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PHYTOREMEDIATION POTENTIAL OF SENNA (*Senna occidentalis*) AND NEEM (*Azadirachta indica*) IN DETOXIFICATION OF SOILS CONTAMINATED WITH Zinc (Zn), Copper (Cu) and Lead (Pb).

Habib, D. W, Mahmud Y. I, Abdurrahman B. L
and Mustapha A. A

Department of Soil Science, Bayero University, Kano,
Kano State

ABSTRACT

A greenhouse and laboratory experiment were carried out to investigate the phytoremediation potential of Neem (Azadirachta indica) and Senna (Senna occidentalis) plants. Soil samples were randomly collected in the teaching and research farm of the Center for Dry Land Agriculture, Bayero University Kano. Samples were collected from both plants and soil for standard analysis. The data obtained was statistically analyzed using one-way ANOVA. The result indicated that the soil was Loamy sand in texture. The soil pH was found to be moderately acidic (5.99), while the OC, TN, and Ap were found to be low. The concentrations of Zn and Cu in both plants were found to be high with mean values ranging from18.11mg/kg to 22.02mg/kg, with the root system having the highest concentration. However, Pb was not absorbed by any of the studied plants but was found in the soil samples with mean concentration of 34.01mg/kg. The bioaccumulation and translocation factors from the study indicated that the test plants can be used as phytoextractors to remediate soils contaminated with Zn and Cu. It is recommended that Neem and Senna plants should be used to detoxify soils contaminated with Zn and Cu. Also, investigation should be carried out on how to recover the extracted metals to avoid reintroduction into the environment.

Keywords: *Phytoremediation, BAF, TF, Zn, Cu, Pb.*

Corresponding author: Habib, D. W can be contacted at dwakilihabib@gmail.com

1. INTRODUCTION

Contamination of the environment is a universal problem emanating as a consequence of human activities amongst which are excessive mining and smelting of metal, ores, gas exhaust, energy and fuel production, indiscriminate use of fertilizers and pesticides, and generation of municipal wastes (Adriano, 2001). Too much concentration of hazardous metals in the soil poses significant health risks to human beings, animals, and plants which is subsequently hazardous to the entire food chain and the ecosystem (Nascimento and Xing, 2006).

Phytoremediation is phenomenon whereby toxic contaminants in soil, water, and air are removed and destroyed through the use of plants, including trees and grasses, and their relatedmicrobes. The technique is based on naturally occurring processes within the plant itself or in its microbial rhizosphere to extract, degrade, and/or stabilize organic and inorganic pollutants (Wilschut et al., 2013). Phytoremediation depends not only on the amount of metal in plant shoots bar also on high biomass production. The determinant for choosing plant species is seldom based on high tolerance but also its affinity for several metals, adaptation to climatic variations, high biomass, good root architecture, and highaffinity for moisture absorption through the roots (Zhao *et al*., 2001). Chelates may be used to releasemetals from the soil into the soil solution if they are not sufficient for plant uptake (Huang and Cunningham, 2001; Huang *et al*., 2003; Bhargava *et al*., 2012). Amongst the several environmental problems, toxic contamination by metals is among the prominent, and yet most conventional remediation approaches do not provide acceptable solutions. Excavation, transportation, and treatment are all expensive methods of remediation, while containment has negative environmental consequences (Wilschut et al., 2013). These pollutants have resulted in major environmental issues such as shrinking available land, air pollution, water and soil deterioration, and the ruin of natural landscapes. The most serious issue is the leakage of harmful heavy metals into the food chain.

In view of the above shortcomings, this study aims to determine the phyto-extraction potential of Neem and Senna plants in the detoxification of soils contaminated with Zn, Cu, and Pb and also to suggest ways in which soil pollution be can controlled with limited or no effect on the soil environments.

2. Review of Literature

This section provides an overview of heavy metals, their ability to contaminate the environment, how they influence soil and crops, and the resulting effects on human, animal, and soil health. Their remedial approaches were also examined.

2.1 Pollution

In recent times, the world has faced global difficulties such as increased environmental degradation caused by increasing population, industrialization, urbanization, as well as agricultural, mining, and transportation activities. Heavy metal pollution is regularly featured on the list of extremely polluted cities (Mellem, 2008).

Chemical manufacture, painting and coating, mining, extractive metallurgy, nuclear, and other industries all contribute to the disposal of these metals. The introduction of industrial and municipal solid wastes into the ecosystem has significantly increased heavy metal levels in soil and vegetation established on dumpsites. The soil and vegetation in these locations pose a major hazard to the health of those who live nearby (Inuwa et al., 2007).

A pollutant is any material in the environment that has unfavorable impacts on human health and may eventually lead to death. Such substance has to be present in the natural world beyond an acceptable limit. Thus, environmental pollution is defined as the presence of a pollutant in the environment, which includes air, water, and soil, and can be dangerous or toxic, causing harm to living creatures in the polluted environment (Hernández, 2013).

2.2 Heavy Metals

Any metallic element with a relatively high density that is harmful or poisonous even at low concentrations is referred to as a heavy metal (Lenntech et al., 2013). Heavy metal is a broad word that refers to a class of metals and metalloids. Heavy metal is a broad phrase that refers to metals, as well as metalloids, having an atomic density in excess of four g/cm3, or 5 times or more the density of water (Hawkes, 1997). However, the chemical characteristics of heavy metals have a greater influence than their density. Lead (Pb), Cadmium (Cd), Nickel (Ni), Cobalt (Co), Iron (Fe), Zinc (Zn), Chromium (Cr), Arsenic (As), Silver (Ag), and Platinum (Pt) are examples of heavy metals.

2.2.1 Toxicity of Heavy Metals in Soils

Because of their toxicity and hazard to human existence and the ecosystem, heavy metal poisoning in soil is a major problem. Toxic metals in the environment can cause geo-accumulation, bio-accumulation, and bio-magnification. They build in soils and plants over time and have a deleterious impact on physiological functions such as photosynthesis, gaseous exchange, and nutrient absorption, resulting in decreased plant growth, dry matter accumulation, and yield. Heavy metals enter plants through adsorption (the binding of elements to the surface) or absorption (the entry of metals into the inner matrix). Both methods can occur at the same time. Traces of heavy metals in plants or animals are not harmful in low concentrations, with the exception of lead, cadmium, and mercury, which are toxic even in low amounts. Monitoring soil pollution with heavy metals is important due to their impact on ground and surface water, as well as plants, animals, and humans (Fagbote and Olanipekun, 2010).

