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An Investigation into the Presence of Heavy Metals in Wastewater and Vegetation in Gombe Metropolis, Nigeria

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ABSTRACT

This study was conducted to determine the concentrations of heavy metals, including cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) in both water and plant samples. Each of the study sites represents an important ecological zone, that serves as a habitat for a wide range of flora and fauna, such as aquatic macrophytes, amphibians, riparian vegetation, macroinvertebrates, and fish species. Water and plant samples were collected, processed, and analyzed according to standard methods. Atomic absorption spectrophotometry was used to analyze the heavy metals in both plant tissues/organs and water. Since heavy metals cannot be detected through taste, sight, or smell, appropriate chemical analysis methods are required. By identifying the sources of contamination, preventive actions can be implemented, and health professionals, including doctors and pharmacists, can provide long-term solutions. The main objective was to assess the concentration of heavy metals and their potential health risks to humans. The results of this study showed that magnesium (Mn) had the highest concentration in plants such as *Ludwigia abyssinica* (19.5 mg/l), *Setaria barbata* (20.0 mg/l), *Cyperus esculentus* (18.6 mg/l), and *Eleusine indica* (19.73 mg/l) from various locations like Pantani, Yelenguruza, Nassarawo, Bagadaza, and Mallam Inna. The levels of chromium, nickel, and zinc were found to be below the World Health Organization's (WHO) recommended maximum limits for both plant and water samples.

Keywords: Gombe metropolis, Heavy metals, *Ludwigia abyssinica*, *Setaria barbata*

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Introduction

Pollution refers to the introduction of contaminants into the natural environment, leading to undesirable changes. These contaminants can take various forms, such as chemical substances or different types of energy, including noise, light, or heat. Pollutants can be foreign substances or naturally occurring materials. In 2015, pollution was responsible for the deaths of nine million people globally [1]. While some heavy metals are essential in trace amounts, many can be harmful to all life forms at higher concentrations due to the formation of toxic compounds within cells. Unlike organic pollutants, heavy metals cannot be biodegraded once they enter the environment; they persist and pollute the air, soil, and water indefinitely. The uptake of heavy metals by plants depends on factors such as plant species, genetics, soil type, metal composition, soil conditions, climate, and the surrounding environment. Heavy metals are non-biodegradable, persistent, and can accumulate in biological chains, posing significant risks to human health when consumed through contaminated plants. Contamination may occur from sources such as polluted irrigation water, fertilizers, metal-based pesticides, industrial emissions, and even during harvesting, transportation, and storage processes [2-6]. Plants grown in contaminated soils accumulate higher levels of heavy metals than those in uncontaminated soils. Farmlands near industrial areas are particularly susceptible to pollution, which leads to chemical contamination of crops. Some elements like chromium and cadmium are known carcinogens, while others like iron, copper, manganese, zinc, and nickel are essential trace elements. Heavy metal contamination in water is a growing concern due to its potential impact on aquatic ecosystems. Exceeding the threshold of these metals in water has disrupted ecosystem balance and raised the need for cost-effective, eco-friendly solutions [7, 8]. In aquatic systems, where pollutants may be diluted over time, analyzing plant tissues can offer insights into the quality of the environment [9]. While some heavy metals are naturally found in water and essential for life, excessive concentrations can be toxic. These metals cannot be detected through sight, taste, or smell, but must be identified using appropriate chemical analysis methods. By identifying the sources of contamination, preventive measures can be implemented, and health professionals can provide lasting solutions. Heavy metal pollution is extremely harmful, with detrimental effects on health, the environment, and irrigation. Many heavy metals are toxic to aquatic organisms, even in small quantities. Recently, anthropogenic pollution has become a major global, regional, and local environmental concern. This study was conducted in an analytical laboratory at Abubakar Tafawa Balewa University (ATBU), which is well-equipped and reliable. Despite its socio-economic and ecological importance, there is a lack of sufficient research on the concentration and distribution of heavy metals in the environment.

