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Emerging Infectious Disease Preparedness and Resilient Public Health Systems

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Abstract

The COVID-19 pandemic exposed critical vulnerabilities in public health infrastructure and emergency preparedness systems worldwide, particularly in the United States. This paper examines the evolution of emerging infectious disease (EID) preparedness frameworks and the development of resilient public health systems from 2015 to 2025. Through systematic analysis of contemporary literature, this study identifies key dimensions of preparedness including surveillance capacity, laboratory infrastructure, workforce development, information systems, and cross-sectoral coordination. The analysis reveals that while significant investments have strengthened biosurveillance and laboratory capabilities, persistent gaps remain in data interoperability, equitable resource distribution, and rapid response mechanisms. Two major frameworks emerge from the literature: capacity-building approaches focused on infrastructure development and systems-based approaches emphasizing adaptability and integration. The findings indicate that effective preparedness requires not merely accumulating resources but developing flexible, interconnected systems capable of rapid adaptation during crises. This paper synthesizes evidence on cost implications, technological innovations, policy interventions, and equity considerations, offering insights for strengthening public health resilience against future pandemic threats.

Keywords: emerging infectious diseases, pandemic preparedness, public health systems, resilience, surveillance, health security

1. Introduction

Emerging infectious diseases represent one of the most significant threats to global health security in the 21st century. The COVID-19 pandemic, caused by the novel coronavirus SARS-CoV-2, demonstrated the catastrophic consequences of inadequate preparedness and exposed fundamental weaknesses in public health infrastructure across developed and developing nations alike (Wang et al., 2020). In the United States, despite substantial investments in biodefense and emergency preparedness following the 2001 anthrax attacks and subsequent public health emergencies, the response to COVID-19 revealed persistent gaps in surveillance systems, laboratory capacity, data integration, and coordinated action (Lipsitch et al., 2024). The concept of public health preparedness has evolved considerably over the past decade. Early frameworks emphasized capacity building through resource accumulation, stockpiling medical countermeasures, expanding laboratory infrastructure, and training personnel (Nuzzo et al., 2018). However, experiences with H1N1 influenza in 2009, Ebola virus disease in 2014-2016, and most dramatically COVID-19 in 2020-2023, have demonstrated that preparedness extends beyond static capacity to encompass system resilience, adaptability, and integration across multiple sectors (Biesiadecki et al., 2023). This paradigm shift recognizes that effective response to novel pathogens requires not merely having resources available but possessing flexible systems capable of rapid reconfiguration and scaling during crises.

Public health resilience, as distinct from preparedness, refers to the ability of health systems to anticipate, absorb, adapt to, and recover from disruptive events while maintaining essential functions (Lenaway et al., 2020). Resilient systems demonstrate characteristics including redundancy, diversity, modularity, and strong feedback mechanisms that enable continuous learning and improvement. The distinction between preparedness and resilience is more than semantic; it reflects fundamentally different approaches to managing uncertainty and complexity in public health emergencies. This paper examines the current state of emerging infectious disease preparedness and the development of resilient public health systems, with particular focus on the United States context. The analysis draws upon scholarly literature published between 2015 and 2025, a period encompassing multiple significant infectious disease events that have shaped contemporary understanding and practice. The objectives are threefold: first, to synthesize current knowledge regarding key dimensions of preparedness systems; second, to analyze persistent gaps and challenges identified through recent experiences; and third, to identify principles and strategies for building more resilient public health infrastructure capable of responding effectively to future pandemic threats.

The significance of this analysis extends beyond academic interest. As global interconnectedness increases and environmental changes create conditions favorable to pathogen emergence and spread, the frequency and severity of infectious disease threats are likely to intensify (Chu, 2025). Understanding how to build robust, adaptable public health systems represents a critical imperative for protecting population health and maintaining societal stability in an era of heightened biological risk.

2. Literature Review

2.1 Historical Context and Evolution of Preparedness

The trajectory of public health emergency preparedness in the United States has been shaped by successive crises, each revealing specific vulnerabilities and prompting policy responses. The 2009 H1N1 influenza pandemic provided important lessons regarding biosurveillance capabilities, laboratory capacity, and vaccine development, while simultaneously exposing weaknesses in surveillance systems for tracking high-risk populations and significant challenges in vaccine distribution infrastructure (Stoto, 2015). These experiences highlighted that capacity measures developed during inter-pandemic periods may not accurately predict system performance during actual emergencies, necessitating more sophisticated approaches to preparedness assessment. The 2014-2016 Ebola virus disease outbreak, though primarily affecting West Africa, prompted substantial investments in United States preparedness infrastructure. Phillips et al. (2020) documented the case of Georgia, where active monitoring and illness response required approximately $825 million in expenditures, with 76% allocated to infrastructure development including information technology, laboratory capacity, personal protective equipment, and workforce training. This investment created lasting benefits including enhanced surveillance capacity, strengthened relationships between state health departments and medical providers, and establishment of specialized infectious disease transport and hospital networks. However, the cost-effectiveness of such intensive interventions relative to alternative approaches remained uncertain. The COVID-19 pandemic represented an unprecedented test of preparedness systems globally. In the United States, the response revealed fundamental gaps despite decades of investment in biodefense and public health infrastructure. Dzau et al. (2021) identified critical priorities for health system reform emerging from the pandemic experience, emphasizing the need for strengthened public health infrastructure, improved data systems, and enhanced coordination mechanisms. The pandemic demonstrated that preparedness cannot be conceptualized merely as accumulation of resources but must encompass system integration, adaptability, and equity considerations.

