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Diagnostic and management challenges of animal diseases in global context

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ABSTRACT

Animal diseases impose a significant burden on global health, food security, and economies. More than 25% of livestock are lost to disease annually worldwide. This review provides an overview of the challenges in rapidly diagnosing and effectively managing animal diseases. Key obstacles to rapid diagnosis include shortages of trained veterinary personnel, inadequate infrastructure (limited laboratory networks and equipment), poor access to advanced technologies, biosecurity lapses, high costs, and regulatory hurdles that impede deployment of new diagnostics. Available point-of-care diagnostic tools for major diseases such as foot-and-mouth disease, brucellosis, canine parvovirus, and avian influenza and their limitations in field use (e.g. sensitivity, specificity, and usability constraints) were discussed. Disease management bottlenecks, from vaccine logistics and treatment access in resource-limited areas to weaknesses in surveillance, reporting, and outbreak containment, are discussed. A comparative analysis highlights how India's vast animal population and veterinary infrastructure challenges resemble those in many developing countries. Adopting a One Health perspective require animal disease control ties into zoonotic spillover prevention, intersectoral coordination and strengthened global surveillance. Emerging digital tools and artificial intelligence play important role for early disease detection and forecasting. For effective disease diagnosis and control, policy, economic, and educational reforms including greater investment in veterinary services, workforce development, and research are needed to build resilient veterinary systems.

1. Introduction

Approximately 600 million people around the world are dependent upon livestock and poultry for livelihood (Grace et al., 2012; Randolph et al., 2007) particularly the global poor population (those living on $2 per day or less) that earn at least part of their livelihood from them (Perry et al., 2002). However, this dependence is associated with high burden of zoonotic infections affecting the health and livelihoods of rural communities which are in close contact with animals and are vulnerable to animal diseases (WHO, Dfid, FAO, & OIE, 2006). In India, where over 65% of the

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population is rural and directly or indirectly dependent on agriculture and animal husbandry, the risk of zoonotic spillovers is particularly high (Bedi et al., 2022).

Animal health and productivity are challenged constantly by diseases, particularly infectious diseases, infertility and reproductive disorders, metabolic disorders, and nutrient imbalances. Nearly 25% of the world's livestock is lost to animal disease (Hobbs et al., 2021). Infectious diseases are top-ranking of all the animal diseases. Animal diseases pose threat to global health as zoonoses, food security, and economic growth. Rapid urbanization, biodiversity loss, intensified livestock production, and increasing human-animal-environment interactions increased the risk of emergence of novel zoonotic pathogens (Sakshi et al., 2023). Despite the use of intervention measures, diseases and disorders cause animal deaths, disabilities, threaten global food security and economic losses to the animal food industry worldwide. Increased incidence of infectious diseases, emergence of newer and drug-resistant pathogens, and altered dynamics of the existing pathogens in different geo-climatic zone give rise to emerging and re-emerging diseases. The phenomenon of emerging and re-emerging infectious diseases is influenced by various factors like genetic and biological factors of microbes (like adaptation to new macro and microenvironment, changes in host susceptibility to infection through mutations) environmental factors (like climate change, changes in human and animal population densities and their close interaction), socioeconomic and political factors (increasing international travel and trade, social inequality, poverty, conflict, famine and drought, lack of political will, and changes in economic development and land use) (Webreyes et al., 2014). Most of the emerging infectious diseases (approximately 75%) are zoonotic (Tripathi, 2022) while 71.8% of the emerging zoonotic diseases have originated from wildlife (e.g., severe acute respiratory syndrome, Ebola, Nipah) (Jones et al., 2008). Animal diseases have economic impact in the form of loss of meat and milk leading to human undernutrition. Economically animal diseases cause losses valued around US $300 billion annually (Countryman et al., 2024). For example, foot-and-mouth disease (FMD) alone, leads to loss in billions in the form of yield and trade opportunities each year (Subramaniam et al., 2022; Soomro et al., 2023). Beyond livestock, diseases in companion animals (pets) also carry a significant burden. Canine parvovirus is a ubiquitous killer of puppies globally (Horecka et al., 2020) and canine rabies remains a scourge in many countries –In India about 20,000 human deaths are recorded annually which is 36% of worlds human deaths due to rabies as India has large stray dog population (Goel et al., 2023). These figures underscore that improving animal health is not only an economic imperative but also a public health and welfare priority.

FAO's Emergency Prevention System for animal health has emphasized that diseases of transboundary nature have global impact. The list includes diseases such as foot and-mouth disease, rinderpest, contagious bovine pleuropneumonia, sheep and goat pox, peste des petits ruminants, highly pathogenic avian influenza, Rift Valley fever, Newcastle disease, African and classical swine fever, equine encephalomyelitis, and under certain circumstances rabies and brucellosis (Clemmons et al., 2021). Currently, outbreaks of LSD and African swine fever (ASF) have been reported in India. The first ASF outbreaks occurred in Assam in 2020 and reported in Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Bihar, Kerala, Punjab states, and in Ambala district in Haryana, Gujarat, Karnataka, Madhya Pradesh, Rajasthan, Tripura, Uttarakhand, Uttar Pradesh, and Delhi. Lumpy skin disease outbreaks have affected 2.4 million animals causing over 1,10,000 cattle deaths in India (Tripathi, 2022).

Efficient surveillance, regular monitoring, and effective networking tools are essential to contain zoonotic diseases, prevents their spread, and implement appropriate prevention and control strategies (Gupta et al., 2024). Similarly, effective management like biosecurity, movement control and treatment or vaccination can minimize the impact of diseases. Rapid and accurate diagnosis of animal diseases particularly in field conditions is a challenge. Key obstacles include infrastructure and training gaps, technological and regulatory issues, limitations of point-of-care diagnostic tools in real-world settings and other constraints. In this review, challenges and barriers in diagnosis, containment, monitoring and surveillance of disease are discussed.

