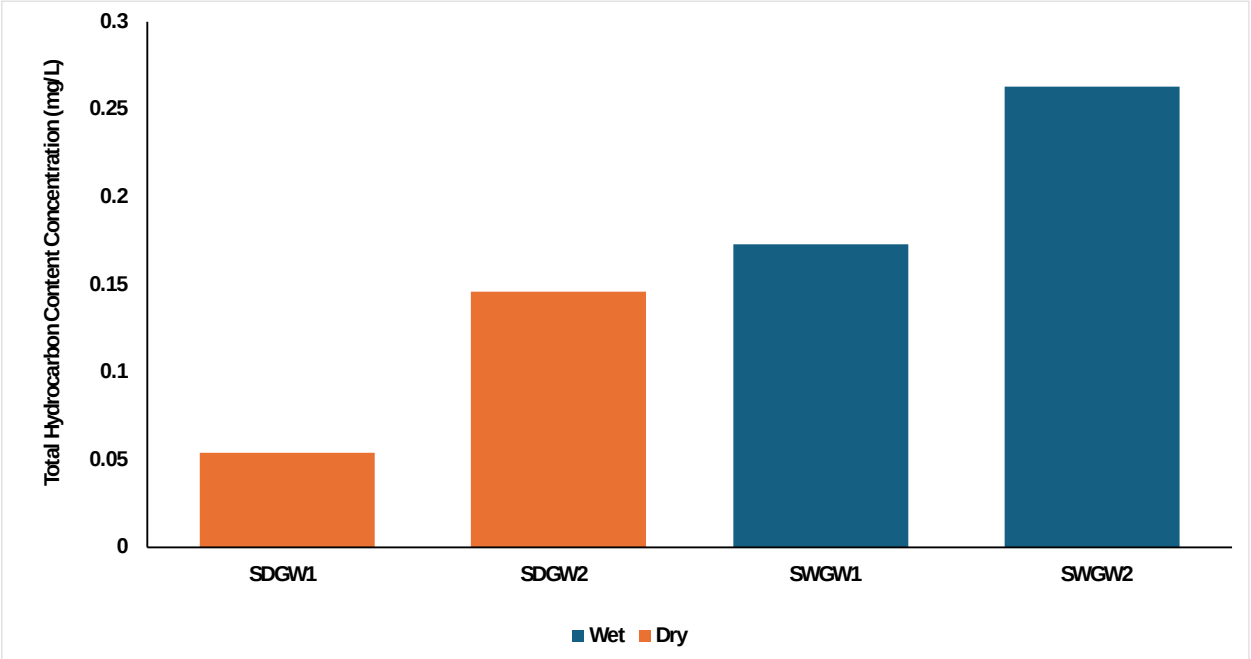

Figure 4. 91: Total Hydrocarbon Content concentration in groundwater samples collected around crude oil spill site during the wet and dry seasons

4.2.3 Organic Compounds in Surface Water

4.2.3.1 Organic Compounds in Surface Water Around Crude Oil Spill Sites

Crude oil spills introduce a myriad of organic compounds into surface water bodies, ranging from volatile hydrocarbons like gasoline and diesel to more persistent compounds such as polycyclic aromatic hydrocarbons (PAHs). This analysis aims to identify the types and concentrations of organic compounds present and evaluate measures to mitigate the ecological damage caused by oil spills.

4.2.3.1.1 Total Hydrocarbon Content (THC)

During the wet season, as shown in Table 4.32 and Figure 4.92, THC concentrations in surface water at crude oil spill sites ranged from 11.62 to 12.05 mg/L, with a mean of 11.835 ± 0.304 mg/L. The highest concentration was recorded at SWSW1 (12.05 mg/L) at Agba-Otuegwe, followed by SWSW2 (11.62 mg/L) at Ibelebiri.THC levels throughout the dry season are shown to range from 9.44 to 10.23 mg/L, with a mean of 9.835 ± 0.559 mg/L. This information is presented in Table 4.33 and Figure 4.92. SDSW2 (10.23 mg/L) in Ibelebiri had the highest concentration, followed by SDSW1 (9.44 mg/L) at Agba-Otuegwe.The seasonal comparison shows a decrease in mean THC concentrations from wet to dry season (11.835 to 9.835 mg/L). Despite this decrease, the concentrations remained drastically elevated across both seasons. This indicates severe and persistent surface water contamination from crude oil spills at these locations. The consistently high levels at both Agba-Otuegwe and Ibelebiri sampling points suggest ongoing impacts from crude oil contamination on surface water quality in these areas.

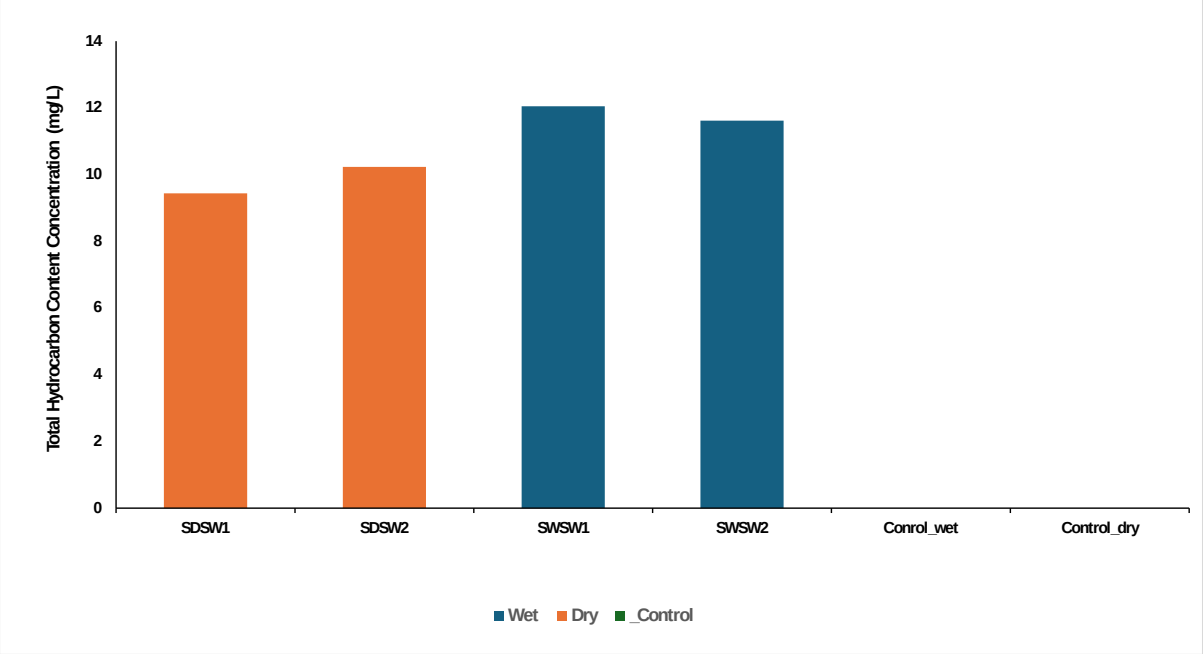

Figure 4. 92: Total Hydrocarbon content concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

4.3 Physcial Characteristics

4.3.1 Physical Characteritics in Soils

Physical characteristics of soil, such as pH and Electrical Conductivity (EC), are essential markers of soil health and appropriateness for a range of applications, such as environmental management, building, and agriculture. In order to guarantee sustainable soil management and ecosystem health, monitoring these attributes aids in determining soil quality, forecasting soil behavior, and directing land use decisions.

4.3.1.1 Physical Characteristics in Soils Around Dumpsites

The leaching of chemicals and organic matter from garbage can drastically change the pH and Electrical Conductivity (EC) of soil at dumpsites, where different kinds of waste are disposed of. The breakdown of organic matter or the presence of acidic or alkaline waste can cause pH fluctuations, which can affect microbial activity and soil fertility. However, the breakdown of salts and other conductive materials can raise EC, which could cause soil salinization and have an impact on plant growth.

4.3.1.1.1 Hydrogen Potential (pH)

The average soil pH at dumpsite locations during the wet season was 6.64±0.51, with values ranging from 5.3 to 7.5 (Table 4.20). The highest pH (7.5) was found at DWS6 (Etelebu off Tombia/Amassoma new dumpsite 3), as illustrated in Figure 4.93. Values of 7.3 were found at both DWS5 (Etelebu off Tombia/Amassoma Road New dumpsite 2) and DWS8 (Tombia junction market 1) locations. DWS1 (Etelebu Tombia/Amassoma Road Old dumpsite) has the lowest pH (5.3). The majority of dumpsite locations exhibited pH values lower than the control sites throughout this time period, with the control sites displaying pH values between 6.7 and 7.3. Soil pH values decreased significantly throughout the dry season, with a mean of 5.79±0.63 and a range of 3.5 to 6.8 (Table 4.19). As shown in Figure 4.93, DDS1 (Etelebu Tombia/Amassoma Road Old dumpsite) had the lowest pH (3.5), whereas DDS6 (Etelebu off Tombia/Amassoma new dumpsite 3) had the highest pH (6.8). The majority of dumpsite

locations had lower pH values than control sites, which ranged from 5.5 to 6.6 during the dry season. From the wet season (mean 6.64±0.51) to the dry season (mean 5.79±0.63), the seasonal variance for pH demonstrated a distinct downward trend. This decline is shown to be constant throughout the majority of sampling locations in Figure 4.93. The Etelebu Tombia/Amassoma Road Old dumpsite (DWS1/DDS1) consistently had the lowest pH values during both seasons, sustaining values that were lower than those of control sites. One possible explanation for this seasonal acidity is that during the dry season, there is less of an effect of dilution, which results in a higher concentration of acidic leachates from the breakdown of garbage.

4.3.1.1.2 Electrical Conductivity (EC)

Electrical conductivity values during the rainy season ranged from 267-864 µS/cm, with an average of 447.92±143.80 µS/cm (Table 4.20). DWS1 (Etelebu Tombia/Amassoma Road Old dumpsite) has the highest EC value (864 µS/cm), followed by DWS6 (755 µS/cm), as seen in Figure 4.94. At the DWS4 (Etelebu off Tombia/Amassoma new dumpsite 1) site, the lowest EC (267 µS/cm) was measured. During this time, the majority of dumpsite locations had higher EC values than control sites, with control sites exhibiting EC values between 265 and 518 µS/cm.EC values increased during the dry season, with a mean of 613.6±197.94 µS/cm and a range of 365–1250 µS/cm (Table 4.19). DDS1 (Etelebu Tombia/Amassoma Road Old dumpsite1) had the highest EC (1250 µS/cm), followed by DDS3 (Etelebu Tombia/Amassoma Road Old dumpsite3) (925 µS/cm), as Figure 4.94 makes evident. At DDS24 (Okaka 1), the lowest value (365 µS/cm) was recorded. During this time, the majority of dumpsite locations had higher EC values than control sites, with control sites exhibiting EC values ranging from 295 to 568 µS/cm.EC values increased significantly from the wet season (mean 447.92±143.80 µS/cm) to the dry season (mean 613.6±197.94 µS/cm), according to the seasonal variation. This upward trend is evident in the majority of the sampling sites (Figure 4.94). Throughout both seasons, the Etelebu Tombia/Amassoma Road Old dumpsite (DWS1/DDS1) continuously displayed the highest EC values, keeping them above control sites. Higher dissolved ion concentrations during the dry

period are shown by the seasonal increase in EC values, which is probably caused by decreased dilution effects and increased ionic accumulation from waste degradation.

4.3.1.2 Physical Characteristics in Soils Around Mechanic Workshops

The pH and EC of the soil can be impacted by the oils, lubricants, and other chemicals that mechanic workshops emit into the ground. Depending on the kind of chemicals utilized, the pH may change to an alkaline or acidic state. Because salts from brake fluids, engine coolants, and other automotive fluids can change the structure of soil and lessen its agricultural potential, high EC levels may be seen.

4.3.1.2.1 Hydrogen Potential (pH)

The mean soil pH at mechanic workshop locations during the wet season was 7.39±0.21, with a range of 6.9 to 7.8 (Table 4.20). Figure 4.95 illustrates that MWS7 (Kpansia Nikton Road) had the highest pH (7.8), with MWS3 (Mechanic Village Imiringi Road 3) having next-highest values (7.7). The pH of MWS11 (Kpansia Melford Okilo Road) was the lowest (6.9). The majority of mechanic workshop locations had pH values higher than the control sites throughout this time period, with the control sites displaying pH values between 6.7 and 7.3. Soil pH values decreased over the dry season, with a mean of 6.76±0.44 and a range of 5.4 to 7.3 (Table 4.19). As shown in Figure 4.95, MDS19 (Oxbow Lake Road Swali) had the lowest pH (5.4), whereas MDS3 (Mechanic Village Imiringi Road 3) had the highest pH (7.3). The pH levels at control sites during the dry season ranged from 5.5 to 6.6, with most mechanic workshop locations exhibiting higher pH values than control sites. From the wet season (mean 7.39±0.21) to the dry season (mean 6.76±0.44), the seasonal variance for pH exhibited a declining trend. This steady decline throughout most sampling sites is shown in Figure 4.95. The pH values at mechanic workshop locations were generally higher than those at control sites in both seasons, despite the seasonal decline. This pattern implies that operations in mechanic workshops might be a factor in the elevated alkalinity of the soil.

4.3.1.2.2 Electrical Conductivity (EC)

Electrical conductivity values during the wet season ranged from 157 to 678 µS/cm, with an average of 419±126.85 µS/cm (Table 4.20). MWS12 (Yenezue-Epie Saptex Road) has the highest EC value (678 µS/cm), followed by MWS8 (Kpansia JJWAKS 1) (534 µS/cm), as seen in Figure 4.96. The lowest EC (157 µS/cm) was recorded at MWS2 location. Control sites during this period showed EC values between 265-518 µS/cm, with several mechanic workshop locations showing higher EC values compared to control sites.EC values increased during the dry season, with a mean of 539.05±154.28 µS/cm and a range of 237-816 µS/cm (Table 4.19). Figure 4.96 clearly illustrates that MDS12 (Yenezue - Epie Saptex Road) recorded the highest EC (816 µS/cm), followed by MDS10 (687 µS/cm). The lowest value (237 µS/cm) was observed at MDS2 (Mechanic Village Imiringi Road 2). Control sites during this period showed EC values between 295-568 µS/cm, with most mechanic workshop locations showing higher EC values than control sites. From the wet season (mean 419±126.85 µS/cm) to the dry season (mean 539.05±154.28 µS/cm), the seasonal fluctuation showed that EC values rose. Figure 4.96 shows this increasing trend across most sampling locations. The Yenezue - Epie Saptex Road location consistently showed the highest EC values in both seasons, maintaining values higher than control sites. The seasonal increase in EC values suggests higher concentration of dissolved ions during the dry period, possibly due to accumulated effects of oil spills and mechanical workshop activities.

4.3.1.3 Physical Characteristics in Soils Around Cassava Mill

Waste from cassava mills has a high organic content, and when it breaks down, organic acids are released, which can reduce the pH of soil. The wastewater from the processing of cassava can also introduce salts and other substances that raise the EC of the soil, which may alter the fertility and health of the soil. It is crucial to keep an eye on these physical characteristics in order to manage the soil quality near cassava mills.

4.3.1.3.1 Hydrogen Potential (pH)

The mean pH of the soil at cassava mill locations during the wet season was 7.32±0.24, with a range of 6.9 to 7.8 (Table 4.20). According to Figure 4.97, CWS1 (Otuasega) and CWS3 (Otuasega) had the greatest pH (7.8), whereas CWS12 (Igbogene) had the lowest pH (6.9). The control sites during this period showed pH values 'between' 6.7-7.3, indicating that most cassava mill locations had pH values higher than the control sites. Soil pH values decreased over the dry season, going from 6.2 to 7.5 with an average of 6.75±0.30 (Table 4.19). CDS18 (Swali) had the lowest pH (6.2), whereas CDS3 (Otuasega) had the highest pH (7.5), as seen in Figure 4.97. Control sites during the dry season showed pH values ranging from 5.5-6.6, with most cassava mill locations maintaining higher pH values compared to control sites. From the wet season (mean 7.32±0.24) to the dry season (mean 6.75±0.30), the seasonal variance for pH exhibited a declining trend. This steady decline throughout the majority of sampling sites is shown in Figure 4.97. Nevertheless, in both seasons, cassava mill locations maintained higher pH values than control sites, even with the seasonal decline. This pattern implies that increasing soil alkalinity may be a result of cassava processing operations.

4.3.1.3.2 Electrical Conductivity (EC)

During the wet season, electrical conductivity values ranged from 395-3563 µS/cm with a mean of 870.38±809.52 µS/cm (Table 4.20). As shown in Figure 4.98, CWS6 (Kpansia market Road 1) showed the highest EC value (3563 µS/cm), followed by CWS7 (Kpansia market Road 2) (3148 µS/cm). The lowest EC (395 µS/cm) was recorded at CWS24 (Yenizue – gene) location. Control sites during this period showed EC values between 265-518 µS/cm, with most cassava mill locations showing significantly higher EC values compared to control sites.EC values increased at a number of locations during the dry season, with a mean of 1222.38±1262.7 µS/cm and a range of 515-5121 µS/cm (Table 4.19). It is evident from Figure 4.98 that CDS6 (Kpansia market Road1) has the highest EC (5121 µS/cm), followed by CDS7(Kpansia market Road 2) (5110 µS/cm). The lowest value (515 µS/cm) was observed at CDS22. Control sites during this

period showed EC values between 295-568 µS/cm, with most cassava mill locations showing higher EC values than control sites. The seasonal variation revealed that EC values increased from wet season (mean 870.38±809.52 µS/cm) to dry season (mean 1222.38±1262.7 µS/cm). Figure 4.98 shows this increasing trend across most sampling locations. The Kpansia market Rd location consistently showed the highest EC values in both seasons, maintaining values higher than control sites. The seasonal increase in EC values suggests higher concentration of dissolved ions during the dry period, possibly due to accumulated effects of cassava processing activities and reduced dilution.

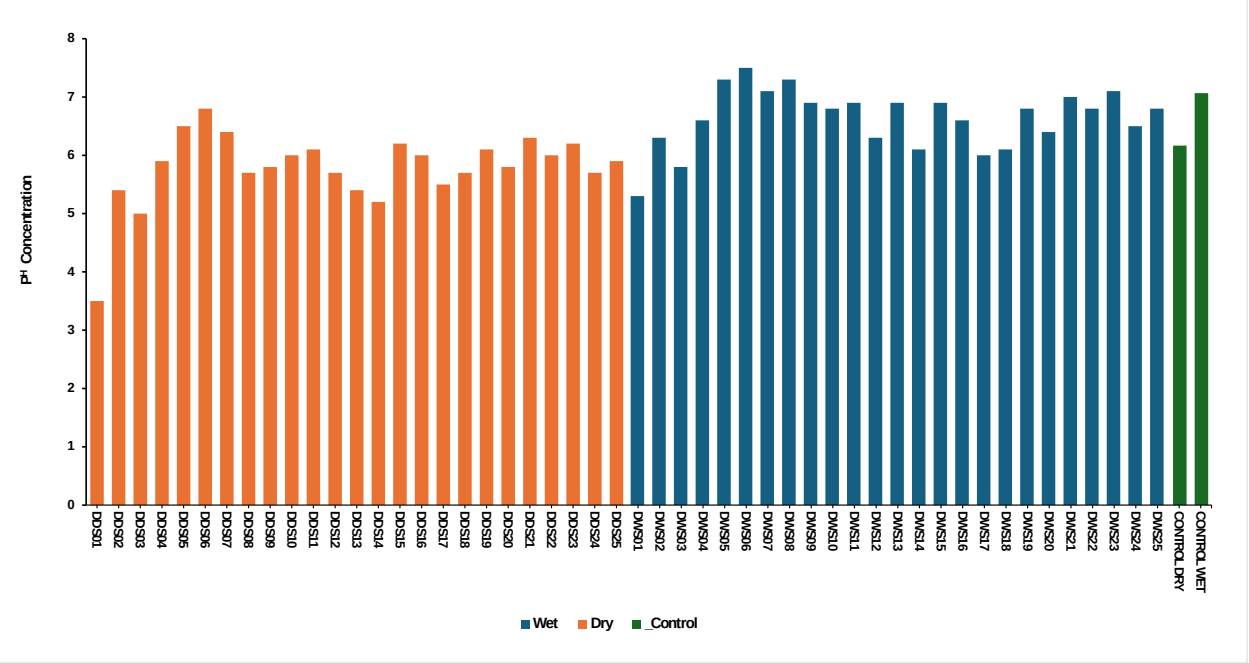

Figure 4. 93: Hydrogen Potential (P^H) concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

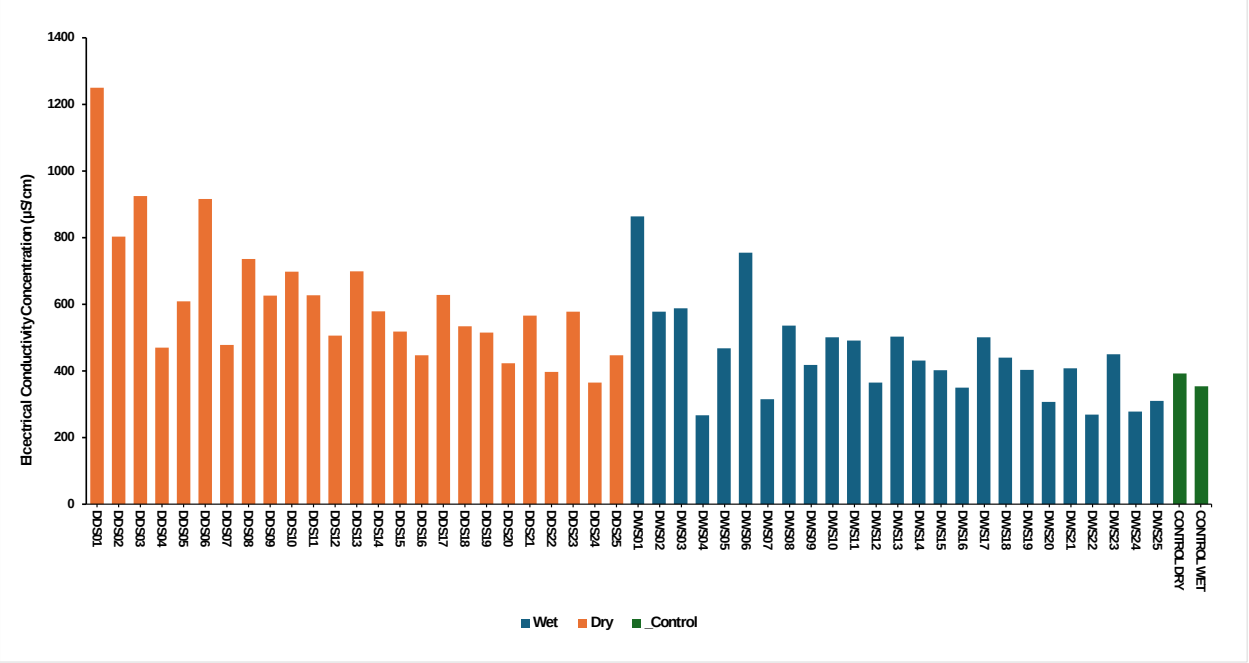

Figure 4. 94: Electrical Conductivity concentration in soil samples collected around dumpsites compared with control during the wet and dry seasons

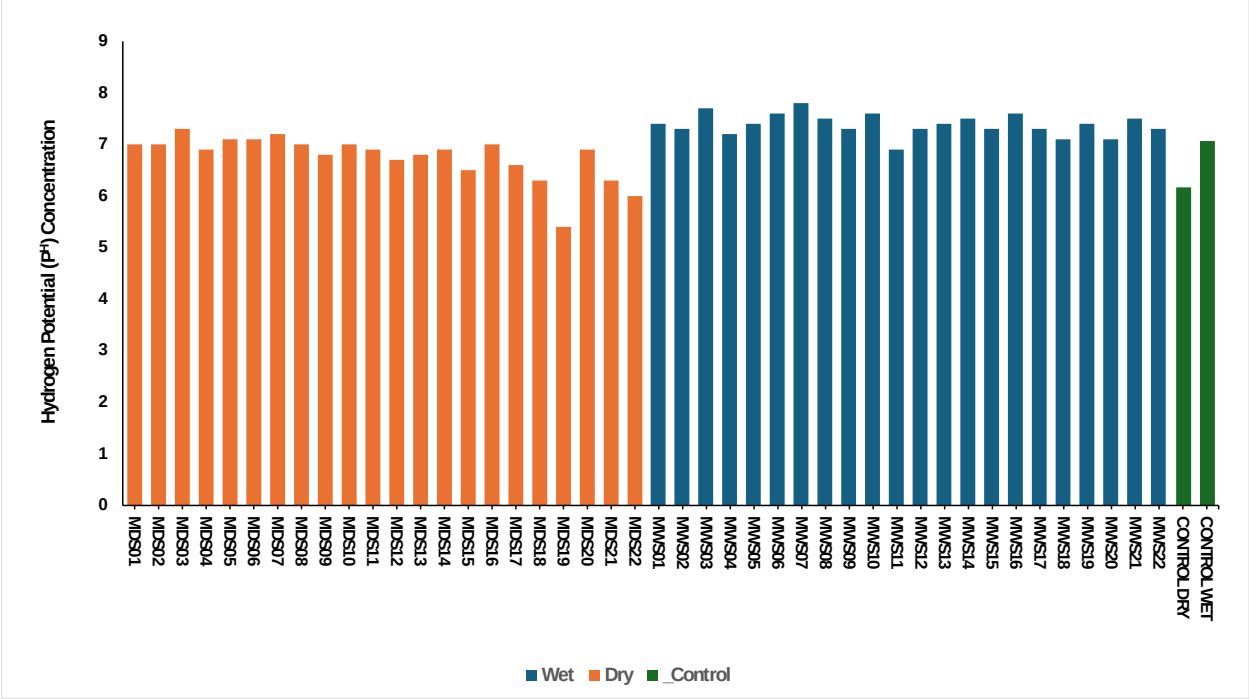

Figure 4. 95: Hydrogen Potential (P^H) concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

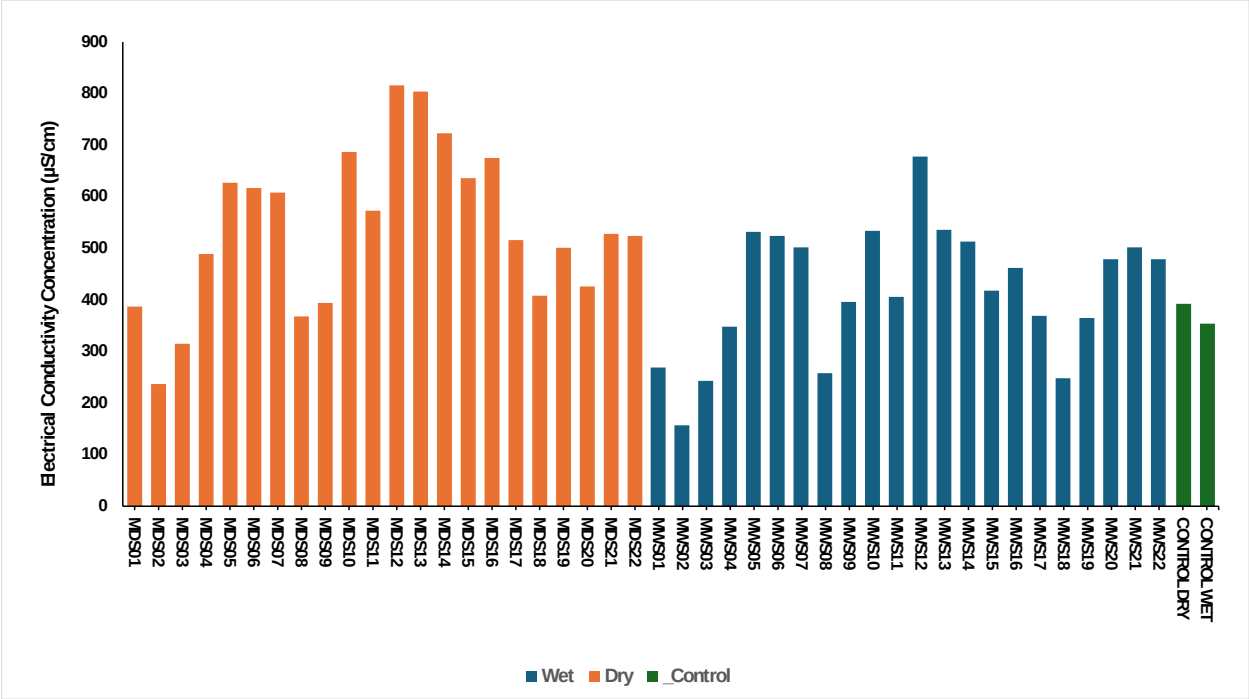

Figure 4. 96: Electrical Conductivity concentration in soil samples collected around mechanic workshops compared with control during the wet and dry seasons

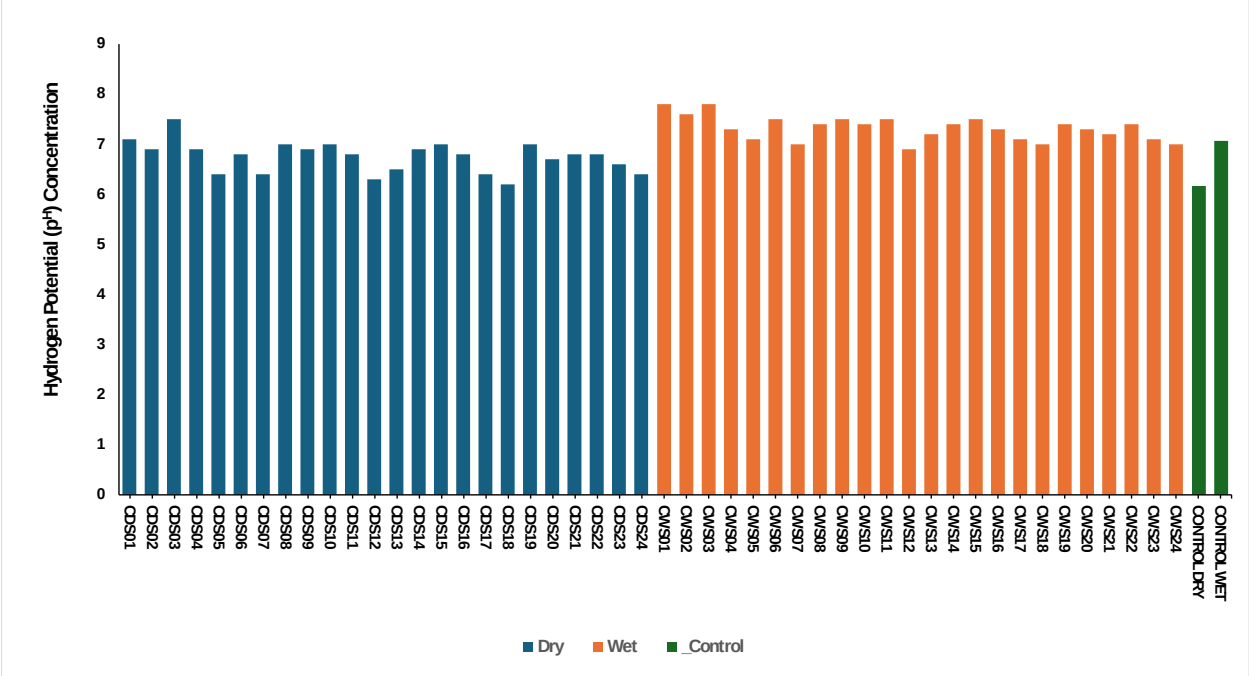

Figure 4. 97: Hydrogen Potential (P^H) concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

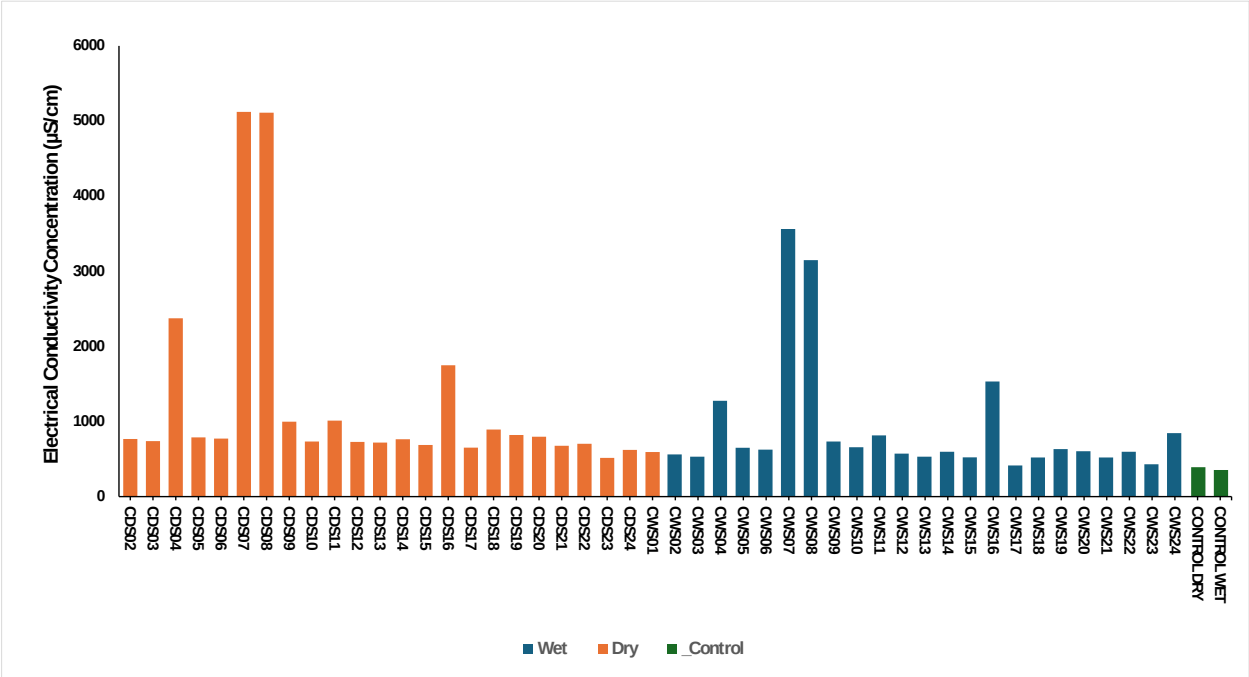

Figure 4. 98: Electrical conductivity concentration in soil samples collected around cassava mills compared with control during the wet and dry seasons

4.3.1.4 Physical Characteristics in Soils Around Crude Oil Spill Sites

Spills of crude oil can significantly alter the pH and EC of soil. Oil hydrocarbons have the ability to decompose into acidic byproducts, which could make the soil more acidic. Additionally, the oil itself and related salts have the potential to raise EC, which can result in microbial ecosystem changes, decreased plant growth, and soil degradation. Comprehending these alterations is essential for evaluating the ecological consequences of oil spills and creating efficient soil restoration plans.

4.3.1.4.1 Hydrogen Potential (pH)

Soil pH values at crude oil spill sites varied from 5.6 to 6.2 throughout the wet season, with an average of 5.93±0.2 (Table 4.20). Figure 4.99 illustrates that SWS2 (Agba Otuegwee 2) had the highest pH (6.2), whereas SWS4 (Ibelebiri 1) had the lowest pH (5.6). The pH values at the control sites during this time ranged from 6.7 to 7.3, suggesting that the majority of the crude oil spill sites had lower pH values than the control sites. Soil pH values decreased further during the dry season, with a mean of 4.13±0.15 and a range of 4.0 to 4.4 (Table 4.19). As shown in Figure 4.99, SDS2 & SDS5 (Agba Otuegwee 2 & Ibelebiri 2) had the lowest pH (4.0), whereas SDS6 (Ibelebiri 3) had the greatest pH (4.4). The majority of oil spill areas had lower pH values than control sites, which ranged from 5.5 to 6.6 during the dry season indicating high acidity. There was a downward tendency in the seasonal variation for pH from the wet season (mean 5.93) to the dry season (mean 4.4). This steady decline is shown in Figure 4.99 for the majority of sampling sites. In both seasons, the pH values at Agba Otuegwee 2 location (SWS2/SDS2) were consistently the lowest, remaining below those at the control locations. This pattern raises the possibility that rising soil acidity is caused by crude oil pollution.

4.3.1.4.2 Electrical Conductivity (EC)

The mean electrical conductivity during the wet season was 113±26.62 µS/cm, with a range of 74-152 µS/cm (Table 4.20). Figure 4.100 illustrates that SWS4 (Ibelebiri 1) had the highest EC value (152 µS/cm), which was followed by SWS2 (Agba -Otuegwe 2) (124 µS/cm). The SWS3

site has the lowest EC (74 µS/cm). All crude oil spill locations had lower EC values than control sites during this time period, with control sites exhibiting EC values ranging from 265 to 518 µS/cm.In the dry season, EC values showed an increase, ranging from 106-230 µS/cm with a mean of 156.83±43.39 µS/cm (Table 4.19). Figure 4.100 clearly illustrates that SDS4 (Ibelebiri 1) recorded the highest EC (230 µS/cm), followed by SDS2(Agba -Otuegwe 2) (183 µS/cm). The lowest value (106 µS/cm) was observed at SDS3. Control sites during this period showed EC values between 295-568 µS/cm, with all oil spill locations showing lower EC values than control sites. From the wet season mean (113 µS/cm) to the dry season mean (156 µS/cm), the seasonal fluctuation showed that EC values rose. The majority of the sampling locations exhibit this growing trend, as seen in Figure 4.100. Throughout both seasons, Ibelebiri 1 site continuously displayed the highest EC values although they were below those of control sites. The seasonal rise in EC values suggests that there were more dissolved ions during the dry period, most likely because of higher hydrocarbon pollutant concentrations and less dilution effects.

