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Cross-sectional survey of antimicrobial resistance awareness, antimicrobial use practices and resistance risk pathways in poultry production and distribution systems in Northeastern Nigeria

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Abstract

Antimicrobial resistance (AMR) remains a critical One Health challenge, particularly in poultry production systems where antimicrobial use (AMU) is often not well regulated. This study assessed AMR awareness, AMU practices, biosecurity measures, environmental exposure and AMR risk among poultry farmers, traders and handlers in northeastern Nigeria. A cross-sectional, questionnaire-based study was conducted among 600 respondents across Bauchi, Gombe, Yobe, and Borno States of northeastern Nigeria, between July 2023 and May 2024. Data were collected using a structured interviewer-administered questionnaire and analyzed using GraphPad Prism version 9.0. Chi-square tests and binary logistic regression were used to assess associations, while composite indices for AMU, biosecurity and AMR risk were used following standardized scoring systems. Overall, AMR awareness was low (33.0%), with variations recorded across the states. A high proportion of the respondents admitted antimicrobial use (89.0%), with most respondents relying on informal drug sources and personal experience for decision-making on antibiotic use. High level of non-therapeutic use, poor adherence to dosage guidelines, and high levels of non-compliance with withdrawal periods were common. Biosecurity practices were generally inadequate, with 50.0% of respondents classified as having poor biosecurity, while unsafe waste management practices were widespread, including open dumping of poultry litter (52.0%) and uncontrolled wastewater disposal (61.0%). Composite indices revealed high antimicrobial use (47.0%) and high AMR risk (53.0%) among respondents. The findings demonstrate a strong convergence of low AMR awareness by a high proportion of the respondents in the study area, and behavioral, managerial and environmental risk factors driving AMR in the poultry systems surveyed. Improving on AMR awareness, strengthening veterinary oversight, improving antimicrobial stewardship and enforcing biosecurity and environmental regulations are urgently required under a One Health framework to mitigate AMR emergence and spread in the study area.

Keywords: Antimicrobial resistance awareness; Antimicrobial use practices; Cross sectional survey; Poultry production systems; Northeastern Nigeria; One Health.

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Introduction

Antimicrobial resistance (AMR) is widely recognized as a complex, multifactorial challenge that threatens global health, food security and sustainable development. While considerable attention has been directed towards the detection and characterization of resistant microorganisms, there is growing consensus that AMR awareness levels, patterns of antimicrobial use (AMU), behavioral practices and system-level vulnerabilities are equally critical to understanding and mitigating the AMR burden (Salam *et al*., 2023; Elbehiry *et al*., 2025). In this regard, evidence generated from field-based assessments of antimicrobial use practices provides an essential foundation for identifying risk pathways and informing context-specific interventions, especially in settings where laboratory surveillance remains limited (Oliveira *et al*., 2024).

Poultry production systems represent an important interface in the epidemiology of AMR due to their rapid expansion, high demand for productivity and frequent reliance on antimicrobial inputs. In many low- and middle-income countries, including Nigeria, antimicrobials are commonly used not only for therapeutic purposes but also for disease prevention, and in some cases, growth promotion (Hedman *et al*., 2020). These practices are often influenced by limited access to veterinary services, informal drug distribution channels and gaps in farmer knowledge regarding prudent antimicrobial use. Consequently, patterns of antimicrobial use in poultry systems may create conditions that favor the emergence and spread of resistance, even in the absence of direct microbiological evidence (Farkas *et al*., 2025; Ahmad *et al*., 2026).

Understanding these patterns requires moving beyond pathogen-centered approaches towards a broader evaluation of behavioral, management and environmental factors that shape antimicrobial use and resistance risk. The One Health framework offers a valuable lens through which these interactions can be examined, recognizing the interconnectedness of human, animal and environmental health. Within poultry production systems, this interconnectedness is reflected in the continuous movement of birds, people, materials and waste across farms, live bird markets (LBMs) and surrounding environments. Each of these components represent a potential pathway through which antimicrobial use practices may influence the development and dissemination of resistance (Oliveira *et al*., 2024).

Live bird markets, in particular, serve as critical nodes within the poultry value chain. These markets aggregate birds from diverse sources and facilitate close interactions among farmers, traders and consumers under conditions that are often characterized by limited biosecurity and sanitation. Such settings may amplify the consequences of inappropriate antimicrobial use by promoting the circulation of potentially resistant microorganisms and increasing opportunities for human exposure (Irin *et al*., 2021; Hassan *et al*., 2022; Mensah *et al*., 2026). Similarly, waste management practices including the handling and disposal of poultry litter, faeces and wastewater constitute an important but often overlooked dimension of AMR risk. Inadequate waste disposal can introduce antimicrobial residues and resistant bacteria into the environment, thereby sustaining transmission cycles beyond the immediate production system (La Rosa *et al*., 2025; Ghanadi *et al*., 2025; Fontaine *et al*., 2026).

