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Global Surveillance Systems for Emerging Infectious Diseases: A Critical Review of Infrastructure, Policy, and Data Sharing

Riaz Ahmed

ABSTRACT

More frequent and increasingly global emerging infectious diseases have made it clear that reliable systems for surveillance are needed to track, address, and mitigate their spread. This review gives an in-depth assessment of the key infrastructure, operational capacity and policies in global disease surveillance systems, checking if they are prepared for future pandemics. It examines key organizations such as World Health Organization's (WHO) Global Outbreak Alert and Response Network, Global Influenza Surveillance and Response System, Global Health Security Agenda, and CDC's Global Disease Detection, as well as networks such as ProMED-mail, Global Public Health Intelligence Network, and HealthMap. It highlights important gains in genomic studies and advancements in artificial intelligence and mobile technologies for data collection. However, there are still major difficulties in improving diagnostics, linking systems, and equal rights in poor and middle-income countries. It analyzes the weaknesses in International Health Regulations (IHR 2005) and the One Health approach when it comes to improving reporting and cooperation between experts in different sectors. Big challenges such as data sovereignty, distrust, and not having standard ways to share data receive close scrutiny. Evaluating innovations and highlights such as Africa CDC's surveillance centers and platforms like BlueDot, the paper suggests measures for future action that center on readiness, openness, and trust. In conclusion, it offers steps to strengthen world governance, promote equal access to data, and allocate money to surveillance systems, which are crucial for global health security.

Keywords: Global health surveillance, Emerging infectious diseases, Data sharing challenges, Genomic epidemiology, International health regulations

Introduction

The continuing emergence and re-emergence of infectious diseases underscore the importance of early warning systems in controlling large-scale health problems. Strong surveillance helps detect, control and reduce outbreaks which protects health and economies.¹ During recent decades, incidents like the 2003 SARS pandemic, the 2009 H1N1 influenza outbreak, the Ebola cases in West Africa 2014–2016 and the COVID-19 pandemic highlighted significant gaps in worldwide disease monitoring systems (Figure 1).²

Each time, we saw that it is crucial to: unite with other nations, avoid being late to act and rely on current data sharing. Though advanced devices and computer tools now make it easier to detect diseases, issues with infrastructure, rules and fairness between areas are still obvious.³

The review looks closely at the current global system for tracking and managing emerging infectious diseases (EIDs).⁴ Key institutions are reviewed, their structural capacities evaluated, their adherence to international regulations assessed, and the challenges of data sharing studied. It involves not only official services such as the WHO's Global Outbreak Alert and Response Network (GOARN) but also forward-looking options like ProMED-mail and HealthMap.⁵

Research Objectives

- To critically examine the infrastructure and design of major global infectious disease surveillance systems.
- To evaluate the effectiveness of these systems in early detection, outbreak containment, and public health response.
- To assess the role and limitations of international policy frameworks, such as the International Health Regulations (IHR 2005), in enabling rapid response.
- To analyze challenges in data sharing, interoperability, and equity between countries and institutions.
- To propose improvements in governance, technology, and collaborative frameworks for strengthening global surveillance.

Looking at both existing and new global surveillance models, the review intends to point out any structural issues and recommend actions to make the architecture fairer, easier to monitor and more stable.

Methodology

The review is conducted using a scoping review methodology following the framework by Arksey and O'Malley and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) recommendations (Figure 2). This study aimed to identify the primary structural gaps and innovations within the architecture, policies, technologies, and data governance of global infectious disease surveillance systems.

A systematic search of the literature was done in PubMed, Scopus, and Google Scholar, as well as gray literature in WHO, CDC, Global Initiative on Sharing All Influenza Data (GISAI), Africa CDC, and other global health agencies. These studies were published between January 2000 and March 2025 and were limited to English only. Included studies and their quality scores are listed in Supplementary Table (Appendix 1).

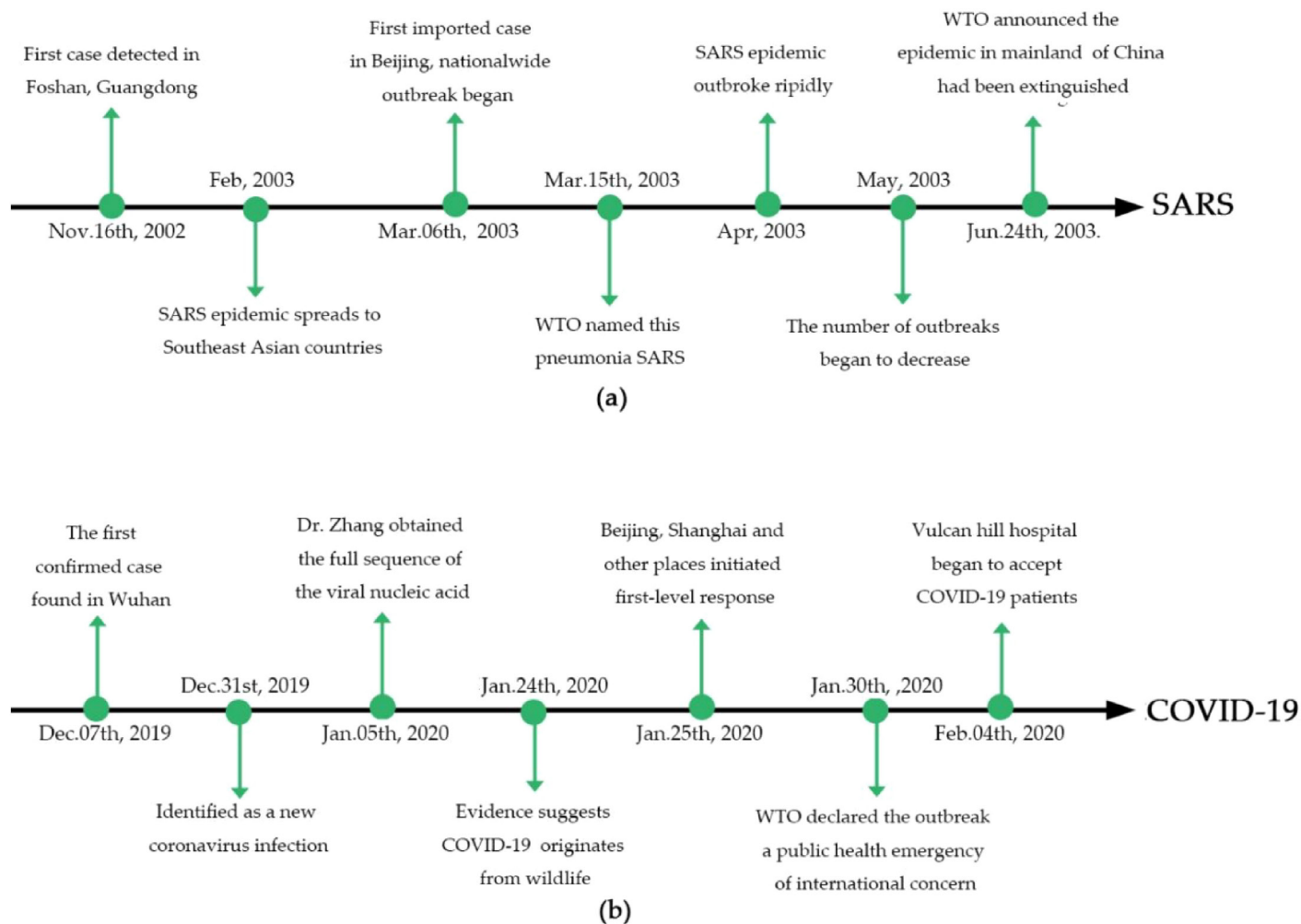


Fig 1 | Timeline of major global outbreaks and surveillance responses (SARS and COVID-19)²

Keywords were combinations of:

Global health surveillance, emerging infectious diseases, GOARN, GISRS, ProMED, HealthMap, BlueDot, digital disease detection, International Health Regulations, genomic surveillance, data sharing, and pandemic preparedness. Searches were conducted between April 2025 to June 2025.

