

Comparative Assessment Of Pesticide Residues In Roots Versus Leaves Of Spinach, Sorrel, And Okra At Alau And Gongolong Irrigation Sites, Maiduguri, Borno State, Nigeria

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Abstract

The rapid increase in population growth and the need to maintain food security, particularly in developing countries, have led to a rise in the use of pesticides to meet the high demand for food. This leads to the high application of pesticides to boost production. This study was conducted to determine the residues of pesticides in vegetables in the study area. 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). 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. The concentrations of pesticide residues in the vegetables, water, and soil samples were determined using GC-MS. Statistical analysis of pesticide residue data was performed using SPSS version 24. 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. A significance level of $P < 0.05$ was adopted. Pesticide residues were detected in the roots and leaves of the vegetable samples from both areas. In Alau, phenanthrene was detected only in sorrel roots at a concentration of 0.007 ± 0.00 , and Dichlorvos was detected only in sorrel roots at 0.020 ± 0.00 , and Dimethoate was detected only in sorrel roots at 0.003 ± 0.00 . Chlorpyrifos was detected in Okra roots at 13.295 ± 0.66 and spinach roots at 0.203 ± 0.01 . Cypermethrin was detected in Okra roots at 0.927 ± 0.05 and leaves at 1.085 ± 0.05 . While Gongolong phenanthrene was only detected in sorrel roots at a concentration of 0.007 ± 0.00 . Chlorpyrifos was detected in Okra roots at 0.610 ± 0.03 . Spinach roots at 0.203 ± 0.01 . Dichlorvos, dimethoate, and cypermethrin were not detected (ND) in any vegetable parts. The findings revealed that the residue concentrations were higher in Alau samples, and root samples had a higher frequency of occurrences. The data indicate that the Alau area had higher pesticide residues compared to Gongolong. Chlorpyrifos was the highest residue detected in root samples of Alau. The presence of pesticide residues in vegetables poses significant risks to human health and the environment. Regular monitoring and testing of vegetables are necessary to determine pesticide residue levels. Farmers should adopt alternative pest control methods, such as biological control, cultural control, and physical control, to reduce dependence on chemical pesticides. The study's findings highlight the need for sustainable agricultural practices to minimize the risks associated with pesticide use.

Keywords: Pesticide residues, vegetables, Lake Alau, Gongolong, Maiduguri.

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I. Introduction

The insurgence of pests, diseases, and other plant pathogens has necessitated the use of pesticides. This eliminates pre-harvest and post-harvest losses to maintain a high yield. The rapid increase in population growth and the need to maintain food security, especially in developing countries, have increased the use of these pesticides. It has been reported that the use of pesticides has increased massively, with an estimated 3 billion kilograms (worldwide) used annually (Farag *et al*, 2011; Tudi *et al.*, 2021) to meet the high demand for food and other agro-allied needs. 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). However, the indiscriminate use of pesticides, often due to limited knowledge of application methods, has adverse effects on both ecological and human health. Excessive usage contaminates the soil surface and groundwater through active ingredient mobility (Srivastava *et al.*, 2010). 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). Indiscriminate use of pesticides, especially at the fruiting and pre-harvesting stages, and non-adoption of safe waiting periods have led to pesticide residues accumulating in most consumable vegetables and fruits, especially in developing countries. The contamination of vegetables and fruits with pesticides has been reported in many developing countries (Bansal 2025). Pesticides and their residues could accumulate in foodstuffs such as vegetables, which could be detrimental to human health (Quandahor *et al.*, 2024). Pesticide compounds primarily from organophosphate, organochlorine, carbamate, and Pyrethroid derivatives have been shown to bioaccumulate in the food chain (Samadi *et al.*, 2009). These compounds form the backbone of agricultural production, but some can persist in the soil or vegetables and fruits (Tudi *et al.*, 2021). For instance, organochlorines could persist and bio-accumulate in living organisms through the food chain. Carbamate is short-lived, and its derivatives could cause genetic mutations and functional disturbances in the CNS (Samadi *et al.*, 2009). Some pesticides, such as organophosphates, could inhibit cholinesterase activity and cause central nervous system (CNS) functional disturbances (Quandahor *et al.*, 2024). Environmental pollution by pesticides has been identified as one of the major environmental impacts of agriculture (Özkara *et al.*, 2016). The post-World War II era saw a significant increase in pesticide use to boost food production. This has led to the development of various pesticide types and their residues being detected in the environment (air, water, soil) and in crops, vegetables, and fruits (El-Sheikh *et al.*, 2022). Among various pesticide classes, the organophosphorus (OPPs) group is the most widely used class of agricultural pesticides (El-Sheikh *et al.*, 2022). Pests significantly impact food production and controlling them is crucial for food security. Pesticides are widely used in agriculture to manage pests, diseases, and weeds, thereby reducing yield losses and maintaining product quality (Ali *et al.*, 2023). 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). Pesticide residues in plants can be unavoidable even with proper use, posing dangers to soil microfauna and microflora. These residues can also accumulate in the food chain, potentially harming humans (Ali *et al.*, 2023). Plant contamination often occurs through root uptake of persistent pesticide residues. The amount of pesticide absorbed by a plant depends on factors like: Water solubility of the pesticide, Pesticide quantity in the soil, and Soil organic matter content. The longer the residue persists, the more pesticide is absorbed by the plant (Akan *et al.*, 2013). Fresh produce like vegetables, fruits, and pulses is nutritious and essential for a healthy diet, but they can also be contaminated with pesticides, making them potential sources of toxic substances (Knezevic and Serdar, 2009).

