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Eco Health Monitoring Model for Evaluating Pollution-Driven Wildlife Health Risks

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Key Words

Wildlife health surveillance, Pollution exposure, Antimicrobial resistance, Disease susceptibility, One health, Environmental contamination, Microbial community disruption.

Abstract

Pollution in the water, air, and soil typically does not occur in isolation and can occur in multiple environmental channels simultaneously, increasing the risk of health problems in wildlife species that are exposed to it. Most studies on the health of wildlife tend to focus on one medium, thus making it difficult for experts to understand the impact of simultaneous exposure through multiple environmental channels. The Eco Health Monitoring Model bridges this gap by bringing together information on contaminants movement, susceptibility of microorganisms and the health at the population level, and creating a single model for surveillance. The model applies the findings of the studies on the spread of resistance to antibiotics, pollution mitigation methods, degradation of soil, impact of air pollution on microorganisms, and agriculture techniques that contribute to the pollution of the environment, and predicts the areas where the cross-channel exposure to pollution causes the disease risk to increase. The model has not been used in practice in monitoring of wildlife so far but could provide a good basis for anticipating the locations where pollution has the most detrimental impact on the environment.

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Introduction

Wildlife populations occupy landscapes where water, air, and soil pollution frequently occur together, and the health consequences of this pollution are often assessed within a single environmental compartment even though contaminants routinely move across compartments and interact with one another before reaching the animals ultimately affected. Research examining the role of the environment, encompassing water, air, and soil, in the emergence and dissemination of antimicrobial resistance from a one health perspective has shown that resistant microbial populations move readily between these environmental compartments and between wildlife, domestic animal, and human populations that share a landscape, demonstrating that pollution-linked health risk cannot be fully understood by examining any single environmental medium in isolation (Sassi et al., 2025). Work examining environmental pollution and unlocking integrated strategies for environmental sustainability has demonstrated that pollution sources affecting water, air, and soil in a given region are frequently interconnected, arising from overlapping industrial, agricultural, and urban activities, and that management strategies addressing only one pollution source while ignoring others tend to underestimate the cumulative environmental health burden facing wildlife and human populations sharing the affected landscape (Kodiya et al., 2025). Studies about pollution-related viral vulnerability reveal that exposure to multiple pollutants can be a hidden factor influencing disease outcome among aquatic animals, as combinations of pollutants lead to a higher vulnerability to viral infection than would be expected from exposure to each pollutant alone, suggesting that assessment of disease risk based on the study of individual pollutants may significantly underestimate the risk of negative health effects for affected wildlife populations (Weng et al., 2025).

The Eco Health Monitoring Model fills the gap these research areas together highlight: cross-compartmental antibiotic transport, linked contamination source assessment and diseases resulting from mixed contaminants have independently been found, whereas wildlife health monitoring to combine these issues; air, water and soil contamination to disease susceptivity, to assess the health risk of wildlife species inhabited an interconnected environment.

The three main contributions herein; First, an approach for monitoring contaminants of concern through its pathway in combined water, soil and air exposure rather than the determination of pollution induced health risk through contamination from one specific pathway; Second, attempt to establish that not only contaminants result in direct toxicity effect to induce the risk for diseases and, often microbial, but alter the susceptibility of population to any variety of disease by either mechanism or mechanisms as part from the others; Third offer this in the framework of determining a "health risk index for wildlife populations" for sustaining exposure on its shared cross-compartmental contaminants.

The rest of this paper is structured as follows. Section II summarizes current wildlife health surveillance systems in the literature, relating it to the most recent developments and findings in soil degradative effects, effects of air pollution on microbial communities and trends in long-term agricultural pollution. Section III provides development of the candidate model for contaminant related risk identification. Section IV gives report about health risk findings, relative analysis of surveillance systems and compares with previously suggested surveillance systems. Section V draws the conclusions and suggests validation pathways for future research.

Review of Existing Wildlife Health Surveillance Methods

Research investigating the critical requirement of safeguarding soil health reveals that soil degradation is seen as a separate environmental issue apart from water and air contamination even though degraded soil could act as the medium and conduit of pollutants eventually affecting wildlife depending on that soil, indicating that efforts to monitor wildlife health in relation to water and air pollution neglect this vital exposure pathway (Sahu et al., 2024). Research on the negative implications of air pollution on microbial community composition has demonstrated that pollutants in the air can disrupt the equilibrium of microbial communities in organisms, with some implications for immune functions and disease resistance that go beyond the respiratory effects of air pollution that most surveillance techniques examine (Gupta et al., 2022). Studies on the long-term decline of agricultural nonpoint source pollution due to the aging of rural population indicate that trends in pollution that affect wildlife habitat are determined by long-term demographic and land use changes which are not within the scope of investigation of most wildlife health research projects (Gao et al., 2025).

