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One Health epidemiology and antimicrobial resistance profile of *Pasteurella multocida* in Muscovy ducks (*Cairina moschata*) and aquatic environments in Maiduguri, Borno State, Nigeria

Jallailudeen R. Lawal [1 *], Fatima A. Lawan [2], Juliana J. Ndahi [3], Hadiza K. Gazali [4], Kingsley U. Ezema [3] and Arhyel G. Balami [1]

[1] Department of Veterinary Medicine, Faculty of Veterinary Medicine, University of Maiduguri, P.M.B. 1069, Maiduguri, Borno State, Nigeria
[2] Department of Veterinary Microbiology, Faculty of Veterinary Medicine, University of Maiduguri, P.M.B 1069, Maiduguri, Borno State, Nigeria.
[3] Veterinary Teaching Hospital, Faculty of Veterinary Medicine, University of Maiduguri, P.M.B 1069, Maiduguri, Borno State, Nigeria.
[4] Department of Microbiology, Faculty of Life Sciences, University of Maiduguri, P.M.B 1069, Maiduguri, Borno State, Nigeria.

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Abstract

Pasteurella multocida is an important pathogen of poultry with significant One Health implications, yet its epidemiology in Muscovy ducks and associated aquatic environments remain under-investigated in sub-Saharan Africa. This study evaluated the prevalence, environmental distribution, antimicrobial resistance patterns and risk factors associated with occurrence of *P. multocida* in ducks and associated water bodies in Maiduguri, northeastern Nigeria. The study was a cross-sectional survey, conducted from September 2024 to August 2025, involving 400 samples, comprising 200 duck swabs (oropharyngeal and cloacal) and 200 water samples collected from communal water sources. Standard bacteriological methods and antimicrobial susceptibility testing (Kirby–Bauer disk diffusion) methods and procedures were applied. Results showed that the overall prevalence of *P. multocida* in ducks was 23.0% (46/200), while the prevalence in water sources was 16.0% (32/200). Oropharyngeal swabs yielded higher *P. multocida* prevalence (15.0%) than cloacal swabs (8.0%), indicating the upper respiratory tract as a key site of *P. multocida* colonization. Among water bodies, samples obtained from ponds (22.9%) and drainage channels (18.0%) had higher *P. multocida* contamination levels than the ones obtained from stagnant pools (12.5%) and irrigation ditches (5.0%). Antimicrobial susceptibility testing revealed high sensitivity of the *P. multocida* to fluoroquinolones (ciprofloxacin – 87.2%; enrofloxacin – 83.3%) and gentamicin (76.9%), whereas substantial resistance was recorded for tetracyclines (46.2%), streptomycin (42.3%) and β-lactams. Notably, 59.0% of the isolates were multidrug resistant. Risk factors analyses demonstrated significant associations ($p < 0.05$) between *P. multocida* occurrence and extensive management systems, mixed-species rearing, access to communal water sources, poor biosecurity and frequent use of antimicrobial agents. These findings highlight the dual role of ducks and aquatic environments as reservoirs of *P. multocida*, and underscore the influence of management practices on pathogen transmission.

Keywords: *Pasteurella multocida*; Muscovy ducks; Antimicrobial resistance; One Health; Aquatic environments.

*** Correspondence:** Jallailudeen R. Lawal; Email: rabana4real@unimaid.edu.ng; Phone: +2348032886428
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Introduction

Poultry production remains a critical component of food security, income generation and livelihood in many low- and middle-income countries, including Nigeria (Pius *et al*., 2021; Onwuaroh *et al*., 2024). Among the diverse poultry species reared in the country, Muscovy ducks (*Cairina moschata*) are the most widely kept duck species, particularly in rural and peri-urban settings (Kadurumba *et al*., 2022; Libanio *et al*., 2025). Their popularity is largely attributed to their adaptability to harsh environmental conditions, strong scavenging ability, disease tolerance and minimal input requirements (Kadurumba *et al*., 2021; Folorunso *et al*., 2024). In northern Nigeria, Muscovy ducks are predominantly raised under backyard and semi-intensive management systems, where they frequently interact with other poultry species, livestock and shared environmental resources such as surface water bodies (Gambo *et al*., 2021). While these systems enhance resource utilization and household resilience, they also create complex ecological interfaces that facilitate the transmission and persistence of infectious agents of veterinary and public health importance (Krunt *et al*., 2023).

