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Research Article

Smallholder Farmers' Perceptions of Irrigation Water Quality, Insect Pest Pressure and Yield of *Amaranthus* spp. in Makurdi, North-Central Nigeria

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Abstract

Water quality deterioration and insect pests are major constraints to sustainable vegetable production, yet farmers' perceptions of their interactions remain poorly understood. This study assessed smallholder farmers' perceptions of irrigation water quality, insect pest pressure and adaptation strategies in irrigated Amaranthus production in Makurdi, North-Central Nigeria. A cross-sectional survey of 90 randomly selected farmers was conducted using a structured questionnaire, and data were analysed using descriptive statistics and five-point Likert perception indices. Respondents were predominantly male (98.9%), cultivated farms smaller than 1.0 ha (100%), and relied mainly on River Benue (43.3%) and boreholes (37.8%) for irrigation. Most farms (76.7%) were located within 1 km of potentially polluted water sources. Farmers exhibited a moderate perception of irrigation water quality (mean index =2.72), despite recognizing widespread contamination (4.58±0.63) and the absence of routine water quality monitoring (1.20±0.40). Conversely, they perceived insect pest pressure to be high (3.99), identifying caterpillars as the most destructive pests (4.51±0.78). Adaptation willingness was very high (4.58), reflecting strong support for improved water management and extension interventions. Therefore, strengthening extension services, routine irrigation water quality monitoring, and integrated water and pest management could substantially improve the productivity, safety and sustainability of irrigated Amaranthus production in Makurdi and similar smallholder vegetable production systems in Nigeria.

Keywords: *Amaranthus spp.; farmer perception; irrigation water quality; insect pest pressure; integrated pest management; smallholder farmers; sustainable vegetable production.*

INTRODUCTION

Vegetable production is fundamental to food and nutritional security, household income generation, and rural livelihoods, particularly in developing countries (Mukaila & Enete, 2025; Zeru *et al*., 2026). Among leafy vegetables, *Amaranthus* spp. is one of the most widely cultivated and consumed crops in sub-Saharan Africa owing to its rapid growth, high nutritional value, adaptability to diverse agro-ecological conditions and year-round market demand (Terzieva *et al*., 2026). In Nigeria, *Amaranthus* is an important component of urban and peri-urban agriculture, where it contributes substantially to household nutrition, employment and income generation (Ayanwale *et al*., 2025). However, increasing climate variability, recurrent dry spells and growing competition for freshwater resources have intensified farmers' dependence on irrigation for sustained vegetable production, making irrigation water quality an increasingly important determinant of crop productivity, environmental sustainability and food safety (Frimpong *et al*., 2023; Johnson *et al*., 2023; Ahmad *et al*., 2024).

Smallholder farmers in Nigeria obtain irrigation water primarily from rivers, streams, shallow wells and boreholes (Vantage Nigeria, 2026). Although these sources sustain dry-season vegetable production, they are increasingly threatened by contamination arising from agricultural runoff, untreated domestic wastewater, livestock activities and

rapid urbanization. Poor-quality irrigation water may adversely affect soil properties, reduce crop performance and facilitate the accumulation of pathogenic microorganisms and potentially toxic elements in edible vegetables, thereby posing risks to consumers and the environment (Mogaji & Oloruntade, 2024; Ajibola & Fayinminnu, 2023; Adewale, 2024). Recent research has emphasized that continuous assessment of irrigation water quality is critical for maintaining sustainable crop production under increasing environmental and anthropogenic pressures (Mogaji & Oloruntade, 2024; Oluwagbayide *et al*., 2025)

Besides irrigation water quality, insect pests remain among the most important biological constraints to vegetable production in tropical agroecosystems (Lin *et al*., 2024). Leaf-feeding caterpillars, flea beetles, aphids and leaf miners frequently cause severe defoliation, reduce marketable yield and diminish the economic value of leafy vegetables (Aderolu *et al*., 2013; Ofuya *et al*., 2023; Plant Grower World, 2025). Consequently, many smallholder farmers rely heavily on repeated applications of synthetic insecticides for pest control. While pesticides can effectively suppress pest populations, indiscriminate use has contributed to pesticide resistance, environmental contamination, destruction of beneficial arthropods and concerns regarding pesticide residues on vegetables. Sustainable vegetable production, therefore, increasingly depends on integrated pest management (IPM) strategies that combine cultural, biological and judicious chemical control measures (Ofuya *et al*., 2023).

