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Farmers' pesticide use and knowledge of aquatic ecosystem contamination with its perceived health risk from contaminated fish consumption in northern Ghana

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ABSTRACT

Pesticide residues in agricultural environments pose significant threats to aquatic ecosystems and human health. Most studies investigate the quantity, environmental, and risk assessment of pesticides in agricultural landscapes. However, farmers' pesticide use and their knowledge on aquatic ecosystem contamination remain limited and poorly documented. This study evaluated pesticide residue concerns in agricultural settings, focusing on farmers' uses and knowledge. It addressed pesticide application methods and their effects on aquatic ecosystems and human health through fish consumption. A cross-sectional design was employed and 300 farmers were selected using a multi-stage sampling technique from two agricultural districts – Savelugu Municipal and Tamale Metropolis. The study revealed that maize was most cultivated (29.6 %) with extensive pesticide treatment, particularly herbicides in the study setting. Findings revealed pesticide overuse (22.3 %), mixing of pesticides at the water bodies (24.7 %), improper leftover pesticide disposal methods (39.0 %) and inadequate storage practices (63.0 %) among farmers. About 21.3 % and 74.0 % of farmers have insufficient knowledge of the resulting consequences and the discharge of pesticides into the aquatic environment, respectively. Though the farmers are aware of the detrimental impact of pesticides on human health, there is still a lack of comprehension regarding the indirect consequences for aquatic ecosystems and non-target species. In the study setting, extension services may be important sources of knowledge. Thus, emphasizes the significance of improving extension programmes and utilizing peer-to-peer communication channels to support the adoption of best practices in pesticide management such as licenced high-temperature incinerators and cement kilns with sufficient emission controls. Focused training and outreach programmes designed to enhance farmers' knowledge and

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implementation of pesticide management plans are urgently needed. These interventions would help in reducing the dangers of pollution to aquatic ecosystems and human health.

Introduction

Pesticide residues in agricultural environments pose significant threats to aquatic ecosystems and human health. Additionally, pesticide residues are a major global health concern [1]. The control of pest and vector-borne diseases has relied heavily on the use of pesticides, resulting in a significant impact on food production to meet the needs of the growing global population. The Food and Agriculture Organisation (FAO) estimates the global annual utilisation of pesticides to be 4.12 million metric tons [2] with Africa accounting for only 2 % of this volume. A significant proportion (30 %) of the pesticides used in Africa are insecticides, which differs from other regions [2]. Ghana, South Africa, and Cameroon are the primary purchasers of pesticides in Africa [3]. The primary agricultural commodities that are commonly subjected to pesticide treatment are oil palm, cotton, coffee, cocoa, and vegetables [4,5]. Annually, a continual stream of new pesticides is introduced into the agricultural space, with improved qualities for targeted application and reduced adverse effects [6].

The use of pesticides is essential in agricultural systems. When employed in appropriate manner, they serve as a vital agricultural supply that safeguard crops against undesirable plants, insects, germs, fungi, and rodents. However, pesticides can cause adverse environmental effects by contaminating water, soil, and non-target organisms, leading to a decline in biodiversity and/or loss in crop productivity [2]. Spraying is a widespread method of applying pesticides across extensive land areas. However, due to factors such as wind, water runoff, and atmospheric weathering, a significant portion of the pesticides applied (up to 95.0 % of herbicides and over 98.0 % of insecticides) may not reach the intended pests [7]. Nonetheless, it seems that the pesticides that do not reach their intended targets are dispersed throughout ecosystems [8]. Aquatic environments, which are common reservoirs of aquatic biodiversity, also end up becoming receptacles of pesticides that do not reach their targeted use. Aquatic habitats including rivers and dams harbour a myriad of biodiversity, including fish and mollusks, which are frequently consumed by humans as a protein source and provide supplementary income for families. According to Adeyinka et al. [9], sediments in aquatic environments including water reservoirs, serve as a repository for harmful pollutants, particularly lipophilic compounds. These play a crucial role in releasing these contaminants. Furthermore, the preferred food source for aquatic biodiversity is found in the sediment, which is contaminated by pesticide residues. These residues contaminate species like fish. This may have severe impacts on their growth and reproductive abilities leading to environmental issues and health consequences when consumed.

The improper and uncontrolled use of pesticides poses a significant risk to human health and cause harm to the natural surroundings [10,11]. Therefore, it is imperative that educating smallholder farmers about pesticide use and implementing pragmatic policies to regulate the practice would curtail the inappropriate usage. This is particularly important for smallholder farmers, who often have limited literacy, small investments, weak extension services, and lack training and access to awareness programmes on the safe use of pesticides [12]. Despite these challenges, smallholder farmers handle significant quantities of pesticides. Though there is an increasing amount of scientific research on pesticide problems, there are still a limited number of unsolved questions.

Therefore, it is important to assess the agricultural and pesticide usage practices that lead to contamination of aquatic ecosystems and the level of knowledge among farmers regarding the risks associated with pesticides. This study contributes to enhance safety in all aspects of pesticide handling. It also evaluates the pesticide usage practices and knowledge of the dangers due to pesticide exposure. Furthermore, it examines their knowledge of the relationship between human health and the aquatic environment in two farming communities in northern Ghana. These findings may help in decision-making and regulations to mitigate the potential health hazards associated with pesticide exposure in Ghana.

Materials and methods

Study design

This study employed a quantitative approach and a cross-sectional design to collect data between December 2023 and January 2024. The respondents were smallholder farmers applying pesticides in their farming practices.

Study area

Northern region is found in the Savannah zone of Ghana, covering about 41 % of the country's agricultural land area. According to Asravor and Sarpong [13], almost 80 % of the population residing in the Savannah zone of Ghana is engaged directly or indirectly in agriculture. The land use pattern in the northern area is predominantly agricultural, with a focus on small-scale subsistence farming of cereals and legumes. Smallholder agriculture is a crucial means of sustenance for the majority of rural households in the Northern region, making a substantial contribution to their overall income. The Northern region, despite its significant role in cereal-legume production, experiences a single farming season due to its unimodal rainy season. Savelugu Municipal and Tamale Metroplis are two of the largest populated local government administrative districts within the northern region and home to approximately 80 % of smallholder farmers. The study purposively selected two local communities; Libga and Builpela due to their proximity to the White Volta river. Agriculture is the primary industry in the region [14].

Study population

The study focused on all farmers who use pesticides in any type of crop cultivation within the two selected agricultural communities (Libga and Builpela) in the northern area of Ghana. Their selection was determined by two specific criteria: (1) engaging in the activity at least once at each of the two places, and (2) engaging in the activity for a minimum duration of three years.

Sampling technique

The study employed the multi-stage sampling technique to choose the farmers. The sites in northern region were selected randomly from a list of agricultural districts obtained from the Ghana Statistical Services (GSS) website (<https://census2021.statsghana.gov.gh/>). Afterwards, the localities were chosen from GSS's roster of agricultural communities in the districts. The GSS collected data on the number of agricultural households in each selected community, which was then used to create a sampling frame. A probability proportional to size sampling method was employed to ascertain the number of farmers, followed by the use of simple random sampling to choose homes within each community. Additionally, to being the head of a household, individuals who had their own individual farms were also considered participants based on the selection criteria.