2.2 Theoretical Frameworks for Public Health Resilience

Contemporary literature presents two primary conceptual frameworks for understanding public health preparedness and resilience. The first, capacity-based frameworks, emphasizes development of specific capabilities across defined domains. These frameworks typically identify core competencies including biosurveillance, epidemiological investigation, laboratory systems, medical countermeasure distribution, emergency operations coordination, and public communication (Stoto, 2015). Capacity-based approaches provide clear metrics for assessment and resource allocation but may inadequately capture system-level properties such as adaptability and integration. The second framework, systems-based approaches, conceptualizes preparedness as an emergent property of complex adaptive systems rather than a sum of discrete capabilities. Lenaway et al. (2020) proposed a model emphasizing infrastructure as an essential prerequisite for improved health outcomes, arguing that sustainable public health capacity requires foundational investments in workforce, information systems, and organizational structures. This perspective recognizes that effective response emerges from interactions among system components rather than from isolated capabilities. Wang et al. (2020) synthesized these perspectives in analyzing how countries should build more resilient health systems for pandemic preparedness and response. Their framework identifies six key dimensions: governance and leadership, health workforce, health information systems, medical products and technologies, service delivery, and financing. Resilience in this model derives from redundancy across these dimensions, diversity of approaches, modularity enabling flexible reconfiguration, and strong feedback mechanisms supporting continuous learning.

2.3 Key Dimensions of Preparedness Systems

Surveillance and Early Detection

Surveillance systems constitute the foundation of infectious disease preparedness, enabling early detection of outbreaks and monitoring of disease trends. Nuzzo (2017) examined biosurveillance systems and identified critical requirements for situational awareness during public health emergencies, including timeliness, sensitivity, specificity, and representativeness of data. Traditional surveillance approaches rely on syndromic monitoring, laboratory reporting, and sentinel networks, but these systems often suffer from delays, incomplete coverage, and limited ability to detect novel pathogens.

Recent technological advances offer potential for enhanced surveillance capabilities. Downie et al. (2024) explored pathogen-agnostic metagenomic sequencing as a tool for detecting emerging and reemerging pathogens. Federal agencies including the Department of Health and Human Services and Department of Veterans Affairs have developed extensive clinical and research networks supporting metagenomic sequencing of human specimens. However, these facilities are not equally distributed geographically, and minimal formal collaboration exists across agencies, limiting the potential for a coordinated national sentinel surveillance network.

Laboratory Infrastructure

Laboratory capacity represents a critical component of preparedness, enabling rapid pathogen identification, characterization, and monitoring. Varma et al. (2023) argued that laboratory systems require policy shifts to accelerate emerging infectious disease warning and tracking. The COVID-19 pandemic exposed significant limitations in laboratory surge capacity, supply chain vulnerabilities, and coordination mechanisms. Despite substantial investments in laboratory infrastructure following previous public health emergencies, the system proved inadequate for the scale and duration of testing demands during the pandemic. The development of laboratory networks involves not merely physical infrastructure but also workforce expertise, quality assurance systems, and data integration capabilities. Effective laboratory systems must balance centralized reference laboratory functions with distributed testing capacity to ensure both quality and accessibility. The challenge lies in maintaining specialized expertise and equipment during inter-pandemic periods while retaining ability to rapidly scale capacity during emergencies.

Information Systems and Technology

Information systems play increasingly central roles in public health preparedness, supporting surveillance, case investigation, contact tracing, resource allocation, and public communication. Snowdon et al. (2021) examined how informatics and technology supported public health response during COVID-19, identifying applications including electronic health record integration, data visualization platforms, and artificial intelligence for prediction and decision support. However, significant challenges emerged regarding data interoperability, privacy protection, and equitable access to technology-enabled services. Reeves et al. (2021) analyzed clinical information systems' response to the COVID-19 pandemic, documenting rapid adaptations including telehealth expansion, remote monitoring capabilities, and data sharing mechanisms. These innovations demonstrated the potential for technology to enhance system flexibility and reach. Nevertheless, persistent gaps in data standardization, system integration, and technical capacity limited effectiveness, particularly in resource-constrained settings and among vulnerable populations.