The objectives of this study are to assess and compare the levels of pesticide residues in roots and leaves of selected vegetables commonly grown in Alau and Gongolong irrigation sites using Gas Chromatography-Mass Spectrometry (GC-MS).

The presence of pesticide residue in food is currently a great concern among vegetable consumers. This study provided information on residue concentrations in roots and leaves of okra, spinach, and sorrel collected from the irrigation sites around Lake Alau and Gongolong agricultural areas.

II. Literature Review

According to Mahmood *et al.* (2016) and Rani *et al.* (2021), Pesticides are toxic chemicals, chemical mixtures, or biological agents that are purposely introduced into the environment to prevent, eliminate, or otherwise harm populations of insect pests, weeds, rodents, fungi, or other pests. Pesticides are substances or mixtures designed to control, destroy, or prevent pests, including Insecticides, Herbicides, Fungicides, Rodenticides, and Plant growth regulators. They protect food, crops, and livestock from damage, disease, and pests, and are used in various stages of production, processing, storage, and transport (FAO, 2023). The reduction in these other organisms can affect the biodiversity of an area and affect natural biological balances (Aktar *et al.*, 2009). According to the FAO, pesticides are substances or mixtures that control, destroy, or prevent pests, including those affecting humans, animals, crops, and food products, and are used in various stages of production, storage, and transport (Akashe *et al.*, 2018). Pesticide residue refers to the pesticides or metabolic products of the pesticides that may remain in food grains, vegetables, and fruits after they are applied to crops (Grewal *et al.*, 2017).

Organophosphate pesticides are potent insecticides with potential health risks. Exposure can harm the nervous system, causing symptoms like Shortness of breath, Abnormal salivation, Vomiting, Headache, Dizziness, Chest issues, Convulsions, Paralysis, and Potential death. These pesticides, such as Diazinon, work by inhibiting an enzyme that regulates the neurotransmitter acetylcholine, leading to toxic effects in humans and other organisms. Due to these risks, their use is often restricted in residential areas (Nematollahi *et al.*, 2022).

Pyrethroids, derived from pyrethrin, have a rich history dating back to the mid-20th century. Key milestones include:

- 1949: Synthesis of allethrin and bioallethrin

- 1962: Introduction of resmethrin, a synthetic pyrethroid with enhanced stability and insecticidal potency, achieved through structural modifications of natural pyrethrins (Hodoşan *et al.*, 2023). Organochlorine pesticides may have substantial short and long-term health consequences even at trace concentrations on non-target organisms (Jadon and Kumar 2023). Organochlorine pesticides are highly toxic, causing severe health effects like Depressed nervous system activity, Seizures, and Bioaccumulation. Prolonged exposure can lead to neurotoxicity and disrupt chloride ion channels. As persistent organic pollutants (POPs), organochlorines bioaccumulate in organisms and Biomagnify in ecosystems (Casida, 2020).

