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Rebuilding Public Health Systems in an Era of Converging Crises: A Climate-Sensitive Resilience Framework

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Abstract

Background: The COVID-19 pandemic exposed deep structural weaknesses in public health systems across the world, including fragmented surveillance, fragile service capacity, inconsistent risk communication, and persistent health inequities. At the same time, the climate crisis is intensifying heat-related illness, vector-borne disease, extreme weather disruptions, displacement, and pressures on health infrastructure and workforces. Contemporary health threats are increasingly converging rather than isolated.

Methods: Drawing on a conceptual synthesis of COVID-19 lessons, health system resilience scholarship, and recent guidance from the World Health Organization and the IPCC, this article develops the Integrated Climate-Sensitive Public Health Resilience (ICPHR) Framework, a four-dimensional and system-based model organized around preparedness, absorption, adaptation, and recovery.

Results: The framework conceptualizes resilience as a dynamic and cyclical process through which public health systems anticipate, withstand, learn from, and transform after shocks while maintaining essential functions. The analysis identifies five strategic pathways for resilient system transformation: integrated surveillance and early warning, stronger primary health care, trust-based risk communication, equity-centered design, and cross-sectoral governance.

Conclusions: Resilience in the coming decade must be climate-sensitive, institutionally embedded, and oriented toward long-term system transformation rather than temporary emergency response. Unlike existing models, the proposed framework explicitly integrates climate-sensitive risks into a cyclical and system-based structure. This framework provides actionable insights for public health system strengthening, particularly in integrating pandemic preparedness with climate-sensitive health risk management. Public health resilience should become the central paradigm guiding health system transformation in an era of converging global crises.

Keywords: public health resilience; COVID-19; climate change; health systems strengthening; global health

1. Introduction

1.1. COVID-19 as a systemic stress test

The COVID-19 pandemic was not only a biomedical emergency. It was a comprehensive stress test of the institutions, infrastructures, and governance arrangements that sustain population health. Across high-, middle-, and low-income settings alike, the pandemic demonstrated that public health emergencies do not merely reveal pathogen-specific weaknesses; they expose the organizational depth, coordination capacity, and social legitimacy of the broader health system. Countries with sophisticated hospital sectors still struggled to coordinate testing, reporting, communication, workforce protection, and service continuity. Systems that appeared well resourced in normal times often proved brittle once confronted with prolonged uncertainty, repeated surges, and the need to balance acute response with routine care. [1,2]

The pandemic also challenged long-standing assumptions about the relationship between health security and health system strength. Before 2020, many policy discussions treated emergency preparedness as a largely technical question of plans, stockpiles, and surveillance compliance. COVID-19 showed that preparedness could not be reduced to formal checklists or legal instruments. The ability to respond effectively depended on whether countries had trusted institutions, integrated data systems, a supported workforce, viable primary care, and governance arrangements capable of rapid coordination across public health, clinical care, social services, and local communities. [1,3] In this sense, COVID-19 made visible the public health consequences of fragmentation that had long been normalized within many systems.

The disruption of essential services further underlined this point. The pandemic did not simply create a new burden of infectious disease; it also interrupted immunization, maternal care, chronic disease management, mental health services, and preventive programs. These disruptions were not incidental side effects. They were signs that many systems lacked the absorptive capacity to protect core public health and health care functions under conditions of prolonged stress. [1,4] A systematic review of health service utilization during the pandemic likewise documented major declines across care settings, reinforcing the point that continuity capacity is a core dimension of resilience rather than an afterthought. [5] The result was a dual crisis: an emergency response crisis and a continuity crisis.

What COVID-19 therefore revealed was not just vulnerability to one novel coronavirus. It revealed that public health systems are embedded in wider political, informational, ecological, and social structures. When those structures are weak, response becomes reactive, uneven, and inequitable. When they are strong, systems are more capable of protecting both populations and routine services simultaneously. This broader lesson is foundational for any serious discussion of resilience after COVID-19.

1.2. Climate crisis as an emerging health driver

If COVID-19 exposed the fragility of public health systems, climate change is steadily increasing the frequency and complexity of the pressures those systems must manage. The IPCC's Sixth Assessment Report makes clear that human-induced climate change is already affecting weather and climate extremes in every region of the world, with direct and indirect consequences for health. [6] WHO similarly identifies climate change as a threat multiplier that undermines environmental and social determinants of health, disrupts health infrastructure, and intensifies morbidity and mortality through heatwaves, floods, storms, wildfires, food insecurity, water insecurity, and the spread of infectious disease. [7]

This means that climate change should not be understood as a distant environmental issue external to public health. It is already reshaping the risk landscape within which public health systems operate. Heat stress is now one of the leading causes of weather-related death, and WHO estimates that approximately 489,000 heat-related deaths occur annually worldwide based on 2000-2019 evidence. [8] Climate change is also altering vector ecology, extending transmission seasons, and shifting the geographic range of vector-borne diseases. WHO notes that several vectors have expanded their latitude and altitude ranges and that the duration of seasonal activity is increasing as temperatures rise. [9] At the same time, extreme weather events can overwhelm health facilities, interrupt supply chains, damage water and sanitation systems, and intensify displacement and mental health burdens.

The 2024 Lancet Countdown report provides an especially stark reminder that climate-related health threats are not stabilizing. Its findings point to record-breaking temperatures, intensifying exposure, and delayed mitigation, all of which increase the burden on already strained health systems. [10] Importantly, climate impacts are unevenly distributed. WHO emphasizes that populations with the weakest infrastructure and the fewest adaptive resources are often the least able to cope, even though they contribute least to historical emissions. [7] In other words, climate change does not simply add new hazards. It deepens existing patterns of vulnerability and threatens to reverse gains in health equity.

For public health systems, climate change thus functions as both a health driver and a system stressor. It increases disease burdens while simultaneously undermining the very institutions tasked with responding. Any serious post-COVID health reform agenda that omits climate risk is therefore analytically incomplete and strategically shortsighted.

1.3. Converging crises and compound risk

The significance of the present moment lies not only in the existence of multiple crises, but in their interaction. Pandemic threats, climate hazards, chronic disease burdens, misinformation, displacement, and political polarization do not occur in isolation. They compound one another. This convergence produces conditions of systemic uncertainty in which shocks cascade across sectors and vulnerabilities accumulate across populations.

The COVID-19 experience already suggested the need for such an integrated perspective. Horton argued that COVID-19 should be understood not simply as a pandemic but as a syndemic because its harms were intensified by the interaction of infectious disease, noncommunicable disease, and social inequality. [11] Mendenhall further emphasized that syndemic dynamics are context dependent and shaped by political and structural conditions. [12] These arguments are highly relevant for the post-pandemic era because climate change is likely to intensify the same biosocial interactions: heat worsens cardiovascular and respiratory disease, extreme weather disrupts care, food insecurity amplifies malnutrition, and displacement increases exposure to infectious and mental health risks.

The concept of polycrisis pushes this insight even further by drawing attention to how multiple crises become mutually reinforcing rather than merely simultaneous. Kwamie et al argue that the convergence of climate change, conflict, and the lasting effects of COVID-19 calls for complexity-aware forms of evidence and governance. [13] Jorgensen et al similarly describe an Anthropocene characterized by interacting

traps and hard-to-reverse vulnerabilities. [14] For public health systems, the practical implication is clear: institutions designed for single-event emergencies will struggle in an era where crises overlap, feedback into one another, and unfold over different temporal scales.

Compound risk also complicates the classic boundary between acute emergencies and long-term stressors. A pandemic may seem acute, while climate change seems chronic, but in practice both involve repeated waves, delayed effects, uneven exposure, and cumulative strain on institutions. Health systems may be asked to respond to heat emergencies during ongoing respiratory outbreaks, to maintain routine care amid disaster-related displacement, or to address chronic disease burdens intensified by social disruption. The problem is no longer one of isolated preparedness. It is one of systemic resilience under persistent convergence.