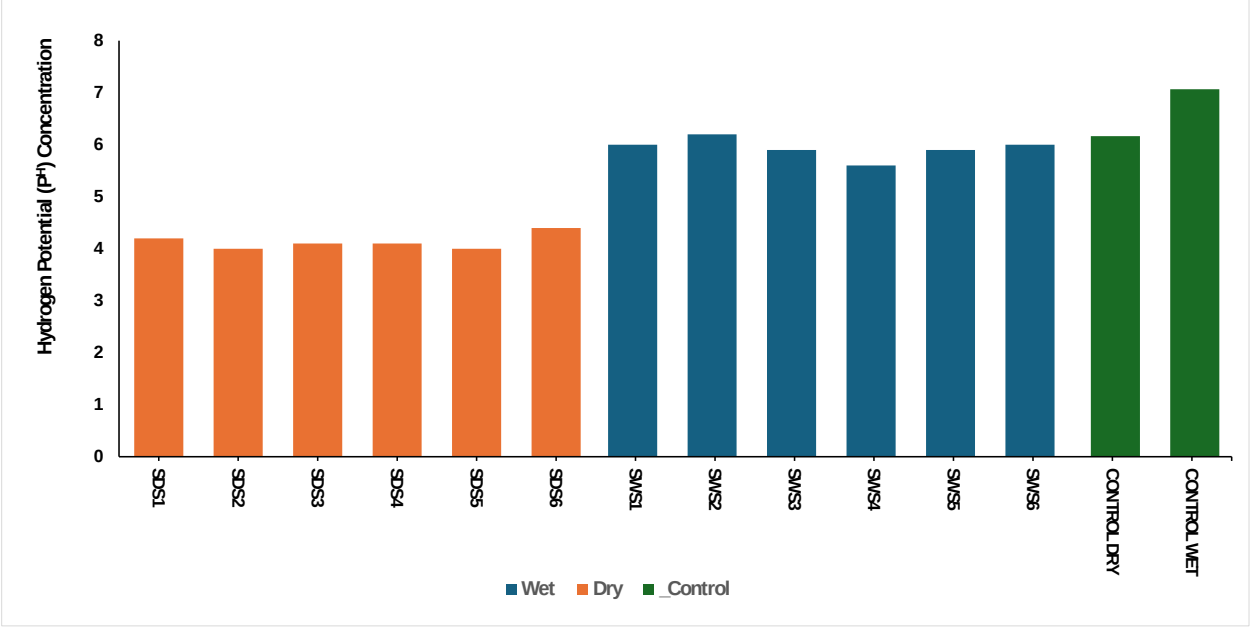

Figure 4. 99: Hydrogen Potential (P^H) concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

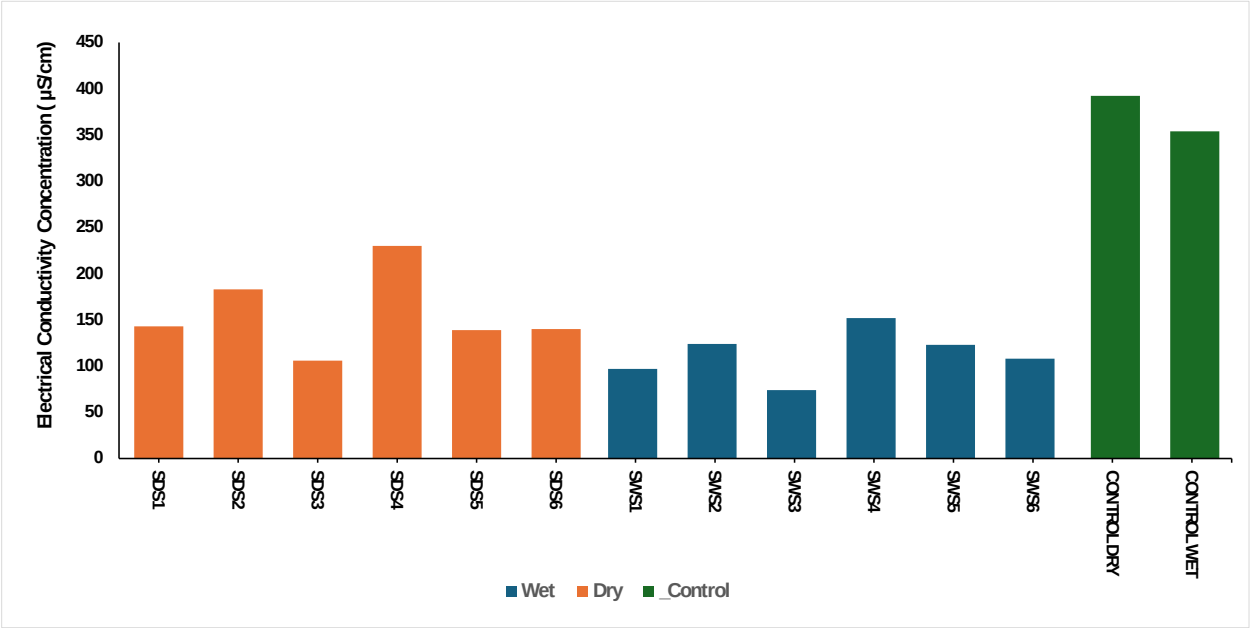

Figure 4. 100: Electrical Conductivity concentration in soil samples collected around crude oils spill sites compared with control during the wet and dry seasons

4.3.2 Physical Characteristics in Groundwater

The physical properties of groundwater, such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity, and Total Suspended Solids (TSS), serve as critical indicators of its quality and appropriateness for diverse applications. Monitoring these properties is vital for evaluating groundwater health, managing aquifers, and ensuring the water is safe for consumption, irrigation, and industrial use, thereby informing remediation and management strategies.

4.3.2.1 Physical Characteristics in Groundwater Around Dumpsites

The physical properties of groundwater, such as pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and total suspended solids (TSS), provide crucial indicators of environmental health and water quality, particularly in areas surrounding dumpsites. This section will explore how physical properties in groundwater are influenced by the presence of dumpsites, focusing on the data collected during both wet and dry seasons to elucidate seasonal variations and their implications.

4.3.2.1.1 Hydrogen Potential (pH)

Groundwater pH levels around dumpsites varied from 5.2 to 6.9 throughout the rainy season, with an average of 6.238±0.542 (Table 4.23). As illustrated in Figure 4.101, DWGW4 (Amarata BH1) had the highest pH (6.9) and DWGW7 (Kingdom RD Swali) had the lowest (5.2). The values were generally within WHO 2011 and NSDWQ 2007 permissible limits (6.5-8.5), though some locations showed slightly acidic conditions. With a mean of 5.463±0.472 and a range of 5.0 to 6.2, pH readings marginally declined over the dry season (Table 4.22). The majority of sites displayed pH values beyond the range of acceptable limits at this time, indicating more acidic circumstances, as shown in Figure 4.101. DDGW2 (Igbogene) had the lowest pH (5.0), and DDGW4 (Amarata BH1) had the highest pH (6.2). As illustrated in Figure 4.101, seasonal variation in pH clearly indicated a declining tendency from the wet season (mean 6.238±0.542)

to the dry season (mean 5.463±0.472). This suggests that the dry season will be more acidic, most likely as a result of concentrated leachate effects and less rainfall-induced dilution.

4.3.2.1.2 Electrical Conductivity (EC)

The mean EC value during the wet season was 194.125±24.32 µS/cm, with a range of 149-230 µS/cm (Table 4.21). All readings were far below the 1000 µS/cm WHO 2011 and NSDWQ 2007 allowable limit, as seen in Figure 4.102. At DWGW6 (Akenfa 1), the maximum EC was measured at 230 µS/cm.EC values increased somewhat during the dry season, ranging from 182-241 µS/cm with a mean of 211.5±18.15 µS/cm (Table 4.31), but they were still below allowable limits. As may be seen in Figure 4.102, DDGW6 (Akenfa 1), has the highest EC (241 µS/cm). Seasonal fluctuations as demonstrated in Figure 4.102 shows that the EC increased from the wet season (mean 194.125±24.32 µS/cm) to the dry season (mean 211.5±18.15 µS/cm). Because of less dilution effects, this rise indicates a larger concentration of dissolved ions during the dry period.

4.3.2.1.3 Total Dissolved Solids (TDS)

The total dissolved solids (TDS) readings during the wet season varied from 65 to 230 mg/L, with a mean of 129.625±64.049 mg/L (Table 4.21). These levels were significantly lower than the allowed WHO 2011 and NSDWQ 2007 permissible limit of 500 mg/L. At DWGW3 (Azikoro), the TDS concentration was measured to be the highest (230 mg/L), as can be seen in Figure 4.103.

TDS values increased throughout the dry season, reaching 85-243 mg/L with a mean of 147±60.18 mg/L (Table 4.31). However, these values remained within permissible limits throughout the dry season. The highest total dissolved solids (TDS) was found in DDGW3 (Azikoro), as shown in Figure 4.103 (243 mg/L).As depicted in Figure 4.103, the seasonal variation demonstrates that the total dissolved solids (TDS) values rose from the wet season (mean 129.625±64.049 mg/L) to the dry season (mean 147±60.18 mg/L), exhibiting a trend that

is comparable to that of the EC. The higher concentration of dissolved chemicals that occurred during the dry period is reflected in this, as well.

4.3.2.1.4 Turbidity

During the wet season, the values of turbidity varied from 0.8 to 2.3 NTU, with a mean of 1.525±0.609 NTU (Table 4.21). Most of the results were lower than the WHO 2011 and NSDWQ 2007 limit of 5 NTU, as can be seen in Figure 4.104. At DWGW6 (Akenfa 1), the turbidity was measured to be at its highest value (2.3 NTU). Although turbidity rose during the dry season, with a mean of 1.513±0.939 NTU (Table 4.31) and values ranging from 0.5 to 3.1 NTU, it was still within WHO and NSDWQ allowable limit. DDGW2 (Igbogene) recorded the maximum turbidity (3.1 NTU), as seen in Figure 4.104. Figure 4.104 illustrates slight seasonal variation in turbidity between wet season (mean 1.525±0.609 NTU) and dry season (mean 1.513±0.939 NTU). While maximum values were higher in the dry season, average values remained relatively stable across seasons.

4.3.2.1.1 Total Suspended Solids (TSS)

During the wet season, TSS values ranged from 0.4-1.0 mg/L with a mean of 0.663±0.213 mg/L (Table 4.30). As shown in Figure 4.105, the highest TSS was recorded at DWGW2 (Igbogene). In the dry season, TSS values decreased slightly to 0.3-0.7 mg/L with a mean of 0.475±0.128 mg/L (Table 4.21). Figure 4.105 illustrates that DDGW6 (Akenfa 1), showed the highest TSS (0.7 mg/L). Figure 4.105 showing seasonal variation demonstrates TSS values showing a decreasing trend from wet season (mean 0.65±0.45 mg/L) to dry season (mean 0.48±0.32 mg/L). This decrease could be attributed to reduced surface runoff and particle transport during the dry season.

Figure 4. 101: Hydrogen Potential (P^H) concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

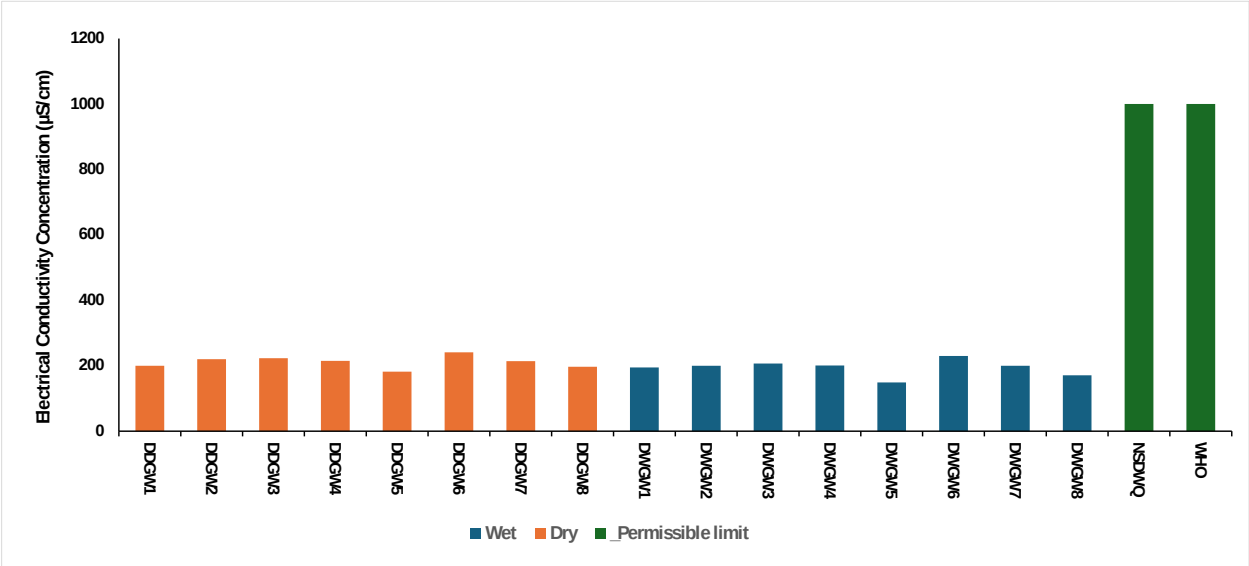

Figure 4. 102: Electrical Conductivity concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

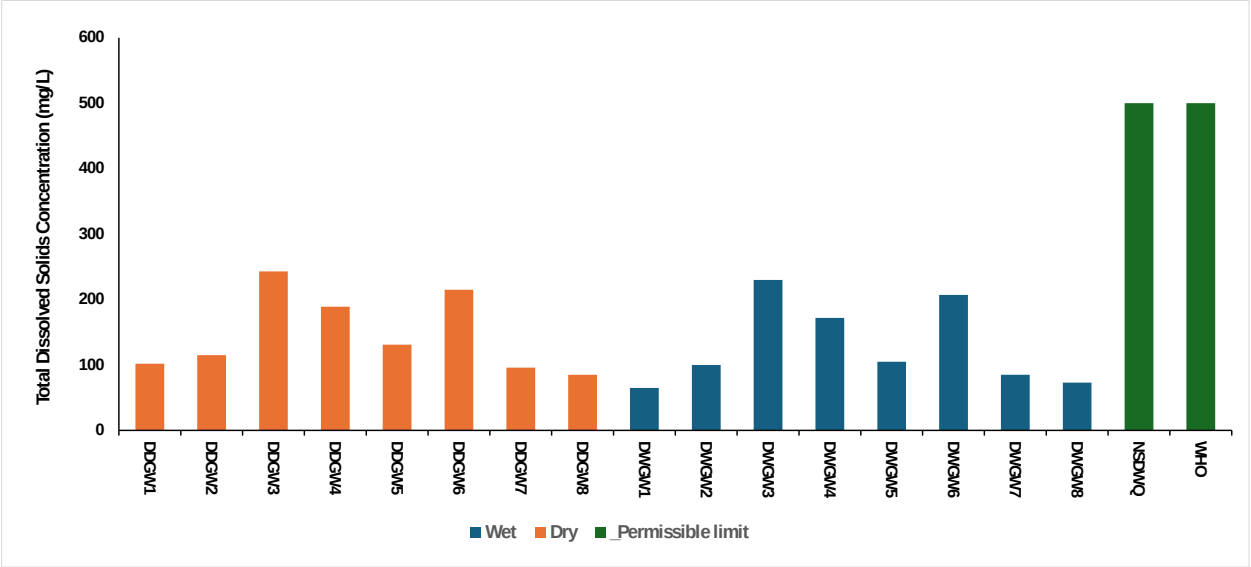

Figure 4. 103: Total Dissolved Solids concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

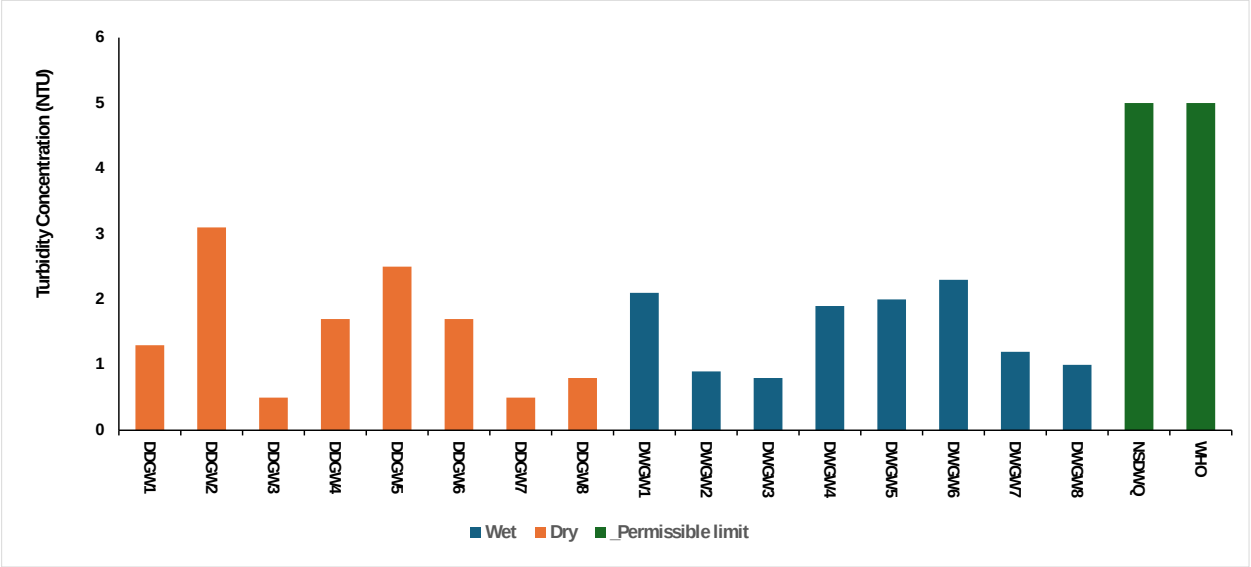

Figure 4. 104: Turbidity concentration in groundwater samples collected around dumpsites compared with permissible limit during the wet and dry seasons

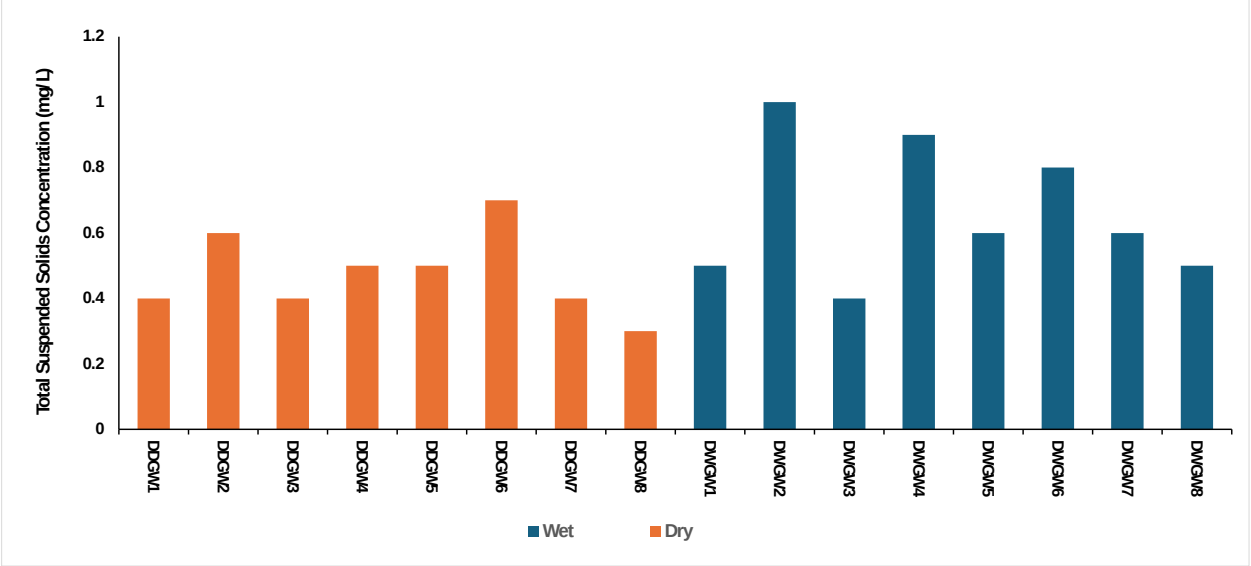

Figure 4. 105: Total Suspended Solids concentration in groundwater samples collected around dumpsites during the wet and dry seasons

4.3.2.2 Physical Characteristics in Groundwater Around Mechanic Workshops

Mechanic workshops, which are used for automobile maintenance and repairs, frequently contribute to the pollution of groundwater. Waste materials from mechanic operations can seep into the groundwater in these locations, changing its physical characteristics, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and TSS. This section will examine how mechanic workshops impact the physical properties of groundwater, offering insights derived from data gathered during both the wet and dry seasons to emphasize seasonal fluctuations and their consequences for environmental preservation and water management. Figures 4.106-4.110 shows physical characteristics of groundwater around mechanic workshop during wet and dry compared with standards.

4.3.2.2.1 Hydrogen Potential (pH)

During the wet season, groundwater pH values around mechanic workshops ranged from 5.9 to 6.9 with a mean of 6.42±0.326 (Table 4.23). As shown in Figure 4.106, the highest pH (6.9) was recorded at MWGW7 (Kpansia Milford Okilo Road) and MWGW9 (Yenizue-Gene Erepa Road), while the lowest pH (5.9) was observed at MWGW4 (Mechanic Village Imiringi Road BH4). Most locations had values within or close to WHO 2011 and NSDWQ 2007 permissible limits (6.5-8.5).

The pH values decreased during the dry season, with a mean of 5.72±0.503 and a range of 5.0 to 6.4 (Table 4.23). As shown in Figure 4.106, MDGW3 (Mechanic Village Imiringi Road BH3) had the lowest pH (5.0), whereas MDGW7 (Kpansia Milford Okilo Road) had the highest pH (6.4). During this time, pH values were below the allowable threshold in many places. Figure 4.106 demonstrates a clear decreasing trend in pH from wet season (mean 6.42±0.326) to dry season (mean 5.72±0.503), indicating more acidic conditions during the dry season. This pattern suggests increased concentration of acidic substances from workshop activities during periods of reduced rainfall.

4.3.2.2.2 Electrical Conductivity (EC)

The electrical conductivity (EC) values throughout the wet season varied from 215 to 693 µS/cm, with a mean of 324.2±148.29 µS/cm, as shown in Table 4.30. Figure 4.107 demonstrates that all of the readings were lower than the permitted limit of 1000 µS/cm that is set by the WHO 2011 and the NSDWQ 2007. The EC that was measured at MWGW8 (Yenizue-Epie Septex Road) was the highest measuring (693 µS/cm). Although they remained within allowable limits, EC values increased somewhat during the dry season, ranging from 225 to 720 µS/cm with a mean of 340.8±152.77 µS/cm (Table 4.23). MDGW8 (Yenizue-Epie Septex Road) has the highest EC (720 µS/cm), as seen in Figure 4.107. Figure 4.107 shows an increasing trend in EC from wet season (mean 324.2±148.29 µS/cm) to dry season (mean 340.8±152.77 µS/cm), indicating higher concentration of dissolved ions during the dry period.

4.3.2.2.3 Total Dissolved Solids (TDS)

The total dissolved solids (TDS) readings during the wet season varied from 100 to 346 mg/L, with a mean of 176.5±72.24 mg/L (Table 4.23). These levels were significantly lower than the WHO 2011 and NSDWQ 2007 permissible limit of 500 mg/L. According to Figure 4.108, the TDS concentration that was measured to be the highest was 346 mg/L at MWGW8 (Yenizue-Epie Septex Road). TDS values increased during the dry season, with a mean of 194.3±80.11 mg/L and a range that went from 117 to 385 mg/L (Table 4.23). However, these values remained within permissible limits throughout the dry season. This is demonstrated in Figure 4.108, which shows that MDGW8 (Yenizue-Epie Septex Road) had the greatest TDS (385 mg/L). Figure 4.108 demonstrates TDS values increased from wet season (mean 176.5±72.24 mg/L) to dry season (mean 194.3±80.11 mg/L), following a similar pattern to EC. This reflects increased concentration of dissolved substances during the dry period.

4.3.2.2.4 Turbidity

The turbidity measurements displayed a range of 0.2-3.7 NTU throughout the wet season, with a mean of 1.5±1.249 NTU, as indicated in Table 4.23. In accordance with the data presented in

Figure 4.109, the values were lower than the WHO 2011 and NSDWQ 2007 threshold of 5 NTU. The turbidity that was measured at MWGW2 (Mechanic Village Imiringi Road BH2) was the highest, coming in at 3.7 NTU.During the dry season, the turbidity levels exhibited comparable values, ranging from 0.2 to 3.9 NTU, with a mean of 1.8±1.411 NTU (Table 4.23). These values stayed within the acceptable limits within the prescribed parameters. The maximum turbidity (3.9 NTU) was observed by MDGW2 (Mechanic Village Imiringi Road BH2), as seen in Figure 4.109.

Figure 4.109 illustrates a slight increase in turbidity from wet season (mean 1.5±1.249 NTU) to dry season (mean 1.8±1.411 NTU), though both seasons maintained values within acceptable limits.

4.3.2.2.5 Total Suspended Solids (TSS)

The total soluble solids (TSS) values during the wet season varied from 0.1 to 5.3 mg/L, with a mean of 1.15±1.477 mg/L, as shown in Table 4.23. At MWGW2 (Mechanic Village Imiringi Road BH2), the TSS concentration was measured to be the highest (5.3 mg/L), as can be shown in Figure 4.110. The TSS readings during the dry season exhibited comparable ranges, ranging from 0.1 to 3.2 mg/L, with a mean of 0.64±0.909 mg/L, as indicated in Table 4.23. As shown in Figure 4.110, MDGW2 (Mechanic Village Imiringi Road BH2) had the greatest total soluble solids (TSS) concentration (3.2 mg/L). From the wet season (mean 1.15±1.477 mg/L) to the dry season (mean 0.64±0.909 mg/L), according to Figure 4.110, the total soluble solids (TSS) values exhibited a modest rise. During the dry season, concentrated workplace effluents may be responsible for this slight rise due to their increased concentration.

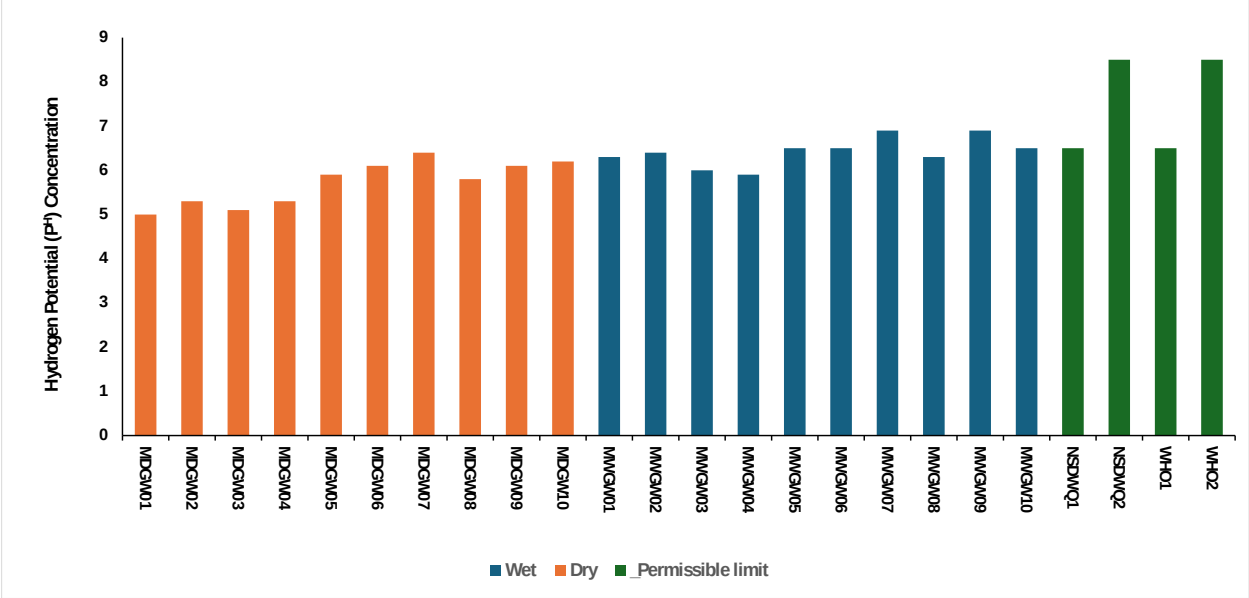

Figure 4. 106: Hydrogen Potential concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

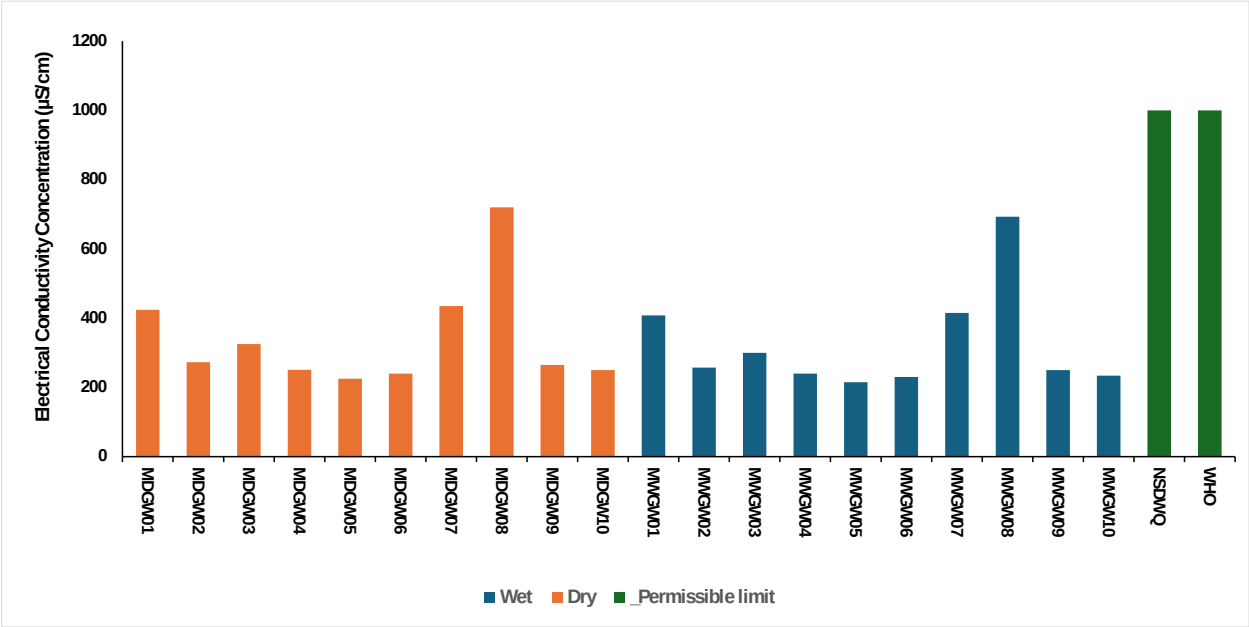

Figure 4. 107: Electrical Conductivity concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

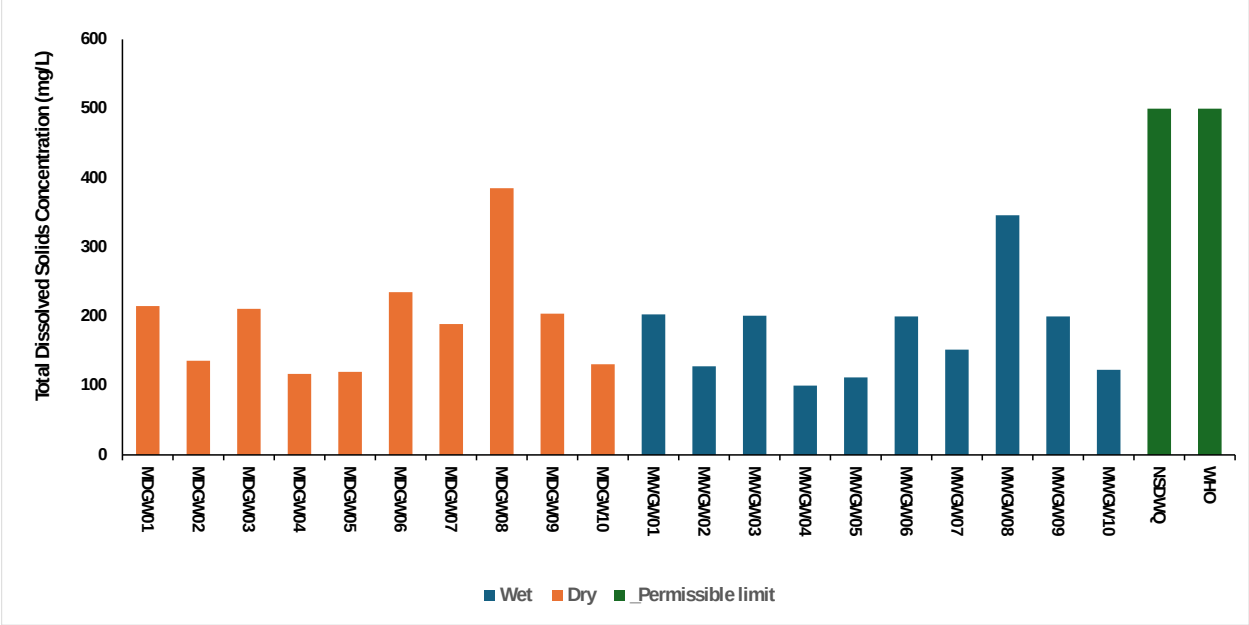

Figure 4. 108: Total Dissolved Solids concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

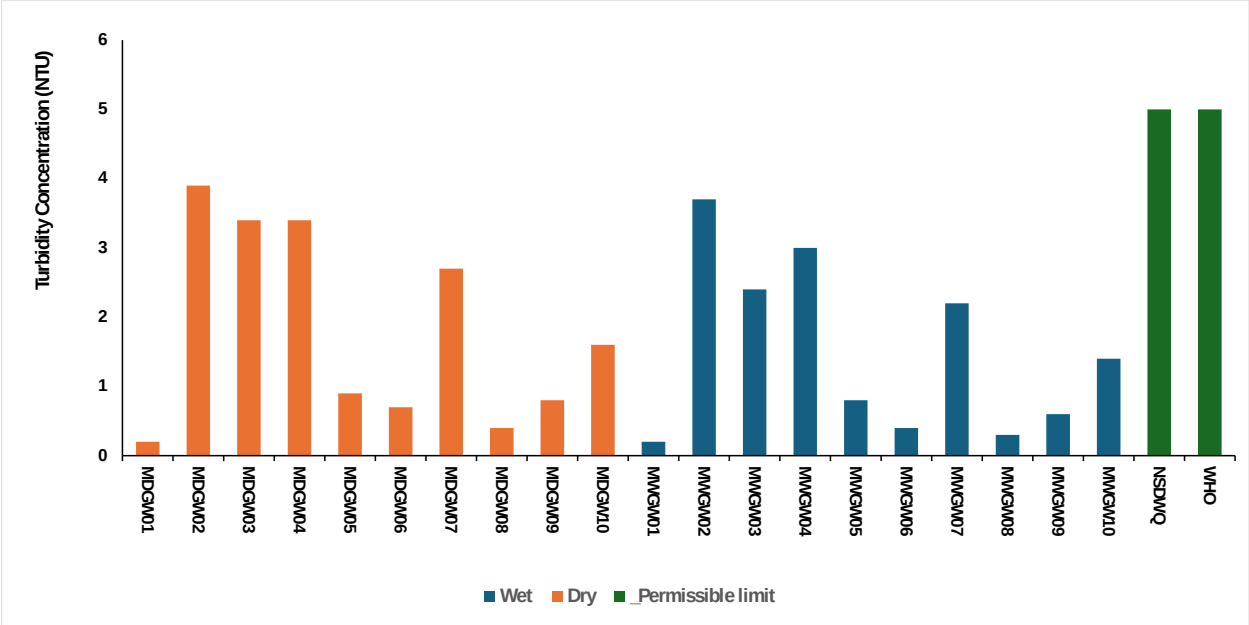

Figure 4. 109: Turbidity concentration in groundwater samples collected around mechanic workshops compared with permissible limit during the wet and dry seasons

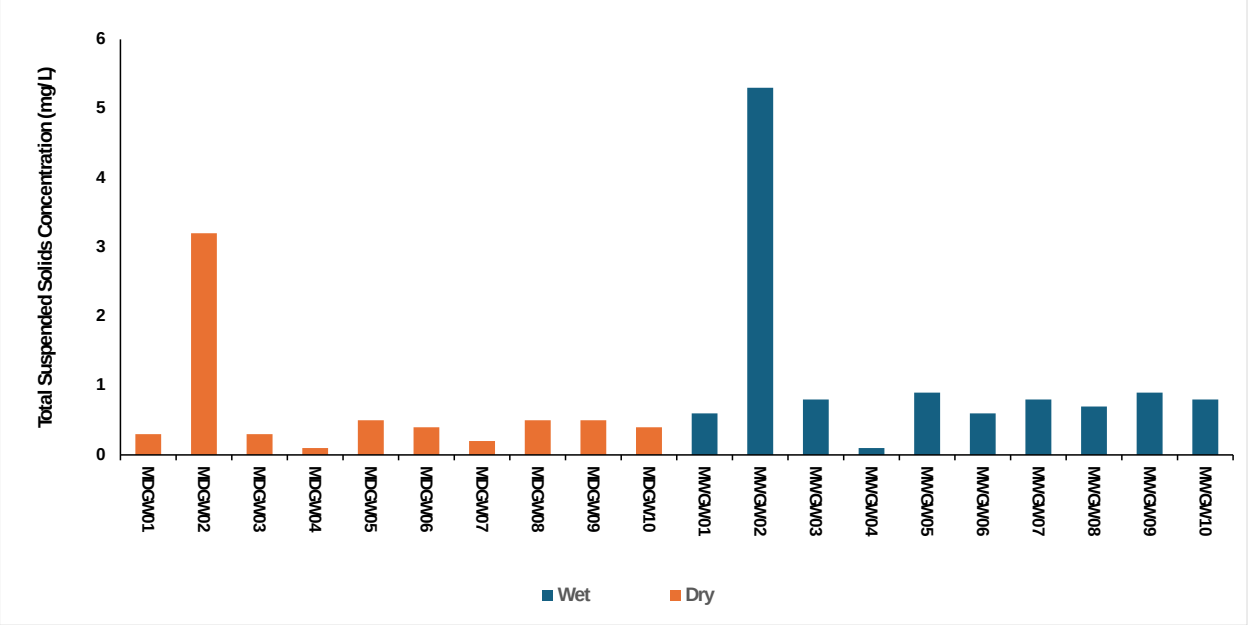

Figure 4. 110: Total Suspended Solids concentration in groundwater samples collected around mechanic workshops during the wet and dry seasons

4.3.2.3 Physical Characteristics in Groundwater Around Cassava Mill

Groundwater quality can be greatly impacted by cassava mills, which convert cassava roots into a variety of products like gari, fufu, and starch. This is because the milling process uses chemicals, disposes of organic waste, and produces processing residues. By interacting with the environment, mill waste can cause significant changes in the physical characteristics of groundwater in these areas, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and TSS. The assessment of possible groundwater contamination, which could impact nearby communities that depend on it for drinking, cooking, and farming, requires an understanding of these changes. Figures 4.111-4.115 shows physical characteristics of groundwater around cassava mill during wet and dry compared with standards.