Sample size calculation

The sample size for this study was determined using the Cochran (1977) formula in the following manner:

$$N_0 = Z^2 pq / e^2$$

The variables used in this study are defined as follows: N_0 is the sample size that needs to be taken. Z is the standard deviation of a normal distribution with a significance level of $\alpha = 0.05$ and a confidence interval of 1.96. p is the estimated percentage of farmers who use pesticides (17.5 % or 0.175). q is the acceptable deviation from the assumed percentage ($1 - p$), and e is the level of accuracy that is wanted (5.0 %).

Thus, the calculated sample size was 221. The sample size may be larger if the population attribute's true variability (p) was used. To account for non-response and missing respondents, an additional 10 % of the anticipated sample size was included. The overall sample size N_0 was 243. However, a total of 300 farmers were selected as the sample for this study.

Data collection instrument

The data was collected using a questionnaire created with the Kobo toolbox and administered through face-to-face interviews using an Android tablet. The questionnaire was pre-tested using a sample of 20 farmers who were randomly chosen from the Libga community in the Savelugu municipality. The pre-test was conducted specifically on farmers in the Nabogu village in Savelugu municipality for two primary reasons. Initially, the community gained recognition for engaging in inappropriate agricultural practices and using chemical fertilisers in the wetlands improperly [15]. Secondly, farmers in this community have convenient access to pesticides for their agricultural needs. The survey tool comprised a synchronised digital tablet and a backend database that was accessed in Excel format for analysis. The survey was conducted using the most recent version of the KoboCollect app on Tecno mobile phones running the Android operating system. The question format consisted of a mix of closed-ended and partially categorised questions. During the study, participants were visited either at their workplaces on the farms or at their residences. The questions were created to assess the agricultural and pesticide usage practices that lead to the contamination of water bodies with pesticide residues. This examination facilitated comprehension and analysis of the relationship between these practices and the contamination of aquatic ecosystems. Furthermore, the survey questionnaire was specifically created to generate a report on any possible risks to aquatic organisms and humans that could result from consuming fish obtained from these impacted ecosystems. The questionnaire was composed in the English language. To obtain accurate data from participants who were unable to speak or understand, research assistants translated the questions into the local language (Dagbani) for them.

Quality assurance

Before collecting the data, the research assistants had a two-day training session that covered theoretical and practical components. The theoretical component covered topics relating to the fundamental concepts of research, study purpose and objectives, data collection, and interviewing methods. An examination of the principles of informed consent and research ethics in studies that involve human beings. The fieldwork encompassed practical exercises employed to evaluate (pre-test) the efficacy of the questionnaire. Subsequently, the questionnaire was improved using the data and feedback acquired from the research assistants.

Statistical analysis

The data was extracted from KoboCollect and transferred to Excel for data cleaning. Then, the cleaned data were loaded into SPSS software version 26.0 for analysis, (SPSS Inc. 2008). Descriptive statistics including frequency, percentages, means, and standard deviations were conducted to gain a deeper understanding of the agricultural practices, pesticide use, and knowledge regarding the

Table 1
Sociodemographic and economic information of respondents in northern Ghana.

Variables	Frequency (%)	P-value (chi square)
Gender		0.402
Male	200 (66.7)	
Female	100 (33.3)	
Age (Year)		0.376
Mean (Standard deviation)	40 (9)	
18–25	14 (4.7)	
26–33	68 (22.7)	
34–41	80 (26.7)	
42–50	86 (28.7)	
> 50	52 (17.3)	
Marital status		0.300
Single	18 (6.0)	
Married	263 (87.7)	
Cohabiting	7 (2.3)	
Divorced	7 (2.3)	
Widow/widower	5 (1.7)	
Educational level		0.003
No formal education	150 (50.0)	
Primary	108 (36.0)	
JHS/Middle/ SHS/Secondary	33 (11.0)	
Tertiary	9 (3.0)	
Main occupation		0.015
Farming	181 (60.3)	
Fishing	40 (13.3)	
Civil servant	9 (3.0)	
Private sector employee	12 (4.0)	
Artisan	39 (13.0)	
Other ^a	19 (6.3)	
Secondary activities		0.486
Farming	119 (39.7)	
Artisan	44 (14.7)	
Fishing	39 (13.0)	
Private sector employee	6 (2.0)	
None	80 (26.7)	
Other ^b	28 (9.3)	
Monthly income from all activities in Ghana Cedis		0.179
Mean (Standard deviation)	1212.91 (757.118)	
< 500	54 (18.0)	
501–1500	176 (58.7)	
> 1500	70 (23.3)	
Years of experience in farming		0.783
Mean (Standard deviation)	13.05 (7.970)	
3–10	136 (45.3)	
11–18	101 (33.7)	
19–26	36 (12.0)	
> 26	27 (9.0)	

^a = student, trader, food vendor.

^b = trader, fishmonger, butcher, moto tricycle rider, driver.

*Multiple response selection variable. Frequency represents the number of times a particular option was selected and the corresponding percentage.

**Income in Ghana Cedis: we assume that 1 US Dollar = 15 Ghana Cedis.

***chi-square p-value.

contamination of aquatic ecosystems with pesticides in the selected districts of northern Ghana. A test of independence or equality of proportions (chi-square test) was conducted to assess the association between nominal variables and between ordinal and nominal variables. In addition, a multiple-response analysis was performed on questions that permitted multiple responses.

Results

Socio-demographic and economic information of farmers

The socio-demographic and economic attributes of the participants are recorded in Table 1. A total of 300 participants were selected for the study, with 60.7 % from Libga and the remaining from Builpela. The majority of participants (66.7 %) were male. The study found that the mean age was 40 years with a standard deviation of 9, suggesting that the majority of farmers are mature and within the working age range. The age distribution shows a significant proportion in the age bracket of 42–50 (26.7 %). The chi-square

Table 2
Farmers' pesticide application practices and storage habits in northern Ghana.

Pesticide application and storage practices	Frequency	Percentage (%)	P-value (chi square)
Number of times pesticides are used			
Mean (Standard deviation)	4.40 (2.29)		0.487 ^a
< 5	206	68.7	
6–10	90	30.0	
> 10	4	1.3	
Quantity of pesticide applied (Liter)			
Mean (Standard deviation)	5.895 (3.77)		0.407 ^a
<10	262	87.3	
11–20	37	12.3	
> 20	1	0.3	
Overuse of pesticides			
Yes	67	22.3	0.311
No	118	39.3	
Don't know	115	38.3	
Overdosage of pesticide			
Yes	67	22.3	0.432
No	114	38.0	
Don't know	119	39.7	
Storage of pesticide			
No specific area	137	45.7	0.009
Special storehouse	25	8.3	
Bedroom	39	13.0	
Kitchen	13	4.3	
Use all immediately	86	28.7	
Mixing pesticide at the water body			
Yes	74	24.7	<0.001
No	226	75.3	

^a P-value of the Likelihood Ratio.

test revealed no significant association between their knowledge of contaminating aquatic habitats with pesticide residue and the variable being tested ($X^2 = 4232$, $df = 4$; $P = 0,376$). The majority of the participants (87.7 %) were married. This indicates that there is a possibility of family involvement in pesticide use. In this study, 50.0 % of farmers had no formal education and farmers with a primary education accounted for 36.0 % of the total. Approximately 9.0 % of farmers possessed a tertiary education. The chi-square test of independence revealed a significant association between farmers' knowledge of damaging aquatic environments with pesticide residue and their education ($X^2 = 15,952$; $df = 4$; $P = 0.003$).