1.4. Research gap

Although the literature on health system resilience has expanded substantially since Ebola and accelerated after COVID-19, an important gap remains. First, much of the resilience literature has focused on general health system capacities without sufficiently centering public health functions such as surveillance, communication, prevention, community engagement, and population-level protection. [15–17] Second, COVID-19 analyses have often concentrated on pandemic preparedness, emergency coordination, or health security lessons, while climate-health research has frequently examined adaptation and vulnerability on a separate track. [18, 19] Third, many frameworks distinguish absorptive, adaptive, and transformative capacities but do not translate them into an integrated and operationally sequenced model for public health systems facing both pandemic and climate pressures.

This separation matters. If pandemic preparedness is framed independently from climate adaptation, policy systems risk building duplicate infrastructures, fragmented data architectures, and siloed governance arrangements. If resilience is discussed only at a high conceptual level, it becomes rhetorically attractive but operationally vague. And if public health is reduced to emergency response rather than understood as a system of continuous population protection, then post-COVID reform may fail to address the deeper institutional weaknesses that made the pandemic so destructive in the first place.

Existing resilience frameworks often remain either conceptually broad or insufficiently integrated with emerging climate-related health risks. [15–19, 45] Moreover, few studies have operationalized resilience as a cyclical and system-oriented process linking pandemic preparedness with long-term climate adaptation. [18, 19, 45] This study addresses these gaps by proposing a climate-sensitive, four-dimensional public health resilience framework.

While existing resilience frameworks have advanced understanding of system capacities, they remain insufficiently operationalized for the context of converging crises. In particular, few models explicitly integrate climate-sensitive risks with pandemic preparedness within a unified, system-oriented architecture. This limits their applicability in guiding real-world public health system transformation.

There is therefore a need for a framework that does three things simultaneously. It must integrate pandemic and climate-related health risks rather than treating them as separate agendas. It must conceptualize resilience as a process rather than a static attribute. And it must connect conceptual analysis to concrete strategic pathways for institutional reform. That is the gap this article seeks to address.

1.5. Study objective and analytical approach

This study adopts a narrative and conceptual synthesis approach, integrating evidence from pandemic response analyses, resilience theory, and climate-health literature to develop a structured analytical framework. The article proposes a resilience-oriented framework for rebuilding public health systems in the post-COVID-19 and climate crisis era. It argues that public health resilience should be understood as the capacity of systems to prepare for, absorb, adapt to, and recover from shocks while maintaining essential functions and improving future performance. The article develops this argument through a conceptual synthesis of three bodies of literature: analyses of structural weaknesses revealed by COVID-19, scholarship on health system resilience, and emerging work and guidance on climate-sensitive health risks and system adaptation from WHO, the IPCC, and related public health scholarship.

The article makes three contributions. First, it integrates pandemic and climate-related health risks into a unified analytical framework. Second, it proposes the Integrated Climate-Sensitive Public Health Resilience (ICPHR) Framework, a climate-sensitive and system-oriented model organized around preparedness, absorption, adaptation, and recovery. Third, it outlines strategic pathways for system transformation in the post-COVID-19 era, with particular attention to surveillance, primary health care, communication, equity, and governance.

This study is a conceptual and analytical framework paper that integrates theory-building with prospective operationalization, aiming to bridge resilience conceptualization and measurement.

The remainder of the article proceeds as follows. Section 2 analyzes the structural weaknesses exposed by COVID-19. Section 3 examines the emerging and converging risks that define the post-pandemic and climate crisis era. Section 4 develops the concept of public health resilience and presents the four-dimensional framework. Section 5 translates the framework into strategic pathways for resilient system building. Section 6 discusses policy implications. Section 7 reflects on the article's theoretical contribution, limitations, and future research directions. Section 8 concludes by arguing that resilience should become the central organizing paradigm for public health system transformation.

2. Lessons from COVID-19: Structural Weaknesses

COVID-19 revealed many weaknesses, but four deserve special emphasis because they reflect system-level failure rather than isolated operational error. These are fragmented surveillance systems, imbalanced health system capacity, ineffective risk communication, and the exacerbation of health inequities. Together they illustrate why post-pandemic reform must go beyond preparedness plans and address the architecture of public health itself.

2.1. Fragmented surveillance systems

Surveillance was one of the most visible weaknesses during COVID-19. In many settings, epidemiological reporting, laboratory data, hospital data, primary care data, mortality statistics, and community intelligence operated in parallel rather than as an integrated whole. Information

frequently arrived late, was inconsistently standardized, or was too fragmented to support timely action. Local decision-makers often lacked access to real-time intelligence, while national dashboards sometimes obscured subnational variation and social disparities.

WHO's post-COVID work on collaborative surveillance directly addresses this problem. The organization argues that the pandemic demonstrated the need to rethink surveillance as a multisource and multisectoral function rather than a narrow disease-reporting exercise. [20] The issue was not simply insufficient data. It was insufficient integration across data types, sectors, and levels of governance. Surveillance systems were often built around administrative silos: communicable disease units separate from environmental monitoring, hospital reporting separate from community-level intelligence, and emergency platforms separate from routine health information systems.

This fragmentation had several consequences. First, it reduced the speed of detection and response, especially during early waves when delayed reporting translated directly into delayed intervention. Second, it weakened situational awareness by privileging narrow indicators over broader patterns such as occupational exposure, care disruption, or differential risk by neighborhood, race, migration status, or income. Third, it made learning difficult because data flows were not organized to connect outbreak detection with policy evaluation, health service continuity, or community feedback. In practical terms, systems often knew how many cases had been recorded but were much less able to see which populations were being excluded from care, where trust was collapsing, or how service disruptions were interacting with disease burden.

The absence of integrated surveillance also limited innovation. Genomic surveillance, wastewater surveillance, digital symptom tracking, and community-based reporting expanded in some places, but these tools were frequently added in an ad hoc manner rather than embedded into a coherent public health intelligence architecture. WHO's later emphasis on future surveillance and wastewater integration reflects the recognition that resilience requires routine interoperability before crises occur, not temporary patchwork during them. [21, 22] Recent work on integrating wastewater epidemiology with public health decision-making and on participatory disease surveillance further supports the need for surveillance systems that connect technical intelligence with community-facing action. [23, 24]

The lesson from COVID-19 is therefore not only that surveillance must be stronger. It must be redesigned as a collaborative system that links epidemiological, clinical, laboratory, environmental, and community data in ways that support action at multiple levels. Fragmentation was not a technical glitch. It was a structural condition that impaired preparedness, response, and learning.

2.2. Imbalanced health system capacity

The second major weakness revealed by COVID-19 was the imbalance in health system capacity. Many countries could mobilize extraordinary hospital surge responses, but these were often achieved by suspending routine care, exhausting staff, and relying on emergency improvisation. The problem was not only limited capacity in an absolute sense. It was the misalignment between different components of the system: hospital care, public health, primary care, supply chains, workforce planning, and social care were often funded and governed as separate worlds.

A review of 28 countries showed that resilience depended not simply on bed numbers or formal preparedness scores, but on governance, workforce flexibility, public health functions, and community engagement. [2] WHO's 2021 position paper made a similar point, arguing that COVID-19 disrupted all parts of society and that even countries scoring well on traditional security and universal health coverage measures struggled to manage the shock. [1]

Related analyses further showed that supposedly high-performing systems were not necessarily resilient and that fragmentation between global health security and universal health coverage weakened response capacity. [25, 26] In many settings, public health agencies lacked sustained investment relative to hospital medicine, while primary care and community-based services were insufficiently integrated into emergency planning.

