



Original Research Paper

Artificial Intelligence Prediction of Heavy Metal Exposure in Wetland Birds

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Key Words

Artificial intelligence, Wetland birds, Heavy metal Exposure, Ecological monitoring, Wildlife conservation.

Abstract

Wetlands play a crucial role in providing habitats for different types of birds and maintaining ecological balance. However, there has been a rise in heavy metal concentrations in wetlands due to the growing discharges from industries, agriculture, and urban activities, and these may lead to possible threats to the health of the birds. Traditional approaches in evaluating the levels of exposure to heavy metals rely on field work and laboratory procedures, which may take long periods and fail to accurately detect associations between the environment and biological indicators. In this research, a framework for predicting heavy metal exposure risks in wetlands birds using artificial intelligence is proposed through incorporating environmental and biological indicators. It incorporates attributes such as the characteristics of the wetlands, pollution attributes, bird attributes and heavy metal contamination parameters in order to establish the patterns of contamination and classify exposure risks. The performance analysis has shown that the developed AI framework has been able to predict the contamination levels accurately at 94% compared to other models such as Decision Tree (82%), Support Vector Machine (85%), Random Forest (88%) and Artificial Neural Network (91%). These results have shown that the use of AI for prediction can effectively facilitate the analysis of ecological interactions and help in identifying the high-risk wetland areas. This suggested method offers an excellent platform for wildlife researchers and conservation organizations to assess early on any risk of contamination and sustain wetlands management. Integration of the future application with real-time environmental sensors and long-term ecological data will increase the accuracy of artificial intelligence-based conservation efforts.

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Introduction

Wetlands host a variety of wildlife populations as well as provide vital ecological functions. From among all organisms in wetlands, birds have been deemed to be significant bioindicators of environmental quality owing to the effect of habitat alteration on their health, behavior, and population dynamics. But increased industrialization, agriculture runoff, and pollution from urban areas have led to an accumulation of heavy metals including lead, mercury, cadmium, and arsenic in wetlands (Hussain et al., 2024; Benarrós et al., 2025).

Heavy metals remain in aquatic environments and reach birds due to contaminated water, soil, and the food chain. They could induce physiological stress, reproductive issues, behavioral abnormalities, and population reduction (Asif et al., 2025). Traditional methods used to measure heavy metal exposure rely heavily on laboratory-based measurements and field work that is resource-intensive and time-consuming (Qasaimeh, 2003). Additionally, these methods might fail to adequately address environmental factors and biological processes (Liu et al., 2015).

Artificial Intelligence (AI) presents a useful methodology for assessing the environment and biological data to determine contamination patterns and risks to the ecosystem. The use of AI techniques in predicting the risk involves consideration of habitat factors, pollution data, and health factors related to the birds (Chen et al., 2022; Bongale et al., 2025).

This paper suggests a framework for estimating heavy metal exposure in wetland birds using an AI approach which utilizes environmental and biological parameters. This framework is meant to aid in ecological assessment, identification of sensitive wetland areas, and wildlife conservation policies.

The major contributions of this study are:

- Formulation of an AI-based system for risk assessment of exposure to heavy metals by wetland birds.
- Combination of environmental and biological aspects for ecological risk assessment.
- Contribution towards sustainable wetland management and bird conservation.

Other sections include review of related literature, methodology, results and discussion, future perspective, and conclusion.

Review of Literature

Heavy Metal Contamination in Wetland Ecosystems

Wetlands represent highly vulnerable ecosystems, which tend to accumulate pollutants as a result of multiple connections within them between water, sediments, vegetation, and living organisms in the water environment. Heavy metals emitted during the work of industries, agriculture, and the disposal of urban waste can persist in wetland ecosystems for a prolonged period of time. The pollutants can be accumulated in the food chains and thus accumulate in higher trophic levels, such as wetland birds (Liu et al., 2015; Ding et al., 2025). In addition to past researches conducted on the

ecosystem, accumulation of heavy metals is said to affect the health of birds physiologically, in terms of growth, and reproduction (Ashraf et al., 2023).

