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Accumulation of Heavy Metals in Soil and Selected Plants in Auto-mobile Workshop Areas in Benue State, Nigeria

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Abstract

This quantitative study determined the heavy metal contamination in soil and selected plants in automobile workshops in Benue state, Nigeria. Heavy metal pollution has severe long-term effects on human and environmental health. Plant species: Mango (*Mangifera indica*), Neem (*Azadirachta indica*), Cashew (*Anacardium occidentale*), and Moringa (*Moringa oleifera*) were evaluated as possible bioindicators of heavy-metal pollution in Benue State, Nigeria. Using a Flame Atomic Absorption Spectrophotometer with proper digestion method, the concentrations of different metals including Arsenic (As), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni) and Zinc (Zn) were determined. The total mean concentrations in soil samples from the various automo-bile workshops were in the following order Fe>Cu>Zn>Pb>Mn>Cr>Ni>Cd>Co>As>Hg. Mean concentrations of heavy metals found in plant samples from the various automobile workshops were in the following order Fe>Mn>Zn>Cu>Cr>Ni>Co>Pb>Cd>As>Hg.

The bio-concentration factor of the plants follows the order: Moringa>Neem>Cashew>Mango. The translocation factor of the plants follows the order: Mango>Neem>Cashew>Moringa. Pollution indices of the soils showed high values in the order of Lead>Chromium>Nickel>Cadmium at the various experimental sites. The biocon-centration and translocation factors of all trees were above the critical value 1.0. The heavy metal accumulation levels in soils and plants in the selected experimental sites are signifi-cantly higher than their corresponding control samples, with some slightly higher than the permissible limits. Our findings posit the hyper-accumulative capabilities of these plants and their applicability as effective bio-indicators of heavy metals contamination.

Keywords:

Heavy metals; Automobile workshops; Pollution; Soil, Plants.

1. INTRODUCTION

Heavy metals pollution is increasingly becoming a public health concern due to its adverse effect on the environment (Briffa et al., 2020). Although naturally occurring, heavy metals concentration in the environment has grown rapidly in the past century due to increased anthropogenic activities resulting from urbanization. Notably, since the 1940s, their mobilization and environmental dis-persion rates have surged (Ali et al., 2019). Heavy metals, being non-biodegradable, resist meta-bolic detoxification, leading to their accumulation (bioaccumulation) in ecosystems to potentially toxic concentrations (Adebawo, et al., 2016). Such persistent contamination in our biosphere is alarming due to its profound, enduring impacts on both human health and ecological systems (Ali et al., 2019). Therefore, mapping high-concentration zones and establishing comprehensive guide-lines and legislation is pivotal.

Effective pollution mitigation necessitates the identification of pollution sources, stringent control over significant emissions, and the development of cost-efficient and sensitive analytical methods. Balancing between risk assessment and economic implications is essential for the concurrent monitoring of diverse contaminants. Bio-monitoring emerges as an economical and straightfor-ward methodology for gauging environmental heavy metal concentrations, subsequently offering insights into population exposure. Within bio-monitoring, bio-indicators convey crucial data on ecosystem shifts (Cakaj et al., 2023). The practice of utilizing plants as bio-monitors, given their propensity to absorb trace elements, has gained traction in environmental monitoring. Historically, plant-based elemental analyses have provided an accessible and effective avenue for ecological studies (Sawidis et al., 2011). Certain plants, because of their adeptness at trace element absorp-tion, have proven instrumental in numerous monitoring ventures, offering an affordable environ-mental quality gauge coupled with simplified sampling processes (Cakaj et al., 2023). The appeal of plants as bio-indicators stems from their rapid responsiveness to environmental chemical alter-ations and their susceptibility to a myriad of pollutants affecting air, soil, and water. Moreover, their ubiquity and affordable sampling methods make them optimal (Gjorgieva et al., 2011). Sig-nificantly, plants not only validate soil trace element presence but can also concentrate these ele-ments in aerial biomass (e.g., leaves/barks) at levels often surpassing those in the soil matrix (Sawidis et al., 2011).

Particular heavy metals of heightened interest include Arsenic, Cadmium, Cobalt, Chromium, Copper, Mercury, Manganese, Nickel, Lead, Tin, and Thallium (Balali-Mood et al. 2021). While some of these metals are required by humans in trace amounts, others are decidedly toxic, im-pacting vital organs such as the central nervous system, kidneys, liver, and skin. Against this backdrop, Onyedikachi et al. (2019) hypothesized in their investigation of food sources from in-dustrialized regions in Eastern Nigeria that plants thriving in heavy metal-polluted locales can potentially serve as robust Pollution Index bio-indicators.

In this research, we aim, to quantify heavy metal concentrations in both soil and plant samples from automobile workshops within Benue state, to assess the bioaccumulation extents in selected trees across varied sites, and to ascertain their suitability as bio-indicators of metal contamination in the state. The heavy metals in focus for this study encompass arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), Cobalt (Co), Iron (Fe), lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), and zinc (Zn). By comparing the detected heavy metal concentrations in plants against established safety benchmarks, we hope to assess their suitability for consumption, me-dicinal use, and other environmental applications.

2. MATERIALS AND METHODS

2.1 Study Area

This research was conducted across three (3) Local Government areas in Benue State-Nigeria. Situated in the Middle-belt region of Nigeria (Fig. 1), Benue boasts a population of approximately 6.1 million, according to the 2022 census. Spanning a total of 30,783 km², it ranks as the country's 11th largest state by land area (City Population, 2023). Notable towns within Benue include Otuk-po, Gboko, Katsina-ala, and the state capital, Makurdi.

In specific areas, artisanal mining is prevalent. Notably, there are lead deposits near Akwana, situated south of the Benue River, and limestone deposits in proximity to Yandev. Additionally, north of the river, saline springs in the Benue valley, with significant deposits of niobium, tin, and marble. (Fatoye, 2023).

2.2 Selection of Sites

This study was carried out in Automobile workshops spread across three (3) Local Government areas in Benue State-Nigeria (Fig. 1). These workshops (sample sites) were selected based on the availability of the tree species of interest in them. Table 1 shows the longitude and latitude of the experimental sites from which samples were taken.