2. Materials and Methods

A structured review of literature was undertaken to assess the challenges related to animal diseases, zoonosis, emerging diseases, one health implementation, and diagnosis. Systematic searches were conducted across major scientific databases, including PubMed, Scopus, Google Scholar, and Web of Science, using a comprehensive set of keywords such as " diagnostic challenges, emerging diseases, zoonosis, AMR, artificial intelligence in veterinary sciences, surveillance, monitoring, One Health, and specific zoonotic diseases including rabies, brucellosis, Nipah virus, leptospirosis, avian influenza, zoonotic tuberculosis, scrub typhus, Japanese encephalitis, Q fever, CCHF, and zoonosis policy. The results were sorted by relevance and the first ten results were selected from each search. Additional results that appeared potentially relevant to the goals of the review were then selected. After the initial search, another search was performed with a date range of 2010 to 2025 to find further, recent results. The search strategy was designed to capture the scope of zoonotic disease challenges in India and to track the evolving discourse around integrated health governance under the One Health framework. In addition, relevant Indian government reports, WHO/FAO/WOAH publications, and institutional action plans were reviewed

3. Results and discussion

3.1. Challenges in rapid diagnosis of animal diseases

Diagnostics in veterinary science is severely impeded by various factors, like under-resourced field veterinary services, poor logistics like difficulties in sending samples to animal health laboratories, limited number of laboratories and that they may have limited number of tests, and a general lack of investment by governments (WHO, Dfid, FAO, & OIE, 2006). Several key factors that contribute to diagnostic delays and gaps are discussed:

3.1.1. Workforce and Training Shortage

A chronic shortage of trained veterinary professionals and diagnosticians exacerbates the diagnosis challenge. According to the report presented at an assembly of the World Organization for Animal Health (OIE) in Paris, the shortage of veterinarians is limiting development and putting food security at risk globally. An international study found that over half of countries surveyed had fewer veterinarians than the needs of their animal populations. There were about 35 public-sector veterinarians per million inhabitants, and under 100 private veterinarians per million. This affects the whole food security and food safety systems (Bonnet et al., 2011).

As the number of veterinarians are less, workload on serving personnel become enormous as indicated by the fact that global average number of livestock units per one public service veterinarian were 9,221. Following countries had maximum shortage of veterinary doctors as they as the average number of livestock units per one public service veterinarian were 63,121 in Australia, 57,244 in New Zealand and 46,886 in USA (Venkateshwarlu et al., 2021).

This shortage means that often untrained farmers or Para veterinary staff must be the first to identify diseases, risking misdiagnosis and less capacity to perform specialized tests. Training programs and veterinary curricula may not sufficiently cover emerging diagnostic technologies, leaving a skills gap. As a result, diagnostic errors or delays occur. The shortage of veterinarian services may also have repercussions on human health related to the spread of zoonoses or chemical substances used to treat sick animals (Teillant et al., 2015). Wang et al. (2015) reported that there is scarcity of veterinarians in rural areas as they don't want to locate in rural areas.

3.1.2. Infrastructure Gaps

Correct and rapid diagnosis of disease requires laboratory-aided diagnostic tests. Advances in chemical, biochemical, biophysical, immunological, hematological, patho-physiological, molecular and cell biology principles and methods, bio-, nano- and instrumentation technologies have directly impacted growth of the laboratory-based diagnostics. Major diagnostic tests in veterinary are culture and isolation of the infectious agent, immunodiagnostic and molecular diagnostic tests, clinical chemistry and biochemistry, hematology, histopathological methods and diagnostic in vivo imaging. Delays in diagnosis and treatment are driven by multiple operational barriers including inadequate lab infrastructure, fragile logistics networks, inaccessible roads, erratic fuel supplies, broken cold chains, and a critical deficit in trained workforce all of which make rapid, affordable diagnostics a persistent challenge in low-resource settings facilities (Hobbs et al., 2020) Furthermore, rural and remote areas often lack local labs and samples must be shipped to central laboratories which take turnaround times of days to weeks for results. This weak infrastructure undermines surveillance and makes rapid point of care testing (POCT) difficult outside of major centers. But India is equipped with robust veterinary infrastructure. India's extensive veterinary network includes over 65,000 facilities comprising hospitals, dispensaries, and mobile aid centers positioning it well to expand access to animal healthcare across both rural and urban regions (DAHD, 2019)."

3.1.3. Limited Access to Technology

Cutting-edge diagnostic technologies such as PCR machines, gene sequencing, or ELISA kits are often limited to reference labs and rarely available on-site where outbreaks occur. Field veterinarians in developing countries may rely on clinical signs or rudimentary tests, because they lack access to rapid test kits or portable devices. Even when technologies exist, there may be issues with supply chains (e.g. difficulty procuring reagents or kits in-country) and maintenance (a PCR machine is useless without stable electricity and technical support) (Ovuru et al., 2024).

3.1.4. Problems and challenges associated with the available diagnostic tools

Advanced genetic diagnostic methods allow direct detection of pathogens from hosts or environmental samples without prior isolation; however, their utility remains limited to the 0.07% of pathogens that are already characterized, leaving the vast majority undetected (Tripathi, 2022). Emergence of novel zoonotic viruses due to increase in contact between wild animals and human beings, increased travel, climatic variation, etc. poses threat to detection and identification of infectious agent. Moreover, mere identification is not sufficient to understand the epidemiological questions related to disease transmission, rate of infection, dispersal, and evolution. Another challenge is the emergence of new variants of existing agents through constant evolution, which reiterate the need for updating of existing diagnostic protocols for efficient diagnosis of evolving pathogens (Kumar et al., 2025).

3.1.5. Biosecurity and Biosafety Issues

Ensuring safe handling of infectious samples and upholding biosecurity protocols remains a persistent challenge. Inadequate infrastructure and training at local laboratories often compromise biosafety, while the need to transport samples over long distances to high-containment labs increases turnaround time and elevates the risk of pathogen spread. (Kantor et al., 2024).

3.1.6. Cost Constraints

Cost is a pervasive barrier to rapid diagnosis. Many rapid test kits and molecular diagnostics are expensive, putting them out of reach for routine use by smallholder farmers or resource-strapped veterinary services. As a result, diseases often go undiagnosed or are only identified late in their course (Hrynick et al., 2019).

3.1.7. Regulatory and Quality Hurdles

Point-of-care diagnostics can greatly improve animal disease control, but regulatory and quality challenges persist. In some countries, weak oversight allows substandard or invalidated kits, leading to false results and mismanagement. Conversely, overly complex approval processes delay access to advanced diagnostics. Import restrictions and bureaucratic hurdles further limit timely availability of test kits. These regulatory inconsistencies contribute to a diagnostic gap where diseases remain undetected or unconfirmed, enabling transboundary and emerging pathogens to spread unchecked. This delay in diagnosis hampers effective response, allowing outbreaks to escalate before containment begins, posing significant risks to animal and public health (Hobbs et al., 2021).