Inclusion criteria: publications and reports describing, evaluating, or comparing health surveillance systems related to international infectious diseases; papers covering surveillance infrastructure, governance, interoperability, or equity; papers with novel technologies, including artificial intelligence (AI), mobile, or genomics concerning surveillance systems.

Exclusion criteria: manuscripts devoted to pure clinical diagnostic, the system entirely country- or area-specific, studies that are not related to the surveillance infrastructure and global policy frameworks.

There was the two-stage screening (review of titles and abstract, and full-text review). A simpler rubric evaluated the quality of the sources based on institutional credibility, methodological transparency, and relevancy as it related to the goals of the review. The

data were categorized by system, function, data model and limitations.

Methodological Rigor

The review is undertaken in line with PRISMA-ScR recommendations, which promote capability and thoroughness. Though it is not given in a protocol, the search method, inclusion and exclusion criteria and appraisal method are clearly explained. Peer-reviewed as well as gray literature sources have been incorporated to reflect the diverse operations of the surveillance systems in their operations. The process of search and its screening is depicted in a PRISMA flow diagram in the supplementary material.

Overview of Global Surveillance Systems

Detecting, monitoring, and responding to infectious disease threats around the globe mainly depends on a variety of national, regional, and international programs.⁶ They are organized differently, cover various issues and use various methods, but all contribute to quick alerts and group reactions. Understanding their operational mechanisms, disease foci, and integration is crucial for assessing their success in dealing with EIDs.⁴

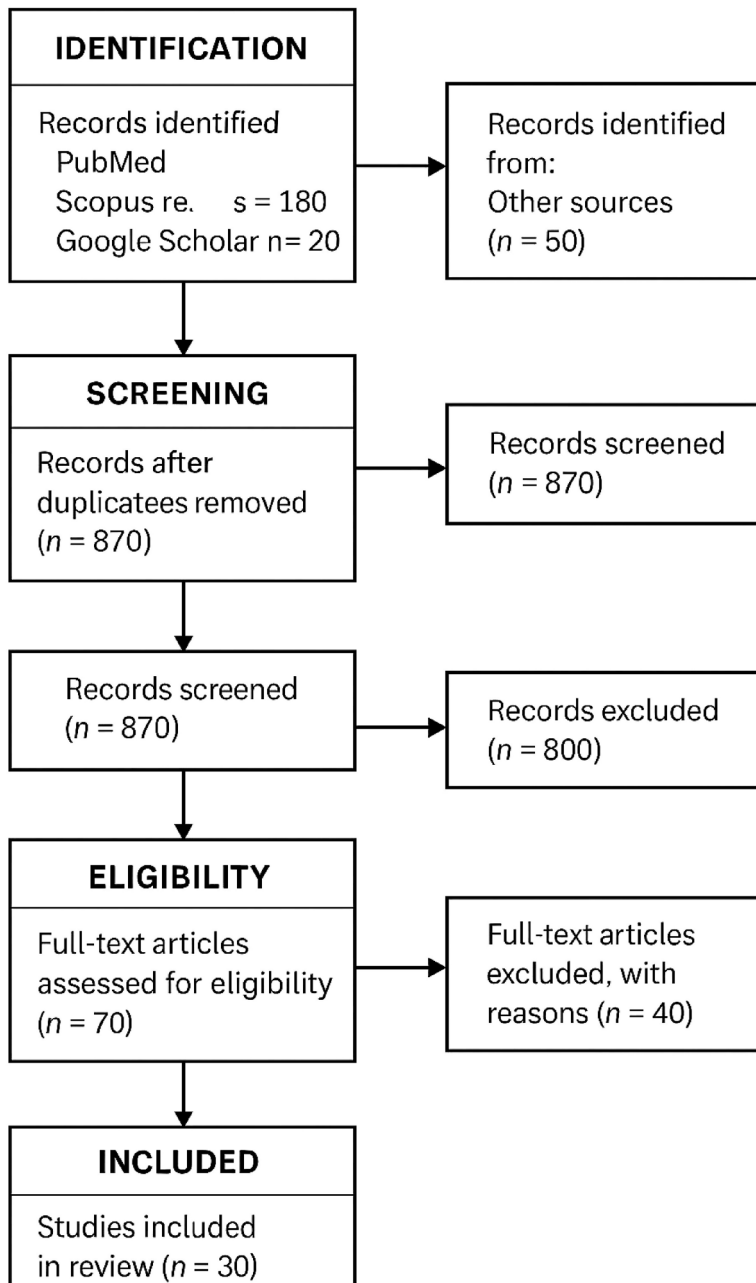


Fig 2 | PRISMA flow diagram

Core Surveillance Mechanisms: Indicator-Based and Event-Based Systems

Surveillance is often divided into indicator-based surveillance (IBS) and event-based surveillance (EBS). Laboratory-confirmed cases, hospital records, and morbidity reports form the basis of IBS. It is very important to keep an eye on endemic diseases and see how their trends develop progressively.⁷ However, IBS frequently takes a long time to gather facts and confirm events which hinders rapid response (Figure 3).⁸

EBS looks at nonstructured data such as news and social media topics and notes from researchers, to identify potential outbreaks. EBS is particularly good at spotting rare or unexpected events ahead of confirmation which helps IBS a lot. A mixed model that

includes both systems is often accepted as being necessary to find outbreaks quickly.⁹

WHO’s GOARN

In 2000, the GOARN started serving as the main response team for the WHO.¹⁰ There are over 250 technical institutions and organizations in this network which join together fast to aid those who are struck by disasters. GOARN increases the global ability to respond during emergencies, but relies on member countries reporting and requests for support.⁵

Global Influenza Surveillance and Response System (GISRS)

Since its establishment in 1952, GISRS has been recognized as one of the oldest and best-working disease monitoring systems. Over 150 laboratories in a wide range of countries contribute to the network, enabling the instant sharing of influenza virus samples and data.⁶ The system watches seasonal flu trends and every 2 years determines the formulation for next year’s flu vaccine based on expert-driven reviews. It is an inspiration for other surveillance systems because of how it uses standardized protocols and helps data travel internationally. However, since it focuses just on influenza, it is not very helpful for dealing with other kinds of pandemic threats (Figure 4).¹¹

Global Health Security Agenda (GHSa)

After the West African Ebola outbreak in 2014, the GHSa was founded as a multilateral initiative to improve global health security more quickly. It helps provide 11 key technical services—such as surveillance, laboratory tasks, staff education and emergency management—mostly in low- and middle-income countries (LMICs). Emphasizing certain activities (such as the Joint External Evaluation (JEE)) helps GHSa tackle common problems faced by countries most prone to undetected outbreaks. On the other hand, its need for donor money and the fact that groups join by choice threaten its sustainability (Figure 5).¹²

CDC’s Global Disease Detection Program (GDD)

The GDD program is managed by the CDC and has regional centers set up in areas like Southeast Asia, Africa, and Latin America.¹³ GDD provides help and solutions during outbreak investigations, works on making labs and epidemiology stronger and improves training offered in the field. Many agree with its evidence-based methods, although their effectiveness can be influenced by changing global interests and policies of the United States (Figure 6).¹⁴

Specialized Networks: ProMED-Mail, Global Public Health Intelligence Network (GPHIN), and HealthMap

Because of advancements in technology these platforms now provide early warnings about novel outbreaks before they spread widely. Started by the International Society for Infectious Diseases in 1994, ProMED-mail shares expertly compiled information