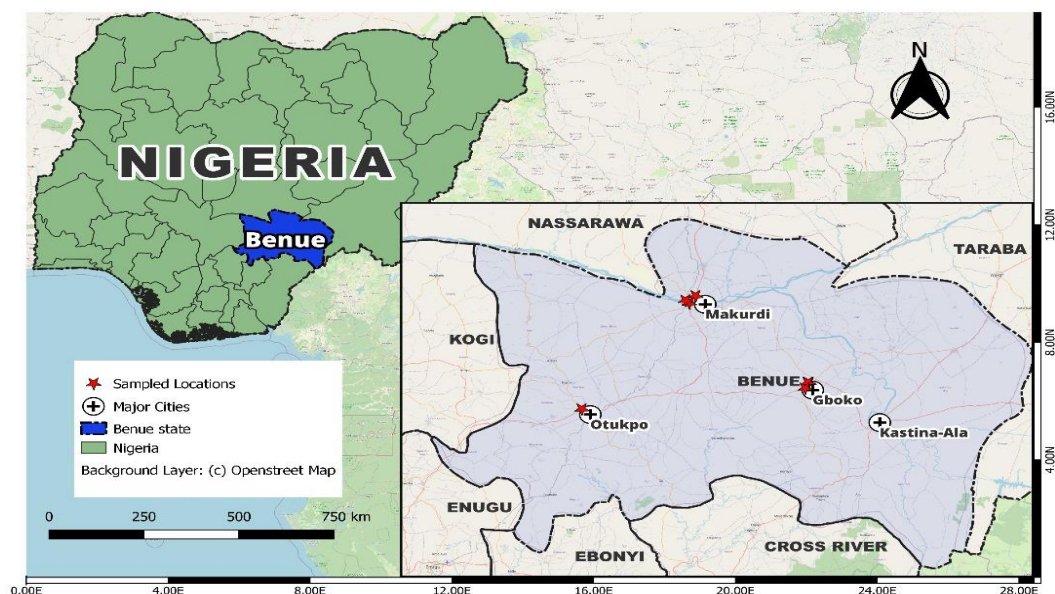


Figure 1: Map of Nigeria showing Benue State and study locations.

Source: Authors illustrations based on data from OpenStreetMap and Global Administrative Areas (GADM, 2023).

Table 1: Longitude and latitude of experimental sites.

Location	Address	Latitude	Longitude
Makurdi	Mechanic Village North Bank	7.770421	8.55783
Makurdi	Mechanic Village in Ministry of Agriculture	7.735095	8.53175
Makurdi	Mechanic Village GRA	7.748064	8.516976
Otukpo	Mechanic Village Enugu Road	7.218117	8.098565
Gboko	Mechanic site Adekaa	7.348173	9.015604
Gboko	Mechanic site Mango Garden, Abagu.	7.348247	9.011967
Gboko	Mechanic village, GRA.	7.320617	9.000632

2.3 Sample Collection and Preparation for Elemental Analysis

Using purposive sampling, Automobile workshops with trees of interest in the three Local Government Areas namely Makurdi, Otukpo and Gboko were selected for sample collection. The soil samples were retrieved using a soil auger from a depth of 0 - 15 cm and placed in plastic bags. Soil samples for control were taken from a residential area in Makurdi, Otukpo, and Gboko Local Government Areas (over 5km away from the closest automobile workshop and

avoiding areas with a topographic gradient that favours seepage pressure and runoffs from automobile work-shops). Plant samples were collected from the same locations as soil samples while control sam-ples were collected from residential areas. Figure 2 and 3 shows one of the sites from which ex-perimental samples were collected with indicative engine oil spillage. All samples were labelled appropriately and transported to the laboratory for elemental analysis. Before laboratory analysis, retrieved plant samples were cleaned with distilled water to clear away any debris and insects. All the reagents used in this study were of analytical grade and from which standard solutions were prepared. The glassware was thoroughly washed with detergent and rinsed with distilled water.

2.4 Laboratory Analysis

The retrieved samples were digested according to the procedure of the Association of Official An-alytical Chemists (AOAC, 2015) for soil and plants. The concentrations of heavy metals were measured using Perk-Elmer Analyst - Atomic Absorption Spectrophotometer (AAS).

Plant Sample Analysis –To determine if plants could be labeled as accumulators, both the bio-concentration factor (BCF) and the translocation factor (TF) were computed using the following:

$$BCF = \frac{C_{shoot}}{C_{soil}} \quad (2)$$

$$TF = \frac{C_{shoot}}{C_{root}} \quad (3)$$

Where C is the concentration of the heavy metal, BCF >1 is a hyperaccumulator and TF >1 has high heavy metal uptake (Paliza et al., 2019).



Figure 2: A mango tree at North bank automobile workshop showing signs of harvest.



Figure 3: Soil of Automobile Workshop showing Engine Oil Spillage.

3. RESULTS

3.1 Heavy metal concentrations in the respective plants at experimental sites.

The concentration levels of each of the heavy metals in the tree samples analyzed from the thirteen (13) experimental sites from the 3 Local Government Areas are represented in the line charts below (Fig. 4 to 12).

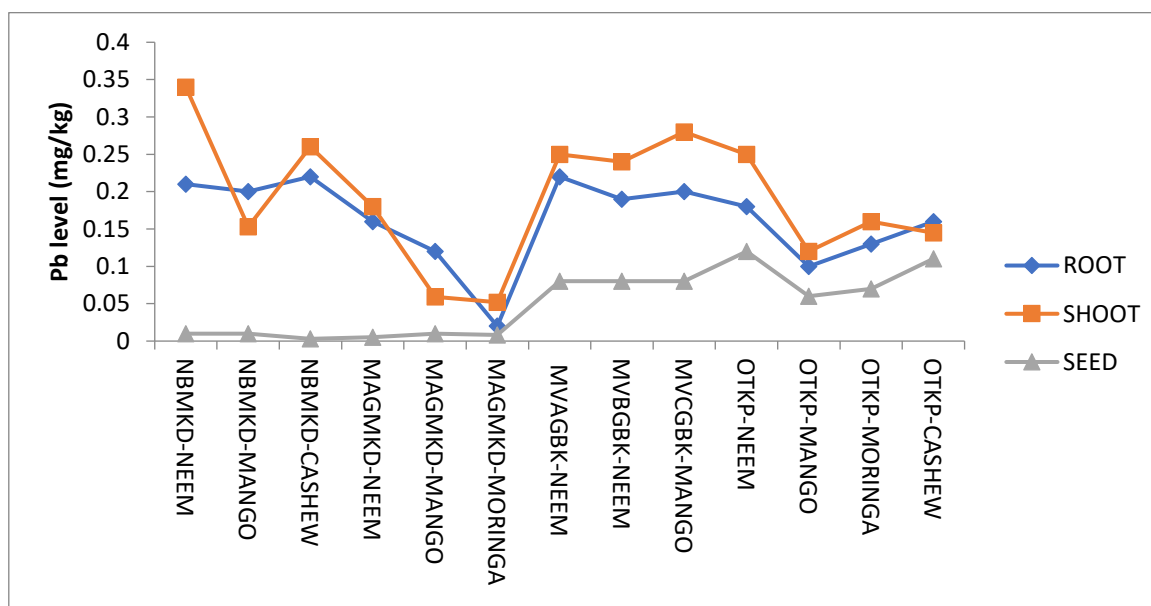


Fig. 4. Line chart showing the Concentrations of Pb across the Experimental Sites.

NBMKD-NEEM = Neem Tree in Automobile Workshop, Northbank Makurdi.

NBMKD-MANGO = Mango Tree in Automobile Workshop, Northbank Makurdi.

NBMKD-CASHEW = Cashew Tree in Automobile Workshop, Northbank Makurdi.

MAGMKD-NEEM = Neem Tree in Automobile Workshop, Min. of Agric., Makurdi.

MAGMKD-MANGO = Mango Tree in Automobile Workshop, Min. of Agric., Makurdi.

MAGMKD-MORINGA = Moringa Tree in Automobile Workshop, Min. of Agric., Makurdi.

MVAGBK-NEEM = Neem Tree in Automobile Workshop, Adekaa, Gboko.