3.1.8. Point-of-care diagnostic tools: current availability and limitations

Recent years have seen a push to develop point-of-care tests (POCTs) for animal diseases. Point-of-care tests (POCTs) are defined as, "a fully or partially automated table-top, portable or disposable device able to be operated in a non-laboratory environment by non-technical staff to deliver a same-day, on-site, clinically relevant, diagnostic test result" (Lehe et al., 2012). POCTs, also known as "rapid diagnostic tests", "point of need tests" and "near patient tests", come in a range of different formats. They are designed to be portable, user-friendly, and simple to operate, with a turnaround time from sample to result typically under an hour. This rapid diagnostic capability enables clinical decision-making and intervention within the same encounter. Point-of-care tests (POCTs) include lateral flow assays, handheld analyzers, portable PCR devices, and simplified test kits suitable for use directly on farms or in veterinary clinics. These tools are increasingly being applied across a broad spectrum of clinical needs—ranging from screening and diagnosis to monitoring, prognosis, disease staging, and real-time surveillance supporting more responsive and decentralized veterinary care (WHO, 2019)

3.1.9. One health approach

In present scenario, with increase in occurrence of emerging infectious diseases, AMR, and environmental changes, traditional isolated health approaches are insufficient (Danasekaran, 2024). New diagnostic techniques and improved knowledge in field of medicine and biology has established more than 300 zoonoses of different etiologies (Gupta et al., 2024). Now, diseases are managed holistically considering animals, humans and environment in one ecosystem known as one health approach. One Health is an integrated, unifying approach to sustainably balance and optimize the health of humans, animals, plants, and environment which are closely linked and interdependent. It involves multiple sectors, disciplines, and communities to work together to maintain and handle threats to health and ecosystems ensuring clean water, air and nutritious food and sustainable development (Adisasmito et al., 2022). OH approach has become a common approach for achieving nearly all United Nations Sustainable Development Goals (SDGs) (Hayman et al., 2023). The concept of OH revolves around antimicrobial resistance (AMR) and control of zoonotic diseases like Ebola, the food-borne bovine spongiform encephalopathy (BSE), salmonella, severe acute respiratory syndrome (SARS). India has made commendable progress in advancing One Health principles. National Institute for One Health (NIOH) in Nagpur under ICMR) has been established to promote interdisciplinary research on zoonoses, AMR, and food safety. India's National Action Plan on AMR (2017-2021) and revised frameworks under the National Rabies Control Programme and Livestock Health and Disease Control Programme highlights importance of the One Health paradigm in the country. Operational coherence of One Health in India is emerging but remains fragmented due to disjointed governance and limited intersectoral collaboration. Challenges like convergence between concerned ministries (health, agriculture, environment), integrated surveillance platforms, and ensuring that grassroots stakeholders like farmers, para-veterinarians, field officers, are well equipped are common. Programme often lack field-level mechanisms for implementation, data-sharing, and capacity-building. Collaborations among epidemiologists, veterinarians, ecologists, and public health officials help in mapping of disease hotspots and further necessary interventions.

3.1.10. Transboundary animal diseases

Transboundary animal diseases (TADs) are highly contagious and transmissible infections that can spread rapidly into new areas, causing massive damage within and across countries (Clemmons et al., 2021). TADs are a major challenge for animal health and livestock industries across the world, despite remarkable progresses in treatment and prevention (Clemmons et al., 2021). These infectious diseases account for 20% of the global animal production losses and cost an estimated $200 billion over 10 years in outbreak control. Among such diseases, FMD and ASF are notably hazardous due to their quick and adaptable propagation (Dixon et al., 2020), their persistence in the environment and wildlife reservoir species, and their economic consequences (Knight et al., 2017). Environmental, anthropogenic, epidemiological, and economic factors can alter how TADs may spread over multiple geographical scales (local, national, or international) and over multiple populations (González et al., 2022). As per FAO and OIE, following diseases are included under TAD: African horse sickness, African swine fever, avian influenza, bluetongue, classical swine fever, contagious bovine pleuropneumonia, foot and mouth disease, haemorrhagic septicaemia, lumpy skin disease, Middle East respiratory syndrome, Newcastle disease, peste des petits ruminants, Rift Valley fever, rinderpest, sheep pox/goat pox, swine vesicular disease, and vesicular stomatitis (Clemmons et al., 2021).

3.1.11. Global burden of animal diseases

The Global Burden of Animal Diseases (GBADs) refers to a program that systematically quantify the impact of animal diseases on animal health, human health, and the environment assessing economic losses, social impacts and environmental consequences. The global burden of animal diseases (GBADs) aims to generate comprehensive, data-driven evidence in animal health, welfare, and associated economic impacts. This information helps in decision-making, evaluating intervention outcomes, and strategic resource allocation (Rushton et al., 2021). GBADs provide insights into the economic impact of animal diseases and their effect on food security and livelihoods (Gilbert et al., 2024). By aligning with the FAIRS (Findable, Accessible, Interoperable, Reusable, and Secure) data principles, GBADs enhances the accessibility, interoperability, and long-term utility of its analytical outputs across disciplines and platforms (Bernardo et al., 2023).

3.1.12. Bottlenecks in disease management and outbreak response

Diagnosing an animal disease is only half the battle the subsequent management and control of the disease is equally, if not more, challenging. One of the most challenging aspects is attaining disease preparedness for unforeseen disease situations Once a disease is identified (whether in an individual animal or at population level), effective management involves measures like vaccination, treatment, quarantine, movement control, culling (if necessary), and continuous monitoring. Unfortunately, bottlenecks often arise at each of these steps, undermining disease control efforts. Here we discuss major management challenges, from vaccines and treatments to surveillance and outbreak containment (Farlow et al., 2023).

3.1.13. Containment and surveillance

The containment and control of outbreak of disease requires early notification of disease and the ability to forecast its spread to new areas. Therefore, novel systems with real-time surveillance of emerging diseases should be established. For this, identification of infectious agent at the earliest is must which require scientific technology at regional levels. Early warning of outbreaks will enable authorities to identify and advise the risk populations and to implement measures and controls to prevent disease spread. In India, National Animal Disease Referral Expert System (NADRES), developed by ICAR-NIVEDI, is a dynamic, remote sensing-enabled Geographic Information System to monitor and predict animal disease outbreaks. Epidemiological data of diseases and their patterns from 652 of India's 735 districts are studied that provide insights for early warning and strategic disease control measures (NADRES, 2019). ICAR-NIVEDI has listed 13 priority economically important livestock diseases including zoonotic disease like anthrax. The NADRES studies disease incidence patterns from data collected through All India Coordinated Research Project on Animal Disease Monitoring and Surveillance (AICRP on ADMAS) centers and also Department of Animal Husbandry and Veterinary Services of all the States on monthly basis (Suresh et al., 2021). The NADRES forewarn every month about livestock disease at district level in the form of a monthly bulletin and alert the animal husbandry departments, both at the National/State level, to take appropriate control measures (Kumar et al., 2021).

