Comparative Assessment of Heavy Metal Concentrations in Soils Across Four Local Government Areas of Southern Kebbi State, Nigeria: A Spatial Variability Study

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Abstract
Spatial variability of heavy metals in agricultural soils is a critical factor in determining the extent of contamination and formulating site-specific management strategies. This study compared the concentrations of heavy metals Cadmium (Cd), Copper (Cu), Iron (Fe), Manganese (Mn), Lead (Pb), and Zinc (Zn) in soils across four Local Government Areas (LGAs) of southern Kebbi State, Nigeria. A total of 48 composite soil samples were collected from Zuru, Danko Wasagu, Yauri, and Shanga LGAs. Heavy metal concentrations were determined using Atomic Absorption Spectrophotometry (AAS). Data were analyzed using Analysis of Variance (ANOVA), and means were separated using Duncan's New Multiple Range Test (DMRT) at a 5% probability level. The comparative analysis revealed no significant differences ($p > 0.05$) among the four LGAs for Cd, Cu, Mn, and Pb concentrations. However, significant differences ($p < 0.05$) were observed for Fe and Zn. Danko Wasagu recorded the highest mean Fe concentration (16.789 mg/kg), while Yauri had the lowest (13.990 mg/kg). For Zn, Shanga LGA recorded the highest mean concentration (0.7283 mg/kg), which was significantly higher than the other three LGAs, which were statistically similar. Cadmium concentrations exceeded the NESREA standard of 3.00 mg/kg in all LGAs, with Shanga recording the highest value (4.0350 mg/kg). The study reveals that while most heavy metals are uniformly distributed across the southern Kebbi State, Fe and Zn exhibit significant spatial variability. The widespread exceedance of Cd across all LGAs, particularly in Shanga, warrants immediate attention and site-specific remediation strategies.

Keywords: *Spatial Variability, Heavy Metals, Comparative Assessment, Soil Contamination.*

1. Introduction

Soil heavy metal pollution has become a worldwide environmental issue that has attracted considerable public attention due to growing concerns about the security of agricultural products (Ozein, 2018). Heavy metals in soil pose a great threat to the health and well-being of organisms and humans due to their potential accumulation through the food chain (Kettkar, 2019). Unlike

organic compounds, most heavy metals do not undergo microbial or chemical degradation, persisting in the environment for long periods (Ozein, 2018).

The sources of heavy metals are classified into natural and anthropogenic sources (Grange, 2021). Natural sources include sedimentary rocks, volcanic eruptions, and rock weathering, while anthropogenic sources include industrial activities, agricultural activities, mining, and domestic effluents. In agricultural settings, the application of phosphate fertilizers, pesticides, and biosolids are major contributors to heavy metal accumulation (Arao *et al*., 2010).

Understanding the spatial distribution of heavy metals in soils is essential for identifying pollution hotspots and implementing targeted remediation measures. In southern Kebbi State, agricultural production is vital, but the spatial variability of heavy metals across different Local Government Areas (LGAs) has not been comprehensively compared. Therefore, this study was designed to compare the concentrations of heavy metals in soils within each sampling area across four LGAs (Zuru, Danko Wasagu, Yauri, and Shanga) in southern Kebbi State. This comparative approach will help identify areas of concern and guide site-specific management practices for sustainable agricultural production.

2. Materials and Methods

2.1 Study Area

The research was carried out in the southern part of Kebbi State, located at latitudes 10°00′–11°00′ N and longitudes 3°30′–60°35′ E. The area covers approximately 11,428 square kilometers and comprises two administrative Emirates (Yauri and Zuru) with seven LGAs. The vegetation is typical tropical savannah woodland, with a mean annual rainfall of about 1004 mm. The soils are generally well-drained sandy loam (Dudu, 2014).

2.2 Sampling Procedure

A multi-stage sampling technique was used. Two LGAs were selected from each emirate: Yauri and Shanga (from Yauri Emirate), and Zuru and Danko Wasagu (from Zuru Emirate). From each LGA, four villages were selected, and from each village, three composite soil samples were collected, resulting in a total of 48 composite samples.

2.3 Analytical Techniques

The processed soil samples were analyzed for heavy metals. Ten grams of soil were shaken with 20 mL of extracting solution (0.005M DTPA, 0.01M $CaCl_2$, and 0.1 TEA buffered at 7.3). The filtrate was analyzed for Cd, Cu, Fe, Mn, Pb, and Zn using an Atomic Absorption Spectrophotometer (AAS) as recommended by Peter *et al*. (2011).

2.4 Data Analysis

The data obtained were subjected to Analysis of Variance (ANOVA) using SPSS. Mean differences were separated using Duncan's New Multiple Range Test (DMRT) at a 5% probability level.

