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Phyto-remediation Potentials of Adunnu Accession of Velvet bean Plants on Heavy-Metals Polluted Soils of Zazzaga, Munya/Shiroro, L.G.A.s, Niger State, Nigeria

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Abstract

Velvet beans are underutilized legume of the Fabaceae family with vast suspected potentials. Zazzaga, in Munya/Shiroro, Local Government Areas of Niger State. It used to be majorly an agrarian community till illegal mining activities of gold, lateritic clay e.t.c. led to contamination of some of its agricultural lands rendering it useless for crop production. This research assessed the impacts Adunnu accession of Velvet bean plants (experimental) and wild Cajanus plant (control) grown by irrigation during dry season had on remediating its soils by up-picking (phyto-remediating) the heavy metals. Statistical comparism of the laboratory test results (data) of the pre-treatment and post-treatment of experimental and control groups revealed that the experimental group was able to significantly reduce the concentration levels of the heavy-metals in the sampled soils more than the control group. This finding points to the phytoremediating potentials of velvet beans. The researchers recommended the cultivation of velvet beans by farmers and communities whose farmlands have been polluted by heavy-metals as well as by ministries/departments/agencies of government who seek to restore environmental lands polluted due to anthropological activities as is the case with parts of Niger State.

Introduction

Velvet beans (*Mucuna pruriens* L.) is a legume crop that is mostly found growing wildly, with few species domesticated and sparsely grown in parts of Asia and Africa (Vadivel and Pugalenthi, 2006). It belongs to the Family Fabaceae, Genus *Mucuna*, and Species *M. pruriens*. It however grows best on loose sandy soils and is mainly used as a food, feed and for soil conservation purpose (Siddhuraju, Vijayakumari and Janardhanan, 1995). Velvet beans is hard when dried, it has a range of colours ranging from dark brown, shades of grey and black. Velvet beans is generally lowly cultivated due to little awareness on its' potentials and also due to the itching effect it causes anyone whose skin comes in contact with its' pods and plant parts (Pugalenthi, Vadivel, Gurumoorthi and Janardhanan, 2005).

Phytoremediation is a process of using plant to free contaminated air, water and soils of their contaminants by either absorbing, stabilizing or degrading the pollutants such as heavy metals, pesticide, radionuclides and hydrocarbons. It offers a cost-effective, eco-friendly and sustainable solution for restoring polluted soil, water and air to normal. The prefix **phyto** means plant and the suffix **remediation** means reverser of damage. Phytoremediation is an economically and environmentally favourable technique that utilizes green plants to contain, sequester or detoxify contaminants from contaminated soil and water (Wuana and Okieimen, 2011). Phytoremediation utilizes many mechanisms such as degradation (rhizo-degradation, phytodegradation), accumulation (phytoextraction, rhizofiltration), dissipation (phytovolatilization and immobilization)and hydraulic control (phytostabilization) to degrade, remove, or immobilize the pollutants (Pivetz, 2001).

Depending upon the contaminants, plants utilize one or more of these mechanisms to reduce their concentrations from soil and water. For examples, plants uptake and accumulate the heavy metals in their tissues (Wuana and Okieimen, 2011) and degrade the organic pollutants (Saleem, Ali, Kamran, Iqbal, Azeem, Tariq, Javed, Ali, ZulqurnainHaider, Irshad, Rizwan, 2020) reducing their toxicity from soil and water resources.

Zazzaga Village of Munya/Shiroro L.G.A.s of Niger State is predominantly a farming community whose primary means of livelihood is currently being threatened by illegal mining activities. These illegal miners often excavate soils and break (underground and surface) rocks in a bid to access mineral resources like gold, lateritic clay, granite and other minerals that interest them. They often contaminate the soil and the environment by exposing heavy-metals to areas of the soil where the roots of crops dwell. This in turn negatively affects germination and establishment of cultivated crops. In the long-run, in cases where the crop grows to maturity and isn't a good phyto-remediant, it leads to concentration of these pollutants in the parts of crops that are desirous to man. A careful understanding of the above points is what prompted the researchers to carry out this research so as to ascertain the usefulness or otherwise of velvet beans to phytoremediate heavy-metal polluted soils of the study areas.

