ASSESSMENT OF PESTICIDE USE PRACTICES AND RESIDUE LEVELS IN LOCALLY PRODUCED KALES AND DOMESTIC WATER SOURCES IN KIEGOI LOCATION, IN THE UPPER NYAMBENE CATCHMENT, MERU COUNTY, KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Environmental Science of Chuka University

CHUKA UNIVERSITY

OCTOBER 2024

DECLARATION AND RECOMMENDATIONS

Declaration

This thesis is the original work of the author and has not been presented for the award of a diploma or conferment of a degree in this university or any other university.

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Recommendations

This thesis has been examined and passed with our approval as the University supervisors.

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DEDICATION

I dedicate this work to my family for their unwavering support and to the researchers and mentors who have guided and inspired me throughout this journey. May this thesis contribute to advancing knowledge in food safety, clean water access and sustainable agriculture.

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ABSTRACT

Pesticides are widely used to protect crops from pests and diseases infestations. However, the use of pesticides in most developing countries poses serious environmental and food safety hazards. These chemicals often leave residues in vegetables post-harvest and may contaminate water sources through runoff and groundwater percolation. Given their intrinsic toxicity, the production, distribution, and use of pesticides require strict regulation and control. This study investigated farmers' compliance to applicable standards by assessing pesticide residues in selected locally produced kales and domestic water sources in the upper, middle and lower zones of Kiegoi location. To achieve this, this study sought to determine the commonly used pesticides, analysed samples of kales and samples of water for domestic use and pesticide use practices was also documented. A total of 68 respondents were purposively sampled using structured questionnaire during October-November 2023 and April-June 2024. Using a stratified random sampling method, 54 water and 54 kale samples were collected and analyzed across wet and dry seasons. Samples were packed in labelled zip-lock bags, placed in a cool box, and transported to KEPHIS Analytical Chemistry Laboratory in Nairobi, Kenya where extracts were analyzed using MO301-GC-MS/MS. The Quick, Easy, Cheap, Effective, Rugged, and Safe (QuEChERS) protocol was followed for sample preparation and data processed using SPSS version 26. An independent t-test determined statistically significant differences in pesticide residue concentrations in kales and domestic water source between dry and wet seasons and compared to WHO's designated MRLs. The results indicated that 97.1% of farmers use pesticides to protect kale from pests and diseases. The most commonly used pesticides were Dithane M-45 (22.1%), Deltanex (14.7%), Nuvan (11.8%), and Captan 50 WP (11.8%). Other pesticides like Diazinol, Cyperkill, and Trophy each accounted for 7.4%, while Rufast and Roundup made up 4.4% and 1.5%, respectively. Alarmingly, 80.9% of farmers did not follow recommended mixing and dilution practices, 69.1% did not use protective gear, 72.1% could not correctly interpret and follow pesticide labelling instructions, 55.9% relied on agrovet stores for pesticide decisions, and 92.6% had no formal training on safe pesticide use. Residue analysis showed Captan concentrations ranged from 0.01533 mg/kg in the wet season to 0.04700 mg/kg in the dry season, showing a statistically significant difference (p=0.001). Deltamethrin residues ranged from 0.01467 mg/kg in the wet season to 0.04200 mg/kg in the dry season, with a significant difference (p=0.000). Diazinon concentrations increased from 0.01567 mg/kg in the wet season to 0.02567 mg/kg in the dry season (p=0.046). Dichlorvos and Diazinon residues exceeded their MRLs of 0.02 mg/kg and 0.01 mg/kg, respectively, while Dieldrin surpassed the WHO MRL of 0.05 mg/kg during the dry season, suggesting a potential food safety hazard. Mancozeb and Deltamethrin concentrations in water were found to be within the WHO MRLs of 0.02 mg/l and 0.5 mg/l, respectively. However, Diazinon and Dieldrin levels exceeded the WHO MRLs of 0.01 mg/l and 0.05 mg/l. According to the WHO classification of pesticides, Dieldrin is a Class 1a pesticide that is extremely hazardous and restricted for use. Cypermethrin, Acetochlor, and Acrinathrin levels were below their respective WHO MRLs of 0.1 mg/l, 0.3 mg/l, and 0.05 mg/l in both seasons.

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ABBREVIATIONS AND ACCRONYMS

DDTs	- Dichloro-diphenyl-trichloroethanes
EU	- European Union
GAP	- Good Agricultural Practices
GC-Ms	- Gas Chromatograph Mass spectrometer
GIS	- Geographical Information System
GPS	- Global Positioning System
HCB	- Hexachlorobenzene
HCHs	- Hexachlorocyclohexanes
KEPHIS	- Kenya Plant Health Inspectoral
MRLs	-Maximum Residue Limits
OCPs	- Organochlorine Pesticides
OCs	- Organochlorines
PPE	- Personal Protective Equipment
QuEChERS	- Quick, Easy, Cheap, Effective, Rugged, and Safe
WHO	- World Health Organization

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Pesticides include many herbicides, insecticides, fungicides, rodents, and nematicides, which are widely used in contemporary agriculture to reduce pests and illnesses and increase crop output for the world's expanding population (Ahoudi *et al*., 2018). Two million tonnes are used annually worldwide, with herbicides accounting for the majority (50%) and insecticides, fungicides, and other types, including nematicides and rodenticides, coming in second and third, respectively (Sharma *et al*., 2019).

The most significant contributors are China, the United States, and Argentina, and the number is rising quickly. By 2020, global pesticide usage has been estimated to increase by 3.5 million tonnes. Although pesticides are beneficial for crop production, injudicious use of pesticides can have severe consequences because of their bio-magnification and persistent nature (Sharma *et al.,* 2019). Pesticides provide a significant health risk to all living things since they contaminate the air, water, soil, and ecosystem as a whole, either directly or indirectly (Sharma *et al.*, 2019). There is a rising concern in Chile regarding safeguarding consumers from potential exposure to pesticide residues in unprocessed food items (Kumari *et al.*, 2021).

In China, control programs addressing pesticide residues often need more resources and less stringent regulations. Some farmers, driven by the high demand for agricultural produce and limited awareness of the toxic effects of pesticide residues in food, need to observe adequate waiting periods for residues to dissipate after spraying before harvesting (Syed *et al.*, 2014). According to Ibrahim and Nasr (2014), food products now contain pesticide residue due to increased pesticide use in farming. A part of controlling the amount of pesticides in food is keeping an eye on pesticide residue.

Over the past few decades, regulatory bodies in many countries have established monitoring systems for agricultural products and the environment, focusing on ensuring the proper authorization and registration of pesticide use (including application rates and pre-harvest intervals) and compliance with Maximum Residue Limits (MRLs). MRLs are crucial in promoting food safety by restricting the permissible concentration of residues on a commodity and specifying the types of commodities they are allowed (Syed *et al.*, 2014).

Farmers in developing nations often need more knowledge about correctly handling pesticides, leading to suboptimal agricultural practices (Ali *et al.*, 2020). The World Health Organization (2020) reported that these countries contribute 20% of global pesticide usage. In the last few decades, there has been an increasing trend in the amount of pesticides used and the number of pesticides used in agriculture (Mwanja *et al*., 2017). While increasing agriculture productivity through pesticides, these chemicals challenge the population's health in addition to causing environmental pollution, especially with vegetables and other crop oils.

Pesticide residues in fresh food items have always been a significant concern, mainly due to potential health risks associated with consumption (Syed *et al.*, 2014). Pesticides have been connected to several human health risks, from short-term ailments like headaches and nausea to more severe conditions, including cancer, damage to the reproductive system, and endocrine system disturbance (World Health Organization, 2020).

In developing countries like China, insecticides such as organophosphorus and pyrethroid and fungicides like triazoles and chloronitriles are frequently used for pest control and disease vector eradication. However, due to inadequate pesticide handling practices by farmers, the use of more toxic pesticides, and insufficient management and regulation of these chemicals, developing countries experience a higher incidence of pesticide poisoning than developed nations (Syed *et al.*, 2014).

Africa's situation worsens due to the use of pesticides banned in developed countries because they impact wildlife reproductive health and behaviour (Ahoudin *et al.*, 2018).

Following the ban on organochlorine pesticides, organophosphates like dichlorvos have become the most commonly used pesticides in Africa despite being classified as "hazardous" by the World Health Organization (WHO) (Mwanja *et al.,* 2017). In documented cases of poisoning leading to acute or chronic adverse health effects, dichlorvos usage is indiscriminately and inappropriately used, leading to harmful environmental and health consequences (Mwanja *et al.,* 2017). Several studies examining pesticide residues in fruits and vegetables have shown that these agricultural products may contain levels of insecticides exceeding the Maximum Residue Limits (MRL) established by the United Nations through the Codex Alimentarius Commission (Mwanja *et al.,* 2017).

Africa contributes 2–4% to the global pesticide market, representing the lowest usage rate worldwide. Wibowo & Adisty (2017) posits that the rapidly growing population and food demand will increase significantly over the next three decades, leading to a higher demand for pesticides, herbicides, and fungicides (Ngadaya *et al.,* 2017). In Africa, a lack of knowledge about proper pesticide usage has led to applying pesticides classified as hazardous by the WHO. In Ethiopia, Sharma et al. (2019) found that 160 out of 302 registered pesticides contained active ingredients classified as WHO class II (moderately hazardous). Similar trends have been observed in other African countries using WHO-classified hazardous pesticides (Mfinanga *et al.,* 2014).

In a study in Nigeria, Sharma et al. (2019) found that 78% of farmers used Monocrotophos, a WHO class Ib pesticide (highly hazardous). Other pesticides used included atrazine and metolachlor, classified as WHO class III (slightly hazardous), and lindane, copper sulphate, and paraquat, classified as WHO class II. Previous studies indicated that 41% of farmers in Zambia used Monocrotophos (class Ib), while over 25% of farmers in Malawi used parathion, a WHO class Ia pesticide (extremely hazardous). A common problem with pesticide use is pest resistance, leading to crop destruction despite proper application. For example, in West Africa, the use of pyrethroids has caused resistance in the tomato bollworm (*Heliothis armigera Hübner*) and the diamondback moth (*Plutella xylostella*), according to Sharma *et al.,* (2019). A study conducted in Tanzania by Marete et al. (2020) found that smallholder farmers commonly use various pesticides.

Insecticides are the most prevalent (59%), followed by fungicides (29%), herbicides (10%), and rodenticides (2%).

The study also found that a considerable portion of the workforce, accounting for 68%, experienced health issues characterized by skin problems, dizziness, and headaches following routine pesticide applications. These workers incurred substantial healthcare expenses due to treating these pesticide-related health complications. The study also noted that even after regularly practicing pesticide application techniques, 68% of the employees had trouble with health issues such as skin troubles, dizziness, and headaches. These workers suffered from high healthcare costs when seeking treatment for these health problems related to the use of pesticides.

The indiscriminate use of pesticides, linked to environmental and health concerns such as soil and water pollution and the spread of diseases among humans and livestock, was identified as the leading cause of these health problems. The research highlighted that pesticide residue levels in water and food exceeded recommended safety levels (Marete *et al.*, 2020).

A study conducted in the Kaliluni sub-location, Kenya, as outlined by Mutuku et al. (2014), observed that pesticides commonly used in the area include pyrethroids, organophosphates, and carbamates. The study found that 36.8% of farmers applied pyrethroid-based pesticides, while 31.5% opted for carbamate-based ones. Pesticides play a crucial role in Kenyan agriculture by reducing crop losses caused by insects, weeds, plant diseases, rodents, and other pests (Wibowo & Adisty, 2017).

Along with enhancing the quality and quantity of agricultural produce, these compounds also help to protect public health by reducing the presence of disease-carrying insects. In spite of their advantages, pesticides are recognized in the study as potentially dangerous compounds that can pollute the environment (Mutuku *et al.*, 2014). The study draws attention to these inherent hazards.

Mutuku et al., (2014) also observed that some farmers simultaneously used multiple pesticides in a single application. A small portion, comprising 1.9% of the respondents, utilized Dimethoate (an insecticide) despite its restricted use for fruits and vegetables, and 0.5% employed Mocap (an insecticide), which was banned. The prohibited chemicals were found to be more effective than other available pesticides. Regarding the frequency of pesticide application, the study found that 86.1% of farmers applied pesticides weekly, while 12.5% applied them fortnightly. Pesticide residues were detected in various food items worldwide, according to Marete *et al., (*2020).

More thorough information on pesticide usage habits and residue levels in horticultural products from the upper Nyambene basin is needed. Kenyan markets see the local and export consumption of these goods. The paucity of such data suggests a need to understand further the possible dangers of pesticide use in this area. This study investigated pesticide use practices and pesticide residue concentrations in kale and domestic water sources. This information will help improve food and water safety, protect the environment, and promote public health.

1.2 Statement of the Problem

Pesticides play a crucial role in protecting food crops from pests and crop losses in horticultural farming. However, some of these pesticides are hazardous and stay long in the environment after application. Their residues may contaminate water, soil and plants posing a threat to the environment and food safety. Just like in many agricultural potential areas in Kenya, Nyambene catchment area has experienced horticultural intensification due to the accessibility of irrigation water and the high returns of kale farming. Farmers in this area apply different types of pesticides (fungicides, herbicides rodenticides) to control pests and diseases. Despite evidence of intensive use of pesticides in this area, there is limited information on pesticide practices and pesticide residues in kales which is the most available vegetable in the local markets. The slopes of Nyambene catchment where spraying of kales with pesticides is done, is a good driver for surface runoff in addition to the porous soils due to the volcanic soil parent material posing a risk to ground water contamination. While majority of the inhabitants in Kiegoi consume water from the flowing rivers, streams and springs for domestic water supplies, information on water quality is not available exposing the community to likely health risks from pesticide contamination in these water sources. This study filled this gap by assessing pesticides practices and residues levels in kales and water in the study area.

1.3 Objectives of the Study

The study was guided by a broad objective and three specific objectives.

1.3.1 Broad Objective

The broad objective of the study was to assess pesticide use practices and residue levels in locally produced kales and domestic water sources in Kiegoi, in the upper Nyambene Catchment, Kenya.

1.3.2 Specific Objectives

The study sought to achieve the following specific objectives:

i. To determine the types of pesticides commonly used by kales farmers in Kiegoi, in the upper Nyambene catchment, Kenya.
ii. To analyse the pesticide residue concentrations in locally produced kales and domestic water sources in Kiegoi location, in the upper Nyambene Catchment, Kenya.
iii. To assess the pesticide practices in Kiegoi location, in the upper Nyambene Catchment, Kenya.

1.4 Research Questions

Based on the research objectives, the study answered the following research questions:

i. What are the commonly used types of pesticides in Kiegoi, Nyambene Catchment?
ii. What concentrations of pesticide residues are in locally produced kales and domestic water sources in Kiegoi, Nyambene Catchment?
iii. What pesticide practices are used in Kiegoi location in the upper Nyambene Catchment, Kenya?

1.5 Significance of the Study

The research holds substantial benefits for various stakeholders, particularly horticultural kales farmers in Kiegoi, Nyambene Catchment and beyond. The findings have the potential to contribute to enhancing food and water safety, protecting the environment, and promoting public health in the Nyambene catchment area. By addressing areas of concern such as improper pesticide application and the risk of water contamination from surface runoff, the study will inform policies and interventions aimed at mitigating pesticide-related risks and improving agricultural practices in the region. The findings generated will inform farmers on safer and more sustainable pesticide use practices including proper storage, disposal, timing, and application techniques. The information on safe pesticide practices not only improves crop yields but also reduces health and environmental risks. The study will empower consumers to make informed and safer food choices by providing information on pesticide labels and encouraging the adoption of sustainable farming methods.

1.6 Scope of the Study

The research was done in Kiegoi location, in the upper Nyambene catchment, Kenya which is known for horticultural crop production supplying kales to the surrounding urban settlements. The study focused on assessment of pesticide use practices and residue levels in locally produced kales and domestic water sources. On pesticides use practices the variables tested include, frequency of application, use of recommended protective gears, discarding of empty pesticide containers, pesticide storage practices, interpretation of pesticides labels, mixing and dilution of pesticides according to recommended ratios. The data on pesticide residue levels in locally produced kales and domestic water sources was collected during the dry (October-November, 2023) and wet season (April-June 2024).

1.7 Limitation of the Study

The study was limited to language barrier during data collection. The study therefore hired the research assistant to ensure effective communication between the researcher and participants. Inaccessibility to the sampling points in the study area was experienced due to rugged terrains and poor roads while trying to access the study area during sampling process. The researcher therefore collaborated with local community leader familiar with the area to facilitate access to sampling points and navigating difficult terrain and identifying alternative routes. The study also involved high cost of sample analysis which affected the number of samples analyzed in the study. To manage the sample analysis cost, the researcher therefore applied for Internal Research Fund (IRF) from Chuka University to collect and analyse the collected data.

1.8 Operational Definition of Terms

Active ingredient: It is the chemical compound responsible for the pesticidal effect found within its formulation.

Assessment: Refers to the process of evaluating the pesticide use practices and residues concentrations in locally produced kales and domestic water sources.

Characterization: This refers to the categorization of pesticides based on their chemical composition

Contact Pesticides: Are chemicals that act upon direct contact with the target pest. They are typically applied to the surfaces of plants or other surfaces where pests are present.

Domestic Water Sources: Refers to the main stream water that is used for drinking and irrigating horticultural crops in the study area.

Kale: Is a leafy green vegetable, belonging to the Brassica oleracea species, which also encompasses crops like sukuma wiki.

Organophosphates: This pertains to chemical compounds initially formed through the reaction between alcohols and phosphoric acid.

Pesticide Residue: Refers to traces of pesticides that may persist on or in agricultural products, such as fruits, vegetables, grains, and other crops, after they have been treated with these chemical substances.

Pesticide: A substance or combination of substances designed to promote growth, eliminate, prevent, or control any pest, including carriers of human or animal diseases, as well as undesired species of plants or animals causing harm.

Phytotoxicity: This refers to the harm caused to plant growth due to toxic compounds left behind by pesticide residues.

