BRIDGING WILDLIFE HEALTH AND ANIMAL GENETIC RESOURCES: A ONE HEALTH APPROACH TO SUSTAINABLE CONSERVATION

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Abstract

Zoonotic diseases are emerging as a major public health challenge in India, driven by complex interactions among humans, animals, and the environment. Analysis of Integrated Disease Surveillance Programme data (2018–2023) revealed that 8.3% of reported outbreaks were zoonotic, with a significant increasing trend, seasonal clustering, and high case fatality rates in diseases such as rabies and Crimean-Congo Haemorrhagic Fever. These patterns highlight the influence of ecological and anthropogenic factors, including climate change, habitat disruption, and intensified human–animal contact, in shaping disease dynamics. This article emphasises the importance of integrating wildlife conservation and Animal Genetic Resources (AnGR) within the One Health framework to enhance ecosystem resilience, reduce disease transmission, and support sustainable livelihoods. Wildlife plays a crucial role as both reservoirs and regulators of pathogens, while conservation of genetically diverse and resilient livestock populations improves disease resistance and adaptive capacity. The One Health approach, through interdisciplinary collaboration, strengthens surveillance, early warning systems, and outbreak response. Advances in genomics and bioinformatics have further transformed disease surveillance, antimicrobial resistance (AMR) tracking, and biodiversity conservation by enabling precise analysis of pathogen evolution, genetic diversity, and adaptive traits. Additionally, open data platforms and global collaborations have improved real-time data sharing and pandemic preparedness. India's national initiatives, policy interventions, and successful models, such as state-level AMR control programs, demonstrate the effectiveness of coordinated, multi-sectoral strategies. Overall, this article highlights that a transdisciplinary One Health approach integrating genomics, conservation, and public health is essential for predicting and mitigating zoonotic risks, preserving biodiversity, and ensuring long-term ecosystem and human health sustainability.

Introduction

Zoonotic diseases are an increasing public health concern in India, reflecting the complex interactions between humans, animals, and the environment. Analysis of the Integrated Disease Surveillance Programme (IDSP) data from 2018 to 2023 revealed that 583 out of 6948 outbreaks (8.3%) were zoonotic in origin, with a rising trend over time and a notable 58.8% increase in 2023 compared to 2022. These outbreaks showed clear seasonal and regional patterns, with a median of 7 outbreaks per month and consistent peaks during the monsoon months June-August. The overall case fatality ratio (6.9%), with higher mortality in diseases like rabies (88%) and CCHF (>30%), underscores the severity of these infections. The increasing trend of outbreaks in the post-COVID period and the emergence of diseases such as Zika, West Nile fever, and monkeypox further indicate evolving epidemiological patterns.

These findings highlight the critical role of ecological and anthropogenic drivers, including deforestation, climate variability, and intensified human-animal interactions, in shaping zoonotic disease dynamics. In this context, wildlife conservation is crucial for maintaining ecological balance and regulating pathogen transmission by preserving natural reservoirs and biodiversity. Simultaneously, conservation of Animal Genetic Resources (AnGR), particularly resilient indigenous livestock breeds, enhances disease resistance and reduces vulnerability to outbreaks.

Therefore, adopting a One Health approach, integrating human, animal, and environmental health systems, is crucial for strengthening surveillance, improving outbreak response, and ensuring sustainable management of zoonotic diseases while safeguarding biodiversity and livestock genetic resources, data published under the Integrated Disease Surveillance Programme (IDSP), Ministry of Health and Family Welfare, Government of India, indicate these trends.