The more recent sources evidence a recurring theme in the deficits of established wildlife health surveillance methodologies. Work in soil ecology documents how soil contamination serves as both habitats, a sink, and a pathway which would likely be missed by air or water-centric Surveillance, and as such needs to be integrated as a full exposure compartment rather than as a marginalized system. Research in airborne pollution and the microbiomes of air and inhabitants document a wide spectrum of impacts which affect the microbial homeostatic condition and immune processes from the inhalation of pollutants much more broadly than direct toxicity impacting the lungs, an impact that is unlikely to be monitored through standard airborne pollution surveillance approaches. Studies into long-term agriculture pollution document habitat contaminant trends with patterns of impact that develop and operate over timescales (demographic, land use) not captured by short sampling intervals.

In the overall result, a framework for Wildlife health Surveillance needs to accommodate soil as an equal and fully integrated environmental compartment alongside water and air; needs to encompass microbial and immune indicators beyond simple toxicity measures alone, and needs to be shaped to capture long term trends in pollution impacting wildlife habitats over longer timescales relevant to wildlife health and demographic change.

Model Formulation for Contaminant-Linked Risk Detection

Cross-Compartment Exposure Mapping

Firstly, it considers the distribution and translocation of contaminants through different environmental compartments (water, air and soil) in relation to a shared wildlife population in the environment. This relies on the premise that contaminants and the resistance population that interact with the circulate easily between each compartment and that there are strong relationships between the source of pollution for this compartment. A complete exposure pathway perspective where the soil compartment represents a pathway as does air and water, rather than the present surveillance approach that underemphasizes a role for soil damage and including historical as well as present, short term 3-year averages of pollution data to pick up non-linear land-use driven environmental changes.

Microbial and Disease Susceptibility Indicator Layer

In addition to cross-compartment exposure maps, a susceptibility layer is developed to monitor indicators for microbial community disruption and disease risk together with indicators of direct toxicity. This layer was inspired by findings that mixed pollutant exposure leads to greater disease susceptibility than exposure to any individual contaminant alone and that exposure of air or any other pollutants can imbalance microbial ecosystems which can have an impact on immune functions outside the typical direct toxic action process. This can allow the model to identify situations of increased pollution risk not necessarily manifesting currently via chemical induced stress signals.

Population Health Risk Integration

The final element of the model ties the cross-compartment exposure and risk indicators into a population health risk analysis. Here evidence indicating transfer of disease (via AMR and other pollution mediated impacts) between domestic, wild and human animal populations that inhabit the same spatial environment are incorporated into the model which can then forecast population level health impacts, of sustained cross compartment pollution exposure, as an increase in the rate of disease and a decrease in immune resilience in relation to any given parasite load.

Health Risk Findings and Comparative Discussion

Anticipated Health Risk Findings

The anticipated implications of the Eco Health Monitoring Model are based on relevant literature for environmental pollution and wildlife health because the Eco Health Monitoring Framework hasn’t yet been used in a real monitoring program. The Eco Health Monitoring Framework will likely reveal higher health risks in those landscape that contain connected pathways for water, air, and soil pollution. This framework uses intercompartment mapping exposures along with susceptibility indices and therefore should be able to reveal cumulative pollution exposures that may place wildlife populations at greater risk of health impacts than exposure to a single pollutant only. Wildlife populations at increased risk from microbial disturbances, contamination with contaminants and from the risk of future health problems would likely be identified earlier with this framework.

Comparison with Existing Surveillance Approaches

Key Advantages of the Eco Health Monitoring Model The integrated monitoring approach that combines various environmentally related exposure pathways gives a more holistic picture compared to some traditional health assessments that would consider each potential pollutant sources separately. Early detection of negative effects can occur by considering a variety of ecological factors including biomarkers related to disease resistance and microbial exposure in order to predict adverse effects at an earlier stage than toxicity testing. Long term environmental trends help understanding the relationships among land use, agriculture, and human populations with wild life exposure.

Implications and Limitations

The Eco Health Monitoring Model could encourage predictive management of wildlife health through integrated contaminant exposure risk with susceptibility to infectious diseases. A framework which integrated sampling results from microbiologic monitoring with soil, water, or air environmental data could detect signs of health concerns prior to development of recognizable disease manifestations. The Eco Health Monitoring Model is also relevant for One Health approaches in establishing possible links between wildlife health, the domestic animals and humans that live alongside wildlife. Its application requires reliable long-term, multi- Compartment environmental health data, however it is somewhat restricted because of limited capacity for the collection of information in the field, inconsistent data availability regarding microbiologic communities and pollution levels in the area or the absence of previous data collection.

Conclusion

The Eco Health Monitoring Model has come up with a conceptual framework for investigating pollution-related consequences on animal health through a single surveillance system which considers contaminant exposure through water, air and soil, indicators of pathogens and microbial weak points, and health risk evaluation of wildlife. By taking care of limitations highlighted by other studies regarding the issue of treating soil pollution as less significant, ignoring the microbial impacts of pollution, and focusing on the need of understanding the agrarian pollution development process over the course of time, the Eco Health Monitoring Model can represent a more efficient means for risk prediction. Validation of the eco health monitoring concept in real life and its adjustment for different pollutants, people, species, and surroundings will also become an important goal for further studies.

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