Sorrel (*Rumex acetosa* L.) is a perennial herb with a long history of use as a wild-gathered and cultivated plant, valued for its medicinal properties (Korpelainen & Pietiläinen, 2020). Rumex is a genus of about 200 species of herbs and shrubs in the buckwheat family, found mainly in the Northern Hemisphere across Europe, Asia, Africa, and North America (Abbasi *et al.*, 2015). Sorrel's leaves are large, ovate, and hairless with pointed basal lobes. The plant produces small, pinkish, unisexual flowers and triangular achenes as fruit. Basal leaves have long stalks, while stem leaves are nearly stalkless (Flora Europaea 1993; Mabberley 2008).

Scientific classification and kingdom of sorrel:

Kingdom: Plantae

Order: Caryophyllales

Family: Polygonaceae

Genus: Rumex

Species: *Rumex acetosa*

Binomial Name: *Rumex acetosa* L.

Spinach (*Spinacia oleracea* L.) is a green leafy vegetable with a rich history and a character for being a nutritional dynamo belonging to the Amaranthaceae family (Gutierrez *et al.*, 2019). It is an economically important leafy vegetable grown in the winter season and consumed worldwide. Spinach is an annual cool-season vegetable mainly cultivated for its tender, dark green leaves, commonly consumed as a fresh salad green or cooked, canned, frozen, in soups, and other dishes (Ozkan *et al.*, 2007). It is presumed that the crop has spread late in history, as no references to spinach from the Greek and Roman cultures have been found (Heine, 2018).

Scientific classification of Spinach

Kingdom: Plantae

Subkingdom: Tracheobionta

Superdivision: Spermatophyta

Division: Magnoliophyta

Class: Magnoliopsida

Subclass: Caryophyllidae

Order: Caryophyllales

Family: Chenopodiaceae

Genus: Spinacia L.

Species: *Spinacia oleracea* L.

(Plants.usda.gov.2010)

Okra, (*Abelmoschus esculentus* L.)

Okra (*Abelmoschus esculentus* L.) is a dicotyledonous plant belonging to the Malvaceae family. It's a popular vegetable crop commonly grown in tropical and subtropical regions (Nwangburuka *et al.*, 2011).

Scientific Classification of Okra (*Abelmoschus esculentus* L.)

Kingdom: Plantae

Phylum: Magnoliophyta

Class: Magnoliopsida

Subclass: Dilleniidae

Order: Malvales

Family: Malvaceae

Genus: Abelmoschus

Subject: *Abelmoschus esculentus L.*
U.S. Department of Agriculture (2024).

III. 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 km², with a maximum storage capacity is 112 Mm³. Alau Dam receives water from the river Yedzram and the river Gombole, which merge at a confluence in Sambisa before flowing into the river Ngadda, which feeds Alau Dam. Alau Dam received a wide variety of waste from agricultural lands. This waste generated contaminates Alau Dam with a variety of pesticides acting as non-point sources. This Lake is also used for commercial fishing. Alau Dam received a wide variety of waste from agricultural activity within this area. Most farmers around the Alau Dam area used synthetic chemical pesticides to control pests on vegetables, including several organophosphorus pesticides and other pesticides.

Lake Alau is one of the numerous lakes in the northeastern part of Nigeria. It was constructed in 1987 on the river Nggada to supply potable drinking water to the Maiduguri metropolis with over 8000 hectares of farmland in the catchment area of the Lake Chad Basin Development Association (CBDA, 1984). It lies at a latitude of 11° 41'N and a longitude of 13° 16'E 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 m³. 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).