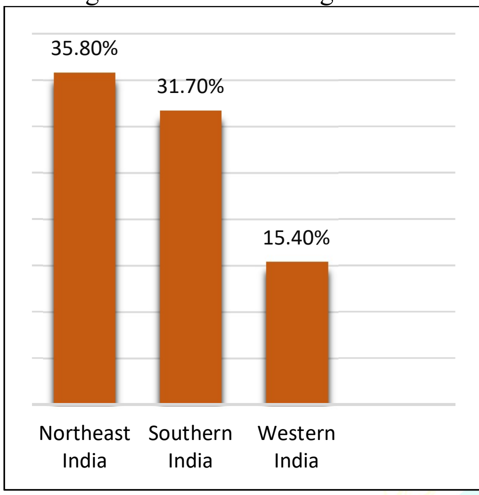

Fig 1. Regional Zoonotic Trends

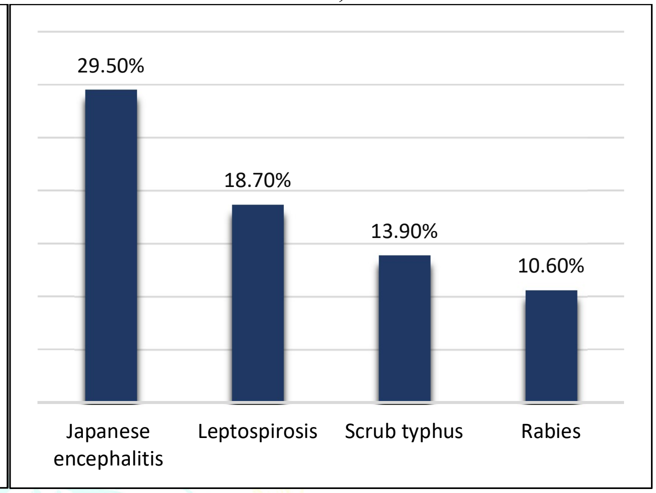

Fig 2. Disease-wise Zoonoses Distribution (IDSP)

"One Health: A Unified Approach to Zoonotic Disease Prevention"

According to Kuhn C *et al.,* (2024), the emergence and transmission of zoonotic diseases pose a significant global challenge, with wildlife acting as major reservoirs of pathogens and contributing to nearly 72% of emerging infectious disease events. Recognising this, the One Health High-Level Expert Panel has emphasised the urgent need for a holistic and interdisciplinary approach to disease prevention. The One Health approach integrates human, animal, and environmental health, promoting collaboration across disciplines and sectors, including governmental agencies, researchers, and local communities. This integrated framework enhances disease prediction, prevention, and preparedness while reducing disease burden and associated economic impacts. Environmental changes such as biodiversity loss, land-use transformation, and climate variability further increase the risk of pathogen spillover from wildlife to humans. The recent COVID-19 pandemic has highlighted the critical role of human-wildlife interactions and the need for sustainable ecosystem management. Therefore, incorporating wildlife and environmental components into surveillance systems, along with strengthening interdisciplinary and transdisciplinary collaboration, is essential for effective zoonotic disease control and for building resilient and sustainable health systems under the One Health framework.

Wildlife plays a vital role in supporting ecosystem services that directly influence human health and livelihoods, particularly among Indigenous Peoples and Local Communities (IPLCs). The One Health approach provides a comprehensive framework that goes beyond disease prevention by integrating human, animal, and environmental health to promote biodiversity conservation and sustainable development. Interactions between wildlife, domestic animals, and humans create pathways for the emergence and transmission of zoonotic diseases, highlighting the need for an integrated, multisectoral strategy to mitigate risks. Incorporating One Health principles into wildlife management can enhance food security, reduce poverty, and prevent disease outbreaks while ensuring the conservation of wildlife and their habitats. Furthermore, sustainable wildlife management supported by policy frameworks, community engagement, risk assessment, and research innovation can contribute to ecosystem balance and resilience. Monitoring wildlife-related supply chains and economic values also aids in informed decision-making. Ultimately, a community-based One Health approach that respects local cultures and traditions is essential for achieving sustainable wildlife conservation and improving overall human well-being, according to Sangkachai N *et al.,* (2025)

“Transdisciplinary One Health Integration for Zoonotic Disease Control”

Sleeman *et al.,* (2017) suggested that emerging infectious diseases exhibit non-random global patterns, necessitating improved capacity for prediction, detection, and response to prevent widespread transmission. Advances in molecular biology, laboratory diagnostics, and computational tools have significantly enhanced pathogen detection and risk characterisation, while spatial databases enable targeted, time and location-specific surveillance. However, existing surveillance systems often remain sector-specific and fragmented, limiting the early identification of threats across wildlife, domestic animals, and humans. For instance, delays in recognising the shared aetiology of human encephalitis cases and bird mortality during the West Nile virus outbreak (1999, New York) highlight gaps in cross-sectoral communication. Similarly, insufficient wildlife surveillance has led to severe consequences, such as the Peste des Petits Ruminants outbreak in saiga antelope, which caused substantial population loss. Integrating wildlife surveillance into broader health systems can provide critical early warning signals and enable rapid response to zoonotic threats. Furthermore, epidemiological interventions, including spatial separation of species, risk communication, and behaviour modification, are essential for mitigating disease transmission. The application of One Health strategies, such as oral vaccination programs for rabies and sylvatic plague, demonstrates the effectiveness of coordinated approaches in protecting both animal and human populations.