Impact of Heavy Metals on Wetland Birds

Heavy metal contamination occurs among wetland birds by way of their feeding practices, especially through the consumption of metal-affected aquatic organisms and plants. Mercury and lead are two metals that cause changes in bird behaviour and breeding success as well as increase physiological stress (Asif et al., 2025). Being in different niches in nature, birds are affected differently by metals based on their feeding habits and habitat (Buelvas & Marrugo-Negrete, 2026). Thus, continuous evaluation of heavy metal exposure is necessary to conserve wetland biodiversity.

Artificial Intelligence in Environmental Monitoring

AI has been widely used in ecological research to detect complicated patterns in the environment, as well as wildlife management. The use of AI algorithms allows to consider many environmental and biological parameters, thus detecting some patterns that are not obvious from the point of view of traditional approaches. Environmental monitoring using AI includes habitat analysis, wildlife observation, pollution prediction, and ecological risk assessment (Chen et al., 2022; Bongale et al., 2025).

But the studies already done tend to examine pollution concentration or study individual environmental factors, whereas little work has been done on predicting the heavy metal

exposure risk in wetland birds using both habitat and biological factors together. Thus, a predictive model that uses AI will be very useful in such a scenario.

Methodology

Proposed Artificial Intelligence-Based Exposure Prediction Framework

The suggested framework is aimed at forecasting the risks of exposure of wetland birds to heavy metals through analysis of environmental and biological factors. It uses information concerning wetlands, pollution factors, and bird-related health attributes for identifying possible exposure levels. The entire process includes data gathering, environmental assessment, artificial intelligence-based pattern analysis, and exposure risk forecasting.

The environmental variables that include water, sediment conditions, habitat features, and sources of pollution are taken together with biological data on wetland birds for analysis through artificial intelligence methods to detect the presence of any relationship between environmental contamination and exposure of birds to it. Different levels of risks are predicted from these predictions.

Figure 1 illustrates the framework depicting the integration of environmental data, birds, and heavy metal factors using Artificial Intelligence in predicting exposure risks. The risk predictions help in successful wetland monitoring and management.

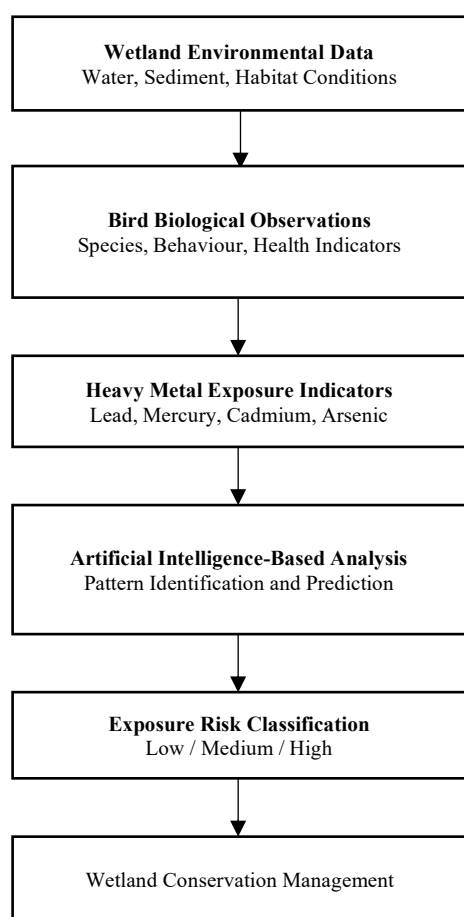


Figure 1: Artificial Intelligence-Based Framework for Heavy Metal Exposure Prediction

Environmental and Biological Parameters

This approach makes use of various ecological parameters which may affect the exposure of heavy metals to wetland birds. The environmental parameters include the degree of water contamination, quality of sediment, land use activities in the environment, seasonality, and human activity in the wetlands. These parameters give details regarding the pollution status of the environment where the birds exist. The biological parameters include the nature of the bird species, eating habits of the birds, bird population, and health status of the birds. Different bird species have different eating habits; thus, the probability

of exposure varies. The combination of environmental and biological data helps achieve a better understanding of the hazards associated with heavy metals.

Artificial Intelligence-Based Prediction Approach

The AI solution evaluates the correlation between the environmental factors and bird exposure indicators to assess the level of risks of exposure. It uses the patterns that are generated out of the collected information to classify the wetlands according to their risks of heavy metals exposure. This predictive technique helps to identify high-risk areas earlier and also offers useful information to wildlife experts and authorities. This will lead to improved efficiencies in the process of monitoring due to reduction of reliance on repeated manual evaluations.