4.3.2.3.1 Hydrogen Potential (pH)

During the wet season, groundwater pH values around cassava mills ranged from 6.1 to 6.9 with a mean of 6.378±0.249 (Table 4.23). As shown in Figure 4.111, the highest pH (6.9) was recorded at CWGW4 (Igbogene BH1) and CWGW7 (Swali), while the lowest pH (6.1) was observed at CWGW2 (Opolo Big Brother Road). Most locations showed values slightly below WHO 2011 and NSDWQ 2007 permissible limits (6.5-8.5). pH levels dropped during the dry season, with a mean of 5.811±0.247 and a range of 5.3 to 6.1 (Table 4.31). As shown in Figure 4.111, CDGW3 (Opolo Big Brother Road) had the lowest pH (5.3), whereas CDGW9 (Onopa) had the highest pH (6.1). During this time, the pH levels at every place were below the allowable limits. The pH clearly shows a downward trend from the rainy season (mean 6.378±0.249) to the dry season (mean 5.811±0.247) in Figure 4.111, suggesting that the dry season is more acidic. Concentrated organic acids from processing cassava during dry spells may be the cause of this pattern.

4.3.2.3.2 Electrical Conductivity (EC)

The electrical conductivity (EC) values throughout the wet season varied between 343-570 µS/cm, with a mean of 460.33±75.9 µS/cm, as indicated in Table 4.23. Figure 4.112 demonstrates that all of the readings were lower than the permitted limit of 1000 µS/cm that is set by the WHO 2011 and the NSDWQ 2007. The EC that was measured at CWGW1 (Otuasega) was the highest, measuring 570 µS/cm. Although the electrical conductivity (EC) values increased during the dry season, with a range of 425-625 µS/cm and a mean of 509.4±71.97 µS/cm (Table 4.23), they remained below the allowed limits. It was shown in Figure 4.112 that CDGW5 (Igbogene BH2) recorded the highest EC, which was 625 µS/cm.The electrical conductivity (EC) of the water is shown to be increasing from the wet season (mean 460.33±75.9 µS/cm) to the dry season (mean 509.4±71.97 µS/cm) in Figure 4.112, which indicates that the concentration of dissolved ions is higher during the dry time period.

4.3.2.3.3 Total Dissolved Solids (TDS)

There was a wide range of TDS levels during the wet season, with a mean of 221.667±39.818 mg/L (Table 4.23). These values were significantly lower than the WHO 2011 and NSDWQ 2007 allowed limit of 500 mg/L. The highest total dissolved solids (TDS) (300 mg/L) was measured at CWGW1 (Otuasega), as can be seen in Figure 4.113. The Total Dissolved Solids (TDS) levels varied during the dry season, with a mean of 232.3±39.85 mg/L and a range of 162-311 mg/L (Table 4.23). However, these values remained within the permitted limits. As shown in Figure 4.113, CDGW 6 (Agbura) exhibited the highest TDS level, which was 311 mg/L. Figure 4.113 demonstrates TDS values increased from wet season (mean 221.667±39.818 mg/L) to dry season (mean 232.3±39.85 mg/L), following a similar pattern to EC. This reflects increased concentration of dissolved substances during the dry period.

4.3.2.3.4 Turbidity

During the wet season, turbidity values ranged from 0.1-0.5 NTU with a mean of 0.233±0.141 NTU (Table 4.23). As shown in Figure 4.114, all values were well below the WHO 2011 and

NSDWQ 2007 limit of 5 NTU. The highest turbidity was recorded at CWGW1 (Otuasega). The dry season exhibited a decrease in turbidity, with values ranging from 0.01-0.2 NTU, with a mean of 0.083±0.078 NTU (Table 4.23). These values were well within the allowed limits throughout the dry season. Figure 4.114 demonstrates that CDGW1 (Otuasega) had the greatest recorded turbidity, which was 0.2 NTU). As depicted in Figure 4.114, the turbidity decreases from the rainy season (mean 0.233±0.141 NTU) to the dry season (mean 0.083±0.078 NTU), indicating a decrease in the amount of suspended particles during the dry season.

4.3.2.3.5 Total Suspended Solids (TSS)

The total soluble solids (TSS) values during the wet season varied from 0.1 to 0.7 mg/L, with a mean of 0.422±0.179 mg/L, as shown in Table 4.23. At CWGW1 (Otuasega), the TSS concentration was measured to be the highest (0.7 mg/L), as shown in Figure 4.115. Table 4.23 shows that during the dry season, total soluble solids (TSS) values declined to 0.01-0.3 mg/L, with a mean of 0.083±0.078 mg/L. In Figure 4.115, it is shown that CDGW1 (Otuasega), and CDGW2 (Opolo Big Brother Road) had the greatest total soluble solids (TSS) levels (0.3 mg/L).The values of total suspended solids (TSS) dropped from the wet season (mean 0.233±0.141 mg/L) to the dry season (mean 0.083±0.078 mg/L), as depicted in Figure 4.115. It is possible that this drop is because, during the dry season, there is less surface runoff and less movement of particle matter.

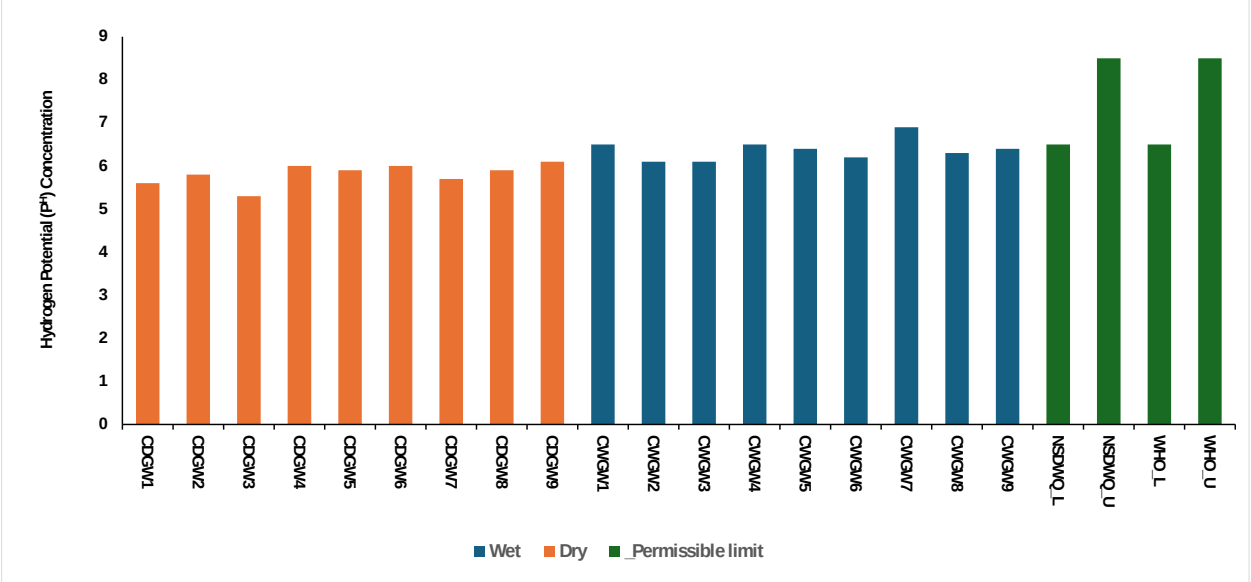

Figure 4. 111: Hydrogen Potential (P^H) concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

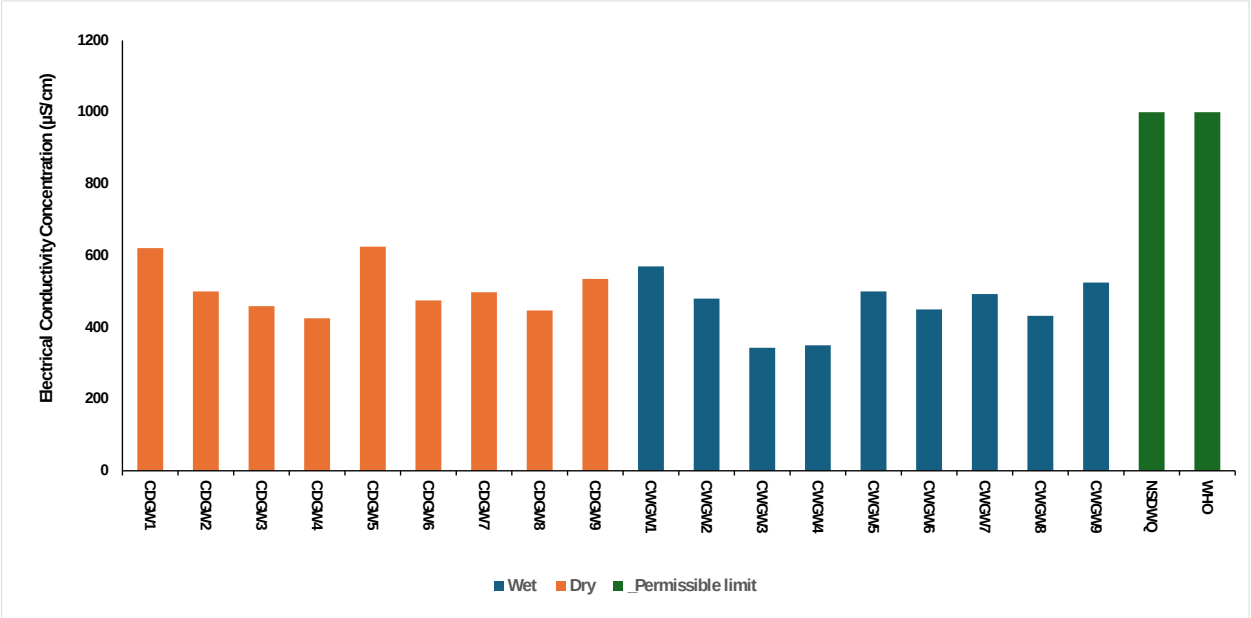

Figure 4. 112: Electrical Conductivity concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

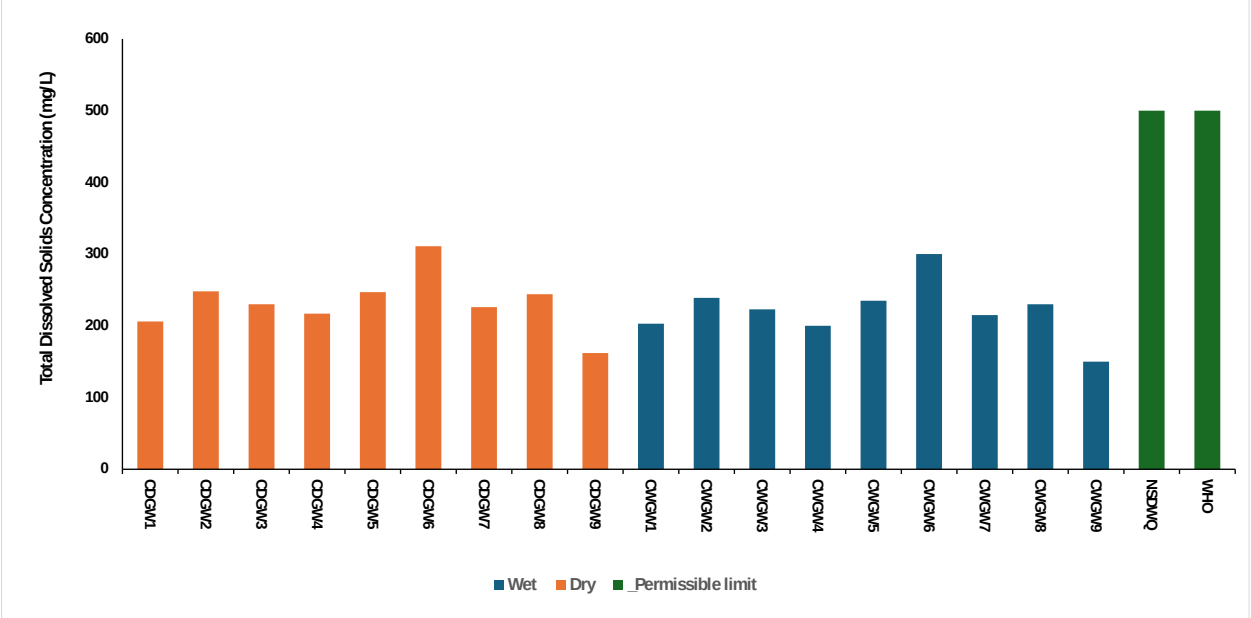

Figure 4. 113: Total Dissolved Solids concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

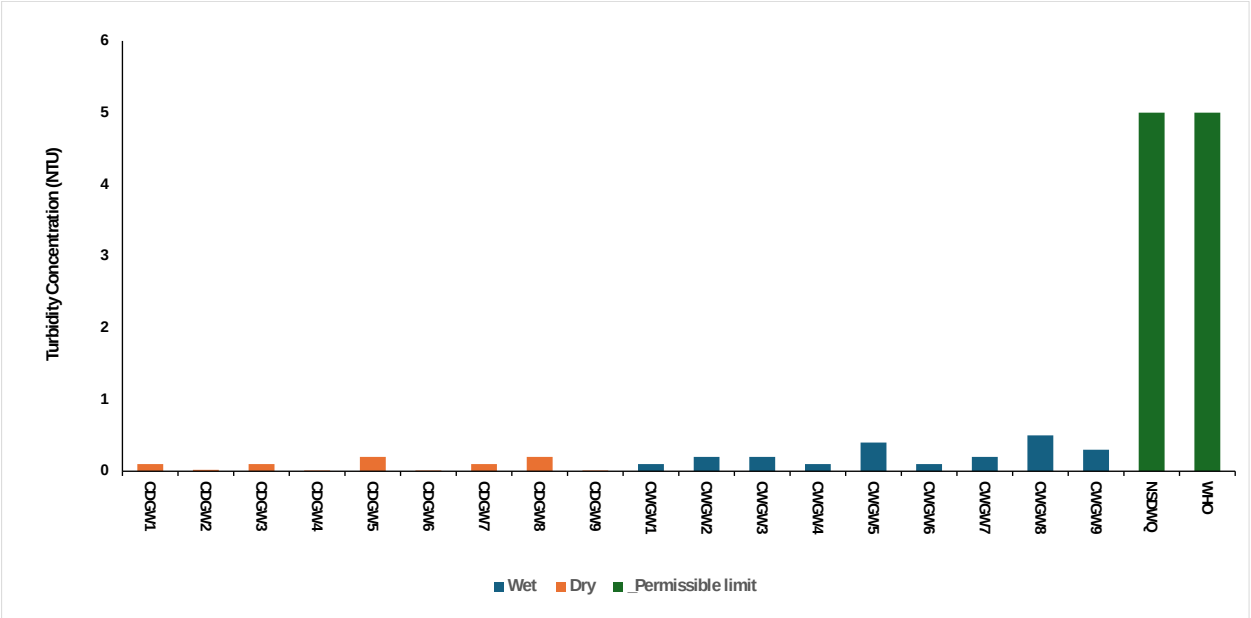

Figure 4. 114: Turbidity concentration in groundwater samples collected around cassava mills compared with permissible limit during the wet and dry seasons

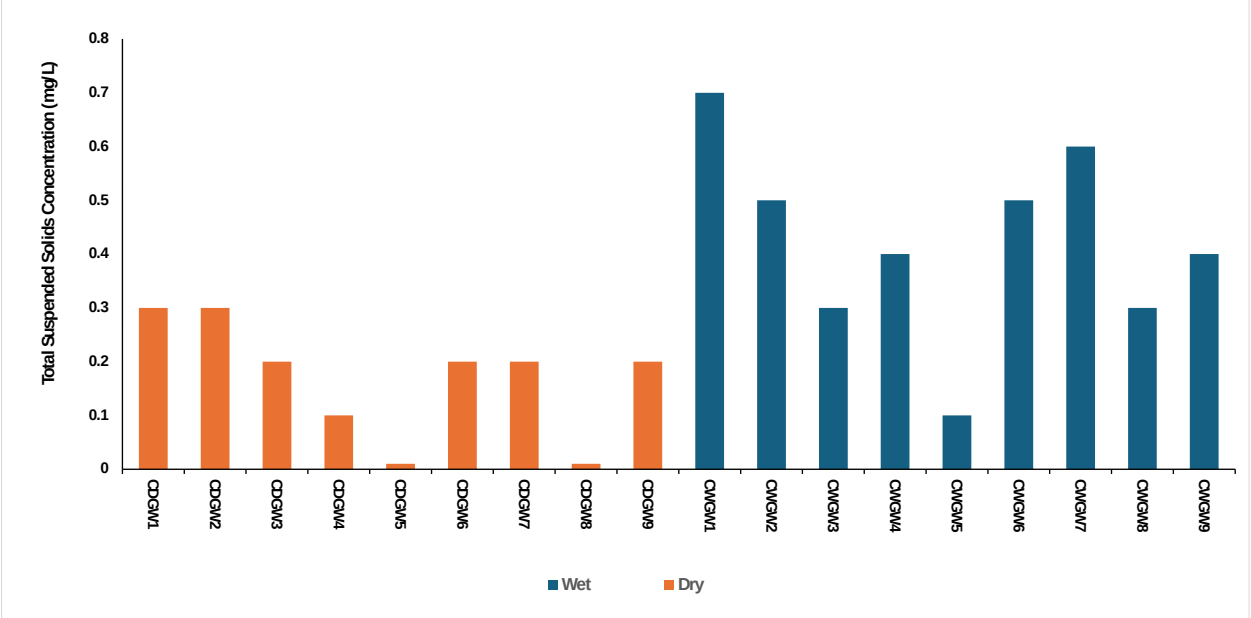

Figure 4. 115: Total Suspended Solids concentration in groundwater samples collected around cassava mills during the wet and dry seasons

4.3.2.4 Physical Characteristics in Groundwwater Around Crude Oil Spill Sites

Groundwater quality is seriously threatened by crude oil spills, whether they are the result of pipeline breaks, unintentional leaks, or other oil-related activities, because they introduce hydrocarbons and other hazardous materials. In these impacted locations, the presence of oil and its byproducts can significantly change the physical characteristics of groundwater, such as pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and total suspended solids (TSS). Figures 4.116-4.120 shows physical characteristics of groundwater around crude oil spill sites during wet and dry compared with standards.

4.3.2.4.1 Hydrogen Potential (pH)

During the wet season, groundwater pH values around crude oil spill sites ranged from 5.3 to 6.1 with a mean of 5.7±0.566 (Table 4.23). As shown in Figure 4.116, the highest pH (6.1) was recorded at SWGW1 (Agba -Otuegwe), while the lowest pH (5.3) was observed at SWGW2 (Ibelebiri). All sampling locations showed values significantly below WHO 2011 and NSDWQ 2007 permissible limits (6.5-8.5), indicating acidic conditions potentially influenced by hydrocarbon contamination. In the dry season, pH values further decreased, ranging from 5.1 to 5.9 with a mean of 5.5±0.566 (Table 4.23). Figure 4.116 illustrates that the lowest pH (5.1) was recorded at SDGW2 (Ibelebiri), while the highest (5.9) was at SDGW1 (Agba -Otuegwe).The continued acidic conditions during this period suggest persistent impacts from crude oil contamination.Figure 4.116 demonstrates a decreasing trend in pH from wet season (mean 5.7±0.566) to dry season (mean 5.5±0.566), indicating increasingly acidic conditions during the dry season. This pattern suggests enhanced concentration of acidic compounds from crude oil degradation during periods of reduced rainfall.

4.3.2.4.2 Electrical Conductivity (EC)

The mean EC value throughout the wet season was 104±5.66 µS/cm, with a range of 100-108 µS/cm (Table 4.23). All values were much below the 1000 µS/cm WHO 2011 and NSDWQ 2007 acceptable limit, as seen in Figure 4.117. At SWGW1 (Agba -Otuegwe), the maximum EC

was measured at 108 µS/cm. The electrical conductivity (EC) values had a little increase throughout the dry season, with a range of 115-120 µS/cm and a mean of 117.5±3.536 µS/cm (Table 4.23). However, these values remained far below the allowed limits. It shown in Figure 4.117 that SDGW1 (Agba -Otuegwe), recorded the greatest EC, which was 120 µS/cm. From the wet season (mean 104±5.66 µS/cm) to the dry season (mean 117.5±3.536 µS/cm), Figure 4.117 demonstrates a little upward trend in electrical conductivity (EC). This indicates that there is a slightly higher concentration of dissolved ions during the dry period, which may be attributed to lower dilution effects.

4.3.2.4.3 Total Dissolved Solids (TDS)

TDS levels were substantially below the WHO 2011 and NSDWQ 2007 allowable limit of 500 mg/L during the rainy season, with a mean of 116.5±6.364 mg/L (Table 4.23) and a range of 112-121 mg/L. SWGW2 (Ibelebiri) had the greatest TDS (121 mg/L), as seen in Figure 4.118.While TDS levels remained well within acceptable bounds during the dry season, they did rise somewhat, ranging from 119 to 129 mg/L with a mean of 124±7.071 mg/L (Table 4.23). As seen in Figure 4.118, SDGW2 (Ibelebiri) had the greatest TDS (129 mg/L). Figure 4.118 demonstrates a slight increase in TDS values from wet season (mean 116.5±6.364 mg/L) to dry season (mean 124±7.071 mg/L), following a similar pattern to EC. This reflects mildly increased concentration of dissolved substances during the dry period.

4.3.2.4.4 Turbidity

The turbidity measurements displayed a range of 0.2-0.4 NTU during the wet season, with a mean of 0.3±0.141 NTU, as indicated in Table 4.23. It is clear from Figure 4.119 that all of the values were far lower than WHO 2011 and NSDWQ 2007 standard of 5 NTU. The turbidity that was measured at SWGW1 (Agba -Otuegwe) was the highest, coming in at 0.4 NTU.During the dry season, the turbidity levels fell, within a range of 0.01-0.1 NTU, with a mean of 0.055±0.064 NTU (Table 4.23). These levels remained well within the legal limits to be considered acceptable. The highest amount of turbidity (0.1 NTU) was measured at SDGW1 (Agba -

Otuegwe), as shown in Figure 4.119. Figure 4.119 illustrates a significant decrease in turbidity from wet season (mean 0.3±0.141 NTU) to dry season (mean 0.055±0.064 NTU), suggesting reduced suspended particles during the dry season, possibly due to decreased surface runoff.

4.3.2.4.5 Total Suspended Solids (TSS)

During the wet season, TSS values ranged from 0.4-0.6 mg/L with a mean of 0.5±0.141 mg/L (Table 4.23). As shown in Figure 4.120, the highest TSS was recorded at SWGW1 (Agba - Otuegwe) 0.6 mg/L. In the dry season, TSS values decreased considerably to 0.1-0.2 mg/L with a mean of 0.15±0.071 mg/L (Table 4.31). Figure 4.120 illustrates that SDGW2 (Ibelebiri) showed the highest TSS (0.2 mg/L). Figure 4.120 shows a marked decrease in TSS values from wet season (mean 0.5±0.141 mg/L) to dry season (mean 0.15±0.071 mg/L). This substantial decrease could be attributed to reduced surface runoff and associated particulate matter transport during the dry season, combined with possible settling of suspended particles.

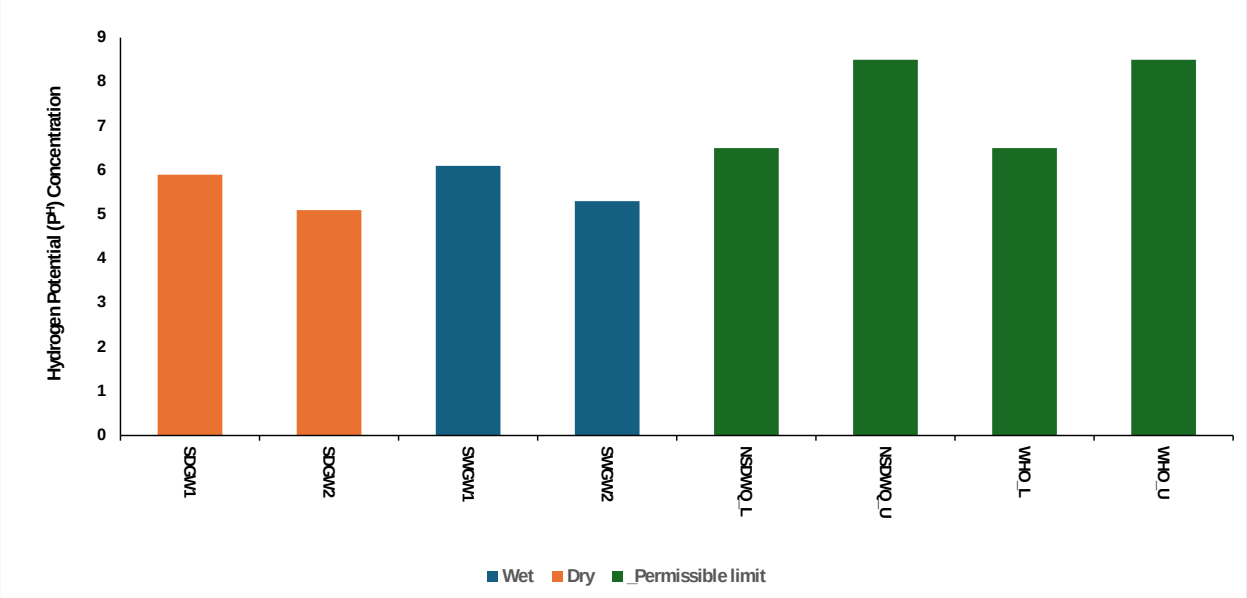

Figure 4. 116: Hydrogen Potential (P^H) concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

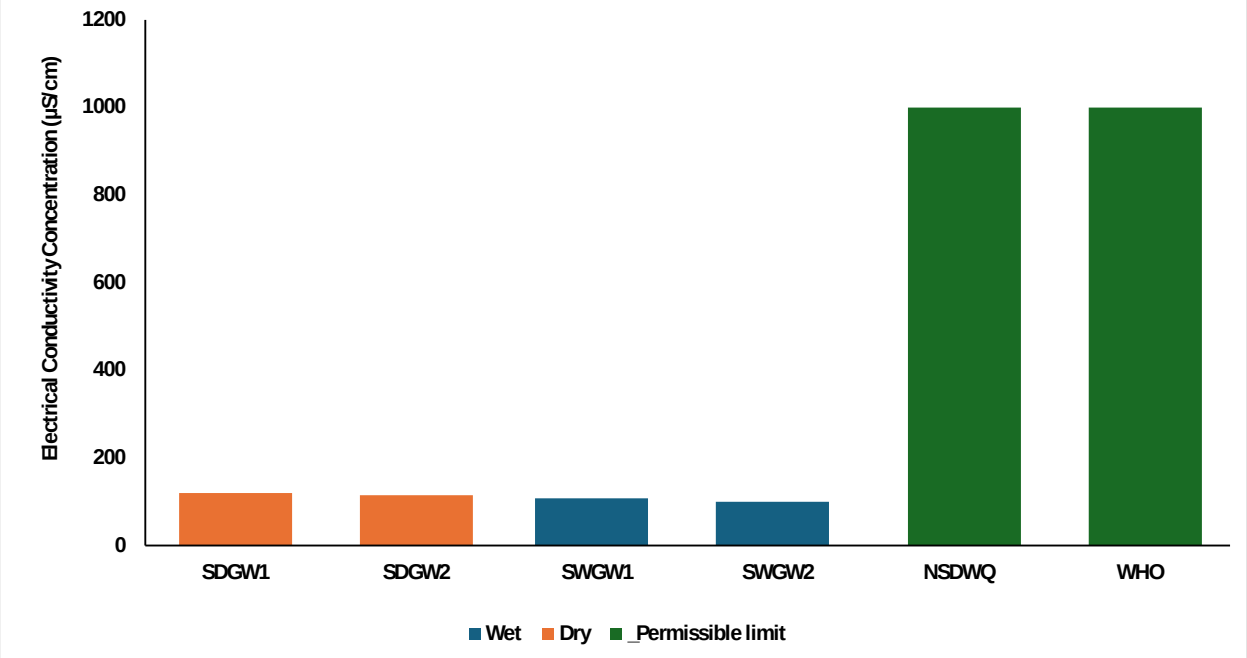

Figure 4. 117: Electrical Conductivity concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

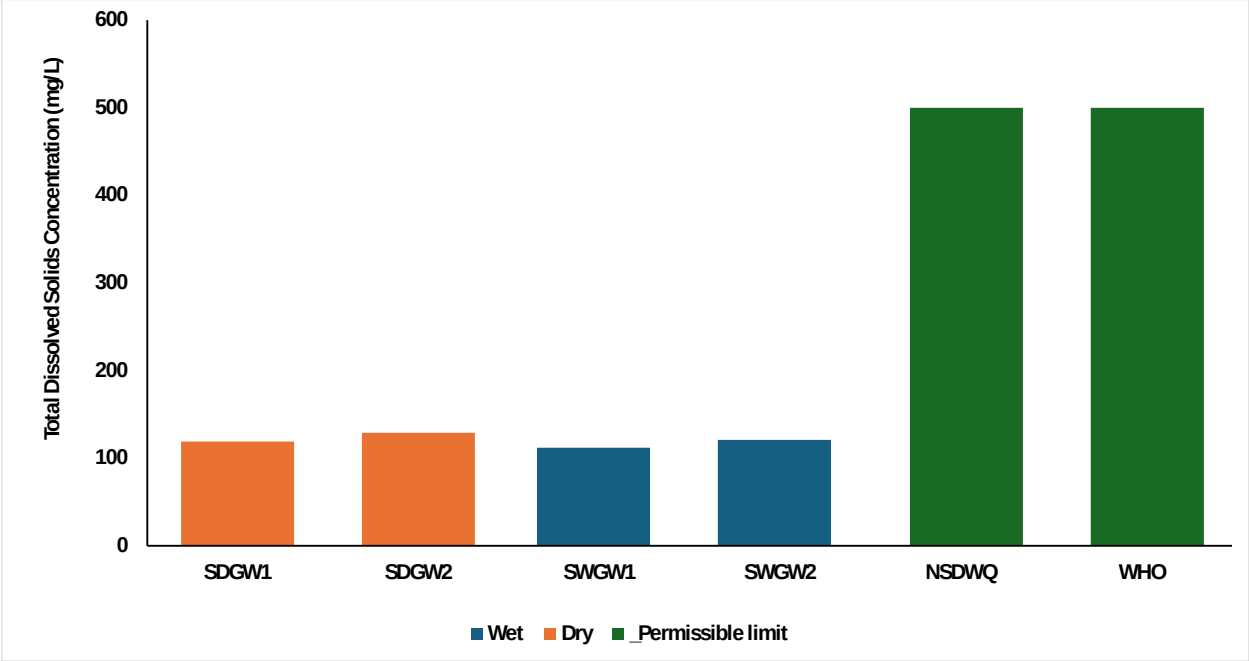

Figure 4. 118: Total Dissolved Solids concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

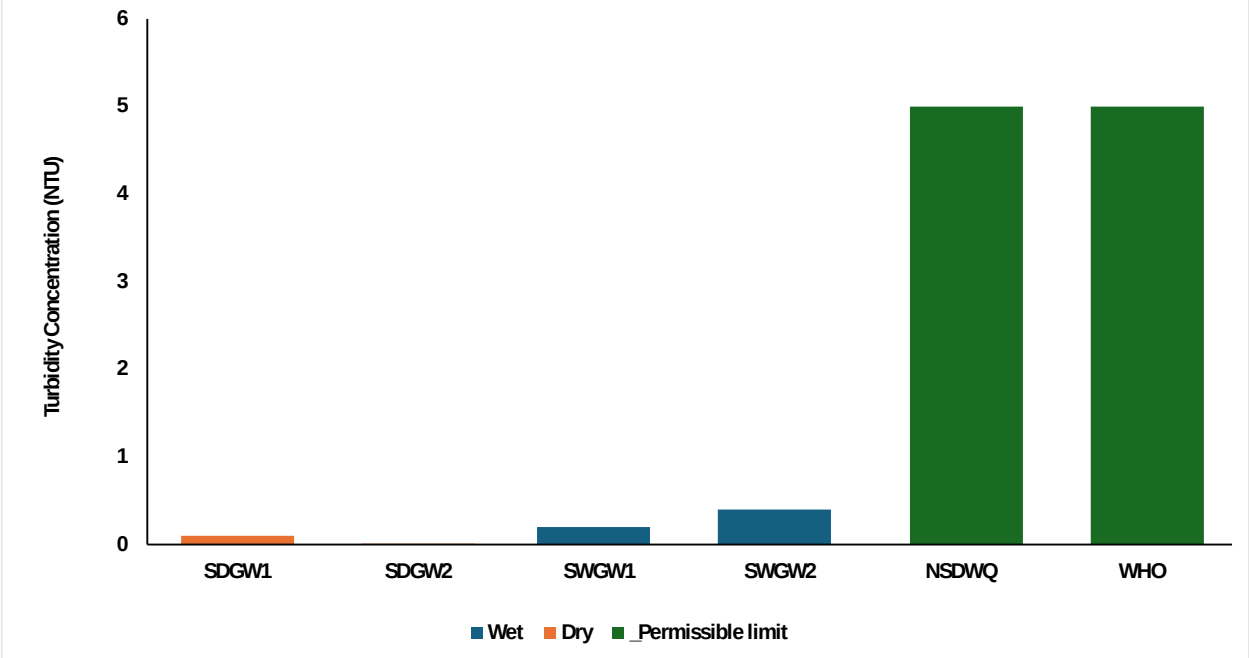

Figure 4. 119: Turbidity concentration in groundwater samples collected around crude oil spill site compared with permissible limit during the wet and dry seasons

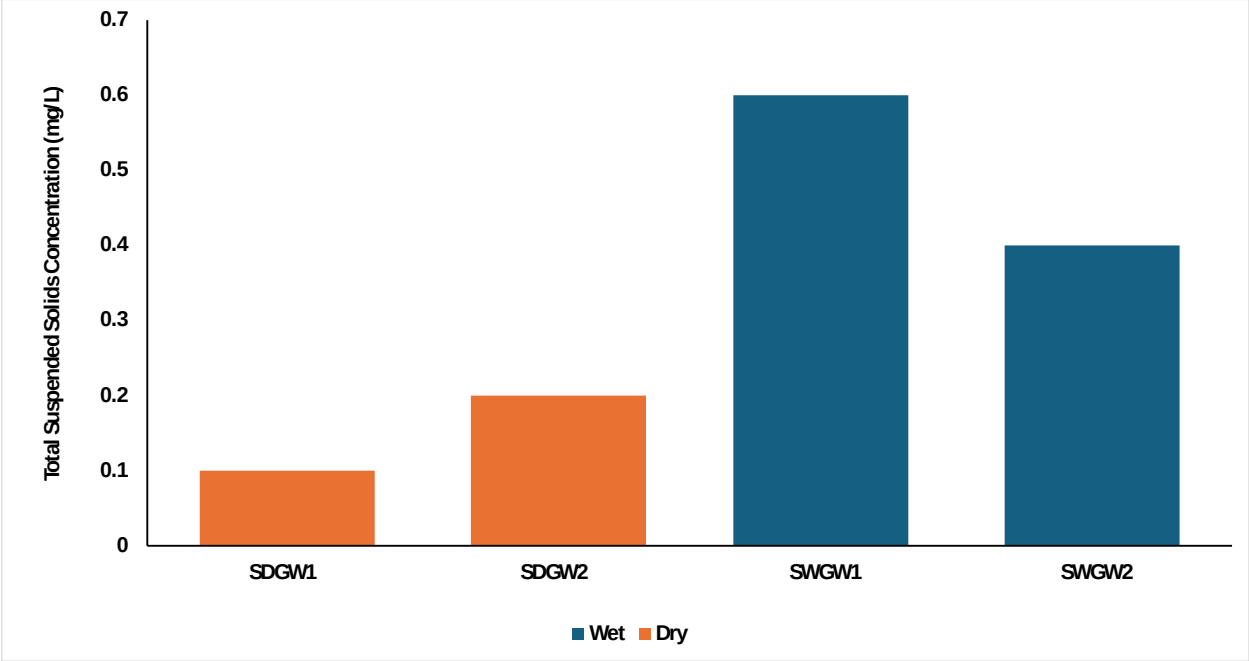

Figure 4. 120: Total Suspended Solids concentration in groundwater samples collected around crude oil spill site during the wet and dry seasons

4.3.3 Physical Characteritics in Surface Water

Rivers, lakes, streams, and wetlands are examples of surface water, which is essential to the hydrological cycle of the planet and supports ecosystems, industry, agriculture, and human consumption. This section looks at surface water's physical characteristics, which include pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and total suspended solids (TSS). These characteristics are essential markers of the water's quality and health. Figures 4.121-4.125 shows physical characteristics of surface water around dumpsites during wet and dry compared with control site.