Pre-harvest Interval (PHI): The shortest duration of time required between the final application of a pesticide and the commencement of harvesting.

Residual Pesticides: This describes a combination of agricultural chemicals that persist for an extended period without rapid decomposition and can effectively manage pests over a prolonged duration.

Systemic Pesticides: Pesticides that are taken up by plants or animals and transported within their untreated tissues. Systemic insecticides or fungicides move throughout the treated plants, targeting specific insects or fungi for elimination.

Residue Levels: The concentration of pesticide residues that may remain on crops or in the environment after application.

Maximum Residue Limits: Regulatory standards specifying the maximum allowable residue levels in food and the environment.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of Pesticide Usage

Farmers rely significantly on pesticides to manage weeds and diseases and combat pests in their crops, as highlighted by the research of Sharma et al. (2019) and Salam et al., (2020). Pest invasions reportedly result in a loss of more than 45 percent of food production each year. The soil and environment of our planet are at risk due to an unsettling trend (Salam *et al.,* 2020). According to Sharma et al., (2019), the widespread use of pesticides and persistent organic pollutants in agricultural soils presents risks with far-reaching consequences.

Globally, approximately 2 million tonnes of pesticides are used annually, with China being the largest consumer, followed by the USA and Argentina. 2020, global pesticide use was expected to increase to 3.5 million tonnes. Significant yearly increases in pesticide imports have been recorded in Cambodia (61%), Laos (55%), and Vietnam (10%) (Sharma *et al*., 2019). In North America, studies have found glyphosate and atrazine in water bodies, along with lower concentrations of Malathion, chlorpyrifos, diazinon, lindane, dieldrin, and dichlorodiphenylethane (DDE). These chemicals are toxic to many creatures, including wildlife and bees. Raptors like the imperial eagle and the bearded vulture (Gypaetus barbatus) are especially detrimentally impacted (Di Vittorio *et al.,* 2018).

In Argentina, pesticide usage has significantly increased, with total consumption increasing from 73 to 236 million kg per year over the past decade. This rise resulted in a turnover of 2,381.16 million USD in 2012. Herbicides are Argentina's most widely used pesticides, accounting for 64% of usage, followed by fungicides at 20% and insecticides at 16%. The Argentine pesticide market is heavily dominated by herbicides (86.8%), primarily glyphosate, 2,4-D, and atrazine. Insecticides constitute 6.2% of the market, with cypermethrin, chlorpyrifos, and lambda-cyhalothrin being the most common, while fungicides make up 2.7%, including epoxiconazole, tebuconazole, and ketoconazole. The observed pesticides pose significant environmental hazards due to difficulties in safe storage and disposal, leading to soil and water pollution and harming microflora and microfauna. In Australia, pesticide contamination of water bodies is a significant concern (Sharma *et al.*, 2019).

In Africa, pesticide usage represents only 2–4% of the global market share; the lowest rate worldwide (Sharma *et al*., 2019). A study in Ghana on pesticide use found that farmers often use pesticides like DDT and HCH, even though these are banned in more developed countries (Aniah *et al*., 2021). These pesticides pose serious threats to the environment and public health because of their detrimental effects on biodiversity, the food chain, and non-target creatures. Moreover, using pyrethroids has caused pests like the tomato bollworm and diamondback moth to develop resistance (Aniah *et al.,* 2021). An aphid species has also developed resistance to pyrethroids and organophosphates, and whiteflies have developed resistance to pyrethroids, organophosphates, and neonicotinoids (Aniah *et al.,* 2021).

Aniah et al., (2021) also emphasize that unsafe pesticide practices in developing countries involve various issues. These include using pesticides banned by the national government, over-spraying, not using protective measures, improper storage, mishandling pesticide containers, and, in extreme cases, reusing washed pesticide containers for storing food and drinking water. Both public health and environmental sustainability are seriously threatened by these practices, which increase the risks connected to pesticide use.

Over 50% of farmers in Botswana rely on Malathion and cypermethrin, which are WHO class II pesticides, according to a study by Marete et al. in 2020. Additionally, the survey found that 1.8% of farmers use dichlorvos, 2.7% use demeton-S-methyl, and 7.1% use methomyl—all designated as very toxic WHO class Ib pesticides. It has been demonstrated that these pesticides present serious dangers to the environment. Additionally, pesticide leaching adds to the local water bodies' pollution (Sharma *et al.,* 2019).

Six rivers in Kenya's Lake Victoria catchment area discharge pollutants into the lake (Sharma *et al.,* 2019), making applying herbicides effectively difficult. These include a lack of application equipment, a lack of trained agricultural extension agents, a lack of knowledge, and weak farming infrastructure and regulations. Pesticide resistance in pests worsens the problem (Marete *et al.*, 2021). The UN has recognized that these pesticide-related challenges in developing nations are primarily due to insufficient training for farm workers, extension workers, and healthcare personnel (Marete *et al.*, 2021). By encouraging the use of protective gear, such as clothes, gloves, and goggles, when handling pesticides and guaranteeing compliance with labelling and package instructions, adequate training would decrease exposure and prevent poisoning (Di Vittorio, 2018 & Marete *et al.*, 2021).

2.2 Pesticide Types

Pesticides are crucial in 21st-century agriculture globally, controlling pests, weeds, and plant diseases to minimize crop losses and ensure high-quality produce (Isah *et al.*, 2020). Each year, approximately 6 million tons of pesticides are used to enhance agricultural productivity, underscoring their significant role in modern farming. Future projections indicate a continued rise in pesticide use until 2027, especially in sub-Saharan Africa, where agricultural output is expected to increase rapidly (Fuhrimann *et al.*, 2020). However, intensive pesticide use contributes to climate change-induced changes in land use, shifts in pest patterns, and outbreaks of diseases carried by vectors. Furthermore, increasing pest resistance necessitates the adoption of diverse active ingredients, with South Africa alone offering over 700 varieties (Fuhrimann *et al.*, 2020).

In Nigeria, especially among farmers in Kano State, the use of pesticides has seen significant advancements over the last twenty years, remaining essential for managing agricultural pests and disease vectors (Isah *et al.*, 2020). Nevertheless, heightened concerns about environmental pollution have raised public awareness regarding the risks of pesticide exposure, which can severely impact ecosystems. For instance, pesticide runoff can pollute water reservoirs and harm non-target organisms (Isah *et al.*, 2020).

According to the World Health Organization (WHO), 20% of global pesticide use occurs in developing nations, where misuse poses significant risks to human health and the environment (Nguyen *et al.*, 2018). Misapplication, responsible for 80% of pesticide usage, not only reduces effectiveness but also increases production costs and environmental toxicity. Pesticides are classified based on their method of entry, chemical makeup, and target organisms, ranging from moderately hazardous to posing little acute risk under normal conditions (Nguyen *et al.*, 2018). In Vietnam, vegetable farmers often apply pesticides excessively, leading to numerous cases of pesticide residue poisoning reported annually. Additionally, pesticides are categorized into three main types- insecticides, herbicides, and fungicides-based on the organisms they target, and their chemical composition includes organochlorines, organophosphorus compounds, carbamates, and pyrethrin/pyrethroids (Kaur *et al.*, 2019).

In Kenya, regulations on pesticides aim to manage the use of specific chemicals to minimize potential risks to human health and the environment. Kenyan authorities have banned several pesticides, such as Dibromochloropropane (DBCP), Ethylene dibromide (EDB), 2,4,5-T phenoxy herbicide, Chlordimeform, all forms of HCH, Chlordane, Captafol, Heptachlor, Toxaphene (Camphechlor), Endrin, and Parathion (methyl and ethyl), due to their adverse effects. Additionally, certain pesticides are subject to specific restrictions. For instance, Lindane is permitted solely for seed treatment, Aldrin and Dieldrin are restricted to use as termite control agents in construction, and DDT is limited to public health purposes for mosquito management. These regulations ensure that these pesticides are used only when their potential risks are carefully minimized and controlled (Warmuth, 2013).

2.2.1 Organochlorine Pesticides

Organochlorines, as described by Ali *et al.,* (2014), are chemicals known for their persistence in environmental degradation and their ability to transport over long distances. These substances remain in soils, air, and water, accumulating in food chains and bio-accumulating in humans through processes like evaporation and washout by rain and floods. In South Asian countries, inadequate waste management practices, including direct dumping of municipal waste into open sites, contribute to organochlorine pollution. Furthermore, runoff and the presence of abandoned factories once producing organochlorine pesticides (OCPs) exacerbate pollution in various environmental areas, prompting concerns about potential adverse effects on local communities and ecosystems.

The widespread use of organochlorine pesticides to enhance agricultural production has led to increased contamination of soil, water, and food chains. Study by (Musa *et al*., 2011), conducted in the Rift Valley region of Ethiopia has observed organochlorine pesticides such as endosulfan and DDTs in soils, posing a persistent threat to ecosystem health. Despite documented health risks linked to organochlorines, there is evidence of continued use in developing countries, especially in sub-Saharan Africa, due to their effectiveness and affordability. Weak import controls and inadequate monitoring further contribute to their widespread distribution (Musa *et al.*, 2011).

Organochlorines have garnered significant attention from the scientific community due to their ability to accumulate in organisms and their harmful impacts on unintended species. Consequently, countries like Kenya, over the past forty years, have implemented bans or restrictions on organochlorine pesticides like DDT (Dichloro-Diphenyl-Trichloroethane), Aldrin, Dieldrin, and Endosulfan, once extensively used and approved by PCPB for managing pests in horticultural crops such as vegetables and fruits due to their harmful effects (Musa *et al*., 2011). Despite these measures, Kenya still faces challenges in managing pesticide and other persistent chemicals, which were prohibited under international agreements like the Stockholm Convention. Poor enforcement of environmental protection laws has worsened the situation, potentially increasing human exposure to these pollutants (Ali *et al*., 2014).

2.2.2 Organophosphate Pesticides

Organophosphate pesticides have been widely used globally for over six decades and are absorbed efficiently through inhalation, ingestion, and skin contact (Otieno, 2019). However, due to concerns about their toxicity and environmental impact, certain organophosphorus compounds such as parathion and chlorpyrifos were restricted or banned over a decade ago (Otieno, 2019). These pesticides have been associated with poisoning from human exposure (Jaipieam *et al*., 2009). When these chemicals are used to control crop pests and diseases, they undergo transformations into various metabolites influenced by environmental factors such as pH, temperature, and light intensity. These transformations can alter their toxicity and effects (Otieno, 2019). Toxicity levels vary depending on factors such as chemical structure, mode of action, dosage, application method, route of entry, and degree of decomposition (Otieno, 2019).

According to Omwenga *et al*., (2021) in their study on pesticide classification, organophosphates were considered safer than organochlorines like aldrin, dieldrin, and DDT. They classified chlorpyrifos as moderately to highly hazardous according to WHO, FAO AND the US Environmental Protection Agency (EPA). The study also underscores the excessive use of organophosphate pesticides in various crops can lead to levels of accumulation exceeding permitted limits, impacting agricultural product quality and raising concerns about human health (Omwenga *et al*., 2021).

In Kenya, pesticide usage remains crucial due to the hot and humid tropical conditions that are prone to pest infestations (Omwenga *et al.*, 2021). Importantly, organophosphate pesticides that are banned in developed regions such as the EU, USA, and Canada-such as chlorpyrifos, profenofos, acephate, metamidophos, dimethoate, and omethoate-continue to be used in developing nations like Kenya (Omwenga *et al*., 2021).

2.2.3 Carbamates

According to Morais and Pereira (2012), carbamates serve various purposes as insecticides, fungicides, nematocides, acaricides, or herbicides. However, the widespread use of carbamate pesticides such as Carbaryl, Carbofuran, Aldicarb, Methomyl, and Oxamyl registered in Kenya under the Pest Control Products Board (PCPB) has raised significant public concerns regarding environmental and food safety. The inappropriate use of these active ingredients can contaminate vegetables from previous soil treatments, leading to cross-contamination. Since their introduction to the agrochemical market in the 1950s, carbamates have become a prominent category of synthetic organic pesticides and are annually employed on a large scale globally (Morais & Pereira, 2012). This versatile class of compounds finds application in insect control, fungal protection, nematode management, mite eradication, mollusc extermination, sprout inhibition, and weed control (Morais & Pereira, 2012).

2.2.4 Pyrethroids

Pyrethroids like Cypermethrin and Deltamethrin are widely used in agriculture due to their effectiveness against a broad range of pests such as aphids, beetles, caterpillars, and mites, making them valuable in horticulture. Deltamethrin, known for its potency, plays a crucial role in controlling aphids, caterpillars, and beetles in agricultural and residential environments. Similarly, Lambda-cyhalothrin is highly efficient in managing agricultural pests like moths, beetles, and aphids, and is also used in public health efforts to combat disease vectors such as mosquitoes. These pesticides have been extensively employed worldwide since the 1980s due to their effectiveness and relatively lower toxicity compared to alternatives such as organophosphorus and carbamate compounds (Tang *et al*., 2018).

While pyrethroid pesticides have reduced potential for environmental pollution, they can still enter organisms through food chains and pose significant toxicity to aquatic life, leading to long-term adverse effects in aquatic environments. Previous research has documented the global presence of pyrethroid insecticides in sediments and their harmful effects on benthic invertebrates. However, comprehensive reports on pyrethroid pollution across various media on a global scale are currently lacking (Tang *et al.,* 2018). Furthermore, recent studies have emphasized the heightened aquatic risks associated with the use of pyrethroid insecticides compared to other types of insecticides (Wang, 2023).

2.3 Pesticide Residues

Agricultural pesticides are crucial for safeguarding crops against diseases and pest infestations. However, their presence in food, water, and the environment raises substantial concerns due to potential negative impacts. Studies indicate widespread pesticide contamination in the air, soil, and water ecosystems, particularly in developing countries like Nigeria. These nations often import a significant proportion of pesticides, including those banned in developed countries (Adeyeye *et al.,* 2021).

Similarly, Kenya has seen a surge in pesticide use due to population growth and increased demand for food. However, misuse of pesticides in farming, as observed in Meru district, has led to soil and water pollution, with pesticides accumulating in food, posing health risks to humans and wildlife (Kariathi & Kimanya, 2016). Insecticides, particularly organochlorines, have attracted considerable global attention due to their affordability, effectiveness, and potential harm to non-target organisms (Adeyeye *et al*., 2021). Despite their intended purpose of pest control, pesticides can contaminate various environmental components, posing risks to biodiversity and ecosystem sustainability. The fate of pesticides in the environment and their toxic effects are reviewed and described in the following section.

2.3.1 Pesticides Residues Concentrations in Domestic Water Sources

Pesticide usage presents significant environmental challenges globally, with diverse impacts observed across different regions. Despite the ban of DDT usage in many countries due to concerns regarding its persistence and environmental accumulation. In Kenya use of DDT (Dichloro-Diphenyl-Trichloroethane) for agricultural use was banned in 1986, under the Pest Control Products Board (PCPB) Act. However, DDT was still permitted for specific public health uses, particularly for malaria vector control, until the early 2000s. In 2006, Kenya officially banned the importation and use of DDT for all purposes except in emergency situations for the control of disease vectors (Ogola & Olale, 2023). In the United States, organophosphates and specific herbicides, including atrazine and metolachlor, have dominated insecticide usage, though the comprehensive understanding of their environmental occurrence and associated risks remains limited (Wang *et al*., 2021).

The aquatic environment, sensitive to pesticide contamination, faces risks from various sources such as agricultural runoff and industrial discharges (Wang *et al.*, 2021). Studies in regions like Thailand have observed increased accumulation of pesticide residues in surface water, with chlorpyrifos and cypermethrin commonly detected as contaminants (Sangchan *et al*., 2014). Similar patterns have been observed around Lake Victoria in Tanzania and Kenya, where the use of organochlorine pesticides for agriculture and vector control has resulted in elevated pesticide residues in nearby riparian zones, soils, and sediments, posing risks to both human health and the environment (Nyaundi *et al*., 2019).

Ngolo et al., (2019) in their study in the Meru region of Kenya on pesticide handling practices, observed cleaning of pesticide cans near riparian zones. Poor handling of empty pesticide containers, coupled with limited knowledge on pesticide management, has led to increased pesticide residue levels, posing threats to food safety and water quality for users. Despite regulatory restrictions, the use of DDT continues, with some farmers resorting to improper disposal methods that contribute to water contamination (Ogola & Olale, 2023). Furthermore, the expansion of floriculture farming around Lake Naivasha has worsened pesticide contamination, as significant amounts of sprayed chemicals reach unintended destinations (Anode *et al*., 2018). However, despite the evident risks and impacts, many cases of pesticide pollution in Kenya remain undetected and unreported, contributing to the degradation of ecosystems such as Lake Victoria (Osoro *et al.*, 2016).

2.3.2 Pesticide Residues Concentrations in Locally Grown Kales

Pesticide residues present a significant food safety concern in especially in fruits and vegetables sensitive to pest infestations such as aphids especially at stage of growth. In Europe, there were 2473 food alert notifications related to pesticide residues in fruits and vegetables between 2015 and 2020. Similar issues have been documented in developing countries, where pesticide residue levels have often surpassed maximum thresholds in fresh kales (Pan *et al.,* 2021). China, being one of the largest producers and consumers of pesticides globally, faces challenges. Instances of export rejections of agricultural products from Japan, Canada, and other nations due to raised pesticide residue levels have been reported. Despite efforts by the Chinese government to tighten controls on pesticide residues in agricultural products, illegal pesticide usage persists, such as the case of toxic cowpeas in southern China.

Pesticide residues pose a significant food safety concern, especially in fruits and vegetables susceptible to pest infestations like aphids during their growth stages. In Europe, there were 2473 food alert notifications related to pesticide residues in fruits and vegetables between 2015 and 2020. Similar issues have been reported in developing countries, where pesticide residue levels have often exceeded maximum thresholds in fresh kale (Pan *et al.,* 2021). China, being one of the largest producers and consumers of pesticides globally, faces challenges in this regard. Instances of agricultural product rejections from Japan, Canada, and other countries due to elevated pesticide residue levels have been documented. Despite efforts by the Chinese government to strengthen controls on pesticide residues in agricultural products, illegal pesticide use persists, as seen with toxic cowpeas in southern China.