3.1.14. *Regulations for trade*

Regulatory standards for international trade of livestock and livestock products and their implementation are a great challenge for management of trans boundary animal and poultry diseases and cause failures in disease control strategies. In India, there are many acts for control and management of animal diseases. The Prevention & Control of Infectious and Contagious Diseases in Animals Act, 2009 help to prevent spread of public health and to promote import and export of animals and animal products by meeting India's international obligations. Livestock Importation (Amendment) Act, 2001 which provides modalities for International Animal Health Certification; Indian Veterinary Council Act, 1984 regulates veterinary practice and veterinary education, etc. Inspite of so many laws, implementation of these acts at the ground level has become a great challenge.

3.2. Disease preparedness for emerging and re-emerging animal diseases

3.2.1. Disease prioritization

The first requirement of preparedness is the prioritization of animal diseases that are likely to pose a problem to the animal and human populations and to the national economy. Disease prioritization should be based on risk assessment, probability of introduction and the potential for rapid spread and transmission amongst humans and animals and ability to evolve into novel virus. Prioritization of disease helps in allocation of resources and ensures effective utilization (Rist et al., 2014). The International Livestock Research Institute (ILRI) recognizes zoonotic diseases as a significant socio-economic burden, affecting the livelihoods of over one billion livestock-dependent individuals, causing approximately 2.7 million human mortalities and 2.5 billion morbidity cases globally each year." (Grace et al., 2012)

3.2.2. Vaccine availability and logistics

Vaccination is a powerful strategy for managing many animal diseases (from FMD and rabies to poultry diseases). However, vaccine-related bottlenecks are common in many countries (Rathod et al., 2016) India is an emerging shareholder in the Global vaccine market, with about 2.58% in 2020, and is the top supplier of vaccines to low-income and low-middle-income countries with a share of 37.43% and 24.53%, respectively (Kumar, 2022). India's growing vaccine export also necessitates comparable quality control facilities and regulations (Salalli et al., 2023).

3.2.3. Challenges in vaccination programs

One issue is insufficient vaccine supply or production. Shortages of vaccines especially for newly emerged or less common strains, for example, during a sudden outbreak of an avian influenza strain, there may simply be no readily available vaccine in country. Even for endemic diseases like FMD, producing enough doses to cover vast livestock populations is a huge undertaking India's FMD control program has had to mobilize hundreds of millions of doses annually (Verma et al., 2023). The cold chain is another critical challenge; vaccines (most of which are heat-sensitive) must be kept refrigerated from factory to farm. In tropical and remote areas with unreliable electricity, maintaining cold chain integrity is difficult. Logistics of reaching scattered small farms present hurdles as well; nomadic and rural livestock keepers may be in hard-to-reach areas with poor transport infrastructure. This means vaccination teams can only cover limited ground, and some animals remain unvaccinated. Coverage gaps then allow disease to persist. Additionally, many vaccines require boosters or annual revaccination which is very difficult to follow up (Warimwe et al., 2021).

3.2.4. Access to treatment and veterinary care

For diseases where treatments exist access to veterinary medicines and care is a bottleneck in much of the world. The cost of treatments can also be prohibitive; a smallholder farmer might not treat an individual animal if the cost of medicine exceeds the animal's value, leading to higher mortality (Suresh et al., 2021).

3.2.5. Surveillance and monitoring weaknesses

Despite the presence of institutional frameworks for veterinary services globally, surveillance weaknesses persist, particularly in developing countries due to chronic underinvestment (Bonnet et al., 2011). Many nations lack sensitive surveillance systems, resulting in under-reporting or delayed detection of disease outbreaks. Farmers often hesitate to report illnesses due to fear, lack of awareness, or distrust, while veterinary services face resource constraints. Global initiatives such as GOARN, PREDICT (Krofah, 2021), and GLEWS+ (Fearnley, 2020) focus on early detection of zoonoses. In India, disease reporting is managed by DAHD through NADRS and NADRES, which collect and analyze field-level data to predict and prevent outbreaks (DAHD, 2019). The ICAR-NIVEDI uses GIS-based systems to generate risk and hotspot maps, while IDSP under the NCDC facilitates lab-based surveillance of epidemic-prone diseases. Collectively, these systems aim to improve outbreak response through timely reporting and spatial analysis (Suresh et al., 2021).

3.2.6. Disease reporting to WOAH

As a member country, India submits Animal Health Information to WOAH under the World Animal Health Information System (WAHIS) platform. In this, India summits the information related to the endemic diseases under the six-monthly report, whereas the emergent and exotic disease are reported under immediate notification. Under WAHIS there is also provision for reporting of diseases in wildlife (Mitra et al., 2025).

3.2.7. Outbreak response and containment

When an infectious disease outbreak is confirmed, containing it involves measures like quarantine, movement control, depopulation (culling) of infected or exposed animals, disinfection of premises, and public awareness to limit spread. Each of these faces practical bottlenecks (Verma et al., 2024).

3.2.8. Quarantine and movement control

Implementing animal movement bans or quarantines is challenging, especially in areas with many smallholder farmers and informal trade. For example, trying to contain FMD in a region where farmers traditionally move cattle through communal grazing or trading can be near impossible without extensive community cooperation and enforcement. Border controls between countries may be porous, allowing transboundary spread despite official restrictions (Tayarani, 2020).

3.2.9. Culling and disposal

Culling is a key strategy for controlling highly contagious diseases like avian influenza and ASF, but it faces major socio-economic and logistical hurdles. Farmers may resist culling without timely and adequate compensation, leading to underreporting or concealment of sick animals. Delays or distrust in authorities further worsen compliance. Disposal of carcasses through burial or incineration is often restricted by environmental regulations or land shortages. Additionally, large outbreaks can overwhelm veterinary teams, causing delays in culling operations and allowing the disease to spread further before containment measures take effect (Leiss et al., 2010).

3.2.10. Biosecurity implementation

Once an outbreak is identified, farms need to implement strict biosecurity (footbaths, no visitor policies, equipment disinfection, etc.). Convincing small farms to adopt these measures consistently is a challenge. Many may lack materials or knowledge to do so. This is a cultural and educational bottleneck changing practices during a crisis is hard, and any weak link (one farm not following protocols) can allow the pathogen to escape containment (Subasinghe et al., 2023).