Despite the recognized importance of these interconnected pathways, there remains a notable gap in integrated studies that examine antimicrobial use practices alongside the behavioral and environmental contexts in which they occur. Existing research in poultry systems has largely focused on laboratory-based assessments of resistance or on isolated

aspects of farm management, with limited attention to how practices across farms, markets and waste disposal systems collectively contribute to resistance risk (Al-Khalaifah *et al*., 2025; Spagnolo *et al*., 2026). This gap is particularly pronounced in regions where informal production systems predominate and where structured surveillance systems are weak or absent.

In Northeastern Nigeria (Taraba, Adamawa, Bauchi, Gombe, Yobe and Borno States), poultry production plays a vital role in supporting livelihoods, enhancing household nutrition and contributing to local economies. However, the sector operates within a context marked by socio-economic constraints, limited veterinary infrastructure and ongoing challenges related to insecurity and population displacement (Onwuaroh *et al*., 2024; Aliyu *et al*., 2025). Poultry production in this region is largely characterized by smallholder and semi-intensive systems, where biosecurity measures are often minimal and access to professional veterinary guidance is inconsistent. In addition, the widespread availability of antimicrobial agents through informal markets may encourage unsupervised and potentially inappropriate use (Lawal *et al*., 2024; Pewan *et al*., 2025).

Furthermore, live bird markets across these states function as key distribution hubs, linking rural producers to urban consumers, while waste disposal practices are frequently unregulated and environmentally exposed. These conditions create a complex network of interactions through which antimicrobial use practices may translate into heightened resistance risk at the human-animal-environment interface. However, empirical data describing these practices and their associated risk pathways in Northeastern Nigeria remain scarce.

Given these considerations, there is a critical need for a comprehensive, system-level assessment that captures antimicrobial use practices and identifies the pathways through which they may contribute to resistance risk within poultry production systems. Such an approach is particularly valuable in contexts where laboratory-based surveillance is limited, as it provides actionable insights into modifiable behaviors and structural gaps that can be targeted through policy and intervention.

The present study assessed the level of antimicrobial resistance awareness, antimicrobial use practices and associated resistance risk pathways in poultry production systems across Bauchi, Gombe, Yobe and Borno States of Northeastern Nigeria. Using a structured questionnaire-based approach grounded in the One Health framework, the study evaluated awareness and practices at the level of poultry farms, live bird markets and waste management systems. By elucidating the patterns, drivers and interconnections of antimicrobial use in these settings, this study seeks to generate evidence that will inform antimicrobial stewardship, strengthen biosecurity practices and support sustainable poultry production in Northeastern Nigeria.

Materials and Methods

Study Area: The study was conducted in four states, namely: Bauchi, Gombe, Yobe, and Borno located in northeastern Nigeria. The region lies within the Sudan-Sahel ecological zone and is characterized by semi-arid climatic conditions, including a unimodal rainfall pattern (May – October) and a prolonged dry season (November – April). Annual rainfall ranges from 500 to 1,000 mm, with temperatures often exceeding 35°C during peak dry periods (Ibrahim and Bawale, 2026).

In the study area, poultry production is predominantly smallholder-based, comprising backyard, semi-intensive and emerging commercial systems. Live bird markets (LBMs)

function as key nodes for poultry aggregation and distribution, typically operating under informal conditions with variable levels of hygiene and biosecurity. Waste management practices are generally unregulated, with common approaches including open dumping, land application of untreated litter and discharge into surrounding environments (Pius *et al*., 2021).

Study Design and Approach: A cross-sectional, questionnaire-based study design was employed to assess AMR awareness, AMU practices and associated resistance risk pathways across poultry production systems. The study adopted a One Health perspective by integrating data from three interconnected domains: poultry farms, live bird markets and waste management environments.

The design focused on capturing the respondents' awareness, behavioral practices, management systems and structural factors that influence antimicrobial use and potential resistance emergence, rather than laboratory-based detection of resistant organisms. This approach is particularly relevant in settings where routine microbiological surveillance is limited and where understanding practice-driven risk pathways is essential for targeted intervention (Ejikeugwu *et al*., 2025; Munene *et al*., 2026).

Study Period: Data collection was conducted over an 11-month period from July 2023 to May 2024**,** covering both wet and dry seasons. This period was selected to capture potential seasonal variations in poultry management practices, disease occurrence, antimicrobial use patterns and waste handling behaviors.