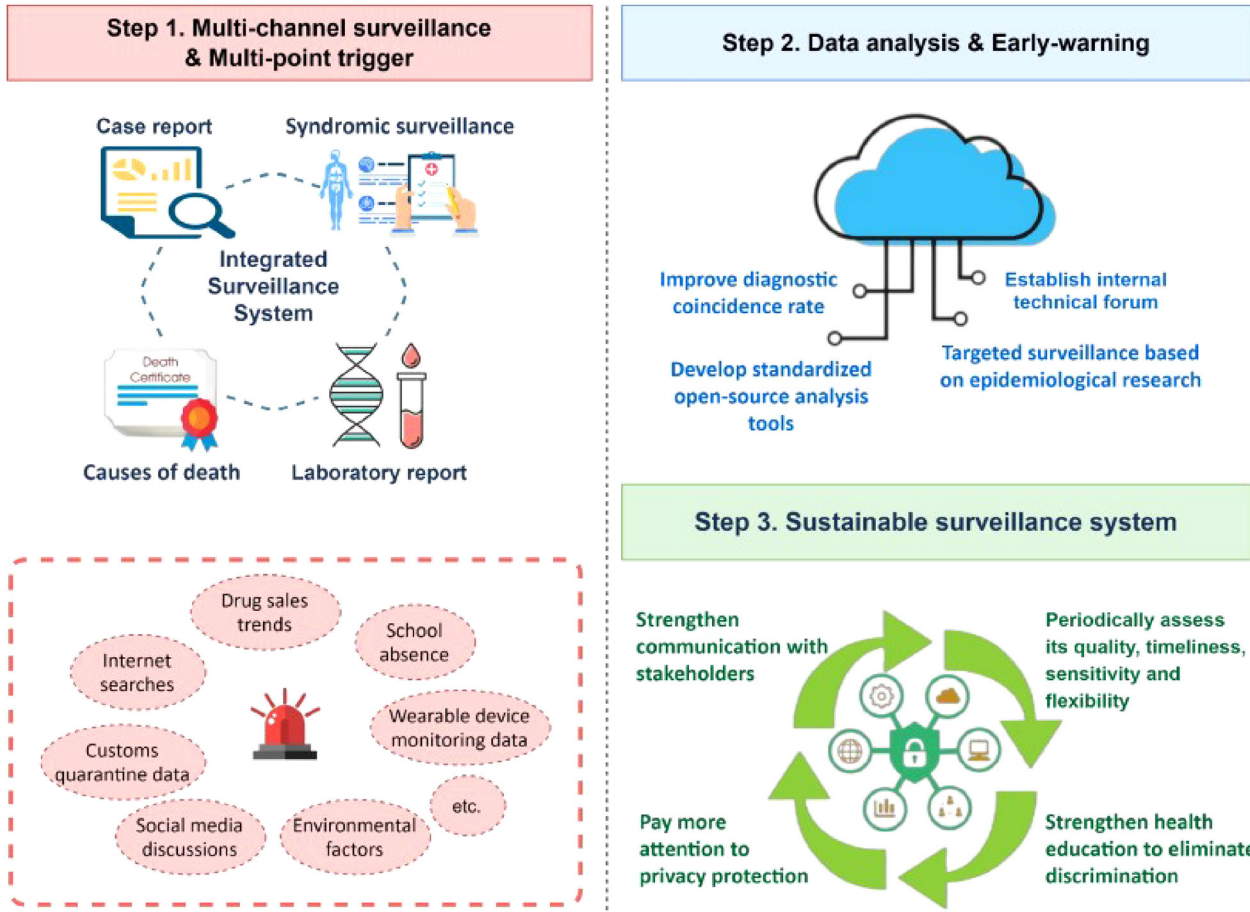


Fig 3 | Typology of global surveillance systems and their integration⁸

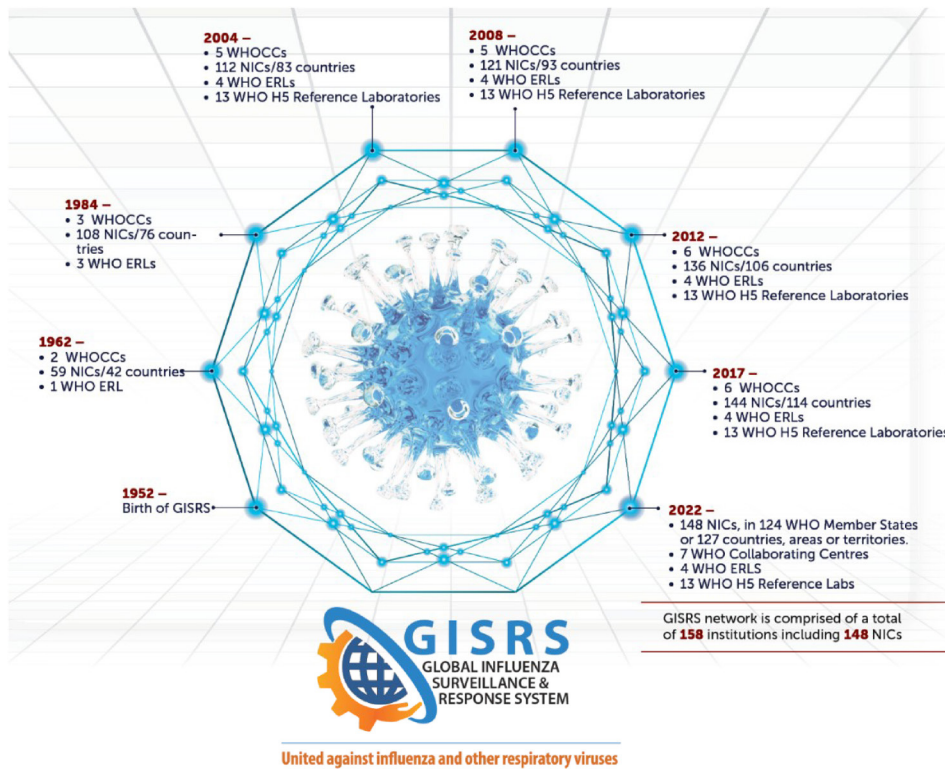


Fig 4 | Evolution of the GISRS, 1952–2022¹¹

from many sources and has issued important alerts on SARS and COVID-19.¹⁵ The Canadian government created GPHIN which uses computer algorithms to review information across multiple languages and identify new public health dangers. HealthMap which is led by Harvard, uses immediate data mining from digital sources to map out the spread of outbreaks (Figure 7).¹⁶

Table 1 below presents a comparative summary of these surveillance systems across key operational dimensions, including coverage, early warning lead-time, estimated costs, and data-sharing policies.

Evaluation of Infrastructure and Capabilities

How well global infectious disease surveillance works depends on the strength and fairness of the supporting infrastructure. Surveillance systems are effective when supported by strong coordination, data collection, diagnostic capacity, and use of new technologies. It is still very difficult to detect and deal with diseases quickly because of the big gaps in infrastructure between high-income nations and LMICs.¹⁷

Laboratory and Diagnostic Capacity

At the heart of IBS systems are the equipment and set-up in laboratories that help with identifying and verifying pathogens. However, capacity is not the same everywhere in the world. Advanced health systems in rich countries allow them to do multiple tests with real-time PCR and next-generation sequencing, but LMICs continue to face challenges such as having basic laboratories, skilled staff and a reliable supply of necessary reagents and equipment.¹⁸ This challenge delays pathogen detection and identification, leading to increased reliance on larger laboratories, which further prolongs outbreak response.¹⁹

The WHO’s Strengthening Laboratory Services initiative and funding via the GHSA are trying to reduce the gap.¹⁸ Through the Regional Integrated Surveillance and Laboratory Network, the Africa CDC is demonstrating that more localized diagnostic systems are possible, although worldwide testing is still limited.¹⁹ Even though RDTs and point-of-care tools provide quick help, they differ in their ability to detect diseases and are often not enough to deal with new infectious pathogens.²⁰