3.2.11. Digital tools and AI in early diagnosis and forecasting

Digital technology and artificial intelligence (AI) are rapidly becoming game-changers in the field of disease surveillance and diagnostics, including in veterinary medicine. Given the challenges described, digital tools offer ways to augment human capacity speeding up data collection, analysis, and even direct disease detection. Innovations like mobile apps, big data analytics, and AI algorithms are being applied to early diagnosis and forecasting of animal diseases to overcome some of the traditional bottlenecks (Afonso et al., 2023).

3.2.12. Mobile Reporting and Information Systems

Mobile applications and SMS-based systems have emerged as effective tools for rapid disease reporting. In India, apps under the NADCP enable vaccinators to log vaccinations and symptoms in real time, generating dashboards of disease hotspots. Similarly, WOAH's WAHIS allows countries to quickly report outbreaks online. These digital tools offer speed, geospatial tracking, and real-time alerts to officials and nearby farms, enabling quicker responses. They also improve data aggregation and analysis. However, their success depends on user participation, training, and network connectivity particularly in rural areas where veterinary services are often limited and infrastructure remains a challenge (Sharan et al., 2023).

3.2.13. Big Data and AI for Surveillance

Big data and AI are revolutionizing disease surveillance by analyzing complex datasets such as climate, livestock movement, and vaccination records to detect emerging patterns and predict outbreaks. Tools like WHO's Early Warning System and BlueDot (Khan et al., 2021) leverage AI for real-time alerts. AI models assess outbreak risks using geolocation, weather, and historical data. Systems like HealthMap and EpiWatch scan online content to detect disease signals early. Technologies like DeepTag use NLP to code veterinary records automatically. Standardized informatics protocols (e.g., VetSCT, HL7) enhance interoperability and consistency in veterinary health data (AVMA, 2004).

3.2.14. AI in diagnostics

Artificial intelligence (AI) is transforming veterinary diagnostics by improving the speed, accuracy, and accessibility of disease detection. AI algorithms, especially those based on machine learning and deep learning, can interpret complex diagnostic images such as X-rays, ultrasound scans, and histopathology slides in less time and with better precision (Xiao et al., 2025). These tools can identify patterns that may be subtle or easily missed by human eyes, enhancing early and accurate diagnosis. For example, AI models have been developed to detect mastitis in dairy cows using sensor data or thermal imaging, enabling real-time monitoring. In laboratory diagnostics, AI helps automate analysis of blood smears, fecal samples, and microbial cultures, reducing human error and increasing throughput. Natural language processing (NLP) is also used to extract diagnostic information from clinical notes, linking them with standardized coding systems like SNOMED-CT. These innovations allow for faster, cost-effective diagnostics, especially in resource-limited settings, and support more targeted treatment and disease control strategies in animal health (Cazzaniga et al., 2023).

3.3. Reforms to be incorporated for better veterinary services

3.3.1. Building resilient veterinary systems: policy, economic and educational reforms

Confronting the global challenges in animal disease diagnosis and management ultimately requires strengthening veterinary systems at their core. The issues like lab capacity and workforce shortages, surveillance gaps and slow outbreak response, all point to the need for robust, well-resourced, and well-governed veterinary services. Key reforms and investments, policy, economic support, and education are needed to build resilience against animal disease threats (Jost et al., 2021).

3.3.2. Education and capacity building

The foundation of a resilient system is knowledgeable people. Veterinary education needs to evolve with changing disease landscapes. Reforms in curricula to include more training in epidemiology, informatics, and One Health approach are crucial (Dunga et al., 2025). Continuous education programmes, hands-on diagnostics and field epidemiology exercises and specialization are need of hour. Routine funding of continuing education should allow every field vet or para-vet to periodically attend trainings or refresher courses in modern techniques. Globally, there is a push to develop Field Epidemiology Training Programs for Veterinarians (FETPV), akin to programs long established for physicians (Queenan et al., 2017). These train vets specifically in outbreak investigation, data analysis, and surveillance – creating a cadre of "disease detectives" on the animal side. Another educational reform is boosting the training of veterinary paraprofessionals (VPPs). These are technicians or community animal health workers who can handle basic tasks (vaccination, sampling, reporting) in areas with few fully-qualified vets. Organizations like FAO and OIE have guidelines for curricula for VPPs and advocate scaling up their use, particularly in Africa and Asia. By empowering VPPs with knowledge and formal recognition, the reach of veterinary services multiplies (Pyatt et al., 2025).

3.3.3. Economic and funding measures

Veterinary services are under-funded relative to the value of animals in the economy. The livestock sector accounts for 4.11 percent of GDP and 25.6 percent of overall agricultural GDP in India. From 2014-15 to 2018-19, it expanded at an annualized rate of 8.24% (Handigund, 2022). Innovative funding mechanisms like, establishing an animal health emergency fund, insurance schemes for livestock farmers, incentivizing private sector involvement like encouraging a private veterinary pharmaceutical industry to produce quality vaccines and diagnostics locally reducing reliance on imports and lowering costs and improved public-private partnerships, like contracting private vets to carry out vaccination campaigns with government oversight, is helpful. International financial support the World Bank, regional development banks, and the new Pandemic Fund are providing grants/loans for countries to strengthen animal health systems (Citaristi, 2022). A critical economic aspect is veterinary workforce incentives. Vets tend to avoid rural areas due to poor remuneration and working conditions. Offering competitive salaries, hardship allowances for remote postings, and career development opportunities can help retain talent in the public veterinary sector. To implement economic reforms in veterinary field strong political will is must. Insufficient political commitment may lead to a lack of financing and support for critical initiatives (WHO, 2014)

3.3.4. Public awareness and farmer education

Resilient systems also include informed animal owners and the public. Education campaigns to raise awareness about reporting diseases, cooperating with vaccination, and adopting biosecurity can change behaviors over time. Community education, teaching pastoral communities about quarantine practices when they mingle herds at water points and use of local radio and drama to communicate messages have been helpful (Mwangi et al., 2025). The goal is to create a "culture of animal health" where farmers understand basic disease signs, are not afraid to report and see value in prevention measures. Rabies control requires not just dog vaccination campaigns but also educating about dog bite prevention, training health workers in post-exposure prophylaxis and legal policies for stray dog population management. Similarly, brucellosis control involves a combination of vaccination of animals, testing and culling of positives, hygiene education for farmers (like boiling milk), and making brucellosis a notifiable disease so its incidence is tracked. Without an integrated approach, such programs falter (Taylor et al., 2017).