This study revealed that a significant proportion of the farmers (60.3 %) were engaged in the agricultural sector, followed by those involved in fishing (13.3 %), and artisans (13.0 %). Civil servants and private sector employees constitute smaller proportions, at 3.0 % and 4.0 %, respectively. A further 6.3 % of participants fell under the 'Other' category and indicated student, trader, and food vendor as main occupation. A statistically significant association between the participants' occupation and their awareness of pesticide-related water contamination has been observed ($X^2 = 14,324$, $df = 5$; $P = 0,015$). On secondary activities, 39.7 % of the participants reported farming as a secondary occupation. Artisan was indicated as the second most common secondary activity, accounting for 14.7 % of respondents. Fishing was also mentioned as a secondary activity (13.0 %). Only 2.0 %, were employed in the private sector. Notably, 26.7 % reported no secondary activities, and 9.3 % (28 individuals) were involved in other activities such as trader, fishmonger, butcher, moto tricycle rider and driver. The average monthly income of farmers was 1212.91 Ghana Cedis (GHS) and equivalent to about US\$80.86, with a standard deviation of GHS757.118 (US\$50.47). The majority of individuals (58.7 %) had an income ranging from GHS501.00 to 1500.00 (US\$33.34 and US\$100.00), while 23.3 % had an income over GHS1500.00 and 18.0 % had an income below GHS500.00 (US\$33.33). On the farmers' experience, the average number of years of farming was 13.05, with a standard deviation of 7.970. The farmers' experience ranged from 3 to 10 years (45.3 %), 11 to 18 years (33.7 %), 19 to 26 years (12.0 %), and over 26 years (9.0 %).

Farmers' agricultural, pesticide use and management practices

Agricultural practices

On the common crops that are cultivated by farmers (Fig. 2) and which crops received pesticide treatments (Fig. 3), 29.6 % of farmers reported cultivating maize, making it the most commonly reported crop. Vegetable crops (such as okro, lettuce, cabbage, bell pepper, carrot, amaranth, tomatoes, eggplant, and hot pepper), rice, and beans are cultivated by 25.9 %, 14.9 %, and 11.7 % of farmers, respectively. About 3.2 % of farmers reported engaging in both sorghum and groundnut farming.

On crops subjected to pesticide treatment, Fig. 3 shows the highest percentage (31.1 %) of farmers utilising pesticides on maize, followed by vegetable (26.3 %) and rice (15.4 %), while 12.1 % of them treated beans with pesticides. Yam and cassava were treated by 5.1 % and 4.1 % of farmers, respectively. Sorghum and groundnut were treated by 2.4 % and 3.4 % of farmers, respectively. Except for

Table 3
Farmers' practices relating to the disposal of used pesticide containers and leftover pesticides.

Pesticide disposal practices	Frequency	Percentage (%)	P-value (Chi square)
i) Action taken with leftover pesticides			0.004 ^a
Store it for another application	183	61.0	
Apply on another crop	10	3.3	
Re-apply on the same crop until it is empty	104	34.7	
Apply on a non-cropped land or pour it water body	3	1.0	
ii) Action taken with used pesticide containers			0.001
a) Throw them Away on the Farm			
Yes	206	68.7	
No	94	31.3	
b) Burning them			
Yes	79	26.3	
No	221	73.7	
c) Throw them Away on the Water Body or close to water body			
Yes	15	5.0	
No	285	95.0	
d) Bury them			
Yes	202	67.3	
No	98	32.7	
e) Disposing of regular waste			
Yes	58	19.3	
No	242	80.7	
f) Keeping for reuse			
Yes	6	2.0	
No	294	98.0	

^a P-value of the Likelihood Ratio.

maize, beans, and vegetable crops, all other crops were exclusively treated with herbicide pesticides.

Pesticide application and management practices

The study found that with a usage rate of 50.7 %, herbicides were the most widely used pesticide category by farmers for crop treatment. Subsequently, insecticides were used by (38.0 %) of the farmers, while 11.1 % of the farmers used fungicides (Fig. 4).

The study aimed to provide a thorough analysis of pesticide use among farmers by investigating the average quantity of pesticides used, the frequency of pesticide application, and identifying any exceptional cases or instances of excessive usage (Table 2). The analysis revealed that the average amount of pesticide used was 5.895 litres for the farming season, with a standard deviation of 3.77. The majority of farmers (87.3 %) used less than 10 litres of pesticide in their agricultural activities, while 12.3 % used from 11 to 20 litres, and only 0.3 % used more than 20 litres. The average frequency of pesticide usage was 4.40, with a standard deviation of 2.29. Approximately 68.7 % of farmers, primarily those cultivating maize, yam, cassava, and sorghum, reported using pesticides less than five times. Another 30.0 % of farmers used pesticides between 6 and 10 times, while a proportion of 1.3 % used pesticides more than 10 times.

On overuse and overdose of pesticides, 22.3 % of farmers reported to overusing. A similar number reported using more than the recommended quantity. Additionally, a considerable proportion of farmers (39.3 % and 39.7 %, respectively) expressed doubt or a lack of awareness about these issues (Table 2). In this study, we found no statistically significant association between the variables of overuse and overdose and the level of awareness of pesticide contamination in aquatic environments ($P > 0.05$).

The findings revealed that 28.7 % of farmers utilised all pesticides immediately after preparation; however, 45.7 % of farmers lacked a designated storage facility for pesticides. Consequently, these farmers resorted to storing pesticides in their bedrooms (13.0 %) and kitchens (4.3 %) (Table 2). The chi-square analysis revealed a statistically significant association between farmers' place of pesticide storage and their awareness of aquatic ecosystems contamination with pesticide ($\chi^2 = 13.648$, $df = 4$, $p < 0.009$).

On the location where pesticides are prepared, the study revealed that 24.7 % of farmers acknowledged mixing pesticides at the closest water reservoir, while 75.3 % did not partake in this activity (Table 2). The chi-square analysis revealed a statistically significant association between this behaviour among farmers and their knowledge of pesticide pollution in aquatic ecosystems ($\chi^2 = 52.634$, $df = 1$, $p < 0.001$).

In evaluating farmers' pesticide application techniques and post-application behaviour to determine how these actions may contribute to the contamination of aquatic ecosystems. All farmers stated that spraying was their primary method of pest control, and only 1.3 % of farmers used crop seed treatment (Table 1 Supplementary data). None of the surveyed farmers employed treatment methods such as irrigation systems or soil treatment. In relation to measures taken after pesticide application, a significant percentage of farmers engage in activities that heighten the likelihood of pesticide pollution in aquatic ecosystems, such as bathing in the closest body of water (7.7 %). Though a large proportion of individuals (83.7 %) reported changing their clothes and (68.0 %) washing their face and hands after applying pesticides (Table 1 Supplementary data). In addition, 29.7 % of respondents stated that they showered at home following pesticide application, as indicated in Table 1 Supplementary data.