Fig 5 | Action packages of GHSA¹²

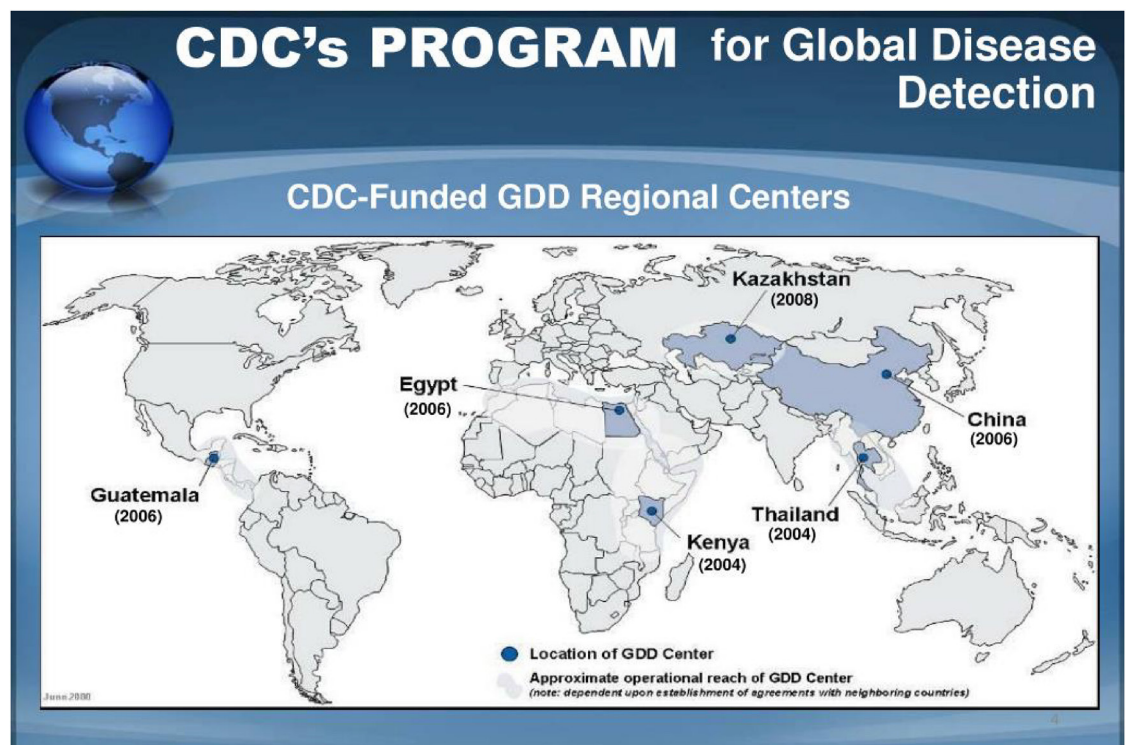
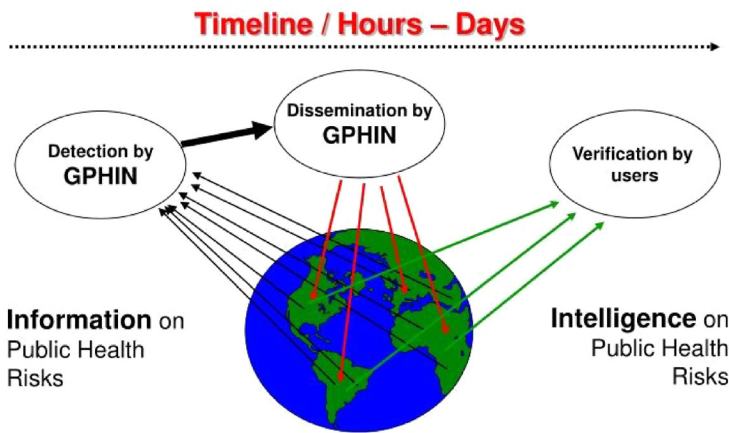


Fig 6 | Regional centers of operation of CDC-funded GDD program¹⁴



- Over 10 000 sources of information
- Arabic, English, French, Spanish, Russian, Chinese (Traditional & Simplified)

Fig 7 | GPHIN early warning system¹⁶

Table 1 | Comparative summary of key global infectious disease surveillance systems by coverage, lead-time, cost, and data-sharing policies

Surveillance System	Coverage	Lead-Time (Early Warning)	Cost Estimate	Data-Sharing Policy
GOARN	Global	Moderate (reactive)	Donor-funded	Restricted (member-driven)
GISRS	Global (Flu)	Seasonal (routine)	WHO-funded	Conditional (lab sharing)
ProMED-mail	Global	Very Fast (7–10 days ahead of WHO)	Low (volunteer-based)	Open Access
HealthMap	Global	Fast (AI-based alerts)	Moderate	Open Access
BlueDot	Global	Very Fast (AI-powered, 10 days ahead)	<\$ 1 M/year	Proprietary (subscription)
GPHIN	Global (Multilingual)	Moderate-Fast (AI screening)	Government-funded	Restricted (government use)

Surveillance Coverage in Low- and Middle-Income Countries

In many LMICs, weak health systems, constant political problems, and insufficient methods for reporting cause difficulty in surveillance. Since many zoonotic diseases start in these less-studied parts of the world, the absence of their data is very concerning. With GHSA and multilateral organizations using tools like the JEE to assess countries, the problem is that funding is often unstable and support from top officials is not always guaranteed.²¹

Fear of economic or political problems could deter a country from transparent reporting, which delays and could reduce the effectiveness of global early warning. For surveillance to improve in LMICs, it needs better technology, legal security, ways to build trust and incentives to be more open.²²

Digital Disease Detection and AI-Driven Analytics

Using AI, machine learning and natural language processing (NLP) in disease surveillance has changed how outbreaks are discovered and followed.²³ BlueDot, Metabiota, and HealthMap take big data from all sorts of open sources and use algorithms to discover signs of a possible disease outbreak.¹⁸

Such tools have been shown to predict and notify people about hazards ahead of official notifications. There are reports that BlueDot spotted signs of COVID-19 much earlier in December 2019 than any international organization.¹⁹ Even so, these systems deal with issues related to the bias found in data, the interpretability of their algorithms, and how alerts should be confirmed. If a model depends too much on theories that have not been properly verified, chances for mistakes or overlooking something are higher.²¹

AI surveillance can lead to collateral issues, such as false positives, mass panic, and algorithmic bias. Overreliance on opaque models has a chance of missing marginalized areas with insufficient digital data.

Although there is limited information on the cost-effectiveness values, the research indicates that ProMED and BlueDot issued alerts about the potential risk of COVID-19 infection up to 7–10 days before the official warnings. During H1N1 and Zika, HealthMap appeared equally efficient in detecting them at an early stage. Models designed by AI like BlueDot were said to cost less than 1 million dollars per year, which is a small fraction in terms of pandemic response expenditures that ran by the billions. Comparative, systematic efficacy cost-per-case averted, lead-time benchmarking, and false positive rates, remain scarce but necessary for future prioritization.

Mobile and Remote Data Collection Tools

With reduced traditional monitoring, mobile tools have greatly boosted how much data can be collected. With SMS reporting, mobile health apps and community involvement in surveillance, health professionals get real-time information about disease in remote places.¹³ Outbreaks Near Me and AfyaData from sub-Saharan Africa show how communities can use their health surveillance data to help overall efforts.²²

Yet, these ways of teaching rely on being familiar with technology, good internet or cellular coverage and users taking part regularly. However, getting mobile-collected data into national and world systems is still hard due to incompatibility among platforms and differences in standards in data validation.²¹

Policy and Regulatory Frameworks

Strong worldwide monitoring for EIDs depends on good technology as well as solid laws and policies that make quick reporting, sharing of information and a coordinated approach possible. Leading the world’s efforts in international public health are the IHR,²³ along with initiatives based on the One Health approach and a wide variety of international arrangements. Even though governments have big plans for these frameworks, they still struggle with enforcement, lack of coordination and fairness.²⁴

IHR (2005): Scope, Compliance, and Limitations

Under the IHR (2005), adopted by 196 countries, healthcare systems internationally must respond to shared illnesses.²³ Countries must develop main public health capacities for noticing threats, judging risks

and dealing with them and must inform the WHO of any PHEIC within a day of assessment.²⁵ Even though the IHR are designed to emphasize cooperation instead of rule-breaking, they have no real enforcement measures.