3.3.5. Global solidarity and standards

Building resilience is also about adhering to international standards and benefiting from knowledge exchange. Comparing different global contexts makes it clear that countries may differ in which diseases they face or the scale of their resources, they share common goals and can learn from each other's successes and failures (Abdul et al., 2024). Countries should be encouraged to undergo WOAH PVS evaluations to objectively identify gaps in their veterinary systems and then implement the recommended improvements. WOAH PVS (Performance of Veterinary Services) evaluations are a tool used by the World Organisation for Animal Health (WOAH) to assess the capacity and performance of a country's veterinary services (Rai et al., 2025). Many low-income countries need technical assistance, international donors and organizations can play a role by funding, training, lab upgrades, and twinning programs (pairing labs or vet schools in developing countries with those in developed ones to transfer expertise). The concept of a "Global Veterinary Rapid Response Team" has been floated, akin to how WHO has teams for human health emergencies. Such teams could assist countries during major animal health emergencies, ensuring support when needed. Embracing such collaborative mechanisms is a policy choice and requires political will.

4. Conclusion

Animal diseases remain a formidable challenge worldwide, but they also present an opportunity by tackling these diseases decisively, we not only improve animal welfare and farmer livelihoods, we also safeguard human health and global food security. This review has highlighted that the burden of animal diseases is immense and widespread, from the loss of one-fifth of all livestock annually to the endemic circulation of zoonoses in many regions. The necessity of a One Health approach, rapid diagnosis of the diseases and the new point-of-care diagnostics proves to be an important strategy for controlling the animal diseases. On the management front, AI and digital surveillance builds resilient veterinary system that helps in overall animal disease diagnostics and in management. The strong foundation from veterinarian experience and expertise accumulated over decades reduce the burden of animal diseases. So, it is now up to the global community, including veterinarians like myself, to apply this wisdom and work tirelessly towards a safer and healthier future for all species.

Reference

Abdul, S., Adeghe, E. P., Adegoke, B. O., Adegoke, A. A., & Udedeh, E. H. (2024). Public-private partnerships in health sector innovation: Lessons from around the world. *Magna Scientia Advanced Biology and Pharmacy*, *12*(1), 045-059.

Adisasmito, W.B., Almuhairi, S., Behravesh, C.B., Bilivogui, P., Bukachi, S.A., Casas, N., Becerra, N.C., Charron, D.F., Chaudhary, A., Zanella, J.R.C., & Cunningham, A.A. (2022). One Health: A new definition for a sustainable and healthy future. *PLoS pathogens,* 18(6), p.e1010537.

Afonso, C. L., & Afonso, A. M. (2023). Next-generation sequencing for the detection of microbial agents in avian clinical samples. *Veterinary Sciences*, *10*(12), 690.

American Veterinary Medical Association (AVMA). Artificial intelligence poised to transform veterinary care. Schaumburg (United States of America): AVMA; 2024. Available at: https://www.avma.org/news/artificial-intelligence-poised-transform-veterinary-care

Bedi, J. S., Vijay, D., & Dhaka, P. (2022). Textbook of zoonoses. John Wiley & Sons.

Bernardo, T. M., Rushton, J., Huntington, B., Stacey, D. A., Raymond, K., Bensassi, N. and Patterson, G. T. (2023). Informatics progress of the Global Burden of Animal Diseases programme towards data for One Health. *Revue Scientifique et Technique (International Office of Epizootics),* 42, 218-229.

Bonnet, P., Lancelot, R., Seegers, H., & Martinez, D. (2011). Contribution of veterinary activities to global food security for food derived from terrestrial and aquatic mammals. 79th General Session, World Organization for Animal Health, Paris, May 22-27, 2011. 79.

Cazzaniga, G., Eccher, A., Munari, E., Marletta, S., Bonoldi, E., Della Mea, V., Cadei, M., Sbaraglia, M., Guerriero, A., Dei Tos, A.P., & Pagni, F. (2023). Natural Language Processing to extract SNOMED-CT codes from pathological reports. *Pathologica*, *115*(6), p.318.

Citaristi, I. (2022). International fund for agricultural development—IFAD. In *The Europa directory of international organizations 2022* (pp. 340-343). Routledge.

Clemmons, E.A., Alfson, K.J., & Dutton, J.W. (2021). Transboundary Animal Diseases, an Overview of 17 Diseases with Potential for Global Spread and Serious Consequences. Animals 11, 2039.

Countryman, A. M., de Menezes, T. C., Pendell, D. L., Rushton, J., & Marsh, T. L. (2024). Economic effects of livestock disease burden in Ethiopia: A computable general equilibrium analysis. *PloS one*, *19*(12), e0310268.

DAHD, G. (2019). Department of Animal Husbandry and Dairying (DAHD). Government of India, Annual Report.

Danasekaran, R. (2024). One Health: A Holistic Approach to Tackling Global Health Issues. *Indian J. Community Med.*, *49*, 260–263.

Dixon, L.K., Stahl, K., Jori, F., Vial, L., & Pfeiffer, D.U. (2020). African Swine Fever Epidemiology and Control. Annu Rev Anim Biosci 8, 221–246.

Dunga, K. E., Okoro, C. I., Onyenama, A. C., Ekuma, U. O., Ohanusi, I. N., & Izah, S. C. (2025). Implementing One Health approach to emerging zoonotic diseases: Bridging surveillance, sustainability and global governance. *Exon,* 2(3), 200-223.

Farlow, A., Torreele, E., Gray, G., Ruxrungtham, K., Rees, H., Prasad, S., Gomez, C., Sall, A., Magalhães, J., Olliaro, P., & Terblanche, P. (2023). The future of epidemic and pandemic vaccines to serve global public health needs. *Vaccines*, *11*(3), p.690.

Fearnley, L. (2020). Viral sovereignty or sequence etiquette? Asian science, open data, and knowledge control in global virus surveillance. *East Asian Science, Technology and Society: An International Journal,* 14(3), 479-505.

Gilbert, W., Marsh, T.L., Chaters, G., Jemberu, W.T., Bruce, M., Steeneveld, W., Afonso, J.S., Huntington, B., & Rushton, J. (2024). Quantifying cost of disease in livestock: a new metric for the Global Burden of Animal Diseases. *The Lancet Planetary Health,* 8(5), 309-317.

Goel, K., Sen, A., Satapathy, P., Kumar, P., Aggarwal, A. K., Sah, R., & Padhi, B. K. (2023). Emergence of rabies among vaccinated humans in India: a public health concern. *The Lancet Regional Health-Southeast Asia*, 9, 210-217.

Grace, D., Gilbert, J., Randolph, T., & Kang'ethe, E. (2012). The multiple burdens of zoonotic disease and an eco-health approach to their assessment. *Tropical animal health and production*, *44*, 67-73.