Meaning of Phytoremediation

Phytoremediation implies the process of using plants to reverse the damaged done to soils, water and air either through oil spillage, pesticides, mining etc that have exposed the soils to hydrocarbons, heavy metals, radionuclides and other pollutants. Thus, restore the soils, water and air normalities leading to clean and sustainable environment.

Types and Process of Phytoremediation

There are several processes of phytoremediation and the essential ones are as follows:

i. **Phytoextraction/Phytoaccumulation**: Phytoextraction is a process where certain plants are used to remove heavy metals and other pollutants from soil or water. The root of these plants, known as hyperaccumulators, absorbs the contaminants, transfer them to their shoot and store them in their tissues. Although it might not be appropriate for all sorts of pollutants or soil conditions, this procedure is thought of as an environmentally beneficial solution to clean up polluted soils and water. The general mechanisms during accumulation of toxic heavy metals include absorption of metal cations followed by metal-phytochelatin complex (M-PC) or metal-ligand complex formation inside the plant cell (Saleem *et al.*, 2020). After forming the M-PC, these complex molecules are translocated to the plants' vacuole for storage (Yadav, 2010). The extraction potential of plant species is mainly determined by plant biomass and

the concentration of heavy metals in above the ground plant tissues (Li, Liao, Lan, Ye, Baker, and Shu, 2010). Therefore, a best suited phytoremediation species not only need to tolerate and effectively absorb heavy metals but also be fast-growing with huge biomass production and provide economic benefits (Hammond, Root, Maier and Chorover, 2018).

ii. **Phytostabilization/Phytosequestration**: Phytostabilization otherwise called Phyto immobilization is the process by which contaminants, especially metals, are absorbed and precipitated by plants, reducing their mobility and preventing their migration into groundwater (leaching), the air (wind transport), or the food chain. They may involve a plant producing biochemicals that are released into the soil or groundwater nearby the roots and that can sequester, precipitate, or otherwise immobilise nearby contaminants (Yadav, Siebel and Van-Bruggen, 2011). Heavy metal precipitation or a decrease in metal valence in the rhizosphere, absorption and sequestration within root tissues, or adsorption onto root cell walls can all result in Phyto stabilization (Hammond, Root, Maier and Chorover, 2018).

iii. **Phytovolatilization**: Pollutants that can be converted into volatile chemicals are subjected to phytovolatilization. These pollutants are absorbed by specialized plants, where they are then vaporized and released into the atmosphere. The volatilization method works well mostly for organic pollutants (Limmer and Burken, 2016).

iv. **Rhizosphere Biodegradation**: In the rhizosphere biodegradation process, the plant secretes natural chemicals from its roots that serve as nutrients for the development of soil microorganisms. The tiny organisms multiply quickly and promote the biological breakdown of soil pollutants. In others words, rhizosphere biodegradation refers to the process of pollutant degradation that occurs in soil surrounding plant roots, known as the rhizosphere. In this process plant release various organic compounds, such as root exudates, into the soil. These exudates can stimulate the growth and activity of micro organisms include bacteria and fungi, which possess the ability to breakdown or transform pollutants (Shaw, Morris and Hooker, 2006).

v. **Rhizofiltration**: Rhizofiltration is a phytoremediation technology that includes filtering and removing pollutants from water, particularly pollutants like heavy metals and certain organic compounds, using the root systems of plants. Aquatic ecosystems are cleansed using this remediation technique using aquatic or terrestrial plants (Hammond, Root, Maier and Chorover, 2018). During this technique, plants are cultivated either on the contaminated site (in situ) or in an ex-situ setting. Terrestrial plants are typically employed in this strategy because of their rapid growth and fibrous roots (Yadav, Siebel and Van Bruggen, 2011). They observed further that adding microorganisms to the rhizosphere promotes the uptake of contaminants. The process works by planting these specialized plants in contaminated areas, such as mine tailings or industrial sites.

Concept of Heavy metals

Heavy metals are naturally occurring high density (≥ 5 g/cm^3), large atomic mass (≥ 23) and high atomic number (≥ 20) metals often toxic even at low concentration such as lead, mercury, arsenic, cadmium and chromium and can be essential to life such as zinc and copper or non-essential. They are accumulated in the environment (soils, water and air), in foods (fruits, shoot and root) and in organisms (fish, animals and humans) causing environmental and food degradation, thus, posing environmental and health issues.

