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PHYTOREMEDIATION POTENTIAL OF NEEM TREE (*AZADIRACHTA INDICA*) FOR HEAVY METAL ABSORPTION IN INDUSTRIAL AREAS OF KANO AND KADUNA, NIGERIA.

[1]Lawal, A.A, [1]Saidu, I., [1]Salami, K.D., [2]Girei, A.H., [1]Muhammad, Y.K., and [1]Bishiriyya, D.S.
[1]Department of Forestry and Wildlife Management, Federal University Dutse, Nigeria.
[2]Department of Soil Science, Federal University Dutse
***Corresponding author:** foristsalam@yahoo.com; lawal.abdulhakeem@fud.edu.ng Tel.: +234 7067881013

ABSTRACT

This study assessed the potential of neem trees (*Azadirachta indica*) to absorb heavy metals (Cd, Cu, Pb, and Zn) in industrial areas of Kano and Kaduna States, Nigeria. Samples of leaves, bark, and roots were collected at 50m, 100m, and 1km radii from Challawa and Sun Seed industrial areas. Atomic Absorption Spectrophotometry determined heavy metal composition. Descriptive statistics and Two-way ANOVA were used to analyze the data. The results showed that at Sun Seed Industrial Area, Cd, Cu, Pb, and Zn concentrations did not differ significantly between points ($P = 0.069$, 0.650, 0.592, and 0.538, respectively), but varied significantly along distances for Cd ($P = 0.001$), Cu ($P = 0.001$), and Zn ($P = 0.019$). In Challawa, significant differences were found in metal concentrations (Cd: $P = 0.011$, Cu: $P = 0.00$, Pb: $P = 0.008$, and Zn: $P = 0.006$). The study concludes that neem trees can effectively absorb heavy metals, demonstrating their potential in phytoremediation. Based on the findings, it is recommended that neem trees be planted in industrial areas to mitigate heavy metal pollution and enhance environmental sustainability.

Keywords: Atomic Absorption Spectrophotometer, *Azadirachta indica*, Heavy metals, Industrial areas, Phytoremediation,

INTRODUCTION

Heavy metal pollution has emerged as a significant environmental concern globally, posing substantial risks to human health, ecosystems, and biodiversity due to its persistence, toxicity, and bioaccumulative nature. Heavy metals are natural elements with high density and atomic weight. While some are essential in small amounts, others are toxic even at low concentrations, posing health risks (Ali *et al.,* 2019; Romero-Estevez *et al.,* 2023). Urbanization and mining activities are significant sources of heavy metal pollution, thereby, causing considerable environmental damage (Fang-Jie *et al.,* 2008; Ishtiyaq *et al.,* 2018; Khanna *et al.,* 2018; Zaynab *et al.,* 2022).

Common toxic heavy metals include aluminum (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) (Tangahu *et al.,* 2011). These metals can contaminate soil and water, harming plants and disrupting their ability to breathe, absorb nutrients, and grow properly (Rout and Sahoo, 2015). The level of toxicity depends on the plant species, the type and amount of heavy metal present, and the soil composition (Nagajyoti *et al.,* 2010; Annam and Singla, 2021). Even at low levels, heavy metals are dangerous to living things, and when they build up in plants, they can enter the food chain, affecting humans and animals (Aleksandra *et al.,* 2014; Thongyuan *et al.,* 2021). The neem tree (*Azadirachta indica*), which grows widely in India, South America, and Africa, is also common in northwest Nigeria (Salami and Lawal, 2018). Its bark has been traditionally used for medicine, pest control, and fertilizer (Aleksandra *et al.,* 2014), but because it absorbs pollutants, it may also collect harmful heavy metals from industrial and mining activities (EPA-USA, 2017). Therefore, studying the levels of heavy metals in different parts of the neem tree is essential for ensuring its safe use.

Scientists use a method called biomonitoring to measure harmful substances in the environment (Nicoletta *et al.,* 2016). Research has shown that exposure to heavy metals like lead (Pb), cadmium (Cd), arsenic (As), manganese (Mn), and nickel (Ni) can affect the nervous system and cause serious health problems (Borylo *et al.,* 2013; Annam and Singla, 2021). Several factors influence how much heavy metal ends up in tree bark, including human activities, traffic levels, bark texture, metal type, and local soil composition (Lawal *et al.,* 2011; Oklo and Asemave, 2012).

Studies have reported dangerously high levels of heavy metals in northwestern Nigeria, especially near roads and industrial areas (Akan *et al.,* 2012; Liu *et al.,* 2020; Su *et al.,* 2022; Rozirwan *et al.,* 2022). These pollutants harm roadside plants, animals, and people living near factories and highways. The levels of heavy metal accumulation in neem trees in our study area remain poorly understood in the study area. This study examines the presence of heavy metals in neem trees growing near industrial areas of Northwest Nigeria with the aim to provide information on the potentiality of *Azadirachta indica* in reducing the concentration of harmful metals in a contaminated environment. The outcome of this study will serve a guide to for future researches in terms of empirical calibrations of heavy metals in northwest Nigeria.