4.3.3.1 Physical Characteristics in Surface Water Around Dumpsites

The indiscriminate disposal of different kinds of waste at dump sites can have a major impact on the condition of surrounding surface water bodies, including lakes, rivers, and streams. Surface water's physical characteristics, such as pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and total suspended solids (TSS), are important markers of pollution and environmental health. For this reason, data gathered during both wet and dry seasons is used to examine these physical characteristics.

4.3.3.1.1 Hydrogen Potential (pH)

During the wet season, surface water pH values around dumpsites ranged from 5.1 to 6.2 with a mean of 5.75±0.507 (Table 4.26). As shown in Figure 4.121, the highest pH (6.2) was recorded at DWSW2 (Igbogene Epie Creek), while the lowest pH (5.1) was observed at DWSW4 (Akenfa 1 Epie Creek). Compared to the control site (pH 6.3), all sampling locations showed lower pH values, indicating acidic conditions likely influenced by leachate percolation. The pH values experienced a further decline throughout the dry season, with a range that extended from 4.9 to 5.9, with a mean of 5.45±0.48 (Table 4.26). As shown in Figure 4.121, the pH level that was recorded at DDSW4 (Akenfa 1 Epie Creek) was the lowest (4.9), while the pH level that was recorded at DDSW2 (Igbogene Epie Creek), was the highest (5.9). The fact that the control site maintained a higher pH of 6 demonstrates the influence that operations at the dumpsite have on

the acidity of the water. Figure 4.121 illustrates a downward trend in pH from the wet season (mean 5.75±0.507) to the dry season (mean 5.45±0.48). On the other hand, the control site exhibited relatively consistent pH values when compared to the wet season (wet: 6.3, dry: 6.2). Due to the concentrated impacts of leachate during the dry season, this pattern indicates that the conditions have become more acidic.

4.3.3.1.2 Electrical Conductivity (EC)

The electrical conductivity (EC) values throughout the wet season varied from 110 to 217 µS/cm, with a mean of 154±45.13 µS/cm, as shown in Table 4.26. As can be seen in Figure 4.122, the EC value at the lowest point was marginally lower than the value at the control location, which was 124 µS/cm. The EC that was obtained at DWSW1 (Tombia Junction Market Epie creek) was the highest, at 217 µS/cm. During the dry season, the electrical conductivity (EC) values gradually increased, with a range of 124-228 µS/cm and a mean of 170±43.03 µS/cm, as shown in Table 4.26. According to Figure 4.122, the DDSW1 (Tombia Junction Market Epie creek) site recorded the highest EC, which was 228 µS/cm. This result is much higher than the control site value, which was 130 µS/cm. Figure 4.122 shows a significant increasing trend in EC from wet season (mean 154 µS/cm) to dry season (mean 170 µS/cm). In comparison, the control site showed slight variation (124 to 130 µS/cm), indicating dumpsite-related ionic contamination.

4.3.3.1.3 Total Dissolved Solids (TDS)

The mean TDS value during the wet season was 106.25±10.28 mg/L, with a range of 97-120 mg/L (Table 4.26). These levels were higher than the control location (63 mg/L), as seen in Figure 4.123. At DWSW4 (Akenfa 1 Epie Creek) the highest TDS was measured at 120 mg/L, while DWSW2 (Igbogene Epie Creek) recorded the lowest at 97 mg/L. TDS levels rose significantly throughout the dry season, with a mean of 149.75±54.78 mg/L and a range of 107-227 mg/L (Table 4.26). As seen in Figure 4.123, DDSW3 (Azikoro canal) had the highest TDS (227 mg/L), which was much greater than that of the control site (73 mg/L).

While the control site exhibited a slight increase (63 to 73 mg/L), Figure 4.123 shows a significant rise in TDS values from the wet season (mean 106.25 mg/L) to the dry season (mean 149.75 mg/L), which is indicative of dissolved compounds connected to dumpsites.

4.3.3.1.4 Turbidity

During the wet season, turbidity values ranged from 4.2-5.4 NTU with a mean of 4.95±0.52 NTU (Table 4.26). As shown in Figure 4.124, all these values were higher than the control site (1.5 NTU). The highest turbidity was recorded at DWSW4 (Akenfa 1 Epie Creek) 5.4 NTU while DWSW1 (Tombia Junction Market Epie creek) observed the lowest (4.2 NTU). In the dry season, turbidity increased, ranging from 0.8-6.1 NTU with a mean of 2.8±2.507 NTU (Table 4.26). Figure 4.124 shows that DDSW3 (Azikoro canal) recorded the highest turbidity (6.1 NTU), significantly exceeding the control site value (2.1 NTU). Figure 4.124 illustrates an increasing trend in turbidity from wet season (mean 2.95±0.85 NTU) to dry season (mean 4±0.9 NTU), while the control site showed slight increase (1.5 to 2.1 NTU), indicating dumpsite-related particulate matter.

4.3.3.1.5 Total Suspended Solids (TSS)

The mean TSS value during the wet season was 3.625±1.245 mg/L, with a range of 2.4-5.2 mg/L (Table 4.26). As seen in Figure 4.125, two samples were higher while the other two were lower than at the control location (3 mg/L). The highest TSS was found at DWSW3 (Azikoro canal) 5.2 mg/L, while DWSW2 (Igbogene Epie Creek) measured the lowest at (2.4 mg/L). In the dry season, TSS values climbed to 2-3.2 mg/L with a mean of 2.575±0.613 mg/L (Table 4.26). Figure 4.125 demonstrates that DDSW3 (Azikoro canal) demonstrated the highest TSS (3.2 mg/L), substantially higher than the control site (3.2 mg/L). Figure 4.125 demonstrates a noticeable increase in TSS values from wet season (mean 3.625 mg/L) to dry season (mean 2.575 mg/L), while the control site similarly showed a slight increase from 3 mg/L to 3.2 mg/L, showing significant seasonal dumpsite-related suspended solids contamination.

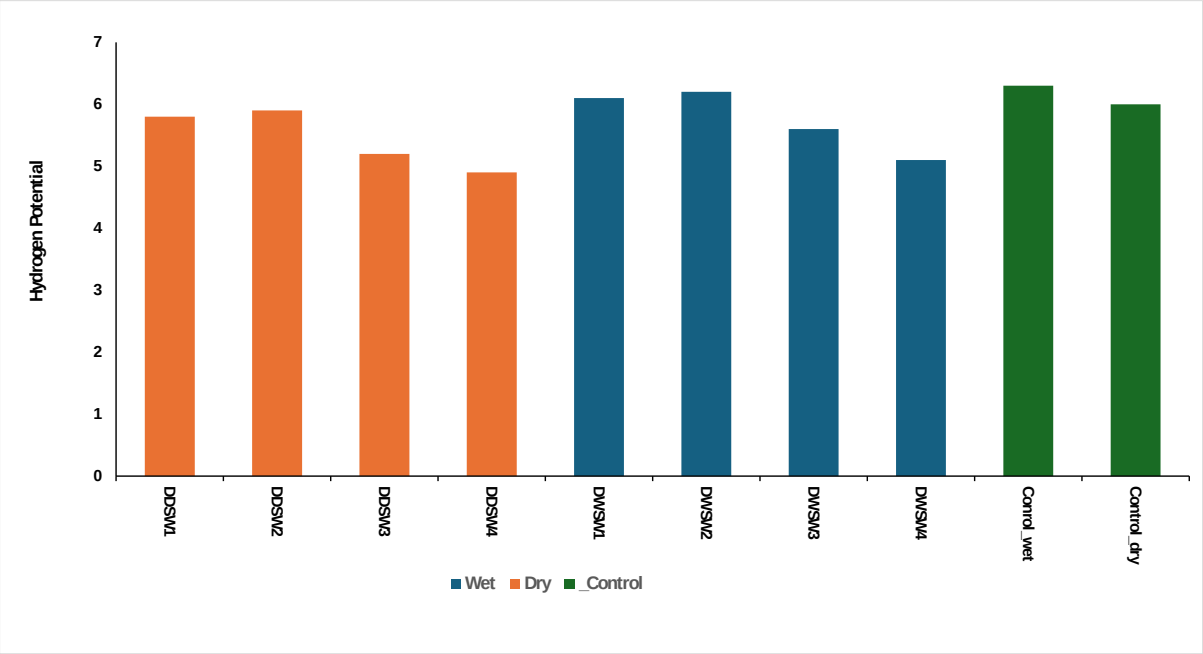

Figure 4. 121: Hydrogen Potential (pH) concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

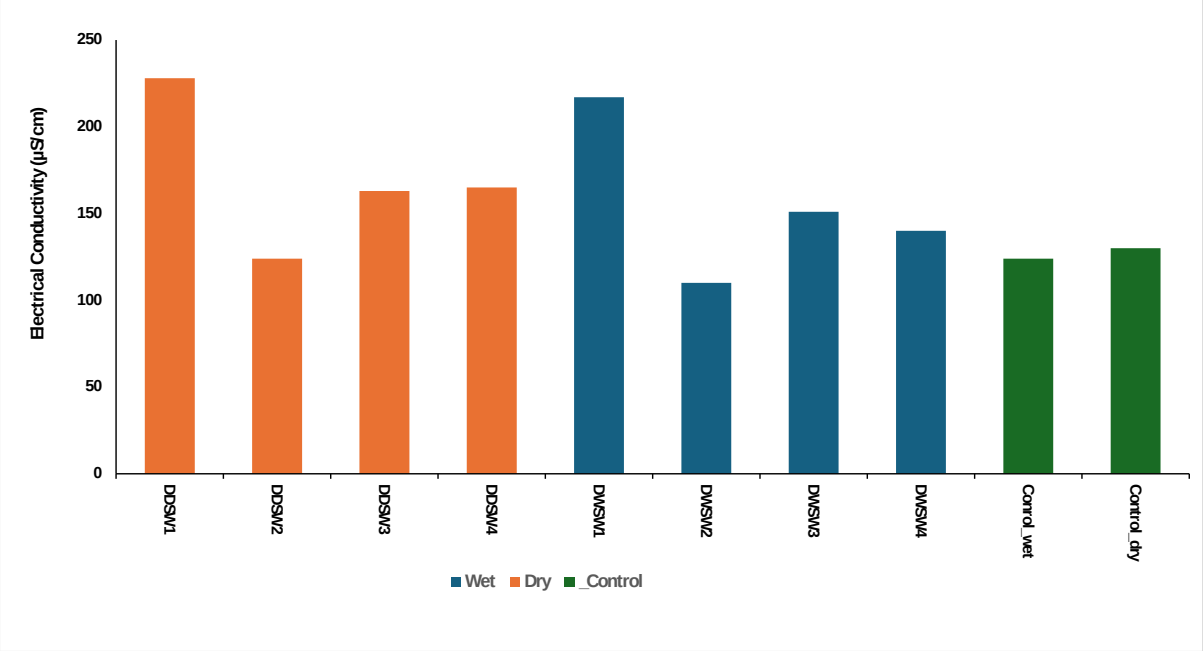

Figure 4. 122: Electrical conductivity concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

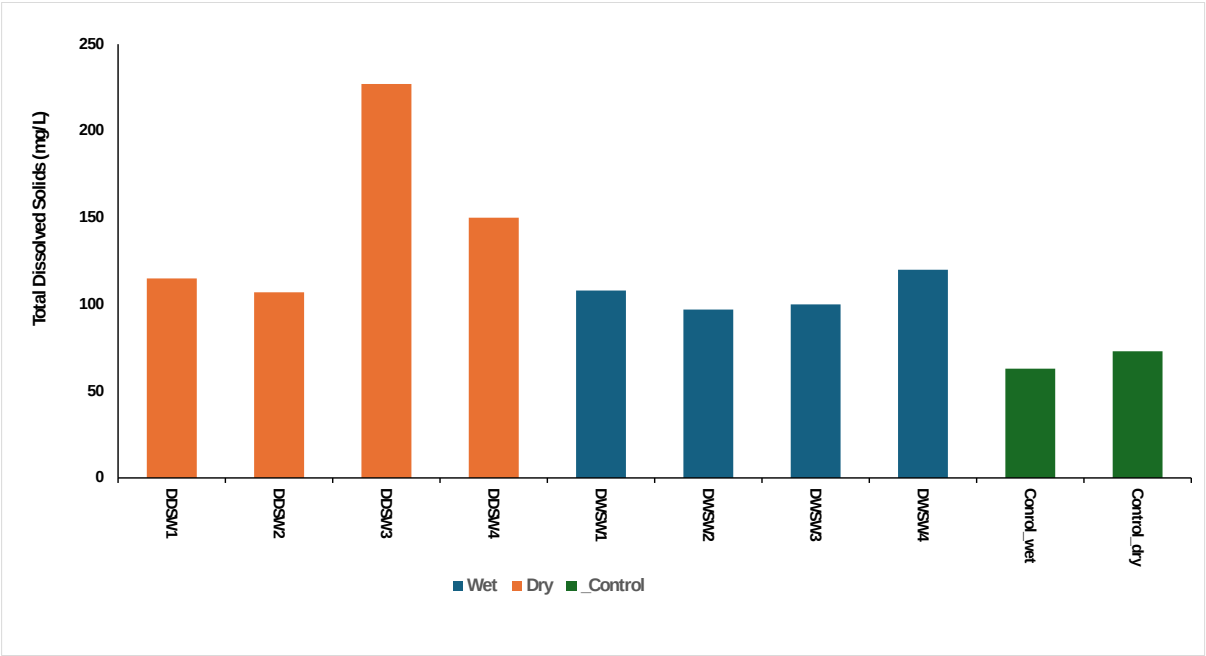

Figure 4. 123: Total Dissolved Solids concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

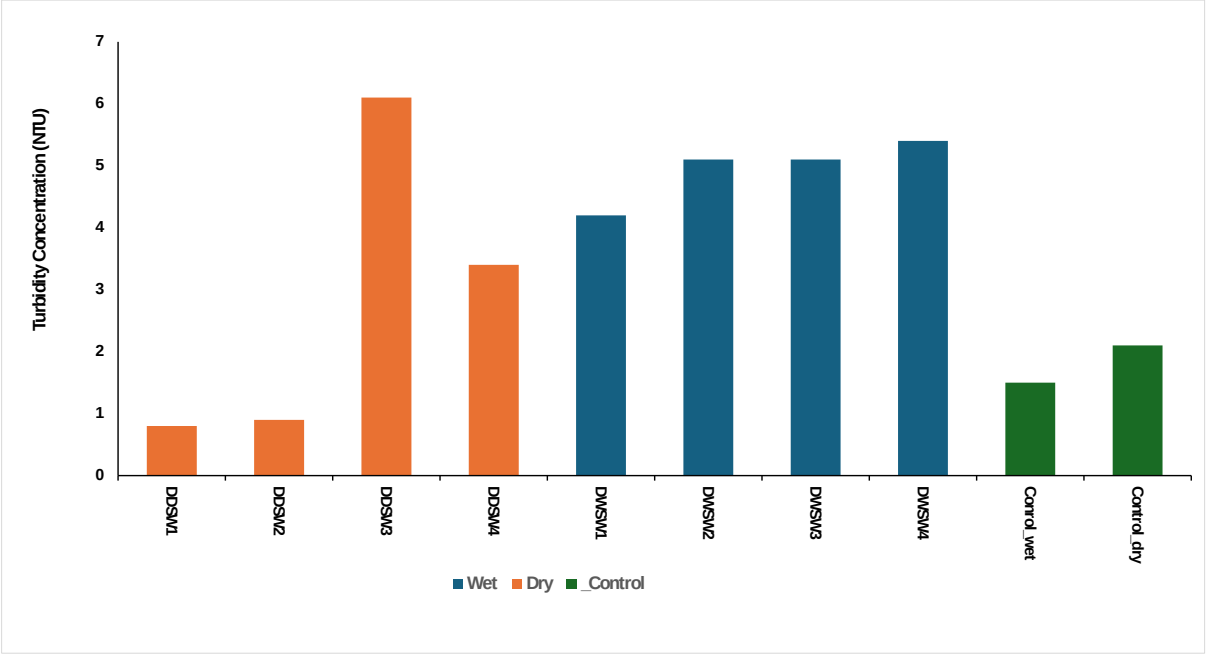

Figure 4. 124: Turbidity concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

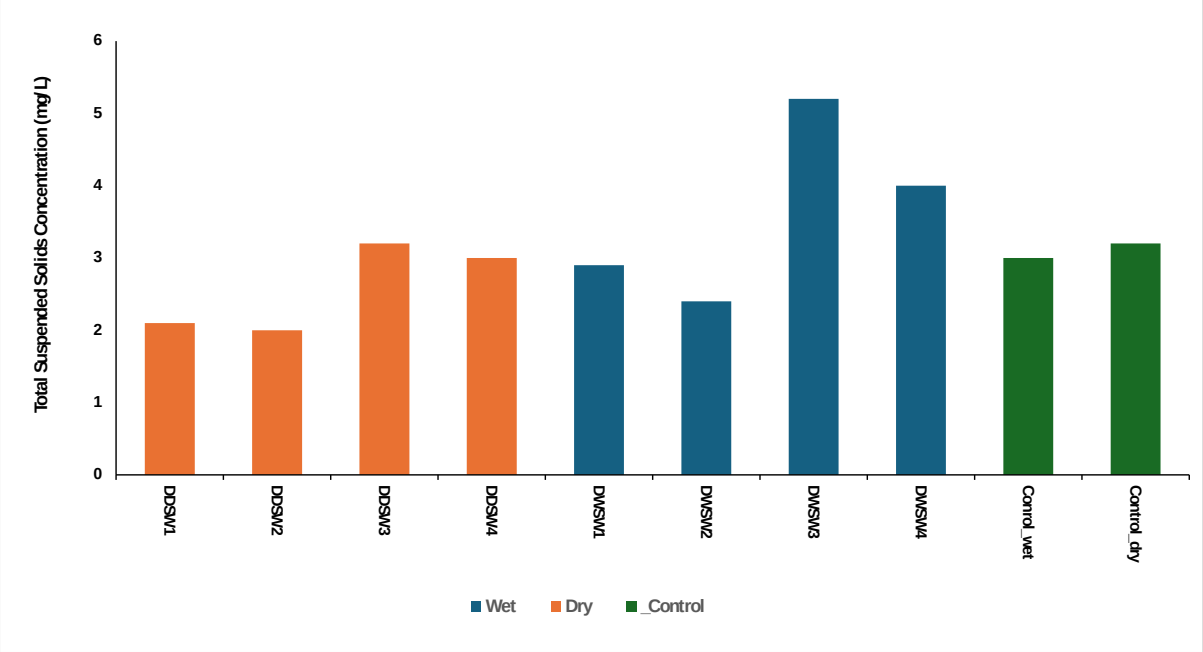

Figure 4. 125: Total suspended solids concentration in surface water samples collected close to dumpsites compared with control during the wet and dry seasons

4.3.3.2 Physical Characteristics in Surface Water Around Crude Oil Spill Site

The quality of surface water is immediately and seriously threatened by crude oil spills close to bodies of water, which affect rivers, lakes, streams, and coastal regions. The analysis of physical characteristics influenced by crude oil spills focuses on data collected during both wet and dry seasons because surface water physical characteristics like pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and total suspended solids (TSS) are important indicators of the environmental impact of oil spills. Figures 4.126-4.130 shows physical characteristics of surface water around crude oil spill sites during wet and dry compared with control site.

4.3.3.2.1 Hydrogen Potential (pH)

Surface water pH values around crude oil spill sites varied from 5.1 to 5.9 throughout the wet season, with an average of 5.5±0.566 (Table 4.26). Figure 4.126 illustrates that SWSW1 (Agba - Otuegwe Kolo creek) had the greatest pH (5.9) and SWSW2 (Ibelebiri - Kolo creek) (had the lowest pH (5.1). All sampling locations displayed noticeably lower pH values than the control site (pH 6.3), suggesting highly acidic conditions influenced by hydrocarbon contamination. The pH values dropped even more during the dry season, with a mean of 4.95±0.071 and a range of 4.9 to 5 (Table 4.26). As seen in Figure 4.126, SDSW2 (Ibelebiri - Kolo creek) had the lowest pH (4.9), while SDSW1 (Agba -Otuegwe Kolo creek) had the highest pH (5). The significant effect of oil contamination on the acidity of surface water is demonstrated by the control site's higher pH of 6.

Figure 4.126 demonstrates a marked decreasing trend in pH from wet season (mean 5.5) to dry season (mean 4.95), while the control site showed minimal variation (wet: 6.3, dry: 6). This pattern suggests intensified acidic conditions due to concentrated hydrocarbon degradation products during the dry season.

4.3.3.2.2 Electrical Conductivity (EC)

With a mean of 82±2.83 µS/cm, EC values throughout the wet season varied from 80 to 84 µS/cm (Table 4.26). Figure 4.127 illustrates that these values were marginally less than those at the control site (124 µS/cm). At SWSW1 (Agba -Otuegwe Kolo creek), the maximum EC was measured at 84 µS/cm, while SWSW2 ((Ibelebiri - Kolo creek) recorded the lowest (80 µS/cm). With a mean of 92.5±4.95 µS/cm and a range of 89-96 µS/cm, EC values significantly rose throughout the dry season (Table 4.26). As seen in Figure 4.127, SDSW1 (Agba -Otuegwe Kolo creek) had the highest EC (96 µS/cm), surpassing the value at the control site (130 µS/cm). Figure 4.127 shows an increasing trend in EC from wet season (mean 82 µS/cm) to dry season (mean 92.5 µS/cm), while the control site showed minimal change (84 to 198 µS/cm).

4.3.3.2.3 Total Dissolved Solids (TDS)

With a range of 30-57 mg/L, the average TDS value for the rainy season was 43.5±19.09 mg/L (Table 4.32). Figure 4.128 shows that these results were lower than those at the control site (63 mg/L). The highest TDS (57 mg/L) was recorded at SWSW2 (Ibelebiri - Kolo creek), while SWSW1 (Agba -Otuegwe Kolo creek) had the lowest (30 mg/L). TDS levels rose dramatically throughout the dry season, with a mean of 52.5±6.01 mg/L and a range of 40–65 mg/L (Table 4.33). SDSW2 (Ibelebiri - Kolo creek) had the highest TDS (65 mg/L), which was much lower than that of the control site (73 mg/L), as shown in Figure 4.128. Figure 4.128 demonstrates considerable increase in TDS values from wet season (mean 43.5 mg/L) to dry season (mean 52.5 mg/L), while the control site showed minimal increase (63 to 73 mg/L), reflecting concentrated dissolved substances from oil contamination.

4.3.3.2.4 Turbidity

During the wet season, turbidity values ranged from 2.1-3.2 NTU with a mean of 2.65±0.778 NTU (Table 4.26). As shown in Figure 4.129, these values exceeded the control site (1.5 NTU). The highest turbidity was recorded at SWSW1 (Agba -Otuegwe Kolo creek) 3.2 NTU, while SWSW2 (Ibelebiri - Kolo creek) demonstrated the lowest at (2.1 NUT). In the dry season,

turbidity decreased slightly, ranging from 2-2.9 NTU with a mean of 2.45±0.636 NTU (Table 4.26). Figure 4.129 shows that SDSW1 (Agba -Otuegwe Kolo creek) recorded the highest turbidity (2.9 NTU), while still higher than the control site value (2.1 NTU) the other location was slightly lower than the control site value. Figure 4.129 illustrates a decreasing trend in turbidity from wet season (mean 2.65 NTU) to dry season (mean 2.45 NTU) suggesting settling of oil-related suspended particles. However, control site showed minimal increase (1.5 to 2.1 NTU).

4.3.3.2.5 Total suspended solids (TSS)

During the wet season, TSS values ranged from 3.6-5 mg/L with a mean of 4.3±0.99 mg/L (Table 4.26). As shown in Figure 4.130, these values were higher than the control site (3 mg/L). The highest TSS was recorded at SWSW2 (Ibelebiri - Kolo creek) (5 mg/L), while SDSW1 (Agba -Otuegwe Kolo creek) had the lowest 3.6 mg/L. The total soluble solids (TSS) values declined to a range of 3-4.3 mg/L throughout the dry season, with a mean of 3.65±0.919 mg/L (Table 4.26). SDSW2 (Ibelebiri - Kolo creek) had the greatest total soluble solids (TSS) concentration (4.3 mg/L), which was higher than the control site (3.2 mg/L), as shown in Figure 4.130. An indication of the settling of oil-related suspended materials during the dry season is shown in Figure 4.130, which depicts a drop in total suspended solids (TSS) values from the wet season (mean 4.3 mg/L) to the dry season (mean 3.65 mg/L). On the other hand, the control site remained rather consistent, between 3 and 3.2 mg/L.

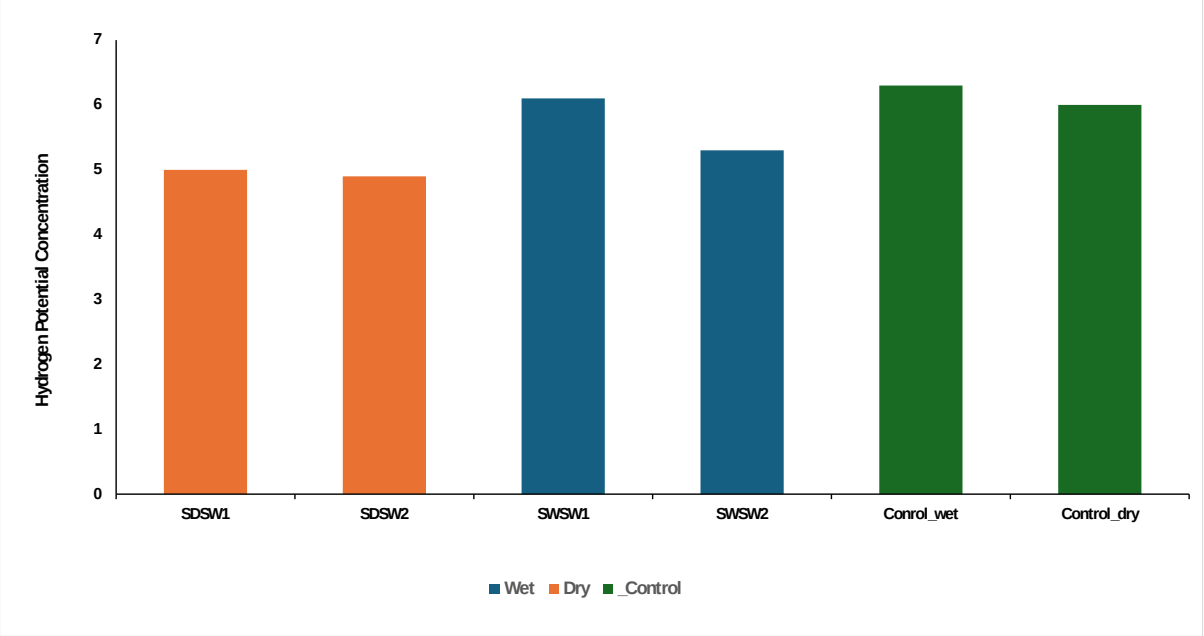

Figure 4. 126: Hydrogen potential (pH) concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

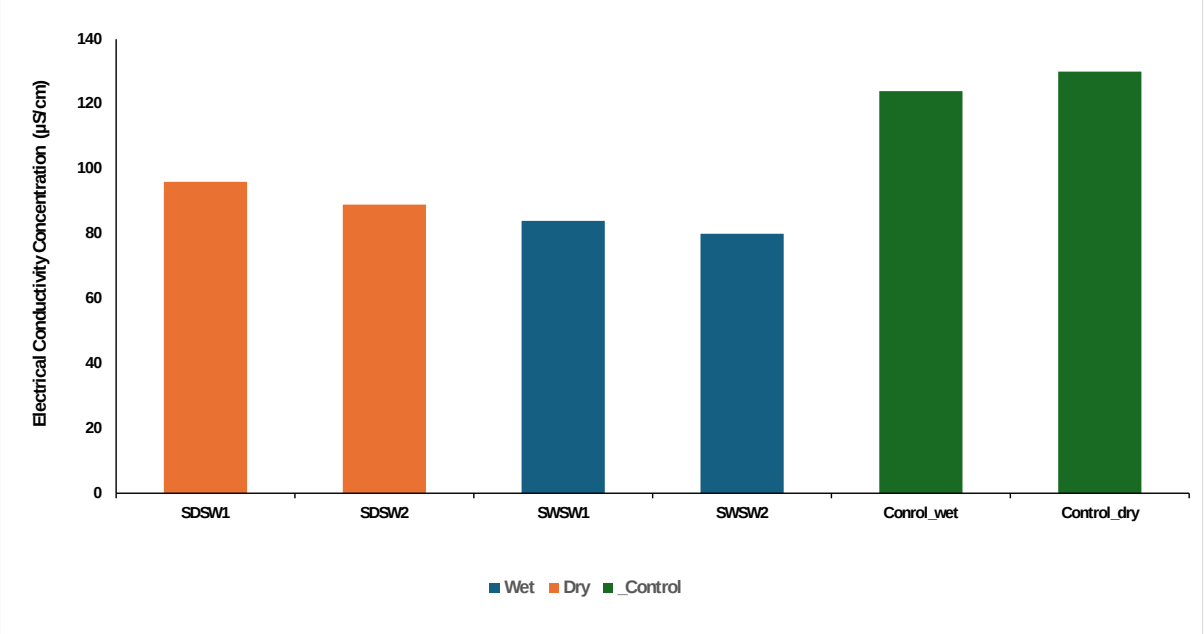

Figure 4. 127: Electrical conductivity concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

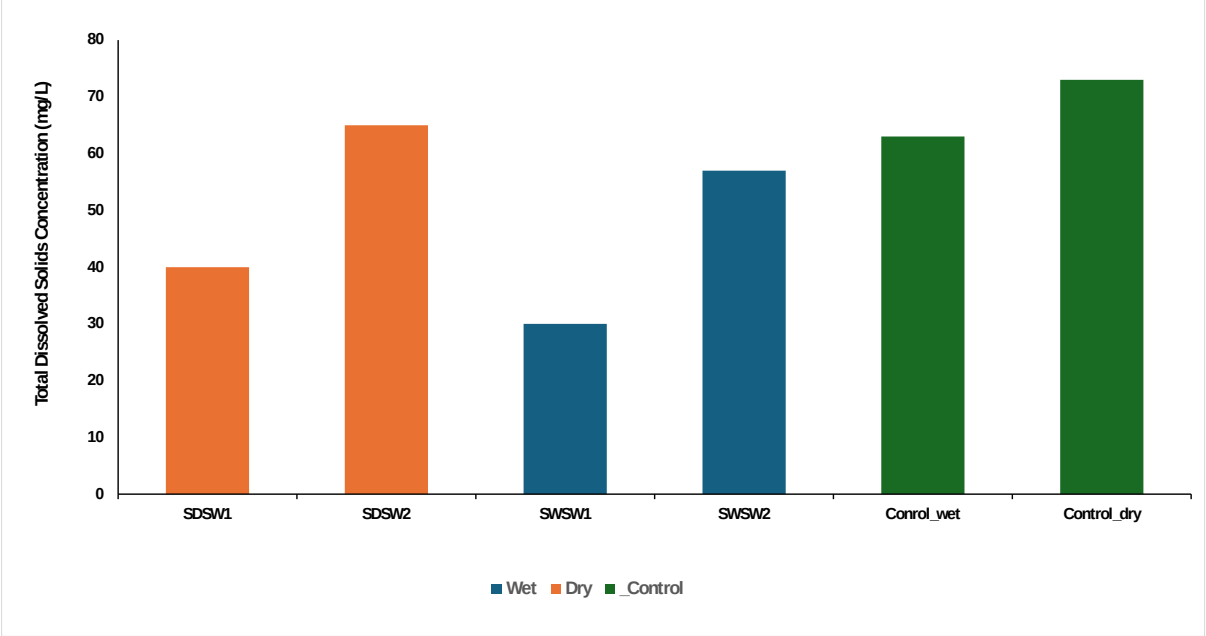

Figure 4. 128: Total dissolved Solids concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

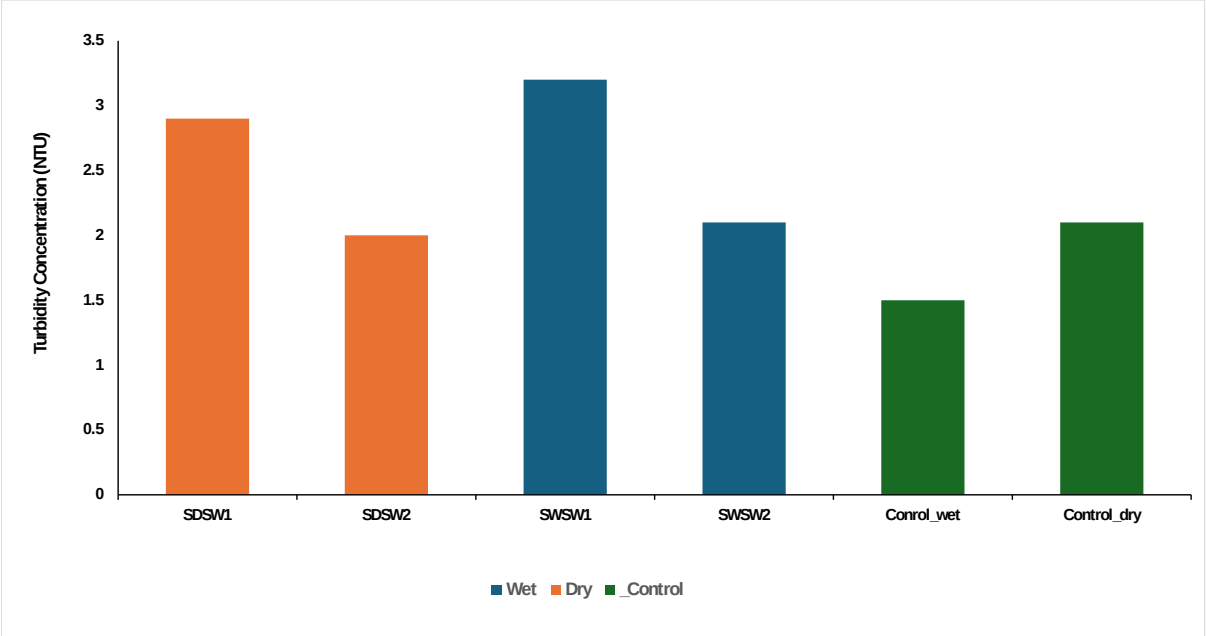

Figure 4. 129: Turbidity concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

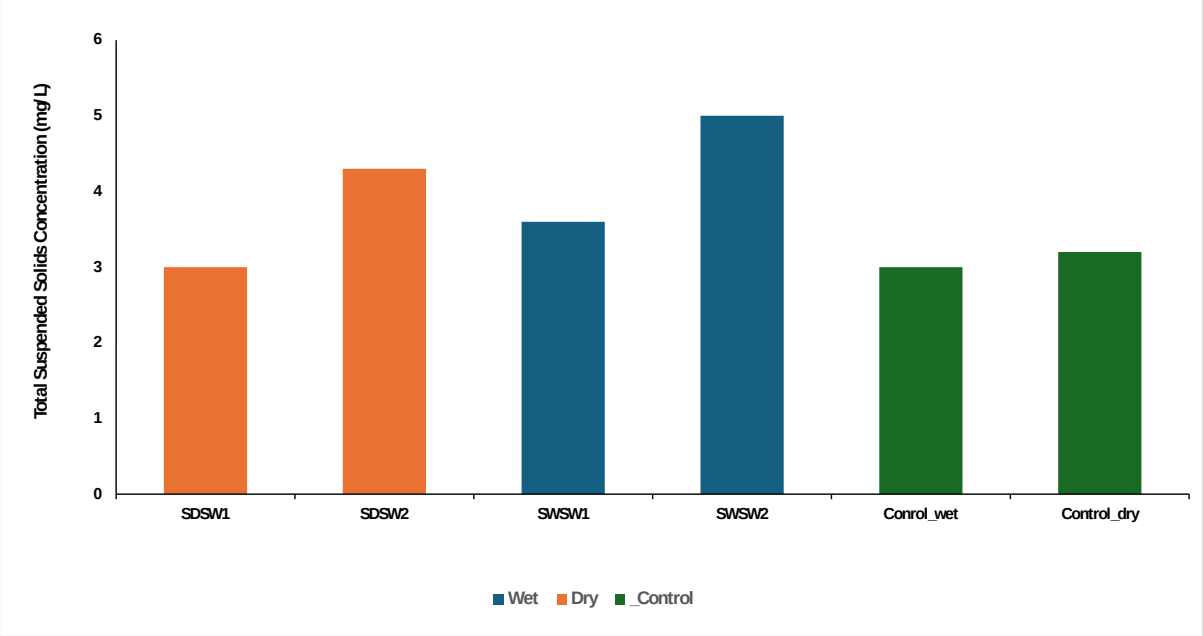

Figure 4. 130: Total Suspended Solids concentration in surface water samples collected close to crude oil spill site compared with control during the wet and dry seasons

4.4 Analysis of Variance

An effective statistical framework for assessing the variations in contamination levels among different environmental media (soil, groundwater, and surface water) is offered by the use of Analysis of Variance (ANOVA) in environmental studies. Understanding how land use patterns, seasonal fluctuations, and human activity affect the quality of these natural resources depends on these assessments. ANOVA makes it easier to identify notable regional and temporal fluctuations by looking at metrics like hydrocarbons, heavy metal concentrations, and other physicochemical characteristics.