Farmers' perceptions are increasingly recognized as an important component of sustainable agricultural management because they influence decision-making regarding irrigation practices, pest control, technology adoption and resource allocation (Baccar *et al*., 2020). Farmers who perceive environmental risks are generally more willing to adopt improved management practices than those with limited awareness of such risks. Studies conducted in West Africa have demonstrated that farmers' perceptions of water-related challenges strongly influence their adaptation strategies and willingness to adopt improved irrigation technologies (Zhang *et al*., 2018; Johnson *et al*., 2023; Akinbode *et al*., 2024). Likewise, understanding farmers' perceptions of irrigation water contamination provides valuable information for designing effective extension programmes, improving risk communication and promoting sustainable agricultural innovations.

Although considerable research has been conducted on irrigation water quality, vegetable production and insect pest management in Nigeria, most studies have addressed these issues independently. Comparatively few investigations have integrated farmers' perceptions of irrigation water quality, insect pest pressure and their implications for *Amaranthus* productivity within a single analytical framework (Lin *et al*., 2024). This knowledge gap is particularly evident in Makurdi, North-Central Nigeria, where intensive dry-season vegetable production along the River Benue floodplain coincides with increasing anthropogenic activities capable of degrading irrigation water quality (Mogaji & Oloruntade, 2024).

Against this background, the present study assessed smallholder farmers' perceptions of irrigation water quality, insect pest pressure and adaptation strategies in irrigated *Amaranthus* production in Makurdi, Nigeria. Specifically, the study characterized the socio-economic profile and irrigation practices of irrigated *Amaranthus* farmers; it evaluated farmers' perceptions of irrigation water quality and its perceived effects on crop health and yield; assessed farmers' perceptions of insect pest pressure and the major pest constraints affecting *Amaranthus* production; and determined farmers' willingness to adopt improved irrigation water management and integrated pest management practices. The findings provide empirical evidence for strengthening extension services, informing irrigation water management policies and promoting sustainable intensification of irrigated vegetable production in Nigeria.

MATERIALS AND METHODS

Study Area

This study was conducted in Makurdi Local Government Area of Benue State, North-Central Nigeria. Makurdi is located between latitude 7°44′–7°52′ N and longitude 8°29′–8°38′ E and lies within the Southern Guinea Savannah agro-ecological zone. The area experiences a tropical wet-and-dry climate (Aw) characterized by a rainy season extending from April to October and a dry season from November to March. Mean annual rainfall ranges from approximately 1,200 to 1,500 mm, while mean daily temperatures range from 25 to 35 °C. The River Benue, which traverses the study area, serves as the principal source of irrigation water for dry-season vegetable production, supplemented by boreholes and hand-dug wells. The soil is predominantly alluvial and sandy-loam, which is highly suitable for cultivating leafy vegetables, including *Amaranthus* spp. (Idoga, 2014) Agriculture remains the dominant livelihood in the area, with irrigated vegetable farming constituting an important source of household income during the dry season (FAO, 2023; Nigerian Meteorological Agency (NiMet), 2023).

Study Design

A cross-sectional survey design was adopted to assess smallholder farmers' perspectives on irrigation water quality, insect pest pressure and perceived effects on the productivity of *Amaranthus* spp. The design was considered appropriate because it enables the collection of information on farmers' perceptions, production practices and management decisions at a single point in time while allowing comparisons across respondents.

Target Population, Sample Size and Sampling Procedure

The target population comprised smallholder farmers engaged in irrigated *Amaranthus* spp. production within Makurdi Local Government Area of Benue State, Nigeria. A multistage sampling procedure was employed. In the first stage, major irrigated vegetable-producing communities located along the River Benue floodplain and surrounding peri-urban farming areas were purposively selected because of their high concentration of dry-season vegetable producers and the diversity of irrigation water sources. In the second stage, lists of registered and active *Amaranthus* farmers were obtained through farmer associations and local agricultural extension personnel. Respondents were subsequently selected using simple random sampling to minimize selection bias.

A total of 90 farmers participated in the survey. The sample size was considered adequate for descriptive survey studies involving relatively homogeneous farming populations and exceeded the minimum number generally recommended for social science perception studies.