According to Shrestha et al., (2010), in Nepal and India, global warming poses a significant threat to pesticide safety in food and human health. They also suggest that climate change affects pesticide safety. Additionally, reports indicate that pesticide usage in vegetables is notably higher compared to other food products in Nepal. However, previous research on pesticide usage in vegetables specifically in the Dhading district is lacking.

Vegetables play a crucial role in human nutrition by providing essential nutrients necessary for various bodily functions. However, like other crops, vegetables are susceptible to pest and disease attacks throughout the production and storage process, resulting in damage that reduces both quality and yield. To mitigate these losses and maintain harvest quality, pesticides are used alongside other pest management strategies during cultivation to eradicate pests and prevent diseases (Tiwari *et al*., 2022).

Pesticide residues in vegetables result from prolonged pesticide use in farming, forming toxic metabolites. A significant portion of these residues in vegetables comprises pesticide mixtures, including commonly used types like organophosphates, organochlorines, and pyrethroids. The issue of food safety arising from pesticide residues exceeding standards has become a pressing health concern in China. In a survey conducted in April 2009, it was found that residents in Beijing, Shanghai, and Guangzhou were potentially exposed daily to a harmful "pesticide cocktail" containing five types of pesticides, some of which are carcinogenic (Liu *et al*., 2023).

A study conducted by Spanish researchers focused on a range of pesticides found in citrus fruits, as well as other fruits and vegetables. The investigation revealed that commercial processing methods significantly reduced pesticide residue levels in the final products of both field-sprayed and processed fruits and vegetables. Furthermore, food processing techniques, including home preparation methods like washing, peeling, and cooking, were found effective in reducing or eliminating insecticide and other pesticide residues on food crops (Shokoohi *et al.*, 2022).

The pesticides including OCPs, Ops, carbamates, pyrethroids, and neonicotinoids are commonly used in different parts of Kenya (Marete *et al.*, 2019). The continuous use of pesticides in agriculture has raised concerns about the possibility of these chemicals infiltrating groundwater. The presence of harmful residues on edible parts of crops and their subsequent entry into water bodies has emerged as a significant source of apprehension. This issue exacerbates as the residues ascend the food chain, with humans being particularly vulnerable as they occupy the apex of the food chain.

The frequency and quantity of pesticide usage play a crucial role in determining contamination levels. In the Ewaso Narok wetland of Laikipia County, Kenya, pesticides are applied at doses exceeding recommended levels, leading to elevated residue levels in vegetables. These residues have the potential to bio-accumulate in primary, secondary, and tertiary consumers of contaminated vegetables, thereby posing irreversible chronic health effects on consumers, even at minimal concentrations (Sarkar *et al*., 2021).

Poor pesticide handling practices, particularly among small-scale farmers in most parts of Kenya, have led to the presence of pesticide residues in Kenyan tomatoes and French beans. A study by Marete et al., (2020) observed residues of carbendazim, imidacloprid, acetamiprid, azoxystrobin, chlorpyrifos, and metalaxyl in tomatoes and French beans grown. Similarly, Ngolo et al., (2019) found pesticide residues in tomatoes grown in the Ewaso Narok wetland, with concentrations of cyproconazole I and II, fenpropathrin, and spiroxamine exceeding the European Union's maximum residue limits (MRLs).

Additionally, dimethoate and chlorpyrifos residues were detected in French bean samples collected from Nairobi and its surroundings (Griffith *et al*., 2020). The consumption of pesticide-contaminated vegetables can lead to various adverse health effects, including endocrine disruption, reproductive disorders, and dermatologic, genotoxic, and carcinogenic effects (Griffith *et al*., 2020). The presence of pesticide residues in fruits and vegetables has emerged as a critical food safety issue globally, with Botswana and Kenya being no exception. Studies reveal alarmingly high levels of pesticide residues, often exceeding recommended limits set by international bodies like the European Union (EU), World Health Organization (WHO), and Food and Agricultural Organization (FAO) (Chamgenzi, 2020).

In Botswana, a significant portion of samples contained pesticide residues, with some vegetables surpassing legislative limits, raising health concerns for consumers (Gondo *et al*., 2021). Similarly, studies in Kenya highlight the widespread use of pesticides in horticultural production, leading to environmental pollution and health risks due to inadequate monitoring and misuse (Marete *et al*., 2020). Moreover, the increased scrutiny from developed countries on chemical residue standards has resulted in the rejection of fresh produce from developing countries like Kenya, impacting export markets and leading to bans on non-compliant firms (Mithibutu *et al*., 2021).

2.4 Assessment of Pesticide Use Practices

Pesticide residues have a major negative influence on agricultural goods' quality, especially those that contain very toxic pesticides, which can be extremely dangerous for quality and safety. The efficiency and selectivity of pesticides and farmers' knowledge of and practices around pesticide use all affect the danger associated with pesticide residues. Safe pesticide application techniques are crucial for preserving agricultural technology and the economy, and they are based on farmers' knowledge of pesticide dangers. According to Sabran and Abas (2021), farmers' knowledge and awareness of pesticide risks play a crucial role in deciding whether or not to use personal protective equipment (PPE).

Farmers are important pesticide users, and it emphasizes how important it is to educate them on the risk's pesticide use poses to human health and the environment. Since farmers are the ones who apply pesticides, their knowledge of pesticide residues greatly influences how they apply the chemicals. The way farmers apply pesticides can directly impact the amount of pesticide residues produced, which in turn can impact the production of safe agricultural products. According to Mehmood et al., (2021), the lack of effective codes of practice, farmers' ignorance of safe food crop production practices, their lack of training and awareness, and inadequate residue monitoring are the main causes of the elevated risks associated with pesticide use.

According to Febriana et al., (2022), farmers tend to apply pesticides excessively and without proper rationale on scanty information regarding the risks associated with pesticide residues, recommended usage guidelines, and standardized regulations in pesticide application (Febriana *et al.*, 2022). For instance, their study on Pesticide management knowledge, attitude, and practices in Indonesian vegetable farmers with Occupational Skin Disease in Magelang, Central Java: Pesticide-related Skin Disease and KAP in Farmers revealed that farm workers in the Gaza Strip extensively used pesticides. The implementation of protective measures was found to be very poor, with the majority of self-reported toxicity symptoms occurring among younger workers.

In Pampaimadu, Sri Lanka, Bhoke's observation indicates that approximately 60% of farmers have a moderate level of knowledge about plant protection practices; 6% of farmers show a good understanding of recommended plant protection measures, but the majority still use chemical pesticides to control pests and diseases, frequently using concentrations that are 35% higher than recommended. The report indicates that many users need more awareness regarding the potential short and long-term risks associated with pesticides, and necessary precautions for their proper application are not consistently taken. Farmers, consumers, and pesticide management officials may need to be made aware of the harmful effects of pesticides, which leads to the problems associated with pesticide residue (Mehmood *et al.,* 2021).

In Vietnam, agrochemicals mitigate insect-borne and endemic diseases and safeguard plants and animals. However, concerns arise due to the escalated usage and misapplication of pesticides, posing risks to agricultural workers, food consumers, and the environment. The study also reveals that improper pesticide usage adversely impacts human health and the environment, disrupts wildlife habitats, fosters pesticide resistance among insects and diseases, and contaminates ground and surface water resources. (Nguyen *et al.,* (2018) observed that inadequate storage, incorrect application rates, improper mixing of pesticides, and inappropriate disposal practices are crucial aspects that farmers should be knowledgeable about (Nguyen *et al.*, 2018).

Research on pesticide usage methods was carried out in Bangladesh by Ali *et al.,* (2020). They noticed they only needed a little information on pesticide handling-techniques. Pesticides have both positive effects on agricultural and human welfare, as well as adverse effects on human health, non-target creatures, and the ecosystem as a whole, as the study has shown

In China, Rijalet et al, (2018) found that most farmers must follow proper pesticide disposal methods, often disposing of them in sensitive areas like streams and rivers. Rijalet et al., (2018) also revealed that many farmers are using highly toxic pesticides, some of which are even banned by the World Health Organization (WHO), without fully understanding the potential health and environmental consequences. These findings indicate that farmers in the global south are frequently exposed to hazardous chemicals due to insufficient technical knowledge of pesticide toxicity levels and the necessary safety measures to protect themselves from exposure. Improper handling of pesticides primarily occurs during mixing, application, storage, and disposal processes.

According to Ali et al., (2020), the utilization of banned pesticides, excessive spraying, inadequate personal protection, improper storage of pesticides and their containers, and the reuse of washed pesticide containers for food and drinking water are prevalent unsafe practices observed in developing nations like Nigeria and Ethiopia. In Nigeria, Marete et al., (2020) investigated farmers' understanding and attitudes regarding pesticide application in tomato farming, identifying the types of pesticides utilized and the application methods. The study revealed that 86% of the farmers applied pesticides without using protective gear, attributed to a lack of education, awareness, and engagement with agricultural extension workers.

According to Marete et al., (2020), farmers who grow crops like tomatoes, cabbages, and onions use pesticides in Tanzanian farming practices. They found several different kinds of pesticides, including herbicides (10%), insecticides (59%), fungicides (29%), and rodenticides (2%). The same study found that 68% of the workers reported experiencing health symptoms, such as skin issues and neurological problems like dizziness and headaches, after routine pesticide applications. Much of their income is spent on treatment for these health issues.

In Kireka ward, Wakiso district in Uganda, Nalwanga and Ssempebwa (2011) found that several communities in low-income countries utilize household pesticides for pest management, with insufficient regulation. The study's results indicated that pesticide application in many households is often conducted inappropriately, primarily stemming from a lack of sufficient knowledge regarding their usage.

In Naivasha, Kenya, a study identified symptoms of pesticide exposure among farmworkers, prompting a recommendation for training individuals involved in various agricultural activities such as planting, spraying, weeding, and harvesting (Marete *et al.,* 2021). The study found a lower incidence of symptoms among trained sprayers. It observed that pesticides are commonly stored in family homes, including bedrooms and kitchens, particularly in developing countries. Pesticide containers are often repurposed to store household drinking water, disregarding potential health risks. The study also reveals the challenge of high poverty levels, particularly in the global south, which hinders farmers' access to and affordability of protective equipment. Illiterate farmers face difficulties in reading pesticide label instructions, resulting in the unsafe use of these chemicals (Mehmood *et al.,* 2021).

2.5 Farmers' Compliance with Applicable Safety Standards

Farmers and farmworkers who handle agricultural pesticides are frequently exposed to high levels of pesticides, mainly by inhalation and skin contact. Pesticide handling involves several steps that can result in exposure, including loading and mixing, spraying, cleaning equipment, and accessing and exiting treated areas. When pesticide handlers engage in dangerous handling techniques and neglect to use personal protective equipment (PPE), the repercussions of pesticide exposure usually follow. Consequently, the hazards connected with pesticide exposure can be reduced by using the proper PPE and adhering to safe handling procedures (Sapbamrer & Thammachai, 2020).

In Chile, there is a growing concern about safeguarding consumers from exposure to pesticide residues in raw food, as observed by Elgueta et al., (2021). Ensuring chemical food safety and security ranks high on the agenda for the country's Ministry of Agriculture and the Ministry of Health. Oversight of food safety falls under the purview of the Agricultural and Livestock Service, an entity operating under the Ministry of Agriculture, and the Institute of Public Health, which operates under the Ministry of Health. These agencies are responsible for enforcing compliance with maximum allowable residue levels and ensuring food safety across the nation (Elgueta *et al*., 2021). Although Chile has established a food safety surveillance program coordinated by the SAG and ISP to regulate the proper use of pesticides in agriculture, it currently lacks evaluation of potential exposure and health risks for humans under this program.

Annually, the national surveillance program in Chile examines over 1500 samples of fresh vegetables and fruits across the country. Since 2017, between 15% and 25% of these samples, predominantly fresh vegetables, have been found to surpass the maximum residue levels permitted by law. Among all the pesticides scrutinized in the surveillance, the primary violations were associated with methamidophos, methomyl, chlorpyrifos, cypermethrin, diazinon, and λ-cyhalothrin. Notably, lettuce, spinach, chard, tomatoes, and peppers were identified as the vegetables with the highest levels of pesticide residues (Elgueta *et al*., 2021).

2.6 Conceptual Framework

The study's conceptual framework was constructed solely from a review of existing literature, aligning with the research objectives outlined in Figure 1.

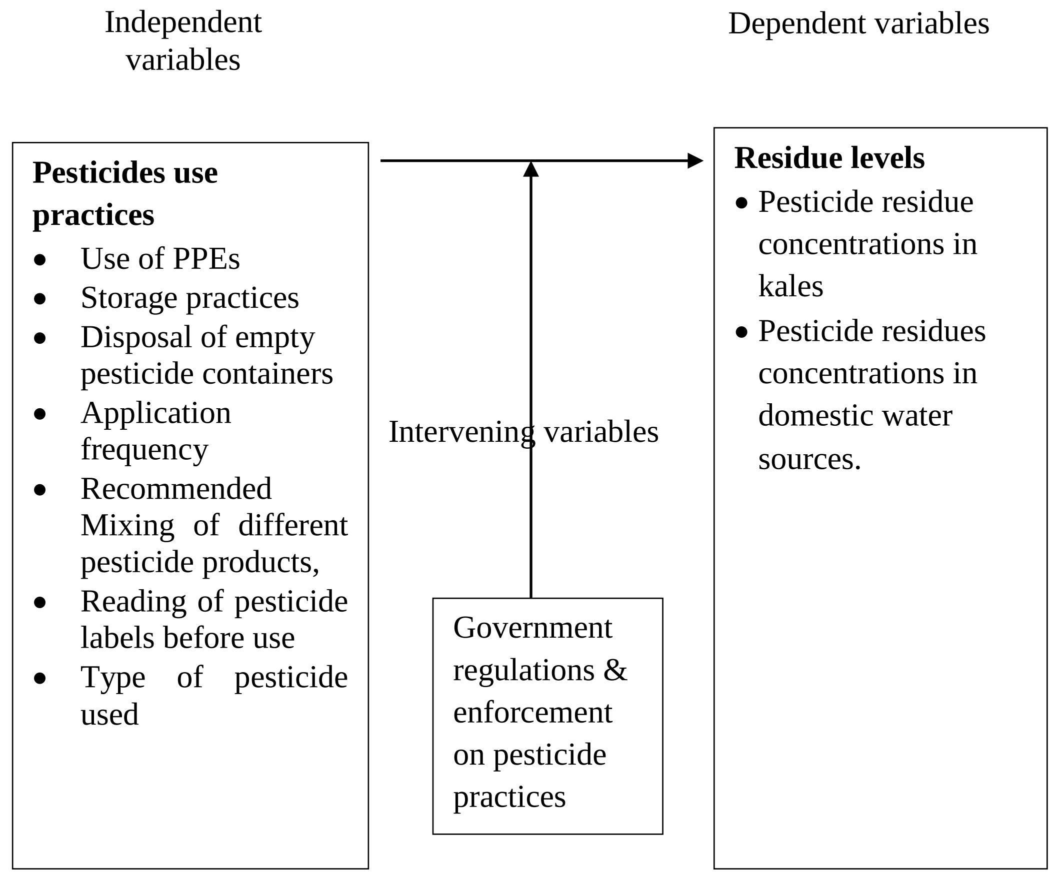

Figure 1: Pesticide Use Practices and Residue Levels among Farmers

The conceptual framework represented in Figure 1 describes the relationships among various variables related to pesticide use practices and residue levels in Kiegoi, Nyambene catchment. It reveals both independent and dependent variables, alongside intervening factors, shaping the dynamics of pesticide management in agricultural settings. The independent variables encompass critical aspects such as the utilization of recommended protective gear, pesticide storage practices, disposal methods, mixing and dilution procedures, and the interpretation of pesticide labels.

These variables directly influence the residue levels found in kales and domestic water sources, serving as key determinants of pesticide exposure and contamination. Concurrently, intervening variables, notably government policy formulation and enforcement, exert a significant indirect influence on pesticide use practices and residue levels. Government policies, regulations, and enforcement mechanisms on safe pesticide use are essential for protecting public health and the environment. These measures are designed to ensure that pesticides are used responsibly and that potential risks are minimized. Policies and regulations typically include guidelines for pesticide registration, labelling, handling, application, storage, and disposal. Government agencies, such as the Pest Control Products Board (PCPB) in Kenya, oversee the implementation of these regulations and enforce compliance through inspections, monitoring, and penalties for non-compliance. By establishing and enforcing policies and regulations, governments can promote safe pesticide practices, prevent misuse and overuse, minimize environmental contamination, and safeguard the health of agricultural workers, consumers, and ecosystems.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Area Characteristics

The study was conducted in Kiegoi location, in the upper Nyambene catchment, , Meru County, Kenya. Kiegoi is within Igembe South constituency and it is in the southwest of Kaathene, and west of Maua town, the area lies approximately between Latitude 0.2336820 and 0.2338350 East and Longitude 37.8747650 and 37.8769230 North. The altitude ranges from around 1,200 meters to over 3,000 meters above sea level.

