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From antimicrobial discovery to public health preparedness: a narrative review of contemporary challenges in infectious disease research

Abstract

Infectious diseases continue to pose substantial challenges to global health despite significant advances in antimicrobial discovery, molecular diagnostics, vaccines, and surveillance systems. The growing burden of antimicrobial resistance (AMR), emergence of novel pathogens, climate-sensitive infectious diseases, and increasing zoonotic spillovers highlight the need for integrated public health preparedness. This narrative review examines contemporary developments in infectious disease research, focusing on antimicrobial discovery, AMR, emerging viral infections, climate-related disease threats, molecular epidemiology, digital health technologies, and health system preparedness. Literature published between 2011 and 2026 was reviewed using major scientific databases and relevant public health reports. Evidence suggests that while antimicrobial discovery from natural sources such as Streptomyces continues to provide opportunities for novel therapeutic development, the global antibiotic pipeline remains inadequate to address the rapidly growing AMR crisis. Lessons from the COVID-19 pandemic demonstrated the importance of genomic surveillance, rapid diagnostics, laboratory strengthening, vaccine innovation, and implementation science. Emerging technologies including artificial intelligence and digital health platforms have improved outbreak detection and disease monitoring; however, challenges related to infrastructure, equity, and governance remain significant. Future preparedness efforts require interdisciplinary collaboration, One Health approaches, sustainable antimicrobial stewardship, and equitable healthcare systems. Strengthening the integration between laboratory science and public health policy will be essential for improving resilience against future infectious disease threats.

Keywords: antimicrobial resistance, streptomyces, infectious diseases, public health preparedness, one health, surveillance, pandemic preparedness

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Neha Singh
Virology Lab, Department of Microbiology, Pt. JNM Medical College, India

Correspondence: Neha Singh, Virology Lab, Department of Microbiology, Pt. JNM Medical College, Raipur, Chhattisgarh, India

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Introduction

Infectious diseases remain a major public health concern worldwide and continue to contribute substantially to morbidity, mortality, and economic burden, particularly in low- and middle-income countries (LMICs).[1,2] Although remarkable advances have been achieved in diagnostics, therapeutics, and vaccination, emerging and re-emerging pathogens continue to challenge global health systems. The increasing frequency of zoonotic spillovers, rapid urbanization, environmental changes, antimicrobial resistance (AMR), and global population mobility have transformed infectious disease control into a complex multidisciplinary challenge.[3,4]

The COVID-19 pandemic exposed significant weaknesses in healthcare preparedness systems worldwide and demonstrated the importance of coordinated surveillance, rapid diagnostics, laboratory capacity, and effective public health communication.[5] Beyond pandemic threats, persistent challenges such as tuberculosis, influenza, rabies, healthcare-associated infections, and vector-borne diseases continue to impose substantial health burdens, particularly in resource-constrained settings.

Historically, antimicrobial discovery has played a pivotal role in reducing infectious disease mortality. Actinomycetes, particularly Streptomyces species, have contributed significantly to antibiotic development through the production of compounds including streptomycin, oxytetracycline, chloramphenicol, and puromycin.[6] Research conducted in India has further highlighted the therapeutic potential of soil-derived Streptomyces isolates as sources of novel antimicrobial compounds.[1-5]

Contemporary infectious disease research extends beyond pathogen identification and treatment. Modern approaches integrate microbiology, molecular epidemiology, environmental sciences, implementation research, digital health technologies, and public health policy.[6-12] This review examines major developments in antimicrobial discovery, AMR, emerging infectious diseases, climate-sensitive health threats, molecular epidemiology, and preparedness strategies while identifying critical research gaps and future priorities.

Methodology

This narrative review was conducted using literature obtained from PubMed, Scopus, Web of Science, and Google Scholar. Searches were performed using combinations of keywords including "infectious disease preparedness," "antimicrobial resistance," "Streptomyces," "pandemic preparedness," "One Health," "mRNA vaccines," "molecular epidemiology," "infectious disease surveillance," and "digital health."