Study Population: The study population comprised individuals directly involved in poultry production and marketing activities within the selected states, including poultry farmers operating at backyard, semi-intensive, and commercial levels, live bird market operators such as traders, retailers and processors, as well as poultry handlers and workers involved in bird management and waste disposal. To ensure the relevance and reliability of the data obtained, only participants with active involvement in poultry-related activities during the study period were included in the survey.

Sample Size Determination and Sampling Strategy: A total of 600 respondents were included in the study, comprising 150 participants from each of Bauchi, Gombe, Yobe and Borno States. This sample size was considered sufficient to generate representative insights into AMR awareness, AMU practices and associated resistance risk pathways across the study area, in line with recommendations for cross-sectional survey studies in comparable settings as described by Gobezie *et al*. (2024) and Chilanga *et al*. (2025). A multistage sampling approach was adopted, beginning with the purposive selection of states based on their relevance to poultry production, followed by the selection of Local Government Areas with active poultry farming activities and live bird markets. Subsequently, farms and markets were selected using stratified random sampling to ensure coverage across different production systems, and respondents within each site were then recruited using systematic or convenience sampling based on availability and willingness to participate. This structured approach facilitated broad representation across varying geographic locations, management systems and operational scales.

Inclusion and Exclusion Criteria: Participants were eligible for inclusion if they were actively engaged in poultry farming, marketing or handling activities, were aged 18 years or older, were willing to provide informed consent, and had a minimum of six months' experience in poultry-related operations. Conversely, individuals who were not directly involved in poultry production or marketing, those who declined participation or did not provide consent, and respondents with

incomplete or inconsistent questionnaire responses were excluded from the study.

Questionnaire Design and Pre-testing: Data were collected using a structured, interviewer-administered questionnaire developed to capture key variables related to antimicrobial use and associated resistance risk pathways. The instrument was designed based on established frameworks for antimicrobial resistance and One Health assessments and was subsequently adapted to suit the local context (Sitotaw and Philipos, 2023). It comprised sections covering socio-demographic characteristics, poultry production and management practices, antimicrobial use patterns including types, frequency, indications, and sources-knowledge and awareness of antimicrobial resistance, biosecurity and hygiene practices, live bird market interactions, and waste management alongside environmental exposure pathways. Prior to the main survey, the questionnaire was pre-tested in a pilot study involving a subset of respondents outside the study area, and necessary adjustments were made to enhance clarity, reliability and contextual relevance.

Data Collection Procedure: Data collection was conducted through face-to-face interviews administered by trained field enumerators who were familiar with the local language and poultry production systems. Interviews were carried out at poultry farms, live bird markets, and other relevant operational sites. To ensure data quality and consistency, enumerators underwent standardized training prior to field deployment, and all interviews were conducted using uniform protocols. Completed questionnaires were cross-checked for completeness and internal consistency, while observational notes were recorded to complement and validate respondents' answers. Participation in the study was entirely voluntary, and strict confidentiality of all responses was maintained throughout the data collection process.

Informed Consent: Informed consent was obtained from all participants prior to data collection. Participation was voluntary, and respondents were assured of confidentiality and anonymity. All procedures were conducted in accordance with established ethical guidelines for research involving human participants.

Measurement of Key Variables and Risk Indicators: To enhance analytical robustness, selected variables were aggregated into composite indices reflecting key dimensions of antimicrobial use and associated resistance risk pathways. The composite indices, including the antimicrobial use index, biosecurity practice score and antimicrobial resistance risk index, were generated by aggregating indicator variables derived from the study questionnaire. Each indicator variable was scored on a binary or ordinal scale and summed to obtain a total score for each index. The composite scores were then normalized to a 0 – 100 scale using the formula: Index score = (Total score obtained/Maximum possible score) × 100. The normalized scores were subsequently categorized into ordinal levels as low, moderate, or high using predefined cut-off points based on tertile distribution (i.e., equal thirds of the observed score range), consistent with established approaches for constructing composite indices in epidemiological studies (OECD and Joint Research Centre, 2008).

AMR awareness was operationalized as a binary outcome variable and categorized as "aware" or "unaware" based on respondents' self-reported knowledge of antimicrobial resistance. The antimicrobial resistance risk index was defined as the primary outcome variable for risk modeling and was categorized into three ordinal levels (low, moderate, and high) based on composite scoring thresholds. The antimicrobial use (AMU) index was

constructed using indicators related to frequency of antimicrobial use, purpose of use (therapeutic, prophylactic, or growth promotion), and source of antimicrobial acquisition. The biosecurity practice score was derived from variables assessing hygiene practices, use of protective clothing, farm access control and cleaning/disinfection routines. The antimicrobial resistance risk index was developed based on key risk behaviors, including unsupervised antimicrobial use, improper dosing practices, failure to observe withdrawal periods and unsafe waste disposal methods (Sanders *et al*., 2021).