MATERIALS AND METHOD

Kano State is located in northern Nigeria, between latitudes 10º 3′ N and 12º 4′ N and longitudes 7º 4′ E and 9º 3′ E. It sits at an altitude of about 468.5 meters (1,537 feet) above sea level and has a semi-arid climate (BSh in the Köppen climate classification). The state shares borders with Katsina to the northwest, Kaduna to the southwest, Jigawa to the northeast, and Bauchi to the southeast. Kano has four main seasons viz: Rani (hot and dry), Damina (warm and rainy), Kaka (cool and dry) and Bazara (hot and dry). These seasons are influenced by the movement of the Intertropical Discontinuity (ITD) zone. The state receives an average of 884 mm of rainfall per year, ranging from 600 mm in the north to 1,200 mm in the south. August is the wettest month, bringing frequent rainstorms. The average temperature is between 26°C and 32°C, with daily temperature differences of around 13°C. Humidity varies from 17% to 90% throughout the year (Augustine *et al.,* 2016).

Challawa Industrial Estate, located at latitude 11° 54′ 26.96″ N and longitude 8° 27′ 55.81″ E, is one of Kano's busiest industrial zones. It is bordered by Madobi, Rimingado, Gwale, and Tarauni Local Government Areas. The estate is home to many tanneries, as well as factories such as the Nigerian Bottling Company and cotton processing plants. This study will focus on analyzing neem trees growing near Challawa Industrial Estate to assess the extent of heavy metal contamination. The findings will provide crucial information for environmental monitoring and public health protection.

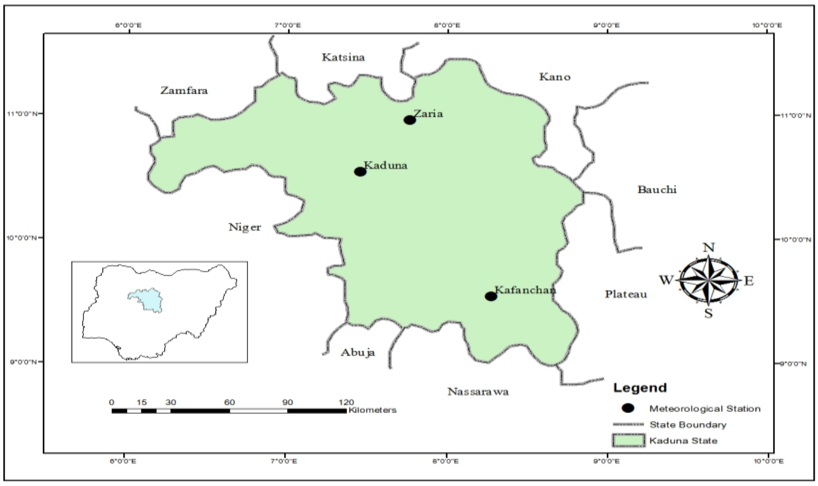

Figure 1. Map of Kaduna State showing Zaria (Abaje *et al.,* 2018

Kaduna State is located in northern Nigeria, between latitudes 9° 02' N and 11° 32' N and longitudes 6° 15' E and 8° 38' E. It sits at an altitude of 585.86 meters (1,922 feet) above sea level. The state has a tropical wet and dry climate (Köppen classification: Aw), meaning it has both rainy and dry seasons (Abaje *et al.,* 2018). Kaduna shares borders with Zamfara, Katsina, and Kano States to the north; Bauchi and Plateau States to the east; Nassarawa State to the south; and Niger State to the west. The Federal Capital Territory (Abuja) is located southwest of the state. The average temperature in Kaduna is 28.46°C (83.23°F), slightly cooler than the national average. The rainy season lasts from April to mid-October, with August being the wettest month. The dry season runs from mid-October to April of the following year. On average, Kaduna receives 1,323 mm of rainfall annually (Abaje *et al.,* 2018). Sunseed Company is an industrial firm located in Dakace village, near Zaria city. The site is positioned at latitude 11° 5' 7.95" N and longitude 7° 43' 11.80" E.

Sample Collection

To study heavy metal contamination, researchers collected leaves, bark, and roots from selected neem trees (*Azadirachta indica*) in industrial areas of Kaduna and Kano States, Nigeria. They measured distances from the industrial sites to the sample collection points using Universal Transverse Mercator (UTM) Area Measure software, selecting locations at 50 meters, 100 meters, and 1 kilometre away. In September 2023, they gathered samples from three different neem trees at each location. A stainless-steel cutlass and hoe were used to collect the samples, which were then wrapped in brown envelopes and properly labelled (Augustine *et al.,* 2016).