Questionnaire Development and Data Collection

Primary data were collected using a structured interviewer-administered questionnaire developed after an extensive review of literature on irrigation water quality, vegetable production, integrated pest management and farmers' perception studies (Dillman *et al*., 2014; Creswell & Creswell, 2018). The questionnaire comprised five sections: (i) socio-economic characteristics of respondents; (ii) irrigation water sources and production practices; (iii) farmers' perceptions of irrigation water quality; (iv) perceived insect pest occurrence and severity; and (v) adaptation and mitigation strategies.

Perception-related variables were measured using a five-point Likert scale, where Strongly Agree (SA) = 5, Agree (A) = 4, Neutral (N) = 3, Disagree (D) = 2, and Strongly Disagree (SD) = 1. This scaling enabled respondents to express varying degrees of agreement with statements regarding irrigation water quality, insect pest pressure, and management practices. The questionnaire was administered through face-to-face interviews to improve response accuracy and participation, particularly among respondents with limited formal education.

Validity and Reliability of the Instrument

Content validity was established through expert review by specialists in agricultural extension, crop protection and agricultural entomology, who assessed the questionnaire for relevance, clarity and coverage of the study objectives. Suggestions arising from the review were incorporated before field administration. The questionnaire was pre-tested among farmers in a neighbouring irrigated vegetable-producing community that was excluded from the final survey. Feedback obtained from the pilot study was used to improve wording, sequencing and clarity of questions. The internal consistency of the perception items was evaluated using Cronbach's alpha coefficient, with a reliability value of at least 0.70 considered acceptable for social science research (Taber, 2018).

Data Quality Assurance

Enumerators received training on interview procedures, ethical conduct and accurate recording of responses before fieldwork commenced. Completed questionnaires were checked daily for completeness, consistency and accuracy. Data were coded immediately after collection and independently verified before statistical analysis to minimize transcription and entry errors.

Ethical Considerations

Participation in the study was voluntary. Before each interview, respondents were informed of the objectives of the study, the intended use of the information collected and their right to decline participation or withdraw at any stage without consequence. Verbal informed consent was obtained from all participants before data collection commenced. No personally identifiable information was collected, and all responses were treated confidentially and used solely for research purposes in accordance with internationally accepted ethical principles for social science research.

Data Analyses

Completed questionnaires were coded, entered into Microsoft Excel, and analysed using SAS 9.2 (SAS Institute Inc., Cary, NC, USA). Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize respondents' socio-economic characteristics, irrigation practices and production constraints. Farmers' perceptions of irrigation water quality, insect pest pressure and adaptation strategies were analysed using weighted mean scores computed from the five-point Likert scale (5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, and 1 = Strongly Disagree), and N is the total number of respondents. The mean scores were interpreted using the following decision rule: 4.50–5.00 = Strongly Agree, 3.50–4.49 = Agree, 2.50–3.49 = Neutral, 1.50–2.49 = Disagree, 1.00–1.49 = Strongly Disagree. Individual perception statements were ranked according to their weighted mean scores to determine their relative importance. A composite Perception Index for each thematic category (irrigation water quality, insect pest pressure and adaptation strategies) was further computed as the arithmetic mean of the corresponding statement scores.

RESULTS

Socio-economic Characteristics of Irrigated Amaranthus Farmers

The socio-economic characteristics of the respondents are presented in Table 1. The respondents were predominantly male (98.9%), with only 1.1% being female, indicating that irrigated *Amaranthus* production in the study area is largely male-dominated. Most respondents (60.0%) were between 41 and 50 years of age, while 38.9% were aged 31–40 years. Only one respondent (1.1%) was aged 30 years or younger. Educational attainment was generally low, with 85.6% of respondents having no formal education and only 14.4% having completed primary education.

Household sizes were relatively moderate, with 63.3% of respondents having households comprising four to six persons, whereas 18.9% had seven or more household members and 17.8% had one to three persons. Farming experience was fairly balanced across respondents, with 52.2% having ten years or less experience in irrigated vegetable production and 47.8% having more than ten years of farming experience. All respondents cultivated *Amaranthus* on farms smaller than 1.0 ha, confirming the predominance of smallholder production systems within the study area.