Materials and Methods

Study area description

The study was conducted within Gombe State, Nigeria, specifically in the Gombe metropolis, with five key locations selected for sampling. These include Pantami, situated at 10°16'21.30” N latitude and 11°10'3.90” E longitude; Yelenguruza at 09°12'11.20” N and 12°12'11.42” E; Nassarawo at 13°11'5.90” N and 09°45'9.30” E; Bagadaza at 10°15'20.40” N and 11°15'12.80” E; and Mallam Inna at 09°42'10.50” N and 09°11'5.70” E. Each of these areas represents an important, though temporary, aquatic ecosystem, supporting a wide range of plant and animal species, including aquatic plants, riparian vegetation, macroinvertebrates, amphibians, and fish. Pollution sources at these sites include chemical fertilizers, pesticides, domestic sewage, and waste accumulation.

Sample collection

A total of 20 plant samples were gathered, with four samples taken from each of the 5 designated locations. The plants collected included *Dactyloctenium aegyptium*, *Eragrostic tremula*, *Ludwigia abyssinica*, *Sida acuta*, *Setaria barbata*, *Ipomoea violacea*, *Hygrophilia rosefolia*, *Cyperus esculentus*, *Eragrostis atrovirens*, *Ipomoea aquatica*, *Cyperus flava*, *Sporobolus alroides*, *Andropogon tectorum*, *Digitaria horizontalis*, *Hydrolea palustris*, *Eleusine indica*, *Stachytorpheta cayennesis*, and *Aeschynomene indica*. The samples were collected along the stream's shoreline using tools like shovels, gloves, polythene bags, and masking tape, and then transported to the laboratory for processing. Water samples from the same locations were collected in bottles and also taken to the laboratory.

Sample preparation

The plant samples were carefully separated, washed with de-ionized water, and then air-dried in the shade until they were ready for grinding. Once dried, the samples were finely ground using a clean porcelain mortar and pestle and then sieved through a 0.5 mm sieve to achieve a fine powder. The powdered samples were placed in small crucibles for proper labeling and identification. Water samples were filtered using Whatman No. 1 filter paper, and the filtered samples were acidified with five milliliters of concentrated nitric acid before being stored in a refrigerator until further analysis.

Digestion process

The glassware was thoroughly cleaned and rinsed with distilled water. A 2-gram portion of each plant sample, in powdered form, was carefully weighed and placed into a beaker. A mixture of 10 ml concentrated nitric acid and hydrochloric acid in a 3:1 ratio was prepared in a separate beaker and added to the powdered plant sample. The mixture was stirred well and left overnight to ensure thorough digestion of the plant material. The resulting digest was then heated in a water bath at 120 °C until it became clear and was allowed to cool. After cooling, the mixture was filtered into a 100 ml volumetric flask, brought to the 20 cm mark with distilled water, and sent for heavy metal analysis [10].

Data analysis

The differences in the concentrations of heavy metals following various digestion methods were examined using ANOVA (SAS Institute, 1982) to compare concentrations in both water and plant samples. The digestion process includes the combustion of volatile components such as carbohydrates, fats, oils, and proteins. There are two primary methods for digestion: Dry ashing and Wet ashing [11]. This process involves fully burning all organic materials in the sample, leaving only inorganic mineral elements. The ignition starts by holding the substance in the non-luminous part of the Bunsen flame until it stops smoking, then transferring it to a muffle furnace heated between 450 °C and 550 °C [12]. The widespread use of insecticides to protect crops poses significant risks to both human health and the environment [13]. However, caution is needed to avoid low results due to reasons such as volatilization of elements, adsorption or combination of elements with the ash or the container, or incomplete extraction. These issues can typically be mitigated. Acid digestion procedures utilize oxidizing agents to decompose organic matter, and this method is preferred over dry ashing, as it avoids volatilization loss. In this approach, nutrient components can be analyzed in a single digest, although it may not work well for harder materials that require more complete digestion. For this study, hydrochloric acid was used because it facilitates a faster digestion process, though it is hazardous, and there is a risk of explosion if handled improperly. After digestion, the solution was adjusted to the mark in the volumetric flask for the final sample preparation [11].

Theory of analysis

Trace elements present in the sample solution can be analyzed using either classical or instrumental techniques, with the latter being considered more dependable. The instrumental approach utilizes devices such as the flame photometer and atomic absorption spectrophotometer [14]. In atomic absorption, there are 2 main methods for introducing thermal energy into the sample. One method, graphite furnace AAS, employs a graphite tube through which a strong electric current is passed to heat the sample. The other method, flame AAS, involves aspirating the sample into a flame using a nebulizer. The flame is then aligned with a beam of light at the correct wavelength. The heat from the flame causes the atoms to transition from their ground state to the first excited state. As the atoms undergo this transition, they absorb a portion of the light from the beam. "The higher the concentration of the solution, the greater the absorption of light energy" [15].