MVBGBK-NEEM = Neem Tree in Automobile Workshop, Abagu, Gboko.

MVCGBK-MANGO = Mango Tree in Automobile Workshop, G.R.A, Gboko.

OTKP-NEEM = Neem Tree in Automobile Workshop, Enugu road, Otukpo.

OTKP-MANGO = Mango Tree in Automobile Workshop, Enugu road, Otukpo.

OTKP-MORINGA = Moringa Tree in Automobile Workshop, Enugu road, Otukpo.

OTKP-CASHEW = Cashew Tree in Automobile Workshop, Enugu road, Otukpo.

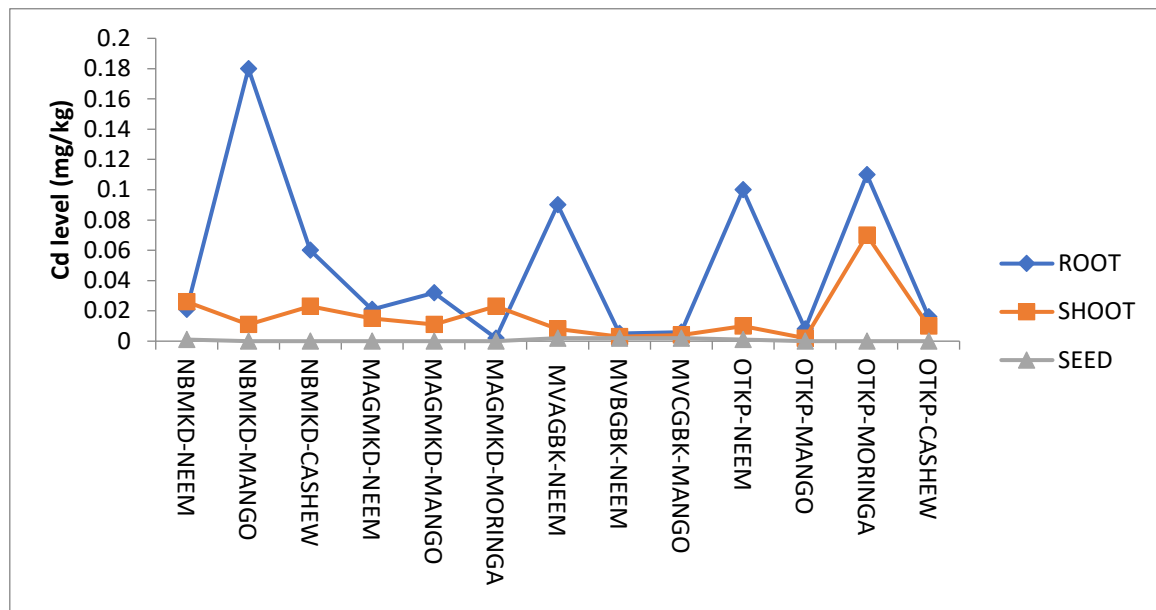


Fig. 5. Line chart showing the Concentrations of Cd across the Experimental Sites.

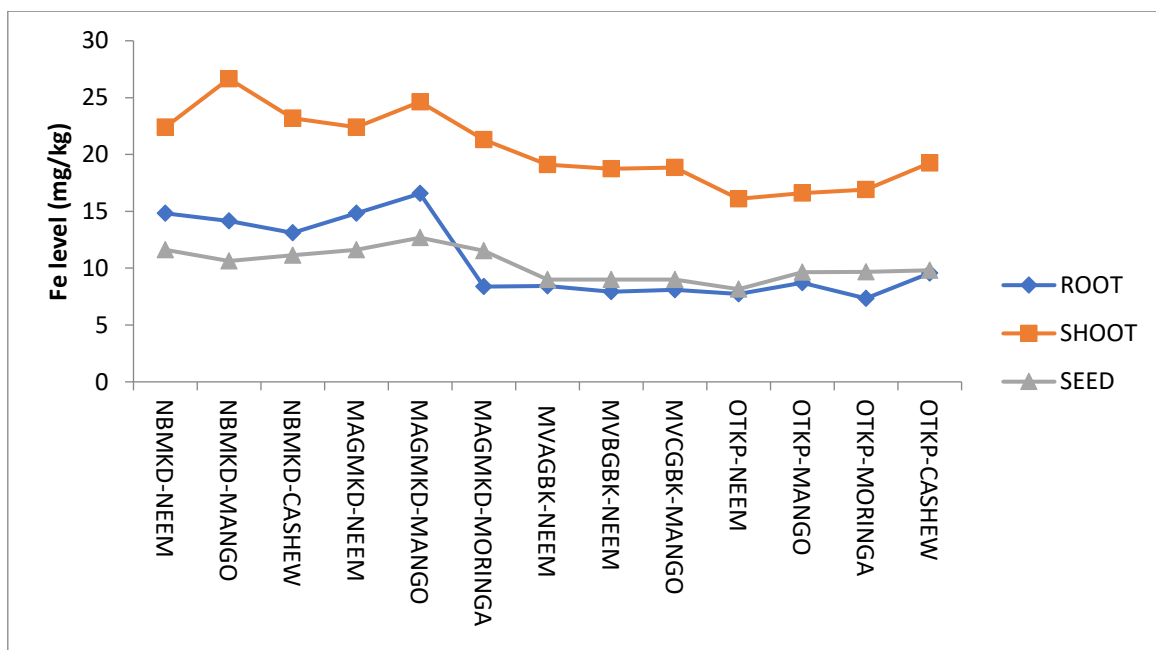


Fig. 6. Line chart showing the Concentrations of Fe across the Experimental Sites.