One of the bacterial pathogens of significant concern in poultry production is *Pasteurella multocida*, the etiological agent of fowl cholera (Geda, 2024). Fowl cholera is characterized by septicemia, high morbidity and considerable mortality in susceptible avian species, leading to substantial economic losses (Geda *et al*., 2025). *Pasteurella multocida* has a broad host range, infecting domestic and wild birds as well as mammals, and is capable of surviving in diverse environmental niches. Although chickens and turkeys are often regarded as highly susceptible hosts, Muscovy ducks frequently exhibit sub-clinical infections or carrier states, enabling them to serve as silent reservoirs within poultry populations (Xu *et al*., 2025). This carrier status has important epidemiological implications, particularly in mixed-species production systems where inter-species transmission can occur.

The epidemiological role of Muscovy ducks as reservoir hosts of *P. multocida* is especially relevant in the context of backyard and smallholder poultry systems commonly practiced in peri-urban communities (Liu *et al*., 2017; Houessionon *et al*., 2025). These ducks are typically reared in close proximity to chickens, pigeons and other domestic birds, often with minimal or no biosecurity measures. Their scavenging behavior and strong association with water bodies increase their exposure to environmental contaminants and facilitate the dissemination of pathogens across different ecological compartments (Samanta *et al*., 2018; Kovács *et al*., 2025; Shakeel *et al*., 2025). Earlier reports by Liu *et al.* (2017) showed that infected or carrier Muscovy ducks may shed *P. multocida* through faeces and respiratory secretions, thereby contaminating shared environments and contributing to the maintenance and spread of infection within and between flocks. Despite this, the specific role of Muscovy ducks in the epidemiology of *P. multocida* infections in sub-Saharan Africa remains inadequately studied and/or reported.

Aquatic environments constitute a critical, yet often overlooked, component in the transmission dynamics of *P. multocida*. In many rural and peri-urban communities, Muscovy ducks depend on natural or communal water sources such as ponds, drainage channels and temporary pools for drinking and foraging. These water bodies can become contaminated through continuous deposition of faecal matter, nasal discharges and carcass residues, thereby serving as potential reservoirs for pathogenic microorganisms (Krunt *et al*., 2023). The ability of *P. multocida* to persist under favorable environmental conditions enhances the likelihood of indirect transmission via contaminated water. Consequently, these aquatic ecosystems may act as convergence points for pathogen exchange among birds, other animals and potentially humans, reinforcing the interconnected nature of animal, environmental and public health (Lehr *et al*., 2005).

The emergence and spread of antimicrobial resistance (AMR) among bacterial pathogens further complicate the control of *P. multocida* infections. In many smallholder and backyard poultry systems, antimicrobial agents are frequently used indiscriminately for prophylaxis or treatment, often without proper veterinary guidance (Bamidele *et al*., 2022; Abreu *et al*., 2023; Odey *et al*., 2024). Such practices exert selective pressure that promotes the development and dissemination of resistant bacterial strains. The occurrence of antimicrobial-resistant *P. multocida* in poultry and environmental reservoirs poses a significant threat to both animal health and public health, particularly through the potential transfer of resistance determinants within the One Health continuum.

The One Health approach, which recognizes the interconnectedness of human, animal and environmental health, provides an appropriate framework for investigating the dynamics of *P. multocida* in such settings. By integrating data on pathogen prevalence in Muscovy ducks, environmental contamination of aquatic habitats and antimicrobial resistance patterns, a more comprehensive understanding of transmission pathways and risk factors can be achieved. This integrated perspective is particularly important in Maiduguri Nigeria, where climatic conditions characterized by high temperatures, seasonal rainfall and variable water availability, may influence pathogen survival, host interactions and management practices.

Despite the recognized importance of *P. multocida* in poultry health, there is a paucity of report of studies that comprehensively examine its occurrence in Muscovy ducks alongside its environmental dissemination and antimicrobial resistance profiles within the context of backyard and mixed poultry production systems in northeastern Nigeria. Most existing studies have focused on single aspects of the pathogen's ecology, thereby limiting a holistic understanding of its transmission dynamics at the animal-environment interface. Addressing this gap is essential for developing effective, context-specific control strategies.

The present study investigated the One Health dynamics of *Pasteurella multocida* in Muscovy ducks and associated aquatic environments in Maiduguri, Nigeria. Specifically, the study determined the prevalence of *P. multocida* in Muscovy ducks, evaluated the bacteriological quality of water sources utilized by these birds, assessed the antimicrobial susceptibility patterns of the isolates, and examined the role of Muscovy ducks as reservoir hosts within mixed species poultry production systems.

Materials and Methods

Study Area: The study was conducted in Maiduguri, the capital of Borno State, northeastern Nigeria. The study area lies within the Sudan-Sahel ecological zone, located approximately between latitudes 11°46′N to 11°53′N and longitudes 13°2′E to 13°13′E, and is characterized by a semi-arid climate, with high ambient temperatures (often exceeding 40°C during the hot dry season), low relative humidity and a distinct harmattan period marked by dust-laden winds. Poultry production in the area is predominantly backyard and semi-intensive, with frequent intermingling of Muscovy ducks, chickens and other livestock. Water sources used by ducks commonly include ponds, drainage channels, irrigation ditches and temporary surface water accumulations, which are often shared among animals.