Each indicator variable was assigned a binary score (1 = presence of risk or poor practice; 0 = absence or appropriate practice). Composite scores were computed by summing individual indicator values for each respondent. The resulting total scores were categorized into low, moderate and high levels using tertile distribution cut-off points. These composite indices enabled quantitative assessment and comparison of antimicrobial use behaviors, biosecurity practices and resistance risk patterns across study participants.

Data Analysis: Data were entered into Microsoft Excel, coded appropriately, and exported for statistical analysis using GraphPad Prism version 9.0.0 (GraphPad Software, San Diego, CA, USA). Descriptive statistics were used to summarize socio-demographic characteristics, AMR awareness, AMU practices, biosecurity measures, environmental exposure indicators, and composite risk indices. Results were presented as frequencies and percentages. Chi-square (χ^2) tests were applied to assess relationships between state of residence, knowledge of antimicrobial resistance (AMR), and other categorical predictors of AMR awareness and resistance risk. For regression modeling, the resistance risk index was further dichotomized into "high risk" and "low/moderate risk" categories. Binary logistic regression analyses were performed to identify predictors of AMR awareness and high antimicrobial resistance risk. Variables found to be statistically significant at the bivariate level ($p < 0.05$) were included in multivariable logistic regression models using the enter method. Multi co-linearity among independent variables was assessed prior to model fitting using variance inflation factors (VIF), and no significant co-linearity was detected. Associations between these indices and explanatory variables were further evaluated using chi-square tests. All statistical tests were two-tailed, and statistical significance was set at $p < 0.05$.

Results

The socio-demographic and production characteristics of respondents are presented in Table 1. The majority of participants were within the economically active age group of 31 – 45 years (246/600 = 41.0%), followed by those aged 46 – 60 years (164/600 = 27.3%), while younger respondents aged 18 – 30 years accounted for 19.7% (118/600), and only 12.0% (72/600) were above 60 years. A substantial gender imbalance was observed, with males constituting 77.0% (462/600) of respondents, compared to 23.0% (138/600) females. Educational attainment varied across respondents, with the largest proportion having secondary education (186/600 = 31.0%), followed by those with no formal education (168/600 = 28.0%) and primary education (162/600 = 27.0%). Only a minority had tertiary education (84/600 = 14.0%). In terms of occupational roles within the poultry value chain, the majority were poultry farmers (348/600 = 58.0%), while live bird market (LBM) traders/retailers accounted for 27.0% (162/600), and farm workers or handlers represented 15.0% (90/600). Regarding production systems, semi-intensive systems were most common (252/600 = 42.0%), closely followed by backyard/extensive systems (246/600 = 41.0%), while

intensive/commercial operations accounted for a smaller proportion (102/600 = 17.0%). With respect to experience in poultry production and marketing, a considerable proportion of respondents had moderate to extensive experience, with 38.0% (228/600) reporting 2 – 5 years of experience and an equal proportion (228/600 = 38.0%) having more than 5 years. Only 24.0% (144/600) had less than two years of experience.

The overall awareness of antimicrobial resistance (AMR) among poultry value chain actors that were surveyed was low, with only 198 out of the 600 (33.0%) respondents reporting awareness, compared to 402/600 (67.0%) who were unaware (Table 2). The proportion of respondents that were aware of AMR ranged from 28.0% recorded for Borno State to 38.7% recorded for Bauchi State (Table 2).

The responses by the participant in the study on some other factors associated with awareness of antimicrobial resistance (AMR) are presented in Table 3. The proportion of respondents that responded correctly with regards to understanding of the AMR concept was low (114 out of 600 = 19%), while those that were aware of withdrawal period were 168 out of the 600 (28.0%) respondents (Table 3). Only 26% (156 out of 600) had knowledge of the consequences of misuse of antimicrobials, while far lower (90 out of 600 = 15%) admitted having been trained on antimicrobial use (Table 3).