Concept of heavy metals Polluted Soils

Heavy metals polluted soils are soils that have been contaminated by heavy metals such as lead, arsenic, zinc as a result of human activities such as mining, quarrying, application of pesticides and fertilizers. Soils may become contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly expanding industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, application of fertilizers and animal manures in farm lands, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition (Angon, Islam, Shreejana, Das, Anjum, Poudel, and Suchi, 2024).

Overview of Processes by which Heavy Metals Contaminate Soil

Heavy metals which include zinc (Zn), lead (Pb), nickel (Ni), arsenic (As), mercury (Hg), copper (Cu), cadmium (Cd) and chromium (Cr) have affected over 20 million hectares of land (Liu, Li, Song and Guo, 2018). Soils are the major sink for heavy metals released into the environment majorly by various anthropogenic activities such as industrial processes, mining, agriculture and some natural/biogenic processes such as volcanic emissions, ocean salt sprays, wind-borne soil particles, forest fires, rock weathering and organic matter decay (Priya *et al.*, 2023; Angon *et al.,* 2024). The levels of discharge of heavy metals into soils through human activities can go way beyond those of natural means, causing potential environmental and health hazards. Accidental spills or leaks from industrial sites or transportation can at times result into heavy metal soil contamination (Priya, Muruganandam, Ali and Kornaros, 2023). Factors that contribute to the presence of heavy metals in soils include rapid industrialization, air deposition, farmyard manure, sewage sludge, and synthetic pesticides and fertilizers used extensively for farming (Angon *et al.*, 2024).Apart from off-site sources, onsite contamination sources of soils, such as mining, smelting and manufacturing can release high concentration of heavy metals into the environment (Priya *et al.*, 2023).

Challenges Posed by Heavy Metals Contaminated Soil

Pollution of natural resources such as soil with heavy metal is a major concern. Serious environmental pollution by heavy metals emanate from various human activities including the rapid urbanization and industrialization, intensified agricultural practices and increased environmental explorations (Kafle, Timilsina, Gautam, Adhikari, Bhattarai and Aryal, 2022). These activities have led to the distortion of soil properties, including the pH, electrical conductivity and cation exchange capacity (Saleem *et al.*, 2020). This in turn have affected the soil microbial population, processes and activities, having a great influence on food crops in terms of production quantity and quality (Kafle *et al.*, 2022; Angon *et al.*, 2024).

Exposure of plants to heavy metals can alter/slow down photosynthetic processes, nutrient uptake and water balance. This can cause stunted growth, chlorosis and plant death (Khalil and Hassan, 2024).Examples of metals capable of interfering with the production of chlorophyll are Pb and Cd, causing photosynthetic inefficiency and overall plants decreased vitality (Rizwan, Ali, Rehman and Maqbool, 2019).

Overview of Ways for Remediation of Heavy Metals Contaminated Soils

The general aim of remediation of heavy metals contaminated soils is to create an eco-friendly environment for humans, plants and animals (Priya *et al.*, 2023). Remediation is an approach using physical, chemical and or biological methods for removing/reducing pollutants/contaminants from the ecosystem (Saleem *et al.*, 2023). The physical and chemical form of the heavy metal contaminants in soil is strongly necessary for determining appropriate remediation treatment, as they influence the choice of selection of a suitable remediation approach (Wuana and Okieimen, 2011).

The physical methods include excavation and land filling, and the soil washing. The former involves removal of contaminated soil and disposal in designated landfills. The later involves extraction of the heavy metals using water/chemical solutions (Rizwan *et al.,* 2019).

In chemical methods, immobilisation/stabilisation and electrokineticremediations can be employed. Immobilisation/stabilisation method involves using binding chemicals such as lime or phosphate to bind heavy metals and reduce their bioavailability. Electro-kinetic remediation uses electrolytic application to migrate heavy metals towards electrodes for removal (Liu *et al.,* 2018; Priya *et al.*, 2023).