Sample Preparation

For each location, the leaf, bark, and root samples were mixed together to form a composite sample representing that area. The samples were then air-dried in the shade to remove moisture before being ground into a fine powder using a clean, dry mortar and pestle. The powdered samples were sieved using a 2-mm sieve to ensure uniformity. Finally, they were stored in labelled polyethylene bags and sent to the laboratory for further analysis (Augustine *et al.,* 2016).

Sample Digestion

To analyze the heavy metal content, researchers used a wet digestion method. They took 1g of each powdered sample and mixed it with aqua regia (a combination of hydrochloric acid (HCl) and nitric acid (HNO_3) in a 3:1 ratio) in a Kjeldahl flask. The mixture was left for 24 hours under a fume hood, then heated gradually first to 40 °C for 40 minutes, then to 100 °C until the solution became clear and no white fumes were visible.

After digestion, they added 10 cm^3 of distilled water, boiled it for 15 minutes, let it cool, and diluted it with more distilled water to the correct level. The solution was filtered using Whatman filter paper into a 100 cm^3 volumetric flask, then transferred into screw-capped polyethylene bottles for storage at the Bayero University Kano Central Laboratory. Later, the samples were tested for heavy metal content using Atomic Absorption Spectrophotometry (AAS).

Data Analysis
The results from the Atomic Absorption Spectrophotometer (AAS) were analyzed using descriptive statistics to calculate the mean, standard deviation, and standard error. The data was also displayed using histograms. Researchers used Factorial ANOVA to compare the levels of heavy metals at different locations and distances, checking for significant differences in contamination levels.

RESULTS AND DISCUSSION

4.1 Results

At 50 m,100 m, and 1 km radius of the study area in Kaduna which has three sampling points, A, B and C, the concentration of the elements in Table 1 below are Cd > Zn > Cu > Pb, Cd > Zn > Cu > Pb and Zn > Cd > Pb > Cu respectively.

Table 1: Heavy metal contents of composite samples of Neem tree (leaves, roots, and barks) around industrial area in Kaduna.

Distance	Conc. (µg/g)			
	Cd	Cu	Pb	Zn
50 m A	0.541	0.332	0.198	0.347
50 m B	0.452	0.327	0.144	0.414
50 m C	0.631	0.373	0.164	0.384
100 m A	0.483	0.243	0.154	0.298
100 m B	0.424	0.292	0.284	0.289
100 m C	0.542	0.294	0.165	0.249
1 Km A	0.183	0.315	0.127	0.276
1 Km B	0.211	0.264	0.168	0.202
1 Km C	0.242	0.458	0.154	0.178

Key: Cd = Cadmium; Cu = Copper; Pb = Lead; Zn = Zinc

The result in Figure 1 below as described by the mean bars, shows that at 50 m radius, the concentration of Pb, Cu, Zn were significantly different within the point, while Cd shows a slightly low difference. At 100 m radius, the concentration of Pb, Cu, Zn were significantly different within the point, while Cd shows a slightly low difference within the point, and at 1 km radius, the concentration of Pb, Cu, Zn were significantly different, and Cd also shows a slightly little difference within the point.
Similarly, at point 50 m radius, Cd has the higher concentration and Pb has lower concentration. At point 100 m radius, Cd has the highest concentration and Pb has the lower concentration, and at 1 km radius, Cu has the higher concentration and Pb also has the lower concentration.