Publications from 2011 to 2026 were considered. Eligible sources included peer-reviewed original research articles, review papers, policy reports, and public health documents relevant to infectious disease research and preparedness. Conference abstracts, duplicate publications, non-English studies, and articles lacking direct relevance were excluded.

The retrieved literature was reviewed and categorized into thematic domains including antimicrobial discovery, antimicrobial resistance, emerging viral diseases, climate-sensitive infections, molecular epidemiology, and health system preparedness. Findings were synthesized narratively with emphasis on current challenges, research gaps, and preparedness implications.

Antimicrobial discovery and antimicrobial resistance

The discovery of antibiotics from actinomycetes represents one of the most important achievements in modern medicine. Streptomyces species continue to serve as a major source of bioactive secondary metabolites with antibacterial, antifungal, antiviral, antiparasitic, and anticancer activities.[6,13] Studies conducted in Chhattisgarh demonstrated that soil-derived Streptomyces isolates possess substantial antimicrobial potential against clinically important bacterial and fungal pathogens.[1,4,5]

Research involving *Streptomyces rimosus* demonstrated enhanced oxytetracycline production through optimization techniques including response surface methodology and immobilized cell technology.[2,3] Similarly, purification and characterization studies identified promising antimicrobial compounds from novel Streptomyces isolates. Recent investigations have also explored environmentally sustainable extraction methods for antibiotic production, reflecting growing interest in green biopharmaceutical technologies.[14]

Despite these advances, the global antimicrobial development pipeline remains insufficient to address the rapidly expanding burden of AMR. Resistance among bacterial, viral, fungal, and parasitic pathogens threatens the effectiveness of existing treatments and increases healthcare costs, morbidity, and mortality.[15,16] Hypervirulent multidrug-resistant Acinetobacter baumannii and other healthcare-associated pathogens have emerged as major concerns in clinical settings.[17]

Several factors contribute to AMR development, including inappropriate antimicrobial prescribing, self-medication, agricultural antibiotic use, inadequate infection control practices, and weak surveillance systems.[15,18] Although antimicrobial stewardship programs have demonstrated effectiveness in reducing inappropriate antibiotic use, implementation remains inconsistent, particularly in LMICs.

Novel therapeutic strategies including antimicrobial peptides, bacteriophage therapy, immunomodulatory approaches, and precision antimicrobial treatments have shown promise in addressing resistant infections.[17] However, significant barriers remain, including limited commercial incentives for antibiotic development, regulatory challenges, and inadequate investment in antimicrobial innovation.

A major gap in current AMR preparedness is the unequal distribution of surveillance capacity. High-income countries increasingly utilize genomic surveillance and advanced laboratory networks, whereas many LMICs continue to face shortages of infrastructure, trained personnel, and diagnostic resources. Addressing these disparities will require sustained investment in laboratory strengthening, international collaboration, and integrated One Health surveillance frameworks.

The future of antimicrobial discovery depends on combining traditional natural-product research with genomics, metabolomics, artificial intelligence-assisted drug discovery, and synthetic biology approaches. Such integration may accelerate the identification of novel antimicrobial agents while improving preparedness against emerging resistance threats.

Emerging viral diseases and pandemic preparedness

The COVID-19 pandemic fundamentally reshaped infectious disease research and public health preparedness worldwide. Beyond causing substantial morbidity and mortality, the pandemic exposed critical weaknesses in surveillance systems, healthcare infrastructure, laboratory capacity, and global coordination mechanisms.[8,9] At the same time, it accelerated scientific innovation, particularly in molecular diagnostics, vaccine development, and genomic surveillance.