Biological methods use phytoremediation and microbial remediation techniques (Priya *et al.*, 2023). Phytoremediation technique involves the use of plants to rid of heavy metals either through absorption (phytoextraction), accumulation (using hyperaccumulators), stabilisation (phytostabilisation) processes (Li, 2010; Liu *et al.,* 2018; Saleeem *et al.*, 2020) and rhizofiltration, where pollutants are absorbed, concentrated, and/or precipitated from

contaminated wastewater (Ahmed, Afroze and Jahan, 2025). Other processes include phytovolatilisation whereby plants convert heavy metal into volatile form and vapourises into the atmosphere, and nanoremediation which employs nanotechnology, using nanomaterials/particles to transform heavy metals into harmless forms (Rizwan *et al.,* 2019). Microbial remediation generally uses microorganisms such as bacteria and fungi to degrade and detoxify soil heavy metals (Liu *et al.,* 2018; Priya *et al*., 2023). Combination of two or more of these methods may, however be more effective and efficient for complex contaminations.

Phytoremediation Potentials of Velvet Beans

Velvet beans, botanically termed *Mucuna pruriens* (L.) DC. is a leguminous and medicinal plant. It belongs to the family Fabaceae and it is grown in the tropical and subtropical regions of Africa, America, Asia, and the Pacific Islands and largely in India (Banadka and Nagella, 2022).

Nigeria is significantly economically important among the world economies due to her abundant natural resources such as oil and gas, water bodies, extensive forestry and massive arable land (Ernest, Gordian and Bernard, 2018). On exposure to heavy metals, Banadka and Nagella (2022) discovered that the germination %, the vegetative growth, and the biochemical characteristics such as the protein, carbohydrate, chlorophyll, total phenol, flavonoid, and proline content varied greatly in the velvet beans treated with heavy metal compared to the control, and that the Levodopa (L-DOPA) content, used in treating Parkinson disease increased as metal concentration increased and then decreased further with higher concentrations of metals. The metal accumulation increased with the increase in the metal concentrations. This showed that *M. pruriens* is a potential remover of the heavy metals tested.

Ernest *et al*. (2018), research on phytoremediation potentials of guinea grass (*Panicum maximum*) and velvet bean (*Mucuna pruriens*) on crude oil impacted soils concluded that velvet beans could not significantly hyper accumulate Pb, Cd, Cr and Ni heavy metals analyzed in crude oil. The research did not, however, carry out analysis of the heavy metals in soil from mining site.

Study Area

Materials and Methods

Velvet Bean Seeds and Wild Cajanus Seeds Collection

Matured seeds accession of velvet beans were collected in their pods from natural habitat stands at different points in Adunu village (ward) of Paikoro L.G.A. of Niger State in

October, 2025. Matured seeds of wild Cajanus plant were collected from the respective study areas of Zazzaga (Munya/Shiroro L.G.A.s). The seeds were identified using Keys by Wilmort-Dear (1987). The specific location where the accession was obtained was recorded. The velvet bean seeds were dried in the sun for 72 hours in order to extract the seeds from their pods and to expel all forms of external moisture. The collected velvet beans seeds were used as the experimental group in the study. Wild Cajanus seeds were selected to be used as the control group since they it was the predominant wild legume of the 3 study areas. The seeds were thoroughly cleaned, broken seeds and foreign materials were removed and the mature seeds were taken to the sampled demonstration plots (study areas) of the heavy-metals polluted soils.

Selection of Study Area

The study area for the study were purposively selected based on evident information of active illegal mining activities and most importantly where the safety of the research team members could be guaranteed. Most importantly, a pre-treatment laboratory analysis of soil samples from selected study areas gave credence to selections made before demonstration plots were constructed. The selected study area; Zazzaga (Munya/Shiroro L.G.As) is in Niger State.

Set-up of Demonstration Plots

On each sampled study site, 20 Randomized demonstration plots of 1m X 1m each were constructed for experimental group and control group respectively on the identified areas where active illegal mining activities were ongoing. This was done after engaging the illegal miners in a friendly dialogue and explaining to them that the purpose of the team’s work was to seek eco-friendly ways to ameliorate the polluted soils. The experimental seeds are Velvet beans while the control seeds are wild Cajanus. 16 seeds of 2 per hole were sown at a spacing of 25cm X 25cm on the experimental and control plots respectively. The demonstration plots were watered (irrigated) to optimum capacity daily. The demonstration plots were setup in November, 2025 during the onset of the dry season in the sampled areas. Records of germination and growth indices were taken weekly.