Metal toxicity has a great impact and significance on plants, and as a result, it impacts the environment in which plants play an important role. However, a few elements, such as copper (Cu), manganese (Mn), cobalt (Co), zinc (Zn), iron (Fe), and chromium (Cr), are required in trace levels for plant metabolism. Only when heavy metals exist in bioavailable forms and at high concentrations do they have the potential to be hazardous to plants (Nagajyoti et al., 2010).

2.2.2 *Bioavailability of Heavy Metals*

The outcome of many metals in natural systems, such as chromium, nickel, copper, manganese, mercury, cadmium, lead, and metalloids such as arsenic, antimony, and selenium, is of major interest. Adriano (2001), David and Joel (2006).

The fraction of total metals available for assimilation into biota (bioaccumulation) is referred to as bioavailability. Metal bioavailability does not always correspond to total metal concentrations. Aluminum (Al), Arsenic (As), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb), Selenium (Se), and Antimony (Sb) are metals of significant interest in bioavailability studies, according to the United States Environmental Protection Agency (EPA) (McKinney and Rogers, 2013). Silver (Ag), Barium (Ba), Cobalt (Co), Manganese (Mn), Molybdenum (Mo), Sodium (Na), Titanium (Tl), Vanadium (V), and Zinc (Zn) are currently of less concern to the EPA. These metals were chosen due to the possibility of human exposure and increased health risks. Different toxic metals have distinct effects on plants. Pb, Cr, and Cu are not highly mobile in trees and are mostly retained in the roots. Cd, Ni, and Zn, on the other hand, are more easily translocated to plant aerial parts (Mohanty et al., 2010). Plant uptake of trace elements is usually the first step in getting through the food system chain, and it is dependent on elements moving from the soil to the plant root, elements crossing the membrane of the root's epidermal cells, and elements moving from the epidermal cells to the xylem. In the phloem transport system, the solution of these components is then transferred from roots to shoots and maybe mobilized, from leaves to storage tissues such as seeds, tubers, and fruit consumed as food. Metals are available to herbivores and people both directly and indirectly after plant uptake. The soil to the root is usually the limiting step for elemental entry into the food chain. This essential stage is often determined by concentrations of elements in soil pore solutions, which are influenced by local soil physical and chemical parameters such as water content, pH, redox reaction, and other variables (Adriano, 2001).

Metal uptake rates are further influenced by plant type, relative abundance, and availability of essential components. An abundance of accessible essential nutrients can reduce plant uptake of non-essential components. Complexer interactions have also been found, and bioavailability might be related to multi-element quantities or ratios. Copper toxicity, for example, is linked to low levels of zinc, iron, molybdenum, and (or) sulfate (Chaney, 2009). Metals can be partitioned into six fractions in solid phases, soil, sediment, and surface water particulates: (a) dissolved, (b) exchangeable, (c) carbonate, (d) iron-manganese oxide, (e) organic, and (f) crystalline (Salomons, 2019). As demonstrated by recurrent partial extraction processes, multiple metals partition differentially among these fractions. Changes in pH, redox state, organic content, and other environmental conditions have a significant impact on partitioning (Salomons, 2019). Carbonate complexes, which concentration increases with pH, and metals in solution, such as metal cation and anion complexes and hydrated ions, whose solubilities are highly affected by pH and tend to increase with lowering pH, comprise the dissolved fraction. (Chaney, 2009). Metals bonded to colloidal or particulate particles make up exchangeable fractions.

The carbonate fraction, which can be newly precipitated in soil, is made up of metals related to carbonate minerals in sedimentary rocks and soil. Metals adsorb to iron-manganese oxide particles or coatings make up the iron-manganese oxide fraction. Metals are bonded to diverse kinds of biological materials in the organic fraction. Metals contained within the crystalline structure of minerals make up the crystalline portion, which is generally unavailable to biota.

2.2.3 Soil Heavy Metals

Soil is a vital component of the biosphere because it not only works as a geochemical sink for contaminants but also as a natural buffer that controls the movement of chemical elements and compounds to the atmosphere and living creatures. The most significant role of soil, however, is production, which is the foundation for human survival (Kataba-Pendias, 2000).

2.2.4 Crop Heavy Metals

Plants have two major structural components: the root system, which anchors the plant in the soil and serves as a location for mineral absorption from the earth, and the shoot system, which consists of stem and leaves. The stem sustains the plant and transports minerals and water to the leaves, as well as carbohydrates produced in the leaves to the roots (Fagbote and Olanipekun, 2010).

Heavy metal incorporation in crops is primarily accomplished through uptake from the soil via the roots, though it may also occur through deposition of the elements on the leaves. Many factors influence plant uptake of these metals, including the growth environment, competition between plant species, plant size, root system, availability of the element in the soil or foliar deposits, and so on. Plants differ in their ability to absorb and accumulate heavy metals in their tissue, and the actual levels of these metals are influenced by a variety of factors such as plant type, specific plant tissues, metal level in the soil, metal availability in the soil, and so on (Fagboteand Olanipekun, 2010).

2.2.5 Copper

Copper is a reddish metal with a face-centered cubic crystalline structure. It has an atomic number of 29, a relative atomic mass of 63.55, a density of 8.9gcm3, a melting point of 1083oC, and a boiling temperature of 2595oC (Lenntech, 2013). It is malleable, ductile, and an excellent heat and electricity conductor. It's softer than zinc and can be polished to a gleaming sheen. The metal is chemically inactive. In moist air, it slowly produces a greenish surface film known as patina, which protects the metal from further oxidation. The metal is mostly used in electrical equipment (60%), construction (such as roofing and plumbing) (20%), industrial machinery (such as heat exchangers (15%), and alloys (5%). Bronze, brass (a copper-zinc alloy), copper-tin-zinc, sometimes known as gun metal, was strong enough to build firearms and cannons, and copper and nickel, known as cupronickel, was the chosen metal for low-denomination coinage (Lenntech, 2013).

Copper can be discharged into the environment through both natural and anthropogenic causes. This essentially means that an increasing amount of copper ends up in the environment. Wind-blown dust, decomposing plants, forest fires, and sea spray are examples of natural sources. Mining, metal manufacture, timber production, and phosphate fertilizer production are a few examples of human activities that contribute to copper release. Copper is relatively common in the environment because it is released both naturally and via human activity. The metal is frequently discovered around mines, industrial areas, landfills, and waste disposal sites. Soil copper content ranges between 2 and 100 parts per million (ppm), with an average value of around 30 ppm. The majority of this is in the form of inaccessible minerals (Schult and Kelling, 2019). The bulk of plant species have copper levels ranging between 20 and 30 mg kg-1 dry weight. The critical copper deficiency level in vegetative plant parts is normally 3 to 5 mg kg-1 dry weight (Robson and Reuther, 2018); it has been observed to be 1.5 mg kg-1 dry weight in early grain plants (Robson et al., 2019).

