

A 2023 perspective



Future surveillance

For epidemic and pandemic diseases

A 2023 perspective

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Foreword



The health and well-being of people around the world continue to be challenged by infectious hazards. Indeed, 2022 saw the third year of the COVID-19 pandemic, a global outbreak of Mpox, an Ebola outbreak in Uganda and cholera outbreaks across multiple countries, among countless other outbreaks and infections. The threats posed by infectious diseases are also becoming more complex and far reaching. In our interconnected world, no one is safe until everyone is safe.

Surveillance is a pillar of the public health response to epidemics and pandemics. Yet, gaps in surveillance, from the local to the global, continue to leave the world vulnerable to infectious hazards. To address these vulnerabilities, the health emergency preparedness, response, and resilience (HEPR) architecture calls for a new approach to future surveillance, collaborative surveillance, that aligns traditional tactics with new initiatives to safeguard health for all. Central to this vision is the understanding that detecting infectious threats begins in communities and links to multi-sectoral, integrated and coordinated approaches globally. From harnessing new technologies and data-driven innovations to better linkages with health systems, to a deeper understanding of communities and our shared natural environment, strengthening surveillance is within our reach. But achieving a truly collaborative surveillance approach will require not only a deep commitment to collaboration but also sustainable investments and commitments from the highest levels to ensure that the most local levels are able to detect, report and act.

This inaugural report reflects the input and advice of leading experts with different skills, worldviews and experiences who share a commitment to better prepare for future infectious hazards. Notably, we acknowledge the breadth of expertise represented by the Strategic and Technical Advisory Group on Infectious Hazards with Pandemic and Epidemic Potential (STAG-IH), which provides independent advice and analysis to WHO and helped guide and inform this report.

Infectious hazards with epidemic and pandemic potential will continue to threaten communities, putting lives and livelihoods at risk. The insights in this report chart a course towards future surveillance and collaborative action.

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Development Process

This annual report builds on pre-existing work and initiatives aimed at prevention and control of communicable diseases. It reflects the work carried out by the three major COVID-19 response reviews including the International Health Regulations Review Committee, Global Preparedness Monitoring Board and The Independent Panel for Pandemic Preparedness & Response. Horizon scanning was conducted as part of the WHO epidemic and pandemic foresight initiative (2021—2022). The process, methodology and stakeholder engagement have been published on the WHO website¹.

The landscape analysis was conducted through a series of face-to-face discussions with WHO technical teams covering over twenty topics including acute and routine public health intelligence, open source epidemic intelligence, surveillance systems, digital and data science, AI-application, GIS/GPS, satellite systems, ethics, influenza, pandemic influenza preparedness framework, public health and social measures, community-based surveillance, participatory surveillance, genomic surveillance, laboratory diagnosis, clinical characterization, human-animal interface/zoonosis, as well as environmental and wastewater surveillance. Additional desk research was conducted by the STAG-IH Secretariat to complement the landscape analysis. A background discussion document was developed prior to the annual STAG-IH meeting, which, in October 2022, convened STAG-IH members, Directors of WHO Collaborating Centres, Chairs/Vice-Chairs of WHO Advisory Groups and representatives from multidisciplinary stakeholder groups. Surveillance experiences and efforts at the regional, national and local levels were invited through WHO Regional Office counterparts and WHO surveillance partners and presented in poster sessions during the annual STAG-IH meeting. Selected presentations are featured in Boxes in this report. The outcome of the STAG-IH consultation was summarized and published in the WHO Weekly Epidemiological Record in March 2023².

This full report was further developed based on discussions and recommendations of the STAG-IH annual meeting and the development of each chapter was led by assigned STAG-IH members and its Secretariat. STAG-IH members conducted outreach to their own networks to collect further information on key topics. These development efforts were paralleled with the defining of collaborative surveillance – a core concept for strengthening the global architecture for health emergency preparedness, response and resilience (HEPR) which were built through facilitated workshops at the three levels of the Organization (Headquarters, Regional Offices and Country Offices). The core concept was published in May 2023³. This report reflects these workshop discussions and outcomes, as it was completed with updated and validated information in July 2023.

¹ <https://pandemic-foresight.who.int/methodology>

² https://apps.who.int/iris/handle/10665/366414?search-result=true&query=STAG-IH&scope=%2F&filtertype_0=relationserie&filter_relational_operator_0=contains&filter_0=Weekly+Epidemiological+Record&rpp=10&sort_by=dc.date.issued_dt&order=desc

³ <https://www.who.int/publications/i/item/9789240074064>

Glossary

Artificial intelligence (AI)

Refers to the performance by computer programs of tasks that are commonly associated with intelligent beings. The basis of AI is algorithms, which are translated into computer code that carries instructions for rapid analysis and transformation of data into conclusions, information or other outputs. A specific definition of AI in a recommendation of the Council on Artificial Intelligence of the OECD states: An AI system is a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy. For more information: <https://www.who.int/publications/i/item/9789240029200>

Basic reproduction number (R0)

An epidemiologic measure to describe the contagiousness or transmissibility of infectious agents. It is affected by biological, social, behavioural and environmental factors that affect pathogen transmission. Also known as the basic reproduction ratio, the basic reproduction rate or the basic reproductive rate.

Big data

Complex data that are rapidly collected in such unprecedented quantities that terabytes (one trillion units [bytes] of digital information), petabytes (1000 terabytes) or even zettabytes (one million petabytes) of storage space may be required as well as unconventional methods for their handling. The unique properties of big data are defined by four dimensions: volume, velocity, veracity and variety. For more information: <https://www.who.int/publications/i/item/9789240029200>.

Biobank

A collection of biological samples and associated information organized in a systematic way for research purposes.

Bluetooth

An open wireless technology standard for transmitting fixed and mobile electronic device data over short distances.

Contact tracing

Contact tracing is the process of identifying, assessing and managing people who have been exposed to someone who has been infected with an infectious pathogen. Contact tracing and quarantine of contacts identified through contact tracing interrupt transmission between people and are essential public health tools for controlling infectious threats.

Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)

A technology that research scientists use to selectively modify the DNA of living organisms. CRISPR was adapted for use in the laboratory from naturally occurring genome editing systems found in bacteria.

Digital health

The field of knowledge and practice associated with the development and use of digital technologies to improve health. For more information: <https://www.who.int/health-topics/digital-health>.

Digital transformation

A process that aims to improve health care delivery, performance and quality, through combinations of information, computing, communication and connectivity technologies.

eHealth

The cost-effective and secure use of information and communications technologies in support of health and health-related fields, including health care services, health surveillance, health literature, and health education, knowledge and research.

Facility-based surveillance

This approach involves a health worker, typically a doctor, identifying a significant disease within their normal professional activities treating patients.

Fourth industrial revolution

A fundamental change in the way we live, work and relate to one another, characterized by a fusion of technologies that connect the physical, digital and biological spheres.

Geographic Information Systems (GIS)

Geospatial technology that enables spatial representation of data to support better public health planning and decision-making. For more information: <https://www.who.int/data/gis>

Global Positioning System (GPS)

A utility that provides users with positioning, navigation and timing services.

Indicator-based surveillance

Reports of specific diseases from health care providers to public health officials.

International Development Association (IDA)

Established in 1960, IDA is a part of the World Bank that aims to reduce poverty by providing zero to low-interest loans and grants for programmes that boost economic growth, reduce inequalities and improve people's living conditions. For more information: <https://ida.worldbank.org/en/home>.

International Health Regulations (2005)

The International Health Regulations (2005) represent a binding international legal agreement involving 196 countries across the globe. They aim to prevent, protect against, control and respond to the international spread of disease while avoiding unnecessary interference with international traffic and trade. For more information: <https://www.who.int/publications/i/item/9789241580410>.

Machine-learning

A branch of AI and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy.

Material transfer agreements (MTAs)

A Material Transfer Agreement (MTA) is a contract between the provider of material and the recipient. It grants the recipient a license to use the proprietary material and ensures that both parties understand how the materials can be used.

Memoranda of Understanding (MOU)

A type of agreement between two (bilateral) or more (multilateral) parties. It expresses a convergence of will between the parties, indicating an intended common line of action.

Multiplex tests

A real-time reverse-transcription polymerase chain reaction (rRT-PCR) laboratory test that can simultaneously detect and differentiate between influenza A, influenza B and SARS-CoV-2 in upper or lower respiratory specimens.

Nanotechnology

Science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers.

Natural Language Processing

The branch of AI concerned with giving computers the ability to understand text and spoken words in the same way as human beings.

One Health

An integrated, unifying approach that aims to sustainably balance and optimize the health of humans, animals, plants, and ecosystems. It recognizes that the health of humans, domestic and wild animals, plants and the wider environment (including ecosystems) are closely linked and interdependent. The approach mobilizes multiple sectors, disciplines and communities at different levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy, and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development.

For more information: <https://www.who.int/publications/i/item/9789240059139>

Open source/open data

Open source is a term that originally referred to open source software (OSS). Open source software is code that is developed in a decentralized and collaborative way, and is designed to be publicly accessible and modifiable.

Pandemic Influenza Preparedness (PIP) Framework

The PIP Framework brings together Member States, industry, other stakeholders and WHO to implement a global approach to pandemic influenza preparedness and response. Its key goals include: to improve and strengthen the sharing of influenza viruses with human pandemic potential; and to increase the access of developing countries to vaccines and other pandemic related supplies. The Framework was developed by Member States. It came into effect on 24 May 2011 when it was unanimously adopted by the Sixty-fourth World Health Assembly (2011). For more information: <https://www.who.int/initiatives/pandemic-influenza-preparedness-framework>.