Irrigation Sources and Production Practices

The irrigation sources and production practices adopted by respondents are summarized in Table 2. River Benue constituted the principal source of irrigation water, accounting for 43.3% of respondents, followed closely by boreholes (37.8%), while hand-dug wells were used by 18.9% of farmers. Most respondents (88.9%) irrigated their fields every two to three days, whereas only 10.0% practiced daily irrigation and 1.1% irrigated once weekly. Irrigated *Amaranthus* production was predominantly undertaken throughout both the dry and rainy seasons (87.8%), while only 12.2% cultivated exclusively during the dry season.

Table 1: Socio-Economic Characteristics of Irrigated *Amaranthus* Farmers in Makurdi, Nigeria

Variable	Category	Frequency	Percentage (%)
Gender	Male	89	98.9
	Female	1	1.1
Age (years)	≤30	1	1.1
	31–40	35	38.9
	41–50	54	60.0
Education level	No formal education	77	85.6
	Primary education	13	14.4
Household size	1–3 persons	16	17.8
	4–6 persons	57	63.3
	≥7 persons	17	18.9
Farming experience	≤10 years	47	52.2
	>10 years	43	47.8
Farm size (ha)	< 1.0	90	100.0

N = 90 respondents

Table 2: Irrigation Sources and Production Practices in Makurdi, Nigeria

Variable	Category	Frequency	Percentage (%)
Primary irrigation source	River Benue	39	43.3
	Borehole	34	37.8
	Hand-dug well	17	18.9
Irrigation frequency	Every 2–3 days	80	88.9
	Everyday	9	10.0
	Weekly	1	1.1
Season of production	Dry season only	11	12.2
	Both seasons	79	87.8
Fertilizer use	Organic only	44	48.9
	Inorganic only	1	1.1
	Organic + inorganic	45	50.0
Pesticide use	Synthetic pesticides	90	100.0
Farm proximity to polluted water (<1 km)	Yes	69	76.7
	No	21	23.3

N = 90 farmers

Fertilizer application was widespread among respondents. Half of the farmers (50.0%) applied both organic and inorganic fertilizers, while 48.9% relied solely on organic fertilizers. Only one respondent (1.1%) reported exclusive use of inorganic fertilizer. Synthetic pesticides were used by all respondents (100%), indicating complete dependence on chemical pest control measures. Furthermore, more than three-quarters (76.7%) of the farms were located within 1 km of potentially polluted water sources, whereas only 23.3% were situated farther away.

Farmers' Perception of Irrigation Water Quality

Farmers' perceptions of irrigation water quality are presented in Table 3. Overall, respondents exhibited a moderate perception of irrigation water quality, with a composite perception index of 2.72 (Figure 1). The highest-rated statement was that agricultural runoff, animal waste, sewage and related contaminants commonly pollute irrigation water (Mean = 4.58 ± 0.63), which was strongly agreed upon by respondents. This finding indicates a strong awareness of contamination risks associated with irrigation water sources. Conversely, respondents strongly disagreed that irrigation water quality was regularly monitored (Mean = 1.20 ± 0.40), representing the lowest-rated perception statement. Similarly, respondents generally disagreed that the irrigation water used on their farms was clean and safe (Mean = 2.60 ± 1.14).

Perceptions regarding the effects of irrigation water on crop performance were less definitive. Respondents remained largely undecided on whether water quality significantly affects *Amaranthus* health and yield (Mean = 2.56 ± 0.69) and whether poor irrigation water contributes to increased insect pest infestation (Mean = 2.68 ± 0.56). The relatively low standard deviations observed for these statements indicate a reasonable level of consistency in respondents' opinions.

Farmers' Perception of Insect Pest Pressure

Farmers' perceptions of insect pest pressure in irrigated *Amaranthus* fields are presented in Table 4. The overall perception index of 3.99 (Figure 1) indicates a high perceived level of insect pest pressure among respondents. The statement that insect pests constitute a major production constraint recorded the highest mean score (Mean = 4.78 ± 0.42), reflecting strong consensus among farmers regarding the severity of pest problems. Likewise, respondents agreed that caterpillars represent the most destructive insect pests affecting *Amaranthus* production (Mean = 4.51 ± 0.78).

Farmers also agreed that pest infestation reaches its peak during both the flowering stage (Mean = 3.98 ± 0.91) and the mid-growth stage (Mean = 3.94 ± 0.97). The comparable mean scores for these two growth stages suggest that farmers perceived insect attack to remain consistently high throughout the major vegetative and reproductive growth phases of the crop.