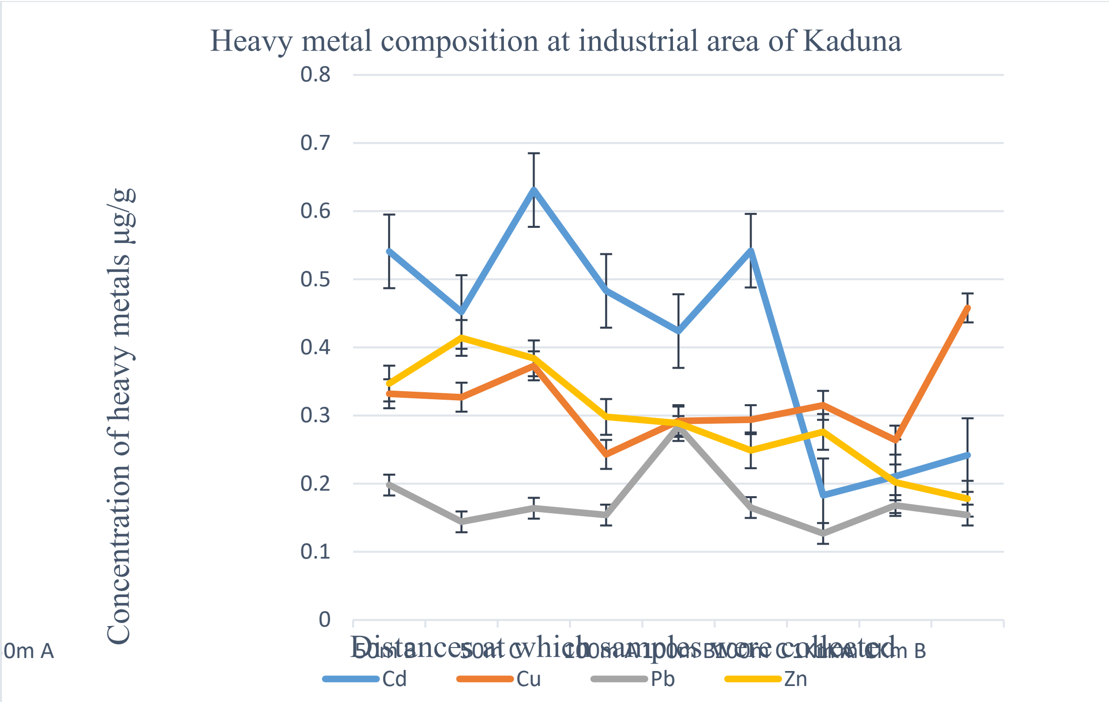

Figure 2: Plate showing heavy metal distribution at Kaduna state

The results presented in Table 2 show that in terms of concentration within the sampled points, Cd, Cu, Pb, and Zn are not significantly different with P values (0.069, 0.650, 0.592, and 0.538, respectively) > 0.05 probability level, but in terms of distance between the sampled points, Cd, Cu, Zn are significantly different with P values (0.001, 0.001, 0.019, respectively) < 0.05, while Pd is not significantly different with P value (0.502) > 0.05 probability level.

Table 2: Tests of Between-Subjects Effects for industrial area of Kaduna

Source	Dependent Variable	Sig.
Corrected Model	Cd	0.003
	Cu	0.002
	Pb	0.625
	Zn	0.047
Intercept	Cd	0.000
	Cu	0.000
	Pb	0.000
	Zn	0.000
Points	Cd	0.069*
	Cu	0.650*
	Pb	0.592*
	Zn	0.538*
Distance	Cd	0.001**
	Cu	0.001**
	Pb	0.502*
	Zn	0.019**
Error	Cd	
	Cu	
	Pb	
	Zn	
Total	Cd	
	Cu	
	Pb	
	Zn	
Corrected Total	Cd	
	Cu	
	Pb	
	Zn	

Note * = No significant difference, and ** = Significantly different

The result in Table 3 reveals that, at 50 m,100 m, and 1 km radius of the study area in Kano which has three sampling points, A, B and C, the concentration of the elements are Cd > Zn > Cu >Pb, Cd > Cu > Zn > Pb and Zn > Cu > Cd > Pb respectively.

Table 3: Heavy Metal Contents of Composite samples of Neem tree (leaves, roots, and barks) around Industrial Area in Kano.

Distance	**Conc. (μg/g)**			
	Cd	**Cu**	**Pb**	**Zn**
50 m A	0.452	0.293	0.097	0.342
50 m B	0.543	0.260	0.195	0.314
50 m C	0.631	0.261	0.168	0.358
100 m A	0.302	0.259	0.127	0.238
100 m B	0.303	0.269	0.147	0.172
100 m C	0.541	0.364	0.236	0.237
1 Km A	0.183	0.273	0.153	0.329
1 Km B	0.152	0.286	0.155	0.257
1 Km C	0.15	0.344	0.131	0.388

Cd=Cadmium Cu=Copper Pb=Lead Zn=Zinc

Results in Figure 2 show that at 50 m radius, the concentration of Pb, Cu, Zn were significantly different within the point, while Cd shows a slightly low difference. At 100 m radius, the concentration of Pb, Cu, Zn were significantly different within the point, while Cd shows a slightly low difference within the point, and at 1km radius the concentration of Pb, Cu, Zn were significantly different, and Cd also shows a slightly little difference within the point.
Similarly, at point 50 m radius, Cd has the higher concentration, and Pb has the lowest concentration. At point 100m radius, Cd has the highest concentration, and Pb has the lowest concentration and at 1km radius, Zn has the higher concentration, and Pb also has the lowest concentration.