Because copper is non-biodegradable, it can accumulate in plants and animals when present in soils. The metal enters the human body via acidic foods cooked on uncoated copper cookware, or from exposure to excess copper in drinking water or other environmental sources. The Maximum Contaminant Level (MCL) in drinking water set by the United States Environmental Protection Agency is 1.3 milligrams per liter. OSHA has established a limit of 0.1 mgm-3 for copper fumes (vapor created from heating copper) and 1 mgm-3 for copper dust (fine metallic copper particles) and mists (aerosol of soluble copper) in workroom air. It is a necessary trace element for human health. Although humans can tolerate high amounts of copper, an overabundance of metal can cause serious health concerns (1991, 2001).

2.2.6 Lead (Pb).

Lead (Pb) is a bluish or silvery-grey metal with an atomic number of 82, a relative atomic mass of 207.19, and a specific gravity of 11.34. It has a melting point of 327.50 degrees Celsius and a boiling point at atmospheric pressure of 17400 degrees Celsius. It is composed of four naturally occurring isotopes with relative atomic masses of 208, 206, 207, and 204 (in decreasing order of abundance) (Ashraf, etal., 2012). Despite having four electrons on its valence shell, lead's usual oxidation state is +2 rather than +4, due to the inert pair effect. Except for nitrate, chlorate, and chloride, most inorganic Pb2+ salts are poorly soluble in water. Lead is currently found in ore with zinc, silver, and copper and is extracted with these metals. The major lead mineral is galena (PbS), but amounts of cerussite and anglesite are also exploited. The element can be found in all aspects of our environment, including the air, soil, and water, as well as inside our dwellings (Ashraf, et al., 2012). Pewter and solder are examples of alloys. Tetraethyl lead (PbEt4) is still used in some types of gasoline (petrol), although it is being phased out since it contributes to metal pollution. Lead is a major component of the lead-acid battery, which is widely used in automobile batteries. It is the usual base metal for organ pipes and is used as an electrode in the electrolysis process. One of its most important applications is in the glass of computer and television screens, where it protects the viewer from radiation. Other applications include sheets, cables, solders, lead crystal glassware, ammunition, and bearings, as well as weight in sporting goods, cosmetics, pipes, and plumbing supplies (Rosen, 2010).

While natural lead levels in soil range from 50 to 400 ppm, mining, smelting, and refining activities have resulted in a significant rise in lead concentration in the environment, particularly around mining and smelting sites (Rosen, 2010). When present in high concentrations, Pb2+ was discovered to be extremely hazardous to humans. Although Pb2+ is not biodegradable, soil contamination remains a long-term source of Pb2+ exposure. The metal occurs naturally in nature. It accumulates in the top 8 inches of soil and is quite immobile. Long-term contamination exists. High soil lead levels will never return to normal unless remedial action is taken. Lead is recognized to be hazardous to plants, animals, and microorganisms in the environment. In general, the effects are restricted to highly contaminated areas (Rolfe et al., 2007). Pb poisoning in the environment persists in an insoluble state, and the hazardous metals constitute a major threat to human health (Holmgren,1993). Lead serves no functional use in the human body. It can enter the human body via food (65%), water (20%), and air (15%). Fruits, vegetables, meats, grains, shellfish, soft drinks, and wine may have high levels of lead.

2.2.7 Zinc

Zinc is a gleaming bluish-white metal. It is found in Periodic Table Group II. At room temperature, it is brittle and crystalline, but when heated between 110°C and 150°C, it becomes ductile and malleable. It has an atomic number of 30, a relative atomic mass of 65.37, a density of 7.11gcm-3, a melting temperature of 420°C, and a boiling temperature of 907°C. It is a moderately reactive metal that interacts with dilute acids to liberate hydrogen and mixes with oxygen and other nonmetals. Emsley

(2003) ranks it as the 23rd most prevalent element in the Earth's crust. Zinc blende, commonly known as sphalerite, is the major ore. Wurtzite, smithsonite, and hemimorphite are also major zinc ores. Recycling meets more than 30% of the world's zinc demand. The metal is mostly used for galvanizing iron, with more than half of it going into galvanizing steel, although it is also utilized in the preparation of specific alloys. It's utilized in some electric batteries' negative plates, as well as roofs and gutters in building construction. The element is the primary metal used in the production of American pennies, and it is also utilized in die casting in the automotive sector. Zinc oxide is used in the rubber industry as an activator and as a white pigment in watercolors and paints. Zinc is utilized as a pigment in plastics, cosmetics, photocopier paper, wallpaper, printing inks, and so on, while in rubber production it serves as a catalyst during manufacturing and as a heat dispersant in the finished product (Emsley, 2003). Most single tablets contain zinc metal, which is thought to have anti-oxidant effects that protect against premature aging of the skin and muscles (AREDS, 2001).

Zinc occurs naturally in air, water, and soil; however, zinc concentrations are increasing unnaturally as a result of zinc addition from human activities. The majority of zinc is added through industrial processes such as mining, coal and waste combustion, and steel manufacturing (Broadley *et al.*, 2007). Some soils are extensively contaminated with zinc, and they can be found in places where zinc is mined or refined, or where industrial sewage sludge has been utilized as fertilizer. Animals will absorb zinc quantities that are harmful to their health if farming soils are polluted with zinc. Water-soluble zinc found in soils has the potential to contaminate groundwater. Zinc cannot only endanger animals but also plant life. Plants frequently experience zinc uptake that their systems are unable to handle as a result of zinc accumulation in soils (Broadley *et al*., 2007). Only a few plants have a possibility of survival in zinc-rich soils. As a result, there is little plant diversity around zinc-disposing facilities.

Only dissolved zinc is bioavailable, and bioavailability is affected by the physical and chemical properties of the environment as well as biological processes. Zinc levels of up to 4mg L^{-1} in water, 35 g kg^{-1} in soil, 15 g L^{-1} in estuary water, and 8 g m^{-3} in air have been reported in anthropogenically contaminated samples (AREDS, 2001). Plants and animals have higher concentrations. Zinc levels in most crops and pastures are normal, ranging from 10 to 100mgkg^{-1} dry weight. Some plants accumulate zinc, however, the quantity of accumulation in plant tissues varies depending on soil and plant features (AREDS, 2001).