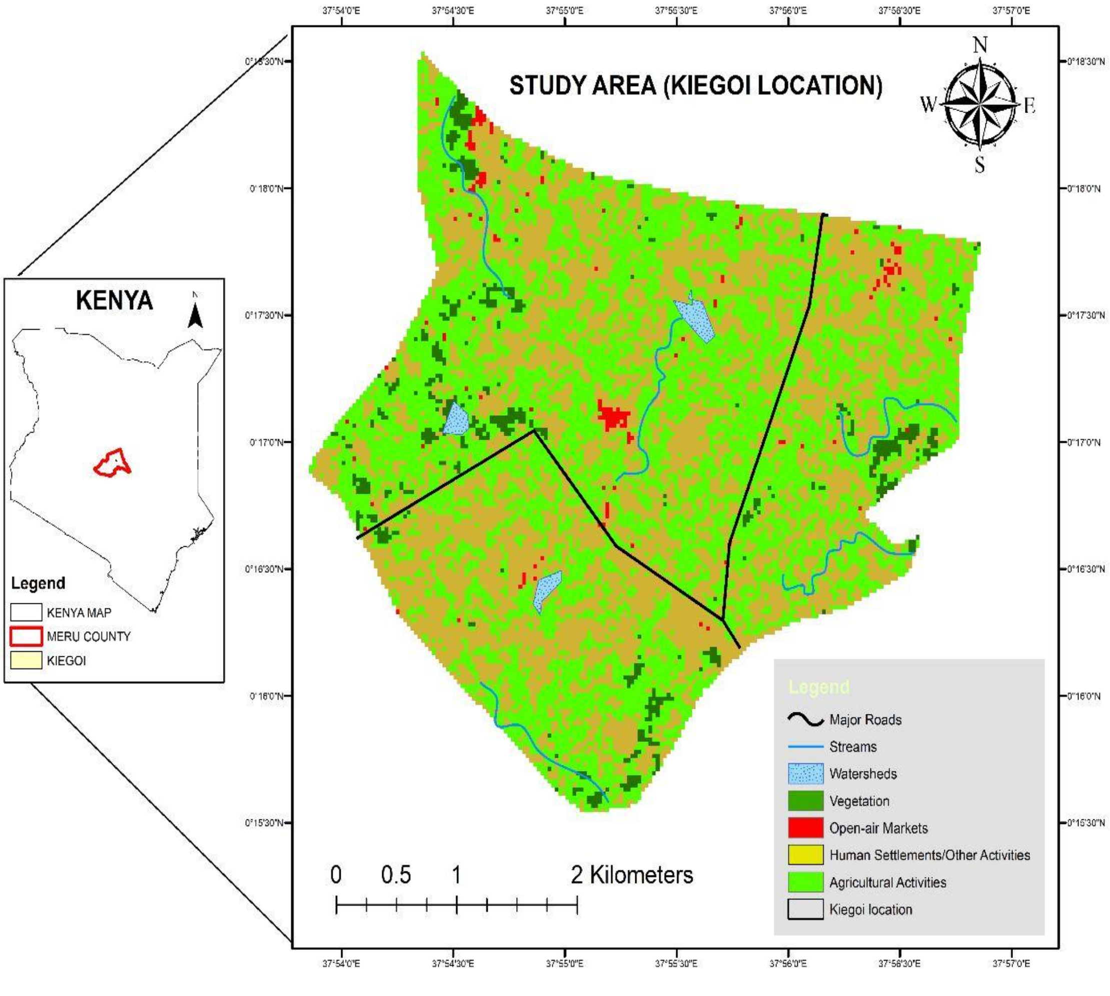

Figure 2: Map of Kiegoi location, Nyambene Catchment Area (Developed Using Arc-GIS Shape Files, 2024)

3.1.1 Climate

The region typically experiences long rains from March to May and short rains from October to December. Annual precipitation ranges widely, from 300mm in the lower midlands to 2500mm in the highlands of the Nyambene catchment area (Eregae *et al*., 2022). The average temperature varies, with minimums around 8°C and maximums reaching 32°C. Rainfall distribution throughout the year is uneven, occurring in two distinct periods (Eregae *et al*., 2022).

3.1.2 Soils

Kiegoi is situated on volcanic terrain, which has contributed to the development of fertile volcanic soils. These soils are rich in minerals and organic matter, making them well-suited for agriculture. The volcanic soils primarily consist of Andosols in the Upper zone, Umbrisols and Nitisols in the Middle Zones, and Cambisols in the valleys. In some lower-lying areas, particularly in the plains, well-drained Nitisols and Cambisols rich in nutrients are suitable for horticultural production (Eregae, 2023).

3.1.3 Vegetation

The climatic characteristics of Kiegoi in the upper Nyambene catchment area influence its vegetation. The region is known for its tea plantations, which thrive in the optimal temperatures between 18°C to 30°C and the ideal annual rainfall between 1,200 mm to 2,500 mm, well-distributed throughout the year. Other vegetation includes grasslands in the lower plain zones, and natural vegetation in the higher-altitude areas. The natural forests harbour indigenous tree species such as *Podocarpus falcatus, Juniperus, Olea africana* (African Olive) and *Croton megalocarpus* and supporting biodiversity conservation. Grasslands, interspersed with scattered shrubs and trees, serve as crucial grazing areas for livestock (Karuri, 2020). Notably, vast tea plantations are a defining feature of the landscape, contributing significantly to the local economy and offering picturesque vistas. Mixed croplands, where maize, beans, bananas, and horticultural products are cultivated alongside trees and shrubs, dominate much of the region (Karuri, 2020).

3.1.4 Economic

Economically, the region depends on livestock production and farming activities; mainly commercial cultivation of crops, which includes the cultivation of fruits and vegetables, as well as tea production, is prevalent. The tea and coffee industries produces approximately 2% of Kenya's total output providing income to numerous small-scale farmers (Kithure, 2022). The area is known for miraa (khat) cultivation, with over 60% of households involved in its cultivation, generating annual revenues estimated at around USD 500 million. Livestock farming, particularly dairy farming, is crucial economic activity in Nyambene. The area has an estimated 300,000 dairy cattle, producing an average of 250 million liters of milk per year. Additionally, there are about 150,000 goats and 50,000 sheep contributing to the local economy (Kithure, 2022).

3.2 Research Design

A cross-sectional study design was used to collect data at a single point in time from a large population of kales farmers in Kiegoi location, in the upper Nyambene Catchment area. The design efficiently captured the types of pesticides and pesticide practices in use by the farmers, providing a snapshot of the prevailing practices. The data on the comparison in pesticide residue concentrations between the dry and wet seasons employed longitudinal study design. The design collected kale and water samples during both seasons, providing data that can be compared over time to understand the impact of seasonal changes on pesticide residue levels.

3.3 Population of the Study

The study area involved a target population of 2,625 individuals, as indicated by the Kenya Population and Housing Census of 2019. According to a report by the Horticultural Crops Development Authority in 2023, 20% of households in Kiegoi, Nyambene catchment area, engaged in horticultural farming. Given that the average household size is 5 persons, the total number of households can be calculated as 2,625 divided by 5, resulting in 525 households. From this, it follows that 20% of 525 households, equivalent to 105 households, comprised the target group of horticultural farmers (sampling frame) for the study.

3.4 Sample Size and Sampling Procedures

The study considered horticultural farming household, water and the kales whose selection was conducted as discussed hereunder:

3.4.1 Horticultural Farming Households

The researchers determined the sample size using Yamane's formula, which is a method commonly used to establish sample sizes that accurately represent the population in research studies. This approach ensures that the sample is sufficiently large to provide reliable and valid results while considering factors like population size and desired level of precision.

$$n = \frac{N}{1+N(e)^2}$$

Where: l

N = target population=105 target households

e = level of precision (0.05)

n = sample size

In substitution:

$$n = \frac{105}{1+105(0.05)^2}$$

$= 83$ Horticultural farming households

The study employed both stratified sampling design and purposive sampling design. Geographically, the study area was stratified into upper, middle, and lower zones of Nyambene catchment area using stratified sampling approach. The horticultural farming households were purposively selected because of their involvement in pesticide use practices. To give each of the stratified zones a uniform number of farmers, the sample size was divided equally across the three zones and a sample of 28 kale farmers was selected from each of the zones.

3.4.2 Kales Sampling

Stratified random sampling was employed to collect locally grown kale samples. A total of 54 kale samples were carefully packed in labelled zip-lock bags, placed in a cool box, and transported to KEPHIS Analytical Chemistry Laboratory in Nairobi, Kenya, for pesticide residue analysis. This procedure ensured a representative sample for pesticide testing across different strata.

3.4.3 Water Sampling

Stratified random sampling was used to collect water samples from Mboone stream, the main tributary in Kiegoi location, Nyambene catchment area. Grab sampling was employed to collect a total of 54 water samples, each 1 litre, in triplicate from the main stream. Sterilized plastic bottles treated with 1 g of mercuric chloride were used to prevent microbial degradation of pesticides. The samples were securely sealed, labeled, stored in a cool box with ice, and transported to the KEPHIS Analytical Chemistry Laboratory for pesticide residue analysis.

3.5 Data Collection Instruments

Two methods were employed for data collection in the study: structured questionnaires and Gas-Chromatography-Mass Spectrometry (GC-MS).

3.5.1 Questionnaires

Structured questionnaires were utilized to gather information regarding the types of pesticides commonly used by kale farmers and the pesticide use practice. Data collection occurred from April 1st to July 21st, 2023, and the analysis was conducted using SPP version 26. Regarding the questionnaires, 68 responses were received out of the targeted sample size of 83 respondents, resulting in an 82% return rate.

3.6 Piloting

A pilot study was carried out using structured questionnaires administered to 12 households in Maili Tatu area in Igembe South constituency. The horticultural households were purposively selected from nearby accessible area. The choice of conducting the pilot study in Maili Tatu area in Igembe Central was based on its similarity in climatic conditions, agricultural activities, and population to the target study area. The pilot study aimed to assess the reliability of the research instruments and identify any weaknesses in the tools before their administration to the target population, as suggested by Cooper and Schindler (2003). Additionally, it evaluated the suitability of the tools, the clarity of questions, and the language used.

3.6.1 Validity of the Research Instruments

Validity assessment was conducted through expert review, wherein the questionnaire underwent scrutiny by experts to evaluate its content validity within the research area or field. Additionally, the researcher collaborated closely with supervisors to ensure that the language used in structuring the questionnaire was straightforward and comprehensible to the respondents. Any extraneous or unnecessary questions were omitted during this process.

3.6.2 Reliability of the Instruments

The researcher employed Cronbach's Alpha reliability test to evaluate the internal consistency of the questionnaires utilized. The overall Cronbach's Alpha Reliability test yielded a score of r=0.712, indicating that the collected data represented approximately 68% of the intended information sought from the research instruments. With a correlation coefficient r value exceeding the threshold of 0.5, the questionnaires were deemed reliable for the study's purposes.

Regarding specific aspects of pesticide use practices in Kiegoi, Nyambene catchment area, and separate Cronbach's Alpha values were calculated. For the pesticide practices, a Cronbach's Alpha value of 0.526 was obtained, suggesting a moderate internal consistency among the items related to pesticide use practices. In terms of the use of protective gear during pesticide application, a Cronbach's Alpha value of 0.671 indicated a moderate internal consistency among the relevant items. Similarly, for the training of farmers on pesticide use, a Cronbach's Alpha value of 0.631 was achieved, indicating a high internal consistency among the items related to pesticide use practices.

3.7 Data Collection Procedures

The study used both questionnaires and laboratory tests as discussed hereunder:

3.7.1 Administration of Questionnaires

The field study utilized pre-tested structured questionnaires containing both open and closed-ended questions. The questionnaires were divided into three sections: Section A focused on demographic information, Section B examined the types of pesticides commonly used by farmers, and Section C assessed the level of community's awareness on pesticide use practices in Kiegoi, Nyambene catchment area. The questionnaires were administered to gather information from horticultural farming households regarding their pesticide use practices in the area. Distribution of the structured questionnaires was carried out among horticultural farmers in the location who could read and respond to the questions independently, while those who were unable to read were assisted by trained enumerators proficient in reading, translating, and asking questions in the farmers' native language, primarily Meru. The survey spanned duration of 2 months.

3.7.2 Laboratory Procedures

The study subjected both kales and water samples to analysis as indicated hereunder:

3.7.2.1 Kale Samples' Extraction

Samples were prepared using the QuEChERS EN method. Initially, 1kg of kale was measured and placed into a clean 50 ml falcon tube. Then, 10 ml of water and 10 ml of acetonitrile were added to the tube. The mixtures were vigorously shaken for 2 minutes to ensure thorough mixing. A QuEChERS salt pouch, containing a mixture of 4 g magnesium sulphate, 1 g sodium chloride, 1 g sodium citrate, and 0.5 g sodium hydrogen citrate sesquihydrate, was included to facilitate phase separation. After shaking for 1 minute, the tube was centrifuged for 5 minutes at 4000 rpm. The resulting upper organic layer, which contained pesticide residues, was then carefully transferred into a clean tube for further sample clean-up.

For the clean-up process, 3 ml of the acetonitrile extract sample was carefully transferred into a clean tube, which was clearly labelled and contained 900 mg of magnesium sulphate and 150 mg of PSA. The mixture was then shaken vigorously for 30 seconds and subsequently centrifuged for 3 minutes at 3000 rpm. Following this, graphitized carbon black (GCB) was introduced into the tube and shaken for 30 seconds. The tube was then centrifuged again at 3000 rpm for 5 minutes to eliminate the highly pigmented chlorophyll.

3.7.2.2 Water Samples Extraction

In the water sample preparation, 10 ml of water was first poured into a clean 50 ml falcon tube, followed by the addition of 10 ml of acetonitrile. The mixture underwent vigorous shaking for 2 minutes to ensure thorough blending. The contents of the QuEChERS salt pouch were then introduced into the tubes to facilitate phase separation. After shaking for 1 minute, the tubes were centrifuged for 5 minutes at 4000 rpm. The resulting upper organic layers, containing the acetonitrile extract, were carefully transferred into clean tubes to proceed with the sample clean-up process.

For the clean-up process, 3 ml of the acetonitrile extracts were carefully transferred into properly labelled clean tubes containing 900 mg of magnesium sulphate and 150 mg of PSA. The mixture was then shaken for 30 seconds and subsequently centrifuged for 3 minutes at 3000 rpm. This same procedure was repeated for all the water samples collected during both the dry and wet seasons, respectively. Following centrifugation, 1 ml of the supernatant layer was transferred into appropriately labelled sample vials for (MO301-GC-MS/MS analysis.

3.8 Method Validation

The analytical method validation was conducted using various parameters, including linearity, limits of detection (LODs), limits of quantification (LOQ), recovery percentage, and relative standard deviation (RSD). Linearity was assessed by creating a calibration curve with a standard solution in acetone, encompassing all pesticides within the range of 50, 100, 200, 300, 400, and 500μg/L. Three injections were performed at each of the six concentration levels. Recovery tests were carried out by adding the mixture to organic-free reagent water at concentrations of 20 μg/L. LODs and LOQs were determined in accordance with established guidelines (Shrivastava & Gupta, 2011). RSD percentages were calculated from triplicate analyses of each water and kale sample.

3.9 Data Analysis

The data was coded and analyzed using SPSS version 26. Descriptive statistics, such as percentages and frequencies, were computed to summarize the data. These descriptive statistics assisted in drawing conclusions and making generalizations about the study population. Data analysis was conducted per objective, allowing for a systematic examination of each aspect under investigation.

i. Objective 1: Data regarding the types of pesticides commonly employed by kale farmers in the research area underwent analysis through descriptive statistics. The findings were then presented using percentages and frequencies.

ii. Objective 2: For inferential analysis independent t-test was employed to make comparison of pesticide residue concentrations in water and kale samples with WHO (MRLs) standards aiming to ascertain whether there were significant differences in mean concentrations between the dry and wet seasons.

iii. Objective 3 was analyzed using descriptive statistics. Information regarding the pesticide practices such as the use of personal protective equipment (PPEs); mixing of pesticides; pre-application mixing of pesticides; disposal of empty containers; and storage practices, was assessed using frequencies and percentages as shown in Table 1.

Table 1: Summary of Data Analysis Methods

Research Objectives	Indices/Parameters	Statistical Test
i. To determine the type of pesticides commonly used in the study area	Frequency of application Type of pesticides used	Percentages and frequencies
ii. To analyse pesticide residue concentrations in kales and domestic water sources	Comparison of the pesticide residue concentrations during the wet and dry seasons (kales &water samples)	Descriptive statistics Independent t-test (means)
iii. To assess the level of community's awareness on safe pesticide use	Use of PPEs Mixing of pesticides, Disposal of empty containers Reading of pesticides labels Pesticides storage practice Timing for pesticide application	Percentages and frequencies

3.10 Ethical Considerations

The ethical standard for conducting the research was observed during the study. This was related to the person conducting the study as the researcher and the respondents was made best interest of the respondents and endeavor to respect the dignity, privacy and autonomy of the respondents. Prior consent was obtained from all participants, and assurances were provided regarding the confidentiality and anonymity of their identities and responses, emphasizing that the information gathered was solely for academic purposes. Participants were informed of their right to participate in the study and their freedom to withdraw at any point. All sources were properly cited and referenced to prevent plagiarism. Additionally, ethical clearance was obtained from the Chuka University Board of Postgraduate Studies Ethics Committee and the National Council of Science, Technology, and Innovation (NACOSTI) before conducting research in Kiegoi, Nyambene catchment area, Kenya.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Social Demographic Characteristics of the Respondents

The description of the participants included an analysis of their gender, age, level of education, and questionnaire return rate.

4.1.1 Response Rate of Farmers

Regarding the questionnaires, 68 responses were collected from the intended sample size of 83 respondents, resulting in an impressive 82% return rate. According to Cooper and Schindler (2014), the return rate for questionnaires is calculated by dividing the total number of returned questionnaires by the total number distributed. The researchers observed that a return rate exceeding 50% is considered acceptable Cooper and Schindler (2014), surpassing 60% is deemed favourable, and exceeding 70% is considered outstanding. This return rate indicates that the data quality surpassed the 70% threshold, as per Cooper and Schindler's criteria (2014). As depicted in Figure 3, this high return rate indicates that the data quality exceeded 70%, according to the assessment by Cooper and Schindler (2014).