Even though the pact is ratified by most nations, many countries still fail to comply with the regulations. Many low- and middle-income countries are unable to meet the IHR core standards mainly due to money, infrastructure, and policy issues. Countries that are rich and powerful have in some instances reported delays or understated risk for economic or strategic reasons.²⁶ The fact that the IHR depends on countries to report their data and does not have strong tools to verify compliance or penalize noncompliance, shows a main gap in its governance. During the first weeks of the COVID-19 outbreak in Wuhan, unclear information from China slowed the world's response, making the weaknesses of the world's system clearer.²⁷

The voluntary nature of the IHR establishes poor incentives toward timely reporting because countries could be afraid of being hit by trade, political, or economic sanctions. Without sanctions or effective enforcement mechanisms, underreporting becomes institutionalized.

One Health Framework: WHO, World Organization for Animal Health (OIE) and Food and Agriculture Organization (FAO) Collaboration

The WHO, OIE and FAO have adopted the One Health approach to unite human, animal and environmental health surveillance. Since over two-thirds of EIDs come from animals, this cooperation helps spot these events early.²²

However, fully adopting One Health has been difficult. Problems with coordinating information, individual data systems and uneven approaches to funding keep sectors apart. Even though initiatives such as the Tripartite Zoonoses Guide create frameworks, their use is often blocked by the lack of coordination between health, agriculture and environment ministries and the bureaucratic hurdles.²⁸

Bilateral vs. Multilateral Coordination

There are several bilateral and multilateral agreements that back global surveillance and each agreement offers its own set of pros and cons. Through the GDD program, the CDC partners with single countries quickly but these steps might not always consider global health equity over the interests of the donor.²⁹

Besides, multilateral initiatives such as the GHSA or projects led by the WHO prefer to work with different countries, but they seldom succeed in building agreements, ensuring funds are present or putting their efforts together to avoid duplication. Having many groups involved without clear rules for accountability often leads to rivalry instead of teamwork which is evident in moments of crisis.¹⁸

Legal and Political Barriers to Timely Reporting

A major problem in disease surveillance management is when outbreak information is influenced by political factors. Trying to protect country sovereignty, the risk

of being banned from travels, or risks to their reputation can lead to deliberately not reporting information or not doing it immediately.¹³ Early in the outbreak of Ebola in West Africa and COVID-19 in China, important information was not shared which limited efforts to stop both viruses.¹⁹

Because no set dispute resolution exists in the IHR, countries do not have many reasons to comply with the guidelines.¹⁵ Political factors usually take priority over health-related decisions and since there is no official accountability, the world system relies a lot on good relationships and gentle diplomacy.

Challenges in Data Sharing and Coordination

Efficient global infectious disease monitoring relies on the fast sharing of reliable information. However, after many years of trying, important obstacles to sharing and coordinating data have not been solved.¹² Political distrust is one issue and others are a mix of tech fragmentation, diverse data rules, ethical issues, and the power of false information. It is necessary to face these issues to make sure the surveillance architecture is sophisticated, politically legitimate, and ethically sound.¹⁶

Transparency, Sovereignty, and Mistrust

It is very difficult to achieve global surveillance because it must balance protecting national independence with the need for openness. Some countries might avoid transmitting full information on an outbreak since they worry it could lead to sanctions, lower their reputation, or influence political advantage.¹⁹ They can seriously get in the way of early detection and response efforts. Examples like the SARS outbreak in 2003 and the early part of the COVID-19 pandemic reveal that not reporting quickly enough given political reasons can expand containable local issues into problems that affect the whole world.⁴

There is also a lack of trust from social groups and individuals toward data-sharing initiatives. Most LMICs feel that providing data, mainly genomic, might not result in receiving fair access to diagnostics, vaccines, or treatments. Since the benefits are not equal, this makes it less likely for people to trust each other and openly share data.²¹

Interoperability and System Fragmentation

It is difficult for different computer systems and groups to exchange, organize and use data which is an important technological problem. There are many platforms for disease surveillance, but most work apart from one another as they do not use the same formats, systems, or protocols.²² Custom platforms that are closed-source and do not support API use are common among authorities in public health, research centers and NGOs which negatively affects the analysis of data gathered in different areas.²⁹

Lack of agreed digital networks during the pandemic resulted in important epidemiological data being used inefficiently and understanding the situation coming more slowly. Projects such as the Digital Square initiative and the Global Digital Health Partnership are working to encourage the use of open standards and

similar data governance, though take-up is not spread evenly around the world. Where there are no laws or rewards for cooperation, setting up digital disease surveillance is still a haphazard project.³⁰

Proprietary vs. Open-Access Models

People are very passionate about the topic of who owns and accesses genomic surveillance data. Because of platforms such as GISAID, virus genome data from many countries could be shared quickly, making it easier to follow the different SARS-CoV-2 variants.³¹ This, however, is not without controversy, as it puts limits on what can be done with the shared data, which some scientists believe compromises transparency and repeatability.²⁵

On the other hand, general-access resources such as GenBank and Nextstrain make their data available for all but run the risk of data being misused by some, not being properly acknowledged and having too little data protection for the countries donating the data. There is a broader issue in science worldwide, since different systems may create tension between patent right and the medical needs of the many.²²

Ethical Concerns and Equity in Data Use

Apart from needing access, using outbreak data can cause serious ethical issues, especially in terms of who

gets the benefits. Many LMICs that give genomic data and pathogen samples are usually prevented from playing a role in the development of the science and property surrounding their donations. Global South countries have provided valuable genomic data, yet most of the vaccines are still not going to them which highlights the injustice.²⁰

Besides, since not everyone has the same access to digital tools and knowledge, many nations are excluded from taking part in or profiting from, global surveillance systems. While ongoing efforts like courses and workshops have been made, they have not managed to equalize access.¹²

Misinformation, Disinformation, and Media Dynamics

The COVID-19 infodemic demonstrated that modern information systems can both help and harm. Digital systems are quick to distribute public messages but also accelerate the spread of false information and conspiracy theories, which reduces trust in health monitoring and support. Algorithms on popular social media sites share emotional content (Figure 8).³²

Therefore, governments and public health agencies should treat strategic communication as a core part of their surveillance efforts.³⁰ Engaging with the public in real time, being transparent about uncertainties, and