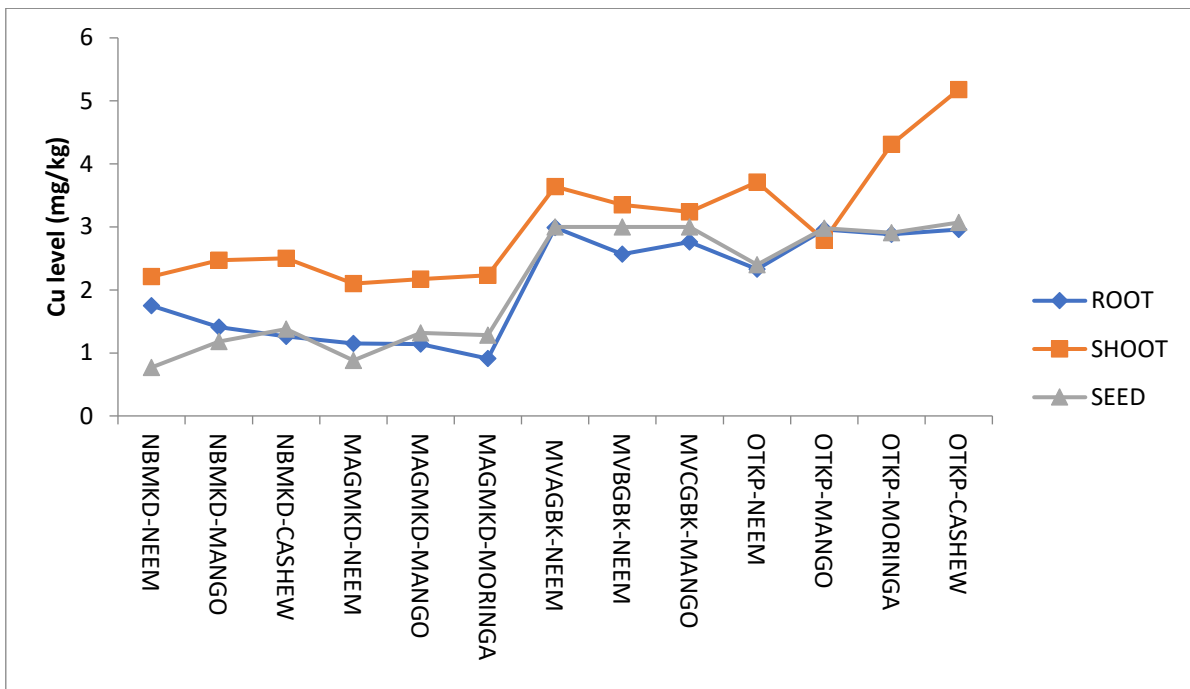


Fig. 7. Line chart showing the Concentrations of Cu across the Experimental Sites.

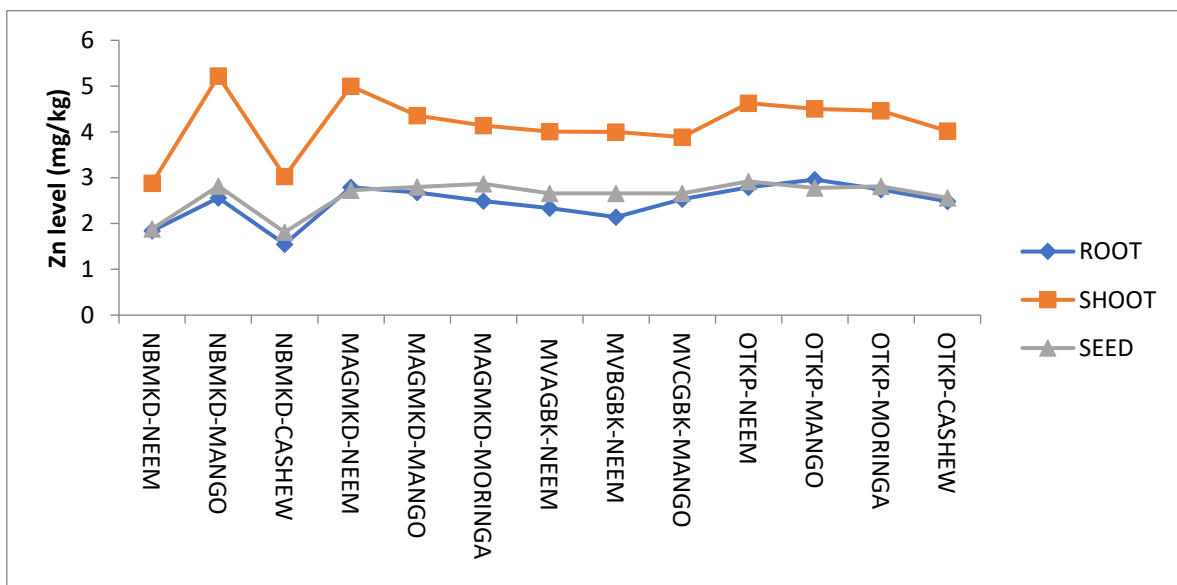


Fig. 8. Line chart showing the Concentrations of Zn across the Experimental Sites.

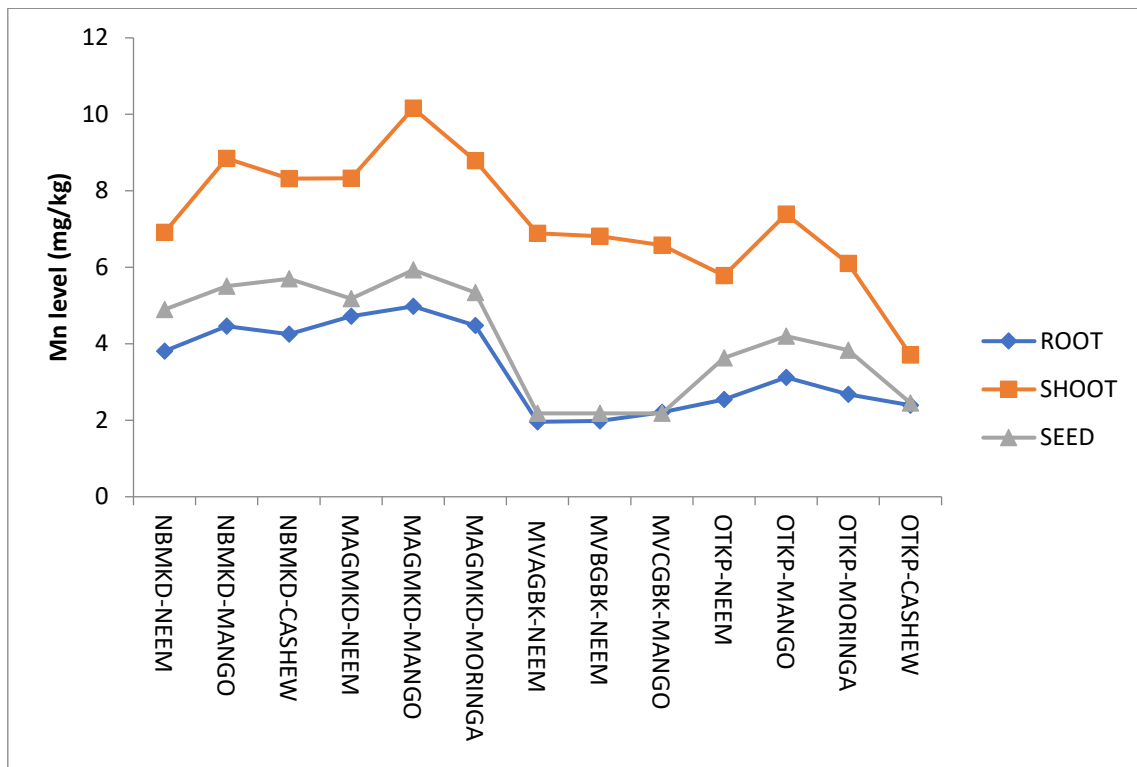


Fig. 9. Line chart showing the Concentrations of Mn across the Experimental Sites.