Table 1. Socio-demographic characteristics and poultry production profiles of poultry value chain actors surveyed in Northeastern Nigeria (n = 600)

Study Variables	Response Category	Number of Respondents, with % in brackets
Age group (years)	18–30	118 (19.7%)
	31–45	246 (41.0%)
	46–60	164 (27.3%)
	>60	72 (12.0%)
Sex of respondents	Male	462 (77.0%)
	Female	138 (23.0%)
Education level	No formal education	168 (28.0%)
	Primary	162 (27.0%)
	Secondary	186 (31.0%)
	Tertiary	84 (14.0%)
Primary occupation within the poultry value chain	Farmer	348 (58.0%)
	LBM trader/retailer	162 (27.0%)
	Farm worker/handler	90 (15.0%)
Poultry production system	Backyard/extensive	246 (41.0%)
	Semi-intensive	252 (42.0%)
	Intensive/commercial	102 (17.0%)
Years of experience in poultry production and marketing	<2 years	144 (24.0%)
	2–5 years	228 (38.0%)
	>5 years	228 (38.0%)

Table 2. Distribution and frequency of awareness of antimicrobial resistance (AMR) among poultry farmers, traders and handlers surveyed in Northeastern Nigeria (n = 600).

Study States	Number of Respondents (n=600)	No. of respondents that are Aware with % in brackets	No. of respondents that are not Aware with % in brackets
Bauchi	150	58 (38.7%)	92 (61.3%)
Gombe	150	46 (30.7%)	104 (69.3%)
Yobe	150	52 (34.7%)	98 (65.3%)
Borno	150	42 (28.0%)	108 (72.0%)
Total	600	198 (33.0%)	402 (67.0%)

Table 3. Responses by poultry farmers, traders and handlers in Northeastern Nigeria on some other factors associated with awareness of antimicrobial resistance (AMR)

Study Variables	Response Category	Number of respondents	Percentage of respondents
Understanding of AMR concept	Correct	114	19.0%
	Incorrect/ Limited	486	81.0%
Awareness of withdrawal period	Yes	168	28.0%
	No	432	72.0%
Knowledge of consequences of misuse	Yes	156	26.0%
	No	444	74.0%
Training on antimicrobial use	Yes	90	15.0%
	No	510	85.0%

The antimicrobial use (AMU) practices of respondents are summarized in Table 4. Majority of respondents (534 out of 600 = 89.0%) admitted having used antimicrobials in poultry production. Agro-veterinary shops and open markets were the predominant sources of antimicrobials used by respondents (372/600 = 69.7%), followed by prescriptions by veterinarians (96/600 = 18.0%), while a smaller proportion obtained drugs from informal vendors (66/600 =12.3%). In terms of decision-making, most respondents selected antimicrobials based on personal experience (312/600 = 58.4%), with a smaller proportion relying on advice from peers (138/600 = 25.8%) or veterinary professionals (84/600 = 15.7%). Therapeutic use was the most commonly reported purpose for the use of antimicrobials (504/600 = 94.4%) among users, although a substantial proportion also reported prophylactic use (336/600 = 62.9%) and use for growth promotion (228/600 = 42.7%). Adherence to recommended dosage guidelines for the use of antimicrobials was generally suboptimal, with only 19.1% (102/600) of respondents reporting to 'always' adhere, while nearly half (258/600 = 48.3%) adhered only 'sometimes' and 32.6% (174/600) 'never' adhered. Furthermore, compliance with withdrawal periods was notably poor, with only 24.7% (132/600) observing recommended withdrawal periods compared to 75.3% (402/600), who did not.

The responses with regards to biosecurity and hygiene practices among poultry value chain actors are presented in Table 5. The use of protective clothing was notably low, with only 14.0% (84/600) of respondents admitting consistent use, while more than half (330.600 = 55.0%) indicated they never used protective gear. Only 27.0% (162/600) admitted always washing hands after handling birds, whereas 37.0% (222/600) did so occasionally and 36.0% (216/600) did not practice hand washing at all. Also, only 23.0% (138/600) of the respondents admitting restricting entry to their poultry houses, while the majority (462/600 = 77.0%) allowed unrestricted access to their poultry houses. Regular cleaning and disinfection of the poultry house environment were admitted by only 24.0% (144/600) of the respondents, whereas 46.0% (276/600) practiced this irregularly and 30.0% (180/600) did not implement such measures at all. Up to 63.0% (378/600) of the respondents admitted keeping sick and healthy birds together.

The respondents' waste management and environmental exposure practices are presented in Table 6. Open dumping of poultry litter (312/600 = 52%) was the most common method of poultry litter disposal, followed by land application of untreated litter (198/600 = 33.0%). Only a small proportion (90/600 = 15.0%) practiced proper disposal or treatment of the litter. 43.0% (258/600) of respondents admitted that they openly dispose of dead birds, compared to 37.0% (222/600) who practiced burial and 20.0% (120/600) who used burning methods of disposal of dead birds. Waste water was discharged into the environment (uncontrolled) by 61.0% (366/600) of the respondents while only 39.0% (234/600) treated waste water or disposed of it in a controlled manner. Nearly half of the respondents (288/600 = 48.0%) operated poultry units within 50 metres of water sources.