This imbalance was visible in several domains. Intensive care and acute care capacity became political symbols, but continuity of vaccination, maternal health, mental health, rehabilitation, and chronic disease management often received less sustained attention. Health workers were celebrated rhetorically while facing shortages of protective equipment, burnout, moral injury, and delayed institutional support. Supply chains for diagnostics, medicines, vaccines, oxygen, and protective equipment were exposed as globally interdependent yet poorly governed. Health systems that could expand one function under pressure often did so by cannibalizing another.

Such capacity imbalance matters because public health emergencies are never only about the target disease. They are about whether a system can manage shock without collapsing into trade-offs that amplify mortality elsewhere. A resilient system needs surge capacity, but it also needs continuity capacity. It must preserve essential and routine services while adapting to elevated demand. This requires flexible financing, workforce redeployment protocols, decentralized service models, and stronger links between public health and primary care. COVID-19 revealed that many systems had been optimized for ordinary throughput rather than extraordinary strain.

In that sense, the capacity problem was systemic rather than episodic. The imbalance between acute clinical expansion and sustained public health functionality reflected years of underinvestment in prevention, community care, and institutional coordination. If not corrected, the same imbalance will recur under future pandemics, heatwaves, floods, or compound emergencies.

2.3. Ineffective risk communication

A third weakness exposed by COVID-19 was ineffective risk communication. In many countries, communication was treated as a downstream task of message delivery rather than a core component of public health governance. The result was frequent inconsistency across agencies, abrupt policy reversals without adequate explanation, insufficient acknowledgment of uncertainty, and poor adaptation of messages to different communities and risk environments.

COVID-19 made clear that information environments are now part of the emergency itself. Research on risk communication and the COVID-19 infodemic showed both the importance of clear communication and the harms caused by information gaps, misinformation, and low-quality evidence flows. [27–29] WHO's infodemic work likewise emphasizes that an overabundance of information, including false and misleading information, can undermine trust, distort risk perception, and weaken adherence to protective measures. [28] The challenge is therefore not only to communicate more, but to communicate in ways that are credible, transparent, locally relevant, and institutionally coordinated.

The most important failure was not public confusion alone. It was the absence of communication systems designed for dialogue, listening, and adaptation. Communication was often centralized, expert-led, and reactive, with limited mechanisms for incorporating community concerns, behavioral insights, or rapidly changing social conditions. Vulnerable populations were particularly poorly served when messages were not

linguistically accessible, not adapted to local media ecologies, or not linked to material support. Community engagement is essential for reaching vulnerable groups; without it, risk communication can widen rather than reduce inequality. [30]

The infodemic dimension made these weaknesses even more consequential. A recent systematic review showed that infodemics affect risk perceptions, trust, and confidence in health systems. [31] Where trust in institutions was already low, misinformation found fertile ground. Where public officials communicated uncertainty poorly or politicized scientific questions, skepticism intensified. Communication therefore became a test of institutional legitimacy as much as informational clarity. This dynamic was particularly visible in settings where trust in public health agencies became polarized or unstable over time. [32]

Public health systems need to treat communication as infrastructure, not public relations. Trust cannot be improvised once a crisis escalates. It depends on long-term transparency, credible spokespeople, strong local partnerships, and the ability to integrate social listening into decision-making. COVID-19 demonstrated that communication failure is a system failure because it directly affects behavioral response, compliance, equity, and social cohesion.

2.4. Exacerbation of health inequities

The fourth and perhaps most morally significant lesson from COVID-19 is that crises do not strike socially neutral populations. Rather, they intensify existing inequalities in exposure, susceptibility, access to care, and protection. The pandemic disproportionately harmed racial and ethnic minorities, lower-income groups, migrants, precarious workers, older adults, people with disabilities, and communities living in overcrowded or underserved conditions. [33, 34]

Importantly, these disparities were not merely demographic correlates. They reflected structural arrangements in labor markets, housing, social protection, transportation, digital access, and health care access. WHO explicitly noted that the burden of pandemic disruption was borne disproportionately by vulnerable communities across countries. [1] Hennis et al likewise argue that COVID-19 in the Americas magnified pre-existing social and health disparities, with implications for essential health services. [35] Vaccine inequity added another layer, both within countries and globally, demonstrating that access to biomedical innovation was mediated by power, purchasing capacity, and geopolitical asymmetry. [36, 37]

The implications for public health resilience are profound. If resilience is measured only by aggregate case decline or macro-level service restoration, it can obscure deep distributional failures. A system may appear effective at the national level while leaving frontline workers, informal settlements, rural communities, or undocumented migrants systematically less protected. Such outcomes are not secondary ethical concerns; they are indicators of weak system design. When inequities are large, disease control becomes less effective, trust deteriorates, and recovery is slower and more uneven.

COVID-19 therefore demonstrated that equity is not an optional add-on to preparedness. It is one of the central tests of whether a public health system is functioning well. Systems that lack disaggregated data, targeted outreach capacity, culturally competent communication, and inclusive financing arrangements are less resilient because they fail to protect the populations at greatest risk. In the next era of climate-amplified and transboundary emergencies, these failures are likely to become even more severe unless equity is placed at the center of resilience planning.

3. Emerging and Converging Risks in the Post-Pandemic and Climate Crisis Era

The weaknesses revealed by COVID-19 would already justify major reform. Yet the urgency is heightened because the next decade is likely to involve a more complex risk environment than the one before 2020. Public health systems are not merely recovering from a pandemic; they are entering an era of converging hazards marked by climate instability, epidemiological transition, and increasing global interdependence.

3.1. Climate-related health risks

Climate-related health risks are increasing in scale, frequency, and complexity. WHO describes climate change as directly contributing to humanitarian emergencies from heatwaves, wildfires, floods, tropical storms, and hurricanes, all of which are increasing in scale, frequency, and intensity. [7] Heat exposure is rising rapidly, with acute effects on cardiovascular, respiratory, renal, occupational, and mental health outcomes. [8] Extreme weather events damage infrastructure, interrupt transport, contaminate water, displace communities, and generate complex recovery needs that extend well beyond the initial event.

Infectious disease risk is also changing. Weather and climate conditions affect the incidence and geographic distribution of many diseases, and climate change is increasing the suitability of some environments for vectors and pathogens. [9, 46] WHO specifically notes that climate-sensitive diseases can be better anticipated when disease surveillance is integrated with weather and climate information. This implies that climate change is altering not only disease incidence, but also the data, forecasting, and governance capacities required for public health action.

The climate-health burden further extends to food and water insecurity, injury, displacement, reproductive health, and mental health. Climate shocks can reduce service access precisely when need rises. They can also degrade the determinants of health over longer time horizons through livelihood loss, ecosystem degradation, and social conflict. Public health systems are therefore increasingly confronted by slow-onset stresses and rapid-onset disasters that interact in complex ways.

3.2. Epidemiological transitions

The post-pandemic era is also characterized by epidemiological transition rather than simple epidemiological replacement. Emerging infectious threats remain a serious concern, but they now coexist with persistent and growing noncommunicable disease burdens, population ageing, and chronic vulnerability to environmental stress. COVID-19 itself demonstrated how infectious disease interacts with underlying burdens of diabetes, hypertension, respiratory illness, and cardiovascular disease. [11] Climate change is likely to intensify these interactions by worsening heat-related morbidity, air pollution exposure, malnutrition, and mental distress.

This creates a demanding policy environment. Health systems must prepare for emerging infectious hazards while sustaining long-term care for chronic conditions, mental health, and rehabilitation. They must do so under fiscal constraint, workforce shortages, and expanding social need.

The conventional separation between communicable disease preparedness and chronic disease management becomes increasingly untenable under these conditions.

The epidemiological transition also has a spatial dimension. Climate change, urbanization, migration, land-use change, and globalization alter where risks concentrate and how quickly they travel. Ferraz and Barreira describe global health as facing a triple challenge: preparing for future pandemics while responding to ongoing infectious threats in the midst of a planetary climate crisis. [38] This framing is useful because it captures the practical reality confronting many health systems: old burdens remain, new burdens emerge, and environmental stress changes the terrain on which both are managed.

