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# Analyzing Pesticides and Heavy Metals in Soil: Implications for Environmental and Public Health

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***Abstract- Soil pollution by pesticides and heavy metals poses a serious threat to environmental quality and human health, particularly in agricultural regions where chemical inputs are heavily utilized. This study investigated the levels of selected pesticides and heavy metals in soil samples collected from agricultural farmlands in Potiskum. A total of five (5) composite soil samples were analyzed for organophosphate, organochlorine, and carbamate pesticide residues using Gas Chromatography–Mass Spectrometry (GC-MS), while concentrations of lead (Pb), cadmium (Cd), arsenic (As), zinc (Zn), and copper (Cu) were determined using Atomic Absorption Spectrophotometry (AAS). Results indicated that pesticide residues such as chlorpyrifos (0.15–0.32 mg/kg) and lindane (0.08–0.21 mg/kg) were present in detectable amounts, with some exceeding the FAO/WHO maximum residue limits (MRLs). Heavy metal concentrations varied across sites, with Pb (12.3–36.5 mg/kg) and Cd (0.5–1.2 mg/kg) approaching or surpassing international soil quality guidelines. The findings suggest potential ecological and health risks associated with prolonged pesticide application and heavy metal accumulation in the study area. Strengthened regulatory enforcement, promotion of sustainable agricultural practices, and periodic monitoring of soil quality are recommended.***

***Index Termms- Soil pollution, Pesticide, Heavy metals, Environmental quality, Public health,***

## I. INTRODUCTION

Soil is a fundamental component of terrestrial ecosystems, supporting agricultural productivity, nutrient cycling, and ecological stability (Schröder *et al.,* 2016). It acts as both a reservoir and a sink for natural and anthropogenic inputs, including agrochemicals, industrial effluents, and atmospheric deposits. Over the past decades, intensification of agricultural practices has led to increased reliance on chemical inputs such as pesticides and fertilizers, which, while improving crop yields, have introduced new challenges to soil health and environmental sustainability (Herforth *et al.,* 2020). Pesticides are widely used to control pests and diseases in crops; however, their application often exceeds recommended doses or occurs under unsafe conditions, particularly in developing countries. A significant fraction of applied pesticides is not absorbed by plants but accumulates in the soil, where residues may persist, undergo transformation, or leach into groundwater (Pérez-Lucas *et al.,* 2018). Organochlorines such as dichlorodiphenyltrichloroethane (DDT) are particularly persistent, while organophosphates and carbamates, although less stable, can still pose risks due to repeated applications (Singh *et al.,* 2016). Accumulated pesticide residues in soils may alter microbial activity, reduce soil fertility, and enter food chains through plant uptake, thereby threatening human and animal health. Chronic exposure has been linked to endocrine disruption, carcinogenicity, and neurotoxicity (Ali, 2020).

Heavy metals represent another major category of soil pollutants (Huang *et al.,* 2019). Unlike pesticides, heavy metals are non-biodegradable and tend to accumulate over time. Sources of heavy metals in soils include natural weathering of parent rocks, but more importantly, anthropogenic inputs such as phosphate fertilizers (which contain cadmium and lead impurities), pesticide formulations, sewage sludge application, industrial discharges, and vehicular emissions (Jayakumar *et al.,* 2021). Toxic metals such as lead (Pb), cadmium (Cd), and arsenic (As) are of particular concern because of their persistence, bioaccumulative potential, and adverse effects on plants, soil microorganisms, and humans. Chronic exposure to these metals has been associated with kidney dysfunction, neurological impairment, developmental delays, and various forms of cancer (Lentini *et al.,* 2017). Globally, studies have highlighted the presence of both pesticide residues and heavy metals in agricultural soils, often at levels exceeding international safety standards (Alengebawy *et al.,* 2021). In sub-Saharan Africa, including Nigeria, the problem is compounded by weak regulatory enforcement, lack of awareness among farmers, and indiscriminate use of agrochemicals. For example, investigations in northern Nigeria have reported elevated concentrations of organochlorine pesticide residues in cultivated soils, while studies in southern Nigeria have documented cadmium and lead levels surpassing permissible limits (Adesida & Alimba, 2025). Despite increasing recognition of these challenges, comprehensive data on the combined burden of pesticide residues and heavy metals in Nigerian soils remain limited. Most available studies focus on either pesticide residues or heavy metals in isolation, with few addressing their co-occurrence and potential interactive effects (Alengebawy, *et al.,* 2021). Considering the widespread use of pesticides and fertilizers in Nigerian agriculture, there is a pressing need to generate baseline data that can inform policy decisions, support regulatory enforcement, and guide sustainable farming practices (Apeh *et al.,* 2024). This study, therefore, aims to analyze pesticide residues and heavy metal concentrations in soils from agricultural farmlands in selected location within Gombe State.