Table 4. Antimicrobial use **(AMU)** practices among poultry farmers, traders, and handlers in Northeastern Nigeria (n = 600).

Study Variables	Response Category	No of respondents	Percentage of respondents
Use of antimicrobials in poultry production	Yes	534	89.0%
	No	66	11.0%
Source of antimicrobials	Agro-vet shops/markets	372	69.7%
	Prescription by a veterinarian	96	18.0%
	Informal vendors	66	12.3%
Basis for antimicrobial selection	Personal experience	312	58.4%
	Advice from peers	138	25.8%
	Advice by a veterinarian	84	15.7%
Purpose of antimicrobial use	Therapeutic	504	94.4%
	Prophylactic	336	62.9%
	Growth promotion	228	42.7%
Adherence to recommended dosage	Always	102	19.1%
	Sometimes	258	48.3%
	Never	174	32.6%
Observance of withdrawal period	Yes	132	24.7%
	No	402	75.3%

Table 5. Biosecurity and hygiene practices in poultry operations among poultry farmers, traders and handlers in Northeastern Nigeria (n = 600).

Study Variables	Response Category	Number of respondents	Percentage of respondents
Use of protective clothing (e.g., boots, overalls, gloves)	Always	84	14.0%
	Occasionally	186	31.0%
	Never	330	55.0%
Hand washing after handling birds	Always	162	27.0%
	Occasionally	222	37.0%
	Never	216	36.0%
Farm access control (restricted entry to poultry houses)	Yes	138	23.0%
	No	462	77.0%
Routine cleaning and disinfection of poultry environment	Regular	144	24.0%
	Irregular	276	46.0%
	None	180	30.0%
Keeping sick and healthy birds together	Yes	378	63.0%
	No	222	37.0%

Table 6. Waste management and environmental exposure practices among poultry farmers, traders and handlers in Northeastern Nigeria (n = 600)

Study Variables	Response Category	Number of respondents	Percentage of respondents
Poultry litter disposal method	Open dumping	312	52.0%
	Land application (untreated)	198	33.0%
	Proper disposal/treatment	90	15.0%
Dead bird disposal method	Open disposal	258	43.0%
	Burial	222	37.0%
	Burning	120	20.0%
Wastewater management practice	Discharged into environment (uncontrolled)	366	61.0%
	Controlled disposal/treatment	234	39.0%
Proximity of poultry units to water sources	< 50 metres	288	48.0%
	≥ 50 metres	312	52.0%

Table 7. Composite indices of antimicrobial use, biosecurity practices and antimicrobial resistance risk among poultry farmers, traders and handlers in Northeastern Nigeria (n = 600).

Index Category	Level	Number of respondents	Percentage of respondents
Antimicrobial use index	Low	96	16.0%
	Moderate	222	37.0%
	High	282	47.0%
Biosecurity practice score	Good	102	17.0%
	Fair	198	33.0%
	Poor	300	50.0%
Antimicrobial resistance risk index	Low	78	13.0%
	Moderate	204	34.0%
	High	318	53.0%

The distribution of composite indices reflecting antimicrobial use, biosecurity practices and antimicrobial resistance (AMR) risk is presented in Table 7. The antimicrobial use index indicated that nearly half of the respondents (282/600 = 47.0%) were classified within the high-use category, while 37.0% (222/600) and 16.0% (96/600) fell into moderate and low use categories, respectively. Half of the respondents (300/600 = 50.0%) had a poor biosecurity practices score, compared to 33.0% (198/600) with fair practices and only 17.0% (102/600) having good biosecurity practice score. Majority of respondents (318/600 = 53.0%) were classified as high risk, while 34.0% (204/600) and 13.0% (78/600) were categorized as moderate and low risk, respectively, with respect to the antimicrobial resistance risk index.

Discussion

The socio-demographic profile of respondents in this study indicates that poultry production and marketing in the study area are dominated by economically active males with moderate levels of education and substantial field experience. The predominance of individuals within the 31 – 45 year age group suggests a workforce capable of adopting improved practices if adequately informed and supported. However, the relatively low proportion of respondents with tertiary education (14%) may limit the absorption of complex AMR concepts without tailored communication strategies. Educational attainment has consistently been identified as a key determinant of antimicrobial stewardship behavior in livestock systems, as higher education levels are reportedly associated with improved compliance with withdrawal periods and reduced reliance on informal drug sources (Filli *et al*., 2021; Oyelami *et al*., 2022; Suleiman *et al*., 2023; Momah *et al*., 2025). The present findings therefore suggest that interventions must be designed in a manner that accommodates low-to-moderate literacy levels, relying on practical, visual and extension-based learning approaches.