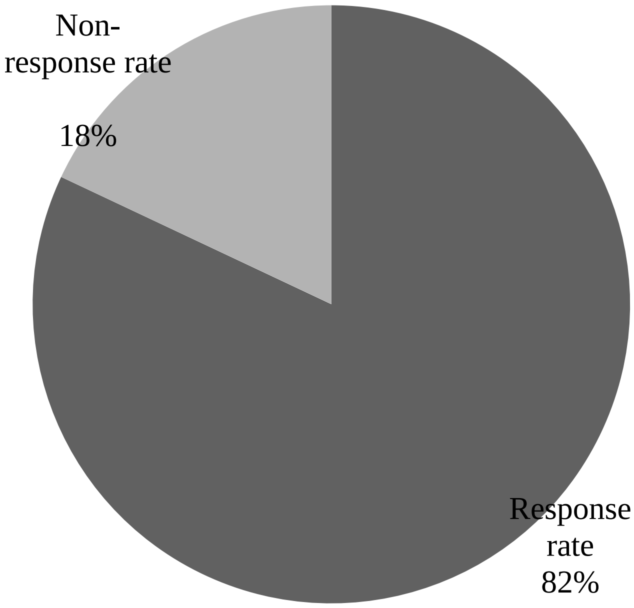

Figure 3: Response Rate of the Farmers

4.1.2 Gender of the Respondents

The study sought information from both men and women. The findings illustrate that the majority of respondents were male, comprising 63.2% of the total participants, whereas female respondents accounted for 36.8% of the sample. The gender distribution is indicated in Figure 4.

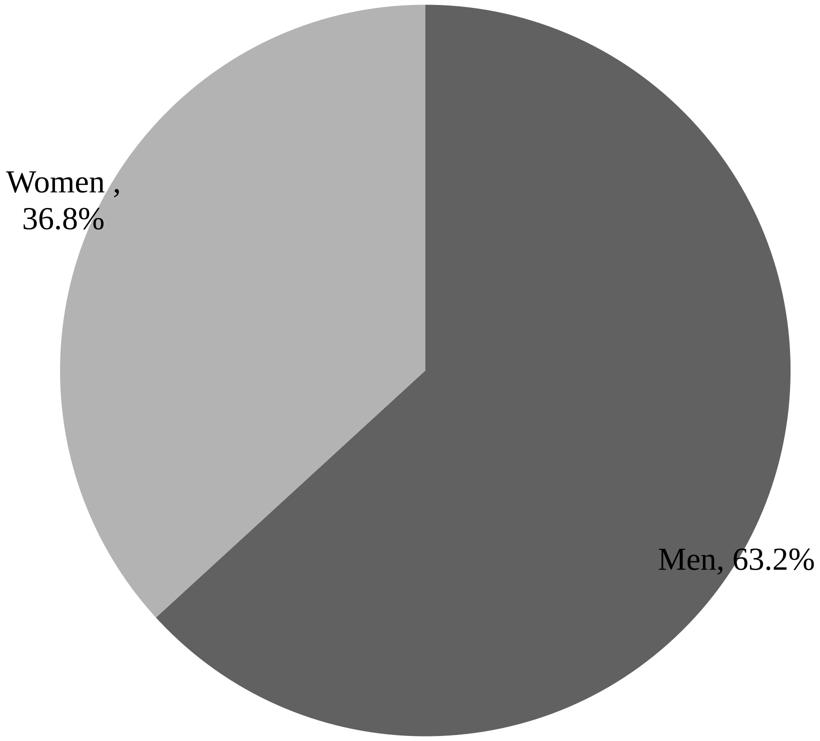

Figure 4: Gender of the Respondents

These results indicate majority (63.2%) of men participants in the study, with women making up a small proportion of the sample. This suggests that farming in the location is dominated by men and the farming is seen as a men occupation, culture, and access to land. This observation suggests a prevalent pattern in the surveyed study area, wherein farming tasks are mainly undertaken by men. These findings are in consensus with previous study by Nguetti *et al.*, (2018), in their study on use of pesticides by the tomato farmers in Mwea Region, Kenya. Their study indicated that 90% of farmers involved in pesticide application were male, with only 10% being female participants.

Kariathi and Kimanya, (2016) similarly, reported high proportions of male farmers engaging on pesticide handling activities in their study in the Meru district of Kenya. The prevalence of male dominance in agriculture was also documented by Obonyo *et al.*, (2017) in their investigation on pesticide handling practices in Kisumu County, Kenya. Similarly, Jallow *et al.*, (2017) observed male predominance in farming activities, particularly those related to pesticide use, as evidenced in their research on pesticide knowledge and safety practices among farm workers in Kuwait.

However, this differs from the findings of Njeru (2020), who found that majority of respondents in his study on adoption of eco-friendly farming practices in Embu County were women. Similarly, Obonyo (2017) in the study on assessment of pesticides handlers' knowledge, practices in Kisumu County, Kenya reported higher proportion of female respondents (52.8%) compared to male respondents (47.2%) in agriculture. Higher proportion of women's participation in agricultural activities such as pesticide handling is attributed to concerns about health and safety.

Other studies have revealed near equal participation of both men and women in agriculture. For example, Nguetti *et al*., (2018) found no notable difference in gender distribution among respondents in their study on farming practices in Nigeria. Likewise, Macharia and Waibel (2013) did not identify a significant disparity in the adoption of agricultural practices among respondents in Jericho County in their investigation into pesticide handling practices by vegetable farmers in Kenya. This near equal participation of both genders in farming is attributed to gender roles where all genders actively participate in agricultural activities.

The gender disparity in pesticide use practices has significant implications for agricultural sustainability, food security, and human health. Male-dominated farming practices may overlook the unique perspectives and needs of female farmers, leading to suboptimal pesticide management strategies. Women, who often play crucial roles in agricultural production, may have limited access to resources, information, and decision-making power regarding pesticide use. Addressing gender disparities in agriculture requires targeted interventions that promote gender equality, enhance women's participation and leadership in decision-making processes, and provide equitable access to resources and information. Incorporating gender-sensitive approaches in pesticide management programs can improve effectiveness and sustainability while reducing the hazards linked to pesticide usage for both male and female farmers.

Understanding these gender dynamics is essential for designing targeted interventions and outreach programs aimed at promoting safer and more sustainable pesticide use practices among both male and female farmers. By recognizing and addressing gender-based differences, it is possible to develop more inclusive and effective strategies for reducing pesticide risks and promoting sustainable agricultural practices in the study area and beyond.

4.1.3 Age of the Respondents

The results revealed that a considerable portion of respondents fell within the 30-40 age range, accounting for 45.6% of the total participants. Additionally, 33.8% of respondents were aged between 20 and 30 years, while 14.7% were in the 40-50 age groups. A smaller percentage, 5.9%, comprised respondents aged over 50 years. The results are illustrated in Table 2.

Table 2: Age of the Respondents

Age bracket	Percent
20 - 30 years	33.8
30-40 years	45.6
40-50 years	14.7
Above 50 years	5.9
Total	100.0

The demographic trend observed in the study area, where individuals in the middle age range (30-40 years) were more actively involved in agricultural activities, including pesticide use. These findings align with previous research by Kariathi and Kimanya (2016) in their investigation on pesticide exposure from fresh tomatoes and its correlation with pesticide application practices in Meru County, Kenya. Similarly, Momanyi et al., (2019) observed a predominance of individuals aged 31-40 years engaging in pesticide handling practices in agriculture in their study on farmers' compliance with pesticide use standards in the Mwea irrigation scheme, Kirinyaga County, Kenya. Other studies for instance, Adejumo, Ojoko and Yusuf (2014), have observed individual aged 29-39 years engaging on pesticide use in rural set up of Nigeria. This demographic trend implies that individuals in the middle age range are more actively engaged in agricultural activities, including pesticide use, in the surveyed area.

Contrarily, Obonyo (2017) found a varied age distribution, specifically within the (21-30) year range, among respondents actively involved in pesticide usage in his study on pesticide handlers' knowledge, practices, and self-reported toxicity symptoms in Kisumu County, Kenya. Likewise, Saowanne et al., (2013) and Nguetti et al., (2018) observed differing age distributions among respondents in their research on pesticide usage practices. These disparities could indicate variations in sample demographics, geographical areas, or methodologies utilized across the studies.

4.1.4 Education Level of the Respondents

The Information showed that the majority of respondents had attained primary education; accounting for 52.9% of the total participants, 39.7% of respondents had attained secondary education, while a smaller proportion (7.4%) had tertiary certificates. The results obtained are presented in Table 3.

Table 3: Education Level of the Respondents

Education level	Percent
Primary	52.9
Secondary	39.7
Tertiary	7.4
Total	100.0

The findings indicate that the majority of farmers have attained a primary education level. These findings aligned with previous research conducted by Nguetti *et al.*, (2018) in their study on pesticide handling practices in Kirinyaga County, which similarly observed a predominance of primary education level among farmers in various geographical areas. The consistency in findings across different studies suggests that there are limited jobs that these people can secure and because of limited options, majority practise farming due to either access to land and also farming does not need specialised skills/training.

The prevalence of primary education among farmers may have implications for agricultural practices and pesticide use. While primary education could provide a basic foundation of knowledge and skills, it may not necessarily encompass advanced agricultural practices or awareness of modern, environmentally friendly pesticide alternatives and safer practices. As a result, farmers with limited education may be less informed about sustainable agricultural techniques and may rely more heavily on the use of chemical pesticides.

Understanding the education levels of agriculturalists in pesticide use practices could be crucial for promoting safer and more sustainable agricultural practices. By addressing knowledge gaps and promoting education, it may be possible to foster a culture of sustainable agriculture and reduce reliance on harmful pesticides in agricultural communities.

4.2 Type of Pesticides Commonly Used by Famers Growing Kales

Different types of pesticides are used by farmers in management of pests and diseases. The study sought information on the type and usage of pesticides among horticultural farmers. The information obtained is discussed hereunder:

4.2.1 Horticultural Farmers Using Pesticides

The study sought information on horticultural farmers using pesticides. The result revealed that the majority of respondents (97.1%) reported employing pesticides on their vegetables to manage weeds, pests, and diseases. Only a small fraction of respondents (2.9%) stated that they did not use pesticides in their agricultural practices in the study area. These findings are displayed in Table 4.

Table 4: Horticultural Farmers Using Pesticides

Response	Percent
Yes	97.1
No	2.9
Total	100.0

The high percentage of respondents (97.1%) indicating the use of pesticides on their kales in the study area is attributed to their widespread utilization in agriculture for managing weeds, pests, and diseases. Pesticides are recognized as effective tools for safeguarding crops and optimizing yields, serving both preventive and reactive purposes against various biotic stresses that threaten crop health and productivity. The incidence of pests and diseases in the area was observed by farmers relying on pesticides to prevent crop losses and protect their agricultural livelihoods. Additionally, pesticides are perceived by farmers in the study area as a convenient and readily accessible solution to address pest and disease management challenges, especially in the absence of alternative methods or resources for sustainable pest control.

The results agreed with the study by Kariathi and Kimanya, (2016) which reported majority of farmers (84%) engaging on pesticide handling activities in their study in Meru district, Kenya. Similarly, Obonyo (2017) in the study on Pesticides use in Kisumu County, Kenya reported majority of farmers (63%) involved on agricultural pesticide use.

4.2.2 Type of Pesticides Commonly Used on Kales

The study sought information on the type of commonly used pesticides by farmers using pesticides. The findings are depicted in Table 5. Refer to Appendix VII for the chemical structures of the active ingredients that aided in the determination of the type of pesticides from the GC-MS/MS chromatogram.

Table 5: Type of Pesticides Commonly Used

Classification of pesticide (chemical composition)	Type of pesticide	Trade Name (Kenya)	WHO class	Toxicity Level	Year of Registration by PCPB	%
Fungicide	Mancozeb	Dithane M-45	U	Unlikely to present acute hazard	1994	22.1
Insecticide	Deltamethrin	Deltanex	II	Moderately hazardous	2000	14.7
Insecticide	Dichlorvos	Nuvan	1b	Highly hazardous	1992	11.8
Fungicide	Captan	Captan 50 WP	U	Unlikely to present acute hazard	1995	11.8
Insecticide	Diazinon	Diazinol	II	Moderately hazardous	1993	10.3
Insecticide	Dieldrin	Dieldrin	1a	Extremely hazardous	1950s	5.9
Insecticide	Cypermethrin	Cyperkill	II	Moderately hazardous	1998	7.4
Herbicide	Acetochlor	Trophy	II	Moderately hazardous	1997	7.4
Insecticide	Acrinathrin	Rufast	II	Moderately hazardous	2005	4.4
Herbicide	Glyphosate	Roundup	U	Unlikely to present acute hazard	1974	1.5
Total						97.3

Information on Table 5 reveals that fungicides and insecticides were the primary categories of pesticides utilized. Among the fungicides, Dithane M-45 was the most commonly used pesticide on kales, accounting for 22.1% of the reported pesticide usage. This fungicide was commonly employed for the regulation of diseases such as powdery mildew and leaf spot diseases in various crops; including kales and potatoes as observed during field study (As shown in appendices Va).

Deltanex was the second most commonly used pesticide, representing 14.7% of reported usage. Deltanex was an insecticide commonly used to control an extensive series of pests, including aphids, caterpillars, and leafhoppers (Appendix Vb.) Other organophosphate pesticides reported in the study include Nuvan, Captan 50 WP, Diazinol, and Cyperkill, each with varying levels of usage. These pesticides were known for their effectiveness against specific pests and diseases, and their application on kales reflects the diverse pest pressures faced by farmers in the study area. Synthetic pyrethroids were also widely used on kales, with a preference of 46% reported in the survey. Pyrethroids such as Trophy and were commonly used insecticides known for their broad-spectrum activity against a wide range of insect pests. Glyphosate herbicide was also mentioned, although less frequently, because herbicide use was not a common practice in weed control in the study area.

The results align with those of Nyakundi et al., (2012) regarding the prevalent use of pesticides among farmers in the Rift Valley and Central Provinces of Kenya. Their research demonstrated that pesticides were easily accessible and widely employed on farms. Primary N-(phosphonomethyl) glycine) included Linurex 50 WP and Diurex 80 WP, while methyl-4-pyrimidinyl] phosphorothioate comprised Diazol 60 EC and Methomex 90 S. The result implies that Dieldrin and carbamates such as Mocap were hardly used on Kales in the study area. These findings are attributed to regulatory restrictions of Dieldrin in Kenya due to their persistence in the environment, environmental concerns and the availability of more effective and safer alternatives like integrated Pest Management (IPM) Nyakundi *et al*., (2012). The preference for certain types of pesticides, such as organophosphates and synthetic pyrethroids, highlights the importance of understanding the specific pest and disease pressures faced by kale growers and selecting appropriate pest management strategies. However, it is crucial to consider the potential risks associated with pesticide use, including environmental contamination, human health impacts, and pesticide resistance.

4.2.3 Frequency of Pesticides Application

The study aimed to establish the frequency of pesticide application on Kales. The findings observed that majority of respondents (80.9%) reported pesticide applications conducted on a weekly basis with Diazinol, Captan 50 WP, and Dithane M-45 being the most frequently applied pesticide while 16.2% of the respondents reported using Glyphosate (Roundup) on a monthly basis. This is illustrated in Table 6.

Table 6: Frequency of Pesticide Application

Type of Pesticide	Application rate	Percent
Diazinol, Captan 50 WP & Dithane M-45	Weekly	80.9
Glyphosate (Roundup)	Monthly	16.2
Total		97.1

The high frequency of weekly applications for Diazinol, Captan 50 WP, and Dithane M-45 was attributed to high pest-related challenges in the areas where kale cultivation occurs. Pesticides play a crucial role in pest and fungal disease management in the study area (Syed *et al.,* 2014). The common infestations were aphids and caterpillars, as well as diseases such as downy mildew and powdery mildew (Appendix 5b).

The findings agreed with the study by Otieno (2017), in Laikipia County, Kenya who observed majority of farmers applying pesticides on the vegetables after every two weeks. This frequent application pattern implies a reliance on pesticides as a primary means of pest management and crop protection in agricultural operations. The study observed a significant frequency of pesticide application may have several implications for agricultural practices and pesticide management. Frequent pesticide use indicated a reactive approach to pest management, where farmers apply pesticides as a response to observed pest infestations or crop diseases. While pesticides can effectively control pests and diseases, their frequent and indiscriminate use may lead to pesticide resistance, where pests develop resistance to the chemicals, rendering them less effective over time (Syed *et al.,* 2014).

The frequent application of pesticides could raise concerns such as food contaminations regarding the potential build-up of pesticide residues in the environment, including water sources and food crops (Adeyeye *et al*., 2021). Pesticide residues have the ability to persist in the environment for prolonged periods, posing risks to both human health and environmental integrity through various exposure routes such as ingestion, inhalation, and skin contact. The variability in pesticide application frequency holds particular significance within the scope of this study, as the researcher aimed to investigate whether the frequency of pesticide application could influence the concentrations of pesticide residues. Understanding the correlation between pesticide application frequency and residue levels was crucial for assessing potential risks to human health and the environment, as well as for guiding pesticide management approaches (Adeyeye *et al*., 2021).

4.2.4 Crops Treated with Pesticides

The study aimed to identify the crops treated with pesticides and the specific pesticides used, along with the diseases and pests they control. The results revealed that 85.3% of respondents use diazinol, captan 50 WP and deltanex on their kale crops to combat aphids, leaf spot diseases, and powdery mildew while a smaller proportion of respondents, 5.9%, reported treating maize and potatoes with Dithane M-45 and Roundup. The findings are illustrated in Table 7.

Table 7: Crops Treated with Pesticides

Type of pesticide	Type of crop	Diseases /pest controlled	Percent
Diazinol, Captan50 WP & Deltanex & Dithane M-45	Kales	Aphids, Leaf Spot Diseases: & Powdery Mildew	85.3
Glyphosate (Roundup)	Maize	Leaf Spot Diseases: &weeds control	5.9
Dithane M-45	Potatoes	Powdery Mildew & Rust	5.9
Total			97.1

The findings indicate that the majority of respondents predominantly apply pesticides to their Kale crops. This trend is closely linked to kale's susceptibility to various diseases like downy mildew, powdery mildew, and bacterial leaf spot in the study area (Appendix 5a). These diseases proliferate swiftly due to the region's high humidity and inadequate air circulation. Consequently, farmers resort to frequent pesticide applications as a key component of their disease management strategy. The survey underscores that most farmers in the area lack awareness of the potential hazards associated with excessive pesticide use, including environmental contamination, pesticide resistance, and adverse effects on beneficial insects. Compounded by the absence of comprehensive education and outreach initiatives, farmers persist in their heavy reliance on pesticides, neglecting alternative methods.