4.4.1 Analysis of Variance in Soil Samples

The physicochemical parameters of soil samples were studied to evaluate the influence of environmental and seasonal factors on the soil samples. These samples were collected from a variety of sites. At various sampling locations, such as dumpsites, mechanic workshops, and control sites, statistical methods such as analysis of variance (ANOVA) were utilized in order to identify patterns of variation that occurred between the wet and dry seasons.Significant insights into the impact of various pollutants on soil quality are shown by the findings of the analysis of variance (ANOVA) that are presented in Tables 18 and 19 for soil samples taken from a variety of polluted situations during the dry and wet seasons. According to ANOVA, soil from crude oil spill areas had significantly higher mean concentrations of many metals throughout the dry season than soil from other contexts. These sites exhibit significant increases in iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), lead (Pb), and vanadium (V), highlighting the severe contamination caused by petroleum hydrocarbons. Certain remediation techniques designed to handle the particular difficulties presented by oil spills are required because the high concentrations of hazardous metals like Pb and Cr indicate a serious risk to the environment and public health. Furthermore, the pH of the soil in crude spill sites is much lower than in other places, indicating acidic conditions that are probably caused by the byproducts of hydrocarbon decomposition. This acidity may make metal mobility in the soil

even worse, which would make it more likely that these contaminants will seep into groundwater or be absorbed by plants. Although the highest metal concentrations are still found in crude oil spill sites during the wet season, the ANOVA shows that metal levels generally decline in all situations. This might be explained by metal leaching, dilution from rainfall, and perhaps certain biological absorption or degradation mechanisms that intensify with higher moisture. In the rainy season, the pH variations between settings are less noticeable, maybe because rainwater acts as a buffer, balancing out some of the acidity. Cassava mills continue to have the highest electrical conductivity (EC), indicating a continuous influence of processing activities on soil ion content, while EC likewise exhibits less variability between settings during the wet season. The comparison between seasons, as detailed in Table 4.20, highlights the statistically significant differences in metal concentrations. The ANOVA shows that Cadmium (Cd), Nickel (Ni), Lead (Pb), and Vanadium (V) concentrations are significantly higher in the dry season than in the wet season. This suggests that these metals are more available in the soil during drier periods, likely due to less dilution and lower mobility of pollutants. The dry season also exhibits a lower pH and higher EC, indicating increased salinity or ion concentration, which might enhance metal retention in the soil. The concentrations of Cd, Ni, Pb, and V are much greater during the dry season, like dumpsites; the only metal that does not change significantly between seasons is Pb. Rainfall may still have an impact on the mobility of metals in the soil, but the constant input of metals from car maintenance activities may be the cause of this. While EC values are greater during the dry season, suggesting a higher ion content in the soil, the pH is also noticeably lower, maybe because of the breakdown of oil and fuel wastes. During the dry season, the concentrations of Cu, Cr, Cd, Ni, Pb, and V in the cassava mill environment are noticeably greater. This could be a result of decreased leaching or evaporation of contaminants. The solubility and bioavailability of certain metals may be improved by the dry season's lower pH. Even though the EC is higher during the dry season, there is no discernible seasonal variation, maybe as a result of the steady intake of organic matter from cassava processing. There are

notable seasonal variations in the crude oil spill environment for Cr, Cd, Ni, Pb, and V, with all elements exhibiting greater concentrations during the dry season. In line with the decreased microbial degradation and dilution effects during the dry season, THC (Total Hydrocarbon Content) also exhibits a notable increase during this time. Because hydrocarbon breakdown products are acidic, the pH of crude oil spill sites is noticeably lower during the dry season. However, because hydrocarbons are always present, the EC does not change much from season to season. According to the ANOVA study, because of less leaching and dilution, the dry season typically leads to greater concentrations of several metals in all settings, especially Cd, Ni, Pb, and V. During the dry season, pH is often lower, which may increase metal availability and mobility. To effectively limit contamination risks, environmental managers must take into account both the kind of pollution and the natural seasonal cycles when developing remediation solutions. This is why these seasonal fluctuations are so important. Based on the results, remediation activities may be more successful during the wet season when natural processes like biodegradation and diffusion are more active, but more intense interventions may be required to address the concentrated contaminants during the dry season. Tables 4.18 amd 4.19 shows Analysis of Variance (ANOVA) of Soil Sample between Different Pollution Environment in the Dry Season, and Table 4.20 shows Soil Sample between Different Pollution Environment in the Wet and Dry Season.

Table 4. 18: Analysis of Variance (ANOVA) of Soil Samples between Different Pollution Environments in the Dry Season

Metals	Dumpsite	Mechanic Workshop	Cassava Mill	Crude Spill
	mean±SD	mean±SD	mean±SD	mean±SD
	min-max	min-max	min-max	min-max
Fe (mg/kg)	103.89±109.03a	98.27±119.24a	108.02±62.249a	438.6±103.7b
	12.3-363.5	8.05-468.7	31.7-255.5	334.8-568.5
Mn (mg/kg)	80.06±55.72a	58.83±73.48a	62.33±28.59a	260.35±39.87b
	15.5-197.3	8.4-248.7	19.7-125.6	216.6-325.7
Zn (mg/kg)	93.47±95.89a	80.26±114.57a	107.34±44.04a	394.27±54.42b
	7.4-333.7	9.3-399.7	14.06-197.9	362.6-457.3
Cu mg/kg	27.63±25.87a	31.24±28.63a	31.76±11.94a	112.53±14.75b
	2.08-84.7	5.4-122.6	7.4-55.4	85.8-126.5
Cr mg/kg	10.64±9.53a	8.06±11.38a	12.70±7.51a	40.40±4.50b
	0.921-31.03	0.098-41.31	1.55-32.7	32.36-45.63
Cd mg/kg	0.92±0.49a	0.87±0.57a	0.71±0.16a	2.09±0.45b
	0.174-2.364	0.085-2.704	0.206-0.964	1.551-2.755
Ni mg/kg	0.62±0.16a	0.47±0.28a	0.21±0.22b	0.59±0.09a
	0.27-1.042	0.051-0.904	0.055-0.767	0.456-0.708
Pb mg/kg	2.84±2.58a	2.72±1.94a	2.46±1.14a	10.48±2.79b
	0.163-7.525	0.602-8.334	0.754-5.466	7.516-15.354
V mg/kg	0.55±0.13a	0.28±0.29b	0.07±0.03c	0.64±0.08a
	0.284-0.821	0.053-0.923	0.046-0.208	0.538-0.716
THC mg/kg	0±0a	0.64±0.95a	0.55±0.27a	12.32±2.19b
	0-0	0.044-3.4	0.056-1.545	9.55-15.78
C N- mg/kg	0±0	0±0	0±0	0±0
	0-0	0-0	0-0	0-0
Hg mg/kg	0±0	0±0	0±0	0±0
	0-0	0-0	0-0	0-0
PH	5.79±0.63a	6.76±0.44b	6.75±0.30b	4.13±0.15c
	3.5-6.8	5.4-7.3	6.2-7.5	4-4.4
EC (µS/cm)	613.6±197.94ab	539.05±154.28ab	1222.38±1262.7b	156.83±43.39a
	365-1250	237-816	515-5121	106-230

Table 4. 19: Analysis of Variance (ANOVA) of Soil Sample between Different Pollution Environment in the wet Season

Metals	Dumpsite	Mechanic Workshop	Cassava Mill	Crude Spill
	mean±SD min-max	mean±SD min-max	mean±SD min-max	mean±SD min-max
Fe (mg/kg)	94.26±104.21a 8-352.1	91.34±115.94a 6.45-450.2	92.10±55.28a 25.6-223	406.95±91.78b 301.6-516.3
Mn (mg/kg)	67.86±51.36a 9.7-184.7	47.67±62.88a 7-236.1	53.42±27.48a 11.7-116.9	234.97±26.79b 200.4-270.8
Zn (mg/kg)	81.30±90.10a 4.1-302.8	74.85±111.68a 7.3-387.1	95.26±41.85a 9.9-191.7	377.82±56.38b 304.2-444
Cu mg/kg	22.41±23.52a 1.35-79.4	25.46±25.04a 3-101.5	24.69±11.27a 4.2-50.3	101.92±11.74b 81.8-116.4
Cr mg/kg	8.02±7.42a 0.129-26.21	5.93±8.95a 0.014-33.51	8.85±5.54a 0.92-24.6	32.92±4.28b 26.43-38.43
Cd mg/kg	0.34±0.32a 0.001-1.156	0.30±0.38a 0.01-1.478	0.32±0.17a 0.106-0.732	1.48±0.15b 1.301-1.695
Ni mg/kg	0.08±0.08a 0.001-0.253	0.09±0.09a 0.011-0.355	0.05±0.05a 0.002-0.176	0.32±0.11b 0.116-0.407
Pb mg/kg	1.59±1.70a 0.103-5.504	1.71±1.71a 0.108-7.038	1.19±0.91a 0.016-3.486	6.75±1.26b 4.607-8.071
V mg/kg	0.02±0.02a 0.001-0.072	0.03±0.03a 0.003-0.106	0.01±0.01a 0.002-0.046	0.09±0.02b 0.071-0.108
THC mg/kg	0±0a 0-0	0.34±0.79a 0.001-2.9	0.05±0.02a 0.007-0.087	8.41±1.24b 7.08-10.75
C N-mg/kg	0±0 0-0	0±0 0-0	0±0 0-0	0±0 0-0
Hg mg/kg	0±0 0-0	0±0 0-0	0±0 0-0	0±0 0-0
PH	6.64±0.51a 5.3-7.5	7.39±0.21b 6.9-7.8	7.32±0.24b 6.9-7.8	5.93±0.20c 5.6-6.2
EC (µS/cm)	447.92±143.80ab 267-864	419±126.85ab 157-678	870.38±809.52b 395-3563	113±26.62a 74-152

Table 4. 20: Analysis of Variance (ANOVA) of Soil samples from Different Pollution Environments between Wet and Dry Season

Metals	Dumpsite			Mechanic Workshop			Cassava Mill			Crude Spill Site		
	Wet	Dry		Wet	Dry		Wet	Dry		Wet	Dry	
	mean±SD min-max	mean±SD min-max	Pvalue	mean±SD min-max	mean±SD min-max	Pvalue	mean±SD min-max	mean±SD min-max	Pvalue	mean±SD min-max	mean±SD min-max	Pvalue
Fe (mg/kg)	94.26±104.21 8-352.1	103.89±109.03 12.3-363.5	P>0.05	91.34±115.94 6.45-450.2	98.27±119.24 8.05-468.7	P>0.05	92.10±55.28 25.6-223	108.02±62.249 31.7-255.5	P>0.05	406.95±91.78 301.6-516.3	438.6±103.7 334.8-568.5	P>0.05
Mn (mg/kg)	67.86±51.36 9.7-184.7	80.06±55.72 15.5-197.3	P>0.05	47.67±62.88 7-236.1	58.83±73.48 8.4-248.7	P>0.05	53.42±27.48 11.7-116.9	62.33±28.59 19.7-125.6	P>0.05	234.97±26.79 200.4-270.8	260.35±39.87 216.6-325.7	P>0.05
Zn (mg/kg)	81.30±90.10 4.1-302.8	93.47±95.89 7.4-333.7	P>0.05	74.85±111.68 7.3-387.1	80.26±114.57 9.3-399.7	P>0.05	95.26±41.85 9.9-191.7	107.34±44.04 14.06-197.9	P>0.05	377.82±56.38 304.2-444	394.27±54.42 362.6-457.3	P>0.05
Cu (mg/kg)	22.41±23.52 1.35-79.4	27.63±25.87 2.08-84.7	P>0.05	25.46±25.04 3-101.5	31.24±28.63 5.4-122.6	P>0.05	24.69±11.27 4.2-50.3	31.76±11.94 7.4-55.4	**P<0.05**	101.92±11.74 81.8-116.4	112.53±14.75 85.8-126.5	P>0.05
Cr (mg/kg)	8.02±7.42 0.129-26.21	10.64±9.53 0.921-31.03	P>0.05	5.93±8.95 0.014-33.51	8.06±11.38 0.098-41.31	P>0.05	8.85±5.54 0.92-24.6	12.70±7.51 1.55-32.7	**P<0.05**	32.92±4.28 26.43-38.43	40.40±4.50 32.36-45.63	**P<0.05**
Cd (mg/kg)	0.34±0.32 0.001-1.156	0.92±0.49 0.174-2.364	**P<0.01***	0.30±0.38 0.01-1.478	0.87±0.57 0.085-2.704	**P<0.01***	0.32±0.17 0.106-0.732	0.71±0.16 0.206-0.964	**P<0.01***	1.48±0.15 1.301-1.695	2.09±0.45 1.551-2.755	**P<0.05**
Ni (mg/kg)	0.08±0.08 0.001-0.253	0.62±0.16 0.27-1.042	**P<0.01***	0.09±0.09 0.011-0.355	0.47±0.28 0.051-0.904	**P<0.01***	0.05±0.05 0.002-0.176	0.21±0.22 0.055-0.767	**P<0.01***	0.32±0.11 0.116-0.407	0.59±0.09 0.456-0.708	**P<0.01***
Pb (mg/kg)	1.59±1.70 0.103-5.504	2.84±2.58 0.163-7.525	**P<0.05**	1.71±1.71 0.108-7.038	2.72±1.94 0.602-8.334	P>0.05	1.19±0.91 0.016-3.486	2.46±1.14 0.754-5.466	**P<0.01***	6.75±1.26 4.607-8.071	10.48±2.79 7.516-15.354	**P<0.05**
V (mg/kg)	0.02±0.02 0.001-0.072	0.55±0.13 0.284-0.821	**P<0.01***	0.03±0.03 0.003-0.106	0.28±0.29 0.053-0.923	**P<0.01***	0.01±0.01 0.002-0.046	0.07±0.03 0.046-0.208	**P<0.01***	0.09±0.02 0.071-0.108	0.64±0.08 0.538-0.716	**P<0.01***
THC (mg/kg)	0±0 0-0	0±0 0-0		0.34±0.79 0.001-2.9	0.64±0.95 0.044-3.4	P>0.05	0.05±0.02 0.007-0.087	0.55±0.27 0.056-1.545	**P<0.01***	8.41±1.24 7.08-10.75	12.32±2.19 9.55-15.78	**P<0.01***
P^H	6.64±0.51 5.3-7.5	5.79±0.63 3.5-6.8	**P<0.01***	7.39±0.21 6.9-7.8	6.76±0.44 5.4-7.3	**P<0.01***	7.32±0.24 6.9-7.8	6.75±0.30 6.2-7.5	**P<0.01***	5.93±0.20 5.6-6.2	4.13±0.15 4-4.4	**P<0.01***
EC (µS/cm)	447.92±143.80 267-864	613.6±197.94 365-1250	**P<0.01***	419±126.85 157-678	539.05±154.28 237-816	**P<0.01***	870.38±809.52 395-3563	1222.38±1262.7 515-5121	P>0.05	113±26.62 74-152	156.83±43.39 106-230	P>0.05

Bold values = Significant; Bold values with * = Highly Significant

4.4.2 Analysis of Variance in Groundwater Samples

ANOVA was used in both the wet and dry seasons to examine the amounts of groundwater contamination in various settings, including dumpsites, mechanic shops, cassava mills, and regions where crude oil spills had occurred. The offered dataset's tables 4.21, 4.22, and 4.23 provide a thorough comparison of important physicochemical properties, such as heavy metals. Seasonal changes and their effects on environmental health are better understood thanks to these findings.

Tables 4.21, 4.22, and 4.23 present the results of the ANOVA analysis of groundwater samples, which shows substantial seasonal variances and variations in metal concentrations across various polluted conditions during the wet and dry seasons. Table 4.21 indicates that there are notable variations in iron (Fe) concentrations among polluted areas throughout the wet season. The mean concentration is higher at dump sites and lowest at crude oil spill sites. This implies that groundwater's Fe availability is influenced by the types of pollution sources. Compared to mechanic shops and cassava mills, dumpsites and crude oil spill sites have far higher copper (Cu) levels. This is probably because the pollutants linked to these operations contain Cu. Crude oil spill areas have much higher levels of cadmium (Cd), indicating the possibility of contamination. Significant variations are also seen in the quantities of nickel (Ni) and lead (Pb), with the highest concentrations seen near crude oil spill locations, suggesting that petroleum hydrocarbons are the source of these metals' introduction into the groundwater. Furthermore, crude oil spill sites have far greater Total Hydrocarbon Content (THC), which is a direct reflection of how oil spills affect the quality of groundwater. Zinc (Zn) concentrations are substantially higher in the rainy season than in the dry season in all environments throughout the dry season, as Table 4.23 illustrates. The diluting effect of rainfall during the rainy season or the greater mobility of zinc because of higher moisture content could be the cause of this. The rainy season continues to see larger concentrations of copper (Cu) in dumpsites and crude oil spill sites, but the dry season also sees a notable rise in Cu in these locations. There is a seasonal

change in the amount of nickel (Ni) in groundwater, as evidenced by the fact that Ni concentrations at crude oil spill locations are much higher during the rainy season. The concentration of lead (Pb) in crude oil spill locations is considerably higher during the dry season, presumably because there is less precipitation-induced dilution. During the dry season, THC levels remain noticeably higher at crude oil spill locations, indicating that hydrocarbons remain in the environment even in the absence of much rainfall. When comparing the wet and dry seasons, as detailed in Table 4.23, several metals exhibit significant variations across different pollution environments. Observation in the dumpsite environment shows that Cadmium (Cd) concentrations are significantly higher in the wet season than in the dry season. This might be due to the leaching of Cd from waste materials during rainfall. Zinc (Zn) also shows a significant increase in the wet season, suggesting that precipitation influences its mobility in the soil. Conversely, Copper (Cu) levels, while still significant in both seasons, show a marked increase in the wet season, indicating that Cu might be more available during wet periods due to the nature of pollutants at dumpsites. Around mechanic workshops, Iron (Fe) concentrations are significantly higher in the dry season, possibly due to less dilution of pollutants in groundwater. Zinc (Zn) levels are significantly higher in the wet season, suggesting that Zn from vehicle maintenance activities becomes more mobile with increased moisture. Copper (Cu) concentrations are significantly higher in the wet season, which could be linked to the degradation of oil and fuel residues. The wet season at the cassava mill site exhibits noticeably higher amounts of zinc (Zn) and copper (Cu), most likely as a result of these metals leaching from processing operations. The rainy season also has a much higer concentration of cadmium (Cd), suggesting that Cd from cassava mill operations is more accessible during periods of increased moisture. But during the dry season, pH levels are much lower, which can increase the availability and movement of metals.

Additionally, crude oil spill site reveals that the wet season is when concentrations of iron (Fe), cadmium (Cd), nickel (Ni), and lead (Pb) are noticeably greater. This implies that precipitation

facilitates the mobility of these metals, which are introduced into groundwater by crude oil spills. However, the dry season has a much greater Total Hydrocarbon Content (THC), indicating that petroleum hydrocarbons remain there even with reduced dilution. The ANOVA results from Table 4.23 highlight the complex interplay between environmental conditions, pollution sources, and seasonal changes in affecting groundwater quality. The data indicates that metals like Cd, Ni, Pb, and THC are more concentrated or mobile in the wet season, likely due to increased leaching and dilution effects, whereas Fe in mechanic workshops and crude oil spill sites shows higher concentrations in the dry season, possibly due to less dilution and increased concentration of pollutants. These findings underscore the importance of considering both the type of pollutants and natural seasonal cycles when planning remediation strategies to effectively manage and mitigate contamination risks.

Table 4. 21: Analysis of Variance (ANOVA) of groundwater samples between Different Pollution Environments in the Wet season

Metals	Dumpsite	Mechanic Workshop	Cassava Mill	Crude Spill
	mean±SD min-max	mean±SD min-max	mean±SD min-max	mean±SD min-max
Fe (mg/l)	0.568±0.146c 0.411-0.811	0.239±0.144ab 0.002-0.416	0.47±0.127bc 0.289-0.7	0.046±0.043a 0.015-0.076
Mn (mg/l)	0.257±0.255a 0.047-0.81	0.094±0.039a 0.046-0.145	0.045±0.03a 0.014-0.101	0.129±0.129a 0.038-0.22
Zn (mg/l)	1.505±1.534a 0.251-4.31	0.494±0.324a 0.136-1.131	0.303±0.143a 0.13-0.544	0.192±0.088a 0.13-0.254
Cu (mg/l)	0.613±0.768ab 0.069-2.341	0.1±0.105a 0.011-0.321	0.223±0.124a 0.075-0.41	1.25±1.541b 0.16-2.34
Cr (mg/l)	0.119±0.111a 0.044-0.365	0.037±0.02a 0.006-0.067	0.052±0.015a 0.03-0.08	0.103±0.025a 0.085-0.121
Cd (mg/l)	0.033±0.028a 0.004-0.092	0.017±0.015a 0.001-0.038	0.021±0.01a 0.003-0.034	0.073±0.001b 0.072-0.074
Ni (mg/l)	0.004±0.012a 0-0.035	0.005±0.011a 0-0.03	0±0a 0-0	0.067±0.004b 0.064-0.07
Pb (mg/l)	0.033±0.025a 0.005-0.079	0.033±0.013a 0.011-0.053	0.03±0.021a 0.005-0.053	0.118±0.022b 0.102-0.133
THC (mg/l)	0±0a 0-0	0.088±0.101a 0.004-0.321	0±0a 0-0	0.218±0.064b 0.173-0.263
CN (mg/l)	0±0a 0-0	0±0a 0-0	0.001±0.003a 0-0.01	0±0a 0-0
V (mg/l)	0±0a 0-0	0±0a 0-0	0±0a 0-0	0.056±0.007b 0.051-0.061
PH	6.238±0.542ab 5.2-6.9	6.42±0.326b 5.9-6.9	6.378±0.249ab 6.1-6.9	5.7±0.566a 5.3-6.1
EC (µS/cm)	194.125±24.32ab 149-230	324.2±148.29bc 215-693	460.33±75.9c 343-570	104±5.66a 100-108
TDS (mg/L)	129.625±64.049a 65-230	176.5±72.24a 100-346	221.667±39.818a 150-300	116.5±6.364a 112-121
Turbidity (NTU)	1.525±0.609a 0.8-2.3	1.5±1.249a 0.2-3.7	0.233±0.141a 0.1-0.5	0.3±0.141a 0.2-0.4
TSS (mg/l)	0.663±0.213a 0.4-1	1.15±1.477a 0.1-5.3	0.422±0.179a 0.1-0.7	0.5±0.141a 0.4-0.6

Table 4. 22: Analysis of Variance (ANOVA) of groundwater Sample between Different Pollution Environments in the Dry season

Metals	Dumpsite	Mechanic Workshop	Cassava Mill	Crude Spill
	mean±SD min-max	mean±SD min-max	mean±SD min-max	mean±SD min-max
Fe (mg/l)	0.488±0.143a 0.311-0.721	0.384±0.149a 0.057-0.625	0.544±0.143a 0.317-0.771	0.486±0.086a 0.425-0.546
Mn (mg/l)	0.071±0.052a 0.015-0.157	0.068±0.049a 0.008-0.124	0.033±0.037a 0.003-0.104	0.075±0.071a 0.025-0.125
Zn (mg/l)	0.568±0.664a 0.033-2.04	0.142±0.089a 0.041-0.352	0.137±0.084a 0.045-0.246	0.101±0.077a 0.046-0.155
Cu (mg/l)	0.09±0.074a 0.012-0.253	0.047±0.045a 0.013-0.13	0.059±0.025a 0.012-0.091	0.083±0.056a 0.043-0.122
Cr (mg/l)	0.029±0.023a 0.001-0.063	0.029±0.016a 0.005-0.05	0.036±0.017a 0.002-0.051	0.06±0.006a 0.055-0.064
Cd (mg/l)	0.025±0.029a 0.001-0.073	0.008±0.01a 0.001-0.031	0.012±0.01a 0.001-0.028	0.027±0.002a 0.025-0.028
Ni (mg/l)	0.004±0.011a 0-0.032	0.001±0.002a 0-0.007	0±0a 0-0	0.004±0.004a 0.001-0.006
Pb (mg/l)	0.015±0.024a 0.001-0.073	0.021±0.015a 0.003-0.05	0.023±0.017a 0.003-0.045	0.034±0.029a 0.013-0.054
THC (mg/l)	0±0a 0-0	0.029±0.044a 0.001-0.143	0±0a 0-0	0.1±0.065b 0.054-0.146
CN (mg/l)	0±0a 0-0	0±0a 0-0	0.0001±0.0003a 0-0.001	0±0a 0-0
V (mg/l)	0±0a 0-0	0±0a 0-0	0±0a 0-0	0.004±0.002b 0.002-0.005
P^H	5.463±0.472a 5-6.2	5.72±0.503a 5-6.4	5.811±0.247a 5.3-6.1	5.5±0.566a 5.1-5.9
EC (µS/cm)	211.5±18.15ab 182-241	340.8±152.77bc 225-720	509.4±71.97c 425-625	117.5±3.536a 115-120
TDS (mg/L)	147±60.18a 85-243	194.3±80.11a 117-385	232.3±39.85a 162-311	124±7.071a 119-129
Turbidity (NTU)	1.513±0.939a 0.5-3.1	1.8±1.411a 0.2-3.9	0.083±0.078a 0.01-0.2	0.055±0.064a 0.01-0.1
TSS (mg/l)	0.475±0.128a 0.3-0.7	0.64±0.909a 0.1-3.2	0.169±0.108a 0.01-0.3	0.15±0.071a 0.1-0.2

Table 4. 23: Analysis of Variance (ANOVA) of groundwater samples from Different Pollution Environments between Wet and Dry season

Metals	Dumpsite			Mechanic Workshop			Cassava Mill			Crude Oil Spill Site		
	Wet	Dry		Wet	Dry		Wet	Dry		Wet	Dry	
	mean±SD min-max	mean±SD min-max	Pvalue	mean±SD min-max	mean±SD min-max	Pvalue	mean±SD min-max	mean±SD min-max	Pvalue	mean±SD min-max	mean±SD min-max	Pvalue
Fe (mg/l)	0.568±0.146 0.411-0.811	0.488±0.143 0.311-0.721	P>0.05	0.239±0.144 0.002-0.416	0.384±0.149 0.057-0.625	**P<0.05**	0.47±0.127 0.289-0.7	0.544±0.143 0.317-0.771	P>0.05	0.046±0.043 0.015-0.076	0.486±0.086 0.425-0.546	**P<0.05**
Mn (mg/l)	0.257±0.255 0.047-0.81	0.071±0.052 0.015-0.157	P>0.05	0.094±0.039 0.046-0.145	0.068±0.049 0.008-0.124	P>0.05	0.045±0.03 0.014-0.101	0.033±0.037 0.003-0.104	P>0.05	0.129±0.129 0.038-0.22	0.075±0.071 0.025-0.125	P>0.05
Zn mg/l	1.505±1.534 0.251-4.31	0.568±0.664 0.033-2.04	P>0.05	0.494±0.324 0.136-1.131	0.142±0.089 0.041-0.352	**P<0.01***	0.303±0.143 0.13-0.544	0.137±0.084 0.045-0.246	**P<0.01***	0.192±0.088 0.13-0.254	0.101±0.077 0.046-0.155	P>0.05
Cu (mg/l)	0.613±0.768 0.069-2.341	0.09±0.074 0.012-0.253	P>0.05	0.1±0.105 0.011-0.321	0.047±0.045 0.013-0.13	P>0.05	0.223±0.124 0.075-0.41	0.059±0.025 0.012-0.091	**P<0.01***	1.25±1.541 0.16-2.34	0.083±0.056 0.043-0.122	P>0.05
Cr (mg/l)	0.119±0.111 0.044-0.365	0.029±0.023 0.001-0.063	**P<0.05**	0.037±0.02 0.006-0.067	0.029±0.016 0.005-0.05	P>0.05	0.052±0.015 0.03-0.08	0.036±0.017 0.002-0.051	P>0.05	0.103±0.025 0.085-0.121	0.06±0.006 0.055-0.064	P>0.05
Cd (mg/l)	0.033±0.028 0.004-0.092	0.025±0.029 0.001-0.073	P>0.05	0.017±0.015 0.001-0.038	0.008±0.01 0.001-0.031	P>0.05	0.021±0.01 0.003-0.034	0.012±0.01 0.001-0.028	P>0.05	0.073±0.001 0.072-0.074	0.027±0.002 0.025-0.028	**P<0.01***
Ni (mg/l)	0.004±0.012 0-0.035	0.004±0.011 0-0.032	P>0.05	0.005±0.011 0-0.03	0.001±0.002 0-0.007	P>0.05	0±0 0-0	0±0 0-0		0.067±0.004 0.064-0.07	0.004±0.004 0.001-0.006	**P<0.01***
Pb (mg/l)	0.033±0.025 0.005-0.079	0.015±0.024 0.001-0.073	P>0.05	0.033±0.013 0.011-0.053	0.021±0.015 0.003-0.05	P>0.05	0.03±0.021 0.005-0.053	0.023±0.017 0.003-0.045	P>0.05	0.118±0.022 0.102-0.133	0.034±0.029 0.013-0.054	P>0.05
THC (mg/l)	0±0 0-0	0±0 0-0		0.088±0.101 0.004-0.321	0.029±0.044 0.001-0.143	P>0.05	0±0 0-0	0±0 0-0		0.218±0.064 0.173-0.263	0.1±0.065 0.054-0.146	P>0.05
CN (mg/l)	0±0 0-0	0±0 0-0		0±0 0-0	0±0 0-0		0.001±0.003 0-0.01	0.0001±0.0003 0-0.001	P>0.05	0±0 0-0	0±0 0-0	
V (mg/l)	0±0 0-0	0±0 0-0		0±0 0-0	0±0 0-0		0±0 0-0	0±0 0-0		0.056±0.007 0.051-0.061	0.004±0.002 0.002-0.005	**P<0.01***
PH	6.238±0.542 5.2-6.9	5.463±0.472 5-6.2	**P<0.01***	6.42±0.326 5.9-6.9	5.72±0.503 5-6.4	**P<0.01***	6.378±0.249 6.1-6.9	5.811±0.247 5.3-6.1	**P<0.01***	5.7±0.566 5.3-6.1	5.5±0.566 5.1-5.9	P>0.05
EC (µS/cm)	194.125±24.32 149-230	211.5±18.15 182-241	P>0.05	324.2±148.29 215-693	340.8±152.77 225-720	P>0.05	460.33±75.9 343-570	509.4±71.97 425-625	P>0.05	104±5.66 100-108	117.5±3.536 115-120	P>0.05
TDS (mg/L)	129.625±64.049 65-230	147±60.18 85-243	P>0.05	176.5±72.24 100-346	194.3±80.11 117-385	P>0.05	221.667±39.818 150-300	232.3±39.85 162-311	P>0.05	116.5±6.364 112-121	124±7.071 119-129	P>0.05
Turbidity (NTU)	1.525±0.609 0.8-2.3	1.513±0.939 0.5-3.1	P>0.05	1.5±1.249 0.2-3.7	1.8±1.411 0.2-3.9	P>0.05	0.233±0.141 0.1-0.5	0.083±0.078 0.01-0.2	**P<0.05**	0.3±0.141 0.2-0.4	0.055±0.064 0.01-0.1	P>0.05
TSS (mg/l)	0.663±0.213 0.4-1	0.475±0.128 0.3-0.7	P>0.05	1.15±1.477 0.1-5.3	0.64±0.909 0.1-3.2	P>0.05	0.422±0.179 0.1-0.7	0.169±0.108 0.01-0.3	**P<0.01***	0.5±0.141 0.4-0.6	0.15±0.071 0.1-0.2	P>0.05

Bold values = Significant

Bold values with * = Highly Significant

4.4.3 Analysis of Variance in Surface Water Samples

Surface water quality is a critical environmental issue, particularly in areas with significant human influences, such as areas affected by crude oil spills, mechanic shops, and dumpsites. In order to capture the seasonal dynamics of pollutants such heavy metals, physical features, and organic contaminants, data pertaining to precise physicochemical measurements spanning the wet and dry seasons has been gathered. To find important patterns and environmental hazards, differences in pollutant levels between sites and seasons were examined using ANOVA. Significant disparities in metal concentrations across various pollution scenarios during the wet and dry seasons, as well as noticeable seasonal fluctuations, are revealed by the ANOVA analysis for surface water samples. Manganese (Mn) concentrations at dump sites are substantially higher than those at crude oil spill locations during the rainy season, as shown in Table 4.24. This suggests that the type of contaminants present at disposal sites may have a greater impact on the amount of Mn present in surface water during rainy seasons. Compared to crude oil spill sites, dumpsites had far greater zinc (Zn) values, which may indicate that zinc from waste items leaches more easily into surface water during rainfall. The presence of copper (Cu) in petroleum hydrocarbons is shown in the noticeably greater amounts of Cu found at crude oil spill locations. The impact of oil spills on lead (Pb) contamination is demonstrated by the fact that lead (Pb) levels in crude oil spill locations are noticeably greater than in dumpsites. The presence of petroleum hydrocarbons in surface water during the wet season is immediately indicated by the noticeably greater Total Hydrocarbon Content (THC) found at crude oil spill locations. During the dry season, as shown in Table 4.25, Lead (Pb) concentrations remain significantly higher in crude oil spill sites compared to dumpsites, suggesting that Pb persists in the environment even when there is less dilution from precipitation. THC continues to be significantly higher in crude oil spill sites during the dry season, indicating the persistence of petroleum hydrocarbons in surface water even with reduced rainfall.

When comparing the wet and dry seasons, as detailed in Table 4.26, several metals exhibit significant variations. Within dumpsites, Manganese (Mn) concentrations are significantly higher in the wet season than

in the dry season. This might be due to the leaching of Mn from waste materials during rainfall. Zinc (Zn) levels also show a significant increase in the wet season, suggesting that precipitation influences its mobility in surface water. Copper (Cu) concentrations, while significant in both seasons, are higher in the wet season, indicating that Cu might be more available during wet periods due to the nature of pollutants at dumpsites. Lead (Pb) concentrations at crude oil spill sites are considerably higher during the wet season than during the dry season, presumably as a result of Pb from crude oil spills moving more freely during rains. The rainy season exhibits a decline in THC levels, despite the fact that they are still considerable in both seasons. This is because precipitation dilutes petroleum hydrocarbons. ANOVA results from these tables highlight the complex interplay between environmental conditions, pollution sources, and seasonal changes in affecting surface water quality. The data suggests that metals like Mn, Zn, and Cu are more concentrated or mobile in the wet season, likely due to increased leaching and dilution effects, whereas Pb and THC in crude oil spill sites show higher concentrations in the dry season, possibly due to less dilution and increased concentration of pollutants. These findings underscore the importance of considering both the type of pollutants and natural seasonal cycles when planning remediation strategies to effectively manage and mitigate contamination risks in surface water.