The study assessed the measures taken by farmers after applying pesticides to get insight into their practices on pesticide management such as proper disposal of empty containers and leftover pesticides (Table 3). The data indicates that a majority of farmers

(61.0 %) preserve and then utilise leftover pesticide solutions in their next application cycle. Due to their inadequate storage procedures, these behaviours could have a negative impact on their health. A small number of farmers admitted to disposing of excess pesticide mixtures into bodies of water (1.0 %). Engaging in this activity may be dangerous. It presents a substantial threat to both people in the food chain and non-target creatures. About 34.7 % of farmers typically reapply the same crop treatment until the spraying tank is empty. Only 3.3 % of farmers reported putting residual pesticides on another crop.

Regarding the disposal of empty pesticide containers (Table 3), a substantial percentage (68.7 %) of farmers choose to discard by either tossing them away on their farms or burying them (67.3 %). Additionally, a significant percentage of individuals either incinerated the containers (26.3 %) or discarded them as ordinary refuse (19.3 %). Half (51.7 %) of study participants reported that it is equally dangerous for farmers and the environment to dispose of pesticide containers by burying, burning, or throwing them away on the farm. Only 2.0 % of farmers retained the containers for future use. On Table 3, about 5.0 % of farmers reported discarding containers in water bodies, whereas 95.0 % did not.

Farmers' knowledge about contaminating water bodies with pesticides and the health risks associated with consuming contaminated fish

It was found that 35.7 % of the farmers reported of being unaware of the discharge of pesticide residues into the environment. More than half (64.3 %) of the farmers were knowledgeable about this information. Similarly, about 47.0 % of the farmers were unaware of the end destination of pesticides, while the remaining 53 % had knowledge about it. The Pearson chi-square test demonstrated a statistically significant correlation between the awareness of pesticide pollution in aquatic habitats ($X^2 = 19,896$; $df = 1$; $P < 0.001$). In this study, the majority (70.9 %) of those who knew the final container gave the answer "soil," with the air or atmosphere coming in second (15.2 %). Only 13.9 % of the farmers were able to accurately identify water bodies.

The findings revealed that about three-quarters (74.0 %) of farmers were unaware of the contamination of aquatic ecosystems caused by pesticides.

Approximately 70.1 % of farmers were familiar with the regulations and guidelines about the disposal and usage of pesticides. Only 21.3 % of farmers were aware of the contamination of fish with pesticides. The results of Pearson's test of independence indicated a statistically significant correlation between farmers' awareness of the contamination of pesticides in aquatic environments ($X^2 = 32,709$; $df = 1$; $P < 0.001$). The farmers in the region seem to have a limited understanding of the potential dangers of pesticide pollution to aquatic organisms, namely fish.

In contrast to the level of awareness regarding the contamination of aquatic species with pesticides, the study found that the majority of farmers (73.0 %) were aware of the negative impact of pesticides on human health. About 27.0 % of farmers expressed a lack of awareness. More than 9 out of 10 farmers (92.2 %) reported of consequences of pesticides on aquatic organisms, with a specific emphasis on the mortality of such organisms as the principal effect. About one-third (34.8 %) of the farmers acknowledged that exposure to pesticides might lead to developmental abnormalities. About 28.8 % of the farmers recognised toxicity to fish and aquatic invertebrates against 71.2 %. Similarly, 27.2 % of farmers reported a disruption in the reproductive process of the species. Additionally, 2.2 % of the participants acknowledged the indirect effects of pesticides on aquatic ecosystems, specifically the stimulation of water plant growth.

Concerning the impact of pesticides on humans who consume contaminated fish (Table 2 supplementary data), 95.9 % of farmers reported gastrointestinal issues. More than 6 out of 10 (61.2 %) farmers reported that reproductive health difficulties were identified as the second most prevalent long-term consequence that humans may experience from consuming contaminated fish. There was a discrepancy in opinions regarding the neurological consequences of pesticides, with 33.8 % of farmers acknowledging such concerns. Similarly, 27.4 % of the farmers reported of a rise cancer risks among them. In addition, less than a quarter (17.8 %) of the farmers acknowledged the connection between pesticide exposure and developmental difficulties in children. Respiratory difficulties were reported by just one percent of respondents (1.8 %), while skin abnormalities were reported by an even lower number (0.5 %), as indicated in Table 2 supplementary data.

The study found that farmers liked getting information about the best ways to use pesticides and protect the environment from extension officers (76.9 %), radio (58 %), input dealers (49.6 %), and local associations (40 %) (Fig. 5). The information flow routes of TV (42.4 %), purchasing clerks (28.6 %), and fellow farmers (0.8 %) were found to be less preferred, as shown in Fig. 5. The farmers' access to information did not show a substantial correlation with their awareness of contamination by pesticides in aquatic ecosystems ($P > 0.05$).

Discussion

This study evaluated agricultural practices, pesticide application, and management techniques, as well as the knowledge of farmers regarding the contamination of aquatic habitats by pesticides and the accompanying health concerns. The findings of this study indicate that the widespread production of maize and the extensive use of pesticides, especially herbicides, provide substantial hazards of pesticide runoff and leaching into adjacent water bodies. The dangers are heightened in the research area because of the intensive agricultural practices and the close proximity of small-scale farms to water bodies. The pesticide application procedures of farmers have been uncovered, revealing: (i) a trend of excessive usage; (ii) inadequate storage and incorrect disposal; (iii) the practice of mixing pesticides near water bodies and the inadequate post-application behaviours; and (iv) a lack of awareness among farmers regarding the discharge of pesticides into the environment and their ultimate destination.

Socio-demographic and economic information of farmers

The majority of participants (66.7 %) were male. The study's findings confirm the population of male farmers in the study setting. This is similar to previous researches which reported 84.2 % of males in Nigeria [16]. The findings of this study are expected due to the prevailing gender disparity in resource distribution in rural farming communities in Ghana, where males tend to have greater access to resources than females [17]. Denkyirah et al. [18] reported that women may not be able to exert the necessary effort to cultivate the crop due to the labour-intensive nature of the activity. The study found that the mean age was 40 ± 9 , suggesting that the majority of farmers are mature and within the working age range. The age distribution shows a significant proportion in the age bracket of 42–50 (26.7 %). The majority of the participants were married. This indicates that there is a possibility of family involvement in pesticide use. In this study, 50.0 % of farmers had no formal education. The level of illiteracy, showing a lack of formal education, differs from the findings of Boateng et al. [3], which reported a high percentage of literate farmers involved in cocoa production in southern Ghana. However, our findings are similar to the outcomes obtained by Abdulahi et al. [19] who found 79.0 % illiteracy among farmers. The education of farmers can have a substantial impact on the promotion of safe pesticide usage and the reduction of excessive pesticide application [20]. The farmers' limited education has been found to impede their comprehension of the hazard warnings issued by the chemical industry and regulatory organisations [21]. Furthermore, as stated by Ríos-Gonzalez et al. [22], literate farmers possess a notably extensive understanding of the impacts of pesticide utilisation on both human health and the environment.