Collection of Soil Samples

The initial heavy-metals profile for each of the set-up demonstration plots of the study area before the commencement of treatment was determined via samples of soils of depth 7cm, 14cm and 21cm that were collected using soil auger and tested for in the soil science laboratory of University of Uyo.

After 16 weeks of treatment, soil samples from the experimental and control plots were collected at depths of 7cm, 14cm and 21cm respectively from all 20 randomized

demonstration plots and were sent to the soil science laboratory of University of Uyo for heavy-metals testing and quantification.

Results and Discussions

Tab. 1: Heavy-metals content of the study areas before treatment

SAMPLE	Zazzaga
Zn	32.410
Cu	4.941
Ni	1.680
Cr	17.880
Cd	10.911
As	1.061
Hg	2.660
Pb	15.710
Co	3.981

Tab. 2: Heavy-metals content of the study areas after 16 weeks of treatment

SAMPLE		Zazzaga
	(C)	32.114
Zn		
	(E)	21.731
	(C) Cu	4.217
	(E)	
		3.233
	(C) Ni	1.596
	(E)	
		0.903
	(C) Cr	17.108
	(E)	
		10.631
	(C) Cd	10.204
	(E)	
		7.741
	(C) As	1.022
	(E)	
		0.731
	(C) Hg	2.593
	(E)	
		2.128
	(C) Pb	15.673
	(E)	
		9.922
	(C) Co	3.810
	(E)	
		3.112

C= control; E= Experimental

Tab. 2: Heavy-metals content of the study areas 16 weeks after treatment

Discussion

The heavy metals present in the demonstration plots; Zn, Cu, Ni, Cr, Cd, As, Hg, Pb, Co content were better reduced in the experimental group as opposed to the control group that sparingly managed to show a slight drop in the heavy metals concentration when their post-treatment results are compared to the pre-treatment value for these heavy metals in the sampled soils. This shows that velvet beans plants (experimental group) did pick up (phytoremediate) more of the heavy metals tested for than wild Cajanus (control group) did. This finding partly agrees with Wuana & Okieimen, (2011) who held that mycoremediation might be needed to remedy high Cu contents of soil before stabilizing with Phytoremediation using specific legumes even though velvet bean plants are good phytoremediators of copper from polluted soils; Saleem *et al.*, (2020) who opined that velvet bean plants are better phytoremediators of cadmium from polluted soils than other species they worked on; Pivetz (2001) who reported that high Ni concentrations may hinder plant growths especially when in conjunction with other growth-inhibiting heavy metals but can be remedied by adopting different Phytoremediation approaches; Priya et al., (2023) who recorded that certain wild plants hold potentials to remedy Hg from polluted soils; Liu et al., (2018) who recorded that velvet bean plants are currently being used by Chinese government to remedy Zn, Pb, Cr and Co from polluted soils as it has proven to be an effective phytoemediator; Khalil & Hassan (2024) who reported that different eco-friendly ways such as inter-planting with velvet beans can be adopted to remedy soils with high concentrations of (As) in quantities much enough to prevent germination of seeds the desired crop; Limmer & Burken (2016) who recorded that certain wild plants hold potentials to remedy polluted soils by phytovolatilization and Banadka & Nagella, (2022) who documented that moderate to high quantities of heavy metals like (Co) may negatively affect germination of seeds planted, as this is the case with the control group that recorded poor growth and hence an abysmal phytoremediating indices when compared to the experimental group.

Conclusion

The presence of heavy metals in any given soil has been proven to be an inhibitor to plants germination and growth. From the findings of this work, it can be inferred that Velvet beans grown on a soil contaminated by heavy metals helps to remedy the soil by extracting these pollutants from the soil thereby freeing the soil for agronomic utilization by man and in the long run help to crop production, ensure food security and improve on the economy eventually

Recommendations

This research has the following recommendations:

1. Velvet beans should be grown by farm owners, ministries and departments of agriculture and environment on lands suffering from heavy-metals pollution due to mining of mineral resources
2. Researchers should undertake further research into using velvet beans to salvage lands affected by other types of environmental pollution such as oil spillage areas of Ogoni land.
3. Researchers are enjoined to undertake further research on more accessions of velvet beans and other parts of velvet plants from other parts of Niger State and beyond.
4. Further research should carried out by researchers into other aspects of neglected and underutilized crops for the benefit of mankind.