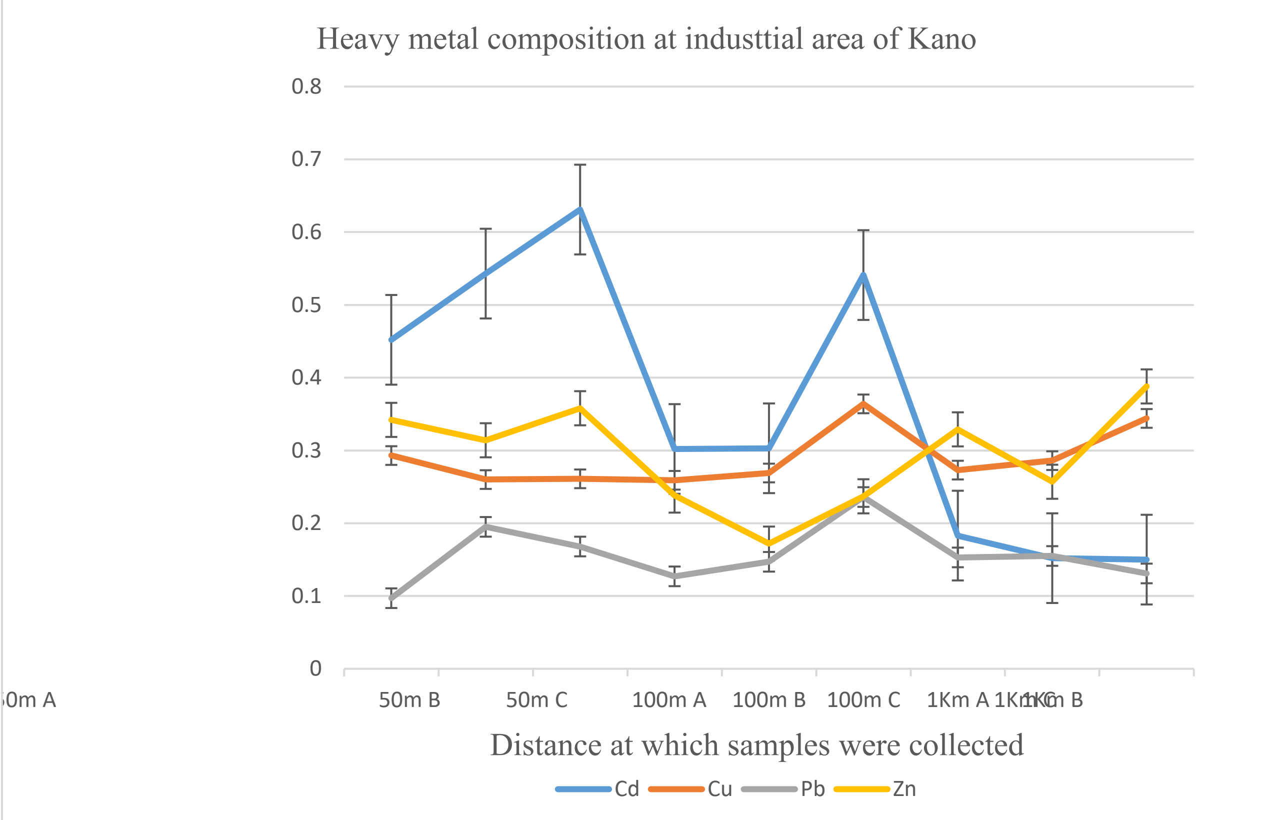

Figure 3: Plate showing Heavy Metal distribution at Kano State.
The results presented in Table 4 show that in terms of concentrations within the sampled points, Cd, Cu, Pb, and Zn are significantly different, and this is because all the P values (0.011, 0.00, 0.008, 0.006, respectively) are < 0.05, but in term distance between the sampled points, Cd, Cu, Zn and Pb are not significantly different with the P values (0.218, 0.317, 0.578, 0.537, respectively) > 0.05 probability level.

Table 4: Tests of Between-Subjects Effects for Kano

Source	Dependent Variable	Sig.
Model	Cd	0.025
	Cu	0.001
	Pd	0.022
	Zn	0.017
Intercept	Cd	0.000
	Cu	0.000
	Pd	0.000
	Zn	0.000
Points	Cd	0.011**
	Cu	0.000**
	Pd	0.008**
	Zn	0.006**
Distance	Cd	0.218*
	Cu	0.317*
	Pd	0.578*
	Zn	0.537*
Error	Cd	
	Cu	
	Pd	
	Zn	
Total	Cd	
	Cu	
	Pd	
	Zn	
Total	Cd	
	Cu	
	Pd	
	Zn	

*= No significant difference and **= Significant difference

DISCUSSIONS

The composition of heavy metals in neem tree samples of different sampling points around industrial areas of Kaduna and Kano States are presented in Table 3 and Table 5, respectively. The levels of heavy metals concentration of Kaduna and Kano states range as follows; Cd; 0.183 to 0.63 µg/g to 0.15 to 0.63 µg/g Cu; 0.101–0.378 to 0.144–0.393 µg/g Pb; 0.127–0.284 to 0.113–0.197 µg/g and Zn 0.178–0.414 to 0.207–0.388 µg/g.

