TECHNOLOGY-DRIVEN DISEASE SURVEILLANCE IN ANIMAL POPULATIONS: BRIDGING ECOLOGY AND HEALTH

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Abstract
Technological innovations have reshaped the field of animal disease surveillance by enabling faster, more integrated, and ecologically informed monitoring strategies. This review synthesizes recent developments from 2019 to 2025 in AI-based analytics, remote sensing, genomic sequencing, wearable sensors, and environmental DNA technologies. The paper highlights how these tools bridge ecology and health under the One Health framework and discusses methodological pathways, limitations, and future prospects.
Keywords: *Disease surveillance, Technology, One Health, Ecology, AI, Wildlife health, eDNA, Genomics*

Introduction

Animal populations play an essential role in the emergence and spread of infectious diseases. Over 70% of emerging zoonotic diseases originate from animals, making surveillance systems vital for global health protection [1]. Traditional disease surveillance—such as physical inspections, trapping, and clinical reporting—often falls short due to delays, limited coverage, and high manpower demands. These limitations become more serious in the context of climate change, habitat alterations, and increasing interactions between wildlife, livestock, and humans [2].

Modern technological tools provide opportunities for earlier detection and improved ecological interpretation of disease patterns. AI models detect subtle behavioral deviations in livestock [3], remote sensing helps track habitat changes influencing pathogen spread [4], and genomic sequencing enables real-time pathogen evolution tracking [5]. Further, environmental DNA (eDNA) allows pathogen detection without the need to physically handle animals [6].

The One Health approach emphasizes the interconnectedness of humans, animals, and the environment. Technological surveillance supports this vision by integrating environmental, ecological, and health data within unified systems [7]. This review highlights technological advancements, evaluates methods used in recent studies, and provides synthesized conclusions while acknowledging existing limitations and future needs [8,9,10].

Materials and Methods

A structured literature search was carried out across Scopus, PubMed, Google Scholar, and Web of Science covering publications from 2019–2025. Search terms included: “technology-driven surveillance,” “One Health monitoring,” “AI in animal health,” “remote sensing ecology,” “eDNA pathogen detection,” and “genomic surveillance wildlife.” Studies were included based on technological relevance, scientific rigor, ecological integration, and contribution to surveillance innovation. Reports from global agencies (FAO, OIE, WHO) were also included when they provided methodological insights [3,4].

We followed established review frameworks like those used in digital epidemiology and integrated One Health assessments [7,8]. A total of 74 papers were screened, and 10 were prioritized based on relevance, impact, and methodological depth. These studies represented diverse ecosystems, species, and pathogens, ensuring a comprehensive synthesis of recent technological progress.

Results

Findings from synthesized literature indicate that modern technologies have significantly improved surveillance sensitivity, scale, and ecological integration. AI systems enable early detection of behavioral changes linked to disease, while remote sensing provides continuous data on ecological factors such as temperature shifts, vegetation density, and water availability. Wearable sensors and biologging devices monitor real-time physiological parameters, improving on-farm health management.

Genomic tools enhance understanding of pathogen transmission networks, and eDNA offers non-invasive monitoring options. Collectively, these innovations represent a shift from reactive to proactive surveillance systems. These results reflect the analytical conclusions derived from the entire reviewed literature.

Discussion

Technology-driven surveillance systems offer strong advantages including improved accuracy, real-time monitoring, and integration of ecological datasets. By combining animal health information with environmental indicators, these systems achieve better risk forecasting. The use of drones, satellite imagery, and AI-based behavior analysis contributes to early warning capabilities in both wildlife and livestock systems.

Despite the benefits, challenges such as uneven access to technology, high cost of devices, lack of technical expertise, and data standardization barriers persist. Ethical considerations regarding wildlife disturbance, data privacy, and responsible AI use must also be addressed. Future surveillance programs will need strong cross-sector collaboration to maximize the potential of technological tools.

Although modern technologies provide major advancements in disease surveillance, several limitations affect their widespread adoption. High initial investment costs restrict access in low- and middle-income countries. Many regions lack the technological infrastructure—such as stable internet connectivity, cloud storage capacity, and trained personnel—required for effective implementation.

Another key limitation is the lack of data standardization. Different technologies generate varied types of data that are often incompatible across systems. Poor calibration standards, limited cross-platform interoperability, and absence of unified frameworks hinder collaborative surveillance.

Ethical and environmental concerns also exist. Continuous monitoring of wildlife may cause behavioral stress if not managed carefully. Privacy issues emerge when AI systems are used in agricultural or protected areas. Additionally, genomic and eDNA methods require careful interpretation to avoid false positives or environmental contamination. These challenges highlight the need for caution, transparency, and responsible scientific practices.

The future of animal disease surveillance is likely to witness deeper integration of AI, machine learning, and automated detection systems. As algorithms continue to improve, predictive models will be able to forecast outbreaks with greater accuracy by predicting animal movements, environmental changes, and pathogen behavior.

The expansion of low-cost wearable sensors, improved battery efficiency, and satellite-based remote sensing will make surveillance more accessible even in remote regions. Portable genomic sequencers may become standard field tools for quick pathogen identification. Moreover, cloud-based dashboards will facilitate rapid sharing of surveillance data between veterinarians, wildlife biologists, ecologists, and public health agencies.

Strengthening interdisciplinary collaboration remains essential. Bringing together ecologists, data scientists, veterinarians, public health professionals, and policymakers will help create more harmonized, scalable, and resilient surveillance systems. The rise of One Health global networks will further promote knowledge exchange and coordinated responses to emerging threats.

Conclusion

Technology-driven disease surveillance in animal populations represents a major step forward for global health. Innovations in AI, remote sensing, genomics, and eDNA have transformed how diseases are detected and understood. Although limitations remain, future developments promise greater accessibility, stronger integration, and more proactive monitoring systems. Continued investment and cross-sector collaboration will shape the next generation of One Health surveillance frameworks.

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