2.3 PHYTOREMEDIATION

Soils polluted with heavy metals are an environmental problem that demands an effective and economical treatment due to their potential toxicity and high persistence. Polluted sites must be remedied to avoid contaminants from leaking into groundwater or being absorbed by food crops. Solidification and stabilization, soil flushing/washing, electrokinetics, chemical reduction/oxidation, lower-temperature thermal desorption, burning, the use of vitrification pneumatic fracturing, excavation/retrieval, and landfill are the existing conventional remediation procedures (Mellem, 2008). Some of these engineering-based conventional remediation techniques include excavation and disposal of polluted soil into a landfill, excavation and off-site treatments, on-site treatments, and containment of polluted soils by plastic, pavement, or a layer of clean soil preventing contact with the polluted soil layer. Excavation, transportation, and treatment are all expensive methods of remediation, while containment has severe environmental consequences (Wilschut *et al.*, 2013). Furthermore, because they interfere with soil structure and fertility, these physical and chemical soil remediation procedures render the land worthless as a medium for plant growth. Because conventional treatments are expensive, the use of plants to clean up contaminated areas (phytoremediation) has emerged (Hosh and Ingh, 2005).

The use of plants, especially trees and grasses, and their associated microorganisms to remove, eliminate, or sequester hazardous pollutants from soil, water, and air is known as phytoremediation. The method relies on naturally occurring mechanisms inside the plant or its microbial rhizosphere to absorb, degrade, and/or stabilize organic and inorganic contaminants (Wilschut *et al.*, 2013). Phytoremediation and phytoextraction are sometimes used interchangeably, although phytoremediation is a concept while phytoextraction is a specific clean-up procedure.

2.3.1 Benefits of Phytoremediation Over Conventional Remediation

The significance of phytoremediation cannot be overstated. It is more economically advantageous to use agricultural tools and supplies. It is less damaging to the environment and does not require the site to be re-colonized by new plant communities.

There is no need for disposal sites, and it is more likely to be accepted by the public because it is more aesthetically beautiful than previous techniques. It avoids the excavation and transfer of tainted medium, lowering the risk of contamination spreading. It has the potential to treat contaminated sites with more than one type of pollutant (Lasat, 2002).

2.3.2 Phytoremediation's Disadvantages in Comparison to Conventional Remediation

One of the concept's disadvantages is that it is dependent on the plant's growing conditions (i.e., climate, geology, altitude, and temperature). Large-scale activities necessitate the use of agricultural equipment and knowledge. The plant's tolerance to the contaminant determines its success. Contaminants gathered in older tissues (leaves) may be discharged back into the environment as they fall off; contaminants may be collected in woody tissues used as fuel; and contaminants may be collected in woody tissues used as fuel. The time required to remediate sites is significantly greater than that required by other technologies, and contaminant solubility may rise, resulting in more environmental damage and the likelihood of leaching (Lasat, 2002). Phyto-extraction, phytodegradation, phytostabilization, phytovolatilization, and rhizofiltration are all methods for phytoremediation (Nascimento & Xing, 2006).

2.3.3 Phytovolatilization

This entails using plants to absorb pollutants from the soil, convert them into volatile form, then expel them into the atmosphere. At low concentrations, some of these pollutants can travel through the plant roots to the leaves and volatilize into the atmosphere (Chaney *et al*., 2009).

2.3.4 Rhizofiltration

It involves the utilization of both terrestrial and aquatic plants to absorb, concentrate, and precipitate pollutants from polluted water sources using roots with low contaminant concentrations. It can treat industrial waste, agricultural runoff, and acid mine drainage in part. It can be utilized as an in-situ or ex-situ application (Chaney *et al*., 2009).

2.3.5 Rhizofiltration

It is mostly utilized for soil, sediment, and sludge cleanup and is dependent on the ability of roots to reduce pollutant mobility and bioavailability in soil. Sorption, precipitation, complexation, or metal valence reduction can all occur. The major objective of the plants is to reduce the amount of water-soluble metals percolating through the soil matrix, which may result in the creation of hazardous leachate and the spread of toxic metals to neighboring places (Chaney *et al*., 2009).

2.3.6 Phytodegradation

It involves the transformation of organic pollutants absorbed by plants (which contain enzymes) into simpler non-toxic compounds that are integrated into plant tissues (Chaney *et al*., 2009). This is also known as phyto-transformation. It entails the breakdown of complex organic compounds into simple ones or their integration into plant tissues (Trap *et al*., 2005). When the phytodegradation system is active, pollutants that have been taken up by the plant are broken down. Plant absorption, like phytoextraction and phytovolatilization, happens only when the pollutants' solubility and hydrophobicity fall within a specified permissible range. Some organic contaminants, such as chlorinated solvents, herbicides, and explosives, have been shown to be remedied by phyto-degradation, and they can address toxins in soil, sediment, or groundwater (EPA, 2000).

2.3.7 Phytoaccumulation

Metals can be removed from polluted soils/sediments by plant roots and transported to leaves and stems for harvesting and disposal without damaging soil structure or fertility (Sun *et al.*, 2011). It is most suited for the remediation of diffusely polluted environments when pollutants are present only in low concentrations and superficially. This can be a useful cleanup strategy for a wide range of pollutants and sites. The efficacy of the phytoextraction process, which successfully removes pollutants from soil, is based on appropriate plant production and/or the efficient transfer of toxins from plant roots to plant aerial parts (Luo *et al.*, 2005; Evangelou *et al.*, 2007). Natural hyper accumulators and high biomass-generating plants are used in phytoextraction (Saifullah *et al.*, 2009). Although different approaches have been used, the two basic phytoextraction strategies that have been used are (i) chelate-assisted phytoextraction or induced phytoextraction, in which artificial chelates are added to treated soil to increase metal contaminant mobility and uptake, and (ii) continuous phytoextraction, in which metal removal is dependent on the plant's natural physiological ability. A potentially beneficial feature of phytoextraction is that heavy metals taken up by phytoextraction into plant biomass can be recovered and recycled (Bhargava *et al.*, 2012).

2.3.8 Hyperaccumulators

Hyperaccumulators are plants that can absorb trace metal concentrations 100 times higher than normal species (Bhargava *et al.*, 2012). They are plants with a greater than one shoot-to-root metal concentration ratio. The ability of certain plant species to flourish in heavy metal-polluted soils, together with heavy metal hyperaccumulation in shoot material, has been identified as a viable strategy for decontaminating polluted soils. This is the most potential commercial application technique. Metal hyperaccumulation has been recorded in over 400 plant species from at least 45 plant families (Lasat, 2002). Plant species are chosen based on their high tolerance and accumulation rate for numerous metals, adaptability to local climates, high biomass, depth root structure, growth rate, ease of planting and maintenance, and ability to absorb large amounts of water through the roots (Saifullah *et al.*, 2009).