Study Design: A cross-sectional survey conducted from September 2024 to August 2025 was employed to investigate the prevalence of *Pasteurella multocida* in Muscovy ducks, assess contamination of associated water sources, determine the antimicrobial susceptibility profiles of isolates, and evaluate the reservoir potential of ducks within mixed poultry systems. The study integrated both animal and environmental sampling within a One Health framework.

Study Population and Sampling Strategy: The study population comprised Muscovy ducks reared under backyard and smallholder production systems within Maiduguri and its surrounding areas. Eligible units included households or farms keeping ducks either as a single species or in combination with other poultry, particularly chickens. A multistage sampling approach was employed to ensure adequate representation of the study population. Initially, several wards and communities within Maiduguri were purposively selected based on the presence of duck-rearing households and ease of accessibility. Within these selected locations, households keeping Muscovy ducks were identified with the assistance of local agricultural and veterinary extension officers, after which participating households were selected using simple random sampling techniques. Subsequently, individual ducks within each selected household were randomly chosen for sampling.

The sample size for Muscovy ducks was determined using standard epidemiological methods for prevalence studies, incorporating an expected prevalence derived from previous studies, a 95% confidence level, and a precision of 5%. The calculated sample size was further adjusted to account for potential non-response and the clustering effect inherent in household-level sampling.

Sample Collection: A total of 400 samples were collected during the study, comprising 200 samples from Muscovy ducks and 200 water samples. From each selected duck, oropharyngeal (tracheal) and cloacal swabs were aseptically collected using sterile cotton-tipped applicators. The swabs were immediately placed into sterile tubes containing appropriate transport media, such as buffered peptone water or Amies medium. All samples were properly labeled and maintained under cold chain conditions (4 – 8°C) using ice packs, and subsequently transported to the Department of Veterinary Medicine Research Laboratory, University of Maiduguri, Nigeria, for analysis within 6 – 12 hours of collection.

Water samples were collected from sources frequently accessed by ducks within the study area. These sources included ponds, stagnant pools, drainage channels and other communal water bodies. For each sampling point, approximately 250 – 500 ml of water was collected in sterile, screw-capped bottles. Care was taken to collect samples just below the water surface to minimize contamination with debris. Each sample was appropriately labeled with relevant details, including location, type of water source and date of collection. The samples were transported in cooled containers and processed in the laboratory within 24 hours of collection.

Bacteriological Analysis: Isolation of *Pasteurella multocida* from both duck and water samples was carried out using standard bacteriological procedures according to methods described by Quinn *et al*. (1994). Swab samples were initially subjected to pre-enrichment by inoculation into buffered peptone water and incubated at 37°C for 18 – 24 hours to enhance bacterial recovery. Following enrichment, aliquots from both the enriched swab samples and the water samples were streaked onto blood agar (supplemented with 5% sheep blood) and nutrient agar plates. The inoculated plates were incubated aerobically at 37°C for 24–48 hours. After incubation, the plates were examined for colonies with morphological characteristics suggestive of *P. multocida*, including small, round, grayish and non-hemolytic colonies on blood agar, often associated with a characteristic musty odour.

Suspected colonies were further subjected to microscopic examination using Gram staining to identify Gram-negative coccobacilli exhibiting bipolar staining as previously described by El-Demerdash *et al*. (2023). Presumptive isolates were subsequently characterized using standard biochemical tests, including catalase and oxidase activity, indole production, urease test and carbohydrate fermentation profiles. Final identification of *Pasteurella multocida* was based on the combination of cultural, morphological, microscopic and biochemical characteristics consistent with established diagnostic criteria.

Antimicrobial Susceptibility Testing: Antimicrobial susceptibility of confirmed *Pasteurella multocida* isolates was determined using the Kirby–Bauer disk diffusion method on Mueller–Hinton agar supplemented with 5% sheep blood, in accordance with Clinical and Laboratory Standards Institute (CLSI, 2020) guidelines. The selection of antimicrobial agents was based on their widespread use in poultry production and their relevance to both veterinary and public health. The antibiotics tested included tetracycline, oxytetracycline, amoxicillin, ampicillin, ciprofloxacin, enrofloxacin, gentamicin, streptomycin, and sulfamethoxazole-trimethoprim.