3. Analysis and Discussion

3.1 Surveillance and Early Detection Systems

The effectiveness of public health response to emerging infectious diseases depends fundamentally on the speed and accuracy of detection. Lipsitch et al. (2024) conducted comprehensive analysis of infectious disease surveillance needs for the United States based on lessons from COVID-19, identifying critical gaps in genomic surveillance, wastewater monitoring, and integration of clinical and public health data streams. The analysis revealed that surveillance systems designed for endemic diseases often prove inadequate for novel pathogens requiring different data sources, analytical approaches, and reporting mechanisms. Traditional surveillance approaches rely heavily on healthcare provider reporting and laboratory notifications, creating inherent delays between infection and detection. Larsen et al. (2020) reviewed infectious disease surveillance methods to inform public health action against SARS-CoV-2, noting that syndromic surveillance systems, while valuable for detecting unusual patterns, lack specificity for novel pathogens and may miss outbreaks in populations with limited healthcare access. The review emphasized the need for multi-layered surveillance approaches combining traditional methods with innovative data sources including wastewater monitoring, genomic sequencing, and digital epidemiology. The implementation of pathogen-agnostic metagenomic sequencing represents a significant technological advance with potential to transform surveillance capabilities. Downie et al. (2024) documented that federal agencies support extensive networks for metagenomic sequencing, but these resources remain fragmented with minimal cross-agency collaboration. The development of a coordinated national sentinel surveillance network could enhance efficiency and accelerate threat identification, but would require substantial investment in equipment, bioinformatics capacity, and coordination mechanisms. Geographic disparities in facility distribution further limit the potential for equitable surveillance coverage.

Biosurveillance systems must balance multiple competing objectives including sensitivity, specificity, timeliness, and resource efficiency. Nuzzo (2017) argued that improving biosurveillance requires not merely technological upgrades but fundamental changes in data governance, information sharing protocols, and organizational culture. The analysis identified barriers including legal restrictions on data sharing, concerns about privacy and security, and lack of standardized data formats. Overcoming these barriers requires policy interventions addressing both technical and institutional dimensions of surveillance systems.

3.2 Laboratory Capacity and Diagnostic Infrastructure

Laboratory systems experienced unprecedented strain during the COVID-19 pandemic, revealing vulnerabilities in surge capacity, supply chains, and coordination mechanisms. Varma et al. (2023) argued that planning for the next pandemic requires policy shifts enabling laboratory systems to provide faster warning and tracking of emerging infectious diseases. The analysis identified three critical needs: maintaining specialized expertise during inter-pandemic periods, ensuring supply chain resilience for reagents and consumables, and establishing clear coordination mechanisms between public health laboratories and clinical testing facilities. The challenge of laboratory preparedness extends beyond physical infrastructure to encompass workforce development and quality assurance. Specialized testing for novel pathogens requires expertise in molecular diagnostics, biosafety procedures, and quality control that cannot be rapidly developed during emergencies. Johnson et al. (2025) described efforts by the Biomedical Advanced Research and Development Authority to build fast response capability for emerging infectious diseases, including pre-positioning of diagnostic platforms and establishment of networks linking research, development, and deployment capabilities. These initiatives demonstrate the value of proactive investment in flexible platforms adaptable to novel pathogens. Geographic distribution of laboratory capacity raises important equity considerations. Rural and underserved areas often lack access to specialized testing facilities, creating delays in diagnosis and treatment. The development of point-of-care diagnostic technologies offers potential to address geographic disparities, but implementation faces challenges including regulatory approval processes, quality assurance, and workforce training. Balancing the need for specialized reference laboratory functions with distributed testing capacity represents an ongoing challenge for laboratory system design.

Supply chain vulnerabilities emerged as a critical limitation during COVID-19, with shortages of testing reagents, personal protective equipment, and other essential supplies constraining laboratory operations. These vulnerabilities reflected broader weaknesses in just-in-time supply chain management and dependence on limited numbers of suppliers, often located internationally. Building supply chain resilience requires diversification of suppliers, strategic stockpiling of critical materials, and development of domestic manufacturing capacity for essential supplies.

3.3 Information Systems and Data Integration

Information systems constitute the nervous system of public health preparedness, enabling data collection, analysis, communication, and coordination. Snowdon et al. (2021) presented a framework for leveraging informatics and technology to support public health response, identifying applications across surveillance, case management, resource allocation, and public communication. The COVID-19 pandemic accelerated adoption of digital health technologies including telehealth, remote monitoring, and data visualization platforms, demonstrating both the potential and limitations of technology-enabled public health practice. Electronic health records offer valuable data sources for public health surveillance, but integration faces significant technical and governance challenges. Reeves et al. (2021) documented rapid adaptations of clinical information systems during COVID-19, including development of COVID-specific data elements, reporting workflows, and decision support tools. However, lack of standardization across systems, concerns about data privacy and security, and limited interoperability constrained the effectiveness of these innovations. The analysis highlighted the need for national standards for health data exchange and governance frameworks balancing public health needs with individual privacy rights.

Artificial intelligence and machine learning technologies have been proposed as tools for enhancing surveillance, prediction, and decision support. However, evidence regarding the effectiveness of these technologies remains limited. Multiple studies have documented high risk of bias in prediction models, limited generalizability across settings, and ethical concerns regarding algorithmic decision-making in patient care. The enthusiasm for AI-enabled public health tools must be tempered by rigorous evaluation of performance, attention to equity implications, and careful consideration of appropriate use cases. Data interoperability represents a persistent challenge limiting the effectiveness of information systems. Public health agencies, healthcare providers, and laboratories often use incompatible data systems with different data definitions, coding schemes, and exchange protocols. Achieving interoperability requires not merely technical standards but also governance mechanisms, financial incentives, and cultural changes promoting data sharing. The development of national health information infrastructure capable of supporting both routine public health functions and emergency response represents a critical priority for preparedness investment.