Studies conducted in India demonstrated important maternal and neonatal implications of COVID-19 infection during pregnancy. Although vertical transmission appeared relatively uncommon, infected mothers experienced increased risks of adverse maternal outcomes, highlighting the importance of targeted surveillance and clinical management strategies.[18,19] Comparative evaluations of RT-qPCR and rapid antigen tests further emphasized the need for accessible diagnostic platforms in resource-limited settings.

One of the most significant achievements during the pandemic was the rapid development of vaccines. Advances in mRNA vaccine technology have expanded opportunities beyond COVID-19 and may influence future vaccine development for influenza, HIV, respiratory viruses, and selected cancers.[20] However, unequal vaccine distribution across countries revealed substantial disparities in global health preparedness. Future pandemic response strategies must therefore prioritize both technological innovation and equitable access.

Pandemic preparedness extends beyond vaccine development. Effective preparedness requires robust surveillance systems, early warning mechanisms, laboratory networks, emergency response frameworks, and community engagement. The pandemic also highlighted the importance of public communication, misinformation management, and behavioural interventions.

Rabies and influenza remain important examples of persistent infectious threats requiring continuous preparedness. Recent studies continue to demonstrate substantial rabies-related mortality in India despite the availability of effective preventive interventions.[21,22] Seasonal influenza surveillance similarly remains essential for early outbreak detection and vaccine planning. Lessons learned from COVID-19 should therefore be applied to strengthen preparedness for both emerging and endemic infectious diseases.

Climate change, one health, and vector-borne diseases

Climate change has emerged as an increasingly important determinant of infectious disease transmission. Rising temperatures, altered rainfall patterns, ecological disruption, urbanization, and environmental degradation influence the distribution of vectors and reservoirs responsible for disease transmission.[12,23]

Vector-borne diseases such as dengue, malaria, chikungunya, and Japanese encephalitis continue to impose significant public health burdens in many regions of India.[24-26] Changes in climate conditions can expand vector habitats, increase transmission seasons, and facilitate the emergence of infections in previously unaffected areas.

Environmental factors also influence respiratory and waterborne infections. Air pollution, poor sanitation, inadequate waste management, and contaminated water sources contribute to increased disease risk and health vulnerability. Studies from Central India have demonstrated associations between environmental exposures and adverse health outcomes, emphasizing the need for integrated environmental surveillance systems.[27,28]

The One Health framework has gained considerable attention as an approach for addressing complex infectious disease challenges. By recognizing the interconnectedness of human, animal, and environmental health, One Health promotes multidisciplinary collaboration for surveillance, prevention, and response activities. Despite widespread acceptance of the concept, implementation remains fragmented in many countries because of limited coordination between sectors, funding constraints, and governance challenges.

Future preparedness efforts should strengthen climate-resilient health systems, environmental monitoring programs, and One Health partnerships to improve the detection and prevention of emerging infectious threats.

Molecular epidemiology and digital health technologies

Advances in molecular biology have transformed infectious disease surveillance and outbreak investigation. Molecular epidemiology enables rapid pathogen characterization, identification of resistance mechanisms, outbreak tracking, and monitoring of transmission patterns. Genomic technologies became particularly important during the COVID-19 pandemic, allowing researchers to identify viral variants and monitor their global spread. Similar approaches are increasingly used for antimicrobial resistance surveillance and outbreak detection across multiple pathogens. Artificial intelligence (AI), machine learning, and bioinformatics are also emerging as valuable tools in infectious disease research. AI-based systems can support outbreak prediction, diagnostic interpretation, risk assessment, and public health decision-making. Digital health technologies facilitate real-time disease monitoring, telemedicine services, and improved communication between healthcare providers and public health authorities. Despite their potential, significant challenges remain. Many healthcare systems lack the infrastructure required for large-scale digital integration. Concerns regarding data quality, privacy, cybersecurity, algorithmic bias, and equitable access must be addressed before widespread implementation can occur. Consequently, technological innovation should be accompanied by appropriate regulatory frameworks and workforce training initiatives.