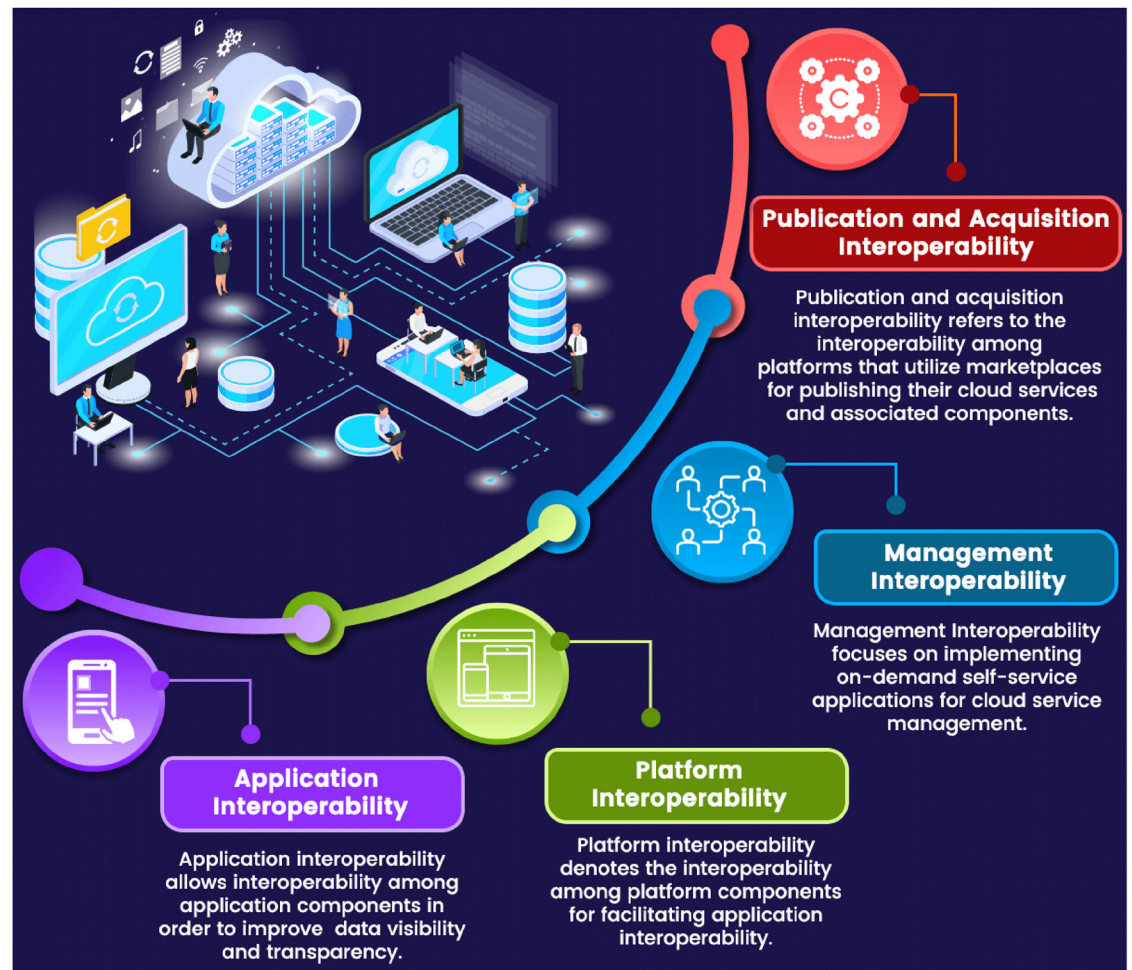


Fig 8 | Data-sharing flowchart with interoperability bottlenecks highlighted³²

collaborating with trusted community members are needed to combat misinformation and build public trust.³²

Innovations and Success Stories

Amid ongoing structural and political hurdles, several bodies have shown to be leaders in innovation, strength, and effectiveness. Such cases highlight how the integration of advanced methods, open research and local impact can improve how global outbreaks are detected and tackled.²⁹

Early Warning from Open-Source Surveillance

The first major alert about the COVID-19 outbreak was generated by ProMED-mail and not public health departments at the state level. On the last day of December 2019, ProMED reported a group of pneumonia cases in Wuhan, China, before the WHO had shared any news.¹³ It demonstrates how EBS can contribute by uncovering critical information from clinicians, media, and similar sources.¹⁸

Likewise, the GISAID made it possible to quickly share genetic information on SARS-CoV-2 soon after

the outbreak was recognized. The open-access system at GISAID, with some licenses, enabled researchers everywhere to monitor the virus and create new tools to address it, much quicker than ever.²¹

Regional Empowerment: Africa CDC

Africa CDC and its network of regional surveillance units are major steps toward letting Africa take the lead in managing epidemic information. These hubs facilitate real-time information sharing and utilization, enhance team training, and foster better cooperation among member countries.³³ The Africa CDC contributed to COVID-19 prevention and control efforts by strengthening genomic surveillance and supporting vaccine distribution which showed that building capacity is crucial for underserved communities.³¹

Genomic Surveillance in Action

Next strain and Pathogenwatch have turned genetic information into useful knowledge. Seeing how pathogens spread in real time helps researchers and health agencies react faster to new variants, measure their mutation rates, and decide on updates to vaccines and restrictions for travel.³⁴ The dashboards developed for interactive diagnosis and infectious disease tracking are strong evidence of what open science and real-time information can do.³⁵

AI-Powered Predictive Models

AI has demonstrated its potential in epidemic prediction. Using NLP and airline information from around the world, the company BlueDot found a possible health threat in Wuhan on December 31, 2019.²⁹ It predicted that COVID-19 would spread within the next week before authorities gave clear reports. It shows that AI-based models may increase the strength of traditional surveillance by recognizing little-known, complex trends in numerous streams of data.³¹

Future Directions and Recommendations

The development of a secure, shared, and smart global surveillance network for new infectious diseases requires changes in structures, technology, and governance. From past experiences with pandemics, changes are needed to close gaps and promote countries working together.

Strengthening Real-Time Genomic Surveillance

Integrating genomic surveillance with other forms of data is needed right away. This integration allows for rapid tracking of pathogen evolution, the emergence of antimicrobial resistance, and the unfolding of disease outbreaks. An unequal distribution of sequencing access worldwide is making it more challenging for early warning systems to work well in LMICs.³⁶ By establishing both decentralizing sequencing and cloud-based data transfer pathways, the goal of democratizing pathogen genomics can be achieved. It is very important to give training in bioinformatics and genomic epidemiology to local scientists and public health workers.³²

Decision-Tree Guiding Policymakers from Hazard → Recommended Surveillance Mix

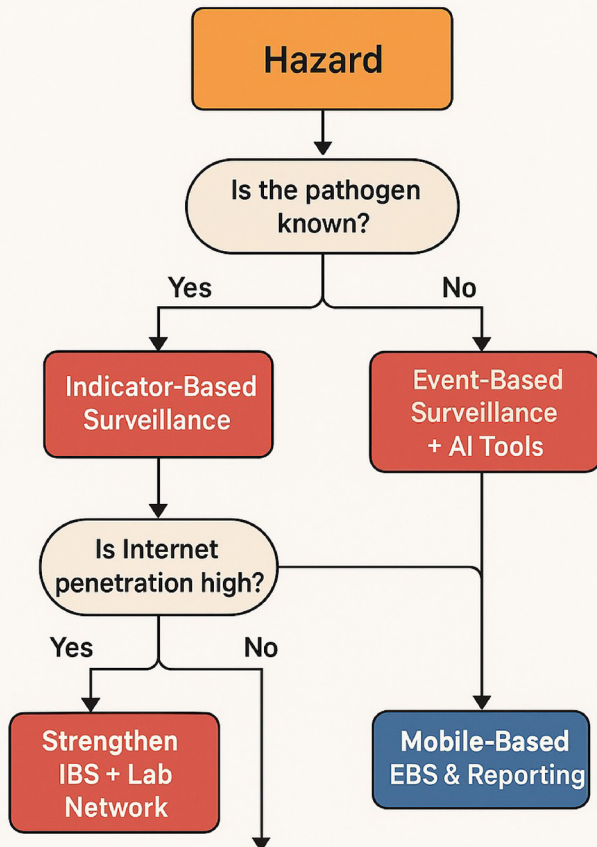


Fig 9 | Decision-tree guiding policymakers from hazard to recommended surveillance strategy

Table 2 | key distinctions between this review and major global health-climate reports (IPCC AR6, lancet countdown)

Theme	IPCC AR6/Lancet Countdown	This Review
Health financing and climate	Discussed broadly; no quantitative focus on surveillance	<1% of climate funds go to surveillance (NEW)
Role of AI in early warning	Limited mention	Detailed evaluation of BlueDot, NLP systems (NEW)
System interoperability	Mentioned in passing	Deep dive into tech fragmentation and APIs (NEW)
Genomic equity	General global access concerns	Detailed on GISAID, GenBank tensions (NEW)

The guide in this flow chart (Figure 9) simplifies how public health officials can align the characteristics of an emerging threat with the most appropriate surveillance strategy given some of the dynamics are pathogen familiarity, infrastructure, and digital access.

Establishing Global Digital Health Governance

Because AI and digital tools are being used quickly in outbreak response and prediction, formal governance systems are now needed. They ought to cover privacy issues, accountability in algorithms and ethical rules. WHO and similar organizations ought to be given the necessary powers and support to oversee agreed standards and help nations collaborate on health issues.³⁴ Digital governance principles can be added to an international treaty or updated IHR to support innovation and rights.