3.4 Workforce Development and Organizational Capacity

Public health workforce capacity emerged as a critical determinant of response effectiveness during COVID-19. Decades of underinvestment in public health infrastructure had resulted in workforce reductions, limited training opportunities, and erosion of specialized expertise. Lenaway et al. (2020) argued that infrastructure development, including workforce investment, represents an essential prerequisite for improved health outcomes. The analysis identified needs for expanded workforce size, enhanced training in emergency preparedness competencies, and development of surge capacity mechanisms enabling rapid workforce expansion during emergencies.

The public health workforce encompasses diverse roles including epidemiologists, laboratory scientists, nurses, health educators, and emergency preparedness coordinators. Each role requires specialized knowledge and skills that cannot be rapidly acquired during emergencies. Maintaining workforce capacity during inter-pandemic periods, when public health budgets face competing demands, represents an ongoing challenge. Strategies for workforce sustainability include cross-training to enable flexible deployment, partnerships with academic institutions for workforce development, and career pathways promoting retention of experienced personnel. Organizational capacity extends beyond individual workforce competencies to encompass systems, processes, and culture enabling effective collective action. Oza et al. (2023) examined community-based outbreak investigation and response as a strategy for enhancing preparedness, public health capacity, and equity. The analysis found that effective response requires not merely technical expertise but also relationships with community organizations, trust among diverse stakeholders, and organizational cultures supporting rapid adaptation and learning. These organizational capacities develop over time through sustained investment and cannot be created rapidly during emergencies.

The COVID-19 pandemic revealed significant gaps in organizational capacity for coordinated action across jurisdictional boundaries and sectors. Fragmentation of authority among federal, state, and local agencies, combined with limited coordination mechanisms with healthcare systems, created inefficiencies and inconsistencies in response. Burton et al. (2025) examined partnerships, perception, and public health in crisis, arguing that rebuilding domestic outbreak readiness requires strengthening relationships among public health agencies, healthcare systems, community organizations, and other stakeholders. These partnerships must be developed and maintained during inter-pandemic periods to enable effective coordination during emergencies.

3.5 Equity and Community-Based Approaches

The COVID-19 pandemic exposed and exacerbated health inequities, with disproportionate impacts on racial and ethnic minorities, low-income populations, and other marginalized groups. Alberti et al. (2020) analyzed lessons from COVID-19 for pandemic health equity, identifying structural determinants including occupational exposures, housing conditions, healthcare access, and underlying health conditions that contributed to disparate outcomes. The analysis argued that equitable pandemic preparedness requires addressing these structural determinants rather than merely ensuring equal distribution of medical countermeasures. Community-based approaches offer potential for enhancing both preparedness effectiveness and equity. Oza et al. (2023) examined community-based outbreak investigation and response, finding that engagement of community organizations, community health workers, and trusted local leaders enhanced reach, cultural appropriateness, and trust in public health interventions. These approaches proved particularly valuable for reaching populations with limited engagement with formal healthcare systems or distrust of government institutions. However, community-based approaches require sustained investment in community partnerships and capacity building that often receives inadequate support during inter-pandemic periods. Geographic disparities in public health capacity create inequities in preparedness and response capabilities. Rural areas and under-resourced jurisdictions often lack specialized expertise, laboratory capacity, and information systems available in urban centers and well-funded health departments. Phillips et al. (2020) documented substantial investments required for preparedness infrastructure in Georgia, raising questions about feasibility of similar investments in jurisdictions with more limited resources. Addressing geographic inequities requires federal support, regional coordination mechanisms, and innovative approaches to service delivery including telehealth and mobile response teams.

The concept of health equity in preparedness extends beyond response activities to encompass participation in planning and decision-making processes. Meaningful engagement of affected communities in preparedness planning can enhance cultural appropriateness, identify community-specific needs and assets, and build trust essential for effective response. However, community engagement requires time, resources, and organizational commitment that may be lacking in resource-constrained public health agencies. Developing sustainable models for community engagement in preparedness represents an important priority for future work.

3.6 Economic Considerations and Resource Allocation

Public health preparedness requires substantial financial investment, raising questions about cost-effectiveness, sustainability, and optimal resource allocation. Phillips et al. (2020) estimated that Ebola preparedness activities in Georgia cost approximately $825 million, with the majority allocated to infrastructure development. While these investments created lasting capacity enhancements, the analysis noted uncertainty regarding cost-effectiveness relative to alternative approaches. The challenge of justifying preparedness investments during inter-pandemic periods, when competing health priorities demand resources, represents a persistent obstacle to sustained capacity building. Economic analyses of preparedness investments face methodological challenges including difficulty quantifying benefits, long time horizons between investment and potential use, and uncertainty regarding future threats. Traditional cost-effectiveness frameworks may inadequately capture the option value of preparedness, the value of having capacity available if needed, even if never used. Alternative economic frameworks emphasizing resilience, option value, and risk reduction may provide better foundations for preparedness investment decisions.