2.4 PHYTOEXTRACTION PLANT

2.4.1 Azadirachta indica A. (Neem)

Neem belongs to the Meliaceae family and is a tropical evergreen plant related to mahogany. It is native to east India and Burma, but it is now found throughout much of Southeast Asia and West Africa; a few trees have lately been planted in the Caribbean and several Central American countries, including México.For centuries, millions of Indians have cleaned their teeth with neem twigs, smeared skin disorders with neem-leaf juice, drank neem tea as a tonic, and placed neem leaves in their beds, books, grain bins, cupboards, and closets to keep away troublesome bugs (Nascimento, and Xing, 2006) Trees can grow up to 30 meters tall, with limbs half that width. The pinnately compound leaves are lustrous dark green and up to 30 cm long. Each leaf has ten to twelve serrated leaflets that are 7 cm long and 2.5 cm broad. It will grow in locations with little water and flourish in areas with intense temperatures of up to 48°C. Even the most skeptical researchers agree that neem deserves to be dubbed a "wonder plant." The neem tree was brought to Baja California Sur, México, in 1989 by a group of private growers in San José del Cabo dedicated to organic agriculture. The first trees were imported from the Philippines (Leos *et al*., 2002), and this species was introduced to Yaqui Valley, Sonora, México, in 1992 (Nascimento, and Xing, 2006). Windbreak trees have been planted in limited sections along roadsides since 1994. Neem populations planted in southern Sonora, México, range in phenotypic and quality characteristics; fruits vary in size and shape, and oil quantity and quality vary.

Table 1. Classification of Neem Plant

Scientific classification of Neem *Azadirachta Indica*
Kingdom: Plantae
Division: Magnoliophyta
Order: Sapindales
Family: Meliaceae
Genus: Azadirachta
Species: A. indica

Azadirachta indica has a high biomass and a great endurance to harsh climatic variations such as protracted drought, flood, submergence, and extreme temperatures ranging from -15oC to 55oC (Truong *et al.*, 2000). Also, the ability to re-grow fast after being afflicted by drought, frost, salt, and other adverse conditions, once the weather improves or soil ameliorants are introduced. It is also resistant to a wide range of soil pH from 3.3 to 12.5 in the absence of soil amendment. It also includes tolerance to herbicides and insecticides. It is extremely effective at absorbing dissolved nutrients such as N and P, as well as heavy metals, from polluted water. It is very tolerant of acidity, alkalinity, salinity, sodicity, and magnesium in soils, as well as Al, Mn, and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se, and Zn (Smeal*et al.*, 2003; Truong *et al.*, 2000).

2.4.2 *Senna Occidentalis (Linn.)*

Senna (Formerly Cassia occidentalis) is a leguminosae weed that grows throughout the world's tropical and subtropical regions. It can be found in open pastures and fields farmed with cereals such as soybean, corn, sorghum, and others; hence, it is nearly impossible to keep this plant from mingling with the cultivated crops during harvest (Barbosa *et al.*, 2005). This plant's leaves and rootbark extracts have been shown to have antibacterial and anti-malarial properties (Samy *et al.*, 2000). The leaves are alternate, compound, and paripinnate; the rachis is channeled, and there is a gland at the base of the rachis; the stipules are obliquely cordate and acuminate; the leaflets are 4-5 pairs, oblate to oblong-lanceolate; acuminate, margin ciliate, glabrous, or pubescent. Complete, bisexual, slightly irregular, zygomorphic, pentamerous, hypogynous, pedicelate; bractate, bracts white with pinkish tinge, thin, ovate-acuminate, caducous; yellow (Leos *et al.*, 2002).

Table 2. Classification of Senna Plant

Scientific classification of *Senna occidentalis*
Kingdom: Plantae
Division: Tracheophytes
Order: Fabales
Family: Fabaceae
Genus: Senna
Species: S. occidentalis

3. MATERIALS AND METHOD

3.1 Experimental Location

The experiment was carried out at the Department of Agronomy, Bayero University, Kano's greenhouse. Uncontaminated soil samples were acquired at the Bayero University Kano Teaching and Research Farm's Center for Dry Land Agriculture. The farm is located in Nigeria's Sudan savanna agro-ecological zone, between latitude 11.97932° and 11.98194°N, and longitude 8.41245° to 8.42205°E. Kano has a tropical wet season (May to September) with an average annual precipitation of 690 mm, with the majority falling from June to September (Adamu and Aliyu, 2012). Throughout the year, the temperature ranges from moderate to hot (KNARDA, 2010).

3.2 Treatments and experimental design

The experiment comprised of twelve (8) treatments which were replicated three (3) times, making a total treatment of twenty-four (24). The experiment was carried out in a completely randomized design (CRD)

3.3 Field/Greenhouse work

Soil samples were randomly collected at a depth of 0 – 15 cm from from the Centre for Dry Land Agriculture Teaching and Research Farm. The samples were air dried and sieved through a 2mm mesh sieve afterward; a complete routine soil analysis was also carried out before contamination at the Soil Science Laboratory, Bayero University Kano.

Pots of 36cm in diameter and 20cm in height were filled with 5 kg of air-dried surface soil samples, which was followed by the contamination of each treatment pot excluding the controls. The metals were applied to the experimental pots in 3 levels, which are 100%, 50%, and 0% (control). Zn, Cu, and Pb were the metals used for the experiment. At 100% level of contamination, the individual threshold limit of each metal was multiplied and added to the soil. While for 50%, half of the threshold limit was added to the soil. 0% was used as a control treatment. Seedlings of *Senna occidentalis and Azadirachta indica* were planted in each of the pots. The pots were watered at 2-day intervals with 500mls of water for 90 days. Afterward, plants and soil samples were collected for laboratory analysis

3.4 Analytical Procedures for Soil Sample

Gee and Or (2002) Bouycous Hydrometer method for determining particle size distribution was used.The soil pH was assessed using a glass electrode pH meter in a soil-water ratio of 1:2.5 (McNealand Coleman, 1965), and the electrical conductivity (EC) was determined using a saturated paste extract in a soil water ratio of 1:2.5 (Agbenin, 1995). Nelson and Summer (1982) described the wet oxidation method of Walkley and Black (1934) for determining organic matter. Bremmer (1996) described the Kjeldahl method for determining total nitrogen. Anderson and Ingram (1993) described a method for extracting heavy metals (Cu, pb, and Zn). An atomic absorption spectrophotometer was used to determine the concentrations of copper, lead, and zinc.