3.3. Syndemic and polycrisis dynamics

The convergence of infectious disease, chronic illness, climate hazards, and social inequality is best understood through syndemic and polycrisis lenses. The syndemic perspective emphasizes that health harms are intensified when diseases and conditions cluster within populations affected by structural vulnerability. [11, 12] The polycrisis perspective emphasizes that multiple crises interact across sectors and scales, creating nonlinear and compounding effects. [13, 14]

These concepts help explain why future health emergencies may be harder to manage than past ones. A heatwave during a respiratory outbreak can increase both infection vulnerability and hospital demand. Flooding can disrupt medication access for people with chronic disease while increasing risk of waterborne illness and displacement. Food insecurity can worsen immune vulnerability and mental stress while undermining social stability. The issue is not that crises arrive one after another in neat sequence. It is that they reshape one another's consequences.

Kwamie et al argue that the convergence of threats such as climate change and the enduring effects of COVID-19 requires systems thinking and complexity-aware evidence. [13] That insight is especially relevant for public health governance, which has often been structured around categorical programs, short budgeting cycles, and narrowly defined indicators. Syndemic and polycrisis thinking instead direct attention to interaction effects, feedback loops, and cross-sector determinants. A resilient public health system must therefore be capable of recognizing and acting on combined vulnerability rather than single-hazard metrics alone.

3.4. Systemic uncertainty and global interdependence

Finally, the post-pandemic risk environment is defined by systemic uncertainty and global interdependence. COVID-19 demonstrated how rapidly local outbreaks can become global disruptions through travel, trade, information networks, and supply chains. It also revealed the fragility of global arrangements for equitable access to diagnostics, vaccines, therapeutics, and manufacturing capacity. [37] Climate change adds additional layers of transboundary complexity through shared ecosystems, migration pressures, cross-border smoke and pollution, food system instability, and simultaneous multi-country disasters.

Systemic uncertainty does not mean that nothing can be known. It means that shocks are increasingly difficult to bound in time, place, or sector. Public health systems must make decisions under ambiguity, partial information, and changing threat profiles. This places a premium on institutional flexibility, interoperability, and trust. It also strengthens the case for resilience as an organizing concept because resilience focuses not only on preventing specific harms, but on maintaining function under uncertain conditions.

In summary, public health systems are moving into an environment where risk is more interconnected, less predictable, and more socially differentiated. The challenge is not to prepare for a single next pandemic or a single next climate disaster. It is to build systems capable of navigating persistent convergence.

4. Conceptualizing Public Health Resilience

4.1. Limitations of traditional emergency response models

Traditional emergency response models remain necessary, but they are insufficient for the risk environment now confronting public health systems. Many such models are event-driven, hazard-specific, and oriented toward short-term control. They assume a relatively clear beginning, escalation, and endpoint to crisis. Their operational logic is often command-and-control: detect the event, mobilize response, suppress impact, and restore normality.

This approach has important strengths in acute emergencies, but it has several limitations. First, it tends to privilege visible response capacity over the less visible institutional foundations that make response sustainable, such as routine surveillance quality, community trust, continuity planning, and workforce well-being. Second, it often separates emergency response from health system strengthening, creating duplicated structures or temporary fixes rather than durable reform. Third, it treats recovery as a return to baseline, even when the pre-shock baseline was characterized by structural inequality, underinvestment, or ecological vulnerability.

The resilience literature has repeatedly criticized these limitations. Foundational and more recent analyses argue that resilience requires attention to governance, uncertainty management, conceptual clarity, and practical implementation rather than a narrow focus on resources alone. [15–17, 19, 39, 40] WHO's more recent guidance is even more explicit: resilience must be intentionally programmed and developed rather than assumed to emerge automatically from generic health investment. [41]

For public health systems, this means that emergency response must be re-situated within a broader logic of continuous system strengthening. The objective is not only to respond better to the next event. It is to build institutions that can anticipate changing risks, protect essential functions under stress, learn in real time, and recover in ways that reduce future vulnerability.

4.2. Defining public health resilience

Public health resilience refers to the capacity of health systems to prepare for, absorb, adapt to, and recover from shocks while maintaining essential functions. This definition emphasizes transformation as an intrinsic component of resilience, rather than an optional outcome.

This definition builds on the broader health system resilience literature but emphasizes several features that are especially important from a public health perspective. First, resilience concerns the maintenance of essential public health functions, not only curative services. Surveillance, prevention, communication, community engagement, health protection, and population-level coordination are central rather than peripheral. Second, resilience is relational and institutional. It depends on how actors, infrastructures, data systems, governance arrangements, and communities interact under stress. Third, resilience is processual. It unfolds across time through anticipation, shock management, adjustment, and post-shock transformation.

Public health resilience should therefore be understood as a complex adaptive system rather than a static capacity. [63] It unfolds over time through feedback loops and iterative learning processes that connect anticipation, response, adaptation, and reform.

Importantly, this definition emphasizes not only functional continuity but also system transformation, distinguishing resilience from mere stability or resistance.

WHO's current resilience framing is highly compatible with this view. WHO's health systems resilience work stresses the need to prevent, prepare for, detect, adapt to, respond to, and recover from public health threats while maintaining essential and routine services. [42] WHO's climate resilience work similarly defines climate-resilient health systems as those able to anticipate, respond to, cope with, recover from, and adapt to climate-related shocks and stresses in ways that sustain population health. [43] These formulations reinforce the idea that resilience is not a single capability but a linked set of temporal capacities.

At the same time, resilience should not be romanticized. A resilient system is not one that simply absorbs infinite stress. Nor is resilience a synonym for endurance or austerity. Systems may survive shocks while reproducing inequity, workforce harm, or institutional opacity. For this reason, public health resilience must include normative criteria. It should be evaluated by whether essential functions are maintained, whether harms are distributed more fairly, whether learning is institutionalized, and whether recovery reduces rather than reproduces structural vulnerability.

4.3. The Integrated Climate-Sensitive Public Health Resilience (ICPHR) Framework

This article proposes the Integrated Climate-Sensitive Public Health Resilience (ICPHR) Framework, a climate-sensitive and system-based model of public health resilience organized around preparedness, absorption, adaptation, and recovery. The framework is intentionally cyclical rather than linear. Public health systems move through these dimensions repeatedly, often simultaneously, as risks evolve. Recovery feeds future preparedness; preparedness shapes absorptive capacity; absorption generates lessons for adaptation; and adaptation influences the quality of recovery. Resilience is therefore best understood as a dynamic loop of institutional capability. This is not a generic resilience model, but a climate-integrated public health framework. This four-dimensional structure builds on and extends prior resilience frameworks that distinguish between absorptive, adaptive, and transformative capacities, while introducing preparedness and recovery as integral temporal dimensions. [15–19, 39, 40]

The ICPHR Framework contains three analytical layers. At the center sits the public health system. The middle layer consists of the four-dimensional resilience cycle. The outer layer captures converging crises, especially pandemic threats, climate change, and other systemic risks, that place continuous pressure on the system while also being shaped by system capacity and response. This layered structure clarifies that resilience is not only an internal system property; it is produced through interaction between institutions and a changing risk environment (see **Figure 1**).

This relationship can be expressed heuristically as:

$$PHR_t = f(P_t, Ab_t, Ad_t, R_t \mid C_t, S_t, E_t, G_t)$$

where PHR_t denotes public health resilience at time t; P refers to preparedness, Ab to absorption, Ad to adaptation, and R to recovery; while C captures climate-sensitive pressures, S pandemic and other systemic shocks, E equity conditions, and G governance capacity. The notation is not intended as a deterministic or mechanical law. Rather, it offers a compact analytical expression of how resilience emerges from the interaction between internal system capabilities and an evolving external risk environment. This formulation reflects a systems-based understanding of resilience as an emergent property arising from interactions between internal capacities and external stressors, rather than a fixed or intrinsic attribute of the system. Framed in this way, the framework can support future comparative operationalization or index development without reducing resilience to a single static score.