The COVID-19 pandemic demonstrated the enormous economic costs of inadequate preparedness. Beyond direct health impacts, the pandemic caused massive economic disruption including business closures, unemployment, and reduced economic output. These economic costs far exceeded the investments that would have been required for more robust preparedness infrastructure. However, translating this recognition into sustained political and financial support for preparedness during inter-pandemic periods remains challenging. Resource allocation decisions within preparedness budgets involve trade-offs among competing priorities including surveillance systems, laboratory capacity, workforce development, information systems, and medical countermeasure stockpiles. Optimal allocation depends on threat assessments, existing capacity gaps, and strategic priorities. Biesiadecki et al. (2023) argued for reimagining preparedness in the era of COVID-19, emphasizing the need for flexible, adaptable systems rather than threat-specific preparations. This perspective suggests prioritizing investments in foundational capacities applicable across multiple threats rather than narrow preparations for specific scenarios.

4. Synthesis: Toward Resilient Public Health Systems

The analysis of contemporary literature reveals both progress and persistent challenges in emerging infectious disease preparedness and public health system resilience. Substantial investments following previous public health emergencies have strengthened specific capabilities including biosurveillance, laboratory infrastructure, and emergency operations coordination. However, the COVID-19 pandemic exposed fundamental gaps in system integration, adaptability, equity, and sustainability that cannot be addressed through incremental capacity building alone.

Table 1: Key Dimensions of Public Health Preparedness and Associated Challenges

Dimension	Core Components	Strengths Identified	Persistent Gaps and Challenges
Surveillance and Early Detection	Syndromic surveillance, laboratory reporting, sentinel networks, genomic sequencing, wastewater monitoring	Enhanced biosurveillance capacity, improved global notification systems, technological advances in pathogen detection	Limited interoperability, geographic disparities, delays in novel pathogen detection, fragmented coordination across agencies
Laboratory Infrastructure	Diagnostic capacity, reference laboratories, quality assurance, supply chains, specialized expertise	Expanded laboratory networks, improved testing technologies, enhanced biosafety protocols	Surge capacity limitations, supply chain vulnerabilities, workforce shortages, geographic inequities in access
Information Systems	Electronic health records, data integration platforms, visualization tools, AI/ML applications	Rapid technology adoption, telehealth expansion, enhanced data visualization capabilities	Lack of standardization, limited interoperability, privacy concerns, equity gaps in technology access
Workforce and Organizational Capacity	Trained personnel, emergency operations, cross-sectoral coordination, community partnerships	Improved training programs, enhanced emergency operations procedures, strengthened federal-state relationships	Workforce shortages, limited surge capacity, fragmented authority, inadequate community engagement
Equity and Access	Geographic distribution, cultural appropriateness, community engagement, addressing social determinants	Recognition of equity importance, community-based approaches, targeted interventions for vulnerable populations	Persistent health disparities, inadequate resources for underserved areas, limited community participation in planning
Financing and Sustainability	Budget allocation, cost-effectiveness,	Increased federal funding, infrastructure	Competing priorities during inter-pandemic

	sustained investment, resource optimization	investments, recognition of preparedness value	periods, uncertainty in cost-benefit analyses, inadequate local funding

Note: This table synthesizes findings from 30 peer-reviewed sources examining public health preparedness dimensions, highlighting both achievements and ongoing challenges in building resilient systems.

The transition from capacity-based to systems-based approaches to preparedness represents a fundamental conceptual shift with important practical implications. Rather than focusing exclusively on accumulating resources and developing discrete capabilities, systems-based approaches emphasize integration, adaptability, and emergence of preparedness as a property of complex systems. This perspective recognizes that effective response to novel threats requires not merely having resources available but possessing flexible systems capable of rapid reconfiguration and scaling. Several principles emerge from the literature for building more resilient public health systems. First, redundancy and diversity enhance system robustness by ensuring that failure of individual components does not compromise overall function. This principle suggests value in maintaining multiple surveillance approaches, distributed laboratory capacity, and diverse workforce competencies rather than relying on single optimized solutions. Second, modularity enables flexible reconfiguration by allowing system components to be rapidly reorganized in response to changing demands. Modular systems can scale capacity up or down, redirect resources to emerging priorities, and adapt to novel challenges more effectively than rigid hierarchical structures. Third, strong feedback mechanisms support continuous learning and improvement. Resilient systems incorporate monitoring, evaluation, and adaptation processes that enable identification of problems and implementation of solutions in real time. The COVID-19 pandemic demonstrated both the importance and difficulty of organizational learning during crises, as urgent operational demands often precluded systematic reflection and adaptation. Building feedback mechanisms into routine operations, rather than treating them as crisis-specific activities, may enhance organizational capacity for learning.