3.5 Plant Analysis

Following harvest, samples were taken from the leaves, stem, roots, and entire plant. After adding 5ml concentrated nitric acid and 5ml hydrochloric acid, one gram of oven-dried plant sample was placed in a 50ml conical flask and left overnight. The following day, 5ml of concentrated nitric acid was added again, and the substance was digested on the hot plate until it turned transparent. The digested material was cooled and its volume was increased to 20ml with double distilled water using a volumetric flask before being stored in clean air-tight bottles for atomic absorption spectrophotometer examination of zinc, copper, and lead (Rashid, 1986).

3.6 Determination of Bioaccumulation and Translocation Factor

Bioaccumulation factor (BAF) and translocation factor (TF) were calculated using the formula of Yadav *et al*. (2009) as:

$$Bio - accumulationfactor(BAF) = \frac{Averagemetalconc.inthewholeplant\ (mg/kg)}{Mentalconc.insoil\ (mg/kg)}$$

$$Translocationfactor(TF) = C_{aerial} \times \frac{1}{C_{root}} = \frac{C_{aerial}}{C_{root}}$$

C_{aerial} = Metal concentration in the aerial part of a plant (shoot).

C_{root} = Metal concentration in root of plant.

3.7 Statistical Analysis

Data collected was subjected to analysis of variance (ANOVA) using JMP15. Mean separation was done using turkey HSD at 5% level of probability.

4. RESULT AND DISCURSION

4.1. Physical and chemical properties of the Experimental Soil

The particle size distribution revealed that the sand fraction (85%) dominated the soil samples utilized for the experiment, followed by silt (13%), and clay (1%). The tested soil's textural class was determined to be loamy sand. The nature of the parent material could explain the prevalence of sand particles in the experimental soils (Brady and Weil, 2013).This study's low clay content values (Table 1) matched with the findings of Akintoye et al. (2012) and Akpan et al. (2017), who worked on similar soils. The low clay percentage may be attributable to the research area's sand-rich parent material. The silt content was. The silt content was also low which was not in agreement with the findings of Askira et al. (2019a) and Askira et al. (2019b) both reported higher silt content in their various studies which could be attributed to the nature of surface movement. The Soil pH in water was found to be 5.99. The obtained soil EC value for the studied soil was 0.03dsm^{-1}, while organic carbon and total nitrogen recorded values of 0.26 and 0.14% respectively. The phosphorus content was found to be 2.48mg kg^{-1} while K, Na, Ca, Mg, exchangeable acidity, and cation exchange capacity (CEC) were found to be 0.14, 0.15, 2.69, 1.80, 0.67, and 5This study's low pH values are similar to those previously reported by Abagyeh et al. (2017), Okoli et al. (2017), and Fekadu et al. (2018). The acidic status of the soils under research may be due to increased oxidation of anions such as sulfides and nitrites, which causes soil acidification (Ahukaemere et al., 2014). Heavy metal solubility is influenced by pH. Heavy metal mobility and availability are often limited in soils with high pH, clay, and organic matter (Askira et al., 2019). Brown (2007) also stated in his research that pH is a crucial factor regulating the availability of elements in the soil for plant absorption and that most metals are more soluble and accessible in slightly acidic soils. Susanna and Stephen, (2013) also reported that metals are soluble and mobile at low pH. The organic matter content shown in Table 1 was rated low (Esu, 1991). The low level of OC recorded in these soils is in line with earlier findings by Abagyeh et al. (2017) and Salem *et al.* (2018) who recorded low OC content for soils in the Savanna zones of Nigeria. This low level of organic carbon in these soils could be attributed to low organic matter returns and other human factors such as crop residue removal, burning, and mineralization. The total mean values of nitrogen as shown in (Table 1) were also rated low as per Esu, (1991) rating scale. Musa et al. (2017a) and Musa *et al*. (2017b) earlier reported low total nitrogen values in their various studies. The low level of total nitrogen obtained in this study could be attributed to the mobility of TN in soils, resulting in its losses through various mechanisms like ammonia volatilization, especially under high temperatures that characterize the climate of the region. Similarly, denitrification, chemical and microbial fixation, leaching, and runoff could result in low soil total nitrogen content. The values of available phosphorus were also termed low according to the rating of Esu (1991). Such low available P values were earlier reported by Imadojemu et al. (2017) and Kebede *et al*. (2017). The low value of available phosphorus recorded in this study could be attributed to the low content in the parent materials and its propensity to sorption on mineral surfacesas earlier reported by Piccolo and Gobena (2012). It could also be due to fixation, as a result of the acidic condition of the soils (Fekadu et al., 2018). The concentration of Cu, Pb, and Zn wasfound to be 0.92, 0.04, and 1.06 (mg kg^{-1}) respectively. (Table 3).

Table 3. Physical and chemical properties of soils of the study area

Physical and chemical properties	Concentration
Clay (%)	1
Silt (%)	13
Sand (%)	85
Soil texture	loamy sand
pH (H_2O)	5.99
EC (dS/m)	0.02
O.C (%)	0.26
P (mg/kg)	2.48
N (%)	0.14
K (cmol/kg)	0.14
Na (cmol/kg)	0.15
Ca (cmol/kg)	2.69
Mg (cmol/kg)	1.80
E.A (cmol/kg)	0.67
CEC (cmol/kg)	5.55
Zn (mg/kg)	1.06
Cu (mg/kg)	0.92
Pb (mg/kg)	0.04

4.2 Phytoremediation Studies

The obtained concentration of Zn in the Neem plant as shown in Tables 4 and 5 proved the studies of numerous researchers who had worked on the phytoextraction potential of the Neem plant. At all levels of contamination, the plant was able to take up Zn which followed the trend 0% < 50% < 100% with a mean concentration of 22.06mg kg^{-1} (Table 2), these show that an increase in contamination rate does not affect the physiology of the plant. Research has shown that Zn is one of the essential micronutrients required by the plant (Sun *et al.*, 2009). It was observed that Zn was not mobile which was in contrast with the findings of (Aydinal *et al.*, 2003) who reported that Zn is found to be highly mobile in acidic soil. However, Cu on the other hand did not follow a similar trend with Zn. Here, an increase in contamination did not increase the plants' ability to take up Cu. Copper is also an important nutrient required for plant growth. As such, it made the plant take up for its metabolic activities (Sun *et al.*, 2009). At 100% level of contamination, the concentration of Cu was highest in the plant tissue which might be because of its requirement by the plant for optimum growth. This was in agreement with Donald (2000) who reported that Cu is an essential micronutrient for plant growth.