The results disagreed with the study on pesticide handling practices by Otieno (2017), in Laikipia County, Kenya which observed majority of farmers applying pesticides on maize crop. The lower frequency of pesticide treatment observed in maize crops compared to kales is attributed to maize being primarily cultivated for subsistence purposes, whereas kales are grown for commercial use. As a result, farmers heavily rely on pesticides to enhance Kales yields in the study area.

The findings imply the significant importance of pesticide application in the production of kales in the agricultural practices of the studied community. The crops identified in the study are widely cultivated food crops in numerous agricultural environments. Kale, maize, and potatoes serve as staple foods for many communities, supplying vital nutrients and playing a key role in ensuring food security (Marete *et al*., (2019). Nevertheless, these crops are vulnerable to a range of pests, diseases, and weed infestations, which have the potential to impact both yield and quality if not properly addressed. The use of pesticides to treat these crops reflects farmers' efforts to protect their crops from pest and disease damage and ensure optimal production. However, it is essential to consider the potential risks associated with pesticide use, including environmental contamination, human health impacts, and pesticide residues in food crops.

The findings also observed the need for tailored pest management strategies for different crops, considering their unique pest profiles, agronomic practices, and production systems. Integrated pest management (IPM) strategies, which integrate cultural, biological, and chemical control techniques, could reduce dependence on pesticides and advocate for more sustainable and eco-friendly approaches to pest management.

4.3 Pesticide Residue Concentrations in Domestic Water Sources and Locally Produced Kales

4.3.1 Pesticide Residue Concentrations in Water

The findings provide the mean concentrations of pesticide residues in Nguondone stream during wet and dry seasons. Mancozeb showed an increase in mean concentration from 0.04267 mg/l during the wet season to 0.05233 mg/l in the dry season. This difference was not statistically significant (p = 0.546). Deltamethrin exhibited a rise from 0.02933 mg/l in the wet season to 0.03467 mg/l in the dry season, with no statistically significant difference observed (p = 0.672). Captan demonstrated an increase in mean concentration from 0.02467 mg/l in the wet season to 0.03033 mg/l in the dry season. This difference was not statistically significant (p = 0.615). Cypermethrin and Acetochlor demonstrated consistent mean concentrations between wet and dry seasons, with no statistically significant differences observed (p = 0.656 for Cypermethrin and p = 0.689 for Acetochlor).

Dichlorvos revealed an increase in concentration during the dry season, with a mean concentration of 0.08067 mg/l, and was below the limit of detection during the wet season. Diazinon was detected during the dry season, with a mean concentration of 0.04800 mg/l and was below the limit of detection during the wet season. Dieldrin was detected during the dry season, with a mean concentration of 0.09067 mg/l, this difference was not statistically significant (p = 0.311). Acrinathrin was detected during the dry season, with a mean concentration of 0.02100 mg/l and was below the limit of detection during the wet season. This is illustrated in Table 8.

Table 8: Pesticide Residue Concentration in Domestic Water Sources

Pesticide type	Season	N	Conc. in Mg/l Mean	Std. Deviation	Std. Error Mean	P-value	WHO MRL mg/l
Mancozeb	wet	3	.04267	.019604	.011319	.547	0.02
	dry	3	.05233	.016166	.009333		
Deltamethrin	wet	3	.02933	.016073	.009280	.672	0.5
	dry	3	.03467	.012342	.007126		
Dichlorvos	wet	3	LOD	.000000	.000000	.336	0.03
	dry	3	.08067	.112077	.064708		
Captan	wet	3	.02467	.011150	.006438	.615	0.7
	dry	3	.03033	.014154	.008172		
Diazinon	wet	3	LOD	.000000	.000000	.011	0.01
	dry	3	.04800	.014731	.008505		
Dieldrin	wet	3	LOD	.000000	.000000	.250	0.05
	dry	3	.09067	.103828	.059945		
Cypermethrin	wet	3	.04833	.007024	.004055	.656	0.1
	dry	3	.05100	.006557	.003786		
Acetochlor	wet	3	.01733	.006351	.003667	.689	0.3
	dry	3	.01500	.006928	.004000		
Acrinathrin	wet	3	LOD	.000000	.000000	.129	0.05
	dry	3	.02100	.010000	.005774		

(Independent t-test, LOD = Limit of Detection)

The increases in mean concentrations of Mancozeb, Deltamethrin, and Captan from the wet to the dry season suggest seasonal fluctuations in pesticide levels. This could be attributed to factors such as changes in agricultural practices and pesticide application patterns during different seasons. This includes intensive application of pesticides on kales crop during dry season as opposed to wet season; weather conditions including dilution effect of higher water volumes during the wet season which may result in relatively lower concentrations of pesticides per unit of water. During dry season, the pesticides concentration in Nguondone stream may increase due to reduced water flow which can lead to decreased dilution of pesticides, resulting in higher concentrations in slow-moving water. As the water levels decrease, pesticides that were previously deposited in sediments or suspended in the water column may become more concentrated. The consistency in mean concentrations of Cypermethrin and Acetochlor between wet and dry seasons could be influenced by factors like persistence or uniform application practices.

The detection of Dichlorvos, Diazinon, Dieldrin, and Acrinathrin during the dry season could be attributed to intensive farming of kales crop during dry season as observed by the researcher. Consequently, the application of pesticides becomes intense and highly concentrated during this period. This finding indicates the importance of understanding and addressing seasonal variations in pesticide contamination to protect aquatic ecosystems and human health. The findings emphasize seasonal dynamics in pesticide contamination of water bodies and the importance of continuous monitoring and adaptive management strategies to mitigate potential risks associated with pesticide residues in aquatic environments, particularly during periods of heightened agricultural activity and environmental stress.

The comparison of pesticide residue concentrations with the WHO Maximum Residue Limits (MRLs) standards across wet and dry seasons reveals significant findings. Mancozeb and Deltamethrin concentrations in both wet and dry seasons are within the WHO MRLs of 0.02 mg/l and 0.5 mg/l, respectively, indicating compliance with safety standards. However, Dichlorvos exceeds the WHO MRL of 0.03 mg/l during the dry season, suggesting a potential risk of contamination. Captan, although within the WHO MRL of 0.7 mg/l, displays a slight increase in mean concentration from the wet to the dry season. Similarly, Diazinon and Dieldrin exceed their respective WHO MRLs of 0.01 mg/l and 0.05 mg/l during the dry season, indicating a potential risk of exceeding acceptable levels. Conversely, Cypermethrin, Acetochlor, and Acrinathrin levels in both seasons remain below their corresponding WHO MRLs of 0.1 mg/l, 0.3 mg/l, and 0.05 mg/l, respectively, suggesting compliance with safety standards. These findings emphasize the importance of ongoing monitoring and regulatory measures to ensure adherence to safety standards and mitigate potential health and environmental risks associated with pesticide residues in water sources.

These findings are in consensus with a study conducted by Nyantakyi *et al.*, (2022) in Greece, which reported similar trends of higher pesticide residue levels during the dry season compared to wet season). However, these findings contradict a study conducted in Nzoia river catchment area in Kenya by (Tarus *et al.*, 2023) which reported increase in concentration of all detected pyrethroid pesticide residues during the wet season because these pesticides were usually applied in farm fields at the beginning of rainy seasons when crops are planted, compared to dry season.

This is different from the study area where intensive pesticide usage on kales grown was observed during the dry season compared to wet season where farmers were growing other horticultural crops as opposed to kale.

4.3.2 Pesticide Residue Concentrations in Locally Produced Kales

The results present mean concentrations of pesticide residue concentrations in locally produced kales during wet and dry seasons. Captan and Deltamethrin show significant increases in mean concentrations from the wet to the dry season. Captan rises from 0.01533 mg/kg during the wet season to 0.04700 mg/kg in the dry season, with a statistically significant difference ($p = 0.001$). Deltamethrin increases from 0.01467 mg/kg in the wet season to 0.04200 mg/kg in the dry season, showing a significant difference ($p = 0.000$). Diazinon displays a significant rise in mean concentration from the wet (0.01567 mg/kg) to the dry (0.02567 mg/kg) season ($p = 0.046$).

Acetochlor demonstrates an increase in mean concentration from 0.02233 mg/kg in the wet season to 0.05200 mg/kg in the dry season, but the difference is not statistically significant ($p = 0.367$). Glyphosate, Dichlorvos, and Dieldrin were detected during the dry season, with concentrations below the limit of detection (LOD) in the wet season. However, the disparity between the two seasons was not statistically significant. Cypermethrin and Acrinathrin levels were below the limit of detection (LOD) in both seasons. This is illustrated in Table 9.

Table 9: Pesticide Residue Concentrations in Locally Produced Kales

Pesticide Type	Season	N	Conc in Mg/kg Mean	Std. Deviation	Std. Error Mean	P-value	WHO MRL mg/kg
Captan	Wet	3	.01533	.002517	.001453	.000	0.5
	Dry	3	.04700	.001000	.000577		
Deltamethrin	Wet	3	.01467	.001528	.000882	.000	0.5
	Dry	3	.04200	.001000	.000577		
Dichlorvos	Wet	3	LOD	.000000	.000000	.032	0.02
	Dry	3	.01807	.004336	.002504		
Diazinon	Wet	3	.01567	.004726	.002728	.037	0.01
	Dry	3	.02567	.003055	.001764		
Dieldrin	Wet	3	LOD	.000000	.000000	.013	0.05
	Dry	3	.02433	.005859	.003383		
Cypermethrin	Wet	3	LOD	.000000[a]	.000000	.000	0.1
	Dry	3	LOD	.000000[a]	.000000		
Acetochlor	Wet	3	.02233	.001155	.000667	.312	0.02
	Dry	3	.05200	.001000	.000577		
Acrinathrin	Wet	3	LOD	.000000[a]	.000000	.000	0.6
	Dry	3	LOD	.000000[a]	.000000		
Glyphosate	Wet	3	LOD	.000000	.000000	.000	0.7
	Dry	3	.02137	.017012	.009822		

(Independent t-test, LOD = Limit of detection)

These findings indicate the pesticide residue concentrations in locally produced kales during the wet and dry seasons in Kiegoi, upper Nyambene catchment. The significant increases in mean concentrations of Captan, Deltamethrin, and Diazinon from the wet to the dry season could be attributed to factors influencing pesticide residue levels in locally produced kales such as the difference in weather conditions between the two seasons, with the dry season characterized by lower humidity and less rainfall. These conditions may lead to reduced degradation and dilution of pesticides, resulting in higher residue levels in crops. Agricultural practices such as increased pesticide application during the dry season to control pests or weeds could contribute to the elevated residue concentrations observed.

The lack of statistically significant difference in mean concentration of Acetochlor between wet and dry seasons indicates relatively stable residue levels regardless of seasonal variations. This could be attributed to factors such as the chemical properties of Acetochlor, its application methods and its persistence in the environment. The detection of Glyphosate, Dichlorvos and Dieldrin during the dry season, with concentrations below the limit of detection in the wet season could be attributed to potential contamination sources such poor disposal of used pesticides containers, poor storage practices, excessive use of pesticides as well as environmental persistence of these pesticides. The detection below the limit (LOD) during wet season could be attributed high humidity and dilution effect leading to low pesticide residues concentrations. The detection of Cypermethrin and Acrinathrin below the limit in both seasons suggests minimal presence or absence of these pesticides in locally produced kales. This could indicate differences in pesticide usage patterns and susceptibility to degradation, between these pesticides.

The comparison of pesticide residue concentrations in mg/kg with the WHO Maximum Residue Limits (MRLs) standards across wet and dry seasons reveals several significant findings. Both Captan and Deltamethrin show substantial increases in mean concentrations from the wet to the dry season. Captan rises from 0.01533 mg/kg to 0.04700 mg/kg, while Deltamethrin increases from 0.01467 mg/kg to 0.04200 mg/kg. However, despite these increases, their concentrations in both seasons remain below the WHO MRLs of 0.5 mg/kg, indicating compliance with safety standards. Dichlorvos, Diazinon, and Dieldrin display concentrations below the limit of detection (LOD) during the wet season but exceed the WHO MRLs in the dry season. Dichlorvos and Diazinon exceed the MRLs of 0.02 mg/kg and 0.01 mg/kg, respectively, while Dieldrin surpasses the WHO MRL of 0.05 mg/kg during the dry season. This suggests a potential risk of contamination during the dry season. On the other hand, Cypermethrin, Acetochlor, Acrinathrin, and Glyphosate either exhibit concentrations below the LOD or maintain consistent levels between wet and dry seasons that comply with WHO MRLs. These findings highlight the importance of ongoing monitoring and regulatory measures to ensure food safety and mitigate potential health and environmental risks associated with pesticide residues in agricultural products.

This finding is in consensus with a study conducted by Nyantakyi *et al*., (2022) on Assessment of pesticides residues levels in vegetables in Greece, which reported similar trends of higher pesticide residue levels of cypermethrin, dieldrin and Diazinon during the dry season compared to rainy season. However, it contrasts with a study by Otieno (2019) in Laikipia County, which demonstrated higher pesticide residues of deltamethrin and Acrinathrin in vegetables grown during the wet season compared to the dry season. The high detection of commonly used pesticide residues in locally produced kales in the study area during the dry season could be associated to excessive pesticide usage on kales grown observed during the study in the farm fields as opposed to wet season where there was minimal vegetable grown.

4.4 Assessment of Pesticide Use Practices

The study sought information on the pesticide uses practices. The results obtained are discussed hereunder:

4.4.1 Pesticides Storage Practices

The study further sought to determine pesticide storage practices, focusing on whether respondents were aware and adhered to recommended storage guidelines. The results revealed that 41.2% of respondents reported being aware of and following proper pesticide storage practices. Conversely, 55.9% of respondents acknowledged to not following proper pesticide storage practices. This information is presented in Table 10.

Table 10: Community Awareness on Proper Pesticide Storage Practices

Proper Pesticide Storage Practices	Response	Frequency	Percent
Farm house & pesticide storage Practices room, Own containers & in the house	Yes	28	41.2
	No	38	55.9
Total			97.1

The information on Table 10 raises concerns because majority of farmers are not adhering to proper pesticide storage protocols. Many farmers reported storing their used pesticide containers in open farm fields, a practice that poses significant risks of soil pollution and potential food safety hazards in the region. This improper storage method could lead to pesticide residues leaching into the soil, contaminating crops, and potentially entering water sources, thereby posing risks to both human health and the environment.

The inadequate storage of pesticides is attributed to a lack of knowledge regarding proper pesticides handling practices among farmers. Insufficient awareness about the potential risks associated with improper storage methods likely contributes to this issue. Without proper education and guidance on the safe handling and storage of pesticides, farmers may inadvertently engage in practices that compromise environmental and food safety standards.

The results were consistent with those of Mequanint et al., (2019) in their investigation of practices related to pesticide handling, storage, and related factors among farmers in irrigated regions of Gondar town, Ethiopia. Their study revealed that 38.4% of respondents stored used pesticides in open farm. This absence of a designated storage area could increase the risk of contamination, thereby posing potential health threat to human and the environment.

While this minority adherence is somewhat encouraging, it still leaves a considerable portion of the farming population at risk due to inadequate storage practices. The majority respondents who agreed not aware of proper pesticide storage practices implied a significant gap in knowledge and understanding regarding the safe handling and storage of pesticides among farmers in the area.

4.4.2 Disposal Practices

The study further sought to determine the disposal practices on the used pesticide containers. The information revealed that majority (51.5%) reported disposing off used containers by throwing them in open fields. 17.6% indicated burying the containers on their farms, while 11.8% reported burning them. Only a small proportion (14.7%) reported using designated disposal sites for these materials. This is shown in Table 11.

Table 11: Disposal Practices of Pesticide Containers and Unused Pesticides

Disposal practices	Frequency	Percent
Thrown in open field	35	51.5
Buried in farm	12	17.6
Burnt	8	11.8
Disposal site	10	14.7
Total	66	95.6

The findings show that the majority of farmers are discarding used pesticide cans in open fields (See appendices 6a, 6b & 6c). This practice poses significant risks, potentially leading to contamination of kale crops due to the mobility of pesticide residues. Consequently, concerns arise regarding both soil pollution and food safety within the region, as pesticides can leach into crops and contaminate water sources.

Improper disposal of pesticides in the study area was primarily attributed to a lack of knowledge regarding appropriate disposal methods among farmers. Insufficient awareness of the potential hazards associated with improper disposal likely contributes to this issue. Without proper education and guidance on safe disposal practices, farmers may inadvertently engage in behaviours that compromise environmental and food safety standards.

These findings of this study align with previous research by Otieno (2019) and Smith et al., (2018) in their studies on pesticide handling practices in Narok County, who documented unsafe pesticide waste disposal practices among farmers. These consistent findings underscore the urgency of addressing this issue to mitigate the potential adverse impacts on food safety, environmental quality, and public health. These findings underscore a concerning trend in improper disposal practices among farmers in the area. Disposing of pesticide containers in open fields or burying them on farms could lead to environmental contamination and pose risks to human health. Similarly, burning these containers may release harmful toxins into the air, further exacerbating environmental pollution.

The low percentage of respondents utilizing designated disposal sites indicates a lack of awareness or access to proper disposal facilities. This highlights the need for increased education and outreach efforts to promote safe disposal practices among farmers. Implementing effective waste management strategies and providing adequate disposal infrastructure can help mitigate environmental risks and protect both human health and the ecosystem.