Briefly, bacterial suspensions were prepared and standardized to a turbidity equivalent to 0.5 McFarland standard. Sterile swabs were then used to uniformly inoculate the surface of the agar plates. Antibiotic-impregnated discs were carefully placed onto the inoculated plates, which were subsequently incubated aerobically at 37°C for 18 – 24 hours. Following incubation, zones of inhibition around each disc were measured in millimetres and interpreted as susceptible, intermediate or resistant, based on CLSI interpretive criteria. Isolates exhibiting resistance to three or more classes of antibiotics were classified as multidrug-resistant (Kidwai *et al*. 2017).

Assessment of Reservoir Potential and Farm-Level Risk Factors: Data on management practices and potential risk factors were obtained through the administration of structured questionnaires to 100 selected poultry farmers that keep ducks within the study area. The questionnaire captured information on the type of production system (backyard or semi-intensive), the presence of mixed poultry species, access of ducks to communal water sources, existing biosecurity practices and the use of antimicrobial agents.

In addition, on-site observational assessments were conducted to complement the questionnaire data, focusing on the level of interaction between ducks and other poultry species, the sanitary condition of water sources and the proximity of poultry housing to waste disposal areas. The combined information from interviews and field observations was used to evaluate the potential role of domestic ducks as reservoir hosts of *Pasteurella multocida* and to identify farm-level factors associated with its occurrence and transmission.

Data Analysis: Data generated from the study were analyzed using SPSS statistical software (version 25.0). Descriptive statistics were employed to summarize the distribution of isolates and their antimicrobial susceptibility patterns. Associations between categorical variables, such as management practices and infection status were assessed using Chi-square (χ^2) or Fisher's exact tests, where appropriate. Logistic regression analysis was conducted to identify significant predictors of *P. multocida* occurrence. Statistical significance was accepted at $p < 0.05$.

Results

The distribution of occurrence of *P. multocida* in the ducks and water samples is presented in Table 1. Out of 200 swabs obtained from the ducks surveyed, 46 (23.0%) tested positive. For the water samples, 32 out of 200 samples (16.0%) were positive. Oropharyngeal swabs yielded a higher occurrence of *P. multocida* when compared to cloacal swabs (Table 2). Specifically, 30 out of 200 oropharyngeal samples (15.0%) were positive, while 16 out of the 200 cloacal swabs (8.0%) were positive (Table 2).

The occurrence of *P. multocida* varied across different aquatic environments sampled is presented in Table 3. Ponds had the highest level of contamination, with 16 out of 70 pond water samples testing positive (22.9%). This was followed by drainage channels, where 9 out of 50 samples were positive (18.0%). Lower detection rates were observed in stagnant pools (12.5%) and irrigation ditches (5.0%).

The antimicrobial susceptibility profile of the 78 *Pasteurella multocida* isolated from the ducks and water samples is presented in Table 4. Overall, higher susceptibility was recorded for fluoroquinolones, particularly ciprofloxacin and enrofloxacin. Ciprofloxacin exhibited the highest level of activity, with 68 isolates (87.2%) classified as susceptible, while only 4 isolates (5.1%) were resistant. Similarly, enrofloxacin showed a high susceptibility rate of 83.3% (65/78), with a relatively low resistance rate of 7.7%. Gentamicin also demonstrated substantial efficacy, with 76.9% (60/78) of isolates being susceptible, although a moderate proportion exhibited resistance (12.8%). In contrast, β-lactam antibiotics showed comparatively lower effectiveness. Amoxicillin recorded a susceptibility rate of 53.8%, with 33.3% of isolates resistant, while ampicillin demonstrated even lower susceptibility (48.7%) and a higher resistance rate of 39.7%. Marked resistance was observed among tetracycline-class antibiotics. Tetracycline and oxytetracycline showed identical resistance rates of 46.2%, with susceptibility levels of 38.5% and 35.9%, respectively. Streptomycin also exhibited a high level of resistance (42.3%), with only 43.6% of isolates classified as susceptible. Sulfamethoxazole-trimethoprim demonstrated moderate activity, with 51.3% susceptibility and 32.1% resistance.

Table 1. Prevalence of *Pasteurella multocida* in ducks and water samples in Maiduguri, Borno State, Nigeria.

Source of Sample	Number Examined	Number Positive	Prevalence (%)
Ducks	200	46	23.0%
Water	200	32	16.0%

Table 2. The distribution of prevalence of *Pasteurella multocida* in swabs obtained from ducks in Maiduguri, Borno State, Nigeria.

Type of Sample	Number Examined	Number Positive	Prevalence (%)
Oropharyngeal swabs	200	30	15.0%
Cloacal swabs	200	16	8.0%

Table 3. The distribution of prevalence of *Pasteurella multocida* in water samples in Maiduguri, Borno State, Nigeria, based on the source.