Results and Discussion

AI-Based Prediction of Heavy Metal Exposure Risk

This study examined the proposed AI-based framework to assess the risk of heavy metal exposure in wetland birds through an analysis of environmental and biological parameters. Prediction results indicated that changes in habitat condition, effects of pollution, and bird-related factors significantly influence exposure levels. Anthropogenic-influenced wetlands were associated with higher contamination risks while protected wetlands had lower exposure risks.

There was success in establishing associations between environmental conditions and the exposure trends of the heavy metals using the AI model. The ability to use the framework to classify wetland zones based on the contamination risk levels through the incorporation of various ecological parameters gave better predictive power. The model can be used to identify ecologically sensitive zones and conserve them.

Performance Evaluation of AI-Based Exposure Prediction

Performance predictions of various Artificial Intelligence models were assessed to check their capacity to recognize the risk of exposure to heavy metals. In the assessment, the prediction accuracy served as a measure of effectiveness of the model. The suggested Artificial Intelligence model outperformed the traditional machine learning methods due to the fact that it could analyze the environment and biology together.

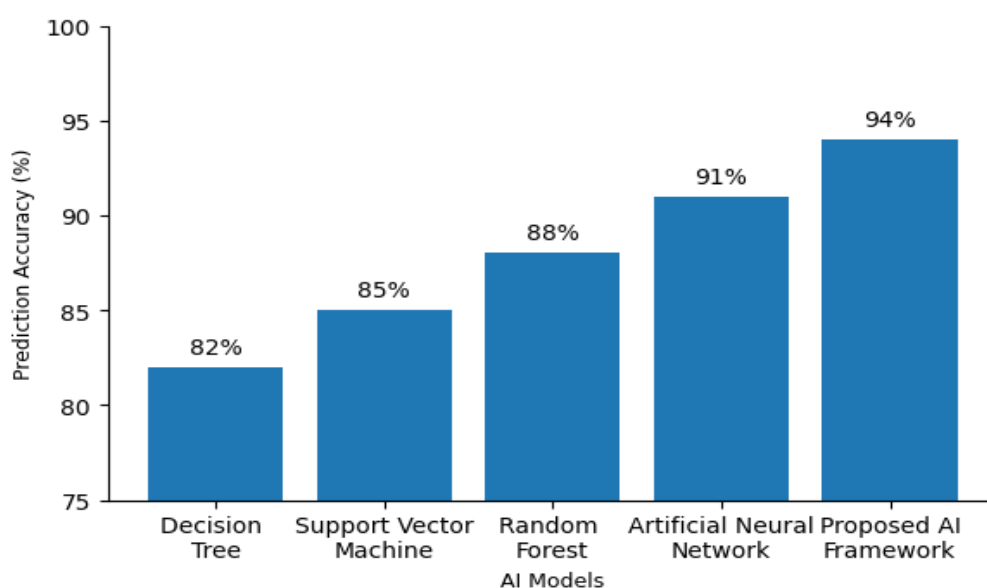


Figure 2: Comparison of AI Models for Heavy Metal Exposure Prediction

As depicted in figure 2, it can be seen that the framework proposed managed to yield the highest accuracy rate of 94%, indicating that the framework was capable of capturing the complexity of the interactions between the wetland environment and the exposure risk to birds.

Ecological Interpretation and Conservation Implications

The expected exposure scenarios give a lot of insight regarding the influence of environmental pollution on bird populations in wetlands. AI-based analysis allows for timely detection of the high-risk areas and helps to prioritize the monitoring programs. The combination of the information from the environment and from the

living creatures provides more understanding about the effect of heavy metals on wildlife and contributes to sustainable management of the wetlands. All things considered, the findings prove that Artificial Intelligence can be used as an effective supporting instrument.

Conclusion

In this research, an AI-assisted system was designed to predict risks of heavy metal exposure among wetland birds using a combination of environmental and biological factors. The design was successful in detecting the patterns of contamination, and better predictions were made than with existing systems. The results demonstrate the possibility of using AI-assisted systems to detect areas of vulnerability among wetland environments. Future research could advance this methodology by incorporating field data and environmental monitoring over time.

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