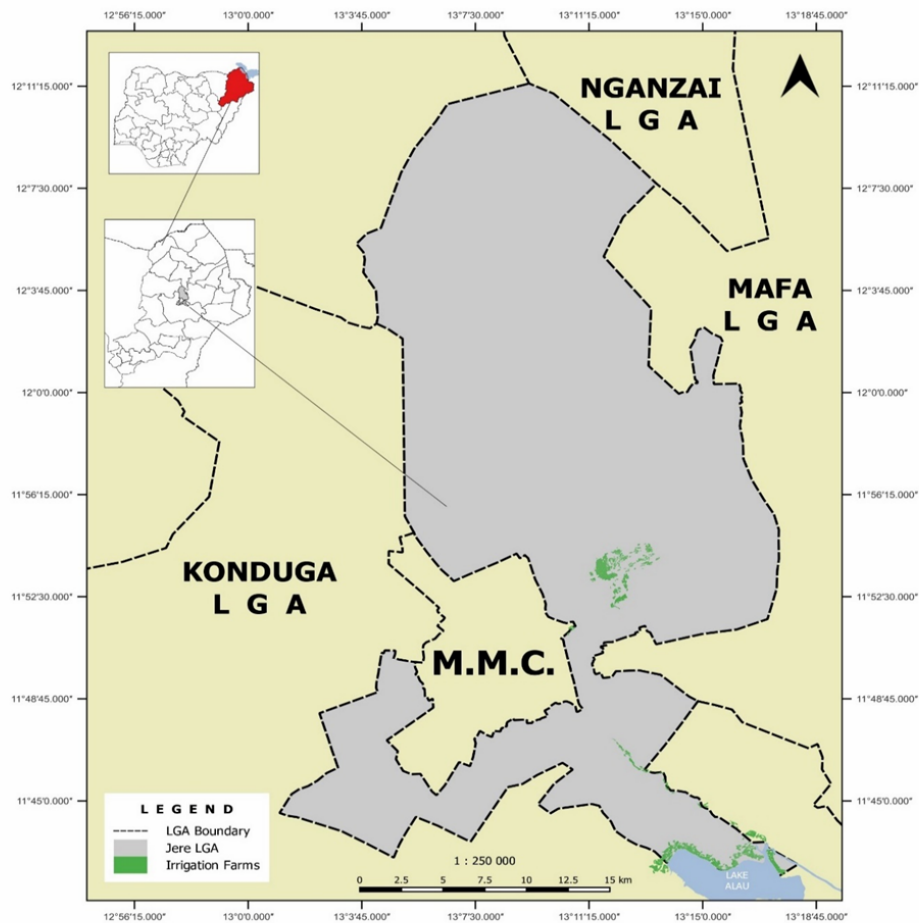
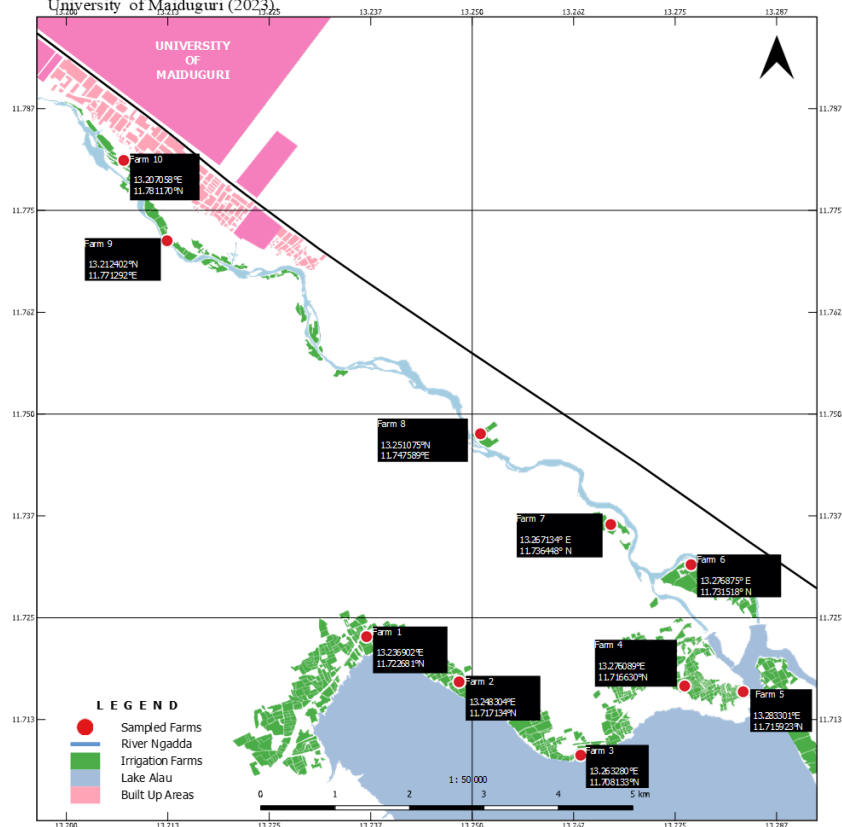
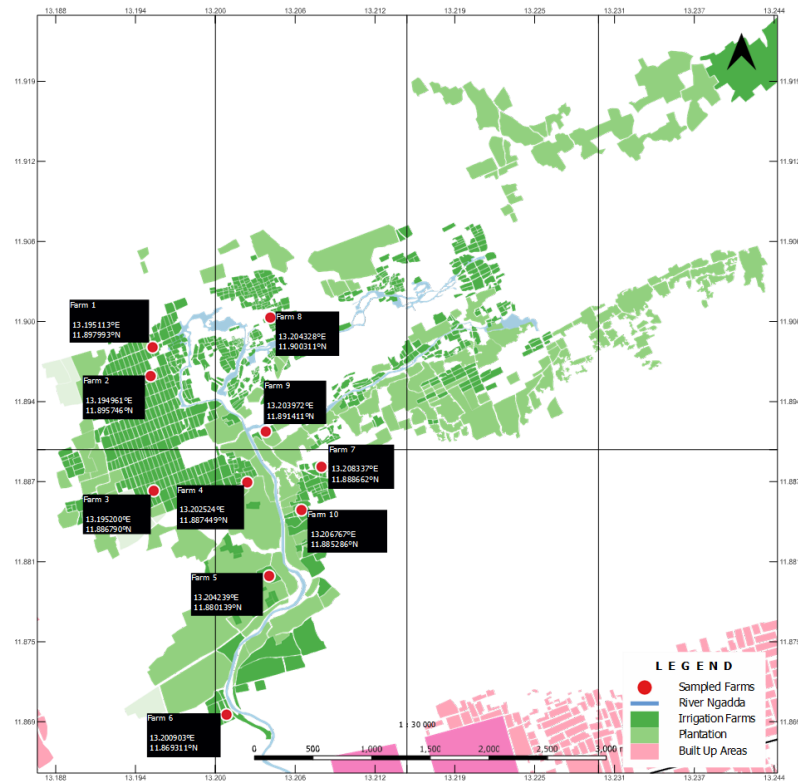


