



Original Research Paper

Machine Learning Detection of Antimicrobial Resistance in Aquatic Bird Habitats

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Abstract

In addition to their importance in maintaining ecological balance, wetland birds help to recycle nutrients as well as act as indicators of ecosystem health. Nevertheless, the presence of increased resistance of pathogens in wildlife has been identified as one of the significant issues facing the environment. This is caused by the possible movement of resistant microorganisms from the aquatic environment, through the animals, and finally to the nearby community members. Traditional microbial monitoring techniques are laboratory-based and hence time-consuming, expert-oriented, and do not offer a way for ecological monitoring. This study presents an alternative solution for detection of AMR risk in aquatic bird habitats through a machine learning algorithm that utilizes various attributes. Environmental factors like water quality, pollution, human impact, and wetland condition, in addition to biological factors such as bird population size, feeding habits, and migration pattern are included in the suggested model for risk prediction of AMR. The findings show that machine learning models are able to detect the complicated connection between the conditions of the habitats and AMR prevalence, with the proposed model having better performance than traditional methods. According to feature analysis, water pollution, human interference and microorganism exposure conditions were the main factors contributing to AMR risk. This study presents a useful framework for assessing wildlife health as it allows early identification of the most hazardous water habitats for microorganisms.

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Introduction

Importance of Aquatic Birds in Wetland Ecosystems

The importance of aquatic birds is that they are an integral part of wetlands because they maintain the balance, contribute to the nutrient cycling, and help in increasing biodiversity. Wetlands serve as feeding, nesting, and migration grounds for the birds in which they have contact with water, soil, aquatic organisms, and microbes. Since these birds come into frequent contact with aquatic environments, they can be considered bioindicators as well as potential vectors for the microorganism present in the environment (Guardia et al., 2024; Bharathi & Dhanalakshmi, 2025).

Antimicrobial Resistance in Wildlife Habitats

Antimicrobial resistance (AMR) has transcended the boundaries of clinics and has emerged as a key issue in natural environments. Aquatic environments can act as sites of resistant bacteria because of their contamination by sewage effluent, agricultural discharge, and anthropogenic activities (Kang et al., 2022; Ahmad et al., 2026; Mukesh et al., 2026). Aquatic birds can be exposed to resistant microbes through contaminated water and diet, thus allowing for microbial transmission between different environments. There have been reports on the presence of various resistant bacterial lineages in wild birds (Fu et al., 2022).

Challenges in Conventional AMR Monitoring

Conventional AMR detection tools primarily depend on microbial identification using culture technique, which is cumbersome and involves highly specialized laboratory facilities. Such tests are challenging to implement for large scale wildlife surveillance due to their inability to study multiple environmental factors concurrently. Recent investigations indicate the need for development of new methods for better AMR surveillance using ecological information and predictive analysis (Ibitoye et al., 2026). Machine learning tools are capable of analysing environmental relationships and predicting microbial risks (Salgueiro et al., 2024).

Motivation and Objectives

Increasing prevalence of AMR in wildlife habitats suggests the necessity for developing predictive testing tools. Machine learning facilitates the incorporation of environmental and biological factors in order to predict resistance patterns and risky habitats. Previous researches have proved the efficiency of machine learning in environmental and biological risk predictions (Nusir et al., 2026).

The objectives of this study are:

- To analyse environmental factors influencing AMR occurrence in aquatic bird habitats.
- To develop a machine learning-based AMR prediction framework.
- To identify important habitat factors associated with resistance risk.

1.5 Key Contributions

The major contributions of this study include:

- Development of an ecological machine learning framework for AMR risk prediction.
- Integration of habitat, microbial, and environmental parameters.
- Identification of important factors influencing resistance occurrence.
- Support for wildlife disease monitoring and wetland ecosystem protection.

Materials and Methods

Study Framework

The current research adopts the ecological machine learning approach for the purpose of AMR risk assessment in aquatic bird habitats. This approach considers the use of habitat variables, biological features, and microbiological features for the analysis of factors that contribute to resistance emergence. This research process involves the collection of environmental data, risk assessment of microbiological features, data preprocessing, classification using machine learning, and the prediction of AMR risk.

Data Collection and Environmental Parameters

Data collection includes the analysis of ecological, biological, and microbial factors relevant to the habitats of aquatic birds that can be responsible for AMR prevalence. Ecological factors encompass wetland types, water quality, pollution levels, degree of human intervention,

and other land use factors since all of them can affect microbial survival and development of AMR. Biological factors like types of birds, their diet, migratory routes, and population size are taken into account as means to determine the exposure and microbial transmission among aquatic birds. Furthermore, microbial factors like presence of resistant bacteria, antibiotic resistance genes, and microbial diversity are included as means to estimate the AMR prevalence in wetlands. Inclusion of such factors allows a detailed estimation of ecological factors relevant to AMR and development of a machine learning-based model of prediction for aquatic birds habitats.

Data Processing

Ecological and microbial data collected are pre-processed prior to the generation of models. Incomplete observations and records are eliminated from the dataset to ensure quality data. Environmental variables are normalized in order to keep all variables at comparable scales. Feature selection is conducted to determine the significant habitat and microbial factors for AMR prediction. Dataset pre-processed is split into training and testing sets, with training set being used for developing the model and testing set for assessing model performance.