“Genomic Approaches in Wildlife Conservation within the One Health Framework”

Animal Genetic Resources (AnGR) encompass the genetic diversity within and between domesticated livestock species, which is essential for adaptation to changing environments, disease resistance, and sustainable food production. AnGR are closely linked with wildlife conservation, as both contribute to maintaining overall biodiversity and ecosystem stability. Loss of genetic diversity in livestock due to intensive breeding, habitat changes, and climate stress parallels the decline seen in wild species, increasing vulnerability to diseases and environmental shifts. Integrating AnGR conservation with wildlife management under the One Health approach promotes the preservation of genetic diversity across species, reduces disease transmission risks at the wildlife-livestock interface, and enhances ecosystem resilience. Therefore, conserving AnGR alongside wildlife is crucial for sustaining biodiversity, securing livelihoods, and supporting long-term ecological and agricultural sustainability.

Anthropogenic pressures, including habitat degradation and climate change, have accelerated global biodiversity loss, with species extinction rates now estimated to be up to 1000 times higher than natural levels and projected to increase further. Currently, thousands of species are threatened, including over 15,000 animal species globally, with significant endemism and vulnerability reported in India. Simultaneously, the erosion of animal genetic resources (AnGR) is evident, with numerous livestock breeds already extinct and many more at risk, thereby reducing resilience to environmental stressors and infectious diseases. While conservation efforts through policy frameworks and protected areas have contributed to biodiversity preservation, emerging genomic technologies provide powerful tools for assessing genetic diversity, population structure, and adaptive potential, thereby supporting targeted conservation strategies for both wildlife and livestock. In the context of wildlife conservation, maintaining genetic diversity is essential for ecosystem stability and for limiting pathogen amplification within wildlife reservoirs. This aligns with the One Health approach, which recognises the interconnectedness of human, animal, and environmental health. Integrating conservation genomics with wildlife health monitoring and disease surveillance can enhance early detection of zoonotic threats, improve species resilience, and reduce spillover risks at the human-animal interface. Therefore, a coordinated One Health framework that incorporates genomic tools, wildlife conservation, and AnGR management is critical for safeguarding biodiversity, strengthening ecosystem health, and ensuring long-term public health and agricultural sustainability, as suggested by Ghildiyal *et al.,* (2023).

“Applications of Genomics and Bioinformatics in One Health: From Disease Surveillance to Biodiversity Conservation”

The integration of genomics and bioinformatics into the One Health approach has demonstrated substantial impact across disease surveillance, outbreak response, antimicrobial resistance (AMR) management, and biodiversity conservation. Continuous genomic surveillance of influenza viruses across human, animal, and environmental interfaces has enabled the identification of novel strains, detection of mutations and viral reassortments affecting transmissibility and virulence, and prediction of potential pandemics, thereby guiding vaccine development and preparedness strategies. Similarly, during the Ebola outbreak in West Africa, genomic sequencing provided critical insights into transmission dynamics, viral evolution, and spatial spread, allowing differentiation of transmission chains, informing diagnostics and therapeutics, and enabling targeted interventions such as contact tracing and quarantine. In parallel, genomic studies in livestock have elucidated the spread of AMR genes through mobile genetic elements like plasmids across animals, humans, and the environment, highlighting zoonotic risks and informing policies to reduce antibiotic misuse, improve biosecurity, and promote sustainable agricultural practices. Furthermore, genomics and bioinformatics have significantly advanced conservation efforts by enabling the assessment of genetic diversity, detection of inbreeding and population bottlenecks, and identification of adaptive traits linked to disease resistance and survival. These insights support evidence-based strategies, including selective breeding, habitat restoration, reintroduction programs, and maintenance of genetic connectivity through wildlife corridors. Overall, the application of genomics within the One Health framework enhances early warning systems, strengthens integrated surveillance, supports informed decision-making, and promotes sustainable management of both health systems and ecosystems in the face of emerging diseases, climate change, and biodiversity loss, as reviewed by Scarpa F *et al.,* (2024)