Point-of-care diagnostics

Laboratory testing conducted close to the site of patient care that provides rapid test results with the potential for improved patient care.

Public health emergency of international concern (PHEIC)

Defined in the International Health Regulations (2005) as an extraordinary event which is determined to constitute a public health risk to other States through the international spread of disease and to potentially require a coordinated international response. For more information: <https://www.who.int/news-room/questions-and-answers/item/emergencies-international-health-regulations-and-emergency-committees>.

Reverse transcription polymerase chain reaction (RT-PCR)

Reverse transcription RT-PCR is used to amplify RNA targets. The RNA template is converted into complementary (c) DNA by the enzyme reverse transcriptase. The cDNA serves later as a template for exponential amplification using PCR.

Serosurveillance

Provides estimates of antibody levels against infectious diseases and is considered the gold standard for measuring population immunity due to past infection or vaccination. It is an important component of disease surveillance and complements notification, hospitalization, mortality and immunization coverage data.

Social media

A variety of online platforms, including blogs, business networks, collaborative projects, enterprise social networks, forums, microblogs, photo sharing, products review, social bookmarking, social gaming, video sharing and virtual worlds.

Syndromic surveillance

Methods relying on detection of individual and population health indicators that are discernible before confirmed diagnoses are made.

Universal Health Coverage (UHC)

Means that all people have access to the full range of quality health services they need, when and where they need them, without financial hardship. It covers the full continuum of essential health services, from health promotion to prevention, treatment, rehabilitation and palliative care. For more information: https://www.who.int/health-topics/universal-health-coverage#tab=tab_1.

Vector-borne disease

Vector-borne diseases are human illnesses caused by parasites, viruses and bacteria that are transmitted by vectors. Vectors are living organisms that can transmit infectious pathogens between humans, or from animals to humans. For more information: <https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases>.

Wearables

Also known as wearable technology. Wearable technology includes smart devices that can be worn on the body. Intelligent devices like activity trackers keep track of data without human interference.

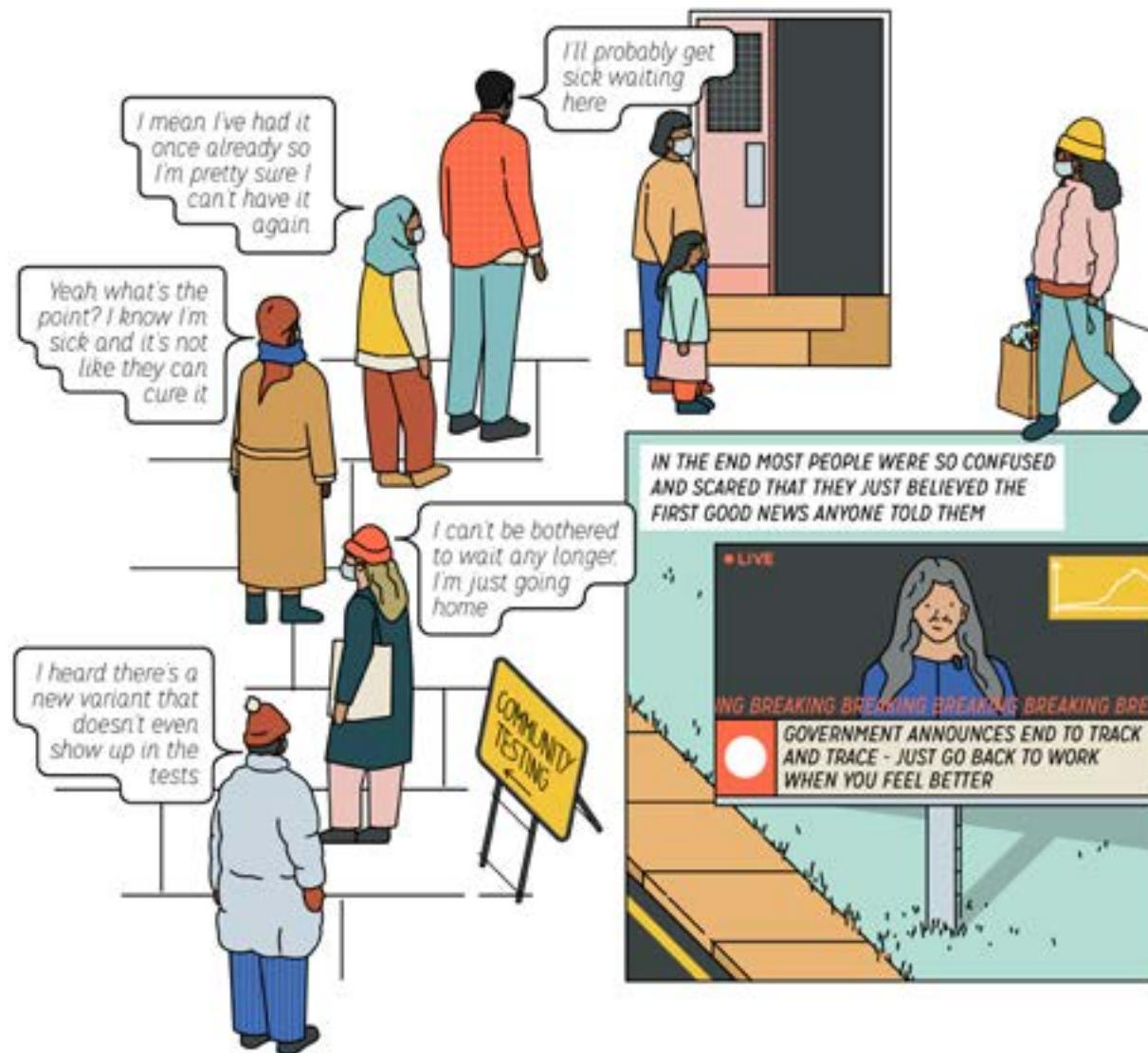
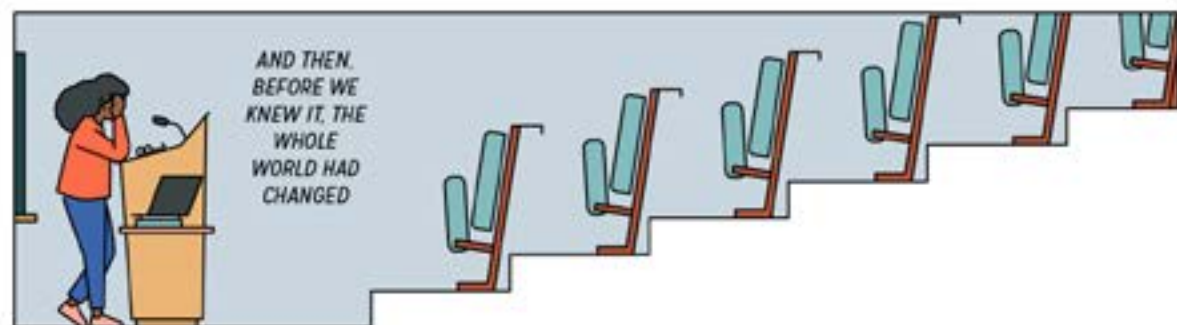
Zoonoses

An infectious disease that has jumped from a non-human animal to humans. Zoonotic pathogens may be bacterial, viral or parasitic, or may involve unconventional agents and can spread to humans through direct contact or through food, water or the environment. For more information: <https://www.who.int/news-room/fact-sheets/detail/zoonoses>.

**Travel to 2050 to check in on
Nala, a retired university lecturer,
as she looks back on the days during
the COVID-19 pandemic in 2020...**







Introduction

Since the beginning of the 21st century, the world has experienced major epidemics and pandemics every four to five years (Fig. 1)(1). According to World Health Organization (WHO) data, 300 to 400 infectious hazard events of public health concern are now detected annually (Fig. 2) (2, 3).

Given the increasing frequency and intensity of exacerbating factors – for example, population and demographic changes, biodiversity and ecological changes, urbanization, livestock production and expanded and higher-volume transportation networks – we can expect the emergence and re-emergence of infectious threats to continue. Most recently, COVID-19 revealed gaps in global preparedness for an infectious threat. Many parts of the world, including high-income countries with advanced health care systems, were unprepared and suffered protracted negative outcomes.

The progression of COVID-19 has indeed proven that “no one is safe until everyone is safe” in this interconnected world (4).

This report builds on the first foresight exercise on epidemic and pandemic preparedness and response conducted by WHO in 2022. Continuing this forward-looking approach, this year the focus is on a critical component of preparedness, prevention and response – surveillance. A functional surveillance system is essential for action on priority infectious diseases with epidemic and pandemic potential.

This report presents;

- global context
- result of horizon scanning
- changing needs for the next decade
- the promise of technological advances
- future vision
- the way forward.

We rely on effective surveillance to detect and monitor infectious threats and to inform the selection and application of interventions. Future surveillance is the surveillance we will be operating in the future. This report, Future surveillance for epidemic and pandemic diseases aims to describe the key considerations, opportunities and innovations that shape a vision of how surveillance will function in the future.

This report describes the global context and the result of horizon scanning of infectious diseases with pandemic and epidemic potential, including newly emerging and re-emerging zoonoses, with a focus on surveillance.