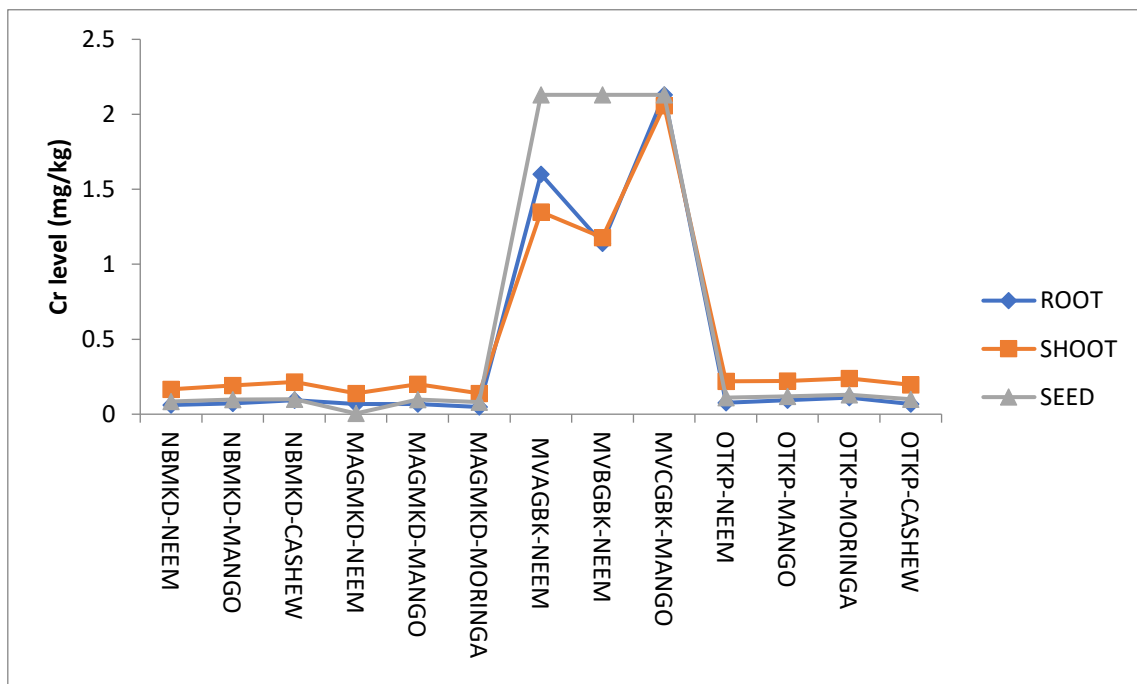


Fig. 10. Line chart showing the Concentrations of Cr across the Experimental Sites

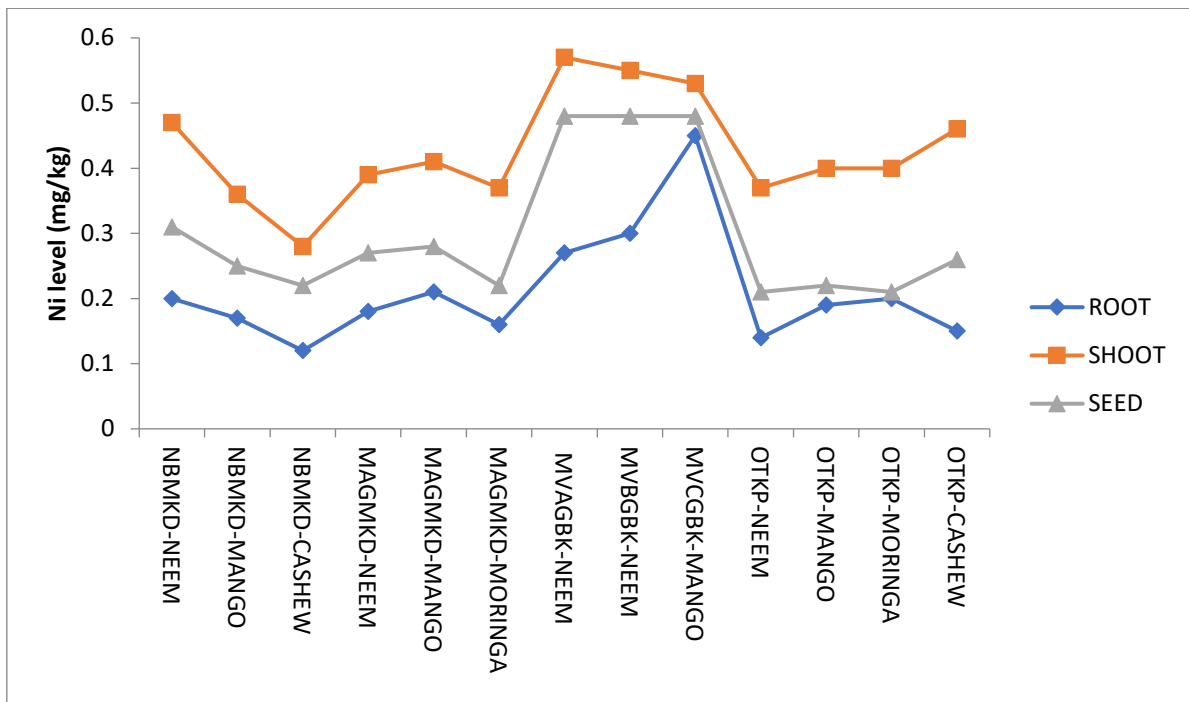


Fig. 11. Line chart showing the Concentrations of Ni across the Experimental Sites.

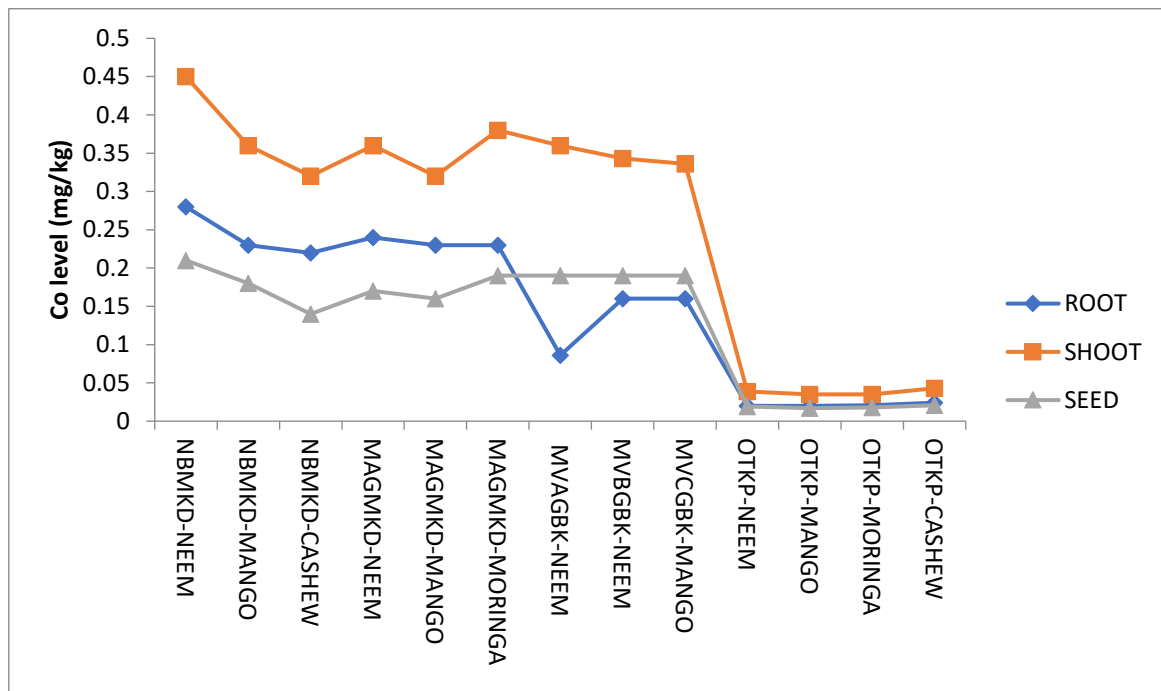


Fig. 12. Line chart showing the Concentrations of Co across the Experimental Sites.