Results and Discussion

The data collected from the measurement of metal cations in soil and plant samples across five locations—Pantami, Nassarawo, Yelenguruza, Bagadaza, and Mallam Inna—within the Gombe State metropolis are displayed in **Tables 1-6**. Additionally, the results from the analysis of metal cations in water samples collected from Gombe are shown in **Table 1**.

Table 1. The levels of metal cations in water samples from different sites across the Gombe metropolis

S/N	Location	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
1	Pantami	–	–	0.025	0.35	15.7	1.9	0.02	–	0.051
2	Yelenguruza	–	–	–	5.0	16.85	1.8	0.01	0.02	0.42
3	Nassarawo	–	–	0.05	2.35	11.50	2.0	0.04	0.01	0.55
4	Bagadaza	–	–	0.08	0.6	17.9	3.4	0.025	–	0.9
5	Mallam Inna	–	–	–	2.1	15.5	0.4	–	–	0.32

A comparison of metal ion concentrations across different study locations was carried out, focusing on micronutrients and heavy metals. The micronutrient levels in water samples taken from the listed locations are shown in **Table 1**. The data reveals that magnesium ions had the highest concentration, followed by manganese, iron, zinc, copper, and nickel, with lead present in lower amounts. Both cadmium and chromium were not detected in any of the samples. The highest concentration of magnesium ions was found in Bagadaza, while the lowest was in Nassarawo. Iron concentrations peaked in Yelenguruza and were lowest in Pantami. Manganese concentrations were highest in Bagadaza, with Mallam Inna showing the least. Zinc ion levels were highest in Bagadaza and lowest in Pantami. Copper concentrations were highest in Bagadaza and absent in Yelenguruza and Mallam Inna. Nickel ions were most abundant in Nassarawo and absent in Mallam Inna. Lead concentrations were highest in Yelenguruza and lowest in Nassarawo, while Pantami, Bagadaza, and Mallam Inna showed no detectable lead. The results for metal cation quantification in plant samples from the Pantami area are provided in **Table 2**.

Table 2. The levels of metal cations found in a selection of plant samples collected from the Pantami area

S/N	Plant	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
1	*Dactyloctenium aegyptium*	–	–	0.045	11.85	17.35	2.9	–	–	–
2	*Ludwigia abyssinica*	–	–	0.155	1.1	19.5	10.85	0.01	–	0.025
3	*Eragrostic tremula*	–	–	0.405	0.8	17.8	4.9	0.01	–	–
4	*Sida acuta*	–	–	0.38	6.7	18.2	1.2	–	–	0.01

Table 2 displays the concentrations of micronutrients found in plant samples collected from Pantami for analysis. The results indicate that magnesium ions were present in the highest concentrations, followed by iron, manganese, copper, zinc, and nickel, in that order, while cadmium, chromium, and lead were absent in all the plant samples. The highest concentration of magnesium ions was found in *Ludwigia abyssinica*, while *Dactyloctenium aegyptium* showed the lowest. For iron ions, *Dactyloctenium aegyptium* had the highest concentration, and *Eragrostic tremula* had the lowest. Manganese ions were most concentrated in *Ludwigia abyssinica*, with *Sida acuta* showing the least. Zinc levels were highest in *Ludwigia abyssinica* and lowest in *Sida acuta*. Copper ion levels were highest in *Eragrostic tremula* and lowest in *Dactyloctenium aegyptium*. Nickel concentrations were consistently low across all samples. The data on metal cation concentrations from plants collected near Yelenguruza are presented in **Table 3**.