The findings in the present study that, overall, a low proportion of the respondents (33.0%) are aware of AMR, alongside pronounced geographic, educational and knowledge-driven disparities, collectively highlight a structurally fragile knowledge ecosystem around antimicrobial stewardship in poultry production systems, with important

implications for resistance emergence and control. The differences in AMR awareness across the states surveyed suggests that spatially differentiated factors influence knowledge dissemination and access to animal health information, and indicates uneven exposure of respondents from the different states to veterinary extension services, training programs and institutional outreach. Such spatial heterogeneity has been reported in similar livestock systems where decentralized veterinary infrastructure and uneven implementation of extension services create "knowledge islands" within the same ecological zone (Bamidele *et al*., 2022; Ejikeugwu *et al*., 2025). These findings imply that AMR awareness in the region is not uniformly distributed but is instead shaped by localized service delivery capacity and possibly differing levels of engagement with public and private animal health interventions. This reinforces the need for geographically targeted stewardship campaigns rather than uniform national messaging strategies (Tang *et al*., 2023).

The low proportion of respondents with awareness of AMR (33.0%) recorded in the present study goes hand in glove with low proportion of respondents that had been trained on antimicrobial use and low proportions that are aware of withdrawal periods and consequences of misuse of antimicrobials. Earlier reports have shown that, exposure to formal training on antimicrobial use emerged as the strongest determinant of AMR awareness and that structured capacity-building interventions significantly improve antimicrobial stewardship outcomes in both human and veterinary sectors (Simegn *et al*., 2022; Fuller *et al*., 2023; Huang *et al*., 2023). Training appears to function not only as an information channel but also as a behavioral reinforcement mechanism that shapes risk perception and decision-making. From a behavioral science perspective, these results support the knowledge-attitude-practice (KAP) framework, which suggests that knowledge acquisition is a prerequisite for attitude formation and subsequent behavioral change in health-related practices (Andrade *et al*., 2020). The findings in this study suggest that AMR awareness in the poultry sector remains largely knowledge-dependent and highly responsive to structured educational interventions.

The antimicrobial use (AMU) practices patterns recorded in this study reflect a deeply entrenched culture of widespread and largely unregulated antimicrobial application within poultry production systems in the study area. The very high proportion of respondents who admitted using antimicrobials (89.0%) indicates near-universal exposure of poultry populations to antimicrobial agents, a scenario that substantially increases selective pressure for the emergence and persistence of resistant bacteria. Similar high-use patterns have been reported in smallholder poultry systems across sub-Saharan Africa, where antimicrobials are frequently integrated into routine management rather than strictly disease-driven interventions (Farkas *et al*., 2025; Hackman *et al*., 2025). A finding worthy of concern is the dominance of informal antimicrobial procurement channels, with agro-veterinary shops and open markets serving as the primary sources, while prescriptions by veterinarians remain limited. This indicates weak enforcement of prescription-only regulations and reflects systemic gaps in veterinary service accessibility. The reliance on personal experience and peer advice for antimicrobial selection further highlights the marginalization of professional veterinary input in therapeutic decision-making. Such informal decision structures have been identified as key drivers of irrational antimicrobial use and are strongly associated with increased AMR emergence in livestock systems (Yakubu *et al*., 2024).

The coexistence of therapeutic, prophylactic, and growth-promoting use of antimicrobials highlights a pattern of non-judicious and overlapping applications. Although therapeutic use predominates, the substantial proportions reporting prophylactic and growth-promoting use indicate continued persistence of non-essential antimicrobial applications despite global stewardship recommendations. These practices are widely recognized as critical accelerators of antimicrobial resistance evolution due to prolonged sub-therapeutic exposure of microbial populations (Bennani *et al*., 2020; Helmy *et al*., 2023; Odey *et al*., 2024).

Equally important is the high proportion of respondents that admitted non-compliance with dosage regimens and withdrawal periods in this study. The high proportion of respondents who admitted that they do not adhere to withdrawal guidelines (75.3%) raises significant public health concerns, particularly regarding antimicrobial residues in poultry products entering the human food chain. Beyond residue risks, such practices contribute to sustained environmental contamination and selection pressure in commensal and pathogenic bacteria, reinforcing the One Health transmission cycle of resistance (Bacanlı, 2024; Gyamfi *et al*., 2024).