Farmers' Adaptation and Mitigation Perceptions

Respondents demonstrated a very high willingness to adopt improved irrigation water quality and pest management practices (Table 5). The overall adaptation perception index was 4.58, indicating a very high level of readiness to implement improved management interventions (Figure 1). The highest-rated statement was respondents' willingness to adopt improved management practices if made available (Mean = 4.83 ± 0.38), indicating almost unanimous acceptance of innovations. Farmers also strongly agreed that training on irrigation water management was urgently needed (Mean = 4.72 ± 0.45) and that government support is essential for improving irrigation water management (Mean = 4.61 ± 0.60).

Table 3. Farmers' Perception of Irrigation Water Quality in Makurdi, Nigeria

Statement	SA	A	U	D	SD	Mean	Std. Dev.	Decision
The irrigation water used on my farm is clean and safe.	5	29	0	42	14	2.60	1.14	Disagree
Water quality significantly affects *Amaranthus* health and yield.	0	2	53	28	7	2.56	0.69	Undecided
The quality of irrigation water is regularly monitored.	0	0	0	18	72	1.20	0.40	Strongly Disagree
Agricultural run-off, untreated domestic wastewater, animal waste, sewage, etc., contamination of irrigation water is common.	58	29	0	3	0	4.58	0.63	Strongly Agree
Poor irrigation water increases insect pest infestation.	0	2	59	27	2	2.68	0.56	Undecided

N = 90 farmers; 5 = Strongly Agree (SA), 4 = Agree (A), 3 = Neutral/Undecided (U), 2 = Disagree (D) and 1 = Strongly Disagree (SD), and *N* is the total number of respondents

Table 4. Farmers' Perception of Insect Pest Pressure in *Amaranthus* Plots in Makurdi, Nigeria

Statement	SA	A	U	D	SD	Mean	Std. Dev.	Decision
Insect pests are a major production constraint.	70	20	0	0	0	4.78	0.42	Strongly Agree
Caterpillars are the most destructive insect pests.	62	15	10	3	0	4.51	0.78	Agree
Pest infestation is highest during mid-growth.	34	33	10	10	3	3.94	0.97	Agree
Pest infestation is highest during flowering.	33	35	12	7	3	3.98	0.91	Agree

N = 90 farmers; 5 = Strongly Agree (SA), 4 = Agree (A), 3 = Neutral/Undecided (U), 2 = Disagree (D) and 1 = Strongly Disagree (SD), and *N* is the total number of respondents

Table 5. Farmers' Adaptation and Mitigation Perceptions

Statement	SA	A	U	D	SD	Mean	Std. Dev.	Decision
Training on irrigation water management is urgently needed.	65	25	0	0	0	4.72	0.45	Strongly Agree
The government should support irrigation water management.	60	25	5	0	0	4.61	0.60	Strongly Agree
Financial assistance is necessary for improved irrigation.	48	30	12	0	0	4.40	0.71	Agree
Extension services should educate farmers on irrigation water quality.	42	38	10	0	0	4.36	0.67	Agree
I am willing to adopt improved practices.	75	15	0	0	0	4.83	0.38	Strongly Agree

N = 90 farmers; 5 = Strongly Agree (SA), 4 = Agree (A), 3 = Neutral/Undecided (U), 2 = Disagree (D) and 1 = Strongly Disagree (SD), and *N* is the total number of respondents

The respondents further agreed that financial assistance would facilitate improved irrigation practices (Mean = 4.40 ± 0.71) and that agricultural extension services should intensify farmer education on irrigation water quality management (Mean = 4.36 ± 0.67). The consistently high mean scores and relatively small standard deviations across all adaptation statements demonstrate broad consensus among respondents regarding the need for institutional support and capacity building.

Comparative Perception Indices

A comparison of the composite perception indices is presented in Figure 1. Farmers exhibited the highest perception score for adaptation and mitigation willingness (Mean Index = 4.58), followed by insect pest pressure (Mean Index = 3.99), while irrigation water quality recorded the lowest perception index (Mean = 2.72). The marked difference among these indices indicates that although respondents clearly recognized insect pests as a major production challenge and expressed strong willingness to adopt improved management practices, their understanding of irrigation water quality issues remained comparatively moderate. The comparatively lower water quality perception index, relative to the adaptation willingness index, suggests an important knowledge gap that could be addressed through targeted extension services, farmer training programmes and regular irrigation water quality monitoring.