4.3.1. Preparedness

Preparedness is the anticipatory dimension of resilience. It refers to the capacity to identify risks, reduce vulnerability, organize resources, and develop operational readiness before severe disruption occurs. Traditional preparedness frameworks often focus on plans, protocols, and stockpiles. These remain important, but preparedness in a resilience framework is broader. It includes interoperable surveillance, risk assessment, workforce planning, community partnerships, continuity arrangements, legal clarity, and flexible financing.

Preparedness also involves cognitive and political readiness. Institutions must be able to imagine compound scenarios rather than only familiar threats. This requires scenario planning that incorporates heat emergencies, vector expansion, supply-chain failure, misinformation surges, workforce attrition, and social protection gaps alongside outbreak response. Preparedness is therefore inseparable from learning, simulation, and cross-sector coordination. It is less about static readiness than about anticipatory capacity.

4.3.2. Absorption

Absorption refers to the capacity to withstand shock while maintaining essential functions. In public health terms, this includes the ability to continue surveillance, emergency coordination, preventive services, risk communication, primary care access, and protection of vulnerable populations even when pressure intensifies. Absorptive capacity depends on reserves, surge arrangements, redundancy, and flexibility, but also on prior trust and coordination.

COVID-19 showed that absorptive capacity is fragile when systems rely on optimization without slack. Hospital expansion achieved at the cost of routine service collapse is only partial absorption. By contrast, resilient absorption means that systems can manage elevated demand without wholly suspending broader functions. This requires decentralized service models, scalable staffing, protected supply chains, continuity planning, and resilient facilities. In climate-sensitive contexts, it also requires the ability to sustain function when energy, water, transportation, or digital networks are disrupted.

4.3.3. Adaptation

Adaptation is the capacity to adjust structures, processes, and interventions in response to changing conditions. It is the learning dimension of resilience. Public health systems rarely confront identical crises twice; pathogens evolve, community expectations change, technologies shift, and climate conditions alter disease ecologies. Adaptation therefore involves institutional learning, evidence uptake, organizational redesign, and policy recalibration.

Adaptive resilience can be observed when health systems revise surveillance architecture, redesign service delivery, expand community health roles, integrate new data streams, improve communication strategies, or reconfigure governance arrangements in light of experience. Importantly, adaptation is not only technical. It also involves social learning about trust, participation, and legitimacy. Systems that learn only about logistics but not about inequity or community exclusion remain incompletely adaptive.

4.3.4. Recovery

Recovery is the capacity to restore and improve after disruption. In a narrow sense, recovery refers to the reactivation of services and institutions damaged by crisis. In a resilience framework, however, recovery must be developmental as well as restorative. WHO's 2024 guidance on health system recovery explicitly describes recovery as an opportunity to address pre-existing gaps, weaknesses, and inequities while building back better. [44] That orientation is central to public health resilience.

Recovery therefore includes rebuilding infrastructure, restoring workforce morale and capacity, institutionalizing lessons learned, correcting inequities exposed by crisis, and creating more sustainable governance and financing arrangements. A recovery that merely reinstates the vulnerabilities of the pre-crisis system is not resilient recovery. Genuine recovery changes the conditions of future preparedness.

4.4. Climate-sensitive resilience integration

The final conceptual step is to integrate climate sensitivity into all four dimensions. Climate change should not be treated as a separate annex to public health resilience. It changes what each dimension requires.

In preparedness, climate-sensitive resilience requires vulnerability assessments, heat-health action plans, climate-informed disease forecasting, and facility planning for extreme weather and energy stress. In absorption, it requires the ability to maintain services during heatwaves, floods, smoke events, and climate-related displacement, including through resilient infrastructure, cooling capacity, backup systems, and decentralized continuity arrangements. In adaptation, it requires public health programs to revise protocols as disease ecologies shift and to incorporate environmental intelligence, low-carbon technologies, and cross-sector data. In recovery, it requires reconstruction and reform that reduce exposure to future climate hazards while improving sustainability and equity.

WHO's 2023 operational framework for climate-resilient and low-carbon health systems is especially important here because it explicitly links climate resilience with health system functions, surveillance, workforce, infrastructure, financing, and governance. [45] Its significance for the present article is not that it replaces general resilience frameworks, but that it shows climate sensitivity can and must be operationalized across the system. Climate-integrated resilience is therefore not a niche adaptation concern. It is a necessary evolution of public health strategy in a destabilized risk environment.

5. Strategic Pathways for Resilient Public Health Systems

If the four-dimensional framework provides a conceptual architecture, public health reform still requires operational pathways. This section identifies five strategic pathways through which resilience can be embedded in institutions, infrastructures, and governance arrangements. These pathways operationalize the four dimensions of resilience by translating abstract system capacities into institutional and governance interventions. They are mutually reinforcing and should be understood as core components of system transformation rather than stand-alone interventions.

5.1. Integrated surveillance and early warning systems

The first strategic pathway is the development of integrated surveillance and early warning systems. COVID-19 revealed that surveillance cannot remain a patchwork of disease-specific and administratively siloed platforms. WHO's concept of collaborative surveillance argues for the integration of multiple sources of intelligence to enable prevention, preparedness, response, and recovery across levels of governance. [20] For resilient public health systems, this means constructing interoperable architectures that connect epidemiological reporting, laboratory systems, clinical data, mortality surveillance, genomic signals, wastewater monitoring, community reporting, and environmental indicators.

This pathway is particularly important because surveillance is both a preparedness tool and an adaptive learning system. Stronger integration enables earlier detection, but it also improves policy calibration, service allocation, and equity monitoring. Disaggregated data can help identify which populations are being missed, which communities face elevated exposure, and where interventions are failing. Without this visibility, even well-funded responses can reproduce blind spots.

These mechanisms enable resilience by linking early detection with timely response, thereby reducing both the scale and duration of system disruption. This linkage is critical because it reduces system lag between risk emergence and institutional response.

The climate dimension is equally critical. WHO's work on climate-informed health early warning emphasizes that integrating disease surveillance with weather and climate surveillance can improve preparedness for climate-sensitive hazards. [46] Likewise, WHO's climate resilience

framework highlights integrated risk monitoring and early warning as a core system component. [45] Public health surveillance in the coming decade therefore needs to move beyond pathogen tracking toward risk intelligence that includes heat alerts, air quality, precipitation patterns, vector ecology, food and water insecurity, and infrastructure stress. One Health preparedness and multisector surveillance research point in the same direction, emphasizing the value of integrated human, environmental, and community data streams. [24,47,48]

Operationally, this requires investment in interoperability standards, subnational analytic capacity, legal frameworks for data sharing, and public governance arrangements that balance rapid use of data with privacy and trust. It also requires designing feedback loops so that data do not remain trapped in dashboards but inform concrete response triggers. Early warning only strengthens resilience when it is linked to action protocols, local decision-making authority, and community communication.

The governance of surveillance is therefore as important as its technology. Resilient surveillance systems need clear institutional custodianship, stable financing, shared metadata standards, and agreed escalation procedures. They also need legitimacy. Communities are more likely to accept expanded data collection when its public value is visible, when safeguards are credible, and when the resulting intelligence is translated into timely protection rather than extractive monitoring.

In this sense, integrated surveillance should be seen as a civic institution as much as a technical system. It works best when it supports both expert decision-making and public accountability. Emerging work on climate-related health indicators and wastewater-based surveillance in lower-resource settings further shows that resilient surveillance requires context-sensitive metrics rather than one-size-fits-all architectures. [23,46,61,62]

Taken together, integrated surveillance functions as the backbone of anticipatory and adaptive resilience.