This study revealed that the average monthly income of farmers was 1212.91 ± 757.118 Ghana Cedis (GHS) and equivalent to about US\$80.86 \pm 50.47. The majority of individuals (58.7 %) had an income ranging from GHS501.00 to 1500.00 (US\$33.34 and US\$100.00). This finding aligns closely with the outcomes of 43.0 % of farmers having an income between 5 and 15000 BDT (Bangladeshi Taka) (US\$63.72 and US\$191.18) reported by Shammi et al. [23] in their study in Bangladesh. This implies that a large proportion of farmers can obtain pesticides without incurring any financial strain. In Ghana, farmers may receive subsidies or aid from politicians to obtain agricultural inputs like fertilisers [24]. In this context, the dynamics of pesticide usage and its environmental consequences can differ. Though subsidies might help reduce the financial challenges related to input costs, they can also unintentionally encourage the use of pesticides without adequately considering environmental sustainability. On the years of farmers' experience, the average number of years of farming experience among farmers was 13.05 ± 7.970 . The majority of farmers in our study were having an experience ranged from 3 to 10 years. This less expertise of farmers is likely to have an impact on the comprehension of the problem of ecosystem contamination and these farmers may be less motivated to take measures to resolve it. This contradicted the findings of Shammi et al. [23], who reported that most farmers (40 %) in Mehendiganj Upazila had farming experience ranging from 10 to 15 years.

Farmers' agricultural, pesticide use and management practices

The study aimed to provide a thorough analysis of pesticide use among farmers by investigating the average quantity of pesticides used, the frequency of pesticide application, and identifying any exceptional cases or instances of excessive usage. The most common crops cultivated by farmers was maize in our study. A study conducted by Kansanga et al. [25] found that farmers are increasingly choosing to grow maize instead of traditional staple crops like pearl millet and sorghum bicolor. This indicates a shift towards market-driven crops, with maize being the preferred choice. On crops subjected to pesticide treatment. A highest proportion of farmers reported utilising pesticides on maize. The significant rate of pesticide treatment on maize farms supports the findings of Ngeleza et al. [26]. The results indicate that growing maize may contribute to the pollution of adjacent water sources due to the runoff or leaching of pesticides. This raises concerns regarding the quantity and variety of pesticides used on these crops, which could heighten the risk of pesticide residues entering aquatic ecosystems. Though other crops including vegetables, rice, beans, yam, and cassava are not as widely cultivated compared to maize, their pesticide treatment rates indicate that they could also contribute to pesticide pollution in aquatic ecosystems. Furthermore, these crops mainly get herbicide pesticides indicates a possible accumulation of particular types of pesticides in agricultural runoff, which could have special ecological effects on aquatic creatures.

The study found that herbicides were the most widely used pesticide category by farmers for crop treatment. This suggests that the extensive use of herbicides may imply a strong emphasis on weed control, while the fluctuating levels of insecticide and fungicide usage could indicate the implementation of diverse pest and disease management approaches by farmers. The stated high utilisation rate of herbicides highlights the substantial role that herbicides play in contributing to pesticide contamination in agricultural landscapes. The extensive use of herbicides indicates a significant possibility of herbicide runoff into adjacent water bodies, which could result in contamination and disturbance to the ecological balance. These findings demonstrate a persistent pattern and prevalence of herbicide pesticides in agriculture. For instance, research was conducted by Kongtip et al. [27] in Thailand. The uniformity observed in several places highlights the extensive dependence on herbicides in contemporary farming methods and their effects on water quality and aquatic ecosystems. Our analysis revealed that there are differences in pesticide usage patterns among various pesticide groups. Though insecticides are employed to manage insect pests and might potentially harm aquatic creatures, their lower usage rate in comparison to herbicides suggests a relatively smaller direct influence on aquatic environments.

The analysis revealed that majority of farmers used less than 10 litres of pesticide in their agricultural activities. Multiple studies have shown the substantial impact of pesticide application rates on the degree of pollution in water bodies [28,29]. An example of this is a study conducted by Anju et al. [30], which discovered that higher rates of pesticide application were linked to higher amounts of pesticides in surface waterways located nearby. According to Damalas & Eleftherohorinos [31], places where agriculture is done intensively and pesticides are used extensively have higher levels of pesticide pollution in streams and rivers. The study findings suggest that farmers in the area typically employ minimal quantities of pesticides in their agricultural practices, as seen by the low

average amount of pesticides used and the prevalence of small application volumes. It is important to recognise that even small amounts of pesticides can harm aquatic creatures and ecosystems, especially when considering aspects such as the toxicity, persistence, and cumulative effects of pesticides on a larger scale over time [32]. Though one farmer may use minimal quantities of pesticides, the cumulative contributions from several sources within a watershed can lead to substantial water pollution.

On overuse and overdose of pesticides, 22.3 % of farmers reported to overusing. A similar number reported using more than the recommended quantity. This indicates a worrisome trend in pesticide usage that could lead to environmental pollution. The excessive use of pesticides can result in an overflow of chemicals from agricultural fields into neighbouring water bodies. Additionally, the excessive application of pesticides increases the chances of residues entering aquatic environments by leaching into groundwater or through direct runoff. These methods present dangers to aquatic organisms and ecosystems, such as fish, invertebrates, and aquatic plants. Pesticides can build up in bodies of water and alter biological processes. In a study conducted by Onwona et al. [33] have identified instances of improper dosage and misuse of pesticides. In the study, it was shown that farmers intentionally applied excessive amounts of seventeen different pesticides for various reasons. In this study, many farmers believed that an excessive dose of chemicals was caused by the presence of dew on plant leaves, particularly in the mornings. They explained that the quantity of pesticide products used is to offset the surplus water on the leaves. This statement requires careful consideration and appropriate corrective measures through education.

To comprehend how farmers mitigated ecological and health hazards linked to pesticide usage, they provided answers regarding the storage and preparation location of pesticide solutions. The findings revealed that of farmers (45.7 %) lacked a designated storage facility for pesticides. Consequently, these farmers resorted to storing pesticides in their bedrooms and kitchens. This is a hazardous practice and concerning behaviour. Storing pesticides in living spaces not only presents a direct health hazard to family members but also heightens the probability of indoor air pollution and surface contamination. The active components of these pesticides have the ability to evaporate and fill the storage areas surrounding the home, making people more susceptible to the risk of poisoning through breathing in the chemicals and consuming contaminated food [34]. Prolonged storage of pesticides in residential areas can result in exposure and the potential for intoxication [35]. Research conducted by Boateng et al. [3] and Okoffo et al. [36] observed a comparable pattern among cocoa farmers. It was found that 22.5 % of these farmers stored pesticides in their bedrooms. This practice has the likelihood of pesticide exposure by direct inhalation. Brice et al. [37] documented a study that found farmers keeping pesticides inside their homes with just 8.3 % of farmers own a designated storage area. This underscores the necessity of implementing education and outreach initiatives targeting Ghanaian farmers to advance the use of secure pesticide storage methods.