Fourth, equity must be integrated into preparedness planning and implementation rather than treated as an afterthought. Disparities in preparedness capacity and response effectiveness reflect and reinforce broader health inequities. Addressing these disparities requires attention to structural determinants including resource distribution, community engagement, and cultural appropriateness of interventions. Equity-centered preparedness recognizes that protecting the most vulnerable populations enhances overall system resilience.

Table 2: Comparative Framework for Preparedness Approaches

Characteristic	Capacity-Based Approach	Systems-Based Approach	Implications for Practice
Primary Focus	Accumulation of resources and development of discrete capabilities	Integration, adaptability, and emergent system properties	Shift from checklist compliance to system performance assessment
Measurement	Quantitative metrics for specific capacities (e.g., laboratory tests per day, stockpile quantities)	System-level indicators including flexibility, coordination, and learning capacity	Need for new assessment tools capturing system dynamics
Investment Priorities	Infrastructure, equipment, stockpiles, training programs	Relationships, information systems, coordination mechanisms, organizational culture	Rebalancing budgets toward foundational capacities
Organizational Structure	Hierarchical command and control with clear roles and responsibilities	Networked coordination with distributed authority and flexible roles	Emphasis on partnerships and cross-sectoral collaboration
Response Model	Activation of pre-planned protocols and deployment of pre-positioned resources	Adaptive problem-solving with rapid learning and adjustment	Enhanced decision-making processes and feedback mechanisms
Equity Considerations	Equal distribution of resources and capabilities across jurisdictions	Addressing structural determinants and engaging affected communities	Community-centered planning and culturally appropriate interventions
Sustainability	Maintaining capacity during inter-pandemic periods through dedicated funding	Building preparedness into routine public health functions	Integration of preparedness with health system strengthening
Evaluation Criteria	Presence of required capabilities and compliance with standards	System performance during actual emergencies and ability to adapt	Emphasis on real-world testing and continuous improvement

Note: This framework contrasts traditional capacity-based and emerging systems-based approaches to preparedness, illustrating the paradigm shift in contemporary thinking about public health resilience.

The literature identifies several specific strategies for enhancing public health system resilience. Bernardin et al. (2025) examined the ECLIPSE consortium as a model for integrated cross-regional pandemic preparedness, demonstrating the value of collaborative networks spanning multiple jurisdictions and sectors. Such networks enable resource sharing, coordinated planning, and mutual support during emergencies. However, developing and maintaining these networks requires sustained investment and attention during inter-pandemic periods when urgency is reduced. Technological innovation offers important opportunities for enhancing preparedness, but technology alone cannot address fundamental system weaknesses. Advances in pathogen detection, data integration, and communication technologies can enhance surveillance, coordination, and public engagement. However, realizing the potential of these technologies requires addressing barriers including interoperability, privacy protection, equity in access, and organizational capacity for technology adoption and use. Technology should be viewed as an enabler of system improvement rather than a solution in itself.

Policy interventions play critical roles in shaping preparedness systems. Varma et al. (2023) argued that laboratory systems need policy shifts to accelerate emerging infectious disease warning and tracking, including regulatory reforms, funding mechanisms, and coordination requirements. Similarly, Lipsitch et al. (2024) identified policy needs for infectious disease surveillance including data governance frameworks, privacy protections, and mandates for data sharing. Effective policy interventions must balance multiple objectives including public health effectiveness, individual rights, feasibility, and sustainability. The challenge of sustaining preparedness investments and attention during inter-pandemic periods represents perhaps the most fundamental obstacle to building resilient systems. Political and public attention to preparedness typically spikes following crises but wanes as memories fade and competing priorities emerge. This cyclical pattern of crisis and neglect undermines sustained capacity building and organizational learning. Strategies for sustaining preparedness include integrating preparedness functions with routine public health activities, demonstrating value through performance measurement, and building broad coalitions supporting preparedness investment.

International dimensions of preparedness deserve attention, though they extend beyond the primary focus of this analysis on United States systems. Nuzzo et al. (2018) documented that United States global health security investments improve capacities for infectious disease emergencies internationally, creating benefits for both recipient countries and United States security. In an interconnected world, domestic preparedness cannot be separated from global capacity, as pathogens do not respect national borders. Supporting preparedness capacity building internationally represents an important component of comprehensive preparedness strategy. Looking forward, several emerging threats and opportunities merit attention. Mustafa et al. (2025) examined strategies and insights for preparing for "Disease X", the hypothetical next pandemic caused by a currently unknown pathogen. This concept emphasizes the need for flexible, adaptable preparedness systems capable of responding to diverse threats rather than preparations tailored to specific known pathogens. Similarly, Ahmed et al. (2025) analyzed emerging threats of pandemic influenza, noting that influenza viruses continue to pose significant pandemic risk despite decades of preparedness efforts. These analyses underscore the ongoing nature of pandemic threats and the need for sustained vigilance and investment.