Fig. 1. Major epidemic and pandemic events in the 21st century
Source: WHO

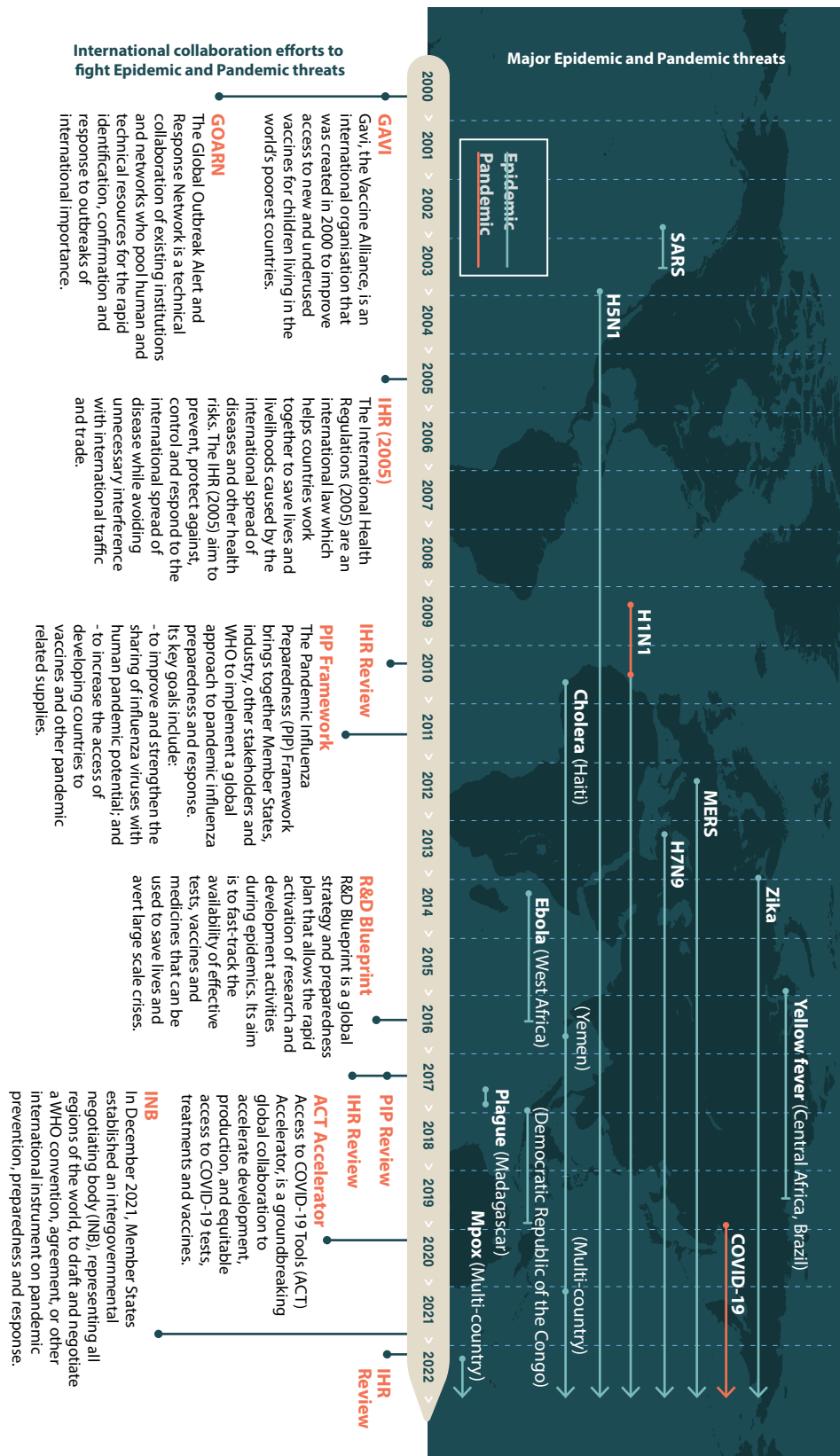
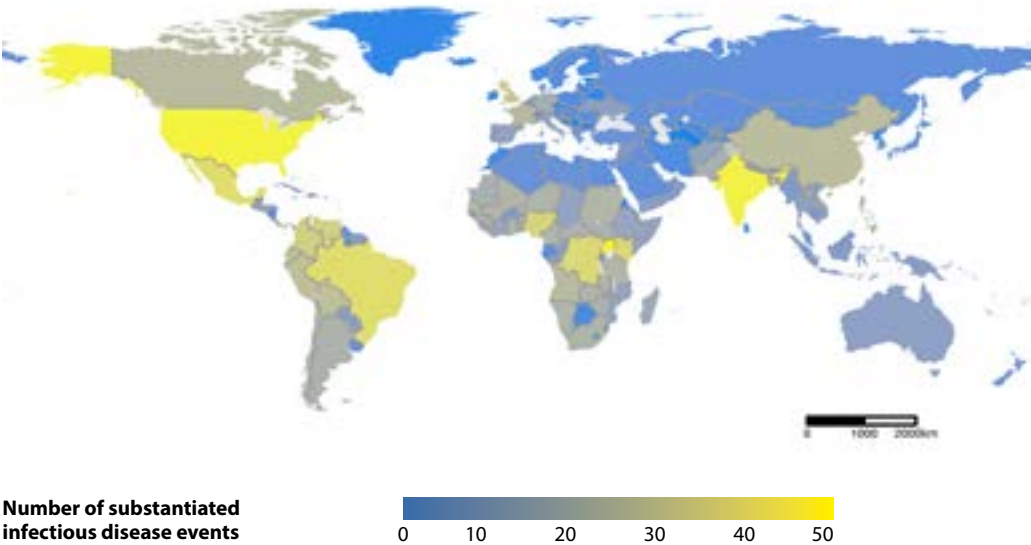


Fig. 2. Map of substantiated acute public health events of infectious disease typology
Source: WHO Event Management System (EMS), reported between 01 January 2011 and 31 Dec 2021



The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of WHO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Led by WHO's Epidemic and Pandemic Preparedness and Prevention Department, the report reflects discussion and conclusions from the October 2022 annual meeting of WHO's Strategic and Technical Advisory Group for Infectious Hazards (STAG-IH) and subsequent research and consultations. Meeting participants included STAG-IH members and representatives from partner organizations, WHO Collaborating Centres, WHO networks, relevant Scientific/Technical Advisory Groups and the WHO Secretariat (See acknowledgments for a list of participants of the 2022 Annual STAG-IH Meeting).

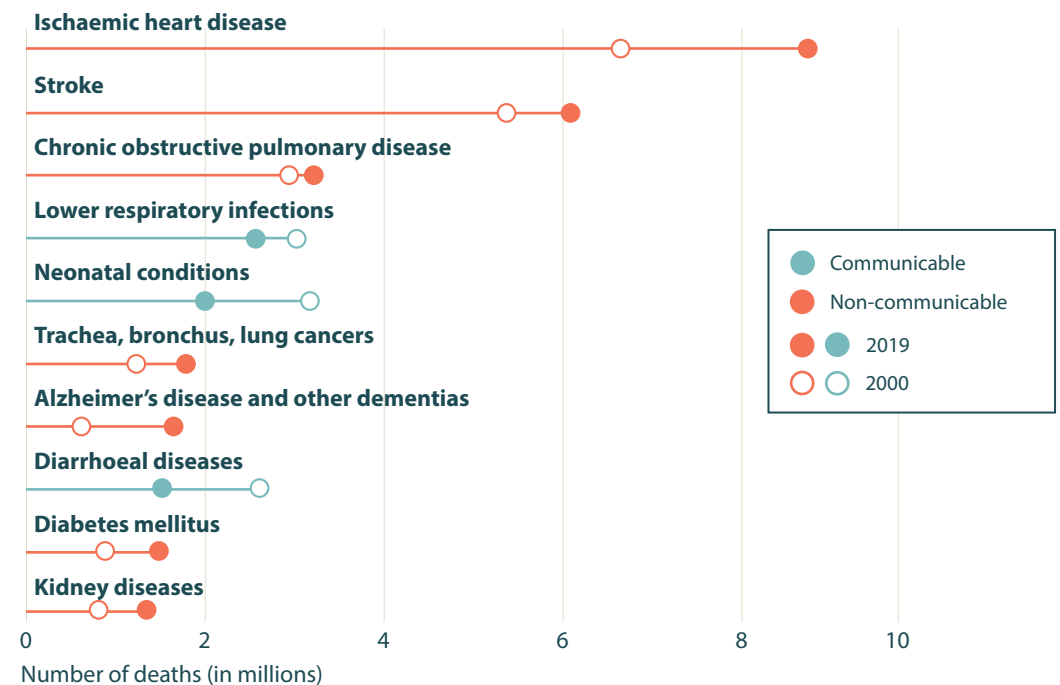
Chapter 1. The evolving surveillance landscape

1.1 Digitalization and advances in data science

In the field of disease surveillance, paper-based reporting is gradually being replaced by digital platforms thanks to progress in global electrification, accelerating internet access and affordable availability of digital technologies (5). In a digital system, trends are presented graphically to identify deviations from norms. Observations can be backed up by advanced statistical methods and reactive data gathering to confirm early signals. With shorter turnaround time for monitoring trends, it is possible to mount more timely interventions and increase the likelihood of containment.

Digitalization also facilitates faster collection of jurisdictional statistics. Digital platforms have enabled timely capturing of demographic changes through population census, immigration data and death notifications. Previously, these statistics took several years to project at the global level. Now, WHO can identify 10 major causes of death globally in a timely manner (Fig. 3) (6). In some advanced circumstances, reports of deaths can be monitored weekly and within a few weeks' time used as an alert mechanism, such as those provided by the United States National Center for Health Statistics Mortality Surveillance System and EURO MOMO (7-10).