5.2. Strengthening primary health care systems

The second pathway is the strengthening of primary health care (PHC). COVID-19 demonstrated that hospital-centric strategies are insufficient when health emergencies disrupt everyday health needs across communities. PHC is essential because it links prevention, early detection, chronic disease management, vaccination, referral, community outreach, and trust-building. WHO's resilience agenda explicitly frames PHC as central to integrating universal health coverage and health security. [42]

From a resilience perspective, PHC performs several functions simultaneously. It supports preparedness by sustaining routine prevention, risk communication, and community engagement before crises intensify. It supports absorption by maintaining access points for diagnosis, triage, chronic care, and social support under stress. It supports adaptation because primary care teams often detect shifting needs earlier than centralized agencies. And it supports recovery by reconnecting populations to essential services after disruption.

PHC also becomes more important under climate stress. Heatwaves increase demand for local outreach, chronic disease monitoring, hydration guidance, and rapid support to older adults and socially isolated people. Extreme weather may require mobile services, decentralized medication access, or adapted referral pathways. Vector-borne disease expansion may demand stronger local case detection and community-based prevention. WHO's climate resilience work and emerging literature on PHC and climate adaptation both suggest that frontline, community-embedded care is indispensable for managing climate-sensitive health risks. [18,45,49]

Yet PHC cannot perform these roles if it remains underfunded, understaffed, and administratively peripheral. Building resilient PHC requires integrating it into emergency planning, digital platforms, referral systems, and financing models. It also requires expanding the role of community health workers and local public health actors who can bridge formal systems and community realities. [50,51] In many countries, resilience will depend less on building more tertiary capacity than on restoring strategic balance between hospitals, public health, and primary care.

This rebalancing has concrete design implications. PHC facilities need continuity protocols for power outages, medicine access, telehealth fallback, referral disruption, and heat-related surges. Community health workers need formal roles in preparedness drills, surveillance escalation, and outreach to climate-vulnerable households. Local clinics should be linked not only to hospitals, but also to social care, pharmacies, schools, and municipal services. Telehealth and teleconsultation evidence from the COVID-19 period also suggests that resilient PHC requires flexible digital access pathways rather than a single physical point of contact. [52] When PHC is institutionally connected in this way, it becomes a distributed resilience platform capable of sustaining care close to where people live. That distributed capacity is especially valuable in crises that do not present first at hospitals, including heat emergencies, medication interruptions, and gradual deterioration among socially isolated populations.

Taken together, resilient PHC functions as the distributed service platform through which preparedness, continuity, and adaptation become operational.

5.3. Risk communication and public trust

The third pathway is the construction of robust risk communication systems grounded in public trust. Communication must be treated as a core public health function that spans preparedness, response, adaptation, and recovery. This requires a shift from one-way messaging toward relationship-based communication infrastructures built on listening, transparency, local tailoring, and iterative feedback.

The evidence from COVID-19 is clear that communication affects not only knowledge but also behavior, adherence, confidence, and institutional legitimacy. [27,31] A resilient communication system does not wait until misinformation spreads uncontrollably. It develops social listening capacity, trusted local intermediaries, multilingual and culturally competent messaging, and clear protocols for communicating uncertainty. It also aligns communication across national and subnational authorities so that changing guidance can be explained rather than merely announced. Reviews of misinformation interventions further suggest that prebunking, rapid correction, and trusted messengers work best when integrated into broader institutional communication systems rather than deployed as isolated campaigns. [54]

Infodemic management should therefore become a routine capability rather than a crisis add-on. WHO's post-pandemic work frames infodemic management as an interdisciplinary public health function linked to community engagement, data science, and emergency preparedness. [28,53] This is especially relevant in an era where future emergencies will unfold within polarized digital environments. Resilience depends not only on the truthfulness of official information, but on the system's ability to understand how people seek, interpret, and act on health information.

Climate-sensitive communication is equally necessary. Heat risk warnings, air quality alerts, flood guidance, water safety information, and vector-borne disease messaging all require public trust and behavioral coordination. Climate risks also unfold over multiple temporalities, which

means communication must connect immediate protective actions with longer-term adaptation and public engagement. Public trust is therefore not just a pandemic variable; it is a core resilience asset for all health emergencies.

One of the most important lessons from COVID-19 is that uncertainty itself must be communicated well. Public health authorities often fear that acknowledging uncertainty will erode confidence, but the opposite is frequently true when uncertainty is transparent, bounded, and paired with clear action guidance. Resilient systems therefore need communication strategies that distinguish between what is known, what is changing, and what citizens can do now. This is particularly relevant for climate-sensitive risks, where warning systems must translate probabilistic forecasts into practical household, workplace, and community action. Trust grows when institutions are honest about limits while remaining visibly competent and responsive.

Taken together, trust-based communication turns information governance into a core resilience capacity rather than a reactive messaging task.

5.4. Equity-centered health system design

The fourth pathway is equity-centered design. COVID-19 showed that systems which fail to identify and protect vulnerable populations are not resilient systems. Equity must therefore be designed into governance, surveillance, service delivery, financing, communication, and recovery planning rather than added retrospectively.

An equity-centered approach has several dimensions. First, surveillance systems must collect and use disaggregated data to identify differential exposure, access, and outcomes. Second, preparedness plans must prioritize populations most likely to be excluded from protection, including low-income households, migrants, informal workers, older adults, people with disabilities, rural communities, and those with high chronic disease burden. Third, service models must reduce practical barriers to access through local delivery, digital inclusion strategies, transport support, and flexible care pathways.

Climate change makes this even more urgent. WHO notes that climate-sensitive health risks disproportionately affect already vulnerable and disadvantaged populations, including children, older people, migrants, poor communities, and those with underlying health conditions. [7] If resilience planning is not equity-centered, climate adaptation may simply protect those already well served while leaving high-risk communities exposed to heat, displacement, infectious disease, and service disruption. In that case, resilience would become exclusionary rather than protective. Recent work on climate justice and community-based climate action likewise shows that adaptation is more effective and more legitimate when vulnerable communities participate directly in defining priorities and implementation pathways. [55, 56]

Equity-centered design also implies participatory governance. Communities should not only be recipients of targeted intervention; they should be involved in defining risk priorities, acceptable trade-offs, communication needs, and recovery goals. This matters both normatively and instrumentally. Public health systems that learn from communities are better able to detect barriers, tailor interventions, and sustain trust. Equity is therefore not a competing objective alongside resilience. It is one of the conditions through which resilience becomes socially legitimate and practically effective.

An equity-centered resilience agenda must also extend to infrastructure and recovery sequencing. Cooling centers, resilient facilities, transport access, digital platforms, and emergency shelters are not neutral assets; their location and design determine who can benefit from them under stress. Recovery planning should therefore prioritize neighborhoods and groups with the highest accumulated exposure to climate risk, chronic illness, and service exclusion rather than simply restoring average system output. In practical terms, this means that resilience metrics should be distribution-sensitive. A public health system should not be judged resilient if it restores routine function while leaving its most climate-vulnerable populations chronically underserved.

Taken together, equity-centered design ensures that resilience is judged not only by continuity, but by who is protected, reached, and restored.

5.5. Cross-sectoral governance and system coordination

The fifth pathway is cross-sectoral governance and coordination. Public health systems cannot build resilience in isolation because the determinants of preparedness and vulnerability extend well beyond the health sector. COVID-19 and climate change both underscore the importance of coordination across health, environment, meteorology, water and sanitation, housing, transport, education, labor, digital governance, and social protection.