3.2. Mean Concentrations of heavy metals in Test plant, Soil and Control Soil.

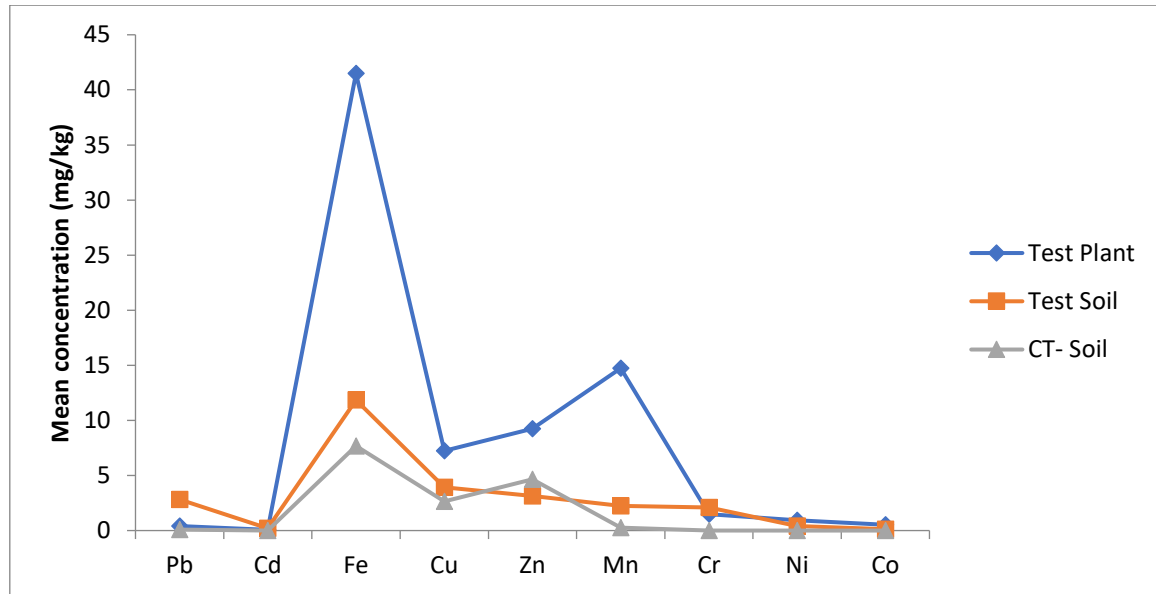


Fig.13. Line Chart showing Mean Conc. of heavy metals in test plant, test soil and soil control.

3.3 Bio-concentration Factor (BCF) of all the samples taken in Benue State.

Fig. 14 is a bar chart showing the Bio-concentration Factor of the samples taken across 13 Au-tomobile workshops in 3 Local Government Areas of Benue State. In the order of the highest to the lowest BCF – NBMKD-MANGO (1.64), MAGMKD-MANGO (1.62), MAGMKD-NEEM (1.49), NBMKD-CASHEW (1.47), MAGMKD-MORINGA (1.43), MVCGBK-MANGO (1.39), MVBGBK-NEEM (1.36), MVAGBK-NEEM (1.33), NBMKD-NEEM (1.31), OTKP-CASHEW (1.18), OTKP-MORINGA (1.17), OTKP-MANGO (1.17) and OTKP-NEEM (1.16).

3.4 Translocation Factor (TF) of all the samples taken in Benue State.

Fig. 15 is a bar chart showing the Translocation Factor of the samples taken across 13 Automo-bile workshops in 3 Local Government Areas of Benue State. In the order of the highest to the lowest BCF – MAGMKD-MORINGA (2.24), MVBGBK-NEEM (2.14), MVAGBK-NEEM (2.01), OTKP-MORINGA (2.01), OTKP-NEEM (1.95), MVCGBK-MANGO (1.93), NBMKD-MANGO (1.89), OTKP-CASHEW (1.85), NBMKD-CASHEW (1.83), OTKP-MANGO (1.77), NBMKD-NEEM (1.67), MAGMKD-MANGO (1.63), and MAGMKD-NEEM (1.61).

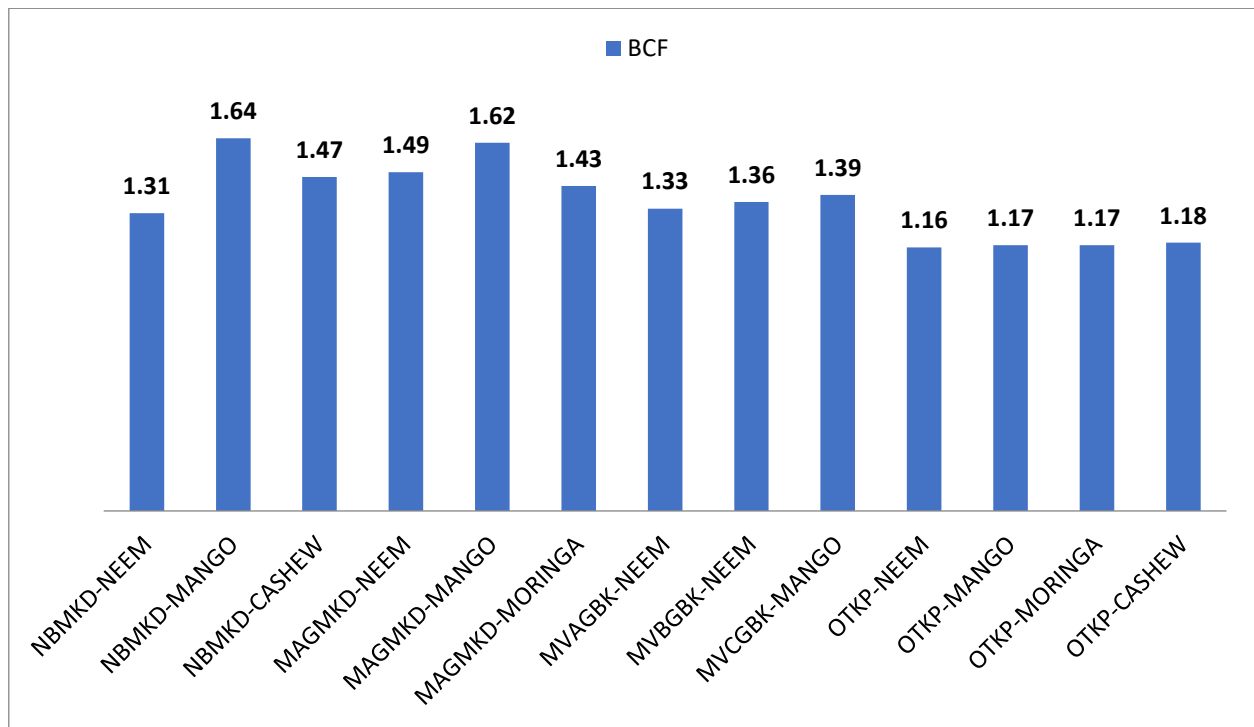


Fig. 14: Bar chart showing the Bio-concentration Factor of the samples taken across 13 Automobile Workshops in 3 Local Government Areas of Benue State.

