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Pesticide Residue Levels in Soil, Water, and Vegetables: A Comparative Study of Alau and Gongolong Irrigation Sites, Maiduguri, Borno State, Nigeria

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Abstract **Original Research Article**

The swift surge in population and increasing demand for food security, particularly in developing countries, has led to an upsurge in pesticide use to enhance agricultural productivity and control pests. This trend signals potential environmental contamination. This study aims to determine and compare pesticide residues in soil samples and selected vegetables from Alau and Gongolong irrigation sites. Soil samples were collected from randomly selected farmlands at 20cm depth, with triplicate composite samples (each comprising 13 subsamples) taken from each site for pesticide residue analysis. Composite samples of spinach, sorrel, and okra were collected from Alau and Gongolong irrigation sites, with each composite consisting of 13 subsamples and replicated three times (A, B, and C). Pesticide residue in samples was analyzed using GC-MS, and statistical analysis was performed using SPSS version 24. The results are presented as mean ± standard error of the mean (SEM). One-way analysis of variance (ANOVA) was used to compare means, followed by the Least Significant Difference (LSD) test at $P < 0.05$. Naphthalene (Gongolong 0.403±0.03 and Alau 1.290±0.13), phenanthrene (Gongolong 0.377±0.06 and Alau 0.000±0.00), dichlorvos (Gongolong 5.347±0.26 and Alau 9.063±0.45), dimethoate (Gongolong 0.000±0.00 and Alau (1.147±0.11), chlorpyrifos (Gongolong 2.930±0.15 and Alau 72.708±3.64), cyhalothrin (Gongolong 0.000±0.00 and Alau 0.447±0.03), 9H-Fluorene (Gongolong 0.030±0.00 and Alau 0.040±0.00) were detected in soil samples from both areas, with higher concentrations mostly detected in Alau. Chlorpyrifos was detected in okra from Alau and Gongolong (12.99 ± 0.65) and (0.305 ± 0.02), respectively. And in spinach at Gongolong (0.203 ± 0.01), while Cypermethrin was detected in okra from Alau (2.012 ±0.10). On the other hand, Phenanthrene was detected in sorrel at Alau (0.008 ± 0.00). Dichlorvos and Dimethoate in sorrel at Alau (0.020±0.00) and (0.033 ± 0.00), respectively. The results indicate higher pesticide residues in soils and vegetables from Alau compared with Gongolong, highlighting the need for continued monitoring and testing to ensure safety.

Keywords: Alau, Gongolong, Pesticides, Residues, GC-MS, Soil and Vegetables.

Introduction

In many developing countries, the excessive and improper application of pesticides, particularly during fruiting and pre-harvesting stages, has resulted in significant pesticide residue accumulation in vegetables and fruits. Studies have consistently shown that fruits and vegetables in these countries are contaminated with pesticide residues, posing potential health risks to consumers (Bansal 2025). Population growth is one of the major factors that necessitate more agricultural activities to provide food and other materials, which leads to the high application of pesticides to boost production and control pests (Quandahor *et al*., 2024). Although the food supply was tripled due to the Green Revolution, food was still insufficient to feed the world's expanding population. Improved crop types have contributed to higher yields in part, but better management practices and the use of agrochemicals, pesticides, and fertilizers have been the main drivers (Pandya, 2018). Pesticide compounds primarily from organophosphate, organochlorine, carbamate, and Pyrethroid derivatives have been shown to bioaccumulate in the food chain (Samadi *et al*., 2009). The physicochemical properties of the pesticides influence the fate of pesticides in soil and water systems, including soil texture, organic matter, pH, biological properties, and other factors (Paras *et al*., 2024). These compounds form the backbone of agricultural production, but some can persist in the soil or vegetables and fruits (Tudi *et al*., 2021). Environmental pollution by pesticides has been identified as one of the major environmental impacts of agriculture (Özkara *et al*., 2016). Pesticide use in agriculture increased after World War II to boost global food production, leading to the development of diverse pesticide types. However, this increased use, combined with industrial emissions during production, has resulted in widespread contamination of the environment, including air, water, soil, crops, vegetables, and fruits. Organophosphorus pesticides are among the most used agricultural pesticides (El-Sheikh *et al*., 2022). Pesticides can contaminate soil and water through various means, including direct application to the soil, drifting from crop spraying, or runoff during rainfall, posing a significant environmental risk (Paras *et al*., 2024). Plants can absorb pesticide residues from the soil, leading to contamination. The amount of pesticide absorbed depends on factors like the pesticide's water solubility, soil concentration, and organic matter content. Persistent residues can lead to increased accumulation in plants over time (Akan *et al*., 2013). Pesticide residue levels in crops are directly linked to farm pesticide usage intensity. Hence, the need for Government and private laboratories around the world is to monitor the levels of pesticide residues (Ma *et al*., 2022). The World Health Organization recommends consuming at least 400 grams of fruits and vegetables daily for optimal health. However, the increasing demand for these nutrient-rich foods has led to higher pesticide use in agriculture, particularly at irrigation sites, posing potential health risks to consumers (Goldberg 2008). The growing demand for food crops, both locally and for export, has led to increased pesticide use in farming to mitigate insect damage. However, organophosphate pesticides persist in the environment, bioaccumulate in living tissues and food chains, and ultimately harm human health and the environment (Bansal 2025). Among various pesticide classes, the organophosphorus (OPPs) group is the most widely used class of agricultural pesticides (El-Sheikh *et al*., 2022). Pests contribute significantly to food losses, and the control of pests is central to achieving food security at all spatial levels. Pesticides are extensively used in agricultural production to check or control pests, diseases, weeds, and other plant pathogens to reduce or eliminate yield losses and preserve high product quality (Ali *et al*., 2023). Although pesticides are manufactured under stringent regulatory processes to function with logical certainty and minimal impact on human health and the environment, serious concerns have been raised about health risks resulting from residues in food (Eskenazi *et al*., 2008). By their very nature, most pesticides show a high degree of toxicity because they are intended to kill certain organisms and thus create some risk of harm (Abdelgadirand and Adam, 2011). Within this framework, pesticide use has evoked grave concerns not only about potential effects on human health but also about impacts on wildlife and sensitive ecosystems (Ali *et al*., 2023). Wrong application techniques, coupled with badly maintained unsuitable spraying equipment, and inadequate storage practices, exacerbate these risks (Al-Wabel *et al*., 2011). Often, the reuse of old pesticide containers for food and water storage also contributes to the risk of exposure. However, pesticide residues in plants may be unavoidable even when pesticides are used following good agricultural practices. Furthermore, pesticide residues constitute a danger to the microfauna and microflora of the soil Ali *et al*., (2023), and their toxic effects manifest themselves in humans when bioaccumulation occurs along the food chain after initial plant uptake (Akan *et al*., 2013). Plant root uptake of persistent residues is a common form of plant contamination. The quantity of pesticides absorbed by a given plant generally depends upon the water solubility of the pesticide, the quantity of pesticide within the soil, and the organic matter content of the soil. The total amount absorbed by a single plant increases with time if the residue is persistent (Akan *et al*., 2013). For nonpolar pesticides, soil organic matter is the most important soil factor influencing the sorption of residues. The hazard posed by pesticide residues in the plant depends on the toxicity of the residue, the ability of the plant to metabolize or eliminate the residue before it is harvested, and the translocation of the residue to the harvested portions of the plant. Non-phytotoxic residues in the plant pose a greater threat to consumers than the phytotoxic ones because the latter type makes the plant sick and identifiable. Bioaccumulation of a contaminant occurs within each organism and each food chain. In the grazing food chain, the lipophilic contaminants could pass on from herbivores to carnivores, and in the detritus food chain, from dead organic matter into micro and macro-organisms and then to detritus-feeding organisms and their predators. Each time a lower food chain organisms are consumed by a higher food chain organism, the pesticide residues could largely be retained by the consuming organism (Leskovac and Petrović, 2023).