Fig. 3. Leading causes of death globally (pre-COVID, 2019) published in 2020
Source: WHO Global Health Estimates 2019



As measures to contain the COVID-19 pandemic limited movement, numerous countries and municipalities with advanced digital environments pursued digital strategies to ensure access to essential services. Many innovative digital initiatives were created to meet people's needs during so-called lockdowns. Digital health, or eHealth, has also evolved in recent years. WHO is accelerating its digital health efforts and has developed a Global Strategy on Digital Health (2020 - 2025) (11).

Indeed, we are in the fourth industrial revolution – the technological revolution has transformed health service delivery in many ways, and wider adoption of digital strategies is expected to accelerate global attainment of health and well-being, while at the same time providing leverage to surveillance systems. For example, eHealth has sparked greater access to information on personal health, diagnoses, insurance and prescriptions that can be applied to various public health purposes. In numerous countries, individuals can now have their full health record available to them on an application (app) on their smartphone. eHealth has also revolutionized health system performance measurement and quality improvement initiatives by providing access to hospital administrative data, including outpatient visits, bed occupancy and health care worker staffing and absenteeism. This information can be used to monitor the severity of epidemics and pandemics and the burden on health care.

Digitalization of information has also led to advances in the use of widely generated and open-source data, known as big data, as part of surveillance activities. During the COVID-19 response, open-data initiatives such as Google Mobility Trends and Meta's Data for Good offered locally granular insights into population mobility that were highly valuable for risk assessment and monitoring of behavioural responses to public health and social measures (12, 13).

Other evolving technologies – such as artificial intelligence (AI) and machine-learning algorithms, which is a subset of AI – offer opportunities to use the latest advances in data science to improve our understanding of the complex factors that drive outbreaks and to better predict and forecast epidemic events. When coupled with big data and other sources, these tools have the potential to greatly increase our knowledge of the dynamics of epidemics. Public-private-academic partnerships are an important model for monitoring acute and evolving situations using emerging technologies. One example of such a collaborative effort is the WHO-led Epidemic Intelligence from Open Sources (EIOS) initiative, a fit-for-purpose web-based system designed to augment and accelerate a strong public health intelligence (PHI) community of practice.



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On 31 December 2019 at 3:18 am (UTC), the EIOS system picked up the first article reporting on a cluster of pneumonia in Wuhan. By the end of 2020, the system had tagged

26.3 million

articles in the “**coronavirus**” category.

This is nearly a **six-fold increase** from the 5 million articles that the system collected in all of 2019, a clear **testimony to the unparalleled flood of information** accompanying the COVID-19 pandemic and an enormous challenge to professionals working in PHI (14).

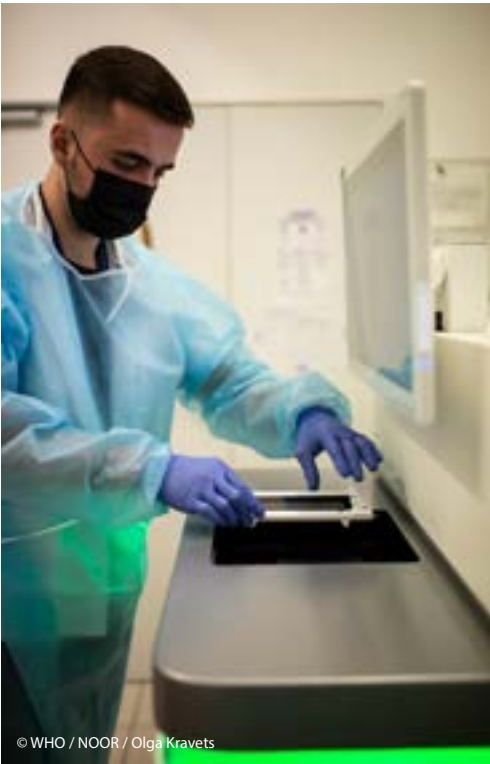
1.2 Genomic information for surveillance

The availability of real-time genomic information has emerged as an important technical asset in disease surveillance, most recently during the COVID-19 pandemic. We can now track the evolution of a virus and see how genetic changes are associated with the epidemiological situation and severity of the disease. We can also determine whether an outbreak is a new event as a consequence of a spillover from wildlife or part of an ongoing event surfacing from an occult transmission chain (15-17). Indeed, many high-risk pathogens have reservoirs in the animal kingdom that must be better understood. For example, research conducted in East Africa has found that dromedary camels are serving as a reservoir that boosts MERS-CoV genetic diversity (18).

During the 2018–2020 Ebola virus disease (EVD) outbreak in the Democratic Republic of the Congo, genetic sequence information enabled response teams to identify the missing link between a newly diagnosed patient and a distant cluster (19). For the COVID-19 response, new capabilities showed great utility, like the United Kingdom’s real-time assessment of community transmission of coronavirus (REACT-1) system, which provided ongoing monitoring of genomic variants through a nation-wide self-collected specimen testing approach that included tens of millions of symptomatic and asymptomatic citizens (20). Genomic epidemiology has also established its importance in monitoring influenza, poliomyelitis, antimicrobial resistance and multidrug-resistant tuberculosis (MDR-TB) (21-24).

One of the **prominent benefits of leveraging** existing influenza work from the onset of the COVID-19 pandemic was the **rapid collation and analysis of genomic sequencing data** (Fig. 4).

Improved **cost-performance** and **widened accessibility** of sequencers enabled **timely and large-scale sequencing**. Existing databases (GISAID and GenBank among others) and analytic capacities allowed for **real-time visualization** of the evolution of circulating viruses.



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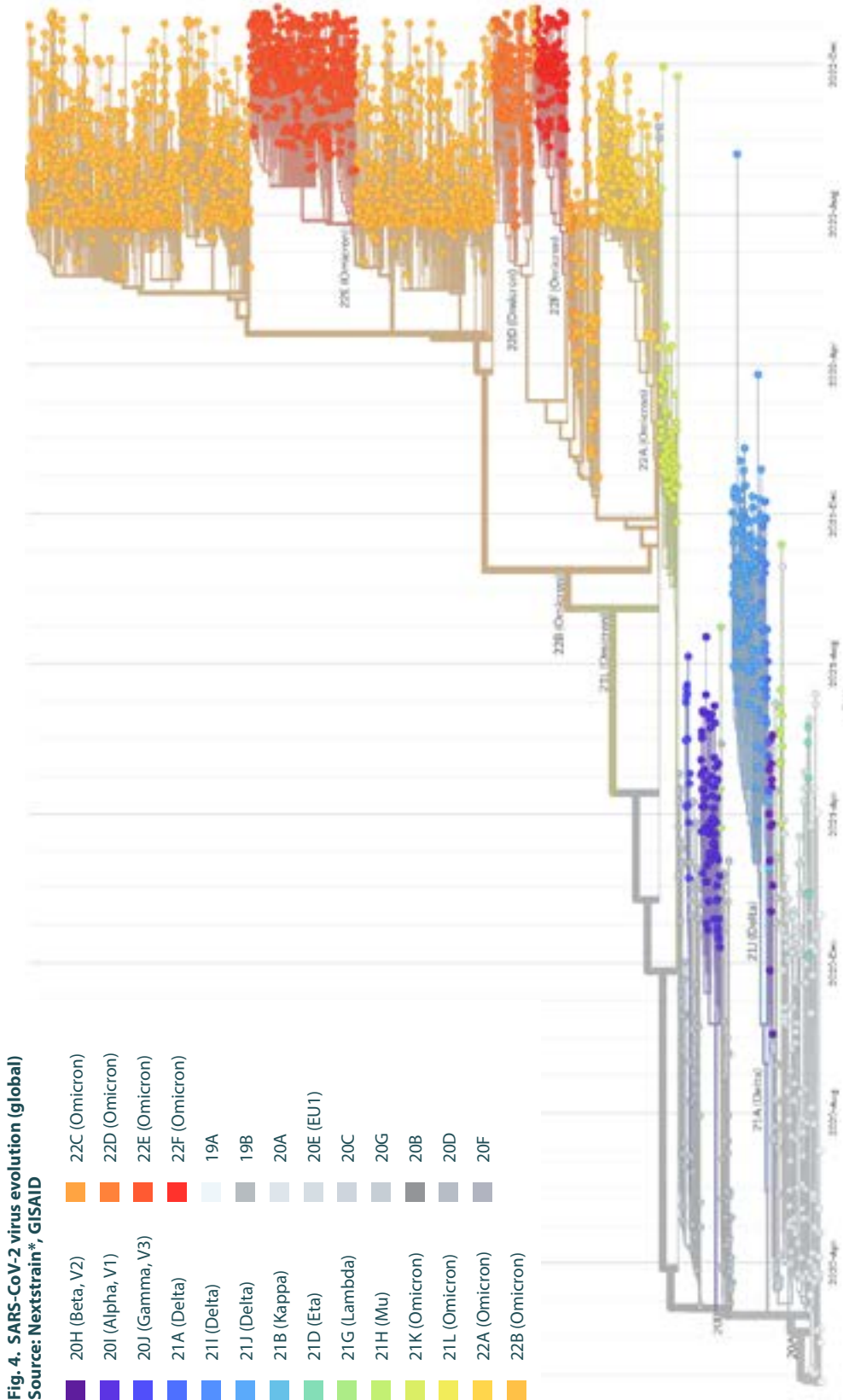


Fig. 4. SARS-CoV-2 virus evolution (global)
Source: Nextstrain*, GISAID

* Note: Hadfield J, Megill C, Bell SM, et al. Nextstrain: real-time tracking of pathogen evolution. Bioinformatics. 2018;34(23):411–4123. doi:10.1093/bioinformatics/bty407



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As sequencing **machines** become **smaller, mobile and less expensive**, they can be **placed more easily in local settings**. Expanding the application of this new tool holds promise for future crises. Recently, WHO published a **global genomic surveillance strategy** for pathogens with pandemic and epidemic potential for the **next 10 years** (25).