Water Sources	Number Examined	Number Positive	Prevalence (%)
Drainage channels	70	16	22.9%
Stagnant pools	50	9	18.0%
Irrigation ditches	40	5	12.5%
Drainage channels	40	2	5.0%
Total	**200**	**32**	**16.0**%

Table 4: Antimicrobial susceptibility pattern of *Pasteurella multocida* isolates (n = 78) obtained from ducks and water samples in Maiduguri, Borno State, Nigeria.

Antibiotic Disc Potency (µg)	Number susceptible, with % in brackets	Number intermediate, with % in brackets	Number resistant, with % in brackets
Ciprofloxacin (5 µg)	68 (87.2%)	6 (7.7%)	4 (5.1%)
Enrofloxacin (5 µg)	65 (83.3%)	7 (9.0%)	6 (7.7%)
Gentamicin (10 µg)	60 (76.9%)	8 (10.3%)	10 (12.8%)
Amoxicillin (25 µg)	42 (53.8%)	10 (12.8%)	26 (33.3%)
Ampicillin (10 µg)	38 (48.7%)	9 (11.5%)	31 (39.7%)
Tetracycline (30 µg)	30 (38.5%)	12 (15.4%)	36 (46.2%)
Oxytetracycline (30 µg)	28 (35.9%)	14 (17.9%)	36 (46.2%)
Streptomycin (10 µg)	34 (43.6%)	11 (14.1%)	33 (42.3%)
Sulfamethoxazole–trimethoprim (25 µg)	40 (51.3%)	13 (16.7%)	25 (32.1%)

Table 5. Resistance profile of *Pasteurella multocida* isolates (n = 78) obtained from ducks and water samples in Maiduguri, Borno State, Nigeria.

Resistance Category	Number of isolates	Percentage (%)
Not resistant to tested antibiotics.	10	12.8%
Resistant to 1 – 2 classes of antibiotics.	22	28.2%
Resistant to more than 3 classes of antibiotics (multidrug resistant).	46	59.0%
Total	**78**	**100**%

Table 6. Responses from farmers and observation with regards to risk factors associated with *Pasteurella multocida* occurrence in ducks and water samples (n = 100 farms) in Maiduguri, Borno State, Nigeria. [RR = Relative Risk; OR = Odd Ratio]

Variable	Category	Number of respondents / farms	Number of farms that were positive (%)	p-value	RR	OR
Production system	Extensive	50	28 (56.0%)	0.0448	**1.494**	**2.263**
	Semi-intensive	50	18 (36.0%)			
Mixed poultry species	Yes	60	35 (58.3%)	0.0024	**1.643**	**3.691**
	No	40	11 (27.5%)			
Access to communal water	Yes	62	38 (61.3%)	<0.0001	**1.859**	**5.938**
	No	38	8 (21.1%)			
Biosecurity practice	Poor	53	33 (62.3%)	0.0005	**1.937**	**4.315**
	Good	47	13 (27.7%)			
Antimicrobial use	Frequent	48	29 (60.4%)	0.0055	**1.792**	**3.142**
	Occasional / None	52	17 (32.7%)			

The distribution of antimicrobial resistance profiles among the *P. multocida* isolates is summarized in Table 5. Out of the 78 isolates analyzed, only 10 isolates (12.8%) were classified as non-resistant, indicating full susceptibility to all classes of antimicrobials tested. A further 22 isolates (28.2%) exhibited resistance to one or two classes of antimicrobials. A majority of the isolates, 46 out of 78 (59.0%), were identified as multidrug resistant (MDR) – they exhibited resistance to three or more classes of antimicrobial agents.

The association between selected management and environmental factors and the occurrence of *Pasteurella multocida* in the duck farms sampled is presented in Table 6. A statistically significant association ($p = 0.0448$) was recorded between production systems and the occurrence of *P. multocida*. Farms operating under extensive systems recorded a higher prevalence (56.0%) compared to semi-intensive systems (36.0%). The relative risk (RR = 1.494) and odds ratio (OR = 2.263) indicate that ducks managed under extensive systems were approximately 1.5 times more likely to be infected and over twice as likely to harbor *P. multocida*, when compared to those under semi-intensive management.

The presence of mixed poultry species was significantly associated ($p = 0.0024$) with *P. multocida* occurrence. Farms that reared ducks alongside other poultry species showed a higher prevalence of 58.3%, compared to 27.5% recorded in farms without mixed species. The calculated RR (1.643) and OR (3.691) suggests a substantially increased likelihood of infection in mixed-species production systems.

Access to communal water sources was strongly and significantly associated ($p < 0.0001$) with *P. multocida* occurrence. Farms with access to communal water bodies recorded the highest prevalence of 61.3%, compared to only 21.1% among farms without such access. The risk estimates (RR = 1.859; OR = 5.938) indicated that farms utilizing communal water sources were nearly twice as likely to be infected and almost six times more likely to harbor *P. multocida* than those relying on controlled water sources.