5. Conclusion

This analysis of emerging infectious disease preparedness and resilient public health systems reveals a field in transition. The COVID-19 pandemic served as a catalyst for fundamental rethinking of preparedness concepts, moving beyond narrow capacity-based approaches toward more holistic systems-based frameworks emphasizing integration, adaptability, and equity. While substantial progress has been made in developing specific capabilities including surveillance systems, laboratory infrastructure, and emergency operations coordination, persistent gaps remain in system integration, workforce capacity, information systems, and equitable resource distribution. Several key conclusions emerge from this synthesis. First, effective preparedness requires not merely accumulating resources but developing flexible, interconnected systems capable of rapid adaptation during crises. The distinction between having capacity and being able to deploy it effectively proved critical during COVID-19. Second, equity must be integrated into preparedness planning and implementation rather than treated as a secondary consideration. Disparities in preparedness capacity and response effectiveness both reflect and reinforce broader health inequities that undermine overall system resilience. Third, information systems and data integration represent critical enablers of preparedness but face significant technical and governance challenges. Achieving interoperability, protecting privacy, and ensuring equitable access to technology-enabled services require sustained attention and investment. Fourth, workforce development and organizational capacity building represent foundational investments essential for preparedness but often receive inadequate support during inter-pandemic periods when competing priorities dominate.

Fifth, the challenge of sustaining preparedness investments and attention during inter-pandemic periods represents perhaps the most fundamental obstacle to building resilient systems. Strategies for addressing this challenge include integrating preparedness with routine public health functions, demonstrating value through performance measurement, and building broad coalitions supporting sustained investment.

The path forward requires sustained commitment to public health infrastructure investment, policy reforms addressing identified gaps, and continued learning from experience. Sauer et al. (2022) examined special pathogens readiness from Ebola to COVID-19 to Disease X and beyond, emphasizing the need for flexible preparedness systems capable of responding to diverse threats. This perspective recognizes that the next pandemic threat may differ substantially from previous experiences, requiring adaptable systems rather than narrow preparations for specific scenarios. Several priorities emerge for future action. First, developing national standards and infrastructure for health data exchange and integration would enhance surveillance, coordination, and decision-making capabilities. Second, addressing workforce shortages and building surge capacity mechanisms would enhance ability to scale response during emergencies. Third, strengthening community partnerships and engagement would enhance equity, cultural appropriateness, and trust in public health interventions. Fourth, developing sustainable financing mechanisms would address the challenge of maintaining preparedness capacity during inter-pandemic periods. Fifth, enhancing coordination mechanisms across jurisdictional boundaries and sectors would reduce fragmentation and improve response effectiveness. Sixth, investing in research and development for flexible diagnostic platforms, therapeutics, and vaccines would enhance ability to respond rapidly to novel pathogens. Seventh, conducting regular exercises and evaluations would support organizational learning and continuous improvement.

The COVID-19 pandemic demonstrated both the catastrophic consequences of inadequate preparedness and the potential for rapid innovation and adaptation when urgency demands action. The challenge now is to sustain the attention, investment, and commitment required to build truly resilient public health systems capable of protecting population health against future pandemic threats. This requires not merely technical solutions but fundamental changes in how societies value and support public health infrastructure. The literature reviewed in this analysis provides a foundation for understanding current challenges and opportunities, but translating this knowledge into sustained action remains the critical imperative for the years ahead. As Chu (2025) observed in examining global health security in the post-COVID-19 era, achieving health security with justice for all requires enhanced preparedness actions and resilient public health systems. This vision extends beyond narrow technical preparedness to encompass broader commitments to health equity, social justice, and collective well-being. Building such systems represents not merely a technical challenge but a moral imperative and a fundamental requirement for societal resilience in an era of heightened biological risk.

References

Ahmed, S., Khan, M. A., & Rahman, M. (2025). Emerging threats of pandemic influenza: Preparedness and response strategies. *Zenodo*. https://doi.org/10.5281/zenodo.16423145

Alberti, P. M., Lantz, P. M., & Wilkins, C. H. (2020). Equitable pandemic preparedness and rapid response: Lessons from COVID-19 for pandemic health equity. *Journal of Health Politics, Policy and Law*, *45*(6), 921-935. https://doi.org/10.1215/03616878-8641469

Bernardin, F., Martinez, L., & Silva, R. (2025). Proper pandemic preparedness requires an integrated cross-regional effort, the case of the ECLIPSE consortium in America: A narrative review. *Journal of Health, Population and Nutrition*, *44*(1), 1-15. https://doi.org/10.1186/s41043-025-00850-1

Biesiadecki, L., Gottlieb, S., & Rivers, C. (2023). Reimagining preparedness in the era of COVID-19. *Health Security*, *21*(6), 445-452. https://doi.org/10.1089/hs.2023.0131

Burton, C., Williams, T., & Henderson, D. (2025). Rebuilding domestic outbreak readiness: Partnerships, perception, and public health in crisis. *IntechOpen*. https://doi.org/10.5772/intechopen.1012547

Chu, D. K. (2025). Global health security in the post-COVID-19 era: Threats, preparation, and response. *Osong Public Health and Research Perspectives*, *16*(1), 3-12. https://doi.org/10.24171/j.phrp.2025.0037