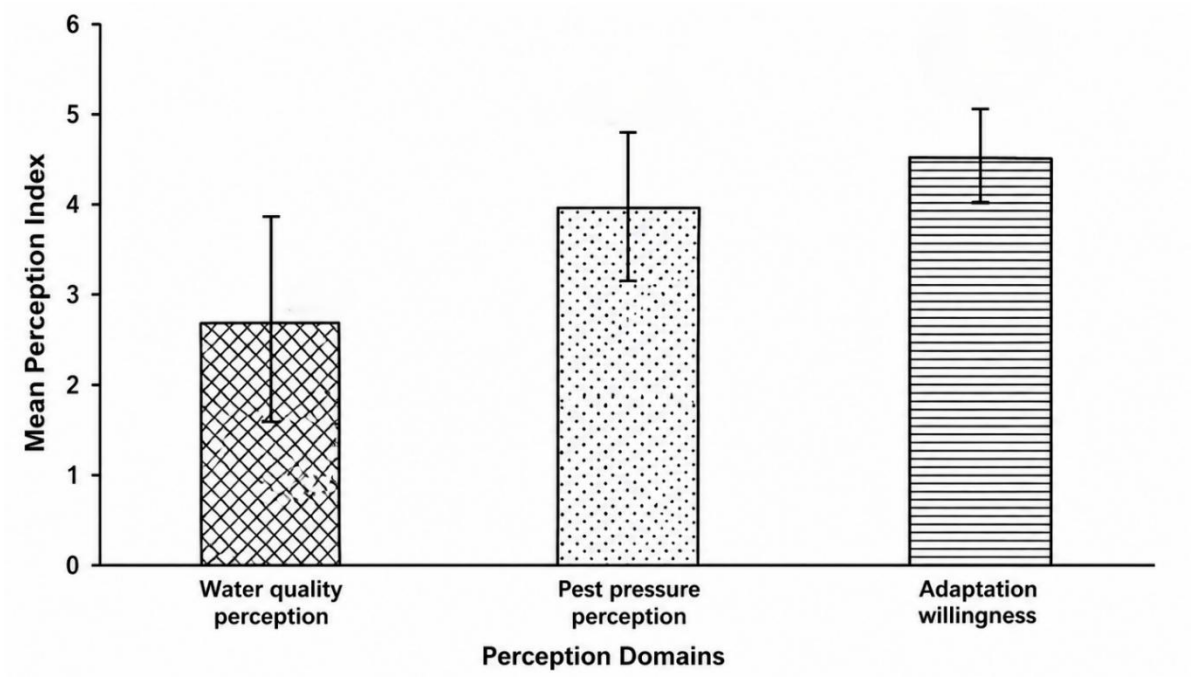

Figure 1. Comparative perception indices of farmers regarding irrigation water quality, insect pest pressure and adaptation willingness among irrigated *Amaranthus* farmers in Makurdi, Nigeria.

DISCUSSION

This study provides new insights into smallholder farmers' perceptions of irrigation water quality, insect pest pressure, and adaptation strategies in irrigated *Amaranthus* production in Makurdi, Nigeria. The results show that while farmers perceived insect pests as major production constraints and demonstrated a high willingness to adopt improved management practices, their perception of irrigation water quality and its implications for crop productivity was only moderate.

The predominance of male respondents and the small-scale nature of *Amaranthus* production in the study area are consistent with the structure of irrigated vegetable farming reported in many parts of Nigeria, where dry-season vegetable production is largely undertaken by male household heads operating on relatively small landholdings (Ofuya *et al*., 2023). The generally low educational attainment recorded among respondents may partly explain the limited awareness of the broader implications of irrigation water quality for crop performance and food safety. Previous studies have shown that educational attainment positively influences farmers' awareness, technology adoption and environmental management practices, thereby enhancing their capacity to implement improved agricultural innovations (Zhang *et al*., 2018; Ofuya *et al*., 2023).

