REVIEW ARTICLE

Strengthening Laboratory Systems for Emerging and Re emerging Zoonotic Diseases: A One Health Approach

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Abstract
Emerging and re-emerging zoonotic diseases (ERZDs) continue to threaten public health, economic stability, and national security worldwide. A resilient and coordinated laboratory system is central to their surveillance, detection, and control. The *One Health* approach recognizes the interconnectedness of human, animal, and environmental health and provides a transdisciplinary framework to strengthen laboratory networks across sectors. In India, institutions such as the Integrated Disease Surveillance Programme (IDSP), the Virus Research and Diagnostic Laboratory (VRDL) network, and the National Centre for Disease Control (NCDC) anchor zoonotic disease surveillance. However, gaps persist in laboratory capacity, biosafety, intersectoral coordination, and genomic integration. This review explores global and national experiences in strengthening laboratory systems for ERZDs using a One Health paradigm, with emphasis on integration, capacity building, quality assurance, and policy frameworks necessary for sustainable response systems.

Keywords
Zoonoses; One Health; Public Health Surveillance; Laboratory Systems; Biosafety; Disease Outbreaks; Health Policy; Epidemiology; India; Communicable Disease Control

Introduction
Zoonoses—diseases transmitted between animals and humans—constitute more than 60% of all emerging infectious diseases[1]. The recent global outbreaks of COVID-19, Nipah virus, avian influenza, and monkeypox underline the significance of strengthening laboratory systems to detect and contain such threats promptly. In India, where vast human–animal interfaces exist due to agrarian livelihoods and biodiversity richness, the risk of zoonotic spillover is disproportionately high[2].
Despite significant strides through networks such as the IDSP (established in 2004) and the

VRDLs under the Indian Council of Medical Research (ICMR), fragmentation across human, animal, and environmental health sectors limits timely information sharing and coordinated response[3]. Implementing a *One Health-based laboratory network* offers a sustainable strategy to bridge these gaps and bolster preparedness for ERZDs.

Global Context of Laboratory Systems and One Health

Globally, initiatives like the WHO's Global Laboratory Directory, the World Organisation for Animal Health (WOAH) Reference Laboratories, and the FAO's Emergency Prevention System (EMPRES) emphasize integrated surveillance for zoonotic diseases[4]. The *PREDICT* project, implemented across Asia and Africa, demonstrated that early viral detection at the animal–human interface could prevent epidemics[5]. However, sustaining such networks requires harmonized biosafety standards, data sharing, and joint simulation exercises between medical and veterinary laboratories[6].

The *One Health* approach, formalized by the WHO, FAO, and WOAH tripartite collaboration, underscores cross-disciplinary laboratory coordination as a pillar of zoonotic preparedness[7]. This model advocates shared sample transport systems, interoperable information databases, and mutual training programs[8].

Status of Zoonotic Laboratory Systems in India

1. Institutional Architecture

India's laboratory surveillance landscape spans multiple ministries:

- **ICMR–VRDL Network**: Established in 2013, consisting of over 100 laboratories providing virological diagnostic capacity for infectious agents of public health importance, including leptospirosis, rabies, Nipah, and influenza[9].
- **IDSP Laboratories** under the NCDC coordinate monthly outbreak monitoring, integrating data from state and district surveillance units[10].
- **Department of Animal Husbandry and Dairying (DAHD)** maintains a parallel *National Animal Disease Referral Expert System* (NADRES) for livestock monitoring[11].
- **Indian Council of Agricultural Research (ICAR)** operates specialized zoonotic reference centers such as the National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI) and the High Security Animal Disease Laboratory (HSADL)[12].

Despite these systems, the absence of a unified *One Health laboratory policy* leads to vertical silos. Integration efforts have accelerated following national *One Health* consultative workshops and the upcoming *National Institute of One Health (NIOH)* at Nagpur[13].

2. Surveillance Integration

The *Integrated Health Information Platform* (IHIP), launched under IDSP in 2021, aimed to digitize disease data capture down to the primary health level[10]. Yet, interoperability between human and animal databases remains limited. Linking NIVEDI's NADRES and IDSP-IHIP platforms can enable real-time cross-sectoral alerts on zoonotic trends[14].

3. Capacity and Quality Systems

ICMR-VRDLs serve as regional hubs mentoring district labs, ensuring biosafety level-2 (BSL-2) or higher compliance, implementing quality assurance and external proficiency testing[15]. However, animal health laboratories often lack ISO 15189 accreditation and standardized molecular diagnostic protocols. National Quality Assurance Programs (NQAP) need to encompass veterinary and environmental sectors under one standard[16].

Laboratory Components in One Health

1. Surveillance and Early Detection

Zoonotic surveillance must blend **syndromic**, **risk-based**, and **event-based** approaches. Sentinel sites at animal farms, slaughterhouses, and environmental interfaces are crucial for pre-human detection[17]. Joint sampling strategies reduce duplication of effort and cost. For instance, collaborative avian influenza surveillance between ICAR and ICMR in Assam successfully detected multiple influenza A subtypes before human spillover[18].

2. Biosafety and Biosecurity

Laboratory biosafety is essential to prevent laboratory-acquired infections and cross-contamination. Following the COVID-19 experience, India reassessed its containment infrastructure and adopted the *National Biosafety Guidelines, 2023*, harmonizing with WHO norms[19]. However, veterinary laboratories often lag in containment capacity. Establishing regional "One Health Containment Hubs" with shared BSL-3 facilities could optimize resource utilization[20].