Pb was not detected at any level of contamination (Table 4) which might be a result of its less important to plant growth. Furthermore, losses due to leaching and evapotranspiration were not accounted for in this study. The findings of this study are in line with the work of (David *et al* 2006) who stated those heavy metals are lost while irrigating or through evapotranspiration. Pb is an immobile element which is partly because it does not form precipitate and is not readily bioavailable. (Aydinal *et al*, 2003). The bioavailability of heavy metals is also greatly affected by the soil pH (Prasad 2003), which might have affected the bioavailability of Pb in this research.

Table 4. Effects of plant type and Contamination levels on Concentration of Heavy Metals in plants and soils of the study area.

Parameters	Conc. In plants	Conc. In soil (mg/kg)
Plants type		
Neem	15.80	11.22
Senna	11.04	15.27
S. E	0.82	1.29
LOS	**	*
Contamination levels (%)		
0	6.38c	3.24c
50	13.14b	14.44ab
100	20.73a	22.07a
S. E	0.01	1.29
LOS	**	**
Heavy Metals		
Zn	22.06a	2.78b
Cu	18.16ab	2.96b
Pb	ND	34.01a
S. E	1.08	1.29
LOS	**	**
Interaction		
Plants * Heavy Metals	*	*
Heavy Metals	*	*
Plants * Contamination levels	*	*

Key: SE = Standard error of means. Values followed by the same letters are not statistically different at $p < 0.05$, LOS= Level of Significance.

At all levels of contamination, the ability of Senna to absorb Zn as shown in Tables4, 6, and 7 was generally moderate compared to the Neem plant. The result showed that the concentration of Zn in the plant did not increase with an increase in contamination level, which might be a result of its demand for metabolic activities (Sun *et al*., 2009). While Cu on the other hand, recorded a decrease in the concentration of Cu in plant tissue with an increase in contamination. This might be attributed to the toxicity of the heavy metal to the plant (Agamuthu 2010). The plant showed some symptoms of toxicity after 30days of planting such as reduced growth, wilting, and death of the shoot tip unlike zinc toxicity, there was little chlorosis of the leaves. The result from this study was in contrast with the findings of Agamuthu 2010 and Nazir et al. (2006) who reported that the phytoremediation efficiency of metals greatly depends on the concentrations of such metals in solutions and the higher concentrations of heavy metals in the solution, the lower the removal efficiency. In the current study, despite the increase in the contamination levels, the plant was able to absorb some heavy metals, which is in contrast with earlier findings of Hernández (2013) who reported that, heavy metals in plants lead to degeneration of main cell organelles and even death of the plant.

The concentration of Cu taken up by the plant was because it's also a micronutrient in plants and it is involved in numerous physiological processes (redox and detoxification reaction) which is in line with the findings of Yadav et al. (2019).who worked on the role of micronutrients in plant growth and development.

Heavy metal concentrations in all plant tissue at 0 (control) level of pollution were lower than values obtained from similar research and recommended values (DPR, 2002; Suchkovq et al., 2014; Guidi Nissim et al., 2018). The plant's growth was slightly reduced near the end of the trial, which could be attributed to soil interference with water as well as nutrient immobilization and the presence of heavy metals which is in corroboration with the previous works conducted by several researchers (Akintola, 2019; Akintola and Bodede 2019).

Table 5. Effects of plant type and Contamination levels on Concentration of Heavy Metals in shoo t and root of the studied plants

Parameters	Conc. In shoot (mg kg^{-}	Conc. In root (mg kg^{-1})
Plants		
Neem	7.91	5.83
Senna	5.58	3.53
S. E	1.43	0.57
LOS	*	NS
Contamination		
0	0.29c	0.17c
50	7.93ab	5.15b
100	12.01a	8.73ab
S. E	1.74	0.98
LOS	*	*
Heavy Metals		
Zn	11.21a	7.58a
Cu	9.03a	6.46a
Pb	ND	ND
S. E	1.74	0.98
LOS	*	*
Interaction		
Plants * Heavy	*	*
Heavy Metals *	*	*
Plants *	*	*

Key: ND = Not detected, SE = Standard error of means. Values followed by the same letters are not statistically different at $p < 0.05$, LOS= Level of significance

The ability of Neem and Senna to ingest heavy metals from the soil can be linked to the reported drop in heavy metal concentration in soil after planting. This is consistent with the findings of (Akintola and Bodede, 2019). The high fall in Zn and Cu concentrations in growth media after planting could be attributed to their role in plant metabolic activities (Sun et al., 2009). The level of heavy metal enrichment in Neem and Senna seedlings was revealed by the considerable reduction of Zn and Cu in the growing media.

The absence of Pb could be attributable to some small leaching processes. In this study, greater Zn and Cu values correspond with changes in physical and chemical characteristics (Nick, 2013). According to Kataba-pendia (2004), Cu and Zn should be treated not only as soil contaminants but also as important micronutrients for plant growth. According to Fernandes and Henriquues (1991), the concentration of Zn and Cu in non-hyperaccumulation plant shoots is often less than 20mg/kg. In this study, the concentrations of Zn and Cu in the shoots of both Neem and Senna were less than 20mg/kg, implying that the findings from this study were consistent with those of Fernandes and Henriquues (1991), which could be attributed to the level of metal concentration in the soil, the time, and other factors (Akintola and Bodede 2019).The most frequently inorganic pollutant in the soil is Pb whichis not an essential element but can be toxic even at low concentrations to plants, animals, and humans. Levels of Pb above 400mg kg^{-1} can be hazardous to human health. (USEPA, 2001).

Nazir et al. (2013) reported that higher concentrations of heavy metals in the growing media reduced the growth and biomass of their studied plants which are in agreement with the finding of this study for Pb.

The concentration of heavy metal in the shoots and roots of both plants showed a significant (P<0.05) difference. The result as shown in Table 9 indicates that the concentration of Zn and Cu is higher in the root of the plant compared to the shoot of the plant. This indicates that the phyto-extraction technique observed in this study was Phytoaccumulation, and or phytostabilization, which was in agreement with the findings of (Guldi Nissim et al., 2018) who stated that the

Accumulation of heavy metals in the root of plant indicates the plant ability to Phyto stabilize or accumulate heavy metals.