On the location where pesticides are prepared, the study revealed that quarter of farmers acknowledged mixing pesticides at the closest water reservoir. This technique poses a significant risk to the aquatic ecosystem. Multiple investigations have recorded comparable instances of mixing pesticides near water sources [38–41], emphasising the extensive prevalence of this problem. This practice can be linked primarily to a lack of understanding and awareness regarding the impact of these chemicals on aquatic fauna.

The study assessed the measures taken by farmers after applying pesticides to get insight into their practices on pesticide management such as proper disposal of empty containers and leftover pesticides. The data indicates that the majority of the farmers preserve and then utilise leftover pesticide solutions in their next application cycle. Due to their inadequate storage procedures, these behaviours could have a negative impact on their health. A small number of farmers admitted to disposing of excess pesticide mixtures into bodies of water (1.0 %). Engaging in such activity may be dangerous. It presents a substantial threat to both people in the food chain and non-target creatures. In this study, of farmers (34.7 %) typically reapply the same crop treatment until the spraying tank is empty. This finding is in line with the majority of farmers who reported either using up all the spray solution (54.9 %) or applying the remaining solution to another crop listed on the product label (30.2 %) [42].

Regarding the disposal of empty pesticide containers, a substantial percentage of farmers choose to discard by either tossing them away on their farms, burying or incinerated them. This practice can result in the pollution of agricultural soils and nearby water sources through the processes of leaching and runoff. Studies conducted in Ethiopia and Greece found that farmers frequently dispose of pesticide containers by discarding them in fields and incinerating using an open fire [42,43]. Both pesticide providers and national authorities commonly advise disposing of waste pesticides and empty containers by either burying or burning them. Nevertheless, these procedures are not ecologically sustainable as buried chemical waste has the potential to pollute soil and seep into surface or groundwater. Similarly, the incineration of pesticide containers produces environmentally permanent toxic emissions (Food and Agriculture Organisation [44]. The World Health Organisation (WHO) recommends the use of licenced high-temperature incinerators and cement kilns with sufficient emission controls as the most effective method to eliminate plastic containers and pesticides. Nevertheless, this option is either inaccessible or costly for farmers to support [45]. About 5.0 % of farmers reported discarding containers in water bodies. This poses a significant threat to all members of the food chain, particularly aquatic creatures and communities that rely on these water bodies their survival [36].

Farmers' knowledge about contaminating water bodies with pesticides and the health risks associated with consuming contaminated fish

In evaluating farmers' understanding of the consequences of pesticides, it was found that more than one-third (35.7 %) of farmers reported of being unaware of the discharge of pesticide residues into the environment. The lack of awareness indicates a possible underestimation of the environmental repercussions of pesticide utilisation, namely their effects on aquatic ecosystems. A study conducted by Shammi et al. [23] revealed that a comparable percentage of farmers in Bangladesh were uninformed about the act of contaminating the environment. Similarly, around 47.0 % of the farmers were unaware of the end destination of pesticides. The farmers' lack of information regarding the final destination of pesticide residues emphasises a significant gap in their comprehension of the routes through which pesticides might infiltrate aquatic habitats. In the absence of this comprehension, farmers may

unintentionally contribute to the contamination of water bodies with pesticides due to inappropriate disposal or application methods. In this study, only few farmers (13.9 %) were able to accurately identify water bodies as final receptacle of sprayed pesticides on farms. This highlights a discrepancy between farmers' understanding of where pesticides end up and the specific routes through which pesticide remnants infiltrate aquatic ecosystems. This disparity indicates a lack of comprehension or underestimation of the hazards presented by pesticide runoff and leaching to aquatic ecosystems.

The findings revealed that about three-quarters of farmers were unaware of the contamination of aquatic ecosystems caused by pesticides. In contrast, findings from other studies did not align with this conclusion. A study conducted in Bangladesh, the majority of farmers (83 %) surveyed in Savar Upazila were aware of the potential for pesticide contamination of aquatic environments [23]. The differences in awareness can be attributed to changes in factors such as geographical location, agricultural methods, the availability of extension services, and regulatory frameworks.

The study was also intended to evaluate farmers' knowledge of the contamination of fish, other aquatic organisms with pesticides and their familiarity with regulations and guidelines for the disposal and use of pesticides. About 78.7 % of farmers were unaware of the contamination of fish with pesticides. According to Dormann [46], pesticide contamination is one of the most significant dangers to biodiversity in agricultural settings. Based on a study conducted in Ghana by Obiri et al. [47], 7.0 % of the farmers surveyed believed that the overuse of herbicides could potentially lead to the extinction of fish in water bodies. This highlights the need for additional research to investigate the factors that impact farmers' views and attitudes towards pesticide contamination in aquatic environments, due to their limited level of awareness.

In contrast to the level of awareness regarding the contamination of aquatic species with pesticides, the study found that about 27.0 % of farmers expressed a lack of awareness of the detrimental effect of pesticides on health. Multiple studies have examined the extent of farmers' understanding regarding the usage of pesticides and its effects on the environment and health [3,48,47]. In terms of the risk to human health, 27.0 % of farmers were not aware of the negative impact of pesticides on humans. Nearly all farmers (92.2 %) reported of consequences of pesticides on aquatic organisms, with a specific emphasis on the mortality of such organisms as the principal effect. This is consistent with prior research that have emphasised the immediate harmful impacts of pesticides on aquatic creatures, resulting in death among different species [49,50]. Developmental abnormalities was acknowledged by the farmers (34.8 %). This indicates an increasing recognition of the harmful impact of pesticides on growth and health of aquatic organisms [51]. Kumar et al. [52] argue that residues of pesticide have life time threatening consequences. The severity of these effects varies depending on the sex, age groups, species, stressors, and environments of the animals. Pesticide residues have immediate harmful effects, harm the food sources of aquatic larvae, decrease their chances of survival, and disrupt their endocrine system. They can also alter the ratios of male and female individuals within a population, as well as the physical traits related to reproduction. This can negatively impact the ability of organisms to successfully reproduce, limit their overall growth and development, and diminish their capacity to evade natural predators [53]. About 28.8 % recognised toxicity to fish and aquatic invertebrates. Similarly, 27.2 % of farmers reported a disruption in the reproductive process of the species. Despite being aware of the detrimental impact of pesticide residues have on non-target species and ecosystems, the majority of farmers neglected to take any preventive measures during the application procedures [54].

Concerning the impact of pesticides on humans who consume contaminated fish, almost all farmers reported gastrointestinal issues. This indicates a serious health issue for individuals who consume fish that is contaminated. This result is consistent with prior studies that suggest pesticide residues in fish can cause gastrointestinal symptoms in humans including nausea, vomiting, and diarrhoea [55]. Reproductive health difficulties were identified as the second most prevalent long-term consequence that humans may experience from consuming contaminated fish. Other studies have also found that pesticide contamination in aquatic habitats is a significant problem for reproductive health [56]. These findings emphasise the need for more studies to investigate the precise mechanisms by which pesticides impact reproductive health and to create methods to mitigate the risks and safeguard vulnerable groups. The discrepancy in opinions regarding the neurological consequences of pesticides, with 33.8 % of farmers acknowledging such concerns, emphasises the intricate process of evaluating health problems associated with pesticides. Neurological abnormalities have been observed in people who have been exposed to significant amounts of specific pesticides [57]. However, the level of risk perception among farmers may differ based on factors such as their level of education, awareness, and personal experiences. The recognition of cancer risk among farmers highlights the ongoing worry regarding the potential to cause disease linked to specific chemicals. The discovery aligns with other research that has established a connection between exposure to pesticides and several forms of cancer, such as leukaemia, lymphoma, and breast cancer [58,59]. Less than a quarter of the farmers acknowledged the connection between pesticide exposure and developmental difficulties in children, emphasising the long-term effects of pesticide contamination in aquatic ecosystems throughout generations. Studies have demonstrated that being exposed to pesticides during pregnancy and early life can result in negative developmental consequences, such as impaired cognitive function, behavioural abnormalities, and congenital malformations [60,61,62].