River Benue was the principal source of irrigation water, although a substantial proportion of farmers also depended on boreholes and hand-dug wells. The high reliance on surface water is expected because river water remains the most accessible and affordable source of irrigation for smallholder vegetable farmers during the dry season in many parts of Nigeria (Mogaji & Oloruntade, 2024). However, the finding that over three-quarters of farms were located within 1 km of potentially polluted water sources raises important environmental and public health concerns. Previous studies have demonstrated that untreated irrigation water used for leafy vegetable production may harbour pathogenic microorganisms and other contaminants capable of compromising crop quality, food safety and public health (Akinde *et al*., 2016; Kurna *et al*., 2016). Similarly, assessments of irrigation water quality for vegetable production in southwestern Nigeria have emphasized the need for regular monitoring of irrigation water to safeguard crop productivity and consumer health (Eruola *et al*., 2020; Mogaji & Oloruntade, 2024).

Farmers exhibited only a moderate perception of irrigation water quality despite strongly agreeing that agricultural runoff, sewage and animal wastes commonly contaminate irrigation water. This apparent inconsistency suggests that while contamination is visibly recognized, many farmers may not fully appreciate its implications for crop productivity, pest dynamics and food safety. Furthermore, respondents overwhelmingly indicated that irrigation water quality was rarely monitored. Similar observations have been reported in studies of irrigated vegetable production in Nigeria, where routine assessment of irrigation water quality remains limited because of inadequate technical capacity, weak extension services and the high cost of laboratory analysis (Akinde *et al*., 2016; Mogaji & Oloruntade, 2024).

The respondents also remained uncertain about the direct influence of irrigation water quality on *Amaranthus* health, yield and insect pest infestation. This finding may reflect the complexity of pest outbreaks, which are influenced by multiple interacting factors including climatic conditions, crop nutrition, irrigation practices, surrounding vegetation and pest management strategies (Ofuya *et al*., 2023). Farmers often associate visible pest damage with seasonal weather conditions rather than indirect environmental drivers such as irrigation water quality. Consequently, strengthening farmers' understanding of these interactions through extension education could improve integrated crop and water management.

In contrast, farmers expressed a high perception of insect pest pressure, with insect pests identified as one of the major constraints to *Amaranthus* production. Caterpillars were consistently perceived as the most destructive pests, while infestation was considered greatest during the mid-growth and flowering stages. These observations corroborate previous reports identifying lepidopteran caterpillars as major insect pests limiting leafy vegetable production in Nigeria and highlighting integrated pest management as the most sustainable approach for reducing yield losses while minimizing excessive pesticide dependence (Aderolu *et al*., 2013; Ofuya *et al*., 2023).

One of the most encouraging findings of this study was the exceptionally high willingness of respondents to adopt improved irrigation water management and pest control practices. Farmers strongly supported government intervention, extension education and financial assistance, indicating considerable readiness to implement recommended innovations if institutional support becomes available. This finding underscores the importance of strengthening agricultural extension systems and promoting integrated pest and water management approaches that combine improved irrigation practices, routine water quality monitoring, farmer education and environmentally sustainable pest management. Such integrated approaches have been widely recommended for improving vegetable productivity while reducing environmental and food safety risks (WHO, 2022; FAO, 2023; Ofuya *et al*., 2023).

Although this study provides useful baseline information on farmers' perceptions, it relied on self-reported responses rather than direct measurements of irrigation water quality, insect pest abundance or crop yield. Consequently, future studies should integrate farmers' perceptions with physicochemical and microbiological analyses of irrigation water, field assessments of pest populations and quantitative yield measurements to establish causal relationships between irrigation water quality, pest pressure and *Amaranthus* productivity. Such multidisciplinary approaches would provide stronger evidence for developing sustainable irrigation management strategies (FAO, 2023; Mogaji & Oloruntade, 2024).

CONCLUSION

This study showed that irrigated *Amaranthus* production in Makurdi is dominated by smallholder farmers who rely primarily on River Benue and other local water sources for irrigation. Although farmers recognized the widespread occurrence of irrigation water contamination, their overall perception of its effects on crop productivity was only moderate, reflecting important knowledge gaps. In contrast, respondents perceived insect pest pressure to be high and demonstrated a very high willingness to adopt improved irrigation water and pest management practices. Strengthening agricultural extension services through farmer training, routine monitoring of irrigation water quality, and the promotion of integrated water quality and pest management strategies is therefore recommended. Increased institutional support, including technical and financial assistance, would further enhance the productivity, safety and sustainability of irrigated *Amaranthus* production in Makurdi and other smallholder vegetable production systems in Nigeria.

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