Gupta, S., Kaur, R., Sohal, J. S., Singh, S. V., Das, K., Sharma, M. K., Singh, J., Sharma, S., & Dhama, K. (2024). Countering Zoonotic Diseases: Current Scenario and Advances in Diagnostics, Monitoring, Prophylaxis and Therapeutic Strategies. *Archives of medical research*, *55*(6), 103037.

Handigund, P. (2022). Economic Evaluation of Backyard Poultry Enterprise-A Study in South Bengaluru (Doctoral dissertation, University of Agricultural Sciences, GKVK, Bangalore).

Hobbs, E. C., Colling, A., Gurung, R. B., & Allen, J. (2021). The potential of diagnostic point-of-care tests (POCTs) for infectious and zoonotic animal diseases in developing countries: Technical, regulatory and sociocultural considerations. *Transboundary and Emerging Diseases*, *68*(4), 1835-1849.

Horecka, K., Porter, S., Amirian, E. S., & Jefferson, E. (2020). A decade of treatment of canine parvovirus in an animal shelter: a retrospective study. *Animals*, *10*(6), 939.

Hrynick, T.A., Barasa, V., Benschop, J., Cleaveland, S., Crump, J.A., Davis, M., Mariki, B., Mmbaga, B.T., Mtui-Malamsha, N., Prinsen, G., & Sharp, J. (2019). Street-level diplomacy and local enforcement for meat safety in northern Tanzania: knowledge, pragmatism and trust. *BMC Public Health*, 19(1), p.863.

Jones, K. E., Patel, N. G., Levy, M. A., Storeygard, A., Balk, D., Gittleman, J. L., & Daszak, P. (2008). Global trends in emerging infectious diseases. *Nature*, *451*(7181), 990-993.

Jost, C.C., Machalaba, C., Karesh, W.B., McDermott, J.J., Beltrán-Alcrudo, D., Bett, B., Tago, D., Wongsathapornchai, K., Plee, L., Dhingra, M.S., & Pfeiffer, D.U. (2021). Epidemic disease risks and implications for Veterinary Services. *Rev Sci Tech*, 40(2), 497-509.

Kantor, C., Eisenback, J. D., & Kantor, M. (2024). Biosecurity risks to human food supply associated with plant-parasitic nematodes. *Frontiers in Plant Science*, 15, 335-344.

Khan, M., Mehran, M. T., Haq, Z. U., Ullah, Z., Naqvi, S. R., Ihsan, M., & Abbass, H. (2021). Applications of artificial intelligence in COVID-19 pandemic: A comprehensive review. *Expert systems with applications*, 185, 115695.

Knight-Jones, T.J.D., McLaws, M., & Rushton, J. (2017). Foot-and-Mouth Disease Impact on Smallholders - What Do We Know, What Don't We Know and How Can We Find Out More? *Transboundary and Emerging Diseases*. 64, 1079–1094.

Krofah, E., Galson, S. K., Califf, R. M., & Simon, G. (2021). Clinical trials in crisis: building on COVID-19's lessons toward a better future. Health Affairs Forefront.

Kumar, S. (2022). India in the Global Vaccine Market Prior To and During COVID-19: Some Structural Issues. Available from https://isid.org.in/wp-content/uploads/2022/10/WP250.

Kumar, A., Saini, S., Anvikar, A., Mishra, N., & Misra, G. (2025). Evolving Landscape of Emerging Virus Diagnosis: Challenges and Innovations. *Molecular Biotechnology*, 1-23.

Kumar, H.C., Hiremath, J., Yogisharadhya, R., Balamurugan, V., Jacob, S.S., Reddy, G.M., Suresh, K.P., Shome, R., Nagalingam, M., Sridevi, R., & Patil, S.S. (2021). Animal disease surveillance: Its importance & present status in India. *Indian Journal of Medical Research*, 153(3), 299-310.

Lehe, J. D., Sitoe, N. E., Tobaiwa, O., Loquiha, O., Quevedo, J. I., Peter, T. F., & Jani, I. V. (2012). Evaluating operational specifications of point of-care diagnostic tests: A standardized scorecard. *PLoS One*, 7(10), 47459.

Leiss, W., Tyshenko, M. G., Krewski, D., Cashman, N., Lemyre, L., Al-Zoughool, M., & Amaratunga, C. (2010). Managing the risks of bovine spongiform encephalopathy: a Canadian perspective. *International Journal of Risk Assessment and Management,* 14(5), 381-436.

Mitra, A., Sharma., A., Mishra, A., & Jha, A. (2025) Animal Disease Surveillance: Perspectives and Issues, Department of Animal Husbandry & Dairying, Ministry of Fisheries Animal Husbandry & Dairying Epi-Dis-Phere (Publication of Health Resilience) 01, 20-24.

Mwangi, S., Muasya, G. and Wachira, W. (2025). An Analysis of Community Engagement through Community Radio during the Covid-19 Pandemic amongst Select Communities in Kenya. *African Multidisciplinary Journal of Research*, 1(1), 474-488.

National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI). Annual Report 2019. Bengaluru, Karnataka, India: National Animal Disease Referral Expert System (NADRES); 2019.

Ovuru, K. F., Izah, S. C., Ogidi, O. I., Imarhiagbe, O., & Ogwu, M. C. (2024). Slaughterhouse facilities in developing nations: Sanitation and hygiene practices, microbial contaminants and sustainable management system. *Food Science and Biotechnology*, 33(3), 519-537.

Perry, B., McDermott, J., & Randolph, T. (2001). Can epidemiology and economics make a meaningful contribution to national animal-disease control?. *Preventive Veterinary Medicine*, *48*(4), 231-260.

Pyatt, A. Z., Eckford, S., Joseph, N., Borriello, S. P., & Oyati, O. (2025). Veterinary medicinal product regulation in sub-Saharan Africa: identifying barriers and opportunities for enhancing VMP regulatory systems. *Frontiers in Veterinary Science*, 12, 1532098.

Queenan, K., Garnier, J., Nielsen, L.R., Buttigieg, S., Meneghi, D.D., Holmberg, M., Zinsstag, J., Rüegg, S., Häsler, B., & Kock, R. (2017). Roadmap to a One Health agenda 2030. CABI Reviews, 01, 1-17.

Rai, B.D., Tenzin, T., Tshering, D., Dahal, N., Tessema, G.A., Fritschi, L., Dodzi, S.N., & Pereira, G., 2025. Knowledge, attitude, and practice of One Health and zoonotic diseases among multisectoral collaborators in Bhutan: Results from a nationwide survey. *PLOS Global Public Health*, 5(1), 4142.