Declarations

Declaration of interests

 The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

 The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Prof. Solomon Adekojo Adeolu reports financial support and administrative support were provided by Tertiary Education Trust Fund. Prof. Solomon Adekojo Adeolu reports a relationship with Federal College of Education Kontagora that includes: employment. Dr. Daramola Olamide Temitope reports a relationship with Federal College of Education Ididep that includes: employment. There are no other conflict of interest to declare as non of the authors are serving in editorial capacity for this submitted article, neither is any of the author under any form of obligation to serve the interest(s) of person(s) or organizations via this submitted article. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures

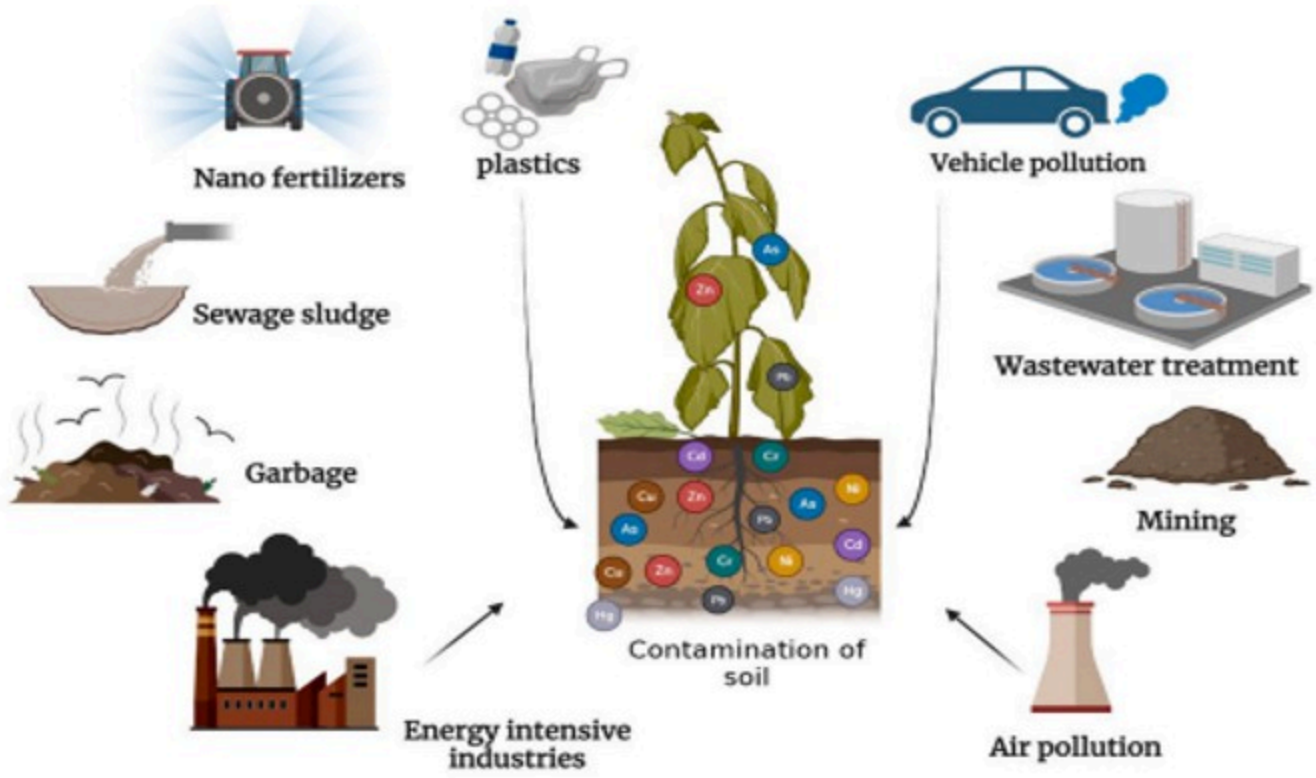


Figure 1

Different Sources of Heavy Metals in Soils (Angon*et al.,* 2024)

Rocks, typically igneous and sedimentary are the commonest natural sources of heavy metals. Parent materials which originally form the rocks, is the main lithogenic source of heavy metals in soils (Priya*et al.,* 2023; Angon*et al.,* 2024).