The study aimed to quantify and compare pesticide residues in soil and three staple vegetables spinach, okra, and sorrel collected from the Alau and Gongolong irrigation schemes. While previous work has examined residues in cabbage, lettuce, onion and tomato, this research fills a gap by simultaneously assessing soil and multiple vegetable types across two distinct irrigation areas, and by focusing on crops that are cheaper in price and dominate the diet of Maiduguri residents. Our results show consistently higher residue levels in Alau’s soils and vegetables than in Gongolong, revealing spatial variability that earlier surveys missed and establishing a baseline for ongoing monitoring.

Materials and Methods

Study Area

Alau Dam is located in Konduga LGA, Borno State, North-eastern Nigeria. The Dam is 9 m high with a square reservoir area of about 50 km^2, with a maximum storage capacity is 112 Mm^3. Lake Alau is a significant water body in northeastern Nigeria, built in 1987 on the Nggada River to provide drinking water to Maiduguri and support over 8,000 hectares of farmland in the Lake Chad Basin Development Authority's catchment area of the Lake Chad Basin Development Association (CBDA, 1984). It lies at a latitude of 11º41N and a longitude of 13º16E in the southeast (SE) part of Maiduguri town at 16 km from Maiduguri. The lake has a surface area of 56,000.00 hectares, a total storage capacity of 9.50 million cubic meters, active storage capacity of 1.12×10^8 m^3. The height of the lake is about 540 meters, with crest length and crest elevation of 31.0 m and 331.50 m, respectively (CBDA, 1987; Mshelia *et al*., 2015).