Health systems preparedness and implementation research

Scientific discoveries alone are insufficient to improve public health outcomes. Effective implementation remains essential for translating evidence into practice. Implementation research therefore plays a critical role in identifying barriers, evaluating interventions, and optimizing healthcare delivery systems. The COVID-19 pandemic demonstrated that countries with stronger surveillance systems, laboratory networks, and coordinated public health responses generally achieved more effective disease control. In India, initiatives such as Integrated Public Health Laboratories (IPHLs) have strengthened diagnostic capacity and disease surveillance networks. Preparedness also depends on workforce development, healthcare financing, supply chain resilience, and equitable healthcare access. Weak laboratory infrastructure, shortages of trained personnel, and fragmented health information systems continue to limit preparedness efforts in many LMICs. A major challenge involves translating scientific evidence into policy and practice. Research findings often fail to reach frontline healthcare settings because of resource limitations, administrative barriers, or inadequate stakeholder engagement. Strengthening collaboration among researchers, policymakers, clinicians, and public health professionals will be essential for improving future preparedness.

Research gaps and future priorities

Despite substantial progress, several important gaps remain in infectious disease research and preparedness. First, antimicrobial resistance surveillance remains unevenly distributed across regions, limiting the ability to monitor emerging threats effectively. Second, antibiotic discovery pipelines remain inadequate despite increasing resistance levels. Economic barriers and limited commercial incentives continue to discourage investment in antimicrobial development. Third, many countries lack integrated surveillance systems capable of linking human, animal, and environmental health data. Fourth, the implementation of AI-based surveillance and digital health solutions remains constrained by infrastructure and governance challenges.

Future research priorities should include:

a) Development of novel antimicrobials and alternative therapeutics.

b) Expansion of genomic and molecular surveillance systems.

c) Advancement of mRNA and next-generation vaccine platforms.

d) Strengthening One Health surveillance frameworks.

e) Integration of climate resilience into preparedness planning.

f) Evaluation of AI-supported public health interventions.

g) Improvement of implementation science methodologies in LMIC settings.

Addressing these priorities will require sustained investment, international collaboration, and multidisciplinary research efforts.

Conclusion

Infectious diseases remain a major global health challenge due to emerging pathogens, antimicrobial resistance (AMR), climate-related disease risks, and recurrent outbreaks. Lessons from the COVID-19 pandemic highlighted the importance of strong surveillance systems, laboratory capacity, rapid diagnostics, and resilient healthcare infrastructure. Future preparedness should focus on antimicrobial innovation, One Health approaches, vaccine development, and evidence-based public health interventions. Strengthening research capacity, healthcare systems, and international collaboration will be essential for improving global preparedness against future infectious disease threats (Table 1).

Limitations of current infectious disease research

Despite substantial advances in infectious disease research, several limitations continue to hinder effective preparedness and response. Global inequities in research funding and healthcare infrastructure create significant disparities in surveillance capacity, diagnostic accessibility, and implementation of evidence-based interventions. Many LMICs lack robust laboratory networks, genomic sequencing facilities, and trained personnel required for timely outbreak detection and response.

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Table 1 Major emerging infectious threats and preparedness strategies