3. Results and Discussion

3.1 Comparative Heavy Metal Concentrations Across the Four LGAs

Table 1: Mean Values of Heavy Metals from Selected Four (4) Local Government Areas of Southern Kebbi State

LGA	Cd (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Zuru	3.000a	0.0434a	15.981ab	1.8527a	0.1727a	0.0544b
D/Wasagu	3.0825a	0.0735a	16.789a	4.0956a	0.2125a	0.1905b
Yauri	2.8325a	0.0623a	13.990b	3.2244a	0.1705a	0.2491b
Shanga	4.0350a	0.0596a	14.982ab	2.2126a	0.1677a	0.7283a
Overall Mean	**3.2375**	**0.0597**	**15.435**	**2.8463**	**0.1808**	**0.3056**
Sig.	**NS**	**NS**	*****	**NS**	**NS**	*****

*Means having different letter(s) along the same column differed significantly ($p < 0.05$). NS = Not Significant; * = Significant at 5% level.*

3.2 Discussion of Spatial Variability

Cadmium (Cd): The results showed no significant difference ($p > 0.05$) in Cd concentration across the four LGAs. However, Shanga LGA recorded the highest mean value of 4.0350 mg/kg, followed by Danko Wasagu (3.0825 mg/kg), Zuru (3.000 mg/kg), and Yauri (2.8325 mg/kg). The overall mean concentration of 3.2375 mg/kg exceeded the NESREA standard of 3.00 mg/kg. The high Cd content across all LGAs could be attributed to the prolonged use of phosphate fertilizers, mining activities, and sewage sludge application (Campbell, 2006). The uniformity of Cd distribution suggests a common source, likely agricultural inputs, affecting the entire region.

Copper (Cu): There was no significant difference ($p > 0.05$) in Cu concentration among the LGAs. Danko Wasagu recorded the highest value (0.0735 mg/kg), followed by Yauri (0.0623 mg/kg), Shanga (0.0596 mg/kg), and Zuru (0.0434 mg/kg). All values were well below the NESREA and WHO maximum permissible limit of 36 mg/kg. The low Cu levels are typical of sandy soils and are essential for plant growth as a micronutrient (Augie, 2020).

Iron (Fe): Significant differences ($p < 0.05$) were observed in Fe concentration across the LGAs. Danko Wasagu recorded the highest mean value (16.789 mg/kg), which was statistically similar to Zuru (15.981 mg/kg) and Shanga (14.982 mg/kg), but significantly higher than Yauri (13.990 mg/kg). The values are within the WHO maximum permissible limit of 20 mg/kg. The variability in Fe could be linked to differences in soil parent material and local geological formations (Arvind, 2015).

Manganese (Mn): No significant difference ($p > 0.05$) was found in Mn concentration among the LGAs. Danko Wasagu recorded the highest value (4.0956 mg/kg), followed by Yauri (3.2244 mg/kg), Shanga (2.2126 mg/kg), and Zuru (1.8527 mg/kg). All values were far below the WHO limit of 2000 mg/kg. The results are consistent with Onwudike *et al*. (2016), who reported 3.13 mg/kg in River State soils.

Lead (Pb): There was no significant difference ($p > 0.05$) in Pb concentration across the LGAs. Danko Wasagu recorded the highest value (0.2125 mg/kg), followed by Zuru (0.1727 mg/kg), Yauri (0.1705 mg/kg), and Shanga (0.1677 mg/kg). All values were well below the NESREA standard of 40 mg/kg, indicating minimal contamination from atmospheric deposition or industrial waste (Mohammad *et al*., 2023).

Zinc (Zn): Significant differences ($p < 0.05$) were observed in Zn concentration across the LGAs. Shanga LGA recorded the highest mean value (0.7283 mg/kg), which was significantly higher than Yauri (0.2491 mg/kg), Danko Wasagu (0.1905 mg/kg), and Zuru (0.0544 mg/kg). The elevated Zn in Shanga could be attributed to local agricultural practices or the use of Zn-based fertilizers and pesticides. All values were below the WHO limit of 50 mg/kg (Mustapha and Abdullahi, 2010).

4. Conclusion and Recommendations

4.1 Conclusion

The comparative assessment of heavy metals across the four LGAs in southern Kebbi State revealed that while Cd, Cu, Mn, and Pb concentrations were statistically similar across the region, significant spatial variability existed for Fe and Zn. Danko Wasagu had the highest Fe concentration, while Shanga recorded the highest Zn concentration. Notably, the overall mean concentration of Cd (3.2375 mg/kg) exceeded the NESREA standard of 3.00 mg/kg in all LGAs, with Shanga recording the highest value (4.0350 mg/kg). This indicates a region-wide contamination issue that requires immediate attention.

4.2 Recommendations

1. **Site-Specific Remediation:** Remediation efforts should be prioritized in Shanga LGA due to its elevated Cd and Zn levels. Phytoremediation using hyperaccumulator plants and soil amendment with biochar or lime should be considered.
2. **Source Identification:** Further research should be conducted to identify the specific sources of Cd contamination in the region, particularly in Shanga and Danko Wasagu LGAs.
3. **Regular Monitoring:** A permanent soil monitoring network should be established across the four LGAs to track changes in heavy metal concentrations over time.
4. **Farmer Education:** Farmers should be educated on the risks associated with excessive use of phosphate fertilizers and the importance of adopting organic farming practices to reduce heavy metal accumulation.

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