Randolph, T.F., Schelling, E., Grace, D., Nicholson, C.F., Leroy, J.L., Cole, D.C., Demment, M.W., Omore, A., Zinsstag, J., & Ruel, M. (2007). Invited review: Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of animal science*, 85(11), 2788-2800.

Rathod, P., Chander, M., & Bangar, Y. (2016). Livestock vaccination in India: an analysis of theory and practice among multiple stakeholders. *Rev Sci Tech Off Int Epiz*, *35*(3), 729-739.

Rist, C. L., Arriola, C. S., & Rubin, C. (2014). Prioritizing zoonoses: a proposed one health tool for collaborative decision-making. *PloS one*, 9(10), 109986.

Rushton, J., Huntington, B., Gilbert, W., Herrero, M., Torgerson, P. R., Shaw, A. P. M., & Mesenhowski,

S. (2021). Roll-out of the Global Burden of Animal Diseases programme. *Lancet,* 397(10279), 1045-1046.

Sakshi, Dhaka, P., Bedi, J.S., Aulakh, R.S., Singh, R., & Gill, J.P.S. (2023). Assessing and prioritizing zoonotic diseases in Punjab, India: a one health approach. *EcoHealth,* 20(3), 300-322.

Salalli, R., Dange, J.R., Dhiman, S., & Sharma, T. (2023). Vaccines development in India: advances, regulation, and challenges. *Clin Exp Vaccine Res.* 12(3):193-208.

Sharan, M., Vijay, D., Yadav, J. P., Bedi, J. S., & Dhaka, P. (2023). Surveillance and response strategies for zoonotic diseases: a comprehensive review. *Science in One Health*, 2, 100050.

Soomro, H., Hassan, M.F., Rajput, Z.I., Soomro, M.A., Junejo, G.A., Saboor, A., Khanzada, M. & Ain, Q, (2023). Foot and Mouth Disease (FMD): A Zoonotic Threat to Animal and Humans. In: Aguilar-Marcelino L, Zafar MA, Abbas RZ and Khan A (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, 3: 637-650.

Subasinghe, R., Alday-Sanz, V., Bondad-Reantaso, M. G., Jie, H., Shinn, A. P., & Sorgeloos, P. (2023). Biosecurity: Reducing the burden of disease. *Journal of the World Aquaculture Society*, 54(2), 397-426.

Subramaniam, S., Mohapatra, J.K., Sahoo, N.R., Sahoo, A.P., Dahiya, S.S., Rout, M., Biswal, J.K., Ashok, K.S., Mallick, S., Ranjan, R., & Jana, C. (2022). Foot-and-mouth disease status in India during the second decade of the twenty-first century (2011–2020). *Veterinary research communications,* 46(4), 1011-1022.

Suresh, K.P., Hemadri, D., Patil, S.S., Krishnamoorthy, P., Jacob, S.S., & Shome, B.R. (2021). Livestock Disease Forewarning Monthly Bulletin- April 2021. 9. Bengaluru: ICAR-NIVEDI; 1–117.

Tayarani, M. (2020). Applications of artificial intelligence in battling against covid-19: A literature review. *Chaos, Solitons and Fractals*, 110338.

Taylor, L.H., Wallace, R.M., Balaram, D., Lindenmayer, J.M., Eckery, D.C., Mutonono-Watkiss, B., Parravani, E., & Nel, L.H., (2017). The role of dog population management in rabies elimination—a review of current approaches and future opportunities. *Frontiers in veterinary science,* 4, 109-115.

Teillant, A., Brower, C. H., & Laxminarayan, R. (2015). Economics of antibiotic growth promoters in livestock. *Annual Review of Resource Economics*, 7(1), 349–374.

Tripathi, B. N. (2022). Global challenges in rapid diagnosis and management of animal and poultry diseases for improved health and productivity International veterinary pathology congress-2022 pg 1-5.

Venkateshwarlu, B. (2021). Analysis of livestock's economic contribution to India's GDP. *J Emerg Technol Innov Res*, 8(12), 706-718.

Verma, N., Agarwal, N., & Misra, L. (2023). Review of some diseases of dairy animals and treatment by ethno-veterinary medicines. *Advancement in Medicinal Plants Research*, 11(01), 9-32.

Verma, S., Malik, Y. S., Singh, G., Dhar, P., & Singla, A. K. (2024). Key concepts and principles of epidemiology, prevention, and control of animal diseases. *Core Competencies of a Veterinary Graduate,* 12(2), 119-137.

Wang, T., Hennessy, D. A., & Park, S. C. (2015). Demand side change, rurality, and gender in the United States veterinarian market, 1990–2010. *Agribusiness,* 32(2), 236–253

Warimwe, G. M., Francis, M. J., Bowden, T. A., Thumbi, S. M., & Charleston, B. (2021). Using cross-species vaccination approaches to counter emerging infectious diseases. *Nature Reviews Immunology,* 21(12), 815-822.

Webreyes, W. A., Dupouy-Camet, J., Newport, M. J., Oliveira, C. J., Schlesinger, L. S., Saif, Y. M., Kariuki, S., Saif, L. J., Saville, W., Wittum, T., Hoet, A., Quessy, S., Kazwala, R., Tekola, B., Shryock, T., Bisesi, M., Patchanee, P., Boonmar, S., & King, L. J. (2014). The global one health paradigm: challenges and opportunities for tackling infectious diseases at the human, animal, and environment interface in low-resource settings. *PLoS neglected tropical diseases*, 8(11), 3257.

WHO (World Health Organization). Zoonotic Disease: Emerging Public Health Threats in the Region. 2014. Available online: https://www.emro.who.int/about-who/rc61/zoonotic-diseases.html

WHO, Dfid, FAO, and OIE. (2006). The control of neglected zoonotic diseases: A route to poverty alleviation. Report of a joint WHO/DFID-AHP meeting with the participation of FAO and OIE, 20–21 September 2005: World Health Organisation (WHO), United Kingdom Dept. for International Development (DFID), Food and Agriculture Organization of the United Nations (FAO), World Organisation for Animal Health (OIE). Available from: https://apps.who.int/iris/handl e/10665/43485.

WHO. (2019a). Second WHO model list of essential in vitro diagnostics. (WHO/MVP/EMP/2019.05): World Health Organization (WHO). Available from: https://www.who.int/medical_devices/publications/ Standalone_document_v8.pdf?ua=1

Xiao, S., Dhand, N. K., Wang, Z., Hu, K., Thomson, P. C., House, J. K., & Khatkar, M. S. (2025). Review of applications of deep learning in veterinary diagnostics and animal health. *Frontiers in Veterinary Science*, 12, 1511522.