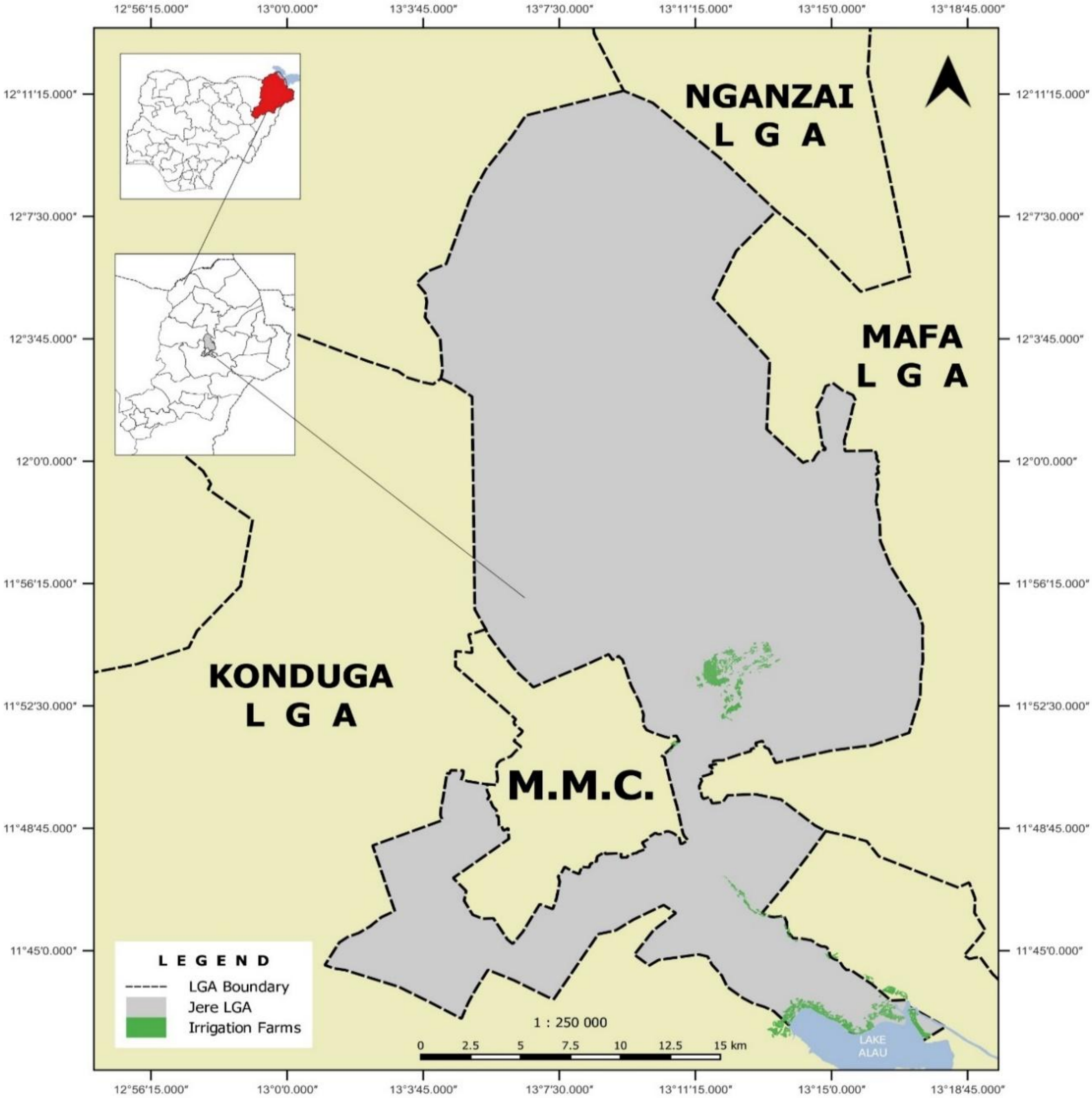

Figure 3.3 : Jere Local Government Area showing Irrigation Farms.
Source : Department of Urban and Regional Planning,Faculty of Environmental Studies,University of Maiduguri (2023).