Results of the biosecurity and hygiene practice profile recorded in this study reveals systemic weaknesses across both personal and structural infection control measures. The very low proportion of respondents that admitted that they always use protective clothing and hand hygiene practices indicate limited awareness of zoonotic and occupational health risks among poultry actors. These findings are consistent with reports from comparable low-resource poultry systems where biosecurity is often deprioritized due to cost constraints, behavioral norms and limited risk perception (Arjmand *et al*., 2025; Gemeda *et al*., 2026).

More critically, the low level of respondents who admitted lack of farm access control and the higher proportion that admitted irregular disinfection practices and frequent keeping of sick and healthy birds together, create optimal conditions for pathogen transmission and amplification. The practice of co-mingling diseased and healthy birds is particularly significant, as it facilitates rapid intra-flock spread of infectious agents and increases antimicrobial dependence. Such conditions have been repeatedly identified as key drivers of both disease persistence and antimicrobial overuse in smallholder poultry systems (Islam *et al*., 2025; Kovács *et al*., 2025).

The frequency of waste management practices recorded in this study highlight substantial environmental pathways for antimicrobial resistance dissemination. The predominance of open dumping and untreated land application of poultry litter indicates that antimicrobial residues, resistant bacteria and resistance genes are likely being continuously introduced into surrounding ecosystems. Similarly, the high proportion of respondents who practice uncontrolled waste water discharge and improper dead bird disposal further intensifies environmental contamination risks. These practices are of concern given the recorded close proximity of nearly half of poultry operations to water sources, which creates direct pathways for contamination of surface and potentially groundwater systems. Environmental contamination has been increasingly recognized as a critical but under-addressed component of AMR ecology, particularly in agricultural settings where waste treatment infrastructure is limited (Chen *et al*., 2025; Singh *et al*., 2025). The findings of this study reinforce the concept that poultry production systems function not only as reservoirs of antimicrobial use but also as active environmental dissemination hubs for resistance determinants.

The composite index analysis provided an integrated synthesis of antimicrobial use behavior, biosecurity practices, and resistance risk. The predominance of high antimicrobial use (47%), poor biosecurity (50%), and high AMR risk classification (53%) demonstrates a convergence of behavioral and structural risk factors within the same population. This clustering of risk attributes is particularly important, as AMR emergence is rarely driven by single factors but rather by the interaction of multiple reinforcing practices across production, hygiene, and environmental domains. The observed pattern supports the conceptual framework of AMR as an ecosystem-level phenomenon shaped by interconnected human, animal, and environmental behaviors (Aniokete *et al*., 2025; Elbehiry and Marzouk, 2025). From a One Health perspective, the alignment of high antimicrobial use with poor biosecurity and unsafe waste management suggests a self-reinforcing cycle of infection pressure, antimicrobial dependency, and environmental contamination. This integrated risk profile emphasizes the urgency of multisectoral interventions that simultaneously address behavioral, regulatory, and environmental dimensions of antimicrobial stewardship.

Conclusion: This study provides compelling evidence of low AMR awareness, widespread and largely unregulated antimicrobial use, inadequate biosecurity practices and unsafe waste management behaviors in northeastern Nigeria. Despite the central role of poultry value chain actors in food production and public health, only a minority demonstrated awareness of AMR, with geographic disparities indicating uneven access to information and extension services. These findings highlight that AMR emergence in this setting cannot be attributable to a single practice but rather to interconnected behavioral, structural and environmental drivers within the poultry production ecosystem.

Recommendations: There is a clear imperative to strengthen AMR awareness and capacity building through sustained, state-tailored sensitization campaigns and institutionalized training for poultry farmers, traders, and handlers. These interventions should be embedded within existing extension services, cooperatives and community platforms to ensure wide coverage and behavioral change. It is further recommended that veterinary service delivery be reinforced by improving access to qualified professionals and enforcing prescription-only policies for antimicrobial procurement. This should be complemented by stronger regulation of agro-veterinary outlets to reduce informal and unregulated antimicrobial distribution, while simultaneously restricting non-therapeutic uses such as growth promotion in line with antimicrobial stewardship principles. Biosecurity compliance should be enhanced through practical, low-cost interventions, including improved hygiene practices, use of protective clothing, controlled farm access, and routine sanitation. Incentive-based compliance mechanisms and certification schemes may further encourage adoption among poultry operators. Environmental risk mitigation should be prioritized through enforceable policies on poultry waste management, including proper disposal, treatment of litter and waste water, and promotion of sustainable alternatives such as composting and biogas production. Finally, a coordinated One Health surveillance system integrating human, animal, and environmental monitoring is essential for tracking antimicrobial use and resistance trends. This should be supported by continued research linking behavioral practices with microbiological outcomes to guide evidence-based interventions and policy refinement.

Conflict of interests

The authors declare no conflict of interest.

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