Incentivizing Transparent and Equitable Data Sharing

It is necessary for the global health community to use financial incentives to encourage sharing of data instead of stockpiling it. For example, such actions include credit systems, official agreements on data sharing and systems that guarantee developing countries equal access to important tools related to vaccines, diagnostics, and treatments.³⁷ Consistency in standards and APIs encourages systems to communicate easily among countries and organizations.

Sustained Investment in Capacity Building

A sustainable approach involves ongoing building of surveillance in places where risks are highest. Capacity building should be redefined from development aid to a key aspect of global security.¹⁷ A sustainable financial system should offer stability, flexibility, and high accountability to support infrastructure, foster workforce development, and strengthen regional partnerships. Building trust among stakeholders and community groups can foster greater self-reliance in surveillance efforts.²⁴

Conclusion

This review gave a detailed analysis of how advanced surveillance for infectious diseases is carried out worldwide, looking at systems, rules, and the way data is shared and integrated. Though WHO's GOARN, GISRS, and platforms including ProMED and Health-Map have been good at detecting outbreaks, their overall impact is greatly reduced by the fragmented nature of disease control efforts, inequality, and continuous

noncompliance with important guidelines and treaties such as the IHR (2005).

Ongoing problems like a lack of laboratory access in certain places, data not easily shared between systems, and hesitancy from governments or organizations to divulge outbreak-related data weaken the entire system. Also, few rules exist to manage data ownership and benefit-sharing arrangements for the use of genetic material in medical surveillance.

For future threats to be better managed, the global surveillance system should be effective, united, and just. To achieve this, real-time data from genomes should be matched with clinical and epidemiological signals, legal systems for digital health tools and AI should be ready, and people should be encouraged to share their data openly. Sharing technology should go hand in hand with ensuring equitable access to vaccines and treatments, particularly for countries contributing data.

Although some of the themes of this review can be traced in major publications, like the IPCC AR6 and Lancet Countdown briefs, it introduces a new perspective on surveillance infrastructure, AI adaptation, and data equity. These differences can be listed in Table 2:

Ultimately, preparedness, the ability for information to pass easily, and trust should be the anchors of global health surveillance for the next stage. Now that the world faces ecological issues, climate change, and increased human mobility, having resilient surveillance is both necessary and right. We should not wait for another pandemic to deal with the known problems in the system.

References

- Heymann DL, Rodier G. Global surveillance, national surveillance, and SARS. *Emerg Infect Dis.* 2004;10(2):173. <https://doi.org/10.3201/eid1002.031038>
- Xu J, Zhao S, Teng T, Abdalla AE, Zhu W, Xie L, et al. Systematic comparison of two animal-to-human transmitted human coronaviruses: SARS-CoV-2 and SARS-CoV. *Viruses.* 2020;12(2):244. <https://doi.org/10.3390/v12020244>
- Morens DM, Fauci AS. Emerging pandemic diseases: how we got to COVID-19. *Cell.* 2020;182(5):1077–92. <https://doi.org/10.1016/j.cell.2020.08.021>
- Spermovasilis N, Tsiodras S, Poulakou G. Emerging and re-emerging infectious diseases: humankind's companions and competitors. *Microorganisms.* 2022;10(1):98. <https://doi.org/10.3390/microorganisms10010098>
- Iwasaki H, Salmon S, Matsuzawa Y, Lee S, Takagi K, Nomoto H, et al. Global Outbreak Alert and Response Network (GOARN) focal point engagement meeting with partners in Japan. *West Pac Surveill Response J.* 2024;15(5 Suppl):1. Available from: <https://pmc.ncbi.nlm.nih.gov/articles/PMC10958120/>
- Katz R, Sorrell EM, Komblet SA, Fischer JE. Global health security agenda and the international health regulations: moving forward.