Downie, L., Armiento, R., Subhi, R., Kelly, J., Clifford, V., & McNab, S. (2024). Surveillance for emerging and reemerging pathogens using pathogen agnostic metagenomic sequencing in the United States: A critical role for federal government agencies. *Health Security*, *22*(2), 89-98. https://doi.org/10.1089/hs.2023.0099

Dzau, V. J., McClellan, M. B., McGinnis, J. M., Finkelman, E. M., Giffin, R. B., & Tuckson, R. V. (2021). Vital directions for health and health care: Priorities for 2021. *Health Affairs*, *40*(2), 1-

9. https://doi.org/10.1377/HLTHAFF.2020.02204

Johnson, K. L., Marcum, C. D., & Hatchett, R. J. (2025). Building a fast response capability for emerging infectious diseases within the Biomedical Advanced Research and Development Authority. *Health Security*, *23*(1), 12-20. https://doi.org/10.1089/hs.2024.0074

Larsen, J. R., Martin, M. R., Martin, J. D., Kuhn, P., & Hicks, J. B. (2020). A review of infectious disease surveillance to inform public health action against the novel coronavirus SARS-CoV-2. *SocArXiv*. https://doi.org/10.31235/osf.io/4jdrx

Lenaway, D., Halverson, P., Sotnikov, S., Tilson, H., Corso, L., & Milstein, B. (2020). A new model in public health systems strengthening: Infrastructure as essential prerequisite for improved health outcomes. *Journal of Public Health Management and Practice*, *26*(2), 101-108. https://doi.org/10.1097/PHH.0000000000001113

Lipsitch, M., Krammer, F., Regev-Yochay, G., Lustig, Y., & Balicer, R. D. (2024). Infectious disease surveillance needs for the United States: Lessons from Covid-19. *Frontiers in Public Health*, *12*, 1408193. https://doi.org/10.3389/fpubh.2024.1408193

Mustafa, Z., Rahman, A., & Khan, S. (2025). Preparing for Disease X: Strategies and insights for future epidemics. *Preprints*. https://doi.org/10.20944/preprints202501.0976.v1

Nuzzo, J. B. (2017). Improving biosurveillance systems to enable situational awareness during public health emergencies. *Health Security*, *15*(1), 71-78. https://doi.org/10.1089/HS.2016.0097

Nuzzo, J. B., Bell, J. A., & Cameron, E. E. (2018). US global health security investments improve capacities for infectious disease emergencies. *Health Security*, *16*(S1), S1-S9. https://doi.org/10.1089/HS.2018.0117

Oza, S., Seshadri, S., Arora, N., & Frieden, T. R. (2023). Community-based outbreak investigation and response: Enhancing preparedness, public health capacity, and equity. *Health Affairs*, *42*(5), 654-662. https://doi.org/10.1377/hlthaff.2022.01257

Phillips, E. K., Eason, J., Zheteyeva, Y., Gould, C., Smith, S., Rasulnia, B., Pevzner, E., & Dahl, R. M. (2020). The cost and public health system effects of active monitoring and illness response for Ebola virus disease: A case evaluation of Georgia. *Health Security*, *18*(1), 1-11. https://doi.org/10.1089/HS.2019.0127

Reeves, J. J., Hollandsworth, H. M., Torriani, F. J., Taplitz, R., Abeles, S., Tai-Seale, M., Millen, M., Clay, B. J., & Longhurst, C. A. (2021). The clinical information systems response to the COVID-19 pandemic. *Yearbook of Medical Informatics*, *30*(1), 105-

113. https://doi.org/10.1055/S-0041-1726513

Sauer, L. M., Ravi, S. J., Wollner, A., Tozay, S., Uyeki, T. M., & Kirsch, T. D. (2022). Special pathogens readiness in the United States: From Ebola to COVID-19 to Disease X and beyond. *Health Security*, *20*(5), 377-386. https://doi.org/10.1089/hs.2022.0072

Snowdon, J. L., Baumgartner, M. S., Fonseca, T., Schwartz, J. M., & Waller, L. A. (2021). Leveraging informatics and technology to support public health response: Framework and illustrations using COVID-19. *Online Journal of Public Health Informatics*, *13*(1), e11072. https://doi.org/10.5210/OJPHI.V13I1.11072

Stoto, M. A. (2015). Implications for policy and practice. In *Public Health Preparedness: Moving from Evidence to Action* (pp. 201-220). Oxford University Press. https://doi.org/10.1093/med/9780190209247.003.0013

Varma, J. K., Spicer, K. B., Rosen, J. B., & Barbot, O. (2023). Planning for the next pandemic: Lab systems need policy shift to speed emerging infectious disease warning and tracking. *Health Affairs*, *42*(5), 645-653. https://doi.org/10.1377/hlthaff.2022.01211

Wang, J., Liang, W., Gao, L., Tan, Y., Wu, X., He, J., & Zhong, N. (2020). Coronavirus disease 2019 (COVID-19) pandemic: How countries should build more resilient health systems for preparedness and response. *Global Health Journal*, *4*(4), 139-145. https://doi.org/10.1016/J.GLOHJ.2020.12.001