Figure 3.3 : Jere Local Government Area showing Irrigation Farms.
Source : Department of Urban and Regional Planning, Faculty of Environmental Studies, University of Maiduguri (2023).



Sample Size Determination and Procedure

The sample size was determined using a single population proportion formula. The minimum sample size (n) for the study was calculated as follows. The formula used to calculate the minimum sample size (n) is $n = (Z\alpha/2)^2 * P * (1-P)/d^2$, where $Z\alpha/2$ is the critical value (1.96 for 95% confidence), P is the estimated proportion (0.559 based on a previous study), and d is the desired margin of error (0.05) (Gesese *et al.*, 2016).

n = Sample size: The number of individuals or observations needed for the study.

$Z\alpha/2$ = Critical value: For a 95% confidence interval, the Z-score is 1.96.

P = Estimated proportion: The proportion of the population expected to exhibit the characteristic of interest. In this case, it's 55.9% or 0.559.

d = Margin of error (precision): The acceptable level of error in the results, set at 0.05 (5%) in this case.

$$n = (Z\alpha/2)^2 * P * (1-P) / d^2 \\ = (1.96)^2 * 0.559 * (1-0.559) / (0.05)^2 \\ = 379$$

However, the number was scaled up to three hundred ninety for convenience (that is, $379 + 11 = 390$).