- Biosecur Bioterror. 2014;12(5):231–8. <https://doi.org/10.1089/bsp.2014.0038>
- 7 Nsubuga P, White ME, Thacker SB, Anderson MA, Blount SB, Broome CV, et al. Public health surveillance: a tool for targeting and monitoring interventions. Available from: <https://europepmc.org/article/nbk/nbk11770>
 - 8 Xu L, Zhou C, Luo S, Chan DK, McLaws ML, Liang W. Modernising infectious disease surveillance and an early-warning system: the need for China's action. *Lancet Reg Health West Pac.* 2022;23. <https://doi.org/10.1016/j.lanwpc.2022.100485>
 - 9 Paolotti D, Carnahan A, Colizza V, Eames K, Edmunds J, Gomes G, et al. Web-based participatory surveillance of infectious diseases: the InfluenzaNet participatory surveillance experience. *Clin Microbiol Infect.* 2014;20(1):17–21. <https://doi.org/10.1111/1469-0691.12477>
 - 10 Bogich TL, Chunara R, Scales D, Chan E, Pinheiro LC, Chmura AA, et al. Preventing pandemics via international development: a systems approach. *PLoS Med.* 2012;9(12):e1001354. <https://doi.org/10.1371/journal.pmed.1001354>
 - 11 World Health Organization. Celebrating 70 years of GISRS (the global influenza surveillance and response system); 2022. Available from: [https://www.who.int/news/item/03-02-2022-2022-celebrating-70-years-of-gisrs-\(the-global-influenza-surveillance-and-response-system\)](https://www.who.int/news/item/03-02-2022-2022-celebrating-70-years-of-gisrs-(the-global-influenza-surveillance-and-response-system))
 - 12 Malaria Consortium. Global health security. London: Malaria Consortium; 2025. Available from: <https://www.malariaconsortium.org/pages/global-health-security.htm>
 - 13 Rocha DC, Santos Louro L, Ewald Oliveira H, Cancian de Araujo B, Ryu S, Vicente CR. Use of ProMED as a surveillance system for emerging and re-emerging infectious diseases in Brazil from 2015 to 2020. *Viruses.* 2025;17(1):93. <https://doi.org/10.3390/v17010093>
 - 14 Montgomery JM, Woolverton A, Hedges S, et al. Ten years of global disease detection and counting: program accomplishments and lessons learned in building global health security. *BMC Public Health.* 2019;19(Suppl 3):1056. <https://doi.org/10.1186/s12889-019-6769-2>
 - 15 Brownstein JS, Freifeld CC, Madoff LC. Digital disease detection—harnessing the web for public health surveillance. *N Engl J Med.* 2009;360(21):2153. <https://doi.org/10.1056/NEJMp0900702>
 - 16 Public Health Agency of Canada. Independent review panel final report: global public health intelligence network. Ottawa (ON): PHAC; 2021. Available from: <https://www.canada.ca/en/public-health/corporate/mandate/about-agency/external-advisory-bodies/list/independent-review-global-public-health-intelligence-network/final-report.html>
 - 17 Mattap SM, Mohan D, McGrattan AM, Allotey P, Stephan BC, Reidpath DD, et al. The economic burden of dementia in low-and middle-income countries (LMICs): a systematic review. *BMJ Glob Health.* 2022;7(4):e007409. <https://doi.org/10.1136/bmjgh-2021-007409>
 - 18 Global Health Security Agenda. Action packages overview; 2025. Available from: <https://www.ghsagenda.org/packages>
 - 19 League A, Bangure D, Meyer MJ, Salyer SJ, Wanjohi D, Tebeje YK, et al. Assessing the impact of regional laboratory networks in East and West Africa on national health security capacities. *PLOS Glob Public Health.* 2023;3(5):e0001962. <https://doi.org/10.1371/journal.pgph.0001962>
 - 20 GISAID. Global initiative on sharing all influenza data; 2025. Available from: <https://www.gisaid.org/>
 - 21 Stowell D, Garfield R. How can we strengthen the Joint External Evaluation? *BMJ Glob Health.* 2021;6(5):e004545. <https://doi.org/10.1136/bmjgh-2020-004545>
 - 22 Mudzengi DL, Chomutare H, Nagudi J, Ntshiqha T, Davis JL, Charalambous S, Velen K. Using mHealth technologies for case finding in tuberculosis and other infectious diseases in africa: systematic review. *JMIR Mhealth Uhealth.* 2024;12:e53211. <https://doi.org/10.2196/53211>
 - 23 Aavitsland P, Aguilera X, Al-Abri SS, Amani V, Aramburu CC, Attia TA, et al. Functioning of the international health regulations during the COVID-19 pandemic. *Lancet.* 2021;398(10308):1283–7. [https://doi.org/10.1016/S0140-6736\(21\)01911-5](https://doi.org/10.1016/S0140-6736(21)01911-5)
 - 24 Harman S, Papamichail A. Global health governance. London: Routledge; 2024. <https://doi.org/10.4324/9780203711613>
 - 25 Parinduri RK, Efendy I, Amirah A. Evaluation of PHEIC (public health emergency of international concern) detection implementation on the performance of port health employees class I Medan. *J La Medihealthico.* 2021;2(2):86–93. <https://doi.org/10.37899/journallamedihealthico.v2i2.327>
 - 26 World Health Organization. Evidence as a catalyst for policy and societal change: towards more equitable, resilient and sustainable global health. Meeting report of the WHO global evidence-to-policy summit, 15–17 November 2021. Geneva: WHO; 2022. Available from: <https://books.google.com/books?hl=en&lr=&id=XngOEQA-AQBAJ&oi=fnd&pg=PA4&ots=MtkEzkR9Jv&sig=XamcXH6QzgKZLNfQfPCn89-lxo>
 - 27 Lal A, Erondy NA, Heymann DL, Gitahi G, Yates R. Fragmented health systems in COVID-19: rectifying the misalignment between global health security and universal health coverage. *Lancet.* 2021;397(10268):61–7. [https://doi.org/10.1016/S0140-6736\(20\)32228-5](https://doi.org/10.1016/S0140-6736(20)32228-5)
 - 28 World Health Organization, World Organisation for Animal Health. Workforce development for effective management of zoonotic diseases: operational tool of the Tripartite Zoonoses Guide. Geneva: WHO; 2024. Available from: https://books.google.com/books?hl=en&lr=&id=IoUzEQAAQBAJ&oi=fnd&pg=PR4&ots=sDAB-ZR88f_&sig=bav6xsC8Wx3BLYmOeeOZtgTJNKE
 - 29 World Health Organization. Preparedness, surveillance and response: technical brief for the development of a national action plan for health security. Geneva: WHO; 2022. Available from: <https://www.who.int/publications/b/31508>
 - 30 Gostin LO, Habibi R, Meier BM. Has global health law risen to meet the COVID-19 challenge? Revisiting the international health regulations to prepare for future threats. *J Law Med Ethics.* 2020;48(2):376–81. <https://doi.org/10.1177/1073110520935354>
 - 31 Park JJ, Mogg R, Smith GE, Nakimuli-Pmpungu E, Jehan F, Rayner CR, et al. How COVID-19 has fundamentally changed clinical research in global health. *Lancet Glob Health.* 2021;9(5):e711–20. [https://doi.org/10.1016/S2214-109X\(20\)30542-8](https://doi.org/10.1016/S2214-109X(20)30542-8)
 - 32 101 Blockchains. Cloud interoperability and portability. 101 Blockchains. Available from: <https://101blockchains.com/cloud-interoperability-and-portability/>
 - 33 Lentzen M, Linden T, Veeranki S, Madan S, Kramer D, Leodolter W, Fröhlich H. A transformer-based model trained on large-scale claims data for prediction of severe COVID-19 disease progression. *IEEE J Biomed Health Inform.* 2023;27(9):4548–58. <https://doi.org/10.1109/JBHI.2023.3288768>
 - 34 Sachs JD, Karim SS, Aknin L, Allen J, Brosbøl K, Colombo F, et al. The Lancet Commission on lessons for the future from the COVID-19 pandemic. *Lancet.* 2022;400(10359):1224–80. [https://doi.org/10.1016/S0140-6736\(22\)01585-9](https://doi.org/10.1016/S0140-6736(22)01585-9)
 - 35 World Health Organization. Draft of the WHO convention, agreement or other international instrument on pandemic prevention, preparedness and response (“WHO Pandemic Agreement”). Intergovernmental Negotiating Body Bureau; 2024. Available from: https://apps.who.int/gb/inb/pdf_files/inb9/A_INB9_3-en.pdf
 - 36 Ryan SJ, Carlson CJ, Mordecai EA, Johnson LR. Global expansion and redistribution of Aedes-borne virus transmission risk with climate change. *PLoS Neglect Trop Dis.* 2019;13(3):e0007213. <https://doi.org/10.1371/journal.pntd.0007213>
 - 37 Gilmore AB, Fabbri A, Baum F, Bertscher A, Bondy K, Chang HJ, et al. Defining and conceptualising the commercial determinants of health. *Lancet.* 2023;401(10383):1194–213. [https://doi.org/10.1016/S0140-6736\(23\)00013-2](https://doi.org/10.1016/S0140-6736(23)00013-2)

Appendix

Appendix 1 Included studies and quality assessment scores				
No.	Author(s) and Year	Surveillance System/Topic Focus	Source Type	Quality Score
1	Heymann and Rodier (2004)	SARS Surveillance and Global Response	Peer-reviewed	High
2	Xu et al. (2020)	SARS-CoV and SARS-CoV-2 Comparison	Peer-reviewed	High
3	Morens and Fauci (2020)	Pandemic Emergence Overview	Peer-reviewed	High
4	Spernovasilis et al. (2022)	EIDs	Peer-reviewed	High
5	Iwasaki et al. (2024)	GOARN Engagement and Function	Peer-reviewed	High
6	Katz et al. (2014)	GHSA and IHR Interaction	Peer-reviewed	High
7	Nsubuga et al. (2006)	Surveillance Tools and Interventions	Peer-reviewed	High
8	Xu et al. (2022)	Early Warning System Development	Peer-reviewed	Medium
9	Paolotti et al. (2014)	Web-based Participatory Surveillance	Peer-reviewed	High
10	Bogich et al. (2012)	Systems Approach to Pandemic Prevention	Peer-reviewed	High
11	WHO (2022)	GISRS - Influenza Surveillance	Gray Literature	High
12	Malaria Consortium (2025)	Global Health Security	Gray Literature	Medium
13	Rocha et al. (2025)	ProMED Surveillance in Brazil	Peer-reviewed	High
14	CDC (2025)	GDD Program	Gray Literature	High
15	Brownstein et al. (2009)	Digital Disease Detection	Peer-reviewed	High
16	Zamir (2025)	GPHIN Early Warning System	Gray Literature	Medium
17	Mattap et al. (2022)	Health Burden in LMICs	Peer-reviewed	Medium
18	GHSA (2025)	GHSA Action Packages Overview	Gray Literature	High
19	League et al. (2023)	Regional Laboratory Networks in Africa	Peer-reviewed	High
20	GISAID (2025)	Global Influenza Data Sharing Platform	Gray Literature	High
21	Stowell and Garfield (2021)	Joint External Evaluation Strengthening	Peer-reviewed	High
22	Mudzengi et al. (2024)	Mobile Health Surveillance in Africa	Peer-reviewed	Medium
23	Aavitsland et al. (2021)	IHR Functionality in COVID-19	Peer-reviewed	High
24	Harman and Papamichail (2024)	Global Health Governance	Book Chapter	High
25	Parinduri et al. (2021)	PHEIC Implementation Evaluation	Peer-reviewed	Medium
26	WHO (2022)	Evidence-Based Policy for Health Security	Gray Literature	High
27	Lal et al. (2021)	Health Systems Fragmentation in COVID-19	Peer-reviewed	High
28	WHO/OIE/FAO (2024)	One Health Workforce Development	Gray Literature	High
29	WHO (2022)	National Action Plan for Health Security	Gray Literature	High
30	Gostin et al. (2020)	Global Health Law and IHR Challenges	Peer-reviewed	High