The goal of the strategy is to strengthen and scale genomic surveillance for pathogens with pandemic and epidemic potential for quality, timely and appropriate public health actions, using inputs from local to global surveillance systems. Although disparities exist for genomic surveillance efforts and capacities in countries, they should stand as one of the priorities to improve pandemic preparedness worldwide (26).

Genetic sequencing capacity has also made major strides in recent years. These advances have allowed for rapid molecular epidemiologic understanding of pathogen transmission and ensure the continued efficacy of molecular-based diagnostics and vaccines against new pathogens and variants. Genomic surveillance of wastewater is a particularly powerful surveillance application. For COVID-19, wastewater surveillance has been demonstrated to be an important and significantly simpler surveillance tool for monitoring SARS-CoV-2 variants (27). However, it is critical to ensure adequacy of testing rates, sampling strategies and sequencing proportions to guarantee representativeness and timeliness for genomic epidemiology studies (28).

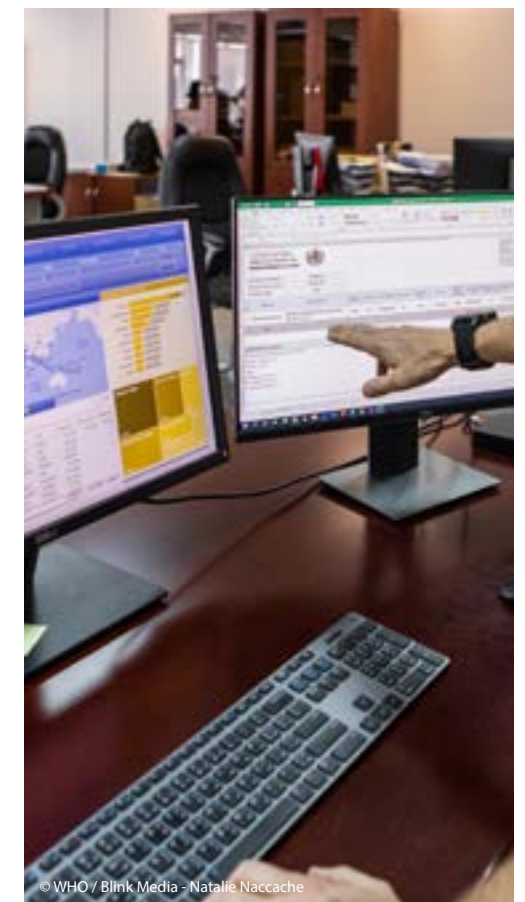
1.3 Lessons from pandemic COVID-19 surveillance

The COVID-19 pandemic has brought both challenges and opportunities in surveillance. Diagnostics for COVID-19 were rapidly developed early in the pandemic, allowing test-positive cases and deaths to be quickly reported to WHO through the International Health Regulations (2005), hereafter referred to as the IHR (2005).

The main challenge, however, was in interpreting the data and tracking situations in countries at different stages of virus transmission. Surveillance was also challenged by a changing landscape as the pandemic unfolded. Indeed, efforts to track and monitor the pandemic were often stymied by an evolving case definition, changing testing strategies and different detection and reporting capacities in countries. Further challenges arose from changes in WHO's requirements for collection, management and analysis of data (29). For example, as the pandemic evolved, WHO introduced new indicators, including transmission characteristics (sporadic, cluster, community transmission), hospital and intensive-care unit (ICU) admissions, health workforce absenteeism, percentage of test positives over tests conducted and basic reproduction number (R_0).

An external review of WHO COVID-19 surveillance conducted in October 2021 noted successes such as the adoption of an existing data management system used for global influenza surveillance to meet the needs of the COVID-19 pandemic (29). Also, data sharing among Member States was facilitated by the strength of existing relationships between WHO Country and Regional Offices, Member States, Ministries of Health and National Public Health Institutes (NPHIs).

However, not all lessons learned from recent large events, such as the 2013–2016 EVD epidemic and the 2009 (H1N1) influenza pandemic, were implemented. Further, WHO's data architecture was not scalable to the needs of such an extensive pandemic. The lack of a pre-existing data architecture and plans for data use and sharing hindered efforts to collect and disseminate timely and useful information.



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Moreover, the lack of compelling strategic information outputs by WHO did not incentivize reporting by the Member States. Instead, negative incentives to reporting were driven by factors such as fear of stigmatization, particularly early in the pandemic, and economic sanctions such as the travel and trade restrictions put in place in 2021 as a reaction to the identification and subsequent reporting of the Omicron variant in South Africa.

While WHO is mandated to collate case numbers reported by the Member States through official channels as per the IHR (2005) requirements, several organizations and institutes played substantial roles in collating global data on the pandemic using other sources of information including published research outcomes. These groups, such as the Johns Hopkins Coronavirus Resource Center and Our World in Data, have demonstrated the ability to gather and present data by providing rapid analysis and visualization of the global COVID-19 situation at-a-glance (30, 31).

Also noteworthy is the unprecedented global-scale monitoring of COVID-19 immunity. SeroTracker synthesizes findings from thousands of COVID-19 seroprevalence studies worldwide, providing a data platform and interactive dashboard for SARS-CoV-2 serosurveillance (32).

By the end of 2021, a **total of 103 countries had started implementing at least one sero-epidemiologic investigation** aligned with the master protocol of WHO's Unity Studies.

The WHO Unity Studies is a global sero-epidemiologic standardization framework and initiative to increase evidence-based knowledge for action with a special focus on low- and middle-income country (LMIC) support (33). Participation represented over 50% of WHO Member States, 65% of which were LMICs. Seroprevalence studies fill the gap between test-positive reporting and real infection, which is certainly undercounted. Seroprevalence studies are crucial to understanding the true extent of the pandemic and vaccine-acquired immunity by measuring population antibody levels, with the caveat that the presence of antibodies does not necessarily indicate immunity (34). More work needs to be done to understand the correlates of immunity, including the role of cell-mediated immunity for COVID-19.



The **COVID-19 pandemic** was accompanied by a **phenomenon termed the infodemic**. An infodemic is an **overwhelming volume of information** – both **accurate** and false or deliberately **misleading** – in **digital and physical environments** during a disease outbreak (35).

In response, WHO and partners developed the Early AI-supported Response with Social Listening ([EARS](#)) social listening platform to monitor populations concerns and sentiments and provide the right information at the right time in the right format. The tool identifies information voids so that health authorities can adapt their risk communication strategies to the dynamic nature of the outbreak. Surveys using big data and AI analytics, supported by Natural Language Processing, are another mechanism for real-time, flexible and locally adaptive digital intelligence.

Chapter 2. Needs and gaps

2.1 Detecting the right signals at the right time

Timely detection of unusual events of potential infectious origin is the first step toward subsequent verification, risk assessment and response. Pandemic and epidemic disease surveillance begins with trained health workers recognizing the patient or a vigilant 'sensor' person in the community reporting to the system, followed by specimen collection for testing at competent laboratories. This first detection and genomic characterization of the causal pathogen can be prompted by a primary health care visit, community-engaged strategies or social media listening. Through this detection, the system mobilizes a series of public health actions alongside ensuring appropriate health services for persons infected by the pathogen.

The IHR (2005) specifically calls for reporting of any unusual health events collected through event-based surveillance, indicator-based surveillance or unofficial communication channels with WHO partners (36). In this interconnected and mobile world, signals can be detected anytime and anywhere. It is important to understand where the first line of defense against harmful pathogens is, and who is on the lookout.

A community, for example, may detect animals dying unexpectedly, local newspapers may report on a mysterious disease outbreak in a remote village or social media users may share rumors of unexplained illnesses or deaths. Within health systems, observant primary care providers may notice clusters of suspicious disease activity or ICU staff may identify unusual illness or severity in their patients with unknown aetiologies. This has certainly been the case for severe acute respiratory syndrome (SARS), H5N1 and H7N9 avian influenza, 2009 H1N1 pandemic influenza, Middle East respiratory syndrome (MERS) and COVID-19.



In these cases, patients with severe acute respiratory illness in ICUs were the first to be recognized, which unfortunately often triggered clusters in health care facilities. A single case can also trigger the start of community propagation of high-threat pathogens, as evidenced by SARS in 2003 in multiple countries and again by MERS in 2015 in Republic of Korea. In ancient times, quarantine guarded the population from high-impact exotic infectious diseases; in the modern world, where people, animal hosts and pathogens can rapidly travel vast distances, the first line of defense is often within communities and health systems rather than quarantine offices at national borders.

Capturing the **right signals at the right time** requires **investment**. Needs include efforts in the **community** and within **health systems** to raise **awareness** about **potential infectious hazards or unusual signs**.



Modern detection of unusual health events has also benefitted from technological innovations, such as the aforementioned PHI that uses web-based systems powered by AI to capture signals and deviations from norms. In addition to built-for-purpose surveillance innovations, the digital revolution has given rise to novel sources of information such as social media platforms that allow users to share reports of ill health or unusual health events. Mobility data from smartphones was used during COVID-19 to understand overall compliance with public health and social measures (PHSM) aimed at limiting people's physical interactions to reduce human-to-human transmission and spread of the disease (37).