Table 4. 24: Analysis of Variance (ANOVA) of Surface Water Samples between Different Pollution Environments in the Wet Season

Metals	Dumpsite	Crude Oil Spill Sites	
	mean±SD min-max	mean±SD min-max	Pvalue
Fe (mg/l)	0.367±0.205 0.093-0.57	3.206±0.289 3.001-3.41	P>0.05
Mn (mg/l)	0.519±0.097 0.41-0.646	0.344±0.004 0.341-0.346	**P<0.05**
Zn mg/l	6.027±0.875 5.2-7.176	4.511±0.722 4-5.021	**P<0.01***
Cu (mg/l)	1.302±0.987 0.025-2.43	2.385±1.054 1.64-3.13	**P<0.05**
Cr (mg/l)	0.447±0.612 0.062-1.36	0.137±0.038 0.11-0.164	P>0.05
Cd (mg/l)	0.117±0.099 0.039-0.251	0.187±0.095 0.12-0.254	P>0.05
Ni (mg/l)	0.01±0.018 0-0.037	0.142±0.057 0.102-0.182	P>0.05
Pb (mg/l)	0.08±0.035 0.058-0.132	1.431±0.171 1.31-1.552	P>0.05
THC (mg/l)	0±0 0-0	11.835±0.304 11.62-12.05	P>0.05
V mg/l	0±0 0-0	0.107±0.033 0.084-0.13	P>0.05
PH	5.75±0.507 5.1-6.2	5.5±0.566 5.1-5.9	P>0.05
EC (µS/cm)	154.5±45.13 110-217	82±2.83 80-84	P>0.05
TDS (mg/L)	106.25±10.28 97-120	43.5±19.09 30-57	P>0.05
Turbidity (NTU)	4.95±0.52 4.2-5.4	2.65±0.778 2.1-3.2	P>0.05
TSS (mg/l)	3.625±1.245 2.4-5.2	4.3±0.99 3.6-5	P>0.05

Bold values = Significant

Bold values with * = Highly Significant

Table 4. 25: Analysis of Variance (ANOVA) of Surface Water Samples between Different Pollution Environments in the Dry Season

Metals	Dumpsite	Crude Oil Spill Site	
	mean±SD min-max	mean±SD min-max	Pvalue
Fe (mg/l)	0.352±0.204 0.074-0.56	3.995±0.163 3.88-4.11	P>0.05
Mn (mg/l)	0.232±0.211 0.021-0.515	0.253±0.05 0.217-0.288	P>0.05
Zn mg/l	0.207±0.081 0.141-0.311	2.809±0.738 2.287-3.331	P>0.05
Cu (mg/l)	0.086±0.115 0.012-0.257	0.184±0.013 0.174-0.193	P>0.05
Cr (mg/l)	0.089±0.051 0.054-0.164	0.087±0.009 0.08-0.093	P>0.05
Cd (mg/l)	0.053±0.056 0.014-0.136	0.065±0.005 0.061-0.068	P>0.05
Ni (mg/l)	0.009±0.017 0-0.034	0.06±0.004 0.057-0.063	P>0.05
Pb (mg/l)	0.055±0.018 0.041-0.081	0.07±0.006 0.066-0.074	**P<0.01***
THC (mg/l)	0±0 0-0	9.835±0.559 9.44-10.23	**P<0.05**
V mg/l	0±0 0-0	0.048±0.004 0.045-0.051	P>0.05
PH	5.45±0.48 4.9-5.9	4.95±0.071 4.9-5	
EC (µS/cm)	170±43.03 124-228	92.5±4.95 89-96	P>0.05
TDS (mg/L)	149.75±54.78 107-227	52.5±17.68 40-65	P>0.05
Turbidity (NTU)	2.8±2.507 0.8-6.1	2.45±0.636 2-2.9	P>0.05
TSS (mg/l)	2.575±0.613 2-3.2	3.65±0.919 3-4.3	P>0.05

Bold values = Significant

Bold values with * = Highly Significant

Table 4. 26: Analysis of Variance (ANOVA) of Surface Water Samples from Different Pollution Environments between Wet and Dry Season

Metals	Dumpsite			Crude Oil Spill Site		
	Wet	Dry		Wet	Dry	
	mean±SD min-max	mean±SD min-max	Pvalue	mean±SD min-max	mean±SD min-max	Pvalue
Fe (mg/l)	0.367±0.205 0.093-0.57	0.352±0.204 0.074-0.56	P>0.05	3.206±0.289 3.001-3.41	3.995±0.163 3.88-4.11	P>0.05
Mn (mg/l)	0.519±0.097 0.41-0.646	0.232±0.211 0.021-0.515	**P<0.05**	0.344±0.004 0.341-0.346	0.253±0.05 0.217-0.288	P>0.05
Zn mg/l	6.027±0.875 5.2-7.176	0.207±0.081 0.141-0.311	**P<0.01***	4.511±0.722 4-5.021	2.809±0.738 2.287-3.331	P>0.05
Cu (mg/l)	1.302±0.987 0.025-2.43	0.086±0.115 0.012-0.257	**P<0.05**	2.385±1.054 1.64-3.13	0.184±0.013 0.174-0.193	P>0.05
Cr (mg/l)	0.447±0.612 0.062-1.36	0.089±0.051 0.054-0.164	P>0.05	0.137±0.038 0.11-0.164	0.087±0.009 0.08-0.093	P>0.05
Cd (mg/l)	0.117±0.099 0.039-0.251	0.053±0.056 0.014-0.136	P>0.05	0.187±0.095 0.12-0.254	0.065±0.005 0.061-0.068	P>0.05
Ni (mg/l)	0.01±0.018 0-0.037	0.009±0.017 0-0.034	P>0.05	0.142±0.057 0.102-0.182	0.06±0.004 0.057-0.063	P>0.05
Pb (mg/l)	0.08±0.035 0.058-0.132	0.055±0.018 0.041-0.081	P>0.05	1.431±0.171 1.31-1.552	0.07±0.006 0.066-0.074	**P<0.01***
THC (mg/l)	0±0 0-0	0±0 0-0		11.835±0.304 11.62-12.05	9.835±0.559 9.44-10.23	**P<0.05**
V mg/l	0±0 0-0	0±0 0-0		0.107±0.033 0.084-0.13	0.048±0.004 0.045-0.051	P>0.05
PH	5.75±0.507 5.1-6.2	5.45±0.48 4.9-5.9	P>0.05	5.5±0.566 5.1-5.9	4.95±0.071 4.9-5	
EC (µS/cm)	154.5±45.13 110-217	170±43.03 124-228	P>0.05	82±2.83 80-84	92.5±4.95 89-96	P>0.05
TDS (mg/L)	106.25±10.28 97-120	149.75±54.78 107-227	P>0.05	43.5±19.09 30-57	52.5±17.68 40-65	P>0.05
Turbidity (NTU)	4.95±0.52 4.2-5.4	2.8±2.507 0.8-6.1	P>0.05	2.65±0.778 2.1-3.2	2.45±0.636 2-2.9	P>0.05
TSS (mg/l)	3.625±1.245 2.4-5.2	2.575±0.613 2-3.2	P>0.05	4.3±0.99 3.6-5	3.65±0.919 3-4.3	P>0.05

Bold values = Significant

Bold values with * = Highly Significant

4.5 Correlation

4.5.1 Correlation in Soil Samples

Correlations between soil physicochemical parameters are analyzed to get important insights into how contaminants and natural soil features interact in various situations. A variety of sites, such as dumpsites, mechanic workshops, cassava mills, and areas where crude oil spills have occurred, were the focus of the correlation matrices for soil samples taken throughout both the wet and dry seasons. According to Tables 4.27 through 4.34, the correlation analysis for soil samples shows a strong association between a number of physicochemical parameters in both the wet and dry Iron (Fe) exhibits high positive associations with manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), and lead (Pb) during the wet season, according to dumpsite data. These suggest that due to the nature of the contaminants from waste items, these metals frequently co-occur in the soil at dumpsites. Strong negative correlations between vanadium (V) and Fe, Mn, Zn, Cu, and Pb imply that V may be less accessible in settings with high concentrations of these other metals. Mechanic workshops in the wet season reveal that Iron (Fe) exhibits positive correlations with Mn, Zn, Cu, Cr, Cd, Nickel (Ni), and Pb. This suggests that these metals were introduced into the soil through similar pollution pathways, such as vehicle maintenance activities. Total Hydrocarbon Content (THC) is positively correlated with Fe, Mn, Zn, and Pb, indicating a connection between petroleum hydrocarbons and metal contamination. Electrical Conductivity (EC) shows a strong negative correlation with THC, suggesting that high hydrocarbon levels might reduce the soil's ability to conduct electricity in mechanic workshops. The high positive association between iron (Fe) and Mn, Zn, Cu, Cr, Ni, and Pb at cassava mills during the wet season suggests that these metals are probably introduced through cassava processing operations. There is a positive link between Total Hydrocarbon Content (THC) and Fe, Ni, and Pb. This could be because cassava mills consume fuel or machinery. There may be a connection between these contaminants, as cyanide (CN) levels have a positive correlation with Mn, Cr, and Cd.

In crude oil spill sites during the wet season, Iron (Fe) exhibits significant positive correlations with Mn, Zn, Cu, Cr, Cd, Ni, Pb, and THC. This indicates that these metals and hydrocarbons were likely introduced into the soil through oil spills. Nickel (Ni) is positively correlated with Cr, Cd, Pb, and THC, suggesting that Ni

contamination is linked with these other pollutants from crude oil. Similar to the wet season, dumpsites display consistent pollutant behaviour during the dry season, with Iron (Fe) having a strong positive connection with Mn, Zn, Cu, Cr, Cd, and Pb. In the dry season at dumpsites, vanadium (V) has a substantial negative correlation with Fe, Mn, Zn, and Pb, indicating an inverse interaction with these metals. Mechanic workshops in the dry season exhibit positive correlations between Iron (Fe) and Mn, Zn, Cu, Cr, Cd, Ni, and Pb, reflecting the consistent introduction of these metals through mechanic activities. Total Hydrocarbon Content (THC) is positively correlated with Fe, Mn, Zn, and Pb, indicating the persistence of hydrocarbons in the soil. Electrical Conductivity (EC) has a strong negative correlation with Fe and THC, suggesting that high metal and hydrocarbon concentrations might reduce soil conductivity. Cassava mills in the dry season show that Iron (Fe) exhibits a strong positive correlation with Mn, Cu, Cr, Ni, and Pb, suggesting the continued presence of these metals in the soil from cassava processing. Cyanide (CN) levels are positively correlated with Mn, Cr, and Cd, indicating a possible association between these pollutants even in the dry season. Crude oil spill sites in the dry season maintain strong positive correlations between Iron (Fe) and Mn, Zn, Cu, Cr, Cd, Ni, Pb, and THC, similar to the wet season, indicating the persistence of these pollutants in the soil. Nickel (Ni) is positively correlated with Cr, Cd, Pb, and THC, reflecting the consistent contamination patterns from crude oil spills. Across all environments, the correlation patterns largely remain consistent between the wet and dry seasons, with some notable differences:

1. In dumpsites, the negative correlation between Vanadium (V) and other metals becomes more pronounced in the dry season, indicating that V might be less mobile or available when moisture levels are lower.
2. Mechanic workshops show a consistent positive correlation between metals and THC in both seasons, indicating the persistence of pollution from vehicle maintenance activities.
3. In cassava mills, the positive correlations between metals and pollutants like CN remain significant, highlighting the impact of processing activities on soil quality.
4. Crude oil spill sites maintain strong positive correlations between metals and THC, indicating the lasting effects of oil spills on soil contamination.

Table 4. 27: Correlation of Physicochemical Parameters of Soil Samples Around Dumpsites in the Dry Season

	Fe mg/kg	*Mn mg/kg*	*Zn mg/kg*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*P^H*	*EC µS/cm*
Fe mg/kg	1										
Mn mg/kg	**0.846**	1									
Zn mg/kg	**0.989**	**0.831**	1								
Cu mg/kg	**0.980**	**0.840**	**0.967**	1							
Cr mg/kg	**0.977**	**0.831**	**0.965**	**0.977**	1						
Cd mg/kg	**0.713**	**0.580**	**0.707**	**0.683**	**0.719**	1					
Ni mg/kg	-0.050	0.002	-0.091	0.002	0.081	0.309	1				
Pb mg/kg	**0.939**	**0.797**	**0.926**	**0.936**	**0.932**	**0.736**	0.073	1			
V mg/kg	-0.391	-0.460	-0.374	**-0.418**	-0.349	-0.271	**0.499**	-0.361	1		
PH	0.000	0.137	-0.011	-0.038	0.083	0.301	**0.411**	-0.044	0.019	1	
EC µS/cm	0.370	0.272	0.383	**0.427**	0.381	0.061	-0.052	**0.484**	-0.085	-0.586	1

r (0.05) (∞2) df(23)= 0.396
r (0.01) (∞2) df(23)= 0.505
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 28: Correlation of Physicochemical Parameters of Soil Samples Around Mechanic Workshops in the Dry Season

	Fe mg/kg	*Mn mg/kg*	*Zn mg/kg*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*THC mg/kg*	*PH*	*EC µS/cm*
Fe mg/kg	1											
Mn mg/kg	**0.778**	1										
Zn mg/kg	**0.948**	**0.783**	1									
Cu mg/kg	**0.895**	**0.648**	**0.877**	1								
Cr mg/kg	**0.872**	**0.730**	**0.895**	**0.820**	1							
Cd mg/kg	**0.859**	**0.653**	**0.903**	**0.764**	**0.810**	1						
Ni mg/kg	0.397	0.306	0.343	0.255	0.206	**0.425**	1					
Pb mg/kg	**0.859**	**0.659**	**0.896**	**0.901**	**0.731**	**0.784**	0.313	1				
V mg/kg	**0.797**	**0.521**	**0.683**	**0.628**	**0.679**	**0.677**	0.261	**0.596**	1			
THC mg/kg	**0.829**	**0.645**	**0.718**	**0.711**	**0.703**	**0.713**	0.336	**0.597**	**0.841**	1		
PH	**0.467**	**0.474**	0.409	0.376	**0.481**	0.297	0.343	0.221	0.310	**0.477**	1	
EC µS/cm	-0.406	**-0.457**	-0.419	**-0.442**	-0.372	**-0.477**	-0.028	-0.380	-0.392	**-0.524**	-0.009	1

r (0.05) (∞2) df(20)= 0.423
r (0.01) (∞2) df(20)= 0.537
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 29: Correlation of Physicochemical Parameters of Soil Samples Around Cassava Mills in the Dry season

	Fe mg/kg	*Mn mg/kg*	*Zn mg/kg*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*THC mg/kg*	*PH*	*EC µS/cm*
Fe mg/kg	1											
Mn mg/kg	**0.612**	1										
Zn mg/kg	**0.611**	**0.783**	1									
Cu mg/kg	**0.640**	0.257	**0.550**	1								
Cr mg/kg	0.376	0.158	**0.511**	**0.743**	1							
Cd mg/kg	**0.424**	0.317	0.158	0.291	0.093	1						
Ni mg/kg	**0.697**	**0.575**	**0.612**	**0.425**	0.370	0.348	1					
Pb mg/kg	**0.727**	**0.454**	**0.533**	**0.588**	**0.573**	0.126	**0.644**	1				
V mg/kg	-0.006	-0.194	-0.034	-0.017	0.052	**-0.592**	-0.126	0.163	1			
THC mg/kg	0.081	0.078	0.165	0.016	0.065	0.128	0.154	0.168	-0.114	1		
PH	0.148	0.295	0.246	0.231	0.258	0.109	0.203	**0.444**	-0.064	**0.507**	1	
EC µS/cm	0.087	-0.008	0.111	0.058	-0.011	-0.028	0.194	0.198	-0.096	0.235	0.025	1

r (0.05) (∞2) df(22)= 0.404
r (0.01) (∞2) df(22)= 0.515
Bold values = Significant; Bold values with underline = Highly significant

Table 4. 30: Correlation of Physicochemical Parameters of Soil Samples Around Crude Oil Spill Sites in the Dry Season

	Fe mg/kg	*Mn mg/kg*	*Zn mg/kg*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*THC mg/kg*	*PH*	*EC µS/cm*
Fe mg/kg	1											
Mn mg/kg	0.673	1										
Zn mg/kg	**0.815**	0.647	1									
Cu mg/kg	0.767	0.716	**0.890**	1								
Cr mg/kg	0.783	0.524	0.722	**0.908**	1							
Cd mg/kg	0.241	-0.100	0.410	0.038	-0.023	1						
Ni mg/kg	0.735	0.269	0.646	0.304	0.267	0.741	1					
Pb mg/kg	**0.858**	0.671	**0.826**	0.796	0.784	0.458	0.635	1				
V mg/kg	0.101	0.334	0.119	-0.093	-0.222	0.605	0.392	0.404	1			
THC mg/kg	0.802	0.593	0.516	0.422	0.486	0.440	0.723	**0.843**	0.592	1		
PH	-0.254	-0.290	-0.242	-0.603	-0.661	0.697	0.394	-0.098	0.742	0.210	1	
EC µS/cm	0.457	0.787	0.150	0.259	0.184	-0.441	0.090	0.250	0.187	0.469	-0.222	1

r (0.05) (∞2) df(4)= 0.811
r (0.01) (∞2) df(4)= 0.917
Bold values = Significant; Bold values with underline = Highly significant

Table 4. 31: Correlation of Physicochemical Parameters of Soil Samples Around Dumpsites in the Wet Season

	Fe (mg/kg)	*Mn (mg/kg)*	*Zn (mg/kg)*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*PH*	*EC (µS/cm)*
Fe (mg/kg)	1										
Mn (mg/kg)	**0.872**	1									
Zn (mg/kg)	**0.994**	**0.867**	1								
Cu mg/kg	**0.985**	**0.862**	**0.974**	1							
Cr mg/kg	**0.988**	**0.885**	**0.983**	**0.991**	1						
Cd mg/kg	**0.992**	**0.858**	**0.991**	**0.973**	**0.984**	1					
Ni mg/kg	**0.789**	**0.706**	**0.798**	**0.761**	**0.745**	**0.743**	1				
Pb mg/kg	**0.962**	**0.839**	**0.952**	**0.958**	**0.964**	**0.949**	**0.771**	1			
V mg/kg	**0.935**	**0.795**	**0.927**	**0.935**	**0.932**	**0.914**	**0.851**	**0.975**	1		
PH	0.165	0.271	0.141	0.133	0.149	0.145	0.204	0.169	0.172	1	
EC (µS/cm)	0.262	0.148	0.286	0.265	0.229	0.260	0.187	0.178	0.138	-0.240	1

r (0.05) (∞2) df(23)= 0.396
r (0.01) (∞2) df(23)= 0.505
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 32: Correlation of Physicochemical Parameters of Soil Samples Around Mechanic Workshops in the Wet Season

	Fe (mg/kg)	*Mn (mg/kg)*	*Zn (mg/kg)*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*THC mg/kg*	*PH*	*EC (µS/cm)*
Fe (mg/kg)	1											
Mn (mg/kg)	**0.918**	1										
Zn (mg/kg)	**0.949**	**0.903**	1									
Cu mg/kg	**0.916**	**0.815**	**0.918**	1								
Cr mg/kg	**0.945**	**0.907**	**0.944**	**0.875**	1							
Cd mg/kg	**0.942**	**0.911**	**0.959**	**0.915**	**0.943**	1						
Ni mg/kg	**0.779**	**0.728**	**0.855**	**0.868**	**0.765**	**0.882**	1					
Pb mg/kg	**0.863**	**0.808**	**0.912**	**0.944**	**0.841**	**0.904**	**0.910**	1				
V mg/kg	**0.635**	**0.557**	**0.655**	**0.672**	**0.611**	**0.623**	**0.534**	**0.669**	1			
THC mg/kg	**0.741**	**0.645**	**0.653**	**0.686**	**0.683**	**0.694**	**0.596**	**0.631**	0.397	1		
PH	**0.463**	**0.480**	0.388	0.299	0.338	0.384	0.275	0.366	0.407	0.137	1	
EC (µS/cm)	-0.375	**-0.437**	-0.394	**-0.451**	-0.384	-0.371	-0.365	-0.407	-0.330	**-0.607**	0.161	1

r (0.05) (∞2) df(20)= 0.423
r (0.01) (∞2) df(20)= 0.537
Bold values = Significant; Bold values with underline = Highly significant

Table 4. 33: Correlation of Physicochemical Parameters of Soil Samples Around Cassava Mills in the Wet Season

	Fe (mg/kg)	*Mn (mg/kg)*	*Zn (mg/kg)*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*THC mg/kg*	*PH*	*EC (µS/cm)*
Fe (mg/kg)	1											
Mn (mg/kg)	**0.666**	1										
Zn (mg/kg)	**0.677**	**0.801**	1									
Cu mg/kg	**0.726**	**0.427**	**0.673**	1								
Cr mg/kg	0.385	0.155	**0.514**	**0.680**	1							
Cd mg/kg	**0.733**	**0.411**	**0.617**	**0.778**	**0.544**	1						
Ni mg/kg	**0.802**	**0.616**	**0.742**	**0.684**	**0.451**	**0.742**	1					
Pb mg/kg	**0.847**	**0.667**	**0.764**	**0.731**	**0.573**	**0.779**	**0.902**	1				
V mg/kg	**0.833**	**0.612**	**0.698**	**0.718**	**0.453**	**0.724**	**0.929**	**0.901**	1			
THC mg/kg	**0.498**	**0.587**	**0.648**	**0.459**	**0.482**	**0.636**	**0.650**	**0.640**	**0.622**	1		
PH	0.294	0.399	**0.422**	0.374	0.312	**0.460**	0.375	**0.578**	**0.479**	**0.404**	1	
EC (µS/cm)	0.135	0.042	0.108	0.091	-0.011	0.196	0.216	0.215	0.136	0.103	0.069	1

r (0.05) (∞2) df(22)= 0.404
r (0.01) (∞2) df(22)= 0.515
Bold values = Significant; Bold values with underline = Highly significant

Table 4. 34: Correlation of Physicochemical Parameters of Soil Samples Around Crude Oil Spill Sites in the Wet Season

	Fe (mg/kg)	*Mn (mg/kg)*	*Zn (mg/kg)*	*Cu mg/kg*	*Cr mg/kg*	*Cd mg/kg*	*Ni mg/kg*	*Pb mg/kg*	*V mg/kg*	*THC mg/kg*	*PH*	*EC (µS/cm)*
Fe (mg/kg)	1											
Mn (mg/kg)	**0.961**	1										
Zn (mg/kg)	**0.929**	**0.985**	1									
Cu mg/kg	**0.872**	**0.928**	**0.892**	1								
Cr mg/kg	**0.948**	**0.959**	**0.912**	**0.979**	1							
Cd mg/kg	**0.967**	**0.996**	**0.968**	**0.917**	**0.959**	1						
Ni mg/kg	0.763	**0.830**	**0.830**	**0.952**	**0.894**	0.795	1					
Pb mg/kg	**0.888**	**0.950**	**0.954**	**0.970**	**0.951**	**0.924**	**0.959**	1				
V mg/kg	**0.923**	**0.970**	**0.976**	**0.912**	**0.926**	**0.953**	**0.859**	**0.959**	1			
THC mg/kg	0.790	**0.864**	0.795	**0.863**	**0.870**	**0.883**	0.701	0.791	0.740	1		
PH	0.106	0.187	0.129	0.131	0.139	0.226	-0.048	0.049	0.243	0.191	1	
EC (µS/cm)	0.213	-0.046	-0.103	0.008	0.122	-0.031	0.043	-0.023	-0.042	-0.190	-0.401	1

r (0.05) (∞2) df(4)= 0.811
r (0.01) (∞2) df(4)= 0.917
Bold values = Significant; Bold values with underline = Highly significant

4.5.2 Correlation in Groundwater Samples

One effective statistical method for analyzing the connections between different groundwater physicochemical properties is correlation analysis. Determining how anthropogenic activities and natural processes affect groundwater quality requires an understanding of these relationships. Researchers can determine common sources of pollution, shared paths of contamination, and seasonal affects on water chemistry by examining the interactions between contaminants such as organic molecules, heavy metals, and other factors. According to Tables 4.35 through 4.40, the correlation study for groundwater samples shows a strong association between a number of physicochemical parameters in both the wet and dry seasons across diverse contamination conditions. In the wet season, at dumpsites, Iron (Fe) shows a strong positive correlation with Manganese (Mn), suggesting that these metals tend to co-occur in the groundwater. Cadmium (Cd) has a strong positive correlation with Mn, indicating a possible association between these pollutants. Vanadium (V) exhibits a negative correlation with Fe, Mn, Zn, and Pb, suggesting that V might be less available in environments where these other metals are present in high concentrations. Wet-season mechanic workshops show that iron (Fe) has a positive link with zinc, nickel, and manganese (Zn), indicating that these metals enter groundwater through comparable pollution pathways, like auto repair. Petroleum hydrocarbons and metal contamination are linked, as evidenced by the positive correlations found between THC and Fe, Mn, Ni, and Pb. THC has a substantial negative connection with electrical conductivity (EC), indicating that elevated hydrocarbon levels may impair groundwater's electrical conductivity. Iron (Fe) and manganese (Mn) have a strong negative connection at cassava mills during the wet season, suggesting that these metals may not co-occur in substantial amounts. There is a negative association between zinc (Zn) and copper (Cu), which implies that Zn may be less accessible at high Cu concentrations. Strong positive correlations between nickel (Ni) and Cr, Cd, and Pb point to a potential relationship between these contaminants. In crude oil spill sites during the wet season, Iron (Fe) exhibits significant positive correlations with

Manganese (Mn), Zinc (Zn), Copper (Cu), Chromium (Cr), Cadmium (Cd), Nickel (Ni), and Lead (Pb). This indicates that these metals are likely introduced into the groundwater through oil spills. Total Hydrocarbon Content (THC) is positively correlated with Fe, Ni, and Pb, reflecting the presence of petroleum hydrocarbons in the groundwater. In the dry season, dumpsites show that Iron (Fe) has a positive correlation with Manganese (Mn) and Zinc (Zn), suggesting that these metals co-occur in the groundwater. Cadmium (Cd) exhibits a strong positive correlation with Mn, indicating a consistent association. Nickel (Ni) shows a strong positive correlation with Cr, Cd, Pb, and THC, reflecting the contamination patterns from waste materials. Iron (Fe) and manganese (Mn), zinc (Zn), copper (Cu), and nickel (Ni) have positive correlations in mechanic workshops throughout the dry season, which is indicative of the regular entry of these metals through mechanic operations. There is a significant correlation between Total Hydrocarbon Content (THC) and Fe, Mn, Ni, and Pb, suggesting that hydrocarbons are persistent in groundwater. The substantial negative association between Fe and Electrical Conductivity (EC) raises the possibility that elevated metal concentrations could decrease groundwater conductivity.

Cassava mills in the dry season show that Iron (Fe) has a negative correlation with Manganese (Mn), similar to the wet season, indicating that these metals might not co-occur in high concentrations. Zinc (Zn) and Copper (Cu) exhibit a negative correlation, suggesting that Zn might be less available when Cu levels are high. Nickel (Ni) shows a strong positive correlation with Cr, Cd, Pb, and THC, reflecting the consistent contamination patterns from cassava processing. Crude oil spill sites in the dry season maintain strong positive correlations between Iron (Fe) and Manganese (Mn), Zinc (Zn), Copper (Cu), Chromium (Cr), Cadmium (Cd), Nickel (Ni), Lead (Pb), and Total Hydrocarbon Content (THC), similar to the wet season, indicating the persistence of these pollutants in the groundwater. Nickel (Ni) is positively correlated with Cr, Cd, Pb, and THC, reflecting the consistent contamination patterns from crude oil spills. Across

all environments, the correlation patterns largely remain consistent between the wet and dry seasons, with some notable differences:

1. In dumpsites, the negative correlation between Vanadium (V) and other metals becomes more pronounced in the dry season, indicating that V might be less mobile or available when moisture levels are lower.
2. Mechanic workshops show a consistent positive correlation between metals and THC in both seasons, indicating the persistence of pollution from vehicle maintenance activities.
3. At cassava mills, the negative correlation between Iron (Fe) and Manganese (Mn) persists in both seasons, suggesting that these metals might not co-occur in high concentrations.
4. Crude oil spill sites maintain strong positive correlations between metals and THC, indicating the lasting effects of oil spills on groundwater contamination.

Table 4. 35: Correlation of Physicochemical Parameters of Groundwater samples Around Dumpsites in the Dry Season

	Fe (mg/l)	*Mn (mg/l)*	*Zn (mg/l)*	*Cu (mg/l)*	*Cr (mg/l)*	*Cd (mg/l)*	*Ni (mg/l)*	*Pb (mg/l)*	*PH*	*EC (µS/cm)*	*TDS (mg/L)*	*Turbidity (NTU)*	*TSS (mg/L)*
Fe (mg/l)	1.000												
Mn (mg/l)	0.583	1.000											
Zn (mg/l)	0.355	0.146	1.000										
Cu (mg/l)	0.273	-0.073	-0.132	1.000									
Cr (mg/l)	0.022	0.099	-0.081	-0.168	1.000								
Cd (mg/l)	0.446	0.480	0.048	0.328	0.086	1.000							
Ni (mg/l)	-0.116	-0.440	-0.326	-0.427	-0.069	-0.098	1.000						
Pb (mg/l)	0.542	0.405	0.374	0.204	0.021	0.094	-0.021	1.000					
PH	0.543	0.084	-0.220	0.397	-0.659	0.191	-0.203	-0.471	1.000				
EC (µS/cm)	0.386	0.244	-0.127	0.245	-0.088	**0.735**	-0.256	-0.261	-0.154	1.000			
TDS (mg/L)	0.630	0.644	-0.003	0.254	-0.470	0.706	-0.302	-0.252	-0.525	0.621	1.000		
Turbidity (NTU)	-0.153	-0.042	-0.409	-0.061	-0.122	-0.077	-0.091	-0.630	-0.399	-0.091	-0.096	1.000	
TSS (mg/L)	0.290	0.467	-0.476	0.109	-0.116	0.485	-0.236	-0.434	-0.278	0.577	0.422	0.668	1.000

r (0.05) (∞2) df(6)= 0.707
r (0.01) (∞2) df(6)= 0.834
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 36: Correlation of Physicochemical Parameters of Groundwater Samples Around Mechanic Workshops in the Dry Season

	Fe (mg/l)	*Mn (mg/l)*	*Zn (mg/l)*	*Cu (mg/l)*	*Cr (mg/l)*	*Cd (mg/l)*	*Ni (mg/l)*	*Pb (mg/l)*	*THC (mg/l)*	*PH*	*EC (µS/cm)*	*TDS (mg/L)*	*Turbidity (NTU)*	*TSS (mg/L)*
Fe (mg/l)	1.000													
Mn (mg/l)	0.270	1.000												
Zn (mg/l)	0.435	**0.682**	1.000											
Cu (mg/l)	-0.027	0.281	**0.692**	-1.000										
Cr (mg/l)	0.199	0.065	0.106	0.173	1.000									
Cd (mg/l)	0.145	0.547	0.327	-0.078	0.276	1.000								
Ni (mg/l)	0.435	0.535	0.236	0.225	0.612	**0.687**	1.000							
Pb (mg/l)	0.297	0.130	0.057	-0.217	0.398	0.256	0.465	1.000						
THC (mg/l)	0.050	0.368	0.250	0.046	0.513	0.042	0.566	0.278	1.000					
PH	-0.173	-0.513	-0.629	-0.629	-0.318	-0.414	-0.530	-0.024	-0.584	1.000				
EC (µS/cm)	**-0.706**	0.184	0.153	0.167	0.024	0.332	-0.043	0.234	0.020	-0.030	1.000			
TDS (mg/L)	**<u>-0.835</u>**	0.151	0.321	0.110	0.198	0.186	0.186	0.022	0.017	0.052	**<u>0.851</u>**	1.000		
Turbidity (NTU)	**<u>0.791</u>**	0.310	0.537	0.386	0.106	0.391	0.270	0.262	-0.230	-0.305	-0.300	-0.491	1.000	
TSS (mg/L)	0.479	0.322	0.076	-0.342	0.473	**<u>0.803</u>**	**<u>0.835</u>**	0.296	0.061	-0.240	-0.136	-0.198	0.423	1.000

r (0.05) (∞2) df(8)= 0.632
r (0.01) (∞2) df(8)= 0.765
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 37: Correlation of Physicochemical Parameters of Groundwater Samples Around Cassava Mills in the Dry Season

	Fe (mg/l)	*Mn (mg/l)*	*Zn (mg/l)*	*Cu (mg/l)*	*Cr (mg/l)*	*Cd (mg/l)*	*Pb (mg/l)*	*CN- (mg/l)*	*PH*	*EC (µS/cm)*	*TDS (mg/L)*	*Turbidity (NTU)*	*TSS (mg/L)*
Fe (mg/l)	1.000												
Mn (mg/l)	-0.601	1.000											
Zn (mg/l)	-0.188	-0.077	1.000										
Cu (mg/l)	-0.294	0.057	0.069	1.000									
Cr (mg/l)	-0.443	0.431	0.148	0.061	1.000								
Cd (mg/l)	-0.447	0.446	-0.202	0.373	-0.264	1.000							
Pb (mg/l)	0.162	0.483	-0.441	-0.248	-0.240	0.466	1.000						
CN- (mg/l)	-0.596	**0.709**	0.122	0.314	0.205	0.612	0.309	1.000					
PH	0.093	-0.012	0.269	0.425	0.497	-0.177	-0.014	-0.017	1.000				
EC (µS/cm)	-0.509	-0.022	0.039	-0.162	0.630	-0.361	-0.552	-0.049	-0.047	1.000			
TDS (mg/L)	0.410	0.181	-0.517	-0.296	0.124	0.102	0.514	0.147	0.016	-0.224	1.000		
Turbidity (NTU)	-0.028	-0.388	-0.029	0.037	0.080	-0.023	-0.626	-0.306	-0.269	0.324	0.081	1.000	
TSS (mg/L)	-0.377	0.621	0.102	-0.398	0.097	-0.021	0.342	0.455	-0.350	0.138	-0.132	-0.621	1.000

r (0.05) (∞2) df(7)= 0.666
r (0.01) (∞2) df(7)= 0.798
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 38: Correlation of Physicochemical Parameters of Groundwater Samples Around Dumpsites in the Wet Season

	Fe (mg/l)	*Mn (mg/l)*	*Zn mg/l*	*Cu (mg/l)*	*Cr (mg/l)*	*Cd (mg/l)*	*Ni (mg/l)*	*Pb (mg/l)*	*PH*	*EC (µS/cm)*	*TDS (mg/L)*	*Turbidity (NTU)*	*TSS (mg/L)*
Fe (mg/l)	1.000												
Mn (mg/l)	-0.434	1.000											
Zn mg/l	0.154	-0.164	1.000										
Cu (mg/l)	0.120	-0.367	0.217	1.000									
Cr (mg/l)	0.056	0.515	-0.420	**0.743**	1.000								
Cd (mg/l)	-0.278	-0.481	-0.228	-0.120	-0.599	1.000							
Ni (mg/l)	-0.304	0.028	-0.325	-0.280	-0.169	-0.055	1.000						
Pb (mg/l)	-0.635	**<u>0.841</u>**	-0.076	-0.034	-0.099	-0.274	-0.169	1.000					
PH	0.054	-0.002	0.078	**0.717**	-0.646	-0.040	0.121	-0.342	1.000				
EC (µS/cm)	0.337	-0.286	-0.016	-0.360	-0.117	0.621	-0.015	-0.351	-0.154	1.000			
TDS (mg/L)	0.358	-0.136	-0.283	-0.086	-0.424	0.551	-0.408	-0.081	0.372	-0.577	1.000		
Turbidity (NTU)	0.260	-0.365	-0.672	-0.019	-0.340	0.376	-0.382	-0.421	-0.044	-0.064	-0.062	1.000	
TSS (mg/L)	0.059	-0.423	-0.685	-0.020	-0.321	0.264	-0.308	-0.232	-0.134	-0.309	-0.088	-0.173	1.000

r (0.05) (∞2) df(6)= 0.707
r (0.01) (∞2) df(6)= 0.834
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 39: Correlation of Physicochemical Parameters of Groundwater Samples Around Mechanic Workshops in the Wet Season

	Fe (mg/l)	*Mn (mg/l)*	*Zn mg/l*	*Cu (mg/l)*	*Cr (mg/l)*	*Cd (mg/l)*	*Ni (mg/l)*	*Pb (mg/l)*	*THC (mg/l)*	*PH*	*EC (µS/cm)*	*TDS (mg/L)*	*Turbidity (NTU)*	*TSS (mg/L)*
Fe (mg/l)	1.000													
Mn (mg/l)	0.591	1.000												
Zn mg/l	0.199	0.122	1.000											
Cu (mg/l)	0.234	0.084	0.228	1.000										
Cr (mg/l)	0.148	0.568	0.420	0.564	1.000									
Cd (mg/l)	0.276	0.497	0.307	0.596	**0.807**	1.000								
Ni (mg/l)	0.357	0.538	0.162	0.033	**0.680**	**0.692**	1.000							
Pb (mg/l)	0.022	0.195	**0.632**	0.123	0.624	0.352	**0.663**	1.000						
THC (mg/l)	0.244	0.375	0.086	0.309	0.621	**0.636**	**0.679**	0.393	1.000					
PH	0.366	0.418	0.077	**0.785**	0.538	**0.673**	0.101	0.228	0.433	1.000				
EC (µS/cm)	**0.773**	0.097	0.422	0.067	0.257	0.249	0.006	0.042	0.023	0.033	1.000			
TDS (mg/L)	**0.705**	0.321	0.247	0.104	0.080	0.065	0.115	0.028	0.009	0.005	**0.825**	1.000		
Turbidity (NTU)	0.433	0.379	0.258	0.592	0.529	0.422	0.284	0.386	0.021	0.314	-0.317	-0.555	1.000	
TSS (mg/L)	0.374	0.372	0.143	0.012	0.467	0.415	**0.745**	0.553	0.114	0.081	-0.150	-0.204	0.560	1.000

r (0.05) (∞2) df(8)= 0.632
r (0.01) (∞2) df(8)= 0.765
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 40: Correlation of Physicochemical Parameters of Groundwater Samples Around Cassava Mills in the Wet Season