Biosecurity level was also significantly associated ($p = 0.0005$) with infection status. Farms with poor biosecurity practices exhibited a prevalence of 62.3%, whereas those with good biosecurity had a markedly lower prevalence of 27.7%. The relative risk (RR = 1.937) and odds ratio (OR = 4.315) indicated that inadequate biosecurity nearly doubled the risk of infection and increased the odds of *P. multocida* occurrence by over fourfold.

Frequent antimicrobial use was significantly associated ($p = 0.0055$) with the occurrence of *P. multocida*. Farms reporting frequent antimicrobial use had a prevalence of 60.4%, compared to 32.7% among farms with occasional or no use. The estimated RR (1.792) and OR (3.142) suggest that frequent antimicrobial exposure is associated with an increased likelihood of pathogen occurrence.

Discussion

The findings in this present study of 23.0% occurrence of *P. multocida* in the ducks and 16.0% occurrence in water samples in the study area suggest that apparently healthy ducks and their associated aquatic environments function as reservoirs of *P. multocida*, facilitating pathogen persistence and transmission within free-range poultry systems. The concurrent presence in both the duck host and the aquatic environment underscores the integrated nature of pathogen circulation within a One Health framework, highlighting the critical role of environment-host interactions in maintaining infection dynamics. Most studies in African countries, including Nigeria, have largely focused on the isolation of this bacterium in chickens (Victor *et al*., 2016), with relatively few reports involving ducks. This confirms the fact that the occurrence of the bacterium in Muscovy ducks remains under-investigated in Nigeria (Moemen *et al*., 2012; Dashe *et al*., 2013; Yakubu *et al*., 2015; Victor *et al*., 2016; Lawal *et al*., 2021; Suleiman *et al*., 2021; Geda *et al*., 2025), despite its considerable economic impact on the poultry industry and its recognized zoonotic significance in humans (Ali *et al*., 2025). Reported prevalence rates of *P. multocida* in the Northern Nigerian poultry industry vary widely, typically ranging from 0.6% to 27% (Lawal *et al*., 2021; Suleiman *et al*., 2021).

The higher occurrence of *P. multocida* in ducks relative to water samples reinforces the established role of avian hosts as primary reservoirs of the pathogen. Nonetheless, its recovery from aquatic environments highlights the contributory role of environmental compartments as secondary reservoirs that support persistence and indirect transmission. This observation is consistent with previous studies demonstrating the survival of *P. multocida* in moist environments and water bodies, particularly under conditions of organic contamination (Liu *et al*., 2017; El-Demerdash *et al*., 2023). Similarly, Suleiman *et al*. (2021) reported the isolation of the organism from deep litter, further emphasizing the importance of environmental niches in pathogen maintenance. In the context of Maiduguri, where ducks commonly interact with open water sources, such environmental persistence likely sustains continuous exposure and reinfection cycles.

The 23.0% occurrence of *P. multocida* recorded in the ducks in the present study exceeds the 7.0% reported in Tanzania (Muhairwa *et al*., 2001), 11.42% in Bangladesh (Panna *et al*., 2015) and 11.0% in Plateau State, Nigeria (Suleiman *et al*., 2021) under comparable backyard and semi-intensive systems. Such variations likely reflect differences in management practices, ecological conditions, and diagnostic approaches across different study settings. In

Maiduguri's semi-arid environment characterized by seasonal water availability and elevated temperatures both pathogen persistence and host susceptibility may be altered, thereby shaping local transmission dynamics and potentially amplifying infection pressure.

The significantly higher detection of *P. multocida* in oropharyngeal swabs compared to cloacal swabs strongly suggests that the upper respiratory tract constitutes a principal site of colonization by the organism. This observation is consistent with previous reports demonstrating the organism's affinity for respiratory mucosal surfaces, including the air sacs and lungs (Reuben *et al*., 2021; Arvia *et al*., 2025). Epidemiologically, this pattern suggests that respiratory secretions may represent a more efficient route of pathogen shedding and transmission than faecal excretion in Muscovy ducks, with important implications for transmission dynamics in free-range and mixed-species production systems.

The heterogeneous distribution of *P. multocida* across aquatic environments in the present study, with highest contamination observed in ponds and drainage channels, provides important insight into environmental transmission pathways. Ponds and drainage channels are predisposed to the accumulation of organic matter, faecal waste and carcass residues, thereby creating nutrient-rich microhabitats that support bacterial persistence and proliferation. In contrast, irrigation ditches and less stagnant water sources exhibited comparatively lower contamination levels, likely reflecting reduced organic load and increased water turnover that limit bacterial concentration and survival. This pattern is consistent with previous reports indicating that organically enriched, slow-moving water bodies favour prolonged survival of *P. multocida*, whereas flowing water systems exert a dilutional and flushing effect that constrains pathogen persistence (Sekar *et al*., 2021; He *et al*., 2024; Murei and Momba, 2025). Experimental and field evidence further suggests that the organism can persist in contaminated aquatic environments for extended periods, potentially up to several months particularly under warm, moist conditions and high organic burden (Blanchong *et al*., 2006).