Open Data Platforms and Genomic Surveillance in One Health

Khare S *et al.* (2021) found that the COVID-19 pandemic highlighted the critical importance of global collaboration and open data sharing within the One Health framework, particularly in addressing zoonotic disease threats at the human-animal-environment interface. The genomics community demonstrated an unprecedented model of international cooperation through real-time sharing of SARS-CoV-2 genomic data via platforms such as GISAID and Virological. These platforms enabled rapid upload, access, and analysis of viral sequences, facilitating early detection of variants of concern such as Alpha, Delta, and Omicron, and informing vaccine development, diagnostics, and public health interventions. GISAID played a central role by providing a transparent yet credit-based data-sharing system that incentivised global participation while supporting genomic analysis and tracking viral evolution and transmission pathways. In parallel, Virological enabled rapid, real-time dissemination of preliminary findings, fostering collaborative problem-solving and accelerating the identification and characterisation of emerging variants without delays associated with traditional publication processes. This open-access, interactive approach allowed scientists, public health agencies, and institutions worldwide to share sequencing protocols, epidemiological insights, and outbreak investigation strategies. Beyond COVID-19, these platforms continue to support surveillance of emerging infectious diseases such as avian influenza and Mpox, reinforcing their long-term value. Overall, the success of these initiatives underscores the necessity of integrated genomic surveillance systems, transparent data sharing, and transdisciplinary collaboration to enhance global preparedness, inform evidence-based policies, and strengthen responses to future pandemics within the One Health paradigm.

"Integrating Genomics, Environment, and Evolution in Wildlife Research"

Genotype environment association (GEA) methods have produced important insights in wildlife landscape genomics and will likely remain key analytical tools; however, landscape genomics should not be reduced to GEA alone, as it is a broader scientific field rather than just a set of methods. While traditional population genetic theories still provide a foundation, theoretical and conceptual development, especially for both neutral (landscape genetics) and adaptive processes, has lagged behind rapid methodological advances. Current models often fail to incorporate realistic spatiotemporal environmental heterogeneity and complex processes such as polygenic selection, balancing selection, genomic architecture, and epigenetics, leading to mismatches between predicted and observed genomic patterns. Therefore, integrating empirical genomic data with theoretical predictions and simulations is essential to identify gaps in understanding adaptive processes in changing environments. Advancing theory will improve predictions of evolutionary trajectories and better inform conservation strategies and policy decisions, particularly in the context of varying life histories and ecological niches. Future landscape genomics should move beyond detecting statistical associations toward a stronger theoretical framework supported by holistic approaches combining experiments, simulations, and empirical analyses. Integrating genome-wide association studies (GWAS) across environmental gradients can link genomic variation to phenotypic traits and fitness, enhancing ecological relevance. Additionally, expanding from single-species studies to community-level approaches, including community landscape genomics, is necessary to account for interspecific interactions shaping genomic patterns. Emerging tools such as environmental DNA (eDNA) hold promise for enabling such studies despite current limitations. Overall, these advancements will help not only in predicting genetic variation under environmental change but also in understanding its functional significance for fitness, population dynamics, and long-term species persistence, as suggested by Forester BR *et al.,* (2018).

"Integrating AMR into Wildlife Conservation and Zoonotic Disease Management"

Antimicrobial resistance (AMR) represents a critical interface between wildlife conservation and zoonotic disease dynamics within the One Health framework. The emergence and dissemination of AMR are driven by the selective pressure exerted by antimicrobial use in humans, livestock, and agriculture, leading to the proliferation of resistant microorganisms and resistance genes in the environment. Wildlife species act as important reservoirs and sentinels of AMR, acquiring resistant bacteria through exposure to contaminated habitats such as water bodies, soil, and anthropogenic waste. These resistant pathogens can be transmitted across species barriers, increasing the risk of zoonotic spillover to humans and domestic animals. Conversely, wildlife may also contribute to the environmental dissemination of resistance genes through migration and ecological interactions, facilitating the spread of AMR across geographic regions. This bidirectional transmission underscores the ecological connectivity between human activities, ecosystem health, and pathogen evolution. From a conservation perspective, AMR poses a threat to wildlife health by reducing the efficacy of therapeutic interventions and potentially altering host–pathogen dynamics, thereby impacting population viability. Moreover, the presence of AMR in wildlife-associated zoonotic pathogens complicates disease control strategies and heightens public health risks. Addressing AMR in the context of wildlife conservation requires integrated surveillance systems, reduced and judicious antimicrobial use, and a deeper understanding of environmental reservoirs and transmission pathways. Ultimately, incorporating AMR into conservation and zoonotic disease research is essential for predicting disease emergence, safeguarding biodiversity, and ensuring sustainable ecosystem health.