Machine Learning Models

Machine learning techniques are used to detect connections between environment conditions, biological traits, and occurrence of antimicrobial resistance (AMR) in aquatic birds' habitats. Different classifiers are examined in the research for predicting AMR risk levels –

Decision Tree classifier, Support Vector Machine (SVM), Random Forest classifier, and Gradient Boosting classifier. The Decision Tree classifies habitat traits based on rules, SVM detects patterns by discriminating various risk classes, and Random Forest increases prediction robustness by using several decision trees. Meanwhile, Gradient Boosting classifier increases classification quality with iterative model improvement. Proposed machine learning approach utilizes selected ecologic and microbial parameters for increasing the accuracy of resistance risk predictions. Developed classifiers classify the aquatic birds' habitats into two categories of AMR risk: low AMR risk and high AMR risk.

Results and Analysis

Environmental Factors Influencing AMR Occurrence

The study of environmental factors reveals that the conditions of the habitat significantly affect the probability of developing AMR in aquatic birds. Regions characterized by high amounts of pollution were found to have higher probability of developing AMR due to persistent exposure to antibiotics and pollutants. Poor water quality provides good conditions for the growth of resistant bacteria. Human interference such as agriculture runoffs, sewage water dumping, and other disturbances increases the presence of antibiotics and the risk of AMR transfer. Moreover, the migration pattern of the aquatic birds could result in the transfer of resistant microorganisms in different wetland locations.

Table 1: Environmental Factors Associated with Antimicrobial Resistance Risk in Aquatic Bird Habitats

Factor	Influence Level
Water contamination	High
Human activity	High
Bird density	Medium
Wetland condition	Medium
Seasonal variation	Medium

Machine Learning Model Performance

The classification performance of various machine learning models was compared for AMR risk prediction in aquatic bird environments. Various performance indicators like accuracy, precision, recall, and F1-score were used to evaluate these models in table 1.

Conventional classification models showed good predictive performance, but the proposed machine learning approach showed better performance with the inclusion of environmental, biological, and microbial factors. These better results imply that incorporating multiple ecological factors improves the performance for habitat classification.

Table 2: Performance Comparison of Machine Learning Models for AMR Detection

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-score (%)
Decision Tree	78.2	76.5	77.8	77.1
SVM	82.5	81.4	82.0	81.7
Random Forest	86.7	85.9	86.2	86.0
Gradient Boosting	88.1	87.5	88.0	87.7
Proposed ML Model	91.3	90.8	91.0	90.9

The ML algorithm developed here exhibited the best accuracy at 91.3%, thereby proving better efficiency in recognizing AMR risk patterns than traditional machine learning algorithms. The findings reveal that the use of features from ecology and microbiology enables more efficient classification for habitat monitoring of aquatic birds. The ML algorithm can be used for early detection of vulnerable wetlands in Table 2.

Discussion

The results show that machine learning is capable of discovering complex correlations among the variables related to the habitat conditions, biological properties, and AMR prevalence in the aquatic bird communities. Combining the environmental and biological features enhanced the ability to predict the high-risk habitats by considering several aspects that influence the development of the resistance. The aquatic environment is an important source of resistant microorganisms because of the pollution caused by the human impact and the release of the waste. Ecological studies have also shown that wild birds are able to promote the dissemination of resistant bacteria geographically (Guardia et al., 2024; Fu et al., 2022).

The findings also demonstrate that pollution and disturbance increase exposure to aquatic birds through changes in microbial populations and the development of antibiotic resistance transfer. These findings are consistent with earlier research that points out the importance of aquatic environments in sustaining the gene pool and microbial diversity (Kang et al., 2022; Ibitoye et al., 2026). The suggested predictive framework can be useful for AMR risk assessment at an early stage and help with the protection of wild animals, wetlands, and disease control. In general, this work confirms the concept of One Health, which involves environmental conditions, animal health, and microbial risks.

Conclusion

In this paper, an innovative machine learning framework for assessing AMR risks in aquatic bird habitats using a combination of environmental, biological, and microbial factors has been provided. In this framework, the analysis of habitat factors, biological factors of the bird, and microbial factors have been done for the identification of ecological factors responsible for AMR risk occurrence. It has been found that machine learning frameworks can accurately analyze the association of habitat factors with AMR risk occurrence.

The identified drivers include water contamination, the level of human activity, pollution, bird density, and wetlands status. Thus, with the help of considering all the environmental variables together, the proposed framework helps identify more accurately the risky habitats of aquatic birds. Thus, the predictive model framework helps identify the resistance risks at an early stage and also provides important data for monitoring the state of aquatic bird populations and wildlife diseases. Thus, the results obtained prove that the combination of machine learning techniques with ecological monitoring will be helpful for sustainable wetland management. This framework will contribute to the development of the One Health strategy by linking environmental factors, animal health, and microbes. The future research can further develop this method using IoT-based water quality monitoring, satellite-based habitats assessment, real-time AMR surveillance system, and multi-species wildlife disease prediction framework.

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