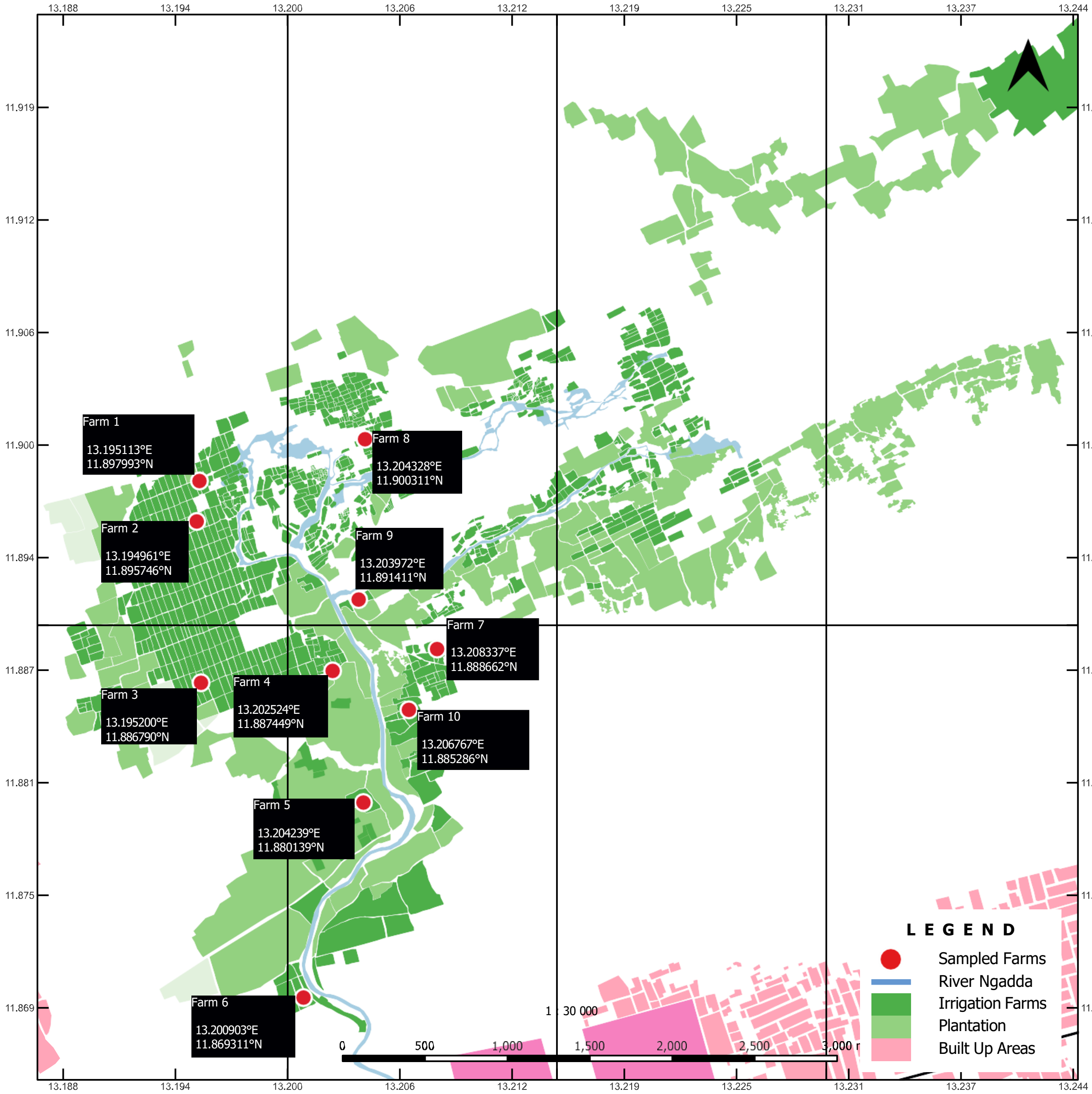

Figure 3.1: Gongulong Irrigation Farms.
Source: Department of Urban and Regional Planning Studio, Faculty of Environmental Studies, University of Maiduguri (2023).

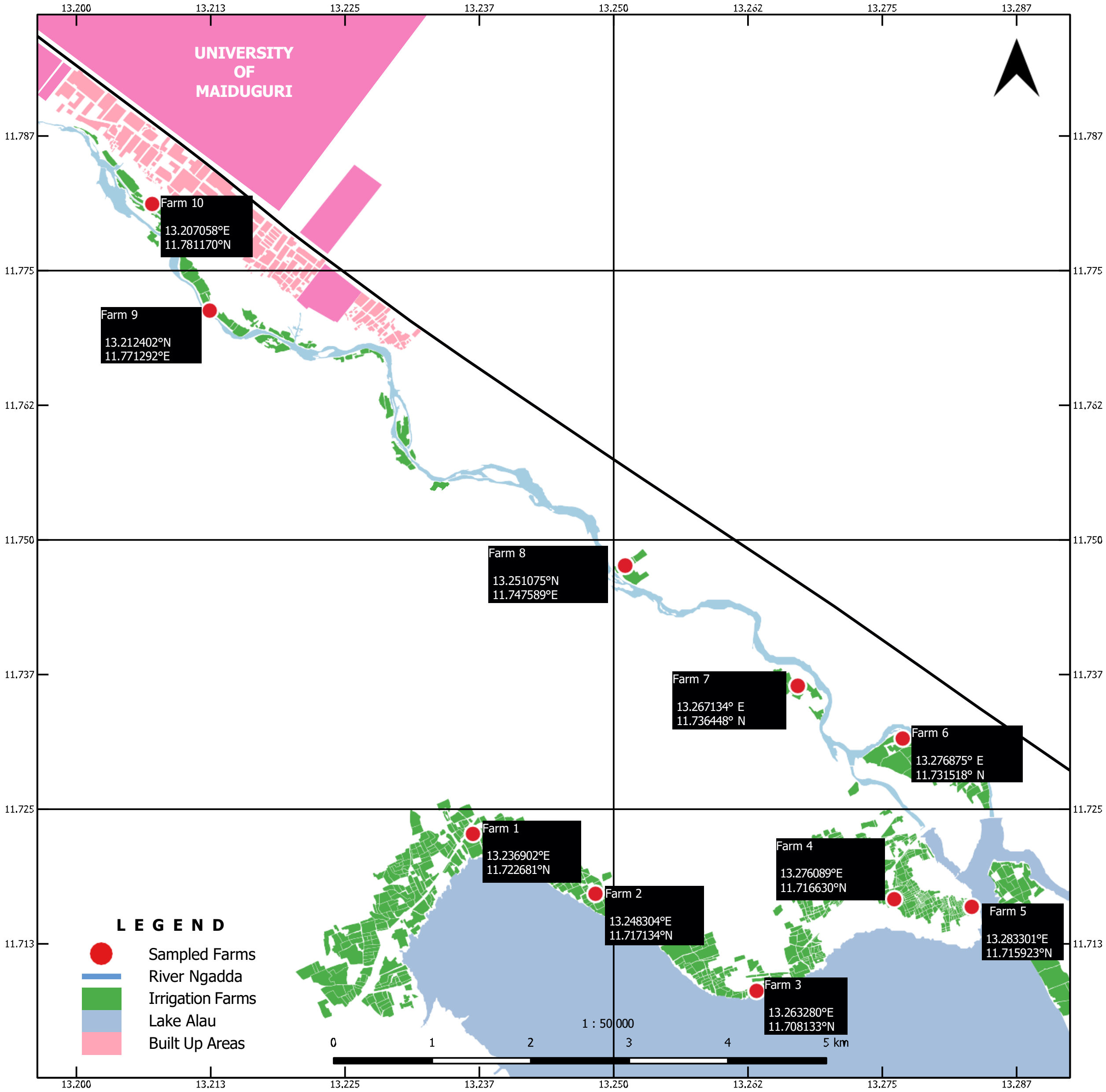

Figure 3.2: Alau Irrigation Farms.
Source: Department of Urban and Regional Planning Studio, Faculty of Environmental Studies, University of Maiduguri (2023).

Sample Size Determination and Procedure

The sample size was determined using Cochran's Formula (EPA 2002).