2.2 Molecular diagnostic capacity and robust laboratory capabilities

The COVID-19 pandemic highlighted the fundamental dependency of the surveillance enterprise on robust laboratory capabilities to detect and characterize the genome of the causal pathogen. Laboratories, including national reference laboratories (NRLs), subnational and international laboratories and connecting networks play a crucial role in identifying and monitoring emerging infectious hazards.

Molecular diagnostics such as polymerase chain reaction (PCR)-based methods in laboratories need to be consolidated and extended. Particularly, major public health laboratories need to become competent in running PCR or reverse transcription-PCR (RT-PCR) methods before commercial test kits become available. In the early stages of pandemics, as seen during the COVID-19 pandemic, these commercial diagnostic kits will have a time lag for widespread availability. In contrast, so-called in-house PCR methods (for example using WHO recommended protocols) are available much earlier and are more readily available than commercial kits. In-house methods require a higher level of technical competence, but it is essential that major public health labs retain that competence. For example, during January and February 2020, a number of countries made their first diagnosis of SARS-CoV-2 infection using WHO-recommended protocols that they were able to operationalize long before commercial kits were widely available. Of note, this global effort could not be triggered without the timely sharing of the whole genome sequence of the virus.



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2.3 Understanding the human-animal-environment interface

The need to integrate **surveillance** on **humans, animals, food** and the **environment** is increasingly **urgent**.

Of the twelve pathogens listed in Figure 1 as the causative agents of major infectious threats;



Zoonotic origin

(SARS, H5N1, MERS, H1N1, H7N9, COVID-19, Ebola, mpox, plague)



Vector-borne

(Zika, Yellow fever)



Water-borne

(cholera)

An estimated **70% of emerging pathogens** have an **animal origin**; these include avian and swine influenza viruses, animal coronaviruses, Nipah and Ebola viruses, among others (38).



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The COVID-19 pandemic has underscored the need for One Health surveillance to anticipate emerging infections and offer early outbreak warnings to expedite control (39-42). Areas with vast biodiversity at the crossroads for human interaction with domestic and wild animals have historically been known as hot spots for emerging pathogens with animal origin. Efforts are ongoing among the quadripartite partners – Food and Agriculture Organization (FAO), World Organization for Animal Health (WOAH, founded as OIE), United Nations Environment Programme (UNEP) and WHO – to map hot spots and detect early warning signals of zoonoses by closely monitoring animal health and conducting strategic sampling and monitoring of microorganisms associated with a high-risk human-animal interface. These efforts will contribute to the implementation of interventions to reduce the risk of spill-over and to the development of medical countermeasures such as vaccines and therapeutics (Fig. 5a, 5b).

Fig. 5a. Map of global distribution of avian influenza virus with zoonotic potential* observed since 1 October 2022 as of Apr 2023 (ongoing)

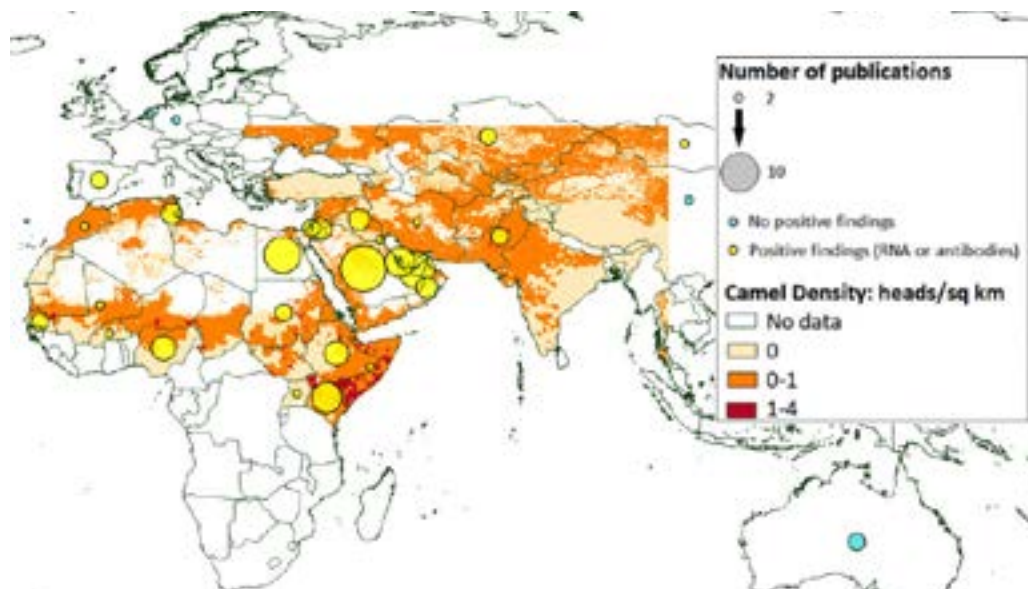
Source: © FAO 2023 Global Avian Influenza Viruses with Zoonotic Potential situation update - Animal Health - accessed August 2023



Note: Symbols may overlap for events in similar geographic locations.
* Includes H5Nx, high pathogenicity avian influenza (HPAI) viruses.

Fig. 5b. Map of MERS-CoV livestock field surveys by country* (Results of published MERS-CoV livestock field surveys conducted up to 14 February 2022)

Source: © FAO 2023 MERS-CoV situation update - Animal Health - accessed August 2023



* Note: Positive findings in Spain refer to samples taken in the Canary Islands. Livestock surveillance in Chile, not pictured, resulted negative.

Both Fig. 5a and 5b maps, the designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of WHO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Understanding the drivers of emergence of infectious diseases can lead to interventions that can reduce risk, for example, strategic interventions in live poultry markets reducing risk of zoonotic influenza or control of the live game animal trade reducing risk of sarbecovirus emergence (43). Considering the substantial economic consequences associated with infectious disease outbreaks, reporting incentives and robust compensation schemes for those that report infectious diseases of zoonotic origin are needed using flexible funding mechanisms.

The proliferation of non-traditional and non-health sector sources of surveillance data also includes proxy data and ecological data from the animal world. Data from the human-animal interface is integral to a One Health approach given increasing urbanization in areas at high risk for spillover events. These advances also hold promise for greater surveillance of AMR as a global health threat.

Vector-borne disease risk is also changing in the face of ongoing climate and environmental change. Accelerating urbanization and deforestation drive ecological changes, vast amounts of travel and trade, as well as global warming, allow for greater range expansion by vectors. These bring vector-borne infectious diseases to new areas and for longer periods. The resurgence of yellow fever outbreaks in 2016 across multiple countries in Africa and South America illustrates the growing scale of these epidemics. The International Coordinating Group (ICG) on Vaccine Provision reported that the annual stockpile of yellow fever vaccines was replenished three times to meet the needs of countries for mass vaccination campaigns within the year. These events show that large scale urban outbreaks of yellow fever will be a major challenge for the future.

Considering the **growing threats** to health globally posed by mosquito-borne and other arthropod-borne diseases, in **March 2022**, WHO launched the **Global Arbovirus Initiative**.

This initiative is an integrated strategic **plan to tackle emerging and re-emerging arboviruses** with epidemic and pandemic potential, focusing on risk monitoring, pandemic prevention, preparedness, detection and response and partner coalitions.

Launch of the Global Arbovirus Initiative: <https://www.who.int/news-room/events/detail/2022/03/31/default-calendar/global-arbovirus-initiative>.



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2.4 Ensuring public health fundamentals

COVID-19 alarmingly reminded us about the importance of the basic functions of public health and epidemiologic investigation during outbreaks. The need for these fundamentals became clear, from collecting a specimen, to detecting the pathogen and reporting the genomic sequence and onwards to cluster investigation and contact tracing, to careful screening and isolation of symptomatic patients and observation or quarantine of contacts in the containment phase (44).

Thorough field epidemiologic investigation is of particular importance in the early stage of epidemics and pandemics. Having well-trained epidemiologists ready to be dispatched to the outbreak site as part of multidisciplinary rapid-response teams is critical for successful early intervention and mitigation. The metrics of a strengthened system should include the number of skilled and competent human resources, including nurses, midwives, physicians, public health and environmental specialists, social scientists, communication specialists, occupational health professionals, laboratory scientists/technicians, biostatisticians, information technology (IT) specialists and biomedical technicians.

The IHR (2005) Monitoring and Evaluation Framework has set an **optimal target** of at least **one trained epidemiologist per 200 000 population** and **one epidemiologist per rapid response team**, ideally deployable at both national and sub-national levels (for example in provinces or districts) in response to an emerging signal (45).

Developing this workforce **requires training**, beginning with **investment in science education** in general schooling, and ensuring both education and career development pathways for the health workforce.



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Adequate public health capacity at local levels with access to communities is particularly critical to ensuring early detection of unusual health events, conducting timely investigations and implementing control measures quickly. In an adequately resourced system with a sufficiently trained workforce, alerts would be signalled by community health workers and local clinicians. An alert would then trigger early warning mechanisms for other health system and public health stakeholders.

Indeed, experience in Africa with EVD shows the **importance** of having **local diagnostic capacity** (46) for:

- screening
- isolation
- clinical management
- infection prevention and control
- contact tracing
- ring vaccination.

Near-patient rapid diagnostic tests with adequate performance are particularly useful to save time and for remote and lower-resource settings. These should be developed against known pathogens, with processes in place for rapid scale-up to detect novel pathogens. Strengthening the triangulation of clinical care, diagnosis and public health reporting is essential for bolstering local capacity (47, 48). To realize the potential of near-patient rapid diagnostic tests, people must be able to access diagnostic testing and care, which requires ongoing commitment to widespread Universal Health Coverage.