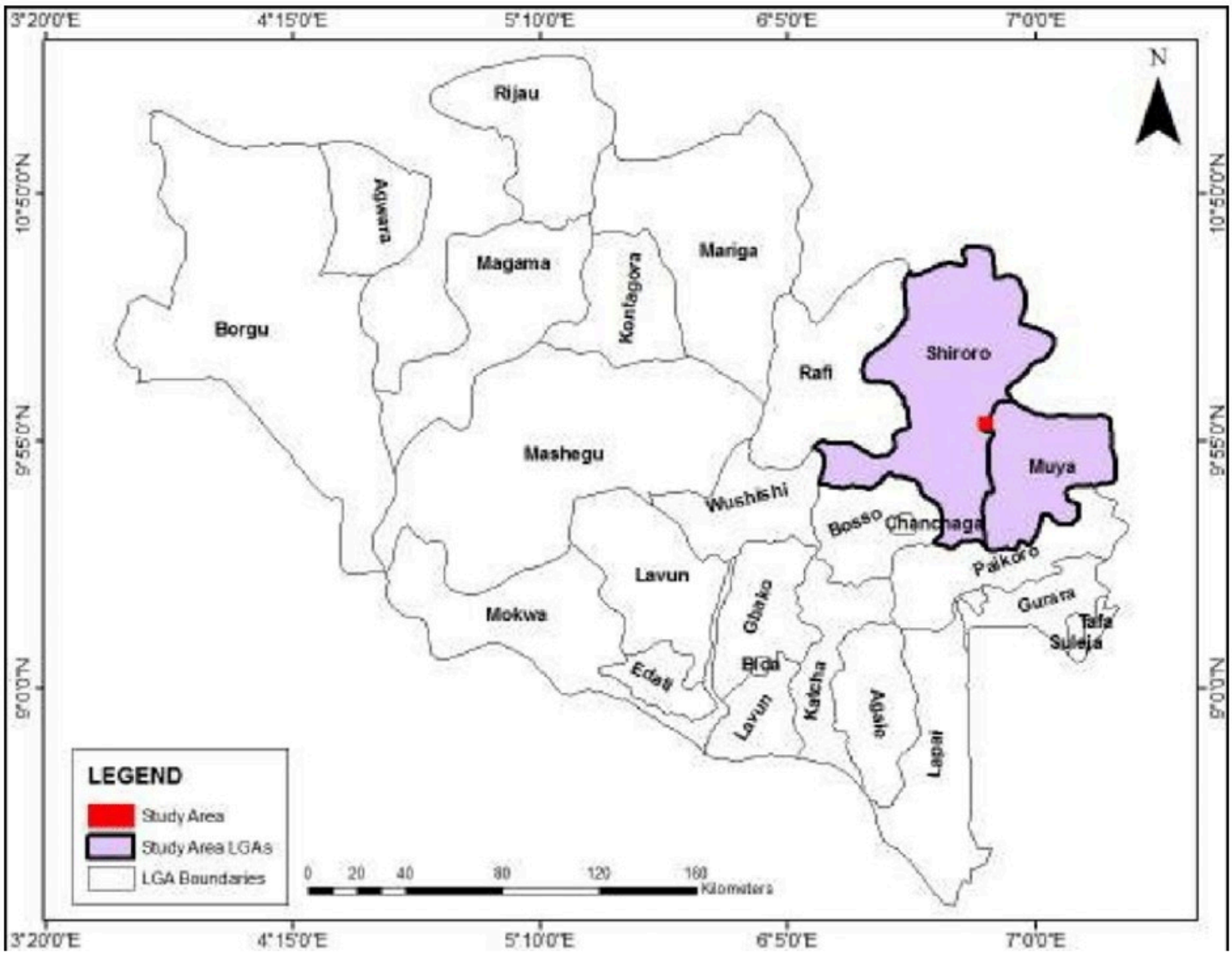


Figure 2

Map of Study Area

Source: Google Map, 2026