3. Data Management and Genomic Integration

Advances in *whole-genome sequencing (WGS)* have transformed outbreak investigations. The *INSACOG* network led by ICMR-NIV has generated crucial insights on SARS-CoV-2 evolution[21]. Expanding such capability to animal pathogens—such as brucellae or lyssaviruses—would offer a fuller picture of zoonotic evolution. Creating a joint *One Health Genomic Repository* supervised by NCDC, ICAR, and the Ministry of Environment could facilitate cross-domain genomic surveillance[22].

Challenges in Laboratory System Strengthening

1. Fragmented Governance

Multiplicity of agencies (MoHFW, MoAHD, ICMR, ICAR, FSSAI, MoEFCC) results in overlapping mandates and data silos[23]. A legislative framework clearly defining *One Health governance*—similar to Indonesia's Zoonosis Control Act—remains absent[24].

2. Human Resource Constraints

Shortage of trained microbiologists, epidemiologists, and biosafety officers limits sub-national laboratory capacity. Periodic refresher trainings under IDSP and FAO-supported Laboratory Twinning Programs are essential[25]. The establishment of *One Health Fellowship Programs* integrating medical, veterinary, and life sciences training could fill this gap[26].

3. Funding and Sustainability

Donor-driven vertical projects (e.g., JEE, GHSA) often taper post-project completion. Institutionalizing budget lines within *National Health Mission (NHM)* and *Livestock Health Mission* for laboratory strengthening ensures continuity[27]. Public-private partnerships may expand diagnostic reach, as demonstrated by TB and COVID-19 laboratories[28].

4. Quality Assurance and Accreditation

Only a fraction of state public health labs are NABL-accredited. Expanding national External Quality Assessment Schemes (EQAS) to cover zoonoses, involving both public and private labs, is critical[29]. Interlaboratory comparison exercises promote reliability and benchmarking[30].

Framework for a One Health Laboratory Network in India

1. Strategic Integration

India's upcoming *National One Health Mission* envisions a *National One Health Laboratory Network (NOHLN)* uniting ICMR, ICAR, NCDC, and VRDLs[31]. Its proposed design features:

- **Three-tier structure**: National reference labs → regional laboratories → district integrated centers
- **Cross-sectoral data dashboard**: Interfacing NADRES, IHIP, and INSACOG portals
- **Joint outbreak investigation teams** with standard operating procedures for sample custody and reporting

2. Leveraging Digital Health

Digital laboratory information management systems (LIMS) enable real-time reporting, barcode-based sample tracking, and analytics dashboards[32]. Cloud-based DHIS2-compliant tools, developed under IHIP, could be expanded to animal and environmental labs[33].

3. Community and Field Linkages

Field veterinarians, Accredited Social Health Activists (ASHAs), and sanitary inspectors must be included as *first-mile biosurveillance actors*. Empowering them with mobile-based reporting tools can reduce diagnostic delay[34]. Field sample transport systems need uniform *tripartite chain-of-custody protocols* consistent with WHO GOARN standards[35].

4. Policy and Legal Support

A draft *National Framework for One Health Governance* (2024) aims to consolidate

laboratory responsibilities across ministries[36]. Embedding the One Health concept within the *National Health Policy 2025* could institutionalize commitments[37].

Learning from Case Studies

1. Kerala's Nipah Response

During the 2018 and 2021 Nipah outbreaks in Kerala, synchronized laboratory networks, comprising ICMR-NIV Pune, state medical colleges, and animal health departments, facilitated rapid diagnosis and containment[38]. This model exemplified multisectoral collaboration under emergency conditions.

2. Avian Influenza Surveillance

Joint sampling between ICAR-NIVEDI, DAHD, and MoEFCC for avian influenza surveillance improved early warning for poultry outbreaks[39]. Such programs underscore value in cross-sampling protocols and risk communication.

3. COVID-19 Experience

The pandemic catalyzed public–private expansion of molecular diagnostics. Over 3,000 RT-PCR laboratories were established under ICMR's guidance by 2021[40]. Lessons in supply chain logistics, biosafety compliance, and digital dashboards are directly transferable to ERZD preparedness.

Future Directions

1. Establishing a Unified Quality Framework

Creating a *National Laboratory Accreditation Board for One Health (NLAB-OH)* could harmonize criteria across human, animal, and environmental laboratories[41]. International collaboration with ISO, WOAH, and WHO reference labs can guide standardization.

2. Strengthening Research-Surveillance Synergy

Linking academic research with state surveillance through data-sharing agreements encourages innovation in pathogen discovery. VRDLs, for example, may partner with veterinary universities for joint pathogen genomics projects[42].

3. Enabling Genomic Epidemiology

Expanding INSACOG's scope to include animal and environmental pathogens establishes a continuum of surveillance. Environmental sewage-based biosurveillance piloted in Gujarat already demonstrates feasibility[43].

4. Building Sustainable Workforce Capacity

Incorporating One Health laboratory sciences into medical and veterinary curricula and offering advanced diploma programs via ICMR and ICAR institutes can ensure sustainability[44].

5. Regional and Global Collaboration

Participation in the *Global Health Security Agenda (GHSA)* and WOAH reference laboratory networks enhances India's geopolitical leadership in biosurveillance[45]. Cross-border surveillance with SAARC countries is especially critical to tackle transboundary zoonoses.

Conclusion

A robust, interoperable, and quality-assured laboratory network forms the backbone of *One Health* implementation and zoonotic disease preparedness. India's progress through VRDLs, IDSP, and upcoming One Health institutional frameworks reflects significant commitment; however, coordinated governance, integrated data systems, and sustainable financing remain pivotal. Strengthening the linkage of human, animal, and environmental laboratories across all levels will not only enhance national health security but also contribute to global pandemic prevention efforts.

Authors Contribution

All authors have contributed equally.

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