NBMKD-NEEM = Neem Tree in Automobile Workshop, Northbank Makurdi.

NBMKD-MANGO = Mango Tree in Automobile Workshop, Northbank Makurdi.

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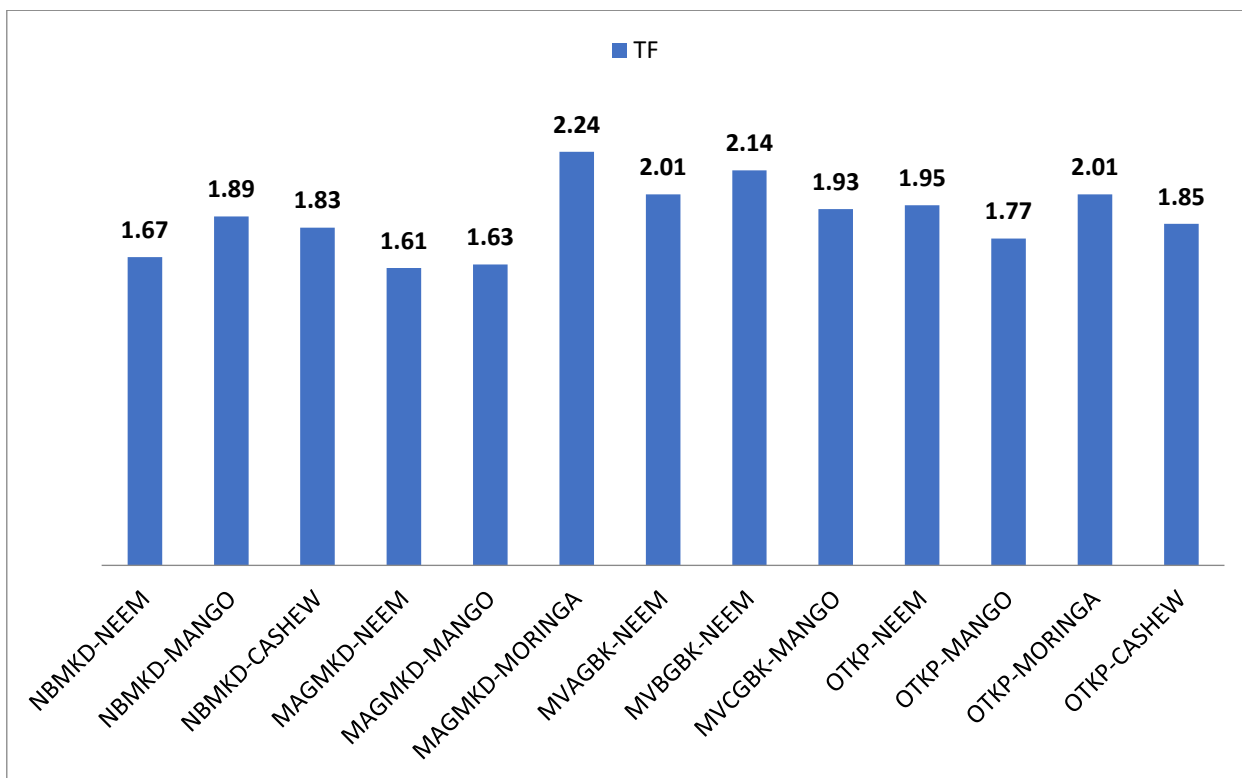


Fig 15. Bar chart showing the Translocation Factor of the samples taken across 13 Automobile Workshops in 3 Local Government Areas of Benue State.

NBMKD-NEEM = Neem Tree in Automobile Workshop, Northbank Makurdi.

NBMKD-MANGO = Mango Tree in Automobile Workshop, Northbank Makurdi.

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OTKP-CASHEW = Cashew Tree in Automobile Workshop, Enugu road, Otukpo.

3.5 Bio-concentration and Translocation Factors in four trees at Mechanic sites in Benue state.

Fig. 16 is a histogram comparing the Bio-concentration and Translocation Factors in four trees at mechanic sites in Benue state. The results are as follows:

BCF: Moringa>Neem>Cashew>Mango (strength of heavy metal accumulation in the plant) TF: Mango>Neem/Cashew>Moringa (strength of heavy metal uptake from the soil).

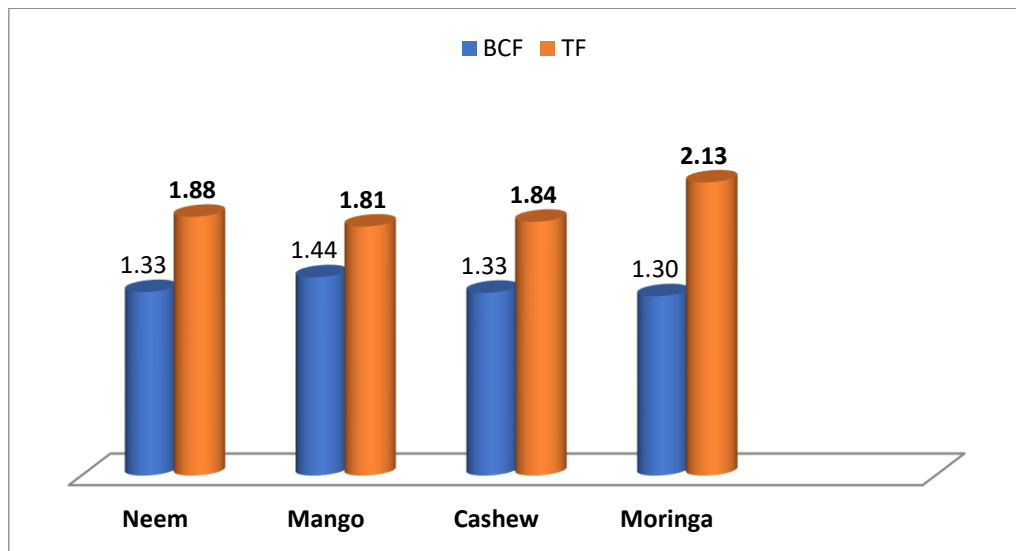


Fig 7. Bio-concentration and Translocation Factors in four trees at Auto mobile workshops.

BCF: Moringa>Neem>Cashew>Mango (strength of heavy metal accumulation in the plant)

TF: Mango>Neem/Cashew>Moringa (strength of heavy metal uptake from soil).

4. DISCUSSION

Heavy metals were detected in soil and tree plant samples taken from across seven (7) Automobile workshops in Benue State. The higher levels of heavy metals in these workshops when compared to the control sites are probably due to the waste-generating activities taking place there. These activities include servicing, maintenance, and repair of vehicle body parts and often lead to the dumping of iron scraps, and spillage of spent oils and other waste products.

The soil samples taken from the experimental sites (Automobile workshop) showed the highest concentrations of heavy metals. Typical of Automobile workshops is the litter of metal scraps and corroding vehicle parts which serve as a steady source for Iron release into the environment. Iron is one of the basic components of Steel alloy, a material used in manufacturing the body of vehicles (Abidemi 2011 and Edori 2012). Also, Dara (1993); Oguntimehin et al. (2008); Adebayo (2017); Bala et al. (2019); and Amaechi et al. (2021) reported iron as having the highest concentrations in soils relative to other heavy metals. In this study, Fe had the highest concentration levels in both plant and control samples, indicating a high pollution index as well as high levels of iron in natural soils.