WHO's climate resilience framework, its PHC resilience agenda, and its collaborative surveillance model all point in the same direction: resilient health systems require integrated and multisectoral action. [20, 42, 45] This is not simply a matter of convening more interagency meetings. It requires institutionalized coordination mechanisms, clear role allocation, shared data protocols, joint planning, and financing structures that support cross-sector implementation. One Health preparedness and multisector surveillance scholarship reinforce this point by showing that fragmented sectoral mandates remain a major barrier to early detection and coordinated action. [47, 48]

Cross-sectoral governance is especially important for climate-sensitive resilience. Heat-health action plans require cooperation between health agencies, weather services, local governments, housing authorities, and labor regulators. Flood preparedness links health facilities with infrastructure, civil protection, and water management. Vector-borne disease control requires coordination with environmental agencies, sanitation services, and urban planning. Similarly, pandemic resilience depends on education systems, workplace policy, social protection, border governance, and supply-chain regulation. Health systems may lead, but they cannot act alone.

A further implication is that public health resilience must be governed across levels as well as sectors. Local authorities often manage the practical realities of implementation, yet national systems control financing, data standards, and legal mandates. Global and regional institutions shape access to intelligence, finance, and countermeasures. Cross-sectoral governance must therefore be multi-level governance. The most resilient systems will be those that can align local responsiveness with national coordination and international cooperation.

Taken together, cross-sectoral governance converts resilience from a sectoral ambition into a coordinated system function.

6. Policy Implications

The framework and strategic pathways outlined above imply a policy agenda centered on implementation rather than aspiration. The critical question is not simply what resilient public health systems should look like, but how governments and institutions can build them in practice.

6.1. Financing and resource allocation

Financing must move from episodic emergency spending toward resilience-oriented investment. This means creating budget mechanisms that support preparedness between crises, flexible allocation during crises, and recovery-oriented reform after crises. Public health financing is often one of the first casualties of political attention cycles: underfunded before emergencies, rapidly expanded during emergencies, and then partially withdrawn once acute pressure subsides. Such volatility undermines institutional memory and preparedness.

Resilience-oriented financing should include dedicated public health preparedness funds, contingency financing for local response, and medium-term investment in surveillance, PHC, workforce capacity, and infrastructure resilience. In climate-sensitive settings, governments should also align health financing with adaptation finance and disaster risk reduction instruments. The policy objective is not simply to spend more, but to structure spending so that institutions can prepare, absorb, adapt, and recover without repeated dependence on exceptional measures.

How funds are allocated is as important as how much is allocated. Centralized budgets alone rarely support timely adaptation because local authorities are often closest to changing risks yet least able to reprogram resources. A resilience-oriented financing model should therefore combine national standards with flexible subnational envelopes linked to clear accountability rules. It should also incentivize long-term capability building rather than only visible crisis response. Surveillance integration, PHC continuity planning, and workforce support are less politically dramatic than emergency procurement, but they are often more consequential for resilience over time.

6.2. Workforce development

No resilience strategy is credible without workforce development. COVID-19 showed that health systems can fail not only because of insufficient infrastructure, but because overburdened workers lack protection, training, and institutional support. Future workforce strategies should include surge planning, cross-training, community health capacity, risk communication skills, digital literacy, and climate-health competencies.

WHO's recent resilience and climate frameworks underscore the importance of workforce preparedness and climate-smart competencies. [41,45] In practical terms, this means training workers to manage compound emergencies, including heat events, outbreaks, displacement, service disruption, and infodemic conditions. It also means strengthening retention through decent working conditions, psychosocial support, and clearer career pathways for public health professionals. Workforce resilience is not merely about personal coping. It is about institutional arrangements that enable staff to function effectively and safely under repeated strain.

6.3. Digital and data infrastructure

Digital and data infrastructure should be treated as a public good for resilience. Interoperable health information systems, common data standards, secure data-sharing arrangements, and user-centered analytic platforms are essential for collaborative surveillance and coordinated action. WHO's 2024 health information systems guidance highlights robust data systems as the foundation of effective public health intervention and resource targeting. [57]

However, digitization alone does not create resilience. Data systems must be linked to governance, local capacity, and trust. Investments should therefore focus on interoperability, timeliness, analytical use at subnational levels, and public transparency where appropriate. Climate-sensitive resilience further requires data linkage across health and environmental systems so that risk signals can be translated into preparedness and response decisions.

6.4. Governance reform

Governance reform is needed to reduce fragmentation and institutional drift. This includes clarifying mandates across ministries and levels of government, embedding after-action review processes into routine governance, and creating accountability frameworks for preparedness, communication, and service continuity. Governance reform should also ensure that public health agencies have sufficient authority and autonomy to coordinate across sectors while remaining democratically accountable.

Recovery planning is especially important here. WHO's guidance on health system recovery emphasizes that recovery should address pre-existing weaknesses and inequities rather than merely restoring prior arrangements. [44] Governments should therefore institutionalize recovery planning as part of broader health system reform, with explicit links to resilience indicators, equity goals, and climate adaptation plans.

6.5. Global and regional cooperation

Finally, resilience policy must include global and regional cooperation. COVID-19 exposed the consequences of unequal access to vaccines, diagnostics, and therapeutics, as well as the limits of fragmented data sharing and manufacturing concentration. [36,37] Climate change likewise requires coordinated monitoring, finance, and transboundary response capacities.

Global cooperation should prioritize equitable access to health products, shared surveillance standards, support for low-resource settings, and stronger institutional links between global health security and climate adaptation agendas. Regional cooperation can be especially valuable for cross-border surveillance, workforce support, environmental monitoring, and mutual aid during multi-country emergencies. In an interdependent risk environment, national resilience depends partly on international solidarity and institutional coordination.

6.6. Implications for public health practice

From a practical perspective, the proposed framework can support public health practitioners in designing more integrated preparedness and response strategies. By linking surveillance, primary health care, risk communication, and equity-focused interventions, the framework helps identify system gaps and prioritize resource allocation under conditions of uncertainty. In particular, climate-sensitive risk integration enables public health systems to move beyond reactive emergency response toward anticipatory and preventive action.

7. Discussion

7.1. Theoretical contribution

This study contributes to the literature in three ways. First, it integrates pandemic and climate-related risks into a unified resilience framework. Second, it operationalizes resilience as a cyclical process across four interdependent dimensions. Third, it links conceptual analysis with actionable system-level strategies. Its central theoretical claim is that public health resilience should be conceptualized as a dynamic and cyclical process rather than a static property or a synonym for emergency response capacity.

The framework advances current discussions in two ways. First, it centers public health functions rather than treating resilience as a generic health system attribute. Second, it explicitly links resilience to converging crises, thereby bridging health security, climate adaptation, and health system strengthening. This integrated perspective is increasingly necessary as public health threats become more ecological, social, and transboundary.

To illustrate how the framework might support future comparative operationalization, it can also be expressed in index form as:

$$PHRI = w_1P + w_2Ab + w_3Ad + w_4R - w_5V$$

where $PHRI$ denotes a public health resilience index; P, Ab, Ad, and R correspond to preparedness, absorption, adaptation, and recovery; and V denotes cumulative vulnerability or inequity burden. Vulnerability (V) may include indicators such as socioeconomic inequality, access disparities, health workforce shortages, and infrastructure fragility, reflecting structural constraints on system resilience. The weights $w_1 - w_5$ are not assumed to be universal but context-dependent. They may be derived through expert elicitation methods such as the Delphi technique, analytic hierarchy process (AHP), or empirical calibration based on system performance indicators. The proposed formulation serves as a conceptual bridge toward future operationalization rather than a finalized measurement tool.

While the linear specification provides a tractable starting point for index construction, resilience is inherently non-linear. The interactions among preparedness, adaptation, and recovery may generate synergistic or constraining effects that cannot be fully captured by additive models. For instance, preparedness may enhance the effectiveness of adaptation, indicating a potential interaction effect between system capacities. Future research may incorporate interaction terms or system dynamics approaches to better reflect these complex relationships.