	Fe (mg/l)	*Mn (mg/l)*	*Zn mg/l*	*Cu (mg/l)*	*Cr (mg/l)*	*Cd (mg/l)*	*Pb (mg/l)*	*CN (mg/l)*	*PH*	*EC (µS/cm)*	*TDS (mg/L)*	*Turbidity (NTU)*	*TSS (mg/L)*
Fe (mg/l)	1.000												
Mn (mg/l)	**-0.694**	1.000											
Zn mg/l	-0.526	0.425	1.000										
Cu (mg/l)	-0.326	0.065	-0.083	1.000									
Cr (mg/l)	0.083	0.327	0.414	-0.539	1.000								
Cd (mg/l)	-0.027	0.402	0.228	**-0.751**	0.393	1.000							
Pb (mg/l)	0.113	0.250	-0.326	-0.317	0.243	0.186	1.000						
CN (mg/l)	-0.534	**0.699**	0.632	-0.220	0.283	0.499	0.401	1.000					
PH	-0.390	0.170	-0.339	0.472	-0.235	-0.485	-0.076	-0.419	1.000				
EC (µS/cm)	-0.522	0.360	**0.673**	0.350	0.370	-0.310	-0.440	0.097	0.334	1.000			
TDS (mg/L)	0.421	0.112	-0.106	-0.510	0.524	0.476	0.483	0.163	-0.372	-0.200	1.000		
Turbidity (NTU)	-0.132	0.141	0.237	-0.071	-0.138	0.468	-0.711	-0.088	-0.083	0.082	-0.129	1.000	
TSS (mg/L)	-0.188	0.167	0.085	0.364	0.023	-0.589	0.368	0.163	0.350	0.397	-0.041	**-0.676**	1.000

r (0.05) (∞2) df(7)= 0.666
r (0.01) (∞2) df(7)= 0.798
Bold values = Significant
Bold values with underline = Highly significant

Table 4. 41: Index of Geo-accumulation of Heavy Metal Around Dumpsite Contaminated Soils in the Dry Season

	Igeo								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
DDS1	2.32	1.91	2.25	1.62	1.26	2.25	2.55	3.42	1.79
DDS2	2.84	2.67	2.61	1.98	1.78	1.48	2.47	3.07	2.33
DDS3	2.41	1.79	2.41	1.82	0.78	2.24	2.11	2.69	1.50
DDS4	3.43	3.14	3.21	2.77	3.14	2.25	2.94	2.45	2.87
DDS5	3.10	2.70	2.96	2.60	2.49	2.51	2.73	2.82	2.55
DDS6	2.76	2.15	2.44	2.30	2.94	3.43	2.85	3.34	1.94
DDS7	2.97	2.12	2.70	2.34	2.05	2.94	2.47	3.14	2.31
DDS8	2.96	2.49	2.82	2.28	2.33	3.08	2.68	3.83	2.28
DDS9	2.78	2.11	2.44	2.07	1.91	2.98	2.42	3.43	1.79
DDS10	2.73	2.28	2.04	2.08	1.92	2.72	2.14	3.82	1.94
DDS11	2.90	-0.69	1.09	-0.02	1.29	2.91	0.46	3.31	-0.77
DDS12	1.06	0.05	0.78	0.48	1.39	3.08	-0.43	3.65	-0.47
DDS13	0.70	-0.44	0.91	0.72	1.45	2.70	-0.61	3.39	-0.33
DDS14	0.49	-0.83	0.66	-0.96	1.86	2.89	-0.85	3.54	-0.57
DDS15	-0.24	-0.41	-0.49	0.17	1.44	2.98	-0.59	3.82	-1.28
DDS16	0.35	-0.70	-0.79	-0.04	1.58	2.89	-0.90	3.98	-1.22
DDS17	0.62	-0.27	-0.45	-0.89	1.75	2.41	-0.68	3.27	-1.14
DDS18	0.30	0.05	0.18	-0.02	1.19	2.43	0.04	3.54	-0.87
DDS19	1.10	-1.06	-1.09	-0.86	1.41	2.41	0.21	3.27	-2.01
DDS20	0.95	-0.98	-0.52	-0.42	-0.62	2.22	-2.59	3.36	-1.44
DDS21	0.07	-0.97	-0.12	-0.47	1.24	2.38	-0.63	3.27	-1.60
DDS22	2.73	-1.39	-1.93	-1.08	1.22	2.41	-0.87	3.02	-1.69
DDS23	2.17	-1.47	-2.14	-1.05	0.91	2.65	-0.97	3.54	-1.49
DDS24	0.10	-2.36	-0.99	-1.70	2.20	2.72	1.67	3.34	-1.41
DDS25	1.04	-0.98	-1.92	-2.31	1.20	2.74	0.31	3.58	-1.27

Table 4. 42: Enrichment Factor of Heavy Metal Around Dumpsite Contaminated Soils in the Dry Season

	Enrichment Factor								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
DDS1	1.45	1.09	1.38	0.89	0.69	1.38	1.69	3.10	1.00
DDS2	1.43	1.27	1.21	0.79	0.68	0.56	1.11	1.67	1.00
DDS3	1.89	1.23	1.88	1.25	0.61	1.67	1.53	2.28	1.00
DDS4	1.47	1.20	1.26	0.93	1.20	0.65	1.05	0.74	1.00
DDS5	1.47	1.12	1.33	1.04	0.96	0.97	1.14	1.21	1.00
DDS6	1.77	1.16	1.41	1.29	2.00	2.82	1.88	2.64	1.00
DDS7	1.58	0.87	1.31	1.02	0.83	1.55	1.11	1.78	1.00
DDS8	1.61	1.16	1.45	1.00	1.04	1.74	1.32	2.94	1.00
DDS9	1.99	1.25	1.57	1.22	1.08	2.29	1.55	3.12	1.00
DDS10	1.74	1.27	1.07	1.10	0.99	1.72	1.15	3.69	1.00
DDS11	12.77	1.06	3.64	1.69	4.17	12.82	2.35	16.89	1.00
DDS12	2.89	1.43	2.37	1.92	3.63	11.70	1.03	17.41	1.00
DDS13	2.04	0.93	2.37	2.08	3.45	8.17	0.83	13.24	1.00
DDS14	2.08	0.83	2.35	0.76	5.38	10.98	0.82	17.23	1.00
DDS15	2.06	1.83	1.73	2.73	6.58	19.18	1.62	34.29	1.00
DDS16	2.97	1.44	1.35	2.27	7.01	17.32	1.25	36.90	1.00
DDS17	3.39	1.83	1.61	1.19	7.42	11.71	1.38	21.26	1.00
DDS18	2.24	1.88	2.07	1.80	4.17	9.84	1.87	21.16	1.00
DDS19	8.63	1.93	1.89	2.23	10.72	21.37	4.66	38.89	1.00
DDS20	5.25	1.38	1.90	2.03	1.77	12.72	0.45	27.96	1.00
DDS21	3.20	1.55	2.79	2.20	7.19	15.78	1.97	29.40	1.00
DDS22	21.42	1.23	0.84	1.52	7.52	17.14	1.76	26.05	1.00
DDS23	12.71	1.02	0.64	1.36	5.27	17.71	1.44	32.65	1.00
DDS24	2.85	0.52	1.34	0.82	12.23	17.53	8.51	26.90	1.00
DDS25	4.95	1.22	0.64	0.49	5.55	16.16	3.00	28.87	1.00

Table 4. 43: Contamination Factor of Heavy Metal Around Dumpsite Contaminated Soils in the Dry Season

Contamination Factor										
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
DDS1	7.50	5.65	7.13	4.62	3.59	7.13	8.79	16.07	5.19	65.67
DDS2	10.72	9.54	9.13	5.92	5.14	4.20	8.31	12.58	7.52	73.06
DDS3	7.99	5.20	7.95	5.28	2.57	7.09	6.46	9.66	4.23	56.43
DDS4	16.22	13.19	13.89	10.21	13.23	7.12	11.54	8.19	11.00	104.58
DDS5	12.85	9.78	11.69	9.09	8.40	8.52	9.97	10.62	8.77	89.69
DDS6	10.16	6.66	8.11	7.39	11.49	16.20	10.81	15.14	5.74	91.69
DDS7	11.76	6.50	9.77	7.62	6.19	11.55	8.30	13.24	7.45	82.38
DDS8	11.70	8.44	10.56	7.29	7.54	12.65	9.61	21.40	7.28	96.46
DDS9	10.31	6.46	8.13	6.31	5.62	11.86	8.03	16.18	5.19	78.08
DDS10	9.98	7.26	6.15	6.33	5.67	9.85	6.61	21.17	5.74	78.76
DDS11	11.21	0.93	3.20	1.48	3.66	11.25	2.06	14.83	0.88	49.50
DDS12	3.13	1.55	2.57	2.09	3.93	12.68	1.11	18.87	1.08	47.02
DDS13	2.43	1.11	2.82	2.48	4.11	9.72	0.99	15.75	1.19	40.58
DDS14	2.10	0.84	2.38	0.77	5.43	11.10	0.83	17.42	1.01	41.89
DDS15	1.27	1.13	1.07	1.69	4.06	11.84	1.00	21.17	0.62	43.86
DDS16	1.91	0.92	0.87	1.46	4.50	11.11	0.80	23.68	0.64	45.90
DDS17	2.31	1.25	1.10	0.81	5.05	7.97	0.94	14.48	0.68	34.59
DDS18	1.84	1.55	1.70	1.48	3.43	8.10	1.54	17.42	0.82	37.89
DDS19	3.21	0.72	0.70	0.83	3.99	7.96	1.74	14.48	0.37	34.00
DDS20	2.89	0.76	1.05	1.12	0.97	7.01	0.25	15.40	0.55	30.01
DDS21	1.58	0.77	1.38	1.09	3.55	7.79	0.97	14.51	0.49	32.12
DDS22	9.99	0.57	0.39	0.71	3.50	7.99	0.82	12.14	0.47	36.59
DDS23	6.77	0.54	0.34	0.72	2.81	9.44	0.77	17.39	0.53	39.32
DDS24	1.60	0.29	0.75	0.46	6.88	9.87	4.79	15.14	0.56	40.36
DDS25	3.07	0.76	0.40	0.30	3.44	10.03	1.86	17.91	0.62	38.39

Table 4. 44: Pollution Load Index of Heavy Metal Around Dumpsite Contaminated Soils in the Dry Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
82.34	7.14	13.37	8.67	67.58	485.61	13.27	1969.92	4.10

Table 4. 45: Index of Geo-accumulation of Heavy Metal Around Dumpsite Contaminated Soils in the Wet Season

	Igeo								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
DWS1	2.21	1.87	1.99	1.40	0.98	0.40	1.36	-0.66	1.70
DWS2	2.63	2.29	2.41	1.81	1.40	0.82	1.78	-0.24	2.12
DWS3	2.32	1.72	2.15	1.51	0.71	0.23	1.11	-0.75	1.40
DWS4	3.34	3.00	3.12	2.52	2.11	1.23	2.49	0.47	2.83
DWS5	2.99	2.64	2.76	2.17	1.75	1.17	2.14	0.11	2.48
DWS6	2.32	1.98	2.10	1.51	1.09	0.51	1.47	-0.53	1.81
DWS7	2.84	2.04	2.54	1.93	1.17	0.29	2.07	-0.12	2.13
DWS8	2.73	2.38	2.50	1.91	1.50	0.91	1.88	-0.15	2.22
DWS9	2.63	2.00	2.25	1.73	0.91	0.79	1.81	-0.03	1.69
DWS10	2.47	2.20	1.64	1.42	1.20	0.50	1.36	-0.75	1.86
DWS11	2.51	-0.94	-0.16	-0.30	-0.78	-2.42	-1.44	-3.38	-1.11
DWS12	0.47	-1.04	0.25	-0.34	-1.32	-2.50	-1.58	-2.38	-0.75
DWS13	0.23	-1.66	0.40	-0.92	-1.02	-2.59	-3.25	-2.53	-0.65
DWS14	-0.18	-1.34	0.11	-0.38	-0.65	-2.79	-2.08	-3.70	-0.85
DWS15	-0.91	-1.44	-1.56	-0.90	-1.21	-3.01	-2.08	-2.89	-1.69
DWS16	-0.28	-1.75	-2.59	-0.92	-1.41	-3.27	-3.03	-2.53	-1.98
DWS17	-0.33	-0.68	-1.35	-1.59	-1.05	-2.89	-1.96	-4.12	-1.62
DWS18	-0.02	-0.32	-0.63	-0.85	-1.21	-2.01	-0.83	-3.38	-1.29
DWS19	0.73	-1.79	-2.06	-0.53	-1.26	-2.69	-2.90	-4.12	-2.63
DWS20	0.70	-1.85	-1.06	-0.60	-1.16	-2.89	-2.90	-3.38	-1.69
DWS21	-0.24	-1.63	-0.61	-0.86	-1.12	-6.59	-2.06	-4.70	-2.29
DWS22	2.48	-2.05	-2.71	-0.42	-1.09	-4.27	-2.85	-5.70	-1.98
DWS23	2.01	-2.16	-1.81	-1.97	-8.07	-0.33	-1.66	-4.12	-2.08
DWS24	-0.35	-3.21	-1.27	-0.86	-1.12	-1.34	1.12	-0.75	-1.94
DWS25	0.81	-1.48	-2.76	-5.14	-4.37	1.39	-2.19	-1.18	-1.79

Table 4. 46: Enrichment Factor of Heavy Metal Around Dumpsite Contaminated Soils in the Wet Season

	Enrichment Factor								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
DWS1	1.42	1.12	1.22	0.81	0.61	0.40	0.79	0.20	1.00
DWS2	1.42	1.12	1.22	0.81	0.61	0.41	0.79	0.19	1.00
DWS3	1.90	1.25	1.68	1.08	0.62	0.44	0.82	0.23	1.00
DWS4	1.42	1.12	1.22	0.81	0.61	0.33	0.79	0.19	1.00
DWS5	1.42	1.12	1.22	0.81	0.61	0.40	0.79	0.19	1.00
DWS6	1.42	1.12	1.22	0.81	0.61	0.40	0.79	0.20	1.00
DWS7	1.65	0.94	1.33	0.87	0.52	0.28	0.96	0.21	1.00
DWS8	1.42	1.12	1.22	0.81	0.61	0.40	0.79	0.19	1.00
DWS9	1.91	1.23	1.47	1.03	0.58	0.53	1.09	0.30	1.00
DWS10	1.53	1.27	0.86	0.73	0.63	0.39	0.71	0.16	1.00
DWS11	12.30	1.12	1.93	1.75	1.25	0.40	0.79	0.21	1.00
DWS12	2.33	0.82	2.00	1.33	0.67	0.30	0.56	0.32	1.00
DWS13	1.84	0.50	2.07	0.83	0.77	0.26	0.17	0.27	1.00
DWS14	1.60	0.71	1.96	1.39	1.15	0.26	0.43	0.14	1.00
DWS15	1.71	1.19	1.09	1.73	1.39	0.40	0.76	0.43	1.00
DWS16	3.23	1.17	0.65	2.08	1.48	0.41	0.48	0.68	1.00
DWS17	2.45	1.92	1.21	1.02	1.48	0.41	0.79	0.18	1.00
DWS18	2.41	1.95	1.57	1.35	1.06	0.61	1.37	0.23	1.00
DWS19	10.28	1.80	1.49	4.28	2.59	0.96	0.83	0.36	1.00
DWS20	5.22	0.89	1.55	2.12	1.44	0.43	0.43	0.31	1.00
DWS21	4.14	1.59	3.22	2.71	2.25	0.05	1.17	0.19	1.00
DWS22	21.94	0.95	0.60	2.94	1.85	0.20	0.55	0.08	1.00
DWS23	17.08	0.95	1.21	1.08	0.02	3.38	1.34	0.24	1.00
DWS24	3.01	0.41	1.60	2.11	1.76	1.51	8.33	2.29	1.00
DWS25	6.08	1.24	0.51	0.10	0.17	9.08	0.76	1.53	1.00

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Table 4. 47: Contamination Factor of Heavy Metal Around Dumpsite Contaminated Soils in the Wet Season

Contamination Factor										
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
DWS1	6.95	5.48	5.95	3.95	2.96	1.97	3.86	0.95	4.88	36.95
DWS2	9.28	7.32	7.95	5.27	3.96	2.64	5.16	1.27	6.52	49.36
DWS3	7.50	4.96	6.66	4.29	2.45	1.76	3.23	0.89	3.96	35.70
DWS4	15.18	11.97	13.02	8.62	6.47	3.53	8.44	2.08	10.66	79.96
DWS5	11.88	9.36	10.18	6.75	5.06	3.37	6.60	1.62	8.34	63.16
DWS6	7.50	5.91	6.43	4.26	3.20	2.13	4.17	1.04	5.27	39.90
DWS7	10.78	6.18	8.74	5.72	3.38	1.83	6.29	1.38	6.55	50.85
DWS8	9.92	7.82	8.51	5.63	4.23	2.81	5.52	1.36	6.97	52.77
DWS9	9.29	5.99	7.11	4.98	2.81	2.60	5.27	1.47	4.85	44.37
DWS10	8.33	6.90	4.69	4.01	3.44	2.11	3.85	0.89	5.45	39.66
DWS11	8.56	0.78	1.34	1.22	0.87	0.28	0.55	0.14	0.70	14.46
DWS12	2.08	0.73	1.79	1.18	0.60	0.26	0.50	0.29	0.89	8.33
DWS13	1.76	0.47	1.98	0.79	0.74	0.25	0.16	0.26	0.96	7.37
DWS14	1.32	0.59	1.62	1.15	0.96	0.22	0.35	0.12	0.83	7.17
DWS15	0.80	0.55	0.51	0.81	0.65	0.19	0.35	0.20	0.47	4.52
DWS16	1.23	0.45	0.25	0.79	0.57	0.16	0.18	0.26	0.38	4.27
DWS17	1.19	0.94	0.59	0.50	0.72	0.20	0.39	0.09	0.49	5.10
DWS18	1.48	1.20	0.97	0.83	0.65	0.37	0.84	0.14	0.61	7.10
DWS19	2.49	0.43	0.36	1.04	0.63	0.23	0.20	0.09	0.24	5.71
DWS20	2.43	0.42	0.72	0.99	0.67	0.20	0.20	0.14	0.47	6.24
DWS21	1.27	0.49	0.98	0.83	0.69	0.02	0.36	0.06	0.31	4.99
DWS22	8.37	0.36	0.23	1.12	0.71	0.08	0.21	0.03	0.38	11.48
DWS23	6.05	0.34	0.43	0.38	0.01	1.20	0.48	0.09	0.35	9.31
DWS24	1.18	0.16	0.62	0.83	0.69	0.59	3.25	0.89	0.39	8.60
DWS25	2.63	0.54	0.22	0.04	0.07	3.93	0.33	0.66	0.43	8.86

Table 4. 48: Pollution Load Index of Heavy Metal Around Dumpsite Contaminated Soils in the Wet Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
42.62	2.81	4.77	3.42	1.05	0.28	1.20	0.06	2.25

Table 4. 49: Index of Geo-accumulation of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Dry Season

	Igeo								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
MDS1	3.35	3.40	3.15	2.69	3.33	2.74	2.90	3.55	2.78
MDS2	2.01	1.72	2.16	1.53	1.80	2.07	1.63	3.75	1.57
MDS3	3.77	3.39	3.74	3.18	2.94	2.81	3.09	4.15	3.24
MDS4	0.21	-0.98	1.91	0.00	2.10	2.90	0.06	3.27	1.46
MDS5	0.70	-0.32	-0.16	-0.42	1.58	2.41	0.62	3.60	0.38
MDS6	2.89	2.56	2.75	2.23	2.42	3.23	2.19	3.10	2.36
MDS7	2.35	1.75	2.15	1.87	1.80	2.67	1.75	3.85	2.11
MDS8	3.66	-0.10	-0.29	-0.42	1.04	2.41	0.46	0.16	-0.06
MDS9	-0.23	-0.69	-0.76	-1.37	1.43	-0.12	-0.28	0.57	-0.13
MDS10	0.30	0.05	-0.01	-1.22	1.27	2.75	0.62	0.90	-0.79
MDS11	0.70	0.26	1.30	2.40	1.65	-0.92	-0.70	0.87	-2.62
MDS12	0.69	-0.46	0.08	-5.54	-1.66	-0.62	0.04	0.28	-0.40
MDS13	-0.42	-0.72	-0.12	-2.66	0.99	3.08	1.32	0.49	-0.88
MDS14	0.65	-2.03	1.63	-1.45	1.04	0.85	1.39	0.25	-0.44
MDS15	0.31	-0.66	1.02	0.03	0.59	-0.40	1.06	0.78	-0.32
MDS16	-0.07	-2.00	2.04	-1.38	1.05	2.54	1.44	0.08	-0.20
MDS17	-0.91	0.57	1.64	-1.46	1.04	2.70	1.37	0.45	-0.32
MDS18	0.10	-0.02	2.54	-2.78	0.73	0.02	1.89	0.08	-0.19
MDS19	-1.12	-0.57	0.96	-2.09	1.66	-0.17	1.64	3.28	-0.53
MDS20	-0.22	0.26	1.92	-1.37	1.67	2.74	1.49	0.34	-0.36
MDS21	0.65	-0.96	-0.29	-1.69	1.49	2.77	1.62	0.03	-0.39
MDS22	-0.33	-0.95	0.01	-2.67	1.71	2.95	0.06	0.74	-0.80

Table 4. 50: Enrichment Factor of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Dry Season

	Enrichment Factor								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
MDS1	1.49	1.54	1.30	0.94	1.47	0.97	1.09	1.71	1.00
MDS2	1.36	1.10	1.51	0.97	1.17	1.41	1.04	4.53	1.00
MDS3	1.44	1.11	1.42	0.96	0.81	0.74	0.90	1.88	1.00
MDS4	0.42	0.18	1.36	0.36	1.55	2.71	0.38	3.51	1.00
MDS5	1.25	0.62	0.69	0.58	2.30	4.10	1.18	9.35	1.00
MDS6	1.44	1.15	1.31	0.91	1.04	1.82	0.88	1.67	1.00
MDS7	1.18	0.78	1.02	0.85	0.81	1.47	0.78	3.34	1.00
MDS8	13.16	0.98	0.86	0.78	2.14	5.55	1.43	1.16	1.00
MDS9	0.93	0.68	0.64	0.42	2.94	1.01	0.90	1.62	1.00
MDS10	2.14	1.80	1.72	0.74	4.17	11.69	2.66	3.23	1.00
MDS11	9.98	7.40	15.14	32.48	19.29	3.25	3.79	11.25	1.00
MDS12	2.14	0.96	1.40	0.03	0.42	0.86	1.36	1.60	1.00
MDS13	1.37	1.11	1.68	0.29	3.65	15.48	4.58	2.58	1.00
MDS14	2.13	0.33	4.21	0.50	2.79	2.45	3.55	1.62	1.00
MDS15	1.55	0.79	2.53	1.28	1.88	0.95	2.62	2.14	1.00
MDS16	1.09	0.29	4.70	0.44	2.37	6.66	3.11	1.21	1.00
MDS17	0.66	1.85	3.89	0.45	2.56	8.08	3.22	1.70	1.00
MDS18	1.22	1.13	6.61	0.17	1.88	1.16	4.23	1.20	1.00
MDS19	0.66	0.97	2.80	0.34	4.54	1.28	4.49	14.02	1.00
MDS20	1.10	1.54	4.85	0.50	4.09	8.55	3.61	1.63	1.00
MDS21	2.05	0.67	1.07	0.41	3.68	8.92	4.02	1.34	1.00
MDS22	1.38	0.90	1.75	0.27	5.68	13.42	1.81	2.91	1.00

Table 4. 51: Contamination Factor of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Dry Season

	Contamination Factor									
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
MDS1	15.32	15.80	13.33	9.66	15.13	9.99	11.21	17.54	10.28	118.27
MDS2	6.05	4.92	6.72	4.34	5.23	6.31	4.65	20.22	4.46	62.91
MDS3	20.44	15.75	20.10	13.59	11.49	10.49	12.78	26.63	14.19	145.45
MDS4	1.73	0.76	5.62	1.50	6.41	11.19	1.57	14.45	4.12	47.36
MDS5	2.44	1.21	1.34	1.13	4.49	7.99	2.30	18.23	1.95	41.08
MDS6	11.14	8.86	10.08	7.05	8.01	14.05	6.82	12.87	7.72	86.60
MDS7	7.66	5.04	6.64	5.50	5.24	9.54	5.06	21.69	6.49	72.87
MDS8	18.93	1.40	1.23	1.12	3.08	7.97	2.06	1.67	1.44	38.91
MDS9	1.28	0.93	0.89	0.58	4.04	1.38	1.23	2.22	1.37	13.93
MDS10	1.85	1.56	1.49	0.64	3.61	10.12	2.31	2.80	0.87	25.24
MDS11	2.43	1.80	3.69	7.91	4.70	0.79	0.92	2.74	0.24	25.24
MDS12	2.42	1.09	1.59	0.03	0.48	0.98	1.55	1.82	1.14	11.09
MDS13	1.12	0.91	1.38	0.24	2.98	12.65	3.74	2.11	0.82	25.94
MDS14	2.35	0.37	4.66	0.55	3.08	2.70	3.93	1.79	1.10	20.53
MDS15	1.86	0.95	3.03	1.53	2.26	1.13	3.13	2.57	1.20	17.67
MDS16	1.43	0.38	6.15	0.58	3.10	8.70	4.07	1.59	1.31	27.30
MDS17	0.80	2.23	4.69	0.54	3.08	9.73	3.88	2.05	1.20	28.21
MDS18	1.60	1.48	8.70	0.22	2.48	1.52	5.57	1.59	1.32	24.48
MDS19	0.69	1.01	2.92	0.35	4.73	1.34	4.68	14.60	1.04	31.36
MDS20	1.29	1.79	5.67	0.58	4.77	9.99	4.22	1.90	1.17	31.40
MDS21	2.35	0.77	1.23	0.47	4.21	10.21	4.61	1.53	1.14	26.52
MDS22	1.19	0.77	1.51	0.24	4.90	11.58	1.56	2.51	0.86	25.13

Table 4. 52: Pollution Load Index of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Dry Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
11.67	3.53	22.17	1.02	30.84	56.01	19.44	38.60	4.11

Table 4. 53: Index of Geo-accumulation of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Wet Season

	Igeo								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
MWS1	3.42	3.40	3.25	2.79	2.30	2.87	2.83	3.00	2.82
MWS2	2.09	1.65	1.93	1.50	1.15	1.54	1.50	1.67	1.49
MWS3	3.84	3.40	3.68	3.25	2.74	3.30	3.26	3.44	3.25
MWS4	-0.02	-1.29	1.85	-0.50	-0.90	-0.47	-0.50	-0.28	1.39
MWS5	0.52	-0.75	-0.07	-0.48	-0.28	-1.47	-1.82	-1.50	0.32
MWS6	2.94	2.50	2.78	2.35	1.83	2.40	2.36	2.53	2.35
MWS7	2.37	1.67	2.27	1.85	0.97	-1.17	0.96	2.61	2.11
MWS8	2.87	-0.82	-0.55	-0.97	-0.22	-0.92	-0.96	-0.50	-0.10
MWS9	-0.89	-1.67	-1.40	-1.83	-4.33	1.21	-1.82	-1.09	-0.51
MWS10	0.09	-0.35	-0.30	-1.13	-0.62	0.00	-0.06	1.67	-1.17
MWS11	0.24	-0.31	0.37	1.60	-0.58	-1.71	-1.83	0.08	-2.87
MWS12	0.25	-0.99	-0.07	-5.90	-3.62	-1.47	-2.77	-0.50	-0.42
MWS13	-0.27	-0.67	0.09	-2.29	-0.75	-1.00	1.15	0.72	-0.81
MWS14	0.54	-2.33	1.26	-1.37	-0.63	1.74	1.54	0.23	-0.54
MWS15	-0.36	-0.87	0.75	0.31	-1.14	0.04	0.63	0.08	-0.51
MWS16	-0.23	1.15	1.93	-1.20	0.12	1.99	1.46	1.82	-0.20
MWS17	-0.95	0.34	1.44	-1.39	-0.56	1.80	0.87	1.30	-0.29
MWS18	-0.30	-0.19	2.44	-3.28	-3.27	0.69	1.80	1.87	-0.52
MWS19	-1.23	-1.12	0.80	-2.16	-2.21	-1.00	0.50	3.64	-0.64
MWS20	-0.50	0.06	2.00	-1.17	1.12	2.19	1.28	1.61	-0.42
MWS21	-0.15	-1.87	-0.58	-7.97	-4.47	-0.42	0.57	1.30	-0.73
MWS22	-0.66	-1.37	-0.17	-7.69	-1.64	0.22	0.32	-0.28	-0.96

Table 4. 54: Enrichment Factor of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Wet Season

	Enrichment Factor								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
MWS1	1.51	1.50	1.35	0.98	0.70	1.04	1.01	1.13	1.00
MWS2	1.51	1.11	1.35	1.00	0.79	1.04	1.01	1.13	1.00
MWS3	1.51	1.11	1.35	1.00	0.70	1.04	1.01	1.14	1.00
MWS4	0.38	0.16	1.37	0.27	0.20	0.28	0.27	0.31	1.00
MWS5	1.15	0.47	0.76	0.57	0.66	0.29	0.23	0.28	1.00
MWS6	1.51	1.11	1.35	1.00	0.70	1.04	1.01	1.13	1.00
MWS7	1.20	0.74	1.12	0.84	0.45	0.10	0.45	1.42	1.00
MWS8	7.86	0.61	0.73	0.55	0.92	0.57	0.55	0.76	1.00
MWS9	0.77	0.45	0.54	0.40	0.07	3.27	0.40	0.67	1.00
MWS10	2.40	1.77	1.82	1.03	1.46	2.25	2.16	7.15	1.00
MWS11	8.65	5.91	9.47	22.30	4.89	2.24	2.06	7.76	1.00
MWS12	1.60	0.67	1.27	0.02	0.11	0.48	0.20	0.95	1.00
MWS13	1.45	1.10	1.86	0.36	1.04	0.88	3.89	2.89	1.00
MWS14	2.12	0.29	3.47	0.56	0.93	4.84	4.22	1.71	1.00
MWS15	1.11	0.78	2.40	1.76	0.65	1.46	2.20	1.51	1.00
MWS16	0.98	2.56	4.38	0.50	1.25	4.57	3.16	4.06	1.00
MWS17	0.63	1.55	3.32	0.46	0.83	4.23	2.23	3.01	1.00
MWS18	1.17	1.25	7.80	0.15	0.15	2.31	5.00	5.23	1.00
MWS19	0.66	0.72	2.73	0.35	0.34	0.78	2.21	19.47	1.00
MWS20	0.94	1.39	5.33	0.59	2.91	6.09	3.25	4.09	1.00
MWS21	1.49	0.45	1.11	0.01	0.07	1.24	2.46	4.09	1.00
MWS22	1.23	0.76	1.72	0.01	0.62	2.27	2.42	1.60	1.00

Table 4. 55: Contamination Factor of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Wet Season

Contamination Factor										
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
MWS1	16.00	15.85	14.28	10.36	7.40	10.96	10.65	12.00	10.58	108.08
MWS2	6.36	4.69	5.70	4.23	3.33	4.38	4.25	4.76	4.22	41.93
MWS3	21.53	15.86	19.27	14.30	9.99	14.79	14.37	16.24	14.28	140.63
MWS4	1.48	0.61	5.39	1.06	0.80	1.08	1.06	1.24	3.93	16.66
MWS5	2.15	0.89	1.42	1.08	1.24	0.54	0.42	0.53	1.87	10.15
MWS6	11.53	8.49	10.31	7.66	5.34	7.92	7.69	8.65	7.64	75.23
MWS7	7.75	4.77	7.22	5.41	2.94	0.67	2.92	9.18	6.47	47.32
MWS8	11.00	0.85	1.03	0.77	1.29	0.79	0.77	1.06	1.40	18.95
MWS9	0.81	0.47	0.57	0.42	0.07	3.46	0.42	0.71	1.06	7.99
MWS10	1.60	1.18	1.22	0.68	0.97	1.50	1.44	4.76	0.67	14.01
MWS11	1.77	1.21	1.94	4.56	1.00	0.46	0.42	1.59	0.20	13.15
MWS12	1.79	0.75	1.42	0.03	0.12	0.54	0.22	1.06	1.12	7.05
MWS13	1.24	0.94	1.59	0.31	0.89	0.75	3.33	2.47	0.86	12.38
MWS14	2.19	0.30	3.59	0.58	0.97	5.00	4.37	1.76	1.03	19.79
MWS15	1.17	0.82	2.53	1.86	0.68	1.54	2.32	1.59	1.05	13.55
MWS16	1.28	3.33	5.72	0.65	1.63	5.96	4.11	5.29	1.30	29.27
MWS17	0.78	1.90	4.08	0.57	1.02	5.21	2.74	3.71	1.23	21.24
MWS18	1.22	1.31	8.16	0.15	0.16	2.42	5.23	5.47	1.05	25.17
MWS19	0.64	0.69	2.62	0.34	0.32	0.75	2.12	18.71	0.96	27.14
MWS20	1.06	1.56	5.98	0.67	3.26	6.83	3.64	4.59	1.12	28.72
MWS21	1.35	0.41	1.01	0.01	0.07	1.13	2.23	3.71	0.91	10.81
MWS22	0.95	0.58	1.33	0.01	0.48	1.75	1.87	1.24	0.77	8.97

Table 4. 56: Pollution Load Index of Heavy Metal Around Mechanic Workshops Contaminated Soils in the Wet Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
7.68	2.60	16.70	0.37	0.85	5.98	6.42	16.36	3.41

Table 4. 57: Index of Geo-accumulation of Heavy Metal Around Cassava Mill Contaminated Soils in the Dry Season

	Igeo								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
CDS1	2.78	2.38	2.60	2.43	1.85	2.99	2.48	0.73	2.25
CDS2	2.24	1.92	2.08	1.75	1.49	2.21	1.87	0.11	1.82
CDS3	1.04	1.01	1.74	1.07	1.54	-0.13	1.42	0.13	0.85
CDS4	2.54	2.20	2.38	1.98	1.69	2.28	1.90	0.18	2.37
CDS5	1.63	1.95	1.96	2.06	1.22	2.44	1.25	0.37	1.73
CDS6	1.96	1.74	1.96	1.67	1.46	2.79	1.85	0.16	1.45
CDS7	1.70	1.63	1.65	1.03	1.27	-0.34	1.40	0.60	1.36
CDS8	2.40	1.86	1.83	1.68	1.52	2.40	1.81	0.03	1.64
CDS9	1.82	1.59	1.83	2.11	1.67	-0.48	1.86	0.55	1.55
CDS10	1.37	1.52	2.31	1.57	1.56	0.01	1.26	0.57	1.43
CDS11	0.97	1.14	1.53	1.67	-0.38	-0.29	1.82	2.00	0.96
CDS12	0.83	0.19	1.23	0.85	1.73	-0.59	0.42	0.08	0.49
CDS13	1.28	1.70	2.07	1.77	1.29	-0.13	-0.16	0.58	-0.16
CDS14	0.96	1.38	1.84	1.16	1.29	0.09	0.57	0.73	-0.64
CDS15	1.45	1.59	2.07	2.00	0.94	-0.73	1.68	-0.18	-0.52
CDS16	0.96	1.39	2.01	2.84	1.27	-0.29	1.32	0.32	-0.45
CDS17	2.03	1.60	2.22	1.68	1.51	-0.57	0.68	0.13	1.32
CDS18	1.58	1.70	1.70	0.30	1.24	-0.38	1.27	0.74	1.22
CDS19	2.54	1.85	-0.31	-0.72	1.02	-0.57	-0.38	0.08	-0.46
CDS20	2.44	1.76	0.17	-0.83	1.51	0.72	0.55	0.55	0.14
CDS21	1.77	0.87	2.07	1.26	1.70	-0.81	0.68	0.39	1.27
CDS22	1.97	0.75	1.64	0.66	1.10	-0.57	1.64	0.11	1.21
CDS23	0.11	-1.43	-0.29	-1.56	1.56	0.68	0.66	0.05	-0.33
CDS24	0.48	-1.03	1.16	-1.23	1.27	0.18	0.11	0.55	0.27

Table 4. 58: Enrichment Factor of Heavy Metal Around Cassava Mill Contaminated Soils in the Dry Season