Access to information is crucial for farmers to enhance their pesticide management, implement safety protocols, and maximise crop production. The study found that extension officers were the used channel for getting information about pesticides use methods and environmental protection measures. This aligns with previous studies by Awudzi et al. [63] and Boateng et al. [3], which also found that a majority of farmers preferred to obtain information through extension services. Similarly as Adu-Acheampong et al. [64], radio (58 %) came out to be the another preferred route of information flow to farmers, and represents a critical medium because of its broad reach, especially in rural communities where these farms are domiciled. To disseminate accurate and timely information to farmers on pesticide use on the radio requires the participation of experts, as this will afford standardised information to all farmers across the country. One notable aspect of this study was the involvement of fellow farmers in the dissemination of chemical knowledge. This implies that peer-to-peer communication among farmers could still have a significant impact on spreading best practices, even if it is not mentioned as often as other formal channels.

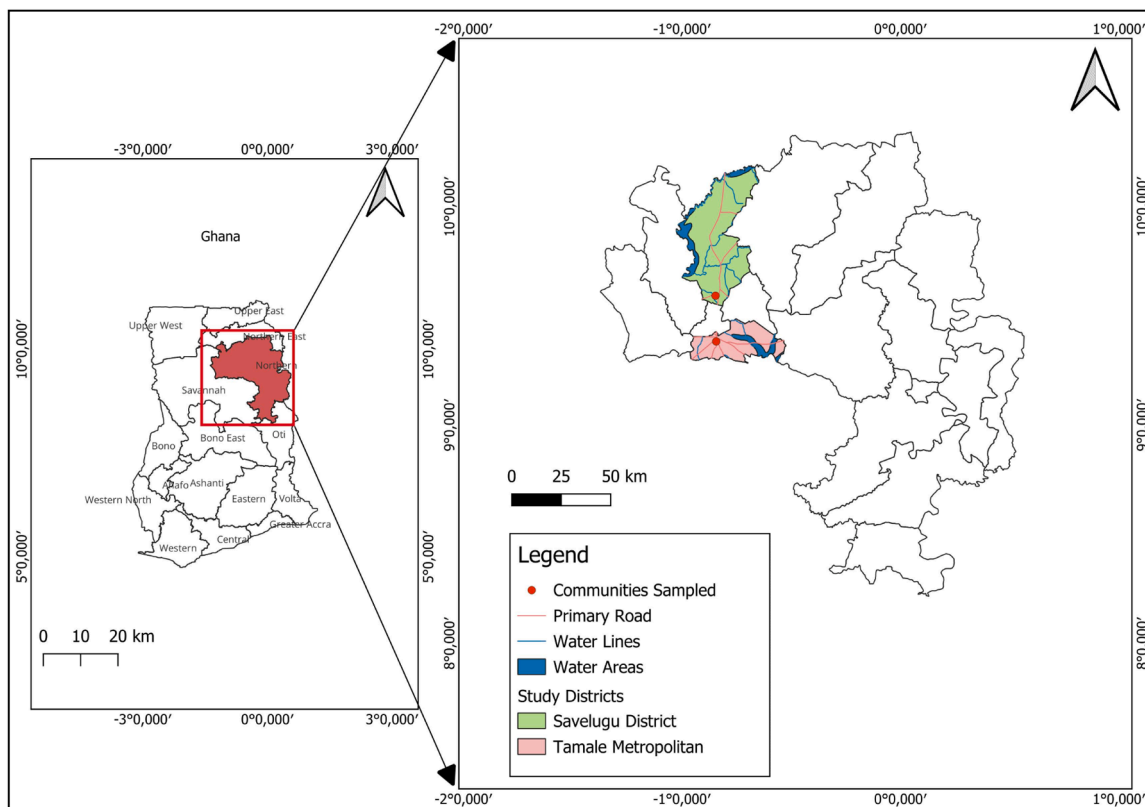


Fig. 1. Study map of the sampled districts in the northern region of Ghana.

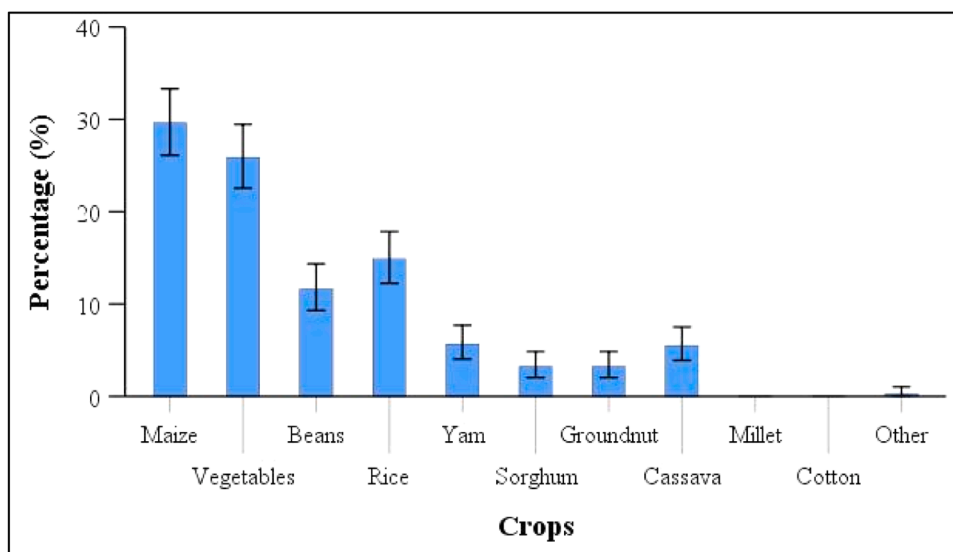


Fig. 2. Prevalence of crops cultivated by farmers in the selected communities.