Cochran's Formula:

$$n = (Z\alpha/2)^2 * (CV^2 / (d^2 * m))$$

where:

- n = number of composite samples needed
- $Z\alpha/2$ = critical value (e.g., 1.96 for 95% confidence)
- CV = coefficient of variation (σ / mean)

- d = desired margin of error (e.g., 0.10 for ±10%)
- m = number of subsamples per composite

Where

- $Z\alpha/2$ = 1.96 (95% CI)
- CV = 0.3
- m = 13 subsamples per composite
- d = 0.10 (±10% margin of error)

Where

$n = (1.96)^2 * (0.3^2 / (0.10^2 * 13))$

$= 3.8416 * (0.09 / (0.01 * 13))$

$= 3.8416 * (0.09 / 0.13)$

$= 3.8416 * 0.6923$

≈ 2.66

Since n ≈ 2.66, I rounded it up to ensure adequacy → n = 3 composites

Soil Sample Collection

Soil samples were collected at a depth of 20 cm using a spiral soil auger (2.5 cm diameter) and a hand spade, following a systematic "W" shaped pattern in randomly selected farmlands, as per the method described by Rahman and Zaim (2015). Triplicate composite samples were collected from Alau and Gongolong irrigation sites, each comprising 13 homogenized subsamples, and transported to the laboratory on ice for analysis. The samples were transported to the Chemistry Research Laboratory, Department of Chemistry, Yobe State University, Damaturu.

Vegetable Sample Collection

Triplicate composite samples of spinach, sorrel, and okra were collected from two irrigation sites (Alau and Gongolong). At each site, 13 subsamples of each vegetable were collected and homogenized to form a composite sample, resulting in a total of three composite samples per vegetable per site (A, B, and C). Approximately 20 g of each composite sample was collected and stored in clean, labeled polyethylene bags (Akan *et al.*, 2013). The samples were transported to the Chemistry Research Laboratory at Yobe State University, Damaturu, in a cooled condition and preserved in a refrigerator at 4°C until analysis.

Extraction of Vegetable Samples

Pesticide residues were extracted from non-fatty crops using USEPA Method 3510 with ethyl acetate as the solvent. Samples were treated with sodium bicarbonate and anhydrous sodium sulphate to remove water and neutralize acidity. The extracts were filtered, centrifuged, and mixed with ethyl acetate and cyclohexane (Radojevic and Bashkin, 1999; Tadeo, 2022).

Cleaning up of Vegetable Extracts

Vegetable extracts were purified using a silica gel chromatographic column, eluted with n-hexane, and stored in sealed vials at controlled temperature (Akan et al., 2013).

Extraction of Soil Samples

Soil samples (25 g) were mixed with pre-cleaned sand and sodium sulfate, then extracted with acetone:hexane (1:1 v/v) using a bulb column. The extract was concentrated to 100 mL and subjected to further clean-up (Akan *et al.*, 2013).

Cleaning up of Soil Extracts

Soil eluates were extracted using liquid-liquid partitioning with saturated sodium sulfate and distilled water, followed by re-extraction with 15% dichloromethane in hexane. The organic layer was washed, filtered through sodium sulfate, and concentrated to 2 ml in hexane via rotary evaporation and nitrogen evaporation (Rahman and Zaim, 2015). The final extract was analyzed by Gas Chromatography.

Determination of Pesticide Residues

The analysis was performed using an Agilent GC 7890B/MSD 5977A Gas Chromatography-Mass Spectrometry (GC-MS) system equipped with a 35% diphenyl, 65% dimethyl polysiloxane column. The GC oven temperature program was set as follows: initial temperature 40°C for 1.5 minutes, ramped to 150°C at 5°C/min (held for 15 minutes), then to 200°C at 5°C/min (held for 7.5 minutes), and finally to 290°C at 25°C/min with a 12-minute hold. The column flow rate was maintained at 1 mL/min. Detection was carried out using GC-ion trap MS in MS/MS mode, offering enhanced selectivity compared to full scan or Selected Ion Monitoring (SIM) modes. This approach improves accuracy, particularly at lower pesticide concentrations, by minimizing interference from matrix ions. The GC-MS/MS analysis involved injecting ions into the ion trap, selectively isolating pesticide ions while destabilizing matrix ions. Quantification was achieved by comparing the retention time, peak area, and peak height of the samples with those of known standards (Akan *et al*., 2013). Method validation parameters were: Method Detection Limit (MDL) of 10-50 ppb, Limit of Quantification (LOQ) of 50-100 ppb, recoveries of 80-110% for spiked samples, and used procedural blanks and certified reference materials for quality control. This study was carried out in the Chemistry Research Laboratory at Yobe State University, Damaturu.

Note that 1 mg/kg is equivalent to 1 ppm (part per million), and 1 ppb (part per billion) is equivalent to 0.001 mg/kg or 1 µg/kg.

Data Analysis

Statistical analysis of pesticide residue data was performed using SPSS version 24. (Mean ± SEM) An analysis of variance (ANOVA) was applied, followed by the Least Significant Difference (LSD) test for mean separation. A significance level of $P < 0.05$ was adopted.

Results

Comparison of Pesticide Concentrations (ppb) in Soil Samples of Gongolong and Alau Areas

This analysis compares pesticide concentrations in soil samples from Gongolong and Alau, revealing detectable residues of various pesticides in both areas. The findings indicate higher pesticide residues in Alau compared to Gongolong, with minor disparities in concentrations of specific pesticides.