Though sample concentrations of Fe were seen to be below their permissible limits, consumption of parts of these trees for medicinal purposes increases the risk of consumers to Dysmetabolic Iron Overload Syndrome (DIOS). Excess iron in vital organs, even in mild cases increases the risk of liver disease and heart attacks.

Copper (Cu) had the second highest concentration across all the soil samples taken from the experimental sites. Amaechi and Onwuka (2021) made a similar report of copper as coming second to Iron in concentration among other heavy metals studied in the soils of automobile workshops in Awka. Copper is an important raw material in the automobile industry as it's used for the manufacture of automobile parts such as starter motors, alternators, wire harnesses, radiators, and break tubes (Chokor, 2016). Pam et al. (2013) and Ajeh et al. (2022) found Copper to be above permissible limits across all soil samples of Automobile workshops in Makurdi, Gboko and Benin City respectively. This study however revealed that concentrations of copper in soil samples taken from the selected automobile workshops were below NESREA, US-EPA, and WHO permissible limits, proposing safer health outcomes for the consumption of biotic and abiotic components of the environment.

Soil samples taken from Automobile workshops in Makurdi revealed significantly high concentrations of Cadmium. This concurs with the findings of Bala et al. (2019) and Amaechi et al. (2021). Their studies in Automobile workshops in Benin City and Awka respectively revealed Cadmium levels that exceeded permissible limits. Soil samples from Otukpo and Gboko automobile workshops also revealed high levels of Cadmium and were slightly below their permissible

limits. In this study, higher levels of Cadmium were recorded in Makurdi which is the State capital with a high propensity for environmental pollution.

Cadmium is plated on many parts of vehicles to give lustre, prevent corrosion, and make them scratch-resistant (Byjus, 2023). Large amounts of Cadmium in soil is considered to negatively affect uptake of nutrients in plants. It impedes the activity of enzymes thereby affecting biosynthesis of chlorophyll (Sharma, 2020).

Cobalt revealed the least concentration in all soil samples taken from both experimental and control sites, presenting far below NESREA, US-EPA, and WHO permissible limits. This may be because, cobalt is a very rare element, occurring at trace amounts in the Earth's crust (Barceloux, 1999). It decreases nitrification and reduces soil microorganisms when in concentrations above permissible limits.

The age of an automobile workshop determines to a great extent, its level of heavy metal contamination (Abidemi, 2011; Edori and Edori 2012; Usman et al., 2013). Automobile workshops in Otukpo had the highest pollution index compared to those in other locations (Makurdi and Gboko). This may be because it is one of the oldest and largest. Otukpo is a corridor town and major trade route linking the South-West and South East to Northern Nigeria, hence accessibility to Otukpo Automobile workshops is high. These metals continue to accumulate through the years since they do not easily decay, thereby increasing their concentrations in the soil. (Pam et al., 2013).

Amongst the two (2) categories of samples studied (soil and plants), plants have the highest mean concentrations. This indicates possible bioaccumulation of these metals in the plants. Plants that have bio-concentration and translocation factors >1 can be used as bio-accumulators (Takarina, et al., 2017). The plant samples at the experimental sites all had bioconcentration and translocation factors >1 , signifying they are bio-accumulators. The bioconcentration factor of the tree samples in the experimental sites was in the order of Mango $>$ Neem $>$ Cashew $>$ Moringa, indicating the Mango tree as a hyper-accumulator. This result is similar to those of Ojekunle et al. (2015) and Langunu et al. (2023) who in their study: Effectiveness of Neem, Cashew, and Mango trees in the uptake of heavy metals in mechanic villages, Nigeria recorded the uptake of heavy metals by trees in the order of Mango $>$ Cashew $>$ Neem. Langunu et al. (2023), also reported the Mango tree as a hyper accumulator. Heavy metal accumulation in plants is affected by factors such as plant growth stage, plant species, tolerance to different contaminants, growth rate, and biomass (Uddin et al., 2021), hence the variation in bioconcentration and translocation factors in the various species (Mango, Cashew, Moringa, and Neem).

The translocation factor of the trees was in the order of Moringa $>$ Neem $>$ Cashew $>$ Mango, suggesting Moringa tree can be used for phytoremediation of these metals. It has been reported in many studies including Amadi and Tane (2014), Vurayai et al. (2020), and Agboola et al. (2016) as an excellent plant for phytoremediation. This may be due to some of its qualities which may include; fast growing, high tolerance for poor soil, and high tolerance for metal concentration.

Heavy metals have been proven to bio-accumulate in different plant parts, but the rate of accumulation may differ, depending on the adsorption and retention potentials of the part (Uddin et al., 2021). Shoot samples showed the highest heavy metal contamination levels which have been reported by Yang et al. (2008), Yabanlı, et al. (2014), and Li et al. (2023). Yang et al. (2008) puts forward that in comparison with normal plants, hyper-accumulators can accumulate heavy metals in their shoots far exceeding those observed in soil, without suffering from detrimental effects. This further suggests that the trees studied are hyper-accumulators since the ratio of absorption varied from shoot to roots with seeds having the lowest levels of these metals. Kılıçel and Dag (2006), Khairiah et al. (2009), and Agboola et al. (2016) also reported the lowest levels of heavy metals in the seeds. This may be because the seeds spend the least amount of time on the trees. The seeds which can be said to be the most important part of these plants, as they are often harvested for food contain elevated levels of heavy metals. Although the levels of contamination of these seeds are below permissible limits in most of the trees and locations, except for Chromium in Mango (2.070mg/kg) at Aunty Ayan, GRA Gboko, and Chromium in Neem (2.110mg/kg) at Abagu Gboko, continuous consumption of these fruits with elevated levels of heavy metals concentration, could lead to the bioaccumulation of these elements in the body, which could result in a serious health consequence in the future.

5. CONCLUSION

Our study provides compelling evidence that automobile workshops in the examined region have significant heavy metal contamination. The ability of plants to assimilate these heavy metals and their subsequent bioaccumulation in human tissues, as well as their biomagnification through the food chain, raises substantial concerns for both human health and the broader environment. Given the high translocation factors observed, the trees examined in this study, particularly mango and neem, present as promising candidates for phytoremediation. Their rapid growth, tolerance to infertile soils, and resilience to high metal concentrations underscore their potential utility in addressing soil heavy metal contamination.

Our findings reveal that both mango and neem trees may work well for phytoremediation tasks as they offer effective solutions to mitigate the presence of heavy metals in the soil. Although the metal concentrations in most of the trees were found to align with the limits permissible by WHO, US-EPA, and NESREA, exceptions were noted for cadmium and chromium in certain samples. Our results also underscore the need for institutional regulation on the use and disposal of materials in the automobile industry that prioritizes human and environmental health. Overall, the trees examined in this study present considerable potential as bioindicators/monitors of heavy metal pollution.

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Conflicts of Interest:

There is no recorded conflict of interest.

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