4.3 Bioaccumulation and Translocation Factor

Translocation factor (TF), the quotient of contaminant concentration in shoots to roots, is used to measure the effectiveness of a plant in transferring a chemical from roots to shoots (Sun et al., 2011). Bioaccumulation factor (BF) is the ratio of chemical concentration in a plant to its concentration in the soil.The BAF measures a plant's ability to absorb heavy metals. The BAF for Neem was greater than one in our investigation, and it was generally higher for Zn and Cu. Senna was calculated to be less than one. This was consistent with the findings of Kabata-pendias and Pendias(2011), who discovered that green plants are more easily able to absorb Zn and Cu. Plants with BAFs larger than one have been shown in studies to be potential heavy metal hyperaccumulators. Plants' ability to thrive successfully in soils containing heavy metal concentrations comparable to those tested in this work has been documented by Blaylock and Huang, (2000), Norwood et al. (2007), and Nazir et al. (2013). The translocation factor in this investigation was 1 for both plants, with Neem closer to 1. The findings from this research is contrary to the findings of Yoon *et al* (2006) who reported that plant species with TF >1 have been suggested for Phytoaccumulation of contaminated soils.

Table 6. Bioaccumulation and translocation factors of Neem and Senna.

Plants	BAF	TF
Neem	1.40	0.75
Senna	0.69	0.64

5. CONCLUSION AND RECOMMENDATION

Relative to their respective control treatments, the plant species utilized in this study (Senna occidentalis and Azadirachta indica) showed significantly higher absorption of Cu and Zn (excluding Pb, which was low).

The bioaccumulation and translocation factors for the metals evaluated by the test plant species indicate that these species have phytoremediation capability. The phytoextraction capability of the plants was discovered to be in the order Azadirachta indica > Senna occidentalis.

The use of plants to remediate heavy metals from the soil is currently gaining considerable importance due to its potential for application to real-world ecosystems. In line with the above findings, it is recommended that Neem and Senna plants should be used to clean up soils contaminated with Zn and Cu. Also, an investigation can be carried out on how to recover these metals extracted to avoid reintroducing the metal contaminants into the environment. The use of environmentally friendly chelating agents could be studied on the phytoextraction of these metals and there is a need to develop new plants (genetically) that can increase phytoremediation potential so as to offer a viable remediation solution for polluted soils or farmlands. Finally, proper and periodic monitoring of mining sites is very necessary, so that appropriate preventive measures can be embarked upon when due, to avoid the gradual accumulation of these metals and for optimum agricultural productivity.

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Appendices

Table 7. Interaction between heavy metals and Plant type on concentration of heavy metals in plant tissue

	Plant type Neem	Senna
Heavy Metals(mg/kg)		
Zn	23.27a	20.55a
Cu	23.95a	12.27b
Pb	0.18c	ND

Key: ND = Not detected, Values followed by the same letters are not statistically different at $p<0.05$.

Table 8. Interaction between Plant type and contamination levels on concentration of heavy metals in plant tissue.

	Plant type	
	Neem	Senna
Contamination levels (%)		
0	6.71c	6.05c
50	15.57b	10.72bc
100	25.12a	16.64b

Key: Values followed by the same letters are not statistically different at $p<0.05$.

Table 9. Interaction between heavy metals and contamination levels on concentration of heavy metals in plant tissue.

	Contamination Levels (%)		
	0	50	100
Heavy metals(mg/kg)			
Cu	8.55c	18.25cd	27.53ab
Zn	10.33de	21.18bc	34.68a
Pb	0.28f	ND	ND

Key: ND = Not detected, Values followed by the same letters are not statistically different at $p<0.05$.

Table10. Interaction between plants type and heavy metals on concentration of heavy metals in soil.

	Plant type	
	Neem	Senna
Heavy metals		
Cu	3.08c	2.86c
Pb	28.21b	39.80a
Zn	2.39c	3.16c

Key: Values followed by the same letters are not statistically different at $p<0.05$.

Table 11. Interaction between plant types and contamination levels in soil

	Contamination Levels		
	0	50	100
Plant types			
Neem	3.24c	14.21b	16.23b
Senna	3.24c	14.67b	27.92a

Key: Values followed by the same letters are not statistically different at $p<0.05$.

Table 12. Interaction between heavy metals and contamination levels in soil

	Contamination Levels (%)		
	0	50	100
Heavy metals(mg/kg)			
Cu	0.77d	3.40c	4.74c
Pb	6.87c	36.52b	58.63a
Zn	2.08c	3.39c	2.86c

Key: Values followed by the same letters are not statistically different at $p<0.05$.

Table 13. Interaction between plant type and heavy metals in the shoot of the plants

Heavy Metals (mg kg^{-1})			
	Cu	Pb	Zn
Plant types			
Neem	9.18a	ND	8.30a
Senna	3.73b	ND	6.87a

Key: ND = Not detected, Values followed by the same letters are not statistically different at $p<0.05$.

Table 14. Interaction between contamination levels and heavy metals in shoot of the plants.

Heavy Metals(mg/kg)	Cu	Pb	Zn
Contamination Levels (%)			
0	0.35c	ND	0.14c
50	7.03b	ND	8.42b
100	11.99ab	ND	14.20a

Key: ND = Not detected, Values followed by the same letters are not statistically different at $p<0.05$.

Table 15. Interaction between plant types and contamination levels in shoot of the plant.

Contamination Levels (%)	0	50	100
Plant types			
Neem	0.19b	6.16ab	11.18a
Senna	0.14b	4.18ab	6.28ab

Key: Values followed by the same letters are not statistically different at $p<0.05$.

Table 16. Interaction between plant type and heavy metals in the root of the plants.

Heavy Metals (mg kg^{-1})	Cu	Pb	Zn
Plant types			
Neem	12.63a	ND	11.10a
Senna	5.43b	ND	11.31a

Key: ND = Not detected, Values followed by the same letters are not statistically different at $p<0.05$.

Table 17. Interaction between contamination levels and heavy metals in root of the plants.

Heavy Metals (mg kg^{-1})	Cu	Pb	Zn
Contamination Levels (%)			
0	0.50c	ND	0.38c
50	11.05b	ND	12.76b
100	15.55ab	ND	20.49a

Key: ND = Not detected, Values followed by the same letters are not statistically different at $p<0.05$.

Table 18. Interaction between plant type and contamination levels in the root of the plants.

Contamination levels (%) Heavy Metals	0	50	100
Plant types			
Neem	0.34c	9.54ab	13.94a
Senna	0.25c	6.42b	10.08ab

Key: ND = Not detected, Values followed by the same letters are not statistically different at $p<0.05$.