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 the US Environmental Protection Agency (USEPA) Method 3510, with ethyl acetate as the extraction solvent. To ensure optimal extraction conditions, sodium bicarbonate (NaHCO_3) was used to neutralize any acidity, and the vegetable samples were thoroughly rinsed with distilled water before analysis. Twenty grams (20 g) of each sample were placed in a mortar, and anhydrous sodium sulphate (Na_2SO_4) was used to remove water from the sample matrix. Using a spatula, the ground sample (paste) was transferred to a conical flask, followed by the addition of 40 mL of ethyl acetate, and the mixture was thoroughly shaken. A 5 g portion of sodium bicarbonate NaHCO_3 was added to the mixture followed by 20 mL of anhydrous sodium sulphate (Na_2SO_4) and the entire mixture was shaken vigorously for 1 hour, to ensure that enough of the pesticide residue dissolved in the ethyl acetate. The procedure was repeated for the samples from each area and the mixture were filtered into a labelled container before centrifugation at 1800 rpm for 5 mins. The organic layer was decanted into a container, and a 1:1 mixture of 5 mL ethyl acetate and cyclohexane was added (Radojevic and Bashkin, 1999; Tadeo, 2022).

Cleaning up of Vegetable Extracts

The vegetable extracts underwent clean-up using a 10 mm chromatographic column packed with 3 g of activated silica gel and topped with 2-3 g of anhydrous sodium sulfate. The column was pre-conditioned with 5 mL of n-hexane. The extract, dissolved in 2 mL of n-hexane, was loaded onto the column and rinsed three times with 2 mL portions of n-hexane. The eluates were collected in 2 mL vials, sealed, and stored in a refrigerator at a controlled temperature to prevent solvent evaporation (Akan *et al.*, 2013).

Determination of Pesticide Residues

GC-MS (Agilent GC 7890B/MSD 5977A), equipped with a fluorescence detector, was used for the chromatographic separation and achieved by using a 35% diphenyl, 65% dimethyl polysiloxane column. The oven was programmed as follows: initial temperature 40 °C, 1.5 min, to 150 °C, 15.0 min, 5 °C/min to 200 °C, 7.5 min, 25 °C/min to 290 °C with a final hold time of 12 min and a constant column flow rate of 1 mL/min. The detection of pesticides was performed using the GC-ion trap MS with optional MSn mode. The scanning mode offers enhanced selectivity over either full scan or selected ion monitoring (SIM). In SIM at the elution time of each pesticide, the ratio of the intensity of matrix ions increases exponentially versus that of the pesticide ions as the concentration of the pesticide approaches the detection limit, decreasing the accuracy at lower levels. The GC-MS tandem MS functions by injecting ions into the ion trap and destabilizing matrix ions, isolating only the pesticide ions. The retention time, peak area, and peak height of the sample were compared with those of the standards for quantization (Akan *et al.*, 2013). The study was conducted in the Chemistry Research Laboratory, Department of Chemistry, Yobe State University, Damaturu.

Data Analysis

Statistical analysis of pesticide residue data was performed using SPSS version 24. 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.

IV. Results

Table 1 presents the comparison of pesticide residue concentrations (ppb) in roots and leaves of Vegetables in the Alau area. Phenanthrene was detected only in sorrel roots at a concentration of 0.007 ± 0.00 , and Dichlorvos was detected only in sorrel roots at 0.020 ± 0.00 , and Dimethoate was detected only in sorrel roots at 0.003 ± 0.00 , all with a significance level of 0.500, indicating no statistical significance. Chlorpyrifos was detected in Okra roots at 13.295 ± 0.66 with a significance level of 0.500, indicating no statistical significance, and spinach roots at 0.203 ± 0.01 (no significance level provided). Cypermethrin was detected in Okra roots at 0.927 ± 0.05 and leaves at 1.085 ± 0.05 . The significance level for okra is 0.006, indicating statistical significance. Okra and sorrel seem to accumulate multiple pollutants, while spinach has fewer detections, and cypermethrin in okra shows statistical significance.

Table 1 Comparison of Pesticide Residue Concentrations (ppb) Roots and Leaves of Vegetables in Alau Area

Chemical parameters	Vegetables	Parts	Mean $\pm$ SE	Significant Level
Phenanthrene	Okra	Roots	ND	ND
		Leaves	ND	ND
	Sorrel	Roots	0.007 ± 0.00	0.500
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND
Dichlorvos	Okra	Roots	ND	ND
		Leaves	ND	ND
	Sorrel	Roots	0.020 ± 0.00	0.500
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND
Dimethoate	Okra	Roots	ND	ND
		Leaves	ND	ND
	Sorrel	Roots	0.003 ± 0.00	0.500
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND
Chlorpyrifos	Okra	Roots	13.295 ± 0.66	0.500
		Leaves	ND	ND
	Sorrel	Roots	ND	ND
		Leaves	ND	ND
	Spinach	Roots	0.203 ± 0.01	0.500
		Leaves	ND	ND
Cypermethrin	Okra	Roots	0.927 ± 0.05	0.006
		Leaves	1.085 ± 0.05	
	Sorrel	Roots	ND	ND
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND

ND=Not Detected, SE=Standard Error

Table 2 presents the comparison of pesticide residue concentrations (ppb) in roots and leaves of vegetables in the Gongolong area. The findings reveal that phenanthrene was only detected in sorrel roots at a concentration of 0.007 ± 0.00 with a significance level of 0.42. Chlorpyrifos was detected in Okra roots at 0.610 ± 0.03 with a significant level of 0.24. Spinach roots at 0.203 ± 0.01 . Dichlorvos, dimethoate, and cypermethrin were not detected (ND) in any vegetable parts. The results suggest that different vegetables accumulate varying levels of pesticide residues, like chlorpyrifos, being more prevalent in certain vegetables (okra and spinach).

Table 2 Comparison of Pesticide Residue Concentrations (ppb) Roots and Leaves of Vegetables in Gongolong Area

Chemical parameters	Vegetables	Parts	Mean $\pm$ SE	Significant Level
Phenanthrene	Okra	Roots	ND	ND
		Leaves	ND	ND
	Sorrel	Roots	0.007 ± 0.00	0.42
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND
Dichlorvos	Okra	Roots	ND	ND
		Leaves	ND	ND
	Sorrel	Roots	ND	ND
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND
Dimethoate	Okra	Roots	ND	ND
		Leaves	ND	ND
	Sorrel	Roots	ND	ND
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND
Chlorpyrifos	Okra	Roots	0.610 ± 0.03	0.24
		Leaves	ND	ND
	Sorrel	Roots	ND	ND
		Leaves	ND	ND
	Spinach	Roots	0.203 ± 0.01	0.24
		Leaves	ND	ND
Cypermethrin	Okra	Roots	ND	ND
		Leaves	ND	ND
	Sorrel	Roots	ND	ND
		Leaves	ND	ND
	Spinach	Roots	ND	ND
		Leaves	ND	ND

ND=Not Detected, SE=Standard Error

Table 3 presents a comparison of pesticide concentrations (ppb) in roots and leaves of the vegetable Samples from Gongolong and Alau areas. The results reveal that most pesticides were not detected in the roots and leaves of the vegetable samples from both Gongolong and Alau areas. However, chlorpyrifos was detected in the roots of vegetable samples from Alau (8.660 ± 0.73) and Gongolong root samples (0.339 ± 0.02). Cypermethrin was detected in roots (0.618 ± 0.03) and leaves (0.723 ± 0.04) of vegetable samples from Alau. Phenanthrene was detected in root samples in Alau (0.004 ± 0.00) and dichlorvos was detected in root samples in Alau (0.013 ± 0.00), and dimethoate was detected in root samples in Alau (0.022 ± 0.00). The findings revealed that the residue concentrations were higher in Alau samples, and root samples had a higher frequency of occurrences.

Table 3: Comparison of Pesticide Concentration in Roots and Leaves of the Vegetable Samples of Gongolong and Alau Areas

Chemical parameters	Location	Vegetables	Mean $\pm$ SE	Sig Level Between Groups
Naphthalene, 1-methyl	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
Phenanthrene	Gongolong	Roots	ND	0.500
		Leaves	ND	ND
	Alau	Roots	0.004 $\pm$ 0.00	0.500
		Leaves	ND	ND
Altrazine	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
Dichlorvos	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	0.013 $\pm$ 0.00	0.500
		Leaves	ND	ND
Dimethoate	Gongolong	Roots	ND	0.500
		Leaves	ND	ND
	Alau	Roots	0.022 $\pm$ 0.00	0.500
		Leaves	ND	ND
Imidacloprid	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
Paraquat dichloride	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND

Table 3: Comparison of Pesticide Concentration in Roots and Leaves of the Vegetable Samples of Gongolong and Alau Areas