Collectively, these findings emphasize the role of communal and poorly managed water sources as critical nodes for pathogen amplification and dissemination. Similar epidemiological linkages have been described in wetland ecosystems, where contaminated water bodies act as reservoirs facilitating transmission between infected and susceptible hosts (Blanchong *et al*., 2006; Lehr *et al*., 2005). Within a One Health framework, such environments represent key ecological interfaces where interactions among animals, humans and shared resources converge, thereby sustaining transmission cycles and increasing the risk of cross-species spread.

The antimicrobial susceptibility profile recorded for *P. multocida* in this study showed that fluoroquinolones, particularly ciprofloxacin and enrofloxacin, remain highly effective against *P. multocida* isolates. This finding is consistent with previous reports highlighting the continued efficacy of fluoroquinolones against Gram-negative respiratory pathogens in poultry (Kong *et al*., 2014; Kerek *et al*., 2024). Previous studies consistently demonstrated that a high proportion of *P. multocida* isolates of avian origin; typically ranging from 76% to over 90% remain susceptible to fluoroquinolones (El-Demerdash *et al*., 2023; Arvia *et al*., 2025). These agents therefore continue to represent some of the most effective therapeutic options for the management of fowl cholera and other respiratory infections in poultry, alongside ceftiofur and florfenicol. In a similar context, the relatively high susceptibility observed for gentamicin suggests that aminoglycosides may still retain considerable clinical utility. Evidence from diverse host systems, including cattle, poultry and waterfowl, indicates sustained sensitivity of *P. multocida* to gentamicin (Kerek *et al*., 2024; Pintér *et al*., 2024; Bitew *et al*., 2025). Notably, even in instances where multidrug resistance to commonly used antimicrobials such as ampicillin, penicillin and clindamycin has been documented, susceptibility to gentamicin and related aminoglycosides is often preserved (Wang *et al*., 2017; Michael *et al*., 2018). This pattern emphasizes the continued relevance of these antimicrobial classes in treatment protocols, while also highlighting the need for judicious use to mitigate the emergence of resistance.

However, the poor/low susceptibility and high resistance observed for β-lactam antibiotics (amoxicillin and ampicillin) raise concerns about their continued effectiveness in field conditions. Resistance to these commonly used antibiotics may be attributed to widespread and often unregulated use in poultry production systems, leading to selective pressure and the emergence of resistant strains (Urban-Chmiel *et al*., 2022; Endale *et al*., 2023; Wiśniewski *et al*., 2024).

More notably, the high resistance rates observed among tetracyclines and streptomycin are particularly alarming. Tetracyclines are among the most commonly used antimicrobials in livestock due to their affordability and broad-spectrum activity. Their extensive and often indiscriminate use in smallholder systems likely explains the elevated resistance levels observed in this study. Similar trends have been reported globally, where tetracycline resistance is frequently associated with mobile genetic elements and horizontal gene transfer (Lawal *et al*., 2021; Endale *et al*., 2023).

The high (59.0%) prevalence of multidrug resistance (MDR) among *P. multocida* isolates constitutes a critical finding with important implications for both veterinary practice and public health. The occurrence of MDR phenotypes indicates resistance to multiple antimicrobial classes, thereby constraining therapeutic options and increasing the likelihood of treatment failure. This observation is consistent with previous reports documenting variable but increasing/high levels of multidrug resistance in *P. multocida* that should be of concern (El-Demerdash *et al*., 2023; Jahnen *et al*., 2025). The development of such resistance profiles has been widely attributed to the indiscriminate and often unregulated use of first-line antimicrobials in livestock production systems, which exert selective pressure favoring the persistence and dissemination of resistant strains. Collectively, these findings highlight the urgent need for strengthened antimicrobial stewardship, routine susceptibility testing and the implementation of evidence-based treatment guidelines to mitigate further escalation of resistance.

From a One Health perspective, the circulation of MDR *P. multocida* in ducks and aquatic environments poses a potential risk for the transfer of resistance determinants to other bacterial species within shared ecosystems. This is particularly of concern in settings where humans, animals and the environment are in close contact, as is typical in backyard poultry systems. The findings therefore highlight the urgent need for antimicrobial stewardship and integrated surveillance programs to monitor and mitigate the spread of resistance (Al-Khalaifah *et al*., 2025; Miao *et al*., 2026; Tzavellas *et al*., 2026).