7.2. Comparison with existing literature

A key limitation of existing resilience frameworks is their tendency to treat resilience as a descriptive attribute rather than an operational system function. As a result, many frameworks lack the specificity required to guide institutional design, governance reform, and cross-sectoral coordination in complex risk environments.

Existing resilience scholarship has generated important insights into absorptive, adaptive, and transformative capacities, governance, and system learning. [15–19, 39, 40] COVID-19 analyses have further clarified the operational significance of governance, workforce, community engagement, and continuity of care. [1–3] Climate-health research has increasingly documented the need for climate-resilient health systems and integrated adaptation strategies. [18, 45]

Despite the growing prominence of resilience in global health discourse, existing frameworks often lack operational specificity and fail to adequately integrate climate-related risks into public health system design. [15–19, 41, 45, 58–60] Many approaches remain either too abstract to guide implementation or too narrowly focused on acute emergency response, neglecting the long-term and compounding nature of contemporary health threats.

Recent reassessments of COVID-19 resilience scholarship have also highlighted the risk of using resilience as an umbrella term without adequate specification of institutions, scale, and politics. [58] Other recent syntheses have likewise emphasized the importance of operationalization, implementation strategies, and measurement challenges. [59, 60] The framework proposed here responds to that concern by anchoring resilience in a temporally ordered but cyclical set of public health functions and by tying those functions to practical reform pathways. In other words, the contribution is not only conceptual integration, but also analytical sharpening: resilience is treated as something systems do across time rather than something they simply possess.

The present framework builds on these contributions but differs in emphasis. Rather than treating climate change as an adjacent issue, it places climate-sensitive risk at the center of resilience thinking. Rather than focusing only on abstract resilience capabilities, it organizes them into a four-dimensional cycle that can guide analysis and policy. Rather than separating preparedness from recovery, it treats both as interdependent phases of a continuous resilience process. In this sense, the framework is intended as a synthesis and extension rather than a replacement of existing work. This framework contributes to an emerging shift from resilience as a retrospective evaluative concept toward resilience as a forward-looking design principle for public health systems. This perspective aligns with broader shifts in policy sciences and systems thinking that emphasize complexity, non-linearity, and adaptive governance. [64]

7.3. Limitations

This article has several limitations. First, it is a conceptual synthesis rather than an empirical comparative study. The framework therefore requires testing across different political, institutional, and resource settings. Second, because it operates at a relatively high level of abstraction, it cannot specify the exact institutional design most appropriate for every context. Public health systems vary widely in centralization, financing, legal authority, and workforce composition. Third, the climate-health evidence base is growing rapidly, and some operational questions, especially around measurement and cost-effectiveness, remain unevenly developed.

There is also a strategic limitation. Resilience can become an overly expansive concept if not operationalized carefully. In particular, the proposed index remains a heuristic construct and may oversimplify complex system dynamics if applied without context-sensitive calibration. Future work must therefore translate the framework into measurable indicators, governance diagnostics, and context-sensitive implementation tools. Without such translation, resilience risks remaining conceptually appealing but administratively diffuse.

7.4. Future research directions

Several research directions follow from this analysis. Comparative work is needed to examine how different public health systems combine preparedness, absorption, adaptation, and recovery under compound pressures. More empirical study is also needed on climate-informed surveillance, heat-health integration in PHC, and the governance conditions that enable effective cross-sector coordination. Equity metrics deserve special attention, since aggregate performance indicators often obscure distributional failure. Future research should also develop standardized indicators and data collection strategies to enable cross-country comparison and longitudinal assessment of resilience. Recent work on climate-related health indicators and wastewater surveillance in low- and middle-income settings suggests that one major research frontier lies in building measurement systems that are both scientifically robust and institutionally feasible across diverse contexts. [61, 62]

Future research should also investigate the political economy of resilience. Which financing arrangements sustain public health investment between crises? Which institutional incentives encourage learning rather than blame avoidance? How can global governance better align climate adaptation, health security, and equitable access to countermeasures? Answering such questions will be essential if resilience is to move from conceptual aspiration to durable institutional practice.

8. Conclusion

COVID-19 exposed the structural fragility of public health systems. The climate crisis is now increasing the frequency, intensity, and complexity of the pressures those systems must confront. The central policy lesson is that public health can no longer be organized around the assumption of isolated, short-lived emergencies. Contemporary threats are converging, compounding, and unfolding across sectors, populations, and time scales.

This article has argued that public health resilience offers a productive framework for responding to this new reality. By conceptualizing resilience as a cyclical process of preparedness, absorption, adaptation, and recovery, it becomes possible to connect emergency response with longer-term system transformation. The resulting agenda is not limited to better outbreak control. It includes integrated surveillance, stronger primary health care, trust-based communication, equity-centered design, and cross-sectoral governance.

Public health resilience should become the central paradigm guiding health system transformation in an era of converging global crises. The goal is not to return to pre-pandemic normality, because that normality was already marked by fragmentation, inequity, and ecological vulnerability. The goal is to build public health systems that can anticipate risk, protect essential functions, learn under pressure, and recover through reform. The framework also offers practical guidance for policymakers and public health professionals seeking to strengthen system resilience in real-world settings. In this sense, resilience represents a critical foundation for improving the sustainability and effectiveness of public health systems in an era of persistent uncertainty.

Author Contributions

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Ethics Statement

This conceptual framework study did not involve human participants, human data, human tissue, or animals. Therefore, ethics committee approval and informed consent were not required.

Conflict of Interest

The authors declare no conflict of interest.

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Figure Legends and Figures

Figure 1. Integrated Climate-Sensitive Public Health Resilience Framework (ICPHR) The framework is presented as a three-layer structure. The outer layer represents converging crises, including pandemic threats, climate change, and other systemic risks. The middle layer is a circular loop linking preparedness, absorption, adaptation, and recovery. At the center sits the public health system. Bidirectional relationships between the outer risk environment and the system indicate that institutions do not merely receive shocks; they also shape the scale, distribution, and downstream consequences of those shocks through preparedness, continuity, adaptation, and recovery.

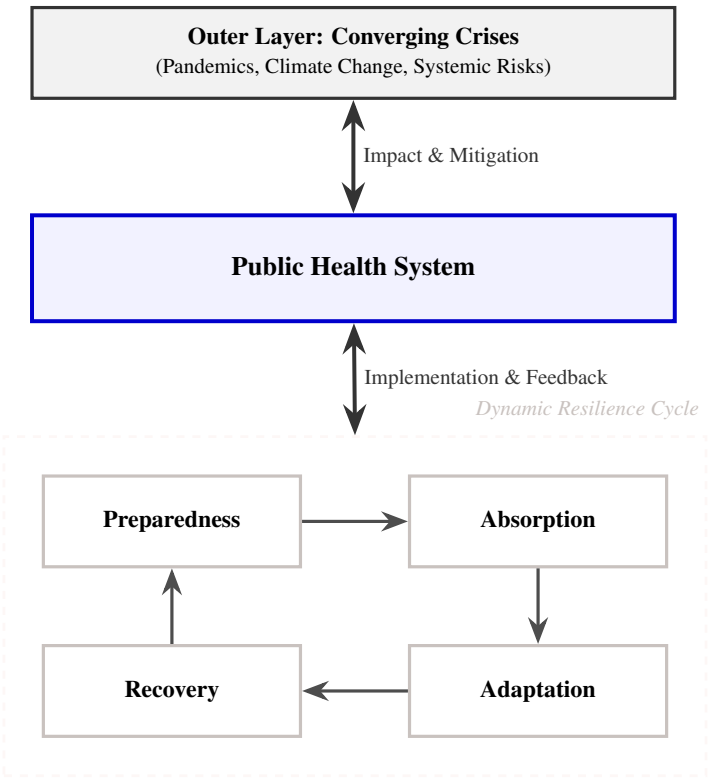

Figure 1. Integrated Climate-Sensitive Public Health Resilience Framework (ICPHR)