Chemical parameters	Location	Vegetables	Mean $\pm$ SE	Sig Level Between Groups
Dieldrin	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
Endrin	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
Endosulfan	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
Cypermethrin	Gongolong	Roots	ND	0.500
		Leaves	ND	ND
	Alau	Roots	0.618 $\pm$ 0.03	0.500
		Leaves	0.723 $\pm$ 0.04	
Cyhalothrin	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
Lambda-Cyhalothrin	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND
9H-Fluorene, 9-methylene	Gongolong	Roots	ND	ND
		Leaves	ND	ND
	Alau	Roots	ND	ND
		Leaves	ND	ND

ND=Not Detected, SE=Standard Error

V. Discussion

The findings show that most pesticides were not detected in the roots and leaves of vegetable samples from both Gongolong and Alau areas. However, Chlorpyrifos, Cypermethrin, Phenanthrene, Dimethoate, and Dichlorvos were detected in the roots of vegetable samples from Alau. The results are in line with the findings, which suggest that roots are expected to accumulate pesticide residues over time due to their slower growth rate and higher storage capacity compared to leaves (Kutschera & Niklas, 2013).

According to the findings of Taiz & Zeiger (2010), roots have decreased metabolic activity than leaves, which implies pesticides may not be broken down as quickly, leading to higher accumulations. Another possible reason for the higher concentration of pesticides in roots is direct contact with the soil, where pesticides are often applied, raising their exposure to these chemicals (Walker, 1987). Chlorpyrifos and Cypermethrin are systemic pesticides, indicating they can be absorbed by plants and translocated to various parts, including roots (Kidd & James, 1991; Shaner & Henry, 2002). Roots have a higher surface area-to-volume ratio than leaves, allowing for greater pesticide uptake and accumulation (Kutschera & Niklas, 2013).

The soil in Alau may have characteristics that enhance pesticide persistence and bioavailability, such as low organic matter content, high pH, or poor drainage (Boesten & van der Linden, 2000).

Chlorpyrifos and Cypermethrin are systemic pesticides, indicating they can be absorbed by plants and translocated to various parts, including roots (Kidd & James, 1991; Shaner & Henry, 2002).

Dichlorvos is an insecticide used on crops, animals, and in pest strips. Acute/short-term and chronic/long-term exposures of humans to dichlorvos result in the inhibition of an enzyme, acetylcholinesterase, with neurotoxic effects including perspiration, vomiting, looseness of the bowels, drowsiness, weakness, headache, and high concentrations, convulsions and coma. No information is available on the reproductive, developmental, or carcinogenic effects of dichlorvos on humans (Das, 2013). Dichlorvos is effective against mushroom flies, aphids, spider mites, caterpillars, thrips, and whiteflies in greenhouses and outdoor crops. It is also used in the milling and grain handling industries and to treat a variety of parasitic worm infections in animals and humans (Das, 2013). Dichlorvos is a widely used insecticide that has been linked to neurological effects and cancer (EPA, 2020).

VI. Conclusion

Chlorpyrifos, Cypermethrin, Naphthalene, and Dichlorvos were detected in both locations, with higher concentrations of Chlorpyrifos in Alau, while Dimethoate, Phenanthrene, and Cypermethrin were detected only in Alau. The study revealed low levels of contamination overall; however, higher concentrations of Chlorpyrifos and Cypermethrin were detected in okra samples.

The findings indicate that the Alau area had higher pesticide residues in soil and water, and vegetables compared to Gongolong. The residue concentrations were slightly higher in root samples compared to the leaves.

VII. Recommendations

There is a need to conduct regular monitoring and testing of soil, water, and vegetable samples from the Alau and Gongolong areas in Borno State, Nigeria, to determine the levels of pesticide residues. Authorities should strengthen regulations and enforcement of pesticide management in the region, including proper labelling, storage, and disposal of pesticides. Encourages integrated pest management (IPM) practices among farmers in the region, which include crop rotation and biological control. Offer regular training and education programs for farmers on integrated pest management (IPM) procedures. Conduct further research to explore the sources, mobility, fate, and transport of pesticides in the irrigation sites and their potential impacts on human health and the environment.

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