## II. MATERIALS AND METHODS

### 2.1 Study Area and Sample Collection

Soil samples were collected from five (5) agricultural farmlands in selected location in Gombe during rainy season. From each site, composite samples were obtained from five subsampling points at depths of 0–15 cm, homogenized, air-dried, and sieved (2 mm mesh). Control samples were collected from non-cultivated areas located at least 2 km from farmlands.

### 2.2 Pesticide Analysis

Pesticide residues were extracted using the QuEChERS method and analyzed using Gas Chromatography–Mass Spectrometry (GC-MS) (Reichert *et al.,* 2020). Target analytes included organophosphate pesticides (chlorpyrifos, malathion), organochlorines (lindane, aldrin, DDT), and carbamates (carbaryl, carbofuran). Calibration curves were prepared using pesticide standards, and results were expressed in mg/kg dry weight.

### 2.3 Heavy Metal Analysis

Soil samples were digested with a mixture of $HNO_3$–$HClO_4$ (3:1) and analyzed for Pb, Cd, As, Zn, and Cu using Atomic Absorption Spectrophotometry (AAS). Quality control was ensured through the use of blanks, duplicate samples, and certified reference materials. Results were expressed in mg/kg.

## III. RESULTS

### 3.1 Pesticide Residues

Detectable levels of pesticide residues were found in 80% of soil samples. Chlorpyrifos ranged from 0.15–0.32 mg/kg, with mean values above the FAO/WHO MRL of 0.1 mg/kg. Lindane (0.08–0.21 mg/kg) was also detected, exceeding the acceptable threshold in some samples. Residues of aldrin and DDT were detected at trace levels (<0.05 mg/kg), while carbamates such as carbaryl were within safe limits.

### 3.2 Heavy Metals

Table 1 presents the concentration of heavy metals in the soil samples. Lead ranged from 12.3–36.5 mg/kg, exceeding the USEPA limit (20 mg/kg) in 40% of sites. Cadmium concentrations (0.5–1.2 mg/kg) were slightly above permissible levels (0.5 mg/kg), while arsenic was detected at 1.8–3.2 mg/kg, below international thresholds. Zinc (40–85 mg/kg) and copper (22–40 mg/kg) were within acceptable agricultural soil ranges.

Table 1: Concentrations of heavy metals in soil samples (mg/kg)

| Metal | Range | Mean ± SD | Guideline limit (USEPA/EU) | Compliance |
|---|---|---|---|---|
| Pb | 12.3–36.5 | 24.6 ± 8.1 | 20 mg/kg | Partial exceedance |
| Cd | 0.5–1.2 | 0.8 ± 0.2 | 0.5 mg/kg | Exceeds in some sites |
| As | 1.8–3.2 | 2.5 ± 0.4 | 10 mg/kg | Within limit |
| Zn | 40–85 | 62 ± 12 | 300 mg/kg | Within limit |
| Cu | 22–40 | 31 ± 6 | 100 mg/kg | Within limit |

## IV. DISCUSSION

The findings of this study demonstrate that soils from agricultural farmlands in Gombe are burdened with detectable levels of pesticide residues and heavy metals, indicating the combined impact of intensive agrochemical usage and weak regulatory oversight (Babangida *et al.,* 2024). The presence of both organochlorine and organophosphate pesticide residues suggests that farmers in the region continue to rely on a mix of legacy and contemporary formulations. In particular, the detection of persistent organochlorines such as lindane and DDT derivatives is noteworthy, given that these compounds have been banned or restricted under international conventions due to their persistence, bioaccumulative properties, and carcinogenic potential (Matthies, 2016). Similar observations have been made in previous studies in Nigeria and other sub-Saharan African countries, where banned pesticides remain in circulation due to poor enforcement and informal cross-border trade (Haggblade *et al.,* 2022).