Similarly**,** the concentration of Cd ranges from 0.18–0.63 µg/g in Kaduna samples to 0.15–0.63 µg/g in Kano samples. The highest and lowest concentrations of Cd metal (0.63 µg/g and 0.15 µg/g) were respectively in plant samples from Kaduna and Kano States. Stunted growth, chlorosis, browning of the root tips, and eventually plant death are signs of cadmium toxicity that are easy to recognize (Kumar *et al.,* 2016). The concentration range for Cu was 0.101–0.378 µg/g in Kaduna samples, to 0.144–0.393 µg/g in Kano samples, with the higher concentration found in Kaduna, and the lowest concentration found in Kano samples. The lower concentration of Cu metal (0.101 µg/g) in plant samples from Kano may be related to fewer commercial and automobile activities surrounding the study area, the higher concentration of Cu metal (0.378 µg/g) in plant samples from Kaduna may be related to industrial activities and high traffic rates (Penkala *et al.,* 2018). Lawan et al. (2011) reported high levels of Zn in Katsina and Dutsinma samples, high levels of Cu in Funtua and Dutsinma samples, and high levels of Mn in Kankara samples in a related study carried out in Katsina state. These findings were all ascribed to the geological condition of these highwayside locations.

The concentration range of Zn was 0.178–0.414 for the samples from Kaduna state, and 0.172–0.388 µg/g for the samples from Kano state, with the highest concentration found in Kaduna sample, while the lowest concentration was obtained in Kano samples. The high concentration of zinc metal (0.414 µg/g) in Kaduna plant samples may be caused by human activity in the area surrounding the study area (Adedokun *et al.,* 2016). However, it could also be because of the geology of the study area (Augustine *et al.,* 2016), as well as the soil topology. The Kano samples had the lowest Zn concentration (0.172 µg/g), which may have resulted from less Zn emission, deposition, and accumulation in the area around the sampling site.

The concentration range of Pb was 0.127–0.284 for the samples from Kaduna state, and 0.113–0.197 µg/g for the samples from Kano state, with the highest concentration found in Kaduna sample, while the lowest concentration was obtained in Kano samples. The result indicates high concentration of Pd metal (0.284 µg/g) in plant samples from Kaduna, with the lowest concentration of Pb (0.113 µg/g) in samples from Kano. Anthropogenic activities such as roadside vehicle operations and other commercial activities in the area that cause the emission of fumes and smoke containing lead are likely to be the cause of the high concentration of lead in the samples from Kaduna (Augustine *et al.,* 2016). Because there aren't many cars or businesses in the study area, the Pb concentrations in the Neem composite (leaves, barks, and roots) samples from the Kano may be lower. Similar findings were found in the leaves and bark of neem (Azadirachta indica) in Katsina city when the burden of heavy metals was studied (Lawal *et al.,* 2011). All the trace elements analysed, cadmium, copper, zinc, and lead, were detected and found at various concentrations in the samples.

According to Oklo and Asemave (2012), the concentrations of heavy metals in tree bark are predicted to fluctuate because of variations in human activity, traffic density, bark characteristics, metal type, and geological factors (Adedokun *et al.,* 2016). However, the concentrations of trace metals such as Pb, Zn, Cd, and Cu are very high in areas of high traffic density, and also correlate with the traffic volume. This observation is similar to that reported by Oklo and Asemave (2012). The combustion of gasoline that has been enhanced with known additives such as tetra-ethyl lead (TEL [Pb (C2H5)4]), which is a common practice in African oil industries (Augustine *et al.,* 2016), the burning of waste, especially tires, and the movement of air pollutants from nearby towns are all potential sources of heavy metals in any environment. The amount of iron and copper in the study area may also be influenced by the vehicle scraps that are scattered throughout it. The result observed from this study is in line with the study conducted by Augustine *et al.* (2012), where it was reported that the concentrations of Ni, Zn, Mn, Cu, Cr, and Pb in neem leaf samples taken from various locations along the Katsina River.

The trend of the results in Figures 1 and 2 follows a similar pattern, showing that Cd > Zn > Cu > Pb; and Cd >Zn > Cu > Pb respectively. This may relatively be due to some activities they shared, as well as absorption potential of the tree species. In Oyo State, Nigeria, Kord et al. (2016) conducted and published a similar study on the levels of heavy metals (ppm) in pine needle samples. Their results showed that the heavy traffic sites had the highest metal concentrations, while the control site had the lowest. According to a study conducted in Katsina and Funtua, the magnitude of these metals found in samples taken from different points along the highway was Zn > Mn >Cu > Pb > Ni > Cr. The higher levels of commercial, industrial, and automotive activity in Katsina and Funtua compared to other highway locations may account for the elevated Pb and Ni levels in these samples along the highway (Lawal *et al.,* 2011). Base on the aforementioned results, it is reasonable to conclude that the soil type, the capacity of individual trees to absorb heavy metals, and human factors may all contribute to the variation in the heavy metal concentration status of the samples under investigation.

Generally, the research shows that there was significant difference in concentrations, with samples from Kaduna showing a slightly higher concentrations of Cd, Cu, Zn, and Pb, while samples from Kano have much lower concentrations as shown in Tables 2 and 4. The slight variation in the concentrations of Cd, Cu, Zn and Pb in the samples of Kaduna could be attributed to geological status of the location, high commercial activities, automobiles, as well as variation in the year of establishment of the two plantations under study. These findings agree with that of Lawal *et al.,* (2011) who reported similar trend with Katsina and Funtua.