Table 1 results show that pesticide residues were detected in soil samples from both the Gongolong and Alau areas. Naphthalene (Gongolong 0.403±0.03 and Alau 1.290±0.13), phenanthrene (Gongolong 0.377±0.06 and Alau 0.000±0.00), dichlorvos (Gongolong 5.347±0.26 and Alau 9.063±0.45), dimethoate (Gongolong 0.000±0.00 and Alau (1.147±0.11), chlorpyrifos (Gongolong 2.930±0.15 and Alau 72.708±3.64), cyhalothrin (Gongolong 0.000±0.00 and Alau 0.447±0.03), 9H-Fluorene (Gongolong 0.030±0.00 and Alau 0.040±0.00) were detected in soil samples from both areas, with higher concentrations mostly detected in Alau.

Table 1: Comparison of Pesticide Concentrations (ppb) in Soil Samples of Gongolong and Alau Areas

Chemical parameters	Location	$Mean \pm SE$	Significant level
Naphthalene, 1-methyl	Gongolong	0.403 ± 0.03	0.001
	Alau	1.290 ± 0.13	
Phenanthrene	Gongolong	ND	ND
	Alau	0.377 ± 0.06	
Altrazine	Gongolong	ND	ND
	Alau	ND	ND
Dichlorvos	Gongolong	5.347 ± 0.26	0.001
	Alau	9.063 ± 0.45	
Dimethoate	Gongolong	ND	ND
	Alau	1.147 ± 0.06	0.001
Imidacloprid	Gongolong	ND	ND
	Alau	ND	ND
Paraquat dichloride	Gongolong	ND	ND
	Alau	ND	ND
Lindane	Gongolong	ND	ND
	Alau	ND	ND
Quintozene	Gongolong	ND	ND
	Alau	ND	ND
Chlorpyrifos	Gongolong	2.930 ± 0.15	0.001
	Alau	72.71 ± 3.64	
p,p'-DDT	Gongolong	ND	ND
	Alau	ND	ND
Aldrin	Gongolong	ND	ND
	Alau	ND	ND
Heptachlor	Gongolong	ND	ND
	Alau	ND	

Table 4.1: Comparison of Pesticide Concentrations (ppb) in Soil Samples of Gongolong and Alau Areas

Chemical parameters	Location	$Mean \pm SE$	Significant level
Pyrazophos	Gongolong	ND	ND
	Alau	ND	ND
Dieldrin	Gongolong	ND	ND
	Alau	ND	ND
Endrin	Gongolong	ND	ND
	Alau	ND	ND
Endosulfan	Gongolong	ND	ND
	Alau	ND	ND
Cypermethrin	Gongolong	ND	ND
	Alau	ND	ND
Cyhalothrin	Gongolong	ND	ND
	Alau	0.447 ± 0.03	0.001
lambda-Cyhalothrin	Gongolong	ND	ND
	Alau	ND	ND
9H-Fluorene, 9-methylene-	Gongolong	0.030 ± 0.00	0.001
	Alau	0.040 ± 0.00	ND

ND=Not Detected, SE=Standard Error

Comparison of Pesticide Concentration (ppb) in Vegetable Samples of Gongolong and Alau Areas

This analysis compares pesticide concentrations in vegetable samples from Gongolong and Alau, revealing detectable residues of a few pesticides, with higher concentrations and frequencies observed in Alau samples. The findings aim to assess pesticide residues in vegetables.

Table 2 reveals that pesticide residues in vegetables from both locations were generally low, with most pesticides undetected. However, some exceptions were noted. Chlorpyrifos was detected in okra from Alau and Gongolong with mean values of (12.99 ± 0.65) and (0.305 ± 0.02), respectively. It was also detected in spinach at Gongolong (0.203 ± 0.01), while Cypermethrin was detected in okra from Alau (2.012 ±0.10). The Alau had a higher concentration than Gongolong vegetables. On the other hand, Phenanthrene was detected in sorrel at Alau (0.008 ± 0.00). Dichlorvos and Dimethoate were detected in sorrel at Alau with mean values of (0.020±0.00) and (0.033 ± 0.00), respectively. The residue concentrations were higher in Alau samples with a high frequency of occurrences in sorrel, followed by okra.

Table 2: Comparison of Pesticide Concentration (ppb) in Vegetable Samples of Gongolong and Alau Areas

Chemical parameters	Location	Vegetables	$Mean \pm SE$	Significant level
Naphthalene	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Phenanthrene	Gongolong	Okra	ND	0.423
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	0.008 ± 0.00	0.423
		Spinach	ND	ND
Altrazine	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Dichlorvos	Gongolong	Okra	ND	0.423
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	0.020 ± 0.00	0.423

		Spinach	ND	ND
Dimethoate	Gongolong	Okra	ND	0.423

Table 2: Comparison of Pesticide Concentration (ppb) in Vegetable Samples of Gongolong and Alau area

Chemical parameters	Location	Vegetables	$Mean \pm SE$	Significant level
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	0.033 ± 0.00	0.423
		Spinach	ND	ND
Imidacloprid	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Paraquat dichloride	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Lindane	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Quintozene	Gongolong	Okra	ND	ND

		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND

Table 2: Comparison of Pesticide Concentration (ppb) in Vegetable Samples of Gongolong and Alau Areas

Chemical parameters	Location	Vegetables	$Mean \pm SE$	Significant level
Chlorpyrifos	Gongolong	Okra	0.305 ± 0.02	0.414
		Sorrel	ND	ND
		Spinach	0.203 ± 0.01	
	Alau	Okra	12.99 ± 0.65	0.414
		Sorrel	ND	ND
		Spinach	ND	ND
p,p'-DDT	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Aldrin	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Heptachlor	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND

		Sorrel	ND	ND
		Spinach	ND	ND
Pyrazophos	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND

Table 2: Comparison of Pesticide Concentration (ppb) in Vegetable Samples of Gongolong and Alau Areas

Chemical parameters	Location	Vegetables	$.Mean \pm SE$	Significant level
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Dieldrin	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Endrin	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
Endosulfan	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND

		Spinach	ND	ND
Cypermethrin	Gongolong	Okra	ND	0.423
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	2.012 ± 0.10	0.423
		Sorrel	ND	ND
		Spinach	ND	ND

Table 2: Comparison of Pesticide Concentration (ppb) in Vegetable Samples of Gongolong and Alau Areas

Chemical parameters	Location	Vegetables	$Mean \pm SE$	Significant level
Cyhalothrin	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
lambda-Cyhalothrin	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
9H-Fluorene, 9-methylene	Gongolong	Okra	ND	ND
		Sorrel	ND	ND
		Spinach	ND	ND
	Alau	Okra	ND	ND
		Sorrel	ND	ND

	Spinach	ND	ND

ND=Not Detected, SE=Standard Error.

Comparison between pesticide concentrations (ppb) in Water samples of Gongolong and Alau areas.

Table 3 results show that pesticide residues were detected in water samples from Alau areas, only no residues were detected in Gongolong. The following concentrations of residues were found in water samples of Alau areas: Naphthalene, 1-methyl (0.060±0.060), dichlorvos (0.020±0.030), dimethoate (3.200±3.100), chlorpyrifos (0.180±0.180), cyhalothrin (1.340±1.340), and anthracene, 1,2,3,4-tetrahydro-9-propyl- (0.020±0.020).

Table 3: Comparison between pesticide concentrations (ppb) in Water samples of Gongolong and Alau areas.

Chemical parameters	Location	$Mean \pm SE$	F value	Significant level
Naphthalene, 1-methyl	Gongolong	0.000 ± 0.000		
	Alau	0.060 ± 0.060		
Phenanthrene	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Altrazine	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Dichlorvos	Gongolong	0.000 ± 0.000		
	Alau	0.020 ± 0.030		
Dimethoate	Gongolong	0.000 ± 0.000		
	Alau	3.200 ± 3.100		
Imidacloprid	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Lindane	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Quintozene	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Chlorpyrifos	Gongolong	0.000 ± 0.000		

	Alau	0.180 ± 0.180
p,p'-DDT	Gongolong	0.000 ± 0.000
	Alau	0.000 ± 0.000
Aldrin	Gongolong	0.000 ± 0.000
	Alau	0.000 ± 0.000
Heptachlor	Gongolong	0.000 ± 0.000
	Alau	0.000 ± 0.000
Pyrazophos	Gongolong	0.000 ± 0.000

Table 3: Comparison between pesticide concentrations (ppb) in Water samples of Gongolong and Alau areas.

Chemical parameters	Location	$Mean \pm SE$	F value	Significant level
	Alau	0.000 ± 0.000		
Dieldrin	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Endrin	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Endosulfan	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Cypermethrin	Gongolong	0.000 ± 0.000		
	Alau	0.000 ± 0.000		
Cyhalothrin	Gongolong	0.000 ± 0.000		
	Alau	1.340 ± 1.340		
Anthracene, 1,2,3,4-tetrahydro-9-propyl-	Gongolong	0.000 ± 0.000		
	Alau	0.020 ± 0.020		

9H-Fluorene, 9-methylene-	Gongolong	0.000 ± 0.000
	Alau	0.000 ± 0.000

Discussion and Conclusion

Pesticide Residues in Soil Samples of Alau and Gongolong

The pesticide residues were detected in soil samples from both the Gongolong and Alau areas. The data indicate that the Alau area had higher pesticide residues in soil compared to Gongolong. Naphthalene, Dichlorvos, Dimethoate, Chlorpyrifos, Cyhalothrin, 9H-fluorene, and 9-methylene were detected in soil samples from both areas, with higher concentrations in Alau. The higher concentration of pesticide residues in Alau (Table 3) could be attributed to their sources of water; most of the farmers used water from Lake Alau, while farmers in Gongolong mostly used water from drilled boreholes. Corresponding to Hamilton *et al*. (2003), who reported that environmental factors, such as water usage, soil type, and climatic conditions, can influence pesticide residues in soils and water. The presence of pesticide residues in soils raises concerns about environmental and health risks, including contamination of groundwater and surface water, as advocated by Winter (2012). Both locations have detectable levels of certain pollutants, such as Naphthalene, Phenanthrene, Dichlorvos, and Chlorpyrifos (Table 1). Pesticide concentrations differ between locations. For example, Alau had higher levels of Naphthalene and Chlorpyrifos, while Atrazine, Lindane, and Endosulfan were not detected in either location. Dimethoate is a systemic insecticide and acaricide that can contaminate soil, water, and air" (Kumar *et al*., 2015). Dimethoate is an organophosphorus insecticide that is highly water-soluble. It is susceptible to hydrolysis under acidic conditions, is moderately stable to microbial degradation, and is non-volatile, as reflected by its low vapor pressure (US EPA 2008). Dimethoate was detected in soil and grape samples from agricultural areas in Turkey (Özkan et al., 2017), while Dimethoate was not detected in soil and grape samples from organic farms in Italy (Bucchini *et al*., 2019).