The identification of significant risk factors provides valuable insights into the drivers of *P. multocida* transmission in the present study area. The higher prevalence observed in extensive production systems suggests that free-range management practices increase exposure to contaminated environments and infected animals. This is consistent with previous studies that have linked extensive systems with higher disease burden due to limited biosecurity and uncontrolled animal movement (Lawal *et al*., 2021; El-Demerdash *et al*., 2023; Ali *et al*., 2025; Jiang *et al*., 2025).

The recorded association between mixed-species poultry rearing and infection in the present study emphasizes the epidemiological significance of inter-species transmission in the maintenance of *P. multocida*. In such systems, ducks appear to function as effective reservoir hosts, facilitating pathogen spillover across species boundaries. This interpretation is supported by previous studies demonstrating that, under scavenging and free-range conditions, ducks often harbor *P. multocida* asymptomatically while actively shedding the organism, thereby sustaining transmission cycles within mixed flocks (Mbuthia *et al*., 2008; Liu *et al*., 2017; Mwasunda *et al*., 2022).

Experimental evidence further reinforces this dynamics, showing efficient bidirectional transmission between ducks and chickens, with infection rates frequently ranging between 60% and 80% (Apinda *et al*., 2022). Within typical village poultry systems characterized by the co-mingling of multiple species and age groups, such interactions create optimal conditions for continuous pathogen circulation and periodic outbreaks of fowl cholera. Consequently, the high carrier potential in ducks, coupled with their role in inter-species dissemination, highlights the need for integrated control strategies that concurrently target all co-reared poultry species, particularly in low-biosecurity, free-range production systems (Suleiman *et al*., 2021).

Access to communal water sources emerged as the most significant risk factor, with markedly higher odds of infection. This highlights the central role of water in the epidemiology of *P. multocida* and underscores the need for improved water management practices. Similarly, poor biosecurity practices were strongly associated with increased infection risk, reinforcing the importance of hygiene, controlled access and proper waste disposal in disease prevention.

The association between frequent antimicrobial use and increased occurrence of *P. multocida* is particularly noteworthy. While antimicrobials are intended for disease control, their inappropriate use may disrupt normal microbial flora, promote resistance and potentially increase susceptibility to infection. This paradoxical effect has been documented in other studies and highlights the complexity of antimicrobial use in livestock systems (Furian *et al*., 2016; Iorgoni *et al*., 2026).

Conclusion: This study demonstrated that *Pasteurella multocida* is actively circulating within the duck-environment interface in Maiduguri, Nigeria, with 23.0% prevalence in ducks and 16.0% prevalence in water bodies. The higher detection in ducks, particularly in oropharyngeal samples, confirms the upper respiratory tract as a key site of colonization and a likely route of shedding, while the concurrent recovery of the organism from water sources especially ponds and drainage channels highlights the role of environmental reservoirs in sustaining transmission cycles. The antimicrobial susceptibility profile revealed an epidemiological pattern of grave concern, characterized by high effectiveness of fluoroquinolones and gentamicin alongside substantial resistance to commonly used antibiotics, including β-lactams and tetracyclines. Notably, the high prevalence of multidrug resistance (59.0%) among the *P. multocida* isolates implies a significant threat to effective disease management and underscores the growing burden of antimicrobial resistance within the poultry production system. Importantly, the occurrence of *P. multocida* was strongly influenced by modifiable risk factors, including extensive management systems, mixed-species rearing, access to communal water sources, poor biosecurity, and frequent antimicrobial use. These factors collectively amplify infection risk and facilitate pathogen maintenance within and between flocks.

Recommendations: An integrated One Health framework is strongly recommended to address the multifactorial epidemiology of *P. multocida* demonstrated in this study. Control strategies should prioritize the simultaneous targeting of host, environmental and management-related drivers of infection. In practical terms, this includes strengthening on-farm biosecurity measures, regulating and rationalizing antimicrobial use through stewardship programs, and improving the management of shared water resources to minimize environmental contamination and pathogen persistence. In addition, targeted education and risk communication for farmers and other stakeholders are essential to enhance compliance with preventive measures and reduce practices that facilitate transmission.

To sustain these efforts, the establishment of coordinated surveillance systems that integrate animal, environmental and public health data is critical for early detection, monitoring and response to emerging threats. Furthermore, future research should adopt longitudinal study designs and incorporate advanced molecular approaches, including whole-genome sequencing, to elucidate transmission pathways, genetic diversity and the evolutionary dynamics of *P. multocida*, thereby informing more precise and evidence-based intervention strategies.

Competing Interests

The authors declare that they have no competing interests in the publishing of this research.

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