Conclusion

The study's findings showed that the following trace metals were present in samples of Neem tree composite (leaves, bark, and roots) from both the industrial areas of Kaduna and Kano State, at different concentrations: Similarly, Zn > Cu > Pd > Cd and Cu > Zn > Pd > Cd. The samples from Kaduna State showed highest contamination by these hazardous metals.

Furthermore, the research also revealed that samples from industrial areas of Kaduna showed significant differences in concentrations with respect to distances, but not with the sampling points, while samples from industrial areas Kano showed no significant difference with respect to distances, but there is significant difference with the sampling points. This research further found that individuals living around industrial areas and highways are at high risk of exposure to dangerous environmental pollutants due to emission from automobiles and other anthropogenic activities.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are hereby made:

1. Since this research work has shown significant differences in heavy metals concentrations based on distances, it is recommended that further studies should be conducted to assess the potential of other tree species as phytoremediators. a study should be carried out to assess other tree species.
2. Since all the heavy metals assessed were found to be present, and their concentrations may continue to increase, posing more risks of exposure to dangerous environmental pollutants, it is recommended that people living near and around industrial areas should consider relocating to a much more pollution free environment.
3. Government should enforce rules and regulation against indiscriminate cutting down of trees (deforestation).
4. Communities should be engaged in tree planting exercises around industrial, commercial, and automobile-heavy areas. This will drastically reduce heavy metals contamination.
5. Government should provide a means of educating people on the importance of phytoremediation to ensure adequate removal of contaminants (heavy metals) from the environment.

REFERENCES

Abaje, I.B., Achiebo, P.J. and Matazu, M.B. (2018). Spatio-Temporal Analysis of Rainfall Distribution in Kaduna State, Nigeria. *Ghana Journal of Geography*. 10(1):1–21 https://dx.doi.org/10.4314/gjg.v10i1.1

Adedokun, A.H., Njoku, K.L., Akinola, M.O., Adesuyi, A.A. and Jolaoso, A.O. (2016). Heavy Metal Content and the Potential Health Risk Assessment of Some Leafy Vegetables Cultivated in Some Flood Plains and Farmlands in Lagos, Nigeria. *FUNAI Journal of Science and Technology,* (3): 30-47. http://dx.doi.org/10.4314/jasem.v20i3.6

Akan, S.M., Yikala, B. S. and Chellube, Z. M. (2012). Study on the Distribution of Heavy Metals in Different Tissues of Fishes from River Benue in Vinikilang, *Journal*. 2(7): 46-123 https://www.researchgate.net/publication/290776488_Study_on_the_Distribution_of_Heavy_Metals_in_Different_Tissues_of_Fishes_from_River_Benue_in_Vinikilang_Adamawa_State_Nigeria?enrichId=rgreq-70372b22f11f01cbeaca0bf375b50155-XXX&enrichSource=Y292ZXJQYWdlOzI5MDc3NjQ4ODtBUzozMTk3MDczMTQzNjAzMjBAMTQ1MzIzNTU3MjAxNQ%3D%3D&el=1_x_2&_esc=publicationCoverPdf

Aleksandra, S., Radmila, P., Dragana, J., Zoran, D., and Alek. (2014) Heavy Metals Content in Selected Medicinal Plants Commonly Used as Components for Herbal Formulations. *Journal of Agricultural Sciences*. 35(3):467-471. http://www.agri.ankara.edu.tr/journal

Ali, H., Khan E, Ilahi I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. Journal of Chemistry, 2019. https://doi.org/10.1155/2019/6730305

Augustine, A.U., Onwuka, J.C. and Albert, C.Q. (2016). Determination of heavy metal concentration in Neem (*Azadirachta indica*) leaves, bark and soil along some major roads in Lafia, Nasarawa State Nigeria. *Journal of Environmental Chemistry and Ecotoxicology*.8(5):38-43. http://www.academicjournals.org/JECE

Augustine, O. I., and Joseph, I. M. 2016. The effects of tree canopy cover on soil fertility in a Nigerian savanna. *Journal of Tropical Ecology* 8.3:329-338. DOI:10.1017/S0266467400006623

EPA-USA. (2017). Information on lead air pollution: fundamental facts. USEPA, Research Triangle Park, NC 27709, 109 TW Alexander Drive. taken from the website on August 14, 2018. Contact us about lead air pollution at https://www.epa.gov/lead-air-pollution/forms/http://iopscience.iop.org/article/10.1088/1748-9326/aac8e6/pdf

Fang-Jie, Z., Michael, T., and Luit, J. (2008). Role of Sulfur for Plant Production in Agricultural and Natural Ecosystems. Dordrecht: Springer, pp. 163–176. https://www.researchgate.net/publication/227214215_Role_of_Sulfur_for_Plant_Production_in_Agricultural_and_Natural_Ecosystems?enrichId=rgreq-29a9c2f8ab874e7c92fe93510f1cf3fa-XXX&enrichSource=Y292ZXJQYWdlOzIyNzIxNDIxNTtBUzo5MjI4Njg1NjUxNTk5MzZAMTU5NzA0MDQyMDAyNw%3D%3D&el=1_x_2&_esc=publicationCoverPdf