4.4.3 Recommended Mixing and Dilution of Pesticides

The study further sought to assess whether the farmer follow recommended mixing and dilution of Pesticides practices. The findings regarding the recommended mixing and dilution of pesticides indicated that majority of respondents, comprising 80.9%, reported that they do not follow recommended mixing and dilution practices. In contrast, only 16.2% of respondents reported following these recommended practices. This is shown in Table 12.

Table 12: Recommended Mixing and Dilution of Pesticides

Response	Frequency	Percent
Yes	11	16.2
No	55	80.9
Total	66	97.1

The results on Table 12 suggest a concerning lack of adherence to recommended mixing and dilution practices for pesticides, as reported by the majority of farmers. Many farmers disclosed that they do not utilize essential measuring equipment like measuring cups, graduated cylinders, and calibrated sprayers. This neglect poses significant risks to both pesticide applicators and the environment at large. The primary contributing factor appears to be a lack of awareness regarding the potential health effects associated with improper handling and application of pesticides.

This disregard for proper mixing and dilution procedures highlights a critical gap in farmers' knowledge and practices related to pesticide safety. Without accurate measurement tools, farmers may inadvertently apply incorrect concentrations of pesticides, leading to ineffective pest control or, worse, overexposure to hazardous chemicals. The absence of calibrated equipment increases the likelihood of environmental contamination, as excessive pesticide runoff or drift can impact non-target areas and organisms.

These findings are in agreement with the study by Otieno (2019) on pesticides handling practices in Laikipia County in Kenya which reported 96% of the farmers were mixing and diluting agrochemicals on their crops in farms before being applied, without cleaning off the previous pesticides.

While this minority adherence is somewhat encouraging, it still underscores a concerning lack of compliance with essential safety and efficacy standards in pesticide application practices. The failure to adhere to recommended mixing and dilution ratios could lead to several adverse outcomes. Inaccurate pesticide concentrations may result in ineffective pest control, leading to reduced crop yields and economic losses for farmers. Conversely, overdosing of pesticides could result in crop damage, phytotoxicity, and contamination of soil and water resources. Additionally, improper mixing and dilution practices may pose risks to human health and safety, as exposure to concentrated pesticide solutions may lead to acute toxicity or long-term health effects for farmers and farmworkers.

The implications of these findings extend beyond the immediate concerns of agricultural productivity and human health to broader environmental sustainability considerations. Misapplication of pesticides could contribute to environmental pollution, including water and soil contamination, disruption of ecosystem balance, and harm to non-target organisms.

4.4.4 Use of Protective Gear in Pesticides Application

Further, the study sought to establish whether farmers are using protective gears during pesticides application on their Kales. The findings indicated a sizeable percentage of respondents (69.1%) reported not using recommended protective gear during pesticide application while, 26.5% of the respondents indicated using recommended protective gear during pesticide application. This is presented in Table 13.

Table 13: Use of Protective Gears in Pesticides Application

Response	Frequency	Percent
Yes	18	26.5
No	47	69.1
Total	66	95.6

The findings were consistent with the research conducted by Kinyua and Nguku (2023) in their investigation on the factors associated with the use of personal protective equipment (PPE) among pesticide handlers. Their study revealed that a majority of farmers were involved in pesticide handling activities. However, their results indicated a low level of PPE usage among pesticide handlers, with none utilizing full PPE and only 25.2% using 4-6 out of the 7 possible PPE items. The most commonly used PPE items were trousers (74.4%), long-sleeved shirts or jackets (65.9%), and hats (60.6%). Conversely, the least utilized PPE items were gumboots (1.6%), gloves (2.8%), and goggles (9.8%).

The observed discrepancy in protective gear usage was attributed to lack of access to information on adoption of safety precaution and high cost of buying PPEs, insufficient education and awareness on adoption of safety measures such as wearing protective clothing among the surveyed farmers. Addressing this issue will be crucial in promoting safer agricultural practices and reducing the risks associated with pesticide exposure for both farmers and consumers.

4.4.4.1 Types of Protective Gear Used by Farmers

Further, the study sought to establish the type of protective gear used by Farmers. The results indicated that majority, comprising 72.1% of participants, reported not wearing any protective gear, which poses serious health risks during pesticide handling. Among those who did use protective gear, gloves were the least common (5.9%), followed by boots (10.3%) and respirators (8.8%). This is presented in Table 14.

Table 14: Type of Protective Gear Used by Farmers

Protective gear	Frequency	Percent
Gloves	4	5.9
Boots	7	10.3
Respirator	6	8.8
Do not wear protective gear	49	72.1
Total	66	97.1

The findings were consistent with the study conducted by Kinyua and Nguku (2023) in their investigation on the use of personal protective equipment (PPE) among pesticide handlers. Their results indicated a low level of PPE usage among pesticide handlers, with none utilizing full PPE and only 25.2% using 4-6 out of the 7 possible PPE items. The most commonly used PPE items were trousers (74.4%), long-sleeved shirts or jackets (65.9%), and hats (60.6%). Conversely, the least utilize PPE items were gumboots (1.6%), gloves (2.8%), and goggles (9.8%).

The findings above indicated lack of comprehensive protective measures, leaving individuals vulnerable to pesticide exposure, which could have detrimental effects on their health and well-being. Addressing this issue requires a concerted effort to promote the use of appropriate protective gear among farmers, coupled with education on the importance of personal safety measures during pesticide application. The results highlight a concerning trend towards inadequate protection among respondents.

4.4.5 Pesticides' Label Instructions

The study also aimed to determine whether farmers follow and correctly interpret and read pesticide label instructions. The findings showed that majority of respondents (72.1%) reported unable to correctly interpret and follow pesticide label instructions. On the other hand, smaller proportions of respondents (25%) indicated that they were following and interpret pesticide label instructions correctly. This is depicted in Table 15.

Table 15: Pesticide Label Instructions

Response	Frequency	Percent
Yes	17	25.0
No	49	72.1
Total	66	97.1

The findings regarding pesticide label instructions indicate a concerning lack of understanding and adherence to these instructions among the respondents. The considerable gap in farmers' comprehension and application of pesticide label instructions could be attributed to inadequate education and training on pesticide use and safety practices, and a lack of awareness about the potential consequences of improper pesticide application. This knowledge gap could potentially lead to various issues such as improper pesticide usage, environmental contamination, and health hazards for farmers and consumers, and reduced efficacy of pest control measures.

These findings contrasted with those of Marete et al., (2021) in their research on pesticide usage practices in Meru County, Kenya. They observed that the majority of farmers (65%) followed and correctly interpret and read labels. The highest proportion of the farmers in the study lack clear understanding of pesticide safe pesticide handling procedures is attributed to insufficient education and training on pesticide use and safety protocols, coupled with a lack of awareness regarding the potential ramifications of incorrect pesticide application.

The highest percentage suggests a widespread lack of understanding or adherence to crucial safety and usage guidelines provided on pesticide labels. According to the results, the inability of farmers to correctly interpret and follow pesticide label instructions could pose serious risks to both human health and the environment. Pesticide labels typically contain essential information regarding proper application rates, safety precautions, protective equipment requirements, storage guidelines, and disposal methods. Failure to adhere to these instructions can lead to pesticide misuse, which may result in health hazards for farmers, farmworkers, consumers, and nearby communities (Mehmood *et al*., 2021).

4.4.6 Factors Influencing Choice of Pesticides Used

The study aimed to shed light on the decision-making process of farmers when selecting pesticides for their crops. The findings indicate that the majority of respondents (55.9%) depended on advice from agrovet stores when deciding on pesticide usage, while advertising's impact relatively minimal (2.9%). This is presented in Table 16.

Table 16: Factors Influencing Choice of Pesticides Use

Factors	Frequency	Percent
Agrovet	38	55.9
Fellow farmers	13	19.1
Level of income	5	7.4
Media	4	5.9
Advertisements	2	2.9
Others	4	5.9
Total	66	97.1

The findings suggest a concerning trend wherein farmers may not be adequately handling pesticides, as they heavily rely on advice from agrovet stores for decision-making regarding pesticide usage. This reliance raises significant safety concerns for both human health and the environment. Moreover, the lack of access to information from media and advertisements exacerbates the issue, contributing to a general lack of awareness regarding safe pesticide usage practices within the study area.

The results suggest that farmers were not able to properly handle pesticide properly as they relied on advice from agrovet stores when making decisions about pesticide usage. This could lead to safety concerns on human health and environment the access to information from media and advertisement is lacking in the study area, this also leads to lack of awareness on safe pesticide usage

These findings are consistent with the observations made by Marete et al., (2021) in their research on pesticide usage practices among horticultural farmers in Meru County, Kenya. Their study indicated that 45% of farmers' decisions regarding pesticide selection were heavily influenced by pesticide retailers. However, these results contrast with those of Nguetti et al. (2018), who conducted a study on pesticide use practices in Ghana and found that 48% of farmers received their initial information from other farmers. Additionally, Nguetti et al., (2018) conducted a study in Sri Lanka, where 48.9% of respondents first learned about pesticides from neighbours, and 51.1% received their initial information from various sources, including extension officers, farmers' cooperatives, and dealers. Nonetheless, Nguetti et al., (2018) document these findings with their study in Pakistan, where 25% of respondents received information from multiple sources. In contrast, these findings diverge from the study by Nyakundi et al., (2012) on pesticide use and application patterns in the Rift Valley and Central Provinces of Kenya. According to their study, the primary sources of information on clinical usage were commercial media (37.6%), government agricultural extension officers (26.4%), village leaders (25%), and other community leaders' opinions.

This highlights the pivotal role that these agricultural input providers play in shaping farmers' choices, serving as trusted sources of information and expertise.

Overall, these findings underscore the complex interplay of factors influencing farmers' choices regarding pesticide usage, necessitating tailored strategies for effective extension and educational outreach initiatives in promoting sustainable pest management practices in the region.

4.3.7 Formal Training on Good Pesticide Practices

Further, the researchers sought to establish weather farmers have ever received training on good pesticide practices in Kiegoi location Meru County. The findings revealed that 92.6% of respondents reported having never received any formal training on the proper and safe use of pesticides while, a small proportion of respondents (7.4%) reported receiving formal training on safe pesticide practices. This is indicated in Table 17.

Table 17: Formal Training on Good Pesticide Practices

Response	Frequency	Percent
No	63	92.6
Yes	5	7.4
Total	68	100.0

These findings aligned with previous observations made by Otieno (2019) in their research on pesticide application and residue levels in the environment, kales, and tomatoes within the Ewaso Narok Wetland, Laikipia County, Kenya. According to the results, a vast majority of farmers (97%) had not undergone any formal training regarding safe pesticide use. Additionally, the study found that farmers were utilizing uncalibrated containers for measuring pesticides, posing challenges in ensuring the accurate proportions of pesticide and water during mixing. This lack of training contributed to improper pesticide practices within the Ewaso Narok wetland, including inadequate use of personal protective equipment (PPE), improper disposal methods for pesticides, utilization of incorrect spraying equipment, mixing different types of pesticides, and failure to adhere to pesticide safety intervals.

The findings are in agreement with the study by Kinyua and Nguku (2023) in their study on pesticide handlers in the Mwea Irrigation Scheme in Kenya. Their results indicated that 67.5% of respondents reported having never received any formal training on pesticide safety while, a small proportion of respondents (32.5%) reported receiving formal training on safe pesticide practices.

The small proportion of respondents (7.4%) suggested that there are some initiatives in place to address this issue, albeit on a limited scale. However, the overall lack of access to training programs highlights the need for more comprehensive and widespread educational efforts aimed at promoting responsible pesticide use. The findings above indicate a significant gap in knowledge and awareness among farmers regarding the potential risks associated with pesticide use and the importance of adhering to safety guidelines. Without adequate training, farmers may unknowingly misuse pesticides, leading to adverse environmental and health consequences.

The absence of training on safe pesticide practices is particularly concerning given the potential hazards associated with pesticide exposure. Without proper guidance on handling, application, storage, and disposal of pesticides, farmers and their families may be at risk of health problems, including acute poisoning and long-term health effects. Furthermore, improper pesticide use could also have adverse effects on the environment, such as soil and water contamination, as well as harm non-target organisms like beneficial insects and wildlife.

4.3.8 Appropriate Timing for Post-Harvest Intervals

The study further, aimed to determine whether farmers observed appropriate timing for post- interval harvest of the kales crop in agricultural cycle. The results revealed that 39.7% of the respondents observed correct timing of post- interval harvest of the kales crop, while a majority of 57.4% admitted to not observing the optimal timing within the post-interval harvesting. This is illustrated in Table 18.

Table 18: Appropriate Timing for Post-Interval Harvest

Response	Frequency	Percent
Yes	27	39.7
No	39	57.4
Total	66	97.1

The information above reveals a concerning lack of knowledge among the majority of the respondents on post-interval harvest, a stage that is considered safe to harvest, as pesticide residues are expected to have reduced to levels within permissible limits set by regulatory authorities. The findings from similar studies aligned closely with those of Otieno (2019) in their study on pesticide application practices in Laikipia County, Kenya. They observed that a majority of farmers did not adhere to proper timing of post-interval harvesting.

This knowledge gap is alarming in the study area as the timing of pesticide application significantly influences its effectiveness and environmental impact. Without proper awareness, there is a risk of improper pesticide usage, which could lead to reduced crop yields, environmental contamination, and potential health hazards for both farmers and consumers in the study area. Addressing this issue requires targeted educational programs aimed at enhancing awareness among community members regarding the optimal timing for pesticide application.

CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This comprehensive analysis focuses on assessment of pesticide use practices and residue levels in locally produced kales and domestic water sources in Kiegoi, upper Nyambene Catchment. The research was guided by three objectives; to determine the types of pesticides commonly used by kales farmers, to analyze the pesticide residue concentrations in locally produced kales and domestic water sources and to assess the level of community's awareness on pesticide use in Nyambene Catchment area, Kenya. This chapter presents the summary of the study findings, conclusions, recommendations of the study and areas for further research.

The study on horticultural farmers using pesticides revealed that 97.1% of respondents employed pesticides on their vegetables to manage weeds, pests, and diseases, with only 2.9% not using pesticides. The most frequently used pesticide is the fungicide Mancozeb (Dithane M-45), accounting for 22.1% of usage. This is followed by the insecticides Deltamethrin (Deltanex) at 14.7%, Dichlorvos (Nuvan) and the fungicide Captan (Captan 50 WP) both at 11.8%, and Diazinon (Diazinol) at 10.3%. Dieldrin, although historically registered in the 1950s and now restricted, still shows a 5.9% usage. Cypermethrin (Cyperkill) and Acetochlor (Trophy) each contribute 7.4% to the total pesticide use.

The findings reveal notable insights regarding seasonal variations in pesticide residue concentrations in Nguondone stream and their compliance with WHO Maximum Residue Limits (MRLs). Mancozeb, Deltamethrin, and Captan showed increased concentrations in the dry season compared to the wet season, though these differences were not statistically significant (p-values: 0.546, 0.672, and 0.615 respectively). Cypermethrin and Acetochlor concentrations remained consistent across both seasons (p-values: 0.656, 0.689). Dichlorvos, Diazinon, Dieldrin, and Acrinathrin were detected only in the dry season, with Dichlorvos and Diazinon being below detection limits in the wet season, and Dieldrin showing a non-significant increase ($p = 0.311$).

When comparing these concentrations against WHO MRLs, it was found that Mancozeb and Deltamethrin remained within safe limits in both seasons. However, Dichlorvos exceeded its MRL of 0.03 mg/l during the dry season, indicating a potential contamination risk. Captan showed a slight increase but stayed within its MRL of 0.7 mg/l. Diazinon and Dieldrin exceeded their MRLs of 0.01 mg/l and 0.05 mg/l, respectively, during the dry season, posing potential risks. Conversely, Cypermethrin, Acetochlor, and Acrinathrin remained below their respective MRLs in both seasons, indicating compliance with safety standards. These findings underscore the importance of continuous monitoring and regulatory measures to mitigate health and environmental risks associated with pesticide residues in water sources.

The study on pesticide residues in locally produced kales revealed significant seasonal variations and their compliance with WHO Maximum Residue Limits (MRLs). Captan and Deltamethrin concentrations significantly increased from the wet to the dry season, with Captan rising from 0.01533 mg/kg to 0.04700 mg/kg ($p = 0.001$) and Deltamethrin from 0.01467 mg/kg to 0.04200 mg/kg ($p = 0.000$). Diazinon also showed a significant increase from 0.01567 mg/kg to 0.02567 mg/kg ($p = 0.046$). Although Acetochlor's concentration rose from 0.02233 mg/kg to 0.05200 mg/kg, the difference was not statistically significant ($p = 0.367$). Glyphosate, Dichlorvos, and Dieldrin were detected only in the dry season, with no significant seasonal disparity, while Cypermethrin and Acrinathrin levels remained below detection limits in both seasons.

When comparing these concentrations with WHO MRLs, it was found that despite the significant increases in Captan and Deltamethrin levels, they remained below the WHO MRL of 0.5 mg/kg, indicating compliance with safety standards. Conversely, Dichlorvos, Diazinon, and Dieldrin, which were below detection limits during the wet season, exceeded their respective WHO MRLs of 0.02 mg/kg, 0.01 mg/kg, and 0.05 mg/kg in the dry season, suggesting a contamination risk. Meanwhile, Cypermethrin, Acetochlor, Acrinathrin, and Glyphosate either remained below detection limits across both seasons, indicating adherence to safety standards. These findings emphasize the need for continuous monitoring and regulatory measures to mitigate health and environmental risks associated with pesticide residues in kales.