Conclusion and recommendation

The study revealed widespread production of maize and the extensive use of pesticides, especially herbicides. Farmers' practices show excessive pesticide use, poor storage and disposal, mixing pesticides near water sources, and inadequate post-application behaviours. While farmers are aware of the direct health impacts of pesticides, they lack understanding of the broader environmental

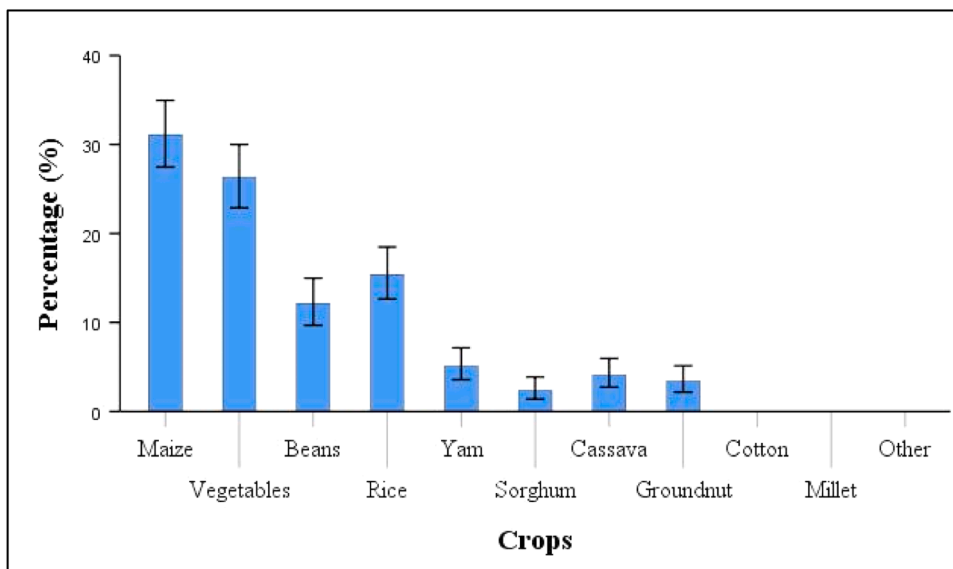


Fig. 3. Crop-specific pesticide usage patterns.

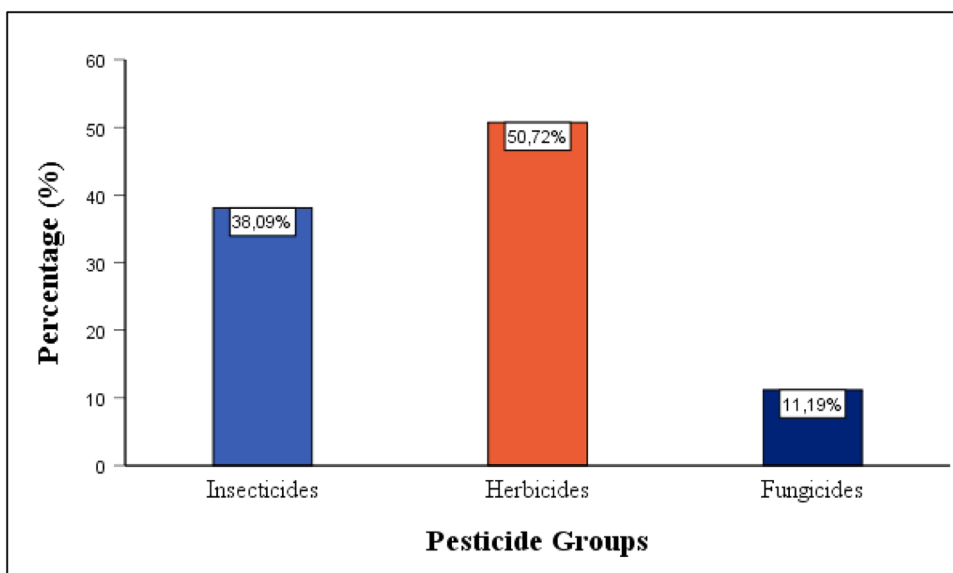


Fig. 4. Prevalence of different pesticide groups employed in agricultural practices.

effects on aquatic ecosystems and non-target species. These findings, showed that there is a need to: (1) Implement targeted educational and outreach initiatives to enhance farmers’ understanding of the ecological repercussions of pesticide utilisation and encourage the adoption of safer methods for application and disposal in the study setting. (2) Enhance regulatory frameworks to effectively enforce appropriate pesticide storage and disposal protocols, thereby mitigating the hazards of environmental contamination. (3) Foster cooperation among many parties involved, such as farmers, extension services, and government agencies, in order to formulate all-encompassing approaches to address the issue of chemical contamination in aquatic ecosystems and ensure the protection of human well-being. Fig. 1

CRedit authorship contribution statement

Abdou Orou-Seko: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Dennis Chirawurah:** Data curation, Methodology, Visualization, Writing – review & editing. **Joyce Aputere Ndago:** Data curation, Methodology, Visualization, Writing – review & editing. **Matilda Nkansah-Baido:** Data curation,

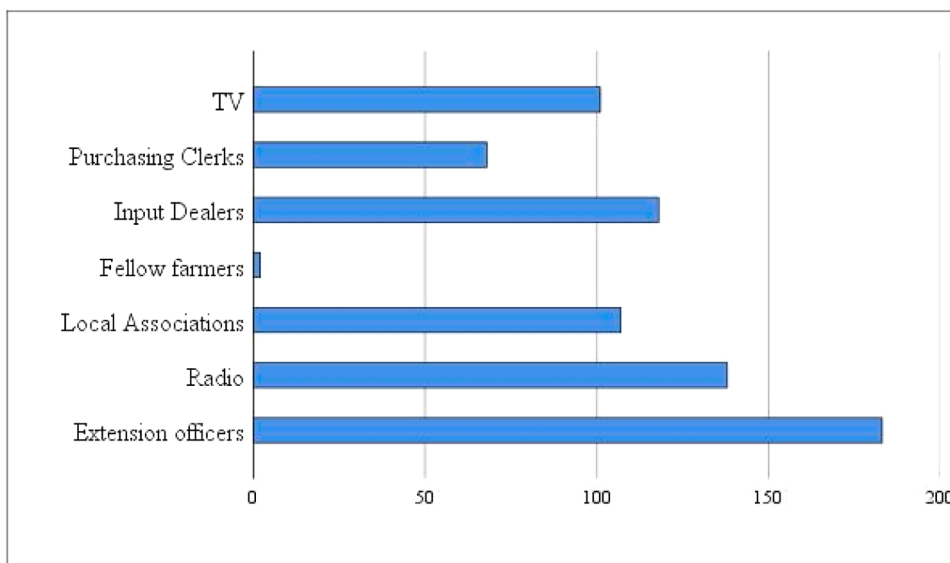


Fig. 5. Farmers' sources of information regarding pesticide use, the effect of pesticides on aquatic organisms, and human health.

Visualization, Writing – review & editing. **Doris Pwatirah:** Data curation, Visualization, Writing – review & editing. **Augusta Soninour Kolekang:** Data curation, Visualization, Writing – review & editing. **Martin Nyaaba Adokiya:** Conceptualization, Formal analysis, Methodology, Supervision, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Institutional review board statement

This study was conducted in accordance with the Declaration of Helsinki, and the objectives, methodologies, and tools of the dissertation research work were thoroughly evaluated and approved by the Committee of Human Research and Publication Ethics (CHRPE) of the Kwame Nkrumah University of Science and Technology (KNUST), Ref: CHRPE/AP/864/23.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Data availability statement

The data presented in this study will be made available upon request.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.sciaf.2024.e02351](https://doi.org/10.1016/j.sciaf.2024.e02351).

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