Enrichment Factor									
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
CDS1	1.44	1.09	1.27	1.13	0.76	1.67	1.17	0.35	1.00
CDS2	1.34	1.07	1.19	0.95	0.80	1.31	1.03	0.30	1.00
CDS3	1.13	1.12	1.85	1.16	1.61	0.50	1.48	0.61	1.00
CDS4	1.12	0.89	1.01	0.77	0.62	0.94	0.72	0.22	1.00
CDS5	0.94	1.17	1.17	1.26	0.70	1.64	0.72	0.39	1.00
CDS6	1.42	1.22	1.42	1.16	1.00	2.52	1.32	0.41	1.00
CDS7	1.27	1.21	1.22	0.79	0.94	0.31	1.03	0.59	1.00
CDS8	1.69	1.16	1.14	1.03	0.92	1.70	1.13	0.33	1.00
CDS9	1.21	1.03	1.21	1.47	1.08	0.24	1.23	0.50	1.00
CDS10	0.96	1.06	1.84	1.10	1.09	0.37	0.89	0.55	1.00
CDS11	1.01	1.13	1.49	1.64	0.40	0.42	1.82	2.06	1.00
CDS12	1.27	0.82	1.68	1.28	2.36	0.47	0.96	0.75	1.00
CDS13	2.71	3.63	4.68	3.82	2.73	1.02	1.00	1.67	1.00
CDS14	3.04	4.07	5.60	3.48	3.83	1.67	2.33	2.59	1.00
CDS15	3.91	4.33	6.04	5.76	2.75	0.86	4.60	1.27	1.00
CDS16	2.66	3.59	5.51	9.82	3.29	1.12	3.41	1.71	1.00
CDS17	1.64	1.22	1.87	1.29	1.15	0.27	0.64	0.44	1.00
CDS18	1.28	1.39	1.39	0.53	1.01	0.33	1.03	0.72	1.00
CDS19	8.00	4.96	1.12	0.84	2.81	0.93	1.06	1.46	1.00
CDS20	4.91	3.08	1.02	0.51	2.59	1.50	1.33	1.33	1.00
CDS21	1.42	0.76	1.74	0.99	1.34	0.24	0.66	0.54	1.00
CDS22	1.69	0.73	1.35	0.68	0.93	0.29	1.34	0.47	1.00
CDS23	1.35	0.46	1.03	0.43	3.69	2.01	1.98	1.30	1.00
CDS24	1.16	0.41	1.86	0.35	2.00	0.94	0.90	1.22	1.00

Table 4. 59: Contamination Factor of Heavy Metal Around Cassava Mill Contaminated Soils in the Dry Season

Contamination Factor										
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
CDS1	10.32	7.82	9.08	8.11	5.40	11.92	8.38	2.48	7.14	70.65
CDS2	7.09	5.68	6.34	5.05	4.23	6.93	5.46	1.62	5.31	47.71
CDS3	3.07	3.03	5.00	3.14	4.36	1.37	4.01	1.64	2.71	28.33
CDS4	8.70	6.90	7.80	5.93	4.83	7.27	5.60	1.70	7.73	56.47
CDS5	4.65	5.81	5.84	6.27	3.50	8.13	3.56	1.93	4.97	44.66
CDS6	5.82	5.00	5.84	4.78	4.12	10.37	5.41	1.67	4.11	47.11
CDS7	4.89	4.65	4.70	3.06	3.61	1.18	3.96	2.28	3.86	32.19
CDS8	7.92	5.43	5.33	4.80	4.29	7.94	5.27	1.53	4.68	47.18
CDS9	5.30	4.51	5.33	6.48	4.76	1.07	5.43	2.19	4.40	39.48
CDS10	3.88	4.29	7.46	4.44	4.41	1.51	3.60	2.22	4.04	35.86
CDS11	2.93	3.30	4.34	4.77	1.15	1.23	5.30	6.00	2.92	31.95
CDS12	2.67	1.72	3.52	2.70	4.98	0.99	2.01	1.59	2.10	22.28
CDS13	3.64	4.88	6.30	5.13	3.67	1.37	1.34	2.25	1.34	29.92
CDS14	2.92	3.90	5.38	3.34	3.68	1.60	2.23	2.48	0.96	26.49
CDS15	4.08	4.52	6.31	6.02	2.87	0.90	4.81	1.33	1.04	31.89
CDS16	2.92	3.93	6.03	10.76	3.61	1.23	3.73	1.88	1.10	35.18
CDS17	6.12	4.56	6.97	4.80	4.28	1.01	2.40	1.64	3.73	35.52
CDS18	4.50	4.87	4.89	1.84	3.53	1.15	3.61	2.51	3.50	30.40
CDS19	8.70	5.39	1.21	0.91	3.05	1.01	1.16	1.59	1.09	24.10
CDS20	8.12	5.08	1.69	0.84	4.28	2.47	2.20	2.19	1.65	28.53
CDS21	5.12	2.74	6.31	3.59	4.86	0.85	2.40	1.96	3.62	31.46
CDS22	5.88	2.52	4.69	2.37	3.22	1.01	4.67	1.62	3.47	29.44
CDS23	1.62	0.56	1.23	0.51	4.41	2.41	2.37	1.56	1.20	15.85
CDS24	2.10	0.74	3.36	0.64	3.62	1.69	1.62	2.19	1.80	17.75

Table 4. 60: Pollution Load Index of Heavy Metal Around Cassava Mill Contaminated Soils in the Dry Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
58.70	32.74	61.61	23.94	35.47	6.82	25.39	6.15	14.59

Table 4. 61: Index of Geo-accumulation of Heavy Metal Around Cassava Mill Contaminated Soils in the Wet Season

	Igeo								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
CWS1	2.83	2.39	2.67	2.24	1.72	2.29	2.25	2.44	2.24
CWS2	2.29	1.85	2.13	1.68	1.18	1.75	1.70	1.87	1.69
CWS3	0.87	1.00	1.64	1.02	0.77	0.92	0.94	1.44	0.86
CWS4	2.58	2.15	2.42	2.00	1.48	2.04	2.00	2.20	1.99
CWS5	1.54	1.87	1.95	2.19	0.55	1.75	1.32	1.67	1.67
CWS6	1.98	1.54	1.82	1.39	0.87	1.43	1.40	1.56	1.39
CWS7	1.69	1.46	1.58	0.99	0.90	0.98	1.01	0.08	1.29
CWS8	2.39	1.82	1.84	1.24	0.28	1.49	1.54	1.23	1.58
CWS9	1.80	1.45	1.40	1.83	1.20	0.29	1.33	-0.50	1.55
CWS10	1.18	1.43	2.23	1.65	1.45	-0.26	0.42	-0.28	1.12
CWS11	0.78	0.96	1.33	1.31	-0.11	-2.00	0.55	-0.09	0.63
CWS12	0.40	0.10	0.89	0.77	-0.23	-3.17	-5.52	-0.77	0.35
CWS13	1.26	1.48	1.93	1.58	0.67	1.27	0.25	-0.09	-0.55
CWS14	0.68	1.24	1.65	1.22	0.47	-3.58	-0.44	-0.50	-0.89
CWS15	1.28	1.44	1.77	1.65	-0.09	-2.17	0.49	-1.50	-0.79
CWS16	0.76	1.24	1.64	2.81	0.13	-2.58	0.46	-0.77	-0.81
CWS17	1.92	1.52	2.02	1.36	-0.45	-1.26	-1.08	-1.09	1.16
CWS18	1.59	1.61	1.45	-0.14	-0.14	-1.71	-0.36	-0.28	1.08
CWS19	2.46	1.72	-0.66	-1.08	-0.75	-1.58	-0.87	-1.50	-0.66
CWS20	2.19	1.41	-0.91	-1.33	-0.91	-2.00	-1.07	-2.09	-0.30
CWS21	1.60	0.78	1.93	1.15	0.69	-3.17	-0.67	-0.09	1.10
CWS22	2.06	0.50	1.45	0.51	-1.07	-4.17	0.49	-0.50	0.87
CWS23	-0.49	-1.89	-0.91	-1.33	-0.24	-1.26	-1.93	-2.09	-0.64
CWS24	0.18	-1.47	0.70	-1.93	-0.75	-2.00	-1.32	-0.77	0.08

Table 4. 62: Enrichment Factor of Heavy Metal Around Cassava Mill Contaminated Soils in the Wet Season

Enrichment Factor									
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
CWS1	1.51	1.11	1.35	1.00	0.70	1.04	1.01	1.15	1.00
CWS2	1.51	1.11	1.35	0.99	0.70	1.04	1.01	1.13	1.00
CWS3	1.00	1.10	1.71	1.11	0.94	1.04	1.05	1.49	1.00
CWS4	1.51	1.11	1.35	1.00	0.70	1.03	1.01	1.15	1.00
CWS5	0.91	1.15	1.21	1.43	0.46	1.05	0.78	1.00	1.00
CWS6	1.51	1.11	1.35	1.00	0.70	1.03	1.01	1.12	1.00
CWS7	1.32	1.13	1.23	0.82	0.77	0.81	0.83	0.43	1.00
CWS8	1.75	1.19	1.20	0.79	0.41	0.94	0.97	0.79	1.00
CWS9	1.19	0.94	0.91	1.22	0.79	0.42	0.86	0.24	1.00
CWS10	1.04	1.24	2.15	1.44	1.26	0.38	0.61	0.38	1.00
CWS11	1.11	1.26	1.62	1.60	0.60	0.16	0.95	0.61	1.00
CWS12	1.04	0.84	1.45	1.34	0.67	0.09	0.02	0.46	1.00
CWS13	3.52	4.09	5.56	4.37	2.34	3.54	1.74	1.38	1.00
CWS14	2.95	4.38	5.80	4.32	2.56	0.15	1.36	1.30	1.00
CWS15	4.21	4.71	5.92	5.42	1.63	0.39	2.44	0.61	1.00
CWS16	2.96	4.13	5.46	12.26	1.92	0.29	2.40	1.03	1.00
CWS17	1.68	1.28	1.81	1.14	0.33	0.19	0.21	0.21	1.00
CWS18	1.43	1.45	1.30	0.43	0.43	0.14	0.37	0.39	1.00
CWS19	8.72	5.21	1.00	0.75	0.94	0.53	0.87	0.56	1.00
CWS20	5.61	3.27	0.65	0.49	0.65	0.31	0.59	0.29	1.00
CWS21	1.42	0.80	1.78	1.04	0.76	0.05	0.29	0.44	1.00
CWS22	2.27	0.77	1.49	0.78	0.26	0.03	0.77	0.39	1.00
CWS23	1.11	0.42	0.83	0.62	1.32	0.65	0.41	0.37	1.00
CWS24	1.07	0.34	1.53	0.25	0.56	0.24	0.38	0.56	1.00

Table 4. 63: Contamination Factor of Heavy Metal Around Cassava Mill Contaminated Soils in the Wet season

Contamination Factor										
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
CWS1	10.66	7.86	9.55	7.08	4.95	7.33	7.12	8.12	7.07	69.74
CWS2	7.31	5.39	6.55	4.81	3.39	5.04	4.88	5.47	4.85	47.71
CWS3	2.74	3.01	4.67	3.04	2.56	2.83	2.88	4.06	2.73	28.52
CWS4	9.00	6.64	8.05	5.98	4.18	6.17	6.01	6.88	5.97	58.88
CWS5	4.38	5.49	5.81	6.84	2.20	5.04	3.74	4.76	4.79	43.06
CWS6	5.91	4.36	5.30	3.93	2.74	4.04	3.97	4.41	3.92	38.58
CWS7	4.84	4.14	4.50	2.99	2.80	2.96	3.03	1.59	3.66	30.51
CWS8	7.84	5.30	5.37	3.54	1.82	4.21	4.35	3.53	4.47	40.44
CWS9	5.22	4.11	3.97	5.33	3.45	1.83	3.76	1.06	4.38	33.12
CWS10	3.41	4.04	7.03	4.69	4.11	1.25	2.01	1.24	3.27	31.04
CWS11	2.58	2.93	3.76	3.71	1.39	0.38	2.20	1.41	2.32	20.67
CWS12	1.98	1.61	2.77	2.56	1.28	0.17	0.03	0.88	1.91	13.19
CWS13	3.60	4.18	5.70	4.48	2.39	3.63	1.78	1.41	1.02	28.20
CWS14	2.40	3.55	4.71	3.50	2.07	0.13	1.10	1.06	0.81	19.34
CWS15	3.65	4.08	5.13	4.69	1.41	0.33	2.11	0.53	0.87	22.80
CWS16	2.53	3.54	4.67	10.50	1.64	0.25	2.06	0.88	0.86	26.93
CWS17	5.66	4.31	6.09	3.84	1.09	0.63	0.71	0.71	3.36	26.40
CWS18	4.52	4.59	4.10	1.37	1.36	0.46	1.17	1.24	3.16	21.96
CWS19	8.27	4.94	0.95	0.71	0.89	0.50	0.82	0.53	0.95	18.56
CWS20	6.83	3.99	0.80	0.60	0.80	0.38	0.71	0.35	1.22	15.67
CWS21	4.56	2.58	5.72	3.33	2.43	0.17	0.95	1.41	3.21	24.35
CWS22	6.25	2.12	4.10	2.13	0.72	0.08	2.11	1.06	2.75	21.32
CWS23	1.07	0.41	0.80	0.60	1.27	0.63	0.39	0.35	0.96	6.47
CWS24	1.70	0.54	2.43	0.39	0.89	0.38	0.60	0.88	1.59	9.40

Table 4. 64: Pollution Load Index of Heavy Metal Around Cassava mill Contaminated Soils in the Wet Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
46.50	24.74	40.29	17.02	5.30	0.81	3.69	2.85	10.12

Table 4. 65: Index of Geo-accumulation of Heavy Metal in Soil within Crude Oil Spill Sites in the Dry Season

	Igeo								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
SDS1	3.93	3.59	3.79	3.32	3.36	2.88	3.97	3.78	3.52
SDS2	3.88	3.49	3.71	3.25	2.79	2.76	3.43	3.37	3.46
SDS3	3.75	3.47	3.68	3.12	3.06	2.52	3.27	3.54	2.88
SDS4	4.16	3.42	3.71	3.15	2.71	2.54	3.56	3.76	3.24
SDS5	3.63	3.11	3.53	3.17	2.53	2.24	3.11	3.44	2.81
SDS6	3.57	3.11	3.23	2.83	3.16	2.67	2.94	3.75	2.76

Table 4. 66: Enrichment Factor of Heavy Metal in Soil within Crude Oil Spill Sites in the Dry Season

	Enrichment Factor								
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
SDS1	1.33	1.05	1.20	0.87	0.90	0.64	1.37	1.20	1.00
SDS2	1.33	1.02	1.19	0.86	0.63	0.62	0.98	0.94	1.00
SDS3	1.83	1.50	1.74	1.17	1.13	0.78	1.31	1.57	1.00
SDS4	1.89	1.13	1.38	0.94	0.69	0.61	1.25	1.43	1.00
SDS5	1.77	1.23	1.65	1.28	0.83	0.67	1.23	1.54	1.00
SDS6	1.76	1.28	1.39	1.05	1.33	0.94	1.14	2.00	1.00

Table 4. 67: Contamination Factor of Heavy Metal in Soil within Crude Oil Spill Sites in the Dry Season

	Contamination Factor									
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
SDS1	22.92	18.08	20.74	15.01	15.42	11.01	23.54	20.65	17.21	164.56
SDS2	22.07	16.83	19.69	14.23	10.37	10.18	16.17	15.52	16.54	141.58
SDS3	20.23	16.66	19.28	13.01	12.54	8.61	14.46	17.42	11.07	133.28
SDS4	26.77	16.06	19.59	13.34	9.82	8.72	17.69	20.34	14.19	146.52
SDS5	18.61	12.91	17.33	13.51	8.68	7.09	12.96	16.24	10.52	117.85
SDS6	17.80	12.97	14.07	10.64	13.44	9.58	11.52	20.22	10.14	120.37

Table 4. 68: Pollution Load Index of Heavy Metal in Soil within Crude Oil Spill Sites in the Dry Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
7.66	6.20	6.94	5.59	5.09	4.36	6.25	6.94	5.52

Table 4. 69: Index of Geo-accumulation of Heavy Metal in Soil within Crude Oil Spill Sites in the Wet Season

Igeo									
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
SWS1	4.04	3.60	3.88	3.45	2.93	3.50	3.46	3.64	3.45
SWS2	3.96	3.52	3.80	3.37	2.85	3.42	3.38	3.67	3.37
SWS3	3.83	3.42	3.68	3.15	2.71	3.29	3.26	3.47	2.93
SWS4	3.87	3.43	3.71	3.28	2.76	3.32	3.28	3.47	3.27
SWS5	3.67	3.11	3.65	3.14	2.59	3.13	3.03	3.20	2.75
SWS6	3.61	3.06	3.37	2.91	2.55	1.69	2.65	3.06	2.67

Table 4. 70: Enrichment Factor of Heavy Metal in Soil within Crude oil Spill Sites in the Wet Season

Enrichment Factor									
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
SWS1	1.51	1.11	1.35	1.00	0.70	1.04	1.01	1.14	1.00
SWS2	1.51	1.11	1.35	1.00	0.70	1.03	1.01	1.23	1.00
SWS3	1.86	1.41	1.68	1.17	0.86	1.29	1.26	1.45	1.00
SWS4	1.51	1.11	1.35	1.00	0.70	1.03	1.01	1.14	1.00
SWS5	1.89	1.28	1.86	1.31	0.89	1.30	1.21	1.36	1.00
SWS6	1.91	1.30	1.62	1.18	0.92	0.51	0.98	1.31	1.00

Table 4. 71: Contamination Factor of Heavy Metal in Soil within Crude Oil Spill Sites in the Wet Season

Contamination Factor										
Sample sites	**Mn mg/kg**	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**	**DOC**
SWS1	24.69	18.20	22.10	16.40	11.45	16.96	16.48	18.71	16.37	161.36
SWS2	23.33	17.19	20.89	15.50	10.82	16.00	15.58	19.06	15.47	153.84
SWS3	21.26	16.02	19.18	13.36	9.80	14.67	14.38	16.59	11.40	136.65
SWS4	21.88	16.11	19.58	14.53	10.14	15.00	14.60	16.59	14.50	142.92
SWS5	19.11	12.91	18.84	13.24	9.05	13.17	12.29	13.76	10.12	122.49
SWS6	18.27	12.47	15.53	11.28	8.79	4.83	9.41	12.53	9.56	102.68

Table 4. 72: Pollution Load Index of Heavy Metal in Soil within Crude Oil Spill Sites in the Wet Season

Pollution Load Index								
Mn mg/kg	**Zn mg/kg**	**Cu mg/kg**	**Cr mg/kg**	**Cd mg/kg**	**Ni mg/kg**	**Pb mg/kg**	**V mg/kg**	**Fe mg/kg**
7.68	6.17	7.18	5.79	4.63	5.38	5.69	6.35	5.42

4.6 Ecological Risk in Soil

At dumpsites, the Index of Geo-accumulation (Igeo) for metals like Vanadium (V) shows extremely severe enrichment with values reaching up to 3.82, indicating significant pollution from anthropogenic sources (Table 4.41). This high degree of pollution indicates that waste disposal practices have had a significant influence on the soil. In contrast to V, metals such as iron (Fe) exhibit lower Igeo values, signifying less severe contamination. With values up to 16.89, the Enrichment Factor (EF) for V (Table 4.42) again demonstrates a significant anthropogenic contribution, but the EF for Fe is more in line with natural background levels. When examining the Contamination Factor (CF) (Table 4.43), V again stands out with CF values greater than 6, signaling very high contamination and considerable ecological risk due to its toxicity. In contrast, the CF for Fe is relatively low, suggesting that while present, it does not pose the same level of ecological threat as V. The Pollution Load Index (PLI) (Table 4.44) for Cd, which also shows high contamination, indicates progressive deterioration of the site, with values reaching 67.58, whereas the PLI for Fe is considerably lower, reflecting its lesser impact on the site's overall pollution load.

The Igeo readings (Table 4.45) for Cd show significant contamination during the wet season, despite a minor dilution impact from rainfall. This suggests that waste disposal pollution is still there. On the other hand, Fe keeps displaying lower Igeo values, suggesting a less severe level of contamination. While Fe displays a more moderate EF, indicating less influence from outside sources, V's EF (Table 4.54) stays high, reaching 19.47, indicating continuous anthropogenic enrichment. The CF values (Table 4.47) for Cd and Ni indicate considerable contamination, with implications for ecological health, while Fe's CF remains relatively low. The PLI (Table 4.48) shows signs of progressive deterioration, particularly for Cd, indicating that the pollution burden on the ecosystem remains a concern, despite the slightly lower values compared to the dry season.

At mechanic workshops, the Igeo values (Table 4.49) for Copper (Cu) and Lead (Pb) are particularly high, reflecting severe pollution from automotive waste and oil spills, indicating a significant impact on soil quality. These metals are among the highest in terms of contamination. Conversely, iron (Fe) exhibits lower Igeo values, indicating a less severe level of contamination. While Fe has a significantly lower EF, suggesting a more natural origin, Vanadium (V) (Table 4.54) exhibits considerable enrichment, with values

as high as 19.47, suggesting significant contamination from lubricants and metal wear. The CF (Table 4.51) for Cu and V indicates very high contamination, posing considerable ecological risks due to their toxicity and potential to bioaccumulate. In comparison, Fe's CF is relatively low, suggesting less immediate ecological impact. The PLI (Table 4.52) for Cd and V indicates progressive deterioration, with values reflecting the heavy metal load's impact on the site, whereas the PLI for Fe is considerably lower, highlighting its lesser contribution to the overall pollution. The wet season shows similar patterns with slightly lower values for Cu (Table 4.54), but the contamination remains significant, particularly for Cu and Pb, which are among the highest contaminated metals. Conversely, Fe's contamination levels remain low. The EF for V (Table 4.54) stays high, suggesting that the soil continues to be enriched with this metal from anthropogenic sources even during the wet season, while Fe shows a more moderate EF. The CF values (Table 4.55) for Cu and V are still high, indicating that the soil's contamination level does not decrease significantly with rainfall, potentially due to the persistence of these metals in the soil. Fe, on the other hand, shows a lower CF. The PLI (Table 4.56) during the wet season shows signs of progressive deterioration for Cu and V, though slightly reduced from the dry season, indicating that the ecological risk persists, while Fe contributes less to this deterioration. At cassava mills, the Igeo values (Table 4.57) for Cadmium (Cd) show considerable contamination, suggesting impacts from cassava processing chemicals, making it one of the more severely contaminated metals. In contrast, iron (Fe) has lower Igeo values, suggesting less severe pollution. For Cd, the EF (Table 4.58) shows moderate to fairly severe enrichment, indicating a sizable human impact from processing residues; for Fe, the EF is lower, indicating more natural enrichment. The CF values (Table 4.59) for Cd and Nickel (Ni) suggest considerate to very high contamination, indicating potential ecological risks due to their toxicity, whereas Fe's CF remains low. The PLI (Table 4.60) shows signs of progressive deterioration for Cd, necessitating careful management to mitigate ecological impact, while Fe's PLI is lower, suggesting a lesser impact on the site's overall contamination. In the wet season, the Igeo values (Table 4.61) for Cd are still high, indicating ongoing contamination issues from cassava processing, while Fe shows lower values. The EF (Table 4.62) for Cd shows a slight reduction but still indicates enrichment from anthropogenic sources, likely due to the wet conditions not entirely washing away the contaminants, whereas Fe's EF remains moderate.The CF (Table 4.63) for Cd and Ni remain high,

suggesting that the contamination is not significantly alleviated by seasonal changes, while Fe's CF stays low. The PLI (Table 4.64) indicates a slight improvement for Cd but still shows signs of progressive deterioration, highlighting the need for ongoing monitoring and remediation, with Fe contributing less to the overall pollution. At crude oil spill sites, the Igeo values (Table 4.65) for most metals, particularly Vanadium (V) and Cadmium (Cd), are high, reflecting the direct impact of oil spills on soil quality, making them among the most contaminated metals. Iron (Fe), however, shows lower Igeo values. The EF (Table 4.66) is very high for V, Cd, and other associated metals, indicating extremely severe enrichment due to hydrocarbons and heavy metals from oil spills, while Fe has a lower EF. The CF (Table 4.67) for Fe is comparatively modest, while the CF for V, Cd, and Nickel (Ni), which are known to be hazardous and capable of upsetting ecosystems, indicates extremely high contamination. Fe is contributing less to this deterioration, and the PLI (Table 4.68) for these sites is the greatest, indicating that they are deteriorating at an alarming rate and that immediate remediation is required. Wet season Igeo values (Table 4.69) remain high for V and Cd, indicating that contamination from oil spills persists despite the potential for leaching, while Fe shows lower values. The EF (Table 4.70) for V, Cd, and Ni are still very high, reflecting that the enrichment of the soil with these metals from oil spills does not significantly decrease with rainfall, whereas Fe's EF is lower. The CF values (Table 4.70) for V, Cd, and Ni continue to indicate very high contamination, with metals like V showing persistent high levels, while Fe's CF remains low. The PLI (Table 4.72) remains high for V, Cd, and Ni, suggesting that while some dilution might occur due to wet conditions, the overall pollution load on the site continues to degrade the ecosystem, with Fe having a lesser impact.

CHAPTER FIVE

SUMMARY AND CONCLUSION

5.1 Summary

This study evaluated the causes, distribution, and environmental effects of heavy metal pollution in groundwater, surface water, and soil in Yenagoa and its environs in the Niger Delta, Nigeria. Through the examination of contamination in a variety of anthropogenic locations, such as trash disposal sites, mechanic shops, cassava mills, and regions affected by crude oil spills, the research aimed to determine the origins of heavy metals and the impact that they have on soil and water resources. A total of 112 samples were chosen at random for each season, consisting of 77 soil samples and 35 surface and subsurface water samples. These samples were then subjected to standard laboratory procedures employing Atomic Absorption Spectrophotometry (AAS) throughout both the wet and dry seasons.

The study found considerable pollution levels across all site categories, with crude oil spill locations registering the highest soil contamination, where lead reached 15.354 mg/kg and cadmium 2.755 mg/kg. Results showed that all environmental settings exhibited elevated concentrations of key heavy metals including iron, manganese, zinc, copper, lead, cadmium, chromium, and vanadium, with contamination indices such as the Geo-accumulation Index and Enrichment Factor indicating extreme pollution at certain locations. The evaluation of the quality of the groundwater revealed that there are continual violations of regulatory standards, with lead concentrations surrounding crude oil spill locations reaching 0.133 mg/L, which is more than thirteen times the allowable limit.

The study identified critical seasonal variations in heavy metal mobility and concentration, with higher metal buildup in soil during the dry season but increased pollution of water resources during the rainy season due to leaching and runoff. This research contributes significantly to understanding how seasonal fluctuations affect heavy metal concentration and mobility in diverse environmental settings, providing crucial information for season-specific pollution management techniques. Etelebu (dumpsites), Mechanic Village Imiringi (workshops), Otuasega (cassava mills), and Agba (crude oil spill site) were identified as pollution hotspots through the study, which enabled focused environmental monitoring and intervention priorities to be established.

5.2 Findings

1. Analysis of soil sample at each site revealed a notable accumulation of heavy metals. Dumpsites like DDS4 (Etelebu) had higher concentrations of iron (363.5 mg/kg), lead (7.525 mg/kg), and zinc (333.7 mg/kg). In mechanic workplaces, especially MDS03 (Mechanic Village Imiringi), extreme levels of copper (122.6 mg/kg) were encountered while at MDS1 (Mechanic village Imiringi) zinc

(399.7 mg/kg), and cadmium (2.704 mg/kg) were discovered. The levels of cadmium and lead at cassava mills location such as CDS01 (Otuasega 1) were found to be 0.964 and 5.466 mg/kg, respectively. The highest levels of pollution were found in crude oil spill locations, especially SDS1 (Agba Otuegwe 1), where lead and iron levels reached 15.354 and 568.5 mg/kg, respectively. These levels confirmed that soils at all locations were far more polluted than acceptable limit, and have high ecological risk values and pollution load indices (such as the lead EF of 1,532).

2. Groundwater was adversely impacted at almost all locations. Lead, cadmium, and iron levels at dumpsites above WHO standards, reaching 0.079 mg/L (DWGW2, Igbogene), 0.092 mg/L (DWGW6), and 0.811 mg/L (DWGW6, Akenfa 1), respectively. In mechanic workshop boreholes, lead levels were 0.053 mg/L and iron levels reached 0.625 mg/L (MWGW2, Mechanic Village Imiringi). Groundwater near Cassava mills exhibited levels of lead and cadmium exceeding safety standards, while cyanide was detected at 0.01 mg/L (CDGW2, Opolo big brother rd.). Crude oil spilled areas had the greatest quantities of lead at 0.133 mg/L (SWGW1, Agba, Otuegwe) and total hydrocarbons at 0.263 mg/L (SWGW2, Ibelebiri). Iron, chromium, and manganese were also frequently found in high concentrations. These results indicated increased groundwater vulnerability and long-term exposure hazards, especially near Etelebu, Akenfa, Imiringi, Otuasega, and Agba.
3. Zinc concentrations as high as 7.176 mg/L and turbidity of 5.4 NTU (DWSW4, Akenfa 1, and Epie Creek) were found in surface waters. Lead and cadmium were present throughout the seasons, and copper recorded as 2.43 mg/L (DWSW1, Tombia Junction Market Epie Creek) was supplied by runoff from mechanic workshops. Extremely high concentrations of lead (1.552 mg/L) and hydrocarbons (12.05 mg/L) both recorded at SWSW1 (Agba/Otuegwe Kolo Creek) were found in surface water around a crude oil spill. These findings point to ongoing pollution discharge, degraded aquatic habitats, and potential biomagnification risks in the surrounding community.
4. According to seasonal studies, a concentration effect caused by reduced diffusion often resulted in higher metal levels during dry spells. Lead levels, for example, rose from 8.071 mg/kg to 15.354 mg/kg at SDS1 (Agba) and from 5.504 mg/kg (wet) to 7.525 mg/kg (dry) at DDS4 (Etelebu dumpsite). Although runoff increased the turbidity and metal levels of surface waters during the wet

season, cadmium and lead levels in groundwater remained consistently above seasonal limits. The results showed that Etelebu, Imiringi, Otuasega, and Agba were pollution hotspots, with the highest levels of contamination across all matrices and seasons.

5.3 Conclusion

The soil, groundwater, and surface water pollution in various environmental situations, such as dumpsites, mechanic workshops, cassava mills, and crude oil spill sites, were thoroughly investigated in this study. The study determined significant pollution levels impacted by seasonal fluctuations by examining the presence and distribution of heavy metals including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), nickel (Ni), lead (Pb), and vanadium (V). The findings draw attention to serious health and environmental issues, as heavy metal concentrations frequently surpass regulatory organizations' allowable limits.

Soil

The study revealed that the quality of the soil around dumpsites is significantly impacted by trash disposal, with iron concentrations varying from 8 mg/kg to 363.5 mg/kg throughout the year. Particularly at sites like DWS4, the high levels of manganese (ranging from 9.7 mg/kg to 184.7 mg/kg during the wet season), zinc (4.1 mg/kg to 302.8 mg/kg during the wet season), copper (1.35% to 79.4% during the wet season), and chromium (2.08% to 84.7 mg/kg during the dry season) indicate serious contamination. The influence of dumpsites on soil quality is particularly evident at sites such as DDS4–DDS8 & DDS24, where the high cadmium contamination factor (CF) exceeds 6. Seasonal water dynamics and waste material breakdown have an impact on metal concentration fluctuation, highlighting the necessity of strict waste management to reduce ecological risks and stop additional soil quality degradation in these locations.

High amounts of metals, including iron (6.45 mg/kg to 450.2 mg/kg) and manganese (7 mg/kg to 236.1 mg/kg), were found in the soil surrounding mechanic workshops, particularly at MWS03 during the wet season. These concentrations are indicative of pollution from mechanical activities and automotive waste. A common source of contamination, most likely from lubricants and auto parts, is suggested by the strong positive association observed between iron, manganese, and other metals such as zinc, copper, and lead during both seasons. Since the ongoing discharge of toxins poses a long-term hazard to soil health and

neighboring ecosystems, our findings necessitate focused remediation strategies to address the high pollution load index (PLI) seen in these regions.

The soil around cassava mills had high metal concentrations during the wet season, iron levels ranged from 25.6 mg/kg to 223 mg/kg. The need to manage waste from processing activities to stop additional soil deterioration is indicated by the seasonal variance, where metal concentrations rise in the dry season due to decreased dilution. This is especially important since the sustainability of the ecosystem and agricultural productivity in these areas may be impacted by the persistence of these toxins.

The highest level of pollution is found in crude oil spill sites, where metal concentrations during the wet season ranged from 200.4 mg/kg to 270.8 mg/kg for manganese and from 301.6 mg/kg to 516.3 mg/kg for iron. Significant hydrocarbon levels are present, and the wet season's THC levels ranged from 7.08 to 15.78 mg/kg, highlighting the long-lasting effects of oil spills on the environment. Geo-accumulation index (Igeo) vanadium's indicates extremely high contamination, requiring immediate remedial measures to prevent more harm to the ecosystem. To avoid irreparable harm to soil ecosystems and possible effects of food chains, the long-term effects of such pollution demand prompt attention.

Groundwater

In the groundwater iron concentrations above allowable limits have been detected ranging from 0.411 to 0.811 mg/L during the rainy season and exhibit a noticeable increase during the dry season, this demonstrates the influence of dumpsites on groundwater quality. This shows that metals are leaching out of garbage, which has a big impact on groundwater quality. The substantial seasonal change in manganese (mean difference of 0.186 mg/L) indicates that rainfall patterns affect the mobility of contaminants, requiring ongoing monitoring for public health and safety. These results emphasize how critical waste management is in preventing toxic compounds from seeping into groundwater supplies.

Iron levels in the groundwater around mechanic shops ranged from 0.239 mg/L during the dry season to 0.384 mg/L during the rainy season, indicating that automotive waste is the source of the contamination. From this study, the mobility of copper and zinc is higher during the rainy season, indicating that as water availability rises, these contaminants are more proned to seep into groundwater.

Moderate iron levels were found in the groundwater close to cassava mills, but cadmium pollution was severe, with amounts ranging from 0.001 mg/L to 0.031 mg/L during the dry season, thus exceeding WHO and NSDWQ guidelines. This trend of pollution shows that groundwater quality is greatly impacted by waste from cassava processing, especially during the dry season when dilution effects are negligible. Cadmium levels in groundwater close to crude oil spill locations range from 0.072 to 0.074 mg/L, which is significantly higher than permissible limits during the rainy season. THC's association with metals such as iron, manganese, and lead indicates that petroleum hydrocarbons are the main cause of contamination, which is made worse by seasonal variations in rainfall.

Surface Water

High zinc concentrations, with a mean of 6.027 mg/L during the wet season, were found in surface water close to dumpsites, indicating substantial anthropogenic input. Despite being high, iron levels during the dry season were within natural background values, indicating that metal concentrations are elevated by diluting effects during rains.Severe hydrocarbon pollution was found in the surface water at crude oil spill locations, with metals including iron and manganese considerably higher than at control sites and THC levels ranging from 11.62 to 12.05 mg/L during the rainy season. Long-term environmental effects are indicated by the fact that this contamination endures even during the dry season. The intricate relationship between THC and other metals highlights the intricacy of oil spill pollution, necessitating coordinated environmental restoration initiatives to stop the continuous deterioration of surface water quality and preserve the natural equilibrium in these regions.

Seasonal Variations

Metal concentrations in surface water exhibit clear patterns in both wet and dry seasons, with more metal mobility during rainy season. From this study, the wet season has noticeably higher levels of lead and zinc, most likely as a result of increased runoff and leaching from contaminated soil into water bodies. Since pollutants' greater mobility during the rainy season might worsen surface water resource contamination and necessitate strategic interventions to reduce pollution levels, it is imperative to comprehend these seasonal dynamics in order to schedule remediation actions efficiently.

5.4 Contribution to Knowledge

1. Ecological risk assessment has shown that Vanadium and Cadmium have the most severe anthropogenic enrichment and contamination
2. Groundwater near waste sites contained seasonally variable levels of zinc, copper, cadmium and lead with significant seasonal differences and correlation pointing to industrial effluents and leaching from contaminated soil.
3. The quantification of ecological and health implications of the detected heavy metal contamination, help bridged the gap between environmental data and risk assessment for the Niger Delta.

5.5 Recommendation

1. Effective waste management techniques must be used since they are essential to stopping additional contamination because the ongoing discharge of metals from human activity poses a serious threat to the quality of groundwater and the well-being of the communities that depend on these water sources.
2. Aquifer protection requires thorough spill response and continuous monitoring, this is based on the fact that the long-term presence of these contaminants can compromise groundwater resource safety and present serious threats to ecosystems and human populations.
3. Monitoring the temporal variations in heavy metal concentrations at the various sites (dumpsites, mechanic workshops, cassava mills, and crude oil spill areas) might be the main objective of a longitudinal study. In order to provide vital information for environmental management and policy creation, this study would evaluate the efficacy of remediation efforts and monitor ecosystem recovery over time.
4. The bioaccumulation of heavy metals in local food chains, especially in soil and water, might be examined further to determine the possible health implications to humans. This can entail assessing the dangers to populations that depend on these resources for survival as well as the way pollutants are transferred from contaminated soil and water to plants, fish, and cattle. Information about the direct effects of pollution on human health in contaminated areas would be invaluable from such studies.

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