From the result of this study, it can be observed that farmers in Kiegoi, in upper Nyambene catchment did not follow appropriate safe pesticide use. The findings on level of community awareness on pesticide use practices of the analysis reveal notable insights. A majority (55.9%) lacked awareness of proper pesticide storage, and 41.2% did not follow proper storage practices. Most respondents (51.5%) disposed of used containers by throwing them in open fields, with fewer burying (17.6%) or burning (11.8%) them, and only 14.7% using designated disposal sites. Additionally, 80.9% did not adhere to recommended mixing and dilution practices. Protective gear usage was low, with 69.1% not using it during application, and 72.1% not wearing any gear. Only 25% could correctly interpret pesticide label instructions. Most farmers (55.9%) relied on advice from agrovet stores for pesticide selection, with minimal influence from advertising (2.9%). A significant 92.6% had never received formal training on safe pesticide use, and 57.4% were unaware of the appropriate timing for pesticide application. These findings highlight the urgent need for improved education and training on safe pesticide handling and practices.

5.2 Conclusions

The study reveals concerning gaps in the level of community's awareness and practices regarding pesticide usage and safety measures. A large proportion of respondents lack understanding of proper pesticide storage, disposal methods for used containers, and recommended mixing and dilution practices. Furthermore, many farmers do not utilize recommended protective gear during pesticide application, increasing their vulnerability to harmful chemicals. The majority also struggle with interpreting and following pesticide label instructions accurately. Decision-making on pesticide selection relies heavily on advice from agrovet stores rather than informed choices, and formal training on safe pesticide practices is lacking for most farmers. Additionally, awareness regarding the appropriate timing for pesticide application in the agricultural cycle is insufficient. These findings underscore the urgent need for comprehensive education and training programs to enhance community awareness and practices related to pesticide safety, storage, handling, and application. Strengthening regulatory oversight and promoting sustainable agricultural practices are crucial steps in mitigating health and environmental risks associated with pesticide use.

Moreover, the study identifies notable variations in pesticide residue concentrations between wet and dry seasons in both water sources and locally produced crops. While some pesticides exhibit consistent concentrations across seasons, others show significant increases during the dry season, suggesting potential seasonal effects on pesticide accumulation. The detection of certain pesticides predominantly during the dry season indicates heightened usage or environmental exposure during this period. However, despite these fluctuations, some pesticides remain undetected in both seasons, highlighting the variability in residue levels across different environmental conditions. These findings emphasize the importance of ongoing seasonal monitoring and management strategies to address potential health and environmental hazards linked to pesticide residues in water sources and agricultural products.

5.3 Recommendations of the Study

Based on the conclusions drawn from the study, the study provides several recommendations to address the gaps in the level of community awareness and practices regarding pesticide usage and safety measures:

i. If pesticides have to be used on locally grown vegetables, then farmers need to undergo training to comply with the safety requirements which include but not limited to information regarding pesticide label instructions, proper application rates, timing, and safety precautions.
ii. Education programs on pesticide safety and sustainable practices should be provided to agrovet store staff to enhance their ability to advise farmers effectively.
iii. Extension officers should be given to farmers to adopt sustainable agricultural practices aimed at reducing reliance on pesticides. This includes embracing integrated pest management (IPM) techniques, crop rotation, and biological pest control methods to minimize pesticide exposure risks for both farmers and consumers.

iv. Implementation of Seasonal Monitoring Programs is essential to monitor fluctuations in pesticide residue concentrations in water sources and agricultural products.

5.4 Suggestions for Future Research

Based on the analysis and findings of the pesticide use practices and residue levels in locally grown crops and domestic water sources in Kiegoi Nyambene catchment area, several recommendations for future studies emerge:

i. The study was limited to kales grown in Kiegoi, Nyambene catchment area. Further research is suggested to be carried to other counties to affirm pesticide use practices and residue levels in locally produced kales.

ii. This study looked at herbicide, fungicide and insecticide; therefore, other researchers should look at other types of pesticide and their effect on crops.

iii. The current study used cross-sectional descriptive design that collected data from farmers at only a specific time of the year. Future research should consider conducting longitudinal studies to track changes in community awareness and practices regarding pesticide usage and safety measures over time. This will provide insights into the effectiveness of education and training programs on improving pesticide handling practices.

iv. Comparative Studies should be conducted on pesticide residue concentrations and community practices across different geographic regions or agricultural systems to identify regional variations and factors influencing pesticide contamination levels. This comparative approach can help prioritize strategies to specific contexts.

v. Impact Assessment Studies can be conducted to assess the environmental and health impacts of pesticide residues on water sources, soil quality, and human health.

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APPENDICES

Appendix I: Questionnaires for the Respondents

Introduction

My name is Kennedy Chumar (NM11/45916/20), a student at Chuka University, undertaking Master's Degree in Environmental Science. I am conducting research on assessment of pesticides use practices and residue levels in locally produced kales and domestic water sources in Kiegoi, in upper Nyambene catchment. I hereby request for your support and contribution in answering the following research questions. Kindly assist in filling in the questionnaire. The information collected in form of answers to the questionnaire will be treated confidentially and will only be used for academic purpose.

Thank you.

SECTION A: Farmer's Demographic Information

(Please tick (√)where appropriate)

Name of the County……… Sub County………… location …………

GPS reading…………………

1. Please indicate your gender Male ( ) Female ( )
2. What is your age bracket? 20-30 years ( ) 30-40 years ( ) 40-50 years ( ) above 50 years ( )
3. Currently what are your education levels? Primary ( ) Secondary ( ) Certificate ( ) Diploma ( ) Tertiary ( )

SECTION B: Type of Pesticides Commonly Used

4. Do you use pesticides for the control of weeds, pests and diseases in your farm? YES ( ) NO ( )
5. If yes, what type of pesticides have you been using, for which crops, pests /diseases and how long?

Common name/Trade name at the stockists (by the farmer)	Frequency daily/Weekly/	which crop being treated

SECTION C: Assessment of Pesticides Use Practices

6. Are you aware of proper pesticide storage practices?

Yes ( ) No ( )

7. How are the used containers disposed of?

Disposal method	**Tick appropriately**
Thrown in open field	
Buried in farm	
Burnt	

8. Do you follow recommended mixing and dilution practices Yes ( ) No ( )

9. Do you wear protective clothing when applying pesticides?

Yes ( ) No ( ) If yes, tick what is applicable;

PPEs	**Tick appropriately**
Gloves	
Face mask	
Eye glass/ Goggles	
Coveralls	
Long sleeve	
Dust mask	
Boots	
Hat	
Respirator	
Ear plugs	
Chemical-resistant apron	
Insect repellent	

10. Do you follow and correctly interpret label instructions?

11. What influence your decision making while choosing pesticide to use on your crops? Farm Supplier (Agrovet) ( ) Farmers ( ) Income ( ) Media ( ) (advertisements ( ) labels on the container ( ) others specify ( )

12. Have you ever received formal training on good pesticide practices?

Yes ( ) No ( )

13. Do you observe appropriate timing for pesticide application in the agricultural cycle? Yes ( ) No ( )

Appendix II: Internal Research Fund Grant

CHUKA UNIVERSITY

Knowledge is Wealth (Sapientia divitia est)

OFFICE OF THE VICE-CHANCELLOR

Telephones: 020-2310512/18 Email: info@chuka.ac.ke P. O. Box 109-60400, Chuka

REF.: K.CHUMAR/ NM11/45914/20 **28th April, 2023**

Kennedy Chumar

Thro'
Dr. Evans Mutuma (Supervisor)
C/o Department of Environmental Sciences & Resources Development.

Dear Mr. Chumar,

RE: INTERNAL RESEARCH FUND GRANT

I am pleased to inform you that the Master's research proposal entitled: **"Assessment of pesticide use practices and residue levels in locally produced kales and domestic water sources in Kiegoi Location, Meru County"** was reviewed and recommended by the Board of Research and Extension for award of innovation and commercialization research grant, totaling **KSh. 130,000 (One hundred and thirty thousand only)**. You are required to complete your research within two years from the date of this letter. You may apply to the National Research Fund (NRF) for additional funding, if necessary. In addition, revise your budget to provide break down of lump sum costs, items' purpose explanatory notes, and then return with acceptance letter.

You shall be required to abide by the stipulations contained in the Chuka University Research Policy, including submission of three quarterly and one final progress reports to the Deputy Vice-Chancellor (Academic, Research and Student Affairs) through the Directorate of Research and Extension in the prescribed format, adherence to the Public Procurement procedures, and accessing of the funds through your internal research supervisor. Disbursement of subsequent funds will depend on receipt of satisfactory progress reports.

I take this opportunity to congratulate you on this achievement.

Yours sincerely,

Prof. Dorcas K. Isutsa, Ph.D.
AG. VICE-CHANCELLOR/CEO

CC. DVC (ARSA) Finance Officer Director (R&E) Director, PC

I, KENNEDY KEMBOI CHUMAR**, do accept the Chuka University Internal Research Funds under the terms and conditions given above.**

Signature ________ **Date** 19/05/2023

Appendix III: Chuka University Institutional Ethics

CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)* Akili ni Mali

CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

Telephones: 020-2310512/18 P. O. Box 109-60400, Chuka
Direct Line: 0772894438 Email: info@chuka.ac.ke, Website: www.chuka.ac.ke

REF: CUIERC/ NACOSTI/339 **1st March, 2023**
TO: **Kennedy Chumar**

RE: ." Assessment of Pesticide use practices and Residue levels in Locally produced Kales and Domestic Water Sources in Kiegoi Location, Meru County

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812.* The approval period is 1st March, 2023 – 1st March, 2024.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC.*
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC.*

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Chuka University is……. …Inspiring Environmental Sustainability for Better Life

Appendix IV: Research License

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 624162

Date of Issue: 25/April/2023

RESEARCH LICENSE

This is to Certify that Mr.. KENNEDY KEMBOI CHUMAR of Chuka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Meru on the topic: Assessment of Pesticide use practices and Residue levels in Locally produced Kales and Domestic Water sources in Kiegoi Location, Meru County for the period ending : 25/April/2024.

License No: NACOSTI/P/23/25218

624162

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix V: Diseased and Pest Infested Kales

(a)Powdery Mildew and Leaf Spot Diseases Source: (Field data, 2023)

(b)Aphids Infested Kale Crop Source: (Field data, 2023)

Appendix VI: Disposal of Empty Pesticide Containers

a) Empty Pesticide Can in Farm Hole

b) An Empty Can in an Open Field

c) Pesticide Container in a Farm Source: (Field data, 2023)

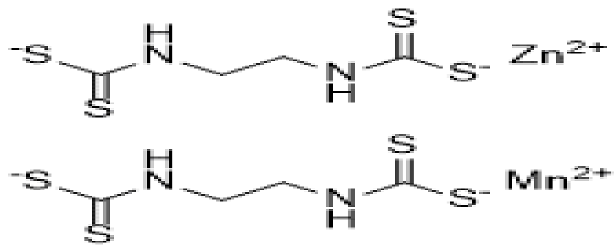
Appendix VII: GPS Sampling Coordinates in Kiegoi Kales Farms

KALES SAMPLES					
No. of samples Sampled in upper zone	**Latitude**	**Longitude**	**Active ingredients**	**SEASONS Mg/kg**	
UPPER ZONE				**Wet**	**Dry**
1	N00^{0} 14.154	E037^{0}54.021	Diazinol	0.012	0.014
2	N00^{0}14.165	E037^{0}53.012	Captan 50 WP	0.131	0.047
3	N00^{0}14.172	E037^{0}54.017	Cyperkill	<LOQ	LOQ
4	N00^{0}14.171	E037^{0}54.543	Basudin	<LOQ	LOQ
5	N00^{0}14.163	E037^{0}54.435	Dithane M-45	<LOQ	0.012
7	N00^{0}14.167	E037^{0}53.535	Roundup	<LOQ	0.021
8	N00^{0}14.162	E037^{0}54.525	Trophy	<LOQ	<LOQ
9	N00^{0}14.159	E037^{0}53.521	Rufast	<LOQ	<LOQ
MIDDLE ZONE					
1	N00^{0}13.973	E037^{0}55.534	Diazinol	0.012	0.013
2	N00^{0}13.720	E037^{0}55.399	Captan 50 WP	0.116	0.061
3	N00^{0}13.762	E037^{0}55.313	Cyperkill	<LOQ	0.031
4	N00^{0}13.790	E037^{0}54.111	Basudin	<LOQ	0.022
5	N00^{0}13.673	E037^{0}55.211	Dithane M-45	<LOQ	0.011
6	N00^{0}13.673	E037^{0}55.008	Roundup	<LOQ	0.031
7	N00^{0}13.673	E037^{0}55.277	Trophy	0.013	0.014
8	N00^{0}13.673	E037^{0}55.342	Rufast	<LOQ	<LOQ
9	N00^{0}13.673	E037^{0}55.535	Dieldrin	<LOQ	<LOQ
LOWER ZONE					
1	N00^{0}12.778	E037^{0}56.073	Diazinol	0.02	0.04
2	N00^{0}12.091	E037^{0} 53.167	Captan 50 WP	0.122	0.05
3	N00^{0}12.761	E037^{0}56.322	Cyperkill	0.05	0.06
4	N00^{0}12.757	E037^{0}57.311	Basudin	<LOQ	<LOQ
5	N00^{0}12.743	E037^{0}57.341	Dithane M-45	0.04	0.05
6	N00^{0}12.778	E037^{0}56.073	Roundup	0.07	0.09
7	N00^{0}12.751	E037^{0} 53.167	Trophy	<LOQ	<LOQ
8	N00^{0}12.720	E037^{0}55.399	Rufast	<LOQ	<LOQ
9	N00^{0}12.520	E037^{0}55.211	K-Othrine	<LOQ	<LOQ

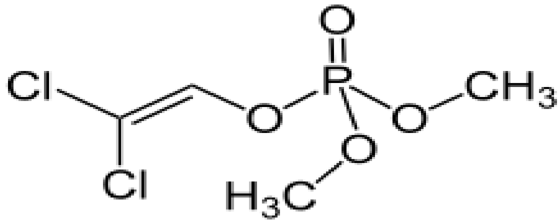
Appendix VIII
Chemical Structures of Active Ingredient of Some Pesticides

Active Ingredients	Chemical Structure

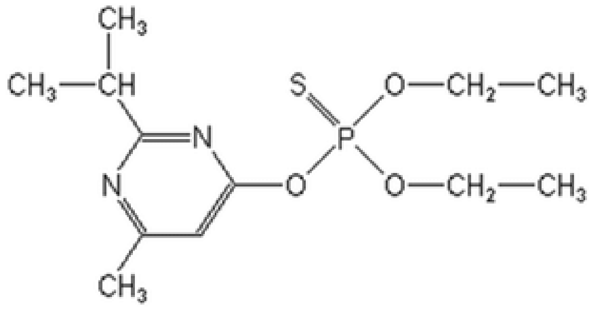
Mancozeb
[manganese (2+) ethane-1,2diylbis(dithiocarbamate) zinc ethane-1,2-diylbis (dithiocarbamate)



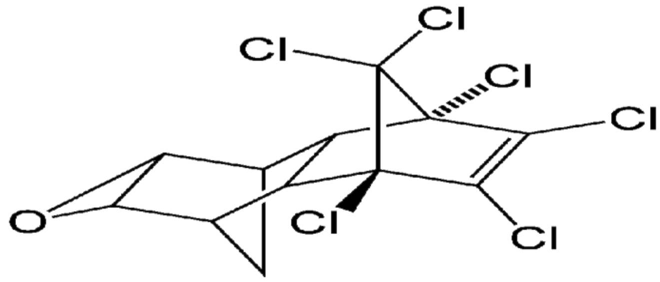
Dichlorvos
(2,2-dichlorovinyl dimethyl phosphate)



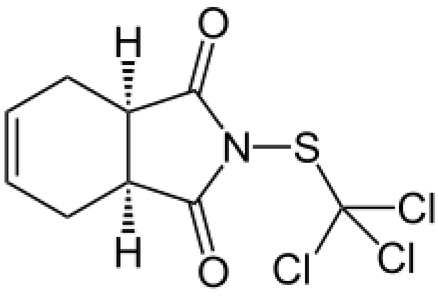
Diazinon
 (DZ) (O, O-diethyl-O-[2-isopropyl-6-methyl-4-pyrimidinyl] phosphorothioate)



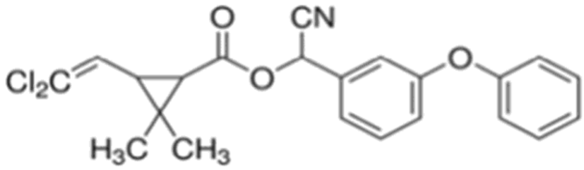
Dieldrin
Dieldrin 60-57-1 Octalox HEOD



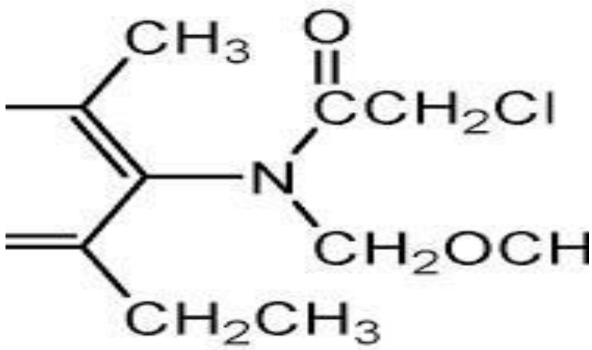
Captan (N-{trichloromethylthio}cyclohex-4-ene-1,2-dicarboximide).



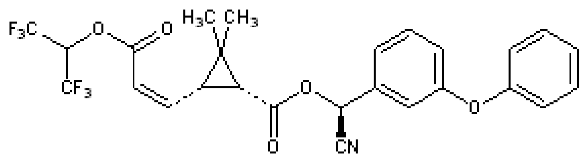
Cypermethrin (C 22 H 19 Cl 2 NO 3)



Acetochlor (2-oxoethanesulfonic acid)



Acrinathrin
(1*R*,3*S*)-2,2-Dimethyl-3-[(1*Z)*-3-oxo-3-[2,2,2-trifluoro-1-(trifluoromethyl) ethoxy]-1-propenyl] cyclopropanecarboxylic acid (*S*)-cyano(3-phenoxyphenyl) methyl ester



Glyphosate
N-(phosphonomethyl)glycine)