Ishtiyaq, S., Kumar, H., Varun, M., Kumar, B., & Paul, M. S. (2018). Heavy metal toxicity and antioxidative response in plants: An overview. *Plants under Metal and Metalloid Stress: Responses, Tolerance and Remediation*, 77-106. https://link.springer.com/chapter/10.1007/978-981-13-2242-6_3

Khanna, K., Kohli, S.K., Bali, S., Kaur, P., Saini, P., Bakshi, P. and Bhardwaj, R. (2018). Microorganisms' Function in Changing Antioxidant Defense in Metal-Toxic Plants. In Metal and Metalloid Stressed Plants (pp. 303-335). Singapore: Springer. DOI: 10.26832/AESA-2019-CAE-0161-04

Kord, B., Mataji, A. and S. Babaie, (2016). Pine (Pinus Eldarica Medw.) needles as Indicator for heavy metals pollution. *Int. J. Environ. Sci., Technol.,* 7(1): 79-84. https://doi.org/10.1007/bf03326119

Kumar, R., Mishra, R.K., Mishra, V., Qidwai, A., Pandey, A., Shukla, S.K. and Dikshit, A. (2016). Heavy metal tolerance and detoxification in in Plant Metal Interaction. pp. 335-359. http://dx.doi.org/10.1016/B978-0-12-803158-2.00013-8

Lawal, A.O., Batagarawa, S.M., Oyeyinka, O.D., and Lawal, M.O. (2011). Estimation of Heavy Metals in Neem Tree Leaves along Katsina – Dutsinma – Funtua Highway in Katsina State of Nigeria *J. Appl. Sci. Environ. Manage. June*, 15 (2) 327 – 330. https://doi.org/10.4314/jasem.v15i2.68516

Liu, Y., Zhou, Y., Lu, J. (2020). Exploring the relationship between air pollution and meteorological conditions in China under environmental governance. *Scientific Reports*. 10(1), 14518. https://doi.org/10.1038/s41598-020-71338-7

Oklo, D.A., and Asemave, K. (2012). Evaluation of Nigerian Tree Barks for Heavy Metals. *Environment and Bioenergy International Journal*. 5(2), 80-89. http://www.modernscientificpress.com/Journals/IJEE.aspx

Romero-Estevez, D., Yanez-Jacome, G.S., Navarrete, H. (2023). Non-essential metal contamination in Ecuadorian agricultural production: A critical review. *Journal of Food Composition and Analysis*. 115, 104932.

Rout, G.R. and Sahoo, S. (2015). Iron's function in plant metabolism and growth. Agricultural *Science Reviews*. 3: 1–24. https://doi.org/10.7831/ras.3.1

Rozirwan, R.Y., Hendri, M., Fauziyah, W.A.E., Agussalim, A. (2022). Phytochemical profile and toxicity of extracts from the leaf of Avicennia marina (Forssk.) Vierh. collected in mangrove areas affected by port activities. *South African Journal of Botany*. 150, 903–919. https://doi.org/10.1016/j.sajb.2022.08.037

Salami, K. D. and Lawal, A. A. (2018). Description of economical trees and shrubs species in Northern part of Nigeria and their potentials. *Proceedings of 6th NSCB Biodiversity Conference of the forests and forest products society 20-25.* *https://doi.org/10.5897/IJBC2020.1463*

Su, J., Huang, G. and Zhang, Z. (2022). Migration and diffusion characteristics of air pollutants and meteorological influences in Northwest China: a case study of four mining areas. *Environmental Science and Pollution Research*. 29(36), 55003–55025. https://doi.org/10.1007/s11356-022-19706-w

Tangahu, B.V., Abdullah, S., Rozaimah, S., Basri, H., Idris, M., Anuar, N. and Mukhlisin, M. (2011). An overview of how plants absorb heavy metals (As, Pb, and Hg) through phytoremediation. Chemical Engineering International, doi:10.1155/2011/939161

Thongyuan, S., Khantamoon, T., Aendo, P., Binot, A. and Tulayakul, P. (2021). Ecological and health risk assessment, carcinogenic and non-carcinogenic effects of heavy metals contamination in the soil from municipal solid waste landfill in Central Thailand. *Human and Ecological Risk Assessment: An International Journal*. 27: 876-897. http://dx.doi.org/10.1080/10807039.2020.1786666

Zaynab, M., Al-Yahyai, R., Ameen, A., Sharif, Y., Ali, L., Fatima, M., Khan, K.A., Li, S. (2022). Impacts of heavy metals on the environment and human health. *Journal of King Saud University of Science.* 34(1), 101653. DOI: 10.12691/aees-11-1-4