National Efforts Against Antimicrobial Resistance in India: Achievements, Challenges, and the Road to NAP-AMR 2.0

The Government of India has undertaken extensive measures to combat Antimicrobial Resistance (AMR) through policy development, surveillance strengthening, capacity building, and international collaborations. Beginning with the constitution of a National Task Force on AMR Containment in 2010 and the launch of the National Policy on AMR Containment in 2011, India established the National Programme on AMR Containment in 2013, followed by the National Action Plan on AMR (NAP-AMR) in 2017, aligned with the Global Action Plan. National AMR surveillance networks have been expanded across the country, generating annual surveillance reports and contributing data to the Global AMR Surveillance System (GLASS). Public awareness materials on antimicrobial stewardship and infection prevention have been widely disseminated, while national guidelines on infection prevention have been translated into training modules and cascaded across all States and Union Territories.

In 2022, multi-sectoral expert

consultations, including representatives from human health, animal husbandry, environment, research, private sector, NGOs, and international bodies, were conducted to design NAP-AMR 2.0 through SWOT analyses and recommendations for future research and policy priorities. The Integrated Disease Surveillance Program (IDSP), operational in all States and UTs, plays a central role in monitoring epidemic- prone diseases and has transitioned from paper-based to real-time digital reporting through the Integrated Health Information Platform (IHIP). IDSP also employs media scanning, verification tools, and Artificial Intelligence to support early outbreak detection.

The National Centre for Disease Control (NCDC) continues to strengthen AMR surveillance networks, build laboratory capacity, and train healthcare workers in infection prevention and control. International collaborations such as with the U.S. CDC, USAID, the Netherlands, the UK Fleming Fund, and Denmark have supported AMR surveillance, standardization of testing procedures, development of SOPs, integrated One Health surveillance models, and national training initiatives. Together, these efforts underscore India's commitment to a coordinated, multi-sectoral response to AMR through improved surveillance, stewardship, research, and global partnership.

Policy Measures & Regulatory Action

In July 2025, the Government of India implemented major policy and regulatory measures to strengthen antimicrobial stewardship in the livestock sector by banning 37 antimicrobial drugs, including 18 antibiotics, 18 antivirals, and one anti-protozoan, specifically restricting their use in milch animals, egg-laying birds, meat animals, and other food-producing species. Alongside this, the Central Drugs Standard Control Organisation (CDSCO) is developing a structured Antimicrobial Use (AMU) reporting framework to formalise the tracking of antibiotic production, sale, import, and usage in animals. As noted in a Parliamentary reply in April 2025, the Department of Animal Husbandry & Dairying (DAHD) has issued Standard Veterinary Treatment Guidelines (SVTGs) for livestock and poultry to promote rational and responsible drug use. Additionally, DAHD is actively encouraging vaccination through its Livestock Health & Disease Control Programme for diseases such as Foot and Mouth Disease (FMD), Peste des Petits Ruminants (PPR), and brucellosis, thereby reducing unnecessary dependence on antibiotics in animal agriculture.

Conclusion

In conclusion, the rising burden of zoonotic diseases in India, as evidenced by Integrated Disease Surveillance Programme data, highlights the growing impact of ecological disruption, climate variability, and intensified human–animal interactions on disease emergence and transmission. The increasing frequency, seasonal clustering, and high case fatality rates of key zoonoses underscore the urgent need for integrated and proactive strategies. Bridging wildlife health with the conservation of Animal Genetic Resources (AnGR) provides a critical pathway for enhancing ecosystem resilience, maintaining biodiversity, and strengthening disease resistance at the wildlife–livestock–human interface. The One Health approach emerges as a central framework to address these interconnected challenges by integrating surveillance systems, fostering transdisciplinary collaboration, and incorporating wildlife, environmental, and genomic data into decision-making processes. Advances in genomics, bioinformatics, and open data platforms have further strengthened early detection, risk assessment, and targeted interventions, while also supporting conservation efforts through improved understanding of genetic diversity and adaptive potential. At the same time, the growing threat of antimicrobial resistance (AMR) adds another layer of complexity, necessitating coordinated action across sectors to limit its spread and safeguard both public and animal health. National initiatives, policy interventions, and successful models such as state-level AMR control programs demonstrate that integrated, evidence-based, and community-driven approaches can yield measurable outcomes. However, sustained progress will depend on strengthening surveillance, promoting responsible antimicrobial use, conserving genetic resources, and enhancing ecosystem-based management strategies. Ultimately, a unified One Health approach that bridges wildlife conservation, genomics, and public health is essential for predicting and mitigating zoonotic risks, ensuring sustainable conservation, and securing long-term health and resilience of both ecosystems and human populations.

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