Table 3. Concentrations of metal cations in selected plant samples collected from the Yelenguruza area

S/N	Plant	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
1	*Ipomoea violacea*	–	–	0.595	1.75	21.3	–	0.02	0.01	0.26
2	*Setaria barbata*	–	–	0.63	0.5	20.0	4.5	–	–	0.15
3	*Hygrophilia rosefolia*	–	–	0.79	0.3	19.2	–	–	–	0.01
4	*Eragrostic atrovirens*	–	–	0.65	11.0	19.2	4.0	–	–	0.01

Table 3 displays the concentrations of micronutrients in plant samples collected from the specified locations. The data reveals that the highest concentration is observed for magnesium, followed by iron, copper, and zinc. The highest concentration of magnesium was observed in *Ipomoea violacea*, while *Hygrophilia rosefolia* and *Eragrostic atrovirens* exhibited the lowest concentrations. The highest iron concentration was found in *Eragrostic atrovirens*, with *Hygrophilia rosefolia* having the lowest. Copper concentrations were highest in *Hygrophilia rosefolia* and lowest in *Ipomoea violacea*. Zinc levels were highest in *Ipomoea violacea* and lowest in both *Hygrophilia rosefolia* and *Eragrostic atrovirens*. Cadmium and chromium were absent, while nickel and lead were found in trace amounts. The results from the quantification of metal cations in plant samples from the Nassarawo region are presented in **Table 4**.

Table 4. Metal cation concentrations in various plant samples collected from the surrounding areas of Nassarawo

S/N	Plant	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
1	*Cyperus esculentus*	–	–	0.645	11.7	18.6	2.6	–	–	–
2	*Ipomoea aquatica*	–	–	0.49	0.2	18.25	2.1	–	–	0.03
3	*Sporobolus alroides*	–	–	0.03	8.65	17.4	1.1	–	–	0.32
4	*Cyperus flava*	–	–	0.02	10.2	18.0	1.7	0.01	–	0.36

The concentrations of micronutrients in the plant samples collected from the aforementioned locations are displayed in **Table 4**. It reveals that magnesium had the highest concentration, followed by iron, manganese, and zinc in descending order. The highest concentration of magnesium was observed in *Cyperus esculentus*, while the lowest was found in *Sporobolus alroides*. The highest level of iron was detected in *Cyperus esculentus*, with the lowest concentration observed in *Ipomoea aquatica*. For manganese, *Cyperus esculentus* had the highest concentration, and *Sporobolus alroides* had the lowest. Zinc concentrations were highest in *Cyperus flava* and lowest in *Ipomoea aquatica*. Copper was most abundant in *Cyperus esculentus*, with the lowest level found in *Cyperus flava*. Cadmium, lead, chromium, and nickel were absent from all samples. The results from the analysis of metal cations in plant samples from the Bagadaza area are displayed in **Table 5**.

Table 5. The concentration of metal cations in selected plant samples from areas around Bagadaza

S/N	Plant	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
1	*Cyperus esculentus*	–	0.01	–	0.5	18.9	6.2	0.02	–	0.51
2	*Andropogon tectorum*	–	0.01	–	0.5	17.9	4.9	0.01	–	0.55
3	*Ludwigia abyssinica*	–	–	–	0.3	18.3	11.05	–	–	0.64
4	*Digitaria horizontalis*	–	0.01	–	4.0	16.5	0.6	–	–	0.34

Table 5 presents the concentrations of micronutrients in plant samples collected from the locations mentioned above. It indicates that the highest concentration was observed for magnesium ions, followed by manganese, zinc, iron, nickel, and chromium. The highest levels of magnesium ions were found in *Cyperus esculentus*, while the lowest levels were found in *Digitaria horizontalis*. The highest iron ion concentrations were observed in *Digitaria horizontalis*, with the lowest in *Ludwigia abyssinica*. The highest manganese ion concentrations were found in *Ludwigia abyssinica*, and the lowest in *Digitaria horizontalis*. Zinc ions were most concentrated in *Ludwigia abyssinica*, with the lowest concentrations in *Digitaria horizontalis*. Nickel, copper, lead, and cadmium ions were absent in the plant samples, and chromium was detected in trace amounts. The results from the metal cation quantification of plant samples found in the vicinity of Mallam Inna are displayed in **Table 6**.