In a study conducted by Ogundiran *et al*. (2013), Naphthalene was detected in soil and water samples from industrial areas in Nigeria; however, Naphthalene was not detected in soil and water samples from agricultural areas in New Zealand (Horswell *et al*., 2016). Naphthalene is a PAH and a potential carcinogen that can contaminate soil, water, and air (ATSDR, 2019). Darko *et al*. (2015) detected Phenanthrene in soil and vegetable samples from agricultural areas in Ghana; however, Phenanthrene was not detected in soil and vegetable samples from organic farms in Sweden (Bergström *et al*., 2017). 9H-Fluorene, 9-methylene- was detected in soil and sediment samples from industrial areas in Poland (Klimczak *et al*., 2018); on the contrary, 9H-Fluorene, 9-methylene- was not detected in soil and sediment samples from agricultural areas in France (INERIS, 2019). Consistent with this result, a study found Anthracene, 1,2,3,4-tetrahydro-9-propyl, in soil and sediment samples from industrial areas in the United States, supporting the presence of similar compounds in different environments (USEPA, 2019), whereas Anthracene, 1,2,3,4-tetrahydro-9-propyl, was not detected in soil and sediment samples from agricultural areas in the United Kingdom (Defra, 2020). According to Oudo and Hansen (2002), Cyhalothrin is adsorbed on soil particles and is non-mobile in the environment, and Cyhalothrin residues were recovered within the top 15 cm of the soil. Furthermore, Cyhalothrin has also been detected in the deeper 10-30 cm soil layer, resulting from preferential flow. Chlorpyrifos was detected in water and sediment samples from rivers in Brazil (Ribeiro *et al*., 2018), although Chlorpyrifos was not detected in water and sediment samples from rivers in Japan (MOE, 2020).

Pesticides in Vegetables (Okra, Sorrel, and Spinach)

The data reveal that pesticide residues in vegetables from both Gongolong and Alau were generally low, with most pesticides undetected. Chlorpyrifos was detected in okra from Alau, and chlorpyrifos was detected in okra at Gongolong. It was also detected in spinach at Gongolong, while Cypermethrin was detected in okra from Alau. Dimethoate, dichlorvos, and phenanthrene were detected in Sorrel at Alau. The Alau had a higher concentration than Gongolong vegetables. The presence of pesticide residues on vegetables was a result of the wide range of insect attacks that attract frequent spraying of insecticides by the farmers. According to Srivastava *et al*. (2021), okra is heavily attacked by pests like shoot and fruit borers, leading farmers to use pesticides to control infestations. Chlorpyrifos and Cypermethrin are commonly used insecticides in okra cultivation. Pesticides can pile up on the surface and within the plant tissues. Sorrel, spinach, and okra's hairy and ridged surfaces can trap pesticide particles, making them more prone to pesticide residue accumulation. Environmental factors like temperature, humidity, and rainfall can influence pesticide degradation and accumulation in okra plants. The detection of Chlorpyrifos and Cypermethrin suggests that these pesticides are being used in agricultural practices in the areas (Racke, 1993; Kumar *et al*., 2015). Environmental factors, such as soil type, climate, and water usage, can affect pesticide residues in vegetables (Hamilton *et al*., 2003). The detection of pesticide residues in vegetables raises concerns about food safety and potential health risks to consumers (Winter, 2012). Cypermethrin was detected in soil and vegetable samples from agricultural areas in China (Li *et al*., 2019), while Cypermethrin was not detected in soil and vegetable samples from organic farms in Australia (APVMA, 2020).

Pesticides in Water Samples

The results show that pesticide residues were detected in water samples from Alau areas, only no residues were detected in Gongolong areas. Naphthalene, 1-methyl, Dichlorvos, Dimethoate, Chlorpyrifos, Cyhalothrin, and Anthracene, 1,2,3,4-tetrahydro-9-propyl- were found in the samples at different concentrations. This finding supports the report by Kumar *et al*. (2017), who also detected Dichlorvos in water and sediment samples from rivers in India but disagree with Canadian report that Dichlorvos was absent in water and sediment samples from rivers in Canada (CCME, 2018). Cyhalothrin is a synthetic pyrethroid insecticide that can be toxic to aquatic organisms and cause human health effects (WHO, 2009). Synthetic pyrethroids can enter the environment through spray drift (using both aerial and ground-based methods) and urban and agricultural runoff (Ranatunga *et al*., 2023). The residues of cyhalothrin have been widely detected in water and sediment samples from streams and river-draining canals in areas of intensive agriculture in northeastern Greece (Vryzas *et al*., 2011). The absence of pesticide residues in Gongolong could be attributed to the source of their water for irrigation (Table 3). The common source of water in Gongolong was a borehole, while in the Alau area, they used water from Alau Dam.

Conclusion

The study found pesticide residues (e.g., chlorpyrifos, cypermethrin, naphthalene, dichlorvos) in soil and vegetables from Alau and Gongolong irrigation sites in Maiduguri, Borno State, Nigeria. Key findings include: Higher pesticide concentrations in Alau compared to Gongolong, Chlorpyrifos and cypermethrin detected in higher levels in okra samples, Poor agricultural practices, such as improper disposal of pesticide containers and non-adherence to application rates, contribute to environmental contamination which is I line with the findings of Tada *et al*., (2025).

Recommendations

To mitigate pesticide risks, the following steps are recommended: Conduct routine testing of soil and vegetable samples for pesticide residues, educate farmers, consumers, and stakeholders about pesticide risks, strengthen regulations and enforcement for proper pesticide labelling, storage, and disposal, Investigate pesticide sources, mobility, fate, and transport in irrigation sites, and their impacts on human health and the environment.

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