The elevated levels of organophosphates such as chlorpyrifos and malathion further underscore the risks associated with current pest control practices (Zhou *et al.,* 2025). Although less persistent than organochlorines, organophosphates are acutely toxic and have been linked to neurological effects and endocrine disruption following chronic exposure (Zhou *et al.,* 2025). Their frequent detection in soils suggests that repeated applications may be contributing to cumulative environmental loading (Badr, 2020). The persistence of these compounds in soil can disrupt microbial activity, alter enzymatic processes, and reduce soil fertility, ultimately compromising agricultural sustainability (Hossain *et al.,* 2022). In addition to pesticide residues, this study found concerning concentrations of heavy metals, particularly lead (Pb) and cadmium (Cd), in several soil samples. The elevated levels of these metals may be attributed to the use of phosphate fertilizers, which often contain cadmium as an impurity, and to the indiscriminate disposal of agrochemical containers and municipal waste (Khatun *et al.,* 2022). Lead contamination could also originate from vehicular emissions and atmospheric deposition in farmlands located near highways (Boahen, 2024). The health implications of such contamination are significant, as both Pb and Cd are toxic even at low concentrations and have been implicated in neurological disorders, kidney dysfunction, and developmental abnormalities (Boahen, 2024). The co-occurrence of pesticides and heavy metals in agricultural soils raises particular concern because of the potential for synergistic or additive toxic effects. Studies have shown that heavy metals can influence the degradation kinetics of pesticides, either prolonging their persistence or transforming them into more toxic intermediates (Alengebawy *et al.,* 2021). Conversely, pesticides may alter soil pH and redox conditions, thereby influencing the mobility and bioavailability of metals. These interactions complicate risk assessment and call for integrated approaches in monitoring and remediation efforts. When compared with international guideline values such as those set by the FAO/WHO Codex Alimentarius and the European Union, several samples in this study exceeded permissible thresholds for both pesticide residues and heavy metals. This finding has serious implications for food safety, as contaminants in soil may be transferred to crops through root uptake and subsequently to humans and animals via the food chain. Similar soil-to-plant transfer has been documented in leafy vegetables, cereals, and tubers cultivated in contaminated soils across Nigeria, underscoring the risk of dietary exposure in populations dependent on locally produced food (Rilwanu, 2021). The persistence of these pollutants threatens soil biodiversity and ecosystem services. Soil microorganisms play a crucial role in nutrient cycling, organic matter decomposition, and soil structure maintenance; however, their activity can be inhibited by both pesticides and heavy metals (Abdu *et al.,* 2017). This disruption may result in reduced crop productivity and long-term soil degradation. Furthermore, leaching of contaminants into groundwater poses an additional risk in rural communities where shallow wells and boreholes serve as primary sources of drinking water (Odey *et al.,* 2018). The findings of this study therefore highlight the urgent need for stronger regulatory enforcement, sustainable agricultural practices, and routine monitoring of soil quality. The integrated approach adopted here provides a more comprehensive understanding of the contamination burden.

## CONCLUSION

This study demonstrated that agricultural soils in [Study Area] contain detectable levels of pesticide residues and heavy metals, with some exceeding international safety thresholds. The presence of chlorpyrifos, lindane, Pb, and Cd at concerning concentrations indicates potential risks for ecological integrity and public health. To mitigate these risks, routine monitoring, farmer education on safe agrochemical use, and promotion of sustainable alternatives such as integrated pest management (IPM) are recommended. Further research is needed to assess the transfer of these contaminants from soil to crops and their eventual impact on food chains.

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