Table 6. Concentrations of metal cations in plant samples collected from areas around Mallam Inna

S/N	Plant	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
1	*Eleusine indica*	–	0.01	–	0.2	19.73	11.1	–	–	0.645
2	*Hydrolea palustris*	–	0.01	–	12.5	19.6	9.05	–	–	0.665
3	*Stachytorpheta cayennesis*	–	0.01	–	8.25	17.9	2.5	0.015	–	0.67
4	*Aeachynomene indica*	–	0.01	–	5.6	18.2	2.9	0.015	–	0.77

The concentrations of micronutrients in soil samples analyzed from the previously mentioned locations are displayed in **Table 6**. The data indicates that the highest concentration was observed for magnesium ions, followed by manganese, iron, and zinc. Magnesium concentrations were highest in *Eleusine indica* and lowest in *Stachytorpheta cayennesis*. Iron levels were highest in *Hydrolea palustris* and lowest in *Eleusine indica*. Manganese concentrations were highest in *Eleusine indica* and lowest in *Stachytorpheta cayennesis*. Zinc was highest in *Achnynomene indica* and lowest in *Eleusine indica*. Cadmium, lead, and copper weren't detected, but chromium and nickel were present in trace amounts.

The findings of this study highlight the levels of heavy metals in wastewater and plant samples. The enrichment factor suggests that metals such as Zn, Cr, Cd, Cu, Pb, and Ni mainly originate from anthropogenic sources, but Fe, Mn, and Mg have contributions from both natural and human activities. The increasing accumulation of toxic metals in water bodies is a rising worry, as a significant portion of these metals exist in mobile forms. Over time, these metals may be absorbed by plants or seep into groundwater, where they can undergo biomagnification. Understanding the available trace metals, as opposed to the total metal content, is crucial for developing remediation strategies for contaminated sites and understanding the relationship between pollutants and the environment. The findings in this study align with similar research on heavy metals in wastewater and plants from different environmental settings.

The findings from Ibrahim-Z in the Jigawa metropolis indicated concentrations of 1.533 mg/l, 0.11 mg/l, 0.222 mg/l, and 1.233 mg/l for Mn, Fe, Zn, and Pb, respectively. In comparison, the results from the current study show concentrations of 2.0 mg/l, 2.35 mg/l, 0.42 mg/l, and 0.01 mg/l for Mn, Fe, Zn, and Pb, respectively, with no detectable traces of cadmium or chromium in all locations. These findings suggest no important difference between the two results.

Overall, elevated levels of heavy metals were detected in the water and plant samples across various locations. The analysis of water samples showed that magnesium had the highest concentration, with the highest levels found in Bagadaza (19.9 mg/l) and the lowest in the Nassarawo area (11.5 mg/l). Notably, cadmium, lead, and chromium were absent in the water samples.

Regarding plant samples collected from Pantami, magnesium levels were highest in *Ludwigia abyssinica* (10.85 mg/l) and lowest in *Dactyloctenium aegyptium* (17.35 mg/l). Cadmium, lead, and chromium were absent, with only trace amounts of nickel detected in the samples. In the Yelenguruza area, copper concentrations varied, with the highest in *Hygrophilia rosefolia*, followed by *Eragrostic atrovirens*, *Setaria barbata*, and the lowest in *Ipomoea violacea*, in the order 0.79 > 0.65 > 0.63 > 0.595 mg/l, respectively. Cadmium, lead, and chromium were absent in Dactyloctenium aegyptium, *Ludwigia abyssinica*, *Eragrostic tremula*, and *Sida acuta*, with minor traces of nickel in the Pantami area. The Mallam Inna area showed no detectable concentrations of cadmium, copper, or lead, with only trace amounts of nickel present.

Based on the analysis, manganese, magnesium, and iron were found in relatively high concentrations compared to other heavy metals. Therefore, magnesium, iron, and manganese are considered significant metals when accumulated in plants, posing relatively less risk.

Conclusion

This study found that magnesium and iron ions were present in high concentrations in both plant and water samples, while cadmium, copper, and lead were generally absent. The plants *Ludwigia abyssinica*, *Cyperus esculentus*, *Ipomoea violacea*, and *Hydrolea palustris* exhibited the highest concentrations of magnesium ions. The concentration of heavy metals in water was generally lower compared to the selected plant species, except for zinc and nickel. It is recommended that farmers focus on cultivating plants that are rich in magnesium, iron, and manganese due to their beneficial properties while avoiding the cultivation of plants contaminated with lead, cadmium, and chromium, which are toxic when ingested by humans. Additionally, market basket surveys must be conducted to obtain reliable data on contaminants, and the adoption of good agricultural practices is encouraged.

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Conflict of Interest: None

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Ethics Statement: This study, which primarily involved plant and water samples (abiotic factors), was conducted under the supervision and monitoring of the Research and Development Cell at Syed Ammal Arts and Science College.

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