Infectious disease threat	Major public health challenge	Key preparedness strategies	Expected outcomes
Antimicrobial resistance (AMR)	Emergence of multidrug-resistant pathogens leading to treatment failure, prolonged hospitalization, and increased mortality	Antimicrobial stewardship programs, resistance surveillance, infection prevention and control (IPC), development of novel therapeutics and diagnostics	Reduced resistance rates, improved treatment outcomes, preservation of antimicrobial effectiveness
COVID-19-like pandemics and emerging respiratory viruses	Rapid global transmission, healthcare system overload, economic disruption, and high morbidity and mortality	Early warning systems, genomic surveillance, rapid diagnostics, vaccine development platforms, emergency preparedness planning	Early outbreak detection, rapid containment, improved pandemic response capacity
Seasonal and pandemic influenza	Recurrent outbreaks, viral mutations, and increased burden among high-risk populations	Continuous surveillance, annual vaccination programs, public awareness campaigns, antiviral preparedness	Reduced disease burden, lower hospitalization and mortality rates
Rabies and other zoonotic diseases	High case fatality rate, inadequate vaccination coverage, and delayed post-exposure management	Mass animal vaccination, public awareness, post-exposure prophylaxis (PEP), One Health surveillance approaches	Reduced human rabies deaths and improved zoonotic disease control
Vector-borne diseases (Dengue, Malaria, Chikungunya, Japanese Encephalitis)	Climate-sensitive transmission, expanding vector habitats, and periodic outbreaks	Integrated vector management, environmental monitoring, vaccination where available, community participation	Reduced vector density, decreased transmission, improved outbreak prevention
Healthcare-associated infections (HAIs)	Multidrug-resistant infections in healthcare settings, increased healthcare costs, and patient morbidity	Infection prevention and control measures, hand hygiene programs, laboratory surveillance, antimicrobial stewardship	Reduced hospital-acquired infections and improved patient safety
Climate-sensitive infectious diseases	Increased transmission due to climate change, flooding, environmental disruption, and changing vector ecology	Climate-informed surveillance systems, environmental monitoring, One Health preparedness, disaster-response planning	Enhanced resilience to climate-related infectious disease threats
Emerging and re-emerging infectious diseases	Unpredictable outbreaks, zoonotic spillovers, and limited population immunity	Integrated surveillance, genomic epidemiology, international collaboration, research and development investments	Improved preparedness and rapid response to emerging threats

Antimicrobial discovery faces additional challenges related to high development costs, lengthy regulatory processes, and limited commercial incentives for antibiotic innovation. Consequently, the rate of emergence of resistant pathogens often exceeds the development of new antimicrobial agents.

Digital health technologies and artificial intelligence offer promising opportunities for disease surveillance; however, concerns regarding data quality, privacy protection, interoperability, and algorithmic bias remain unresolved. Furthermore, translating scientific discoveries into public health practice continues to be constrained by policy, resource, and implementation barriers.

Recognizing these limitations is essential for designing realistic and sustainable preparedness strategies.

Policy implications

The findings of this review have several implications for public health policy and healthcare planning.

First, governments should strengthen national and regional infectious disease surveillance systems through sustained investment in laboratory infrastructure and workforce development. Second, antimicrobial stewardship programs should be integrated across human health, veterinary medicine, and agricultural sectors to reduce inappropriate antimicrobial use.

Third, preparedness planning should incorporate One Health principles that facilitate collaboration among public health, environmental, and animal health sectors. Fourth, investments in genomic surveillance, digital health technologies, and artificial intelligence should be accompanied by appropriate regulatory and ethical frameworks.

Finally, healthcare systems should prioritize equitable access to diagnostics, vaccines, therapeutics, and emergency response resources, particularly in underserved populations and resource-constrained settings.

Future research priorities

Future investigations should focus on:

a) Discovery of novel antimicrobial agents from underexplored microbial ecosystems.

b) Development of alternative therapies, including antimicrobial peptides and bacteriophages.

c) Expansion of genomic epidemiology and real-time pathogen surveillance.

d) Evaluation of mRNA vaccine platforms for emerging and neglected infections.

e) Integration of artificial intelligence into diagnostics and outbreak prediction.

f) Assessment of climate change impacts on infectious disease transmission.

g) Strengthening implementation research to translate evidence into policy and practice.

h) Development of scalable **One Health** preparedness frameworks for low- and middle-income countries (LMICs).

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Ethical approval

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Data availability

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Author contributions

NS conceptualized the review, conducted literature analysis, synthesized findings, and prepared the manuscript.

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Conflicts of interest

The author declares that there are no conflicts of interest.

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