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Contact tracing is one of the most basic and important methods for controlling human-to-human transmission of infectious diseases, as was the case early in the COVID-19 pandemic. Several countries in Asia managed to contain clusters and chains of transmission at some point during the first year of the pandemic by implementing intensive contact tracing in combination with other control measures (49-53). Early epidemiological studies revealed that superspreading events had triggered explosive increases in case counts and that singing and talking, particularly in close, congregated and confined circumstances are risk conditions for superspreading. Outside of these superspreading events, secondary infections were rare (54, 55).

In many countries, the **magnitude of contact tracing needs**, in addition to the unprecedented strain on the public health workforce, led to the adoption of **electronic contact tracing using mobile apps** (56, 57).

Broadly speaking, contact tracing using personal mobile devices and digital technologies were quickly adopted and scaled up, many as pilot programmes that require further evaluation of their implementation and effectiveness and to determine their role in future outbreak responses (58). Challenges in using contact tracing apps included low reliability, mistrust and lack of public engagement, and concerns around privacy, data security and confidentiality (59).

As case numbers rose, and as asymptomatic infection and transmission from asymptomatic individuals increased, many countries ended contact tracing for COVID-19 in consideration of the scale of transmission, pressing human resource shortages and its diminishing importance in the overall control strategy. Despite these challenges, the use of widely available digital technology to support public health in pandemics should be further developed, implemented and monitored.



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2.5 Linking with health systems and digital transformation

The proliferation of digital technologies and wide-ranging data sources has led to a growing and urgent need for robust systems to link surveillance to the digital ecosystems now common in many health systems, as well as to broader national digital transformation strategies. From the highest levels, digital transformation strategies are becoming commonplace and essential to driving progress towards integrated, secure, modernized and user-friendly digital ecosystems and interfaces. Indeed, the United Nations (UN) has embarked on large-scale efforts to spread digital transformation across its agencies. Similarly, many countries have ambitious plans for digitalization, including digital transformation of health systems. In practice, this means harnessing the power of the latest technologies, including electronic medical records and telehealth platforms to deliver integrated and high-quality care to patients. Still, gaps persist in how modernized health systems link to public health systems, especially with regard to interoperability and data sharing.

Box 1. An early-alert surveillance system in Brazil

Brazil's Alert-Early system of outbreaks with pandemic potential (ÆSOP) is a new-generation data-driven system for early warning of respiratory viral disease outbreaks under development by the Oswaldo Cruz Foundation and the Rockefeller Foundation. ÆSOP combines digital and molecular approaches to mathematical and AI methods to anticipate outbreaks and model their evolution to advise decision-making. Information to develop these models is systematically aggregated across sectors, including data from the health system, transport network, and environmental and socio-economic data. ÆSOP's early warning system also benefits from data on medicine sales and rumors on social networks.

Using these various inputs, ÆSOP analyses and provides data interpretation to alert health authorities when and where a new outbreak is likely to occur (areas on primary alert) and the probability and characteristics of evolution and provides a scientific basis for decision-making on the most appropriate way to control or mitigate the outbreak. The system then identifies areas on second-level alert, where a pin-pointed collection of samples for metagenomic analyses is triggered. The results will be integrated with other data sources and contribute to adjusting the models that convey the risk and characteristics of the outbreak's spread.

The intended output of ÆSOP is anticipating approximately one month ahead of the currently available early alert approaches to help streamline logistical issues for mitigating impact and adopting containment measures. Aiming to participate in a coordinated global surveillance system based on collaboration, interoperability, and trust, a priority for pandemic prevention, ÆSOP will have open-source products that interested partners can leverage, adapt, replicate and scale.

Source: [ÆSOP](#)

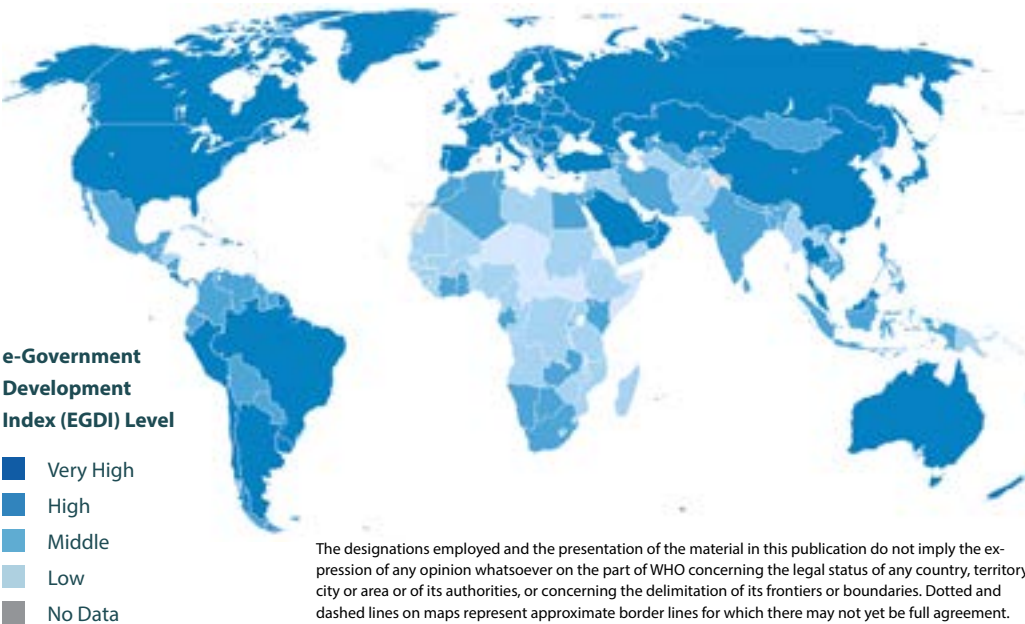
2.6 Digital equity and data justice

Digitalization can help reduce costs, improve organizational efficiency and provide access to data that can be exported and/or imported to complement existing datasets and broaden opportunities for further and deeper analysis. Before these gains can be realized, however, digital readiness must be in place at the national, sub-national and organizational levels. Ensuring that systems are ready to support digitization requires infrastructural investment, creation of data repositories and skilled workforce capacity.

While digitalization and big data resources have broad **population reach**, attention must be paid to **improving the visibility of marginalized and mobile populations** who may be underserved by surveillance initiatives that rely on a digital footprint. Vast numbers of people globally **still do not have access to online services** and are unable to directly access and benefit from **many digital innovations** (Fig. 6) (60).

Digital equity is an important focus of initiatives by the UN and others so that these revolutionary changes can be accessible to all and continue to provide promising opportunities for improving surveillance (61). The interaction between data and social justice is crucial to the future of surveillance. Any approaches to surveillance need to ensure that, in producing and sharing data, individuals are fairly represented and their information is treated appropriately (62, 63).

Fig. 6. UN e-Government survey (2022)
Source: UN E-Government knowledgebase



Chapter 3. Challenges

3.1 Privacy and ethical concerns

While essential to public health, monitoring populations for unusual health events and responding to emerging threats also come with privacy challenges. Surveillance and contact tracing, for example, ultimately rely on individuals to disclose personal information to health workers.

It is **important that people trust** the authorities or institutions collecting their data and **that they understand how it will be used**. In situations where trust has been undermined it can be challenging to carry out the basic functions of public health.

Stigma is another obstacle that increases the need for privacy and data security. During an infectious disease outbreak, modes of transmission and indeed the disease itself may be stigmatized, preventing people from engaging with public health efforts such as testing, treatment and isolation. Both privacy concerns and stigma can disproportionately affect marginalized groups. Marginalized communities may have had previous negative experiences that undermine trust in authorities or institutions and increase hesitancy in complying with public health mandates and processes. These same communities may also already experience stigma that can be compounded by additional stigma related to an infectious disease outbreak.

During the COVID-19 pandemic, the widespread use of digital technologies for contact tracing added a new dimension to privacy and stigma concerns (59). In prior outbreaks, where the volume of contact tracing may have been more manageable, local public health workers would conduct contact tracing and follow up with those exposed to the pathogen.

The sheer magnitude of the COVID-19 pandemic prompted the development of digital contact-tracing technologies that had the potential to spare public health workers from the extreme burden of manually contacting individuals during peak transmission periods. This novel approach, notably from Google and Apple, maintained individual privacy, but nonetheless raised concerns among cell phone users and government officials (64, 65). Many of these featured ongoing monitoring using GPS or Bluetooth functionality based on consent from users.

The Global digital strategy (2020–2025) now set by WHO emphasizes that health data are to be classified as sensitive personal data, or personally identifiable information, that require a high safety and security standard (66). The strategy stresses the need for a strong legal and regulatory base to protect privacy, confidentiality, integrity and availability of data. It also aims to ensure that personal health data is responsibly collected, processed and used. To do so the strategy offers information on cybersecurity, trust building, accountability and governance, ethics, equity, capacity building and literacy, to ensure that good quality data are collected.



3.2 Data sharing challenges

Inherent challenges in data sharing must also be overcome. Initial information about an event may not be collected in a structured way due to lack of standard protocols or reporting forms, and the next step to convert the information into electronic form may be hindered by a lack of trained manpower and time or cost constraints.

Organizing data in a presentable and useful way is another challenge, followed by problems of limited data repositories, insufficient system interoperability, concerns about privacy, confidentiality and licensing, copyright or ownership of software and databases.

A rapid review of COVID-19 surveillance revealed many barriers to data sharing, including fear of stigmatization early in the pandemic, lack of national human resource and technical capacities, as well as privacy regulations (29). In addition to the reticence of some Member States to share data with WHO, the inability of WHO to clearly establish the conditions under which WHO should disseminate collected data significantly delayed the release of a public dashboard.

The most crucial element in overcoming these data sharing challenges is trust-based collaboration. Establishing a well-determined data architecture and data use and sharing plan with Member States will promote epidemic and pandemic data sharing in the future. Other tactics include formal agreements that define the scope of use, confidentiality agreements, Memoranda of Understanding (MoUs) and deployment of technical solutions for security. Another solution might be to develop data processing and analysis capabilities in countries so that anonymized or aggregated data can be shared across countries and entities such as WHO according to standardized methods (67).



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3.3 Implementation of the Nagoya Protocol

The Nagoya Protocol is a supplementary agreement to the Convention on Biological Diversity, which has as one of its main goals the fair and equitable sharing of the benefits derived from the use of genetic resources.

Under the Protocol, genetic resources may be accessed subject to the prior informed consent (PIC) of the country of origin and once mutually agreed terms (MAT) have been reached that include the fair and equitable sharing of benefits arising from the utilization of the concerned genetic resources.

The Nagoya Protocol provides potential opportunities for public health such as:

- 1 Improved equity and fairness, leading to greater trust in the global public health system.
- 2 Improved global access to affordable vaccines and treatments, technologies and knowledge.
- 3 Support for capacity building for public health, particularly in LMICs (68).

Concerns have been voiced, however, that implementation of the Nagoya Protocol could slow or limit the sharing of pathogens owing to uncertainty regarding the scope and implementation of the Nagoya Protocol; the high transactional cost of implementing a bilateral system for access and benefit sharing; and the complexity of varying domestic access and benefit-sharing legislation (69). These factors could have an impact on the comprehensiveness and speed of risk assessment, as well as the timely development of vaccines, diagnostics and other medical countermeasures.

Among the options for improving harmonization between the Nagoya Protocol and existing pathogen sharing systems are to:

1. establish new or identify existing specialised international access and benefit-sharing instruments such as the Pandemic Influenza Preparedness (PIP) Framework for virus and benefit sharing;
2. ensure that implementing legislation is supportive of public health;
3. encourage consultation, dialogue, public awareness and international collaboration.

International coordination on the implementation of the Nagoya Protocol, such as a WHO-led effort to harmonize national implementing legislations, is needed to ensure that laws are consistent with public health.

For the purpose of **pathogen detection and surveillance**, it is critical that **specimens are collected and tested in a timely manner** by qualified reference laboratories. **Strengthening national and local laboratory capacity** is one solution. Still, confirmatory tests and specialized analyses require **prearranged and ready-to-go multilateral material transfer agreements (MTAs)** or an **international sharing mechanism** such as a **biobank** or **biohub** (70).



Virtual biobanks are an alternative solution. These are virtual repositories that provide data extracted from traditional biobanks and characterize samples stored therein. An added feature of virtual biobanks is that samples are collected and available to qualified investigators on site, which can circumvent issues of sample ownership as well as shipping challenges, and also contribute to local laboratory capacity development.

3.4 Changing population, changing data needs

Demographic trends also have consequences for future surveillance. Until recently, the heaviest burden of infectious diseases was in children aged under 5 years, especially in LMICs, and disease surveillance therefore focused mainly on capturing the pediatric population for vaccine-preventable diseases and maternal and child health programmes (71).

The past several decades, however, have shown dramatic progress in improving health and reducing the mortality rate in young children; indeed, the number of children dying before the age of 5 was halved from 2000 - 2017 (72, 73). Concurrently, due to declining fertility rates, the share of the working-age population (those between 25 and 64 years old) has been increasing in most countries of sub-Saharan Africa, as well as in parts of Asia and Latin America and the Caribbean (74). The latest projections by the United Nations suggest that the global population could grow to around 8.5 billion in 2030, 9.7 billion in 2050 and 10.4 billion in 2100 (74). Increasing longevity also contributes to population growth.



In 2021, global life expectancy at birth fell from 72.8 years to 71.0 years, due mostly to the impact of the COVID-19 pandemic (74).

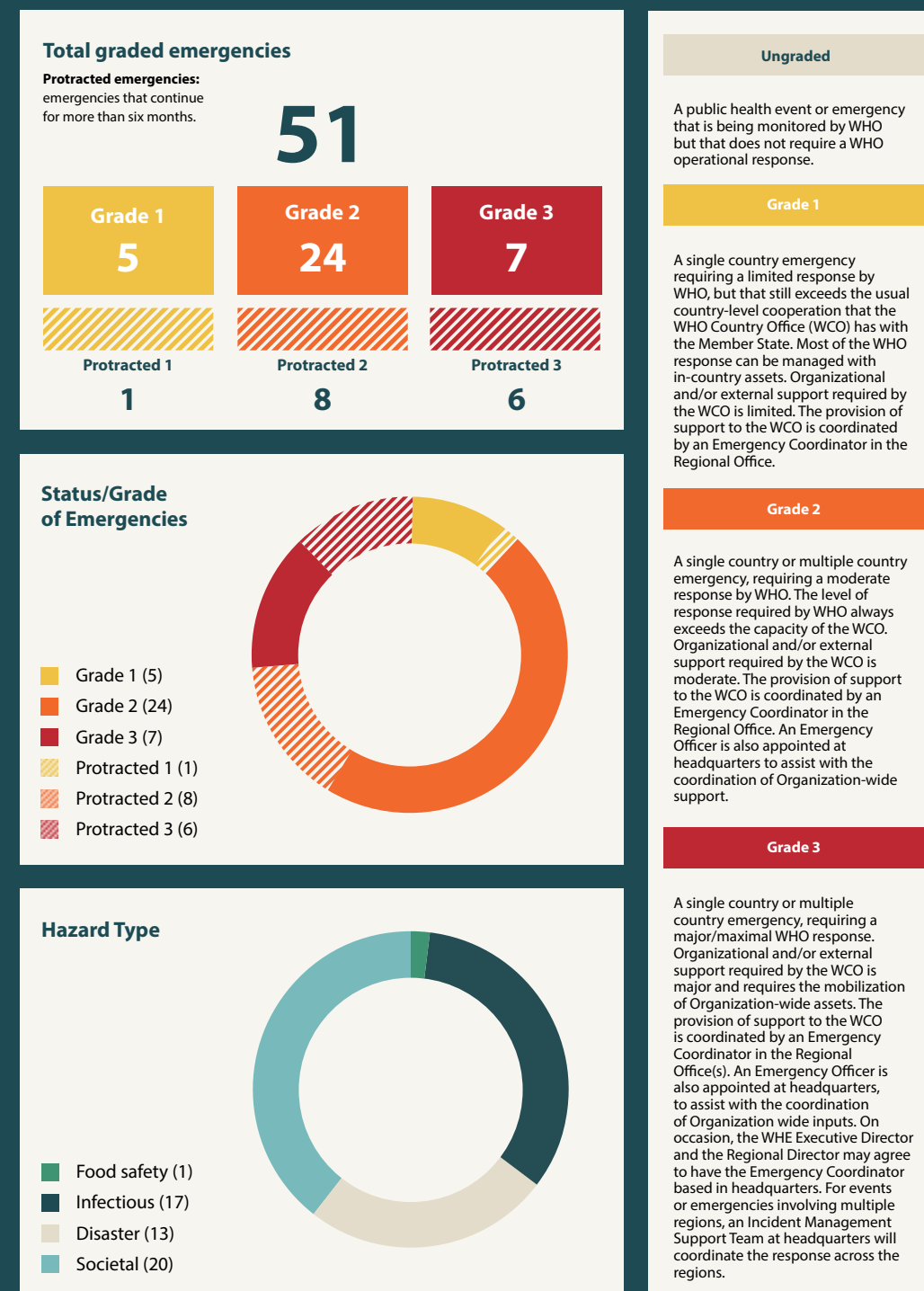
Increased life expectancy and a steadily ageing population are **linked to an increasing convergence of infectious and noncommunicable diseases (NCDs)** as well as **growing care needs for older adults globally (76, 77).**



These challenges call attention to the role and importance of surveillance to more fully understand the spectrum of older adult health. Ageing populations have unique risks related to increased (multi-)morbidity, disability, premature mortality and the cumulative effects of often preventable common chronic conditions (78). The challenges of ensuring healthy ageing are now affecting LMICs as they make the demographic transition from young populations to increasingly older populations with greater, and often more complex, care needs (74, 79). These phenomena indicate changes in the dynamics and effects of epidemic and pandemic disease transmission. COVID-19 and seasonal influenza demonstrate the disproportionate burden of infectious diseases among older adults living with NCDs, notably obstructive lung disease, obesity, hypertension, cancer and autoimmune diseases. In 2021, global life expectancy at birth fell from 72.8 in 2019 to 71.0 years, due mostly to the impact of the COVID-19 pandemic (74).

Beyond the size and age structure of the population, other factors signal important considerations for surveillance planning. For example, populations living in fragile conflict-affected and vulnerable (FCV) settings are likely to be disproportionately affected by infectious disease threats and therefore require different surveillance strategies. Proof of this continues to arise in reports of outbreaks of re-emerging infections for which prevention and medical countermeasures are well established (Fig. 7).

Fig. 7. Global view of health emergencies (as of January 2023)
Source: WHO. Health events and emergencies are graded according to Emergency Response Framework.
<https://www.who.int/publications/i/item/9789241512299>



While it is difficult to accurately estimate **how many people globally live in FCV settings**, as of 2021 an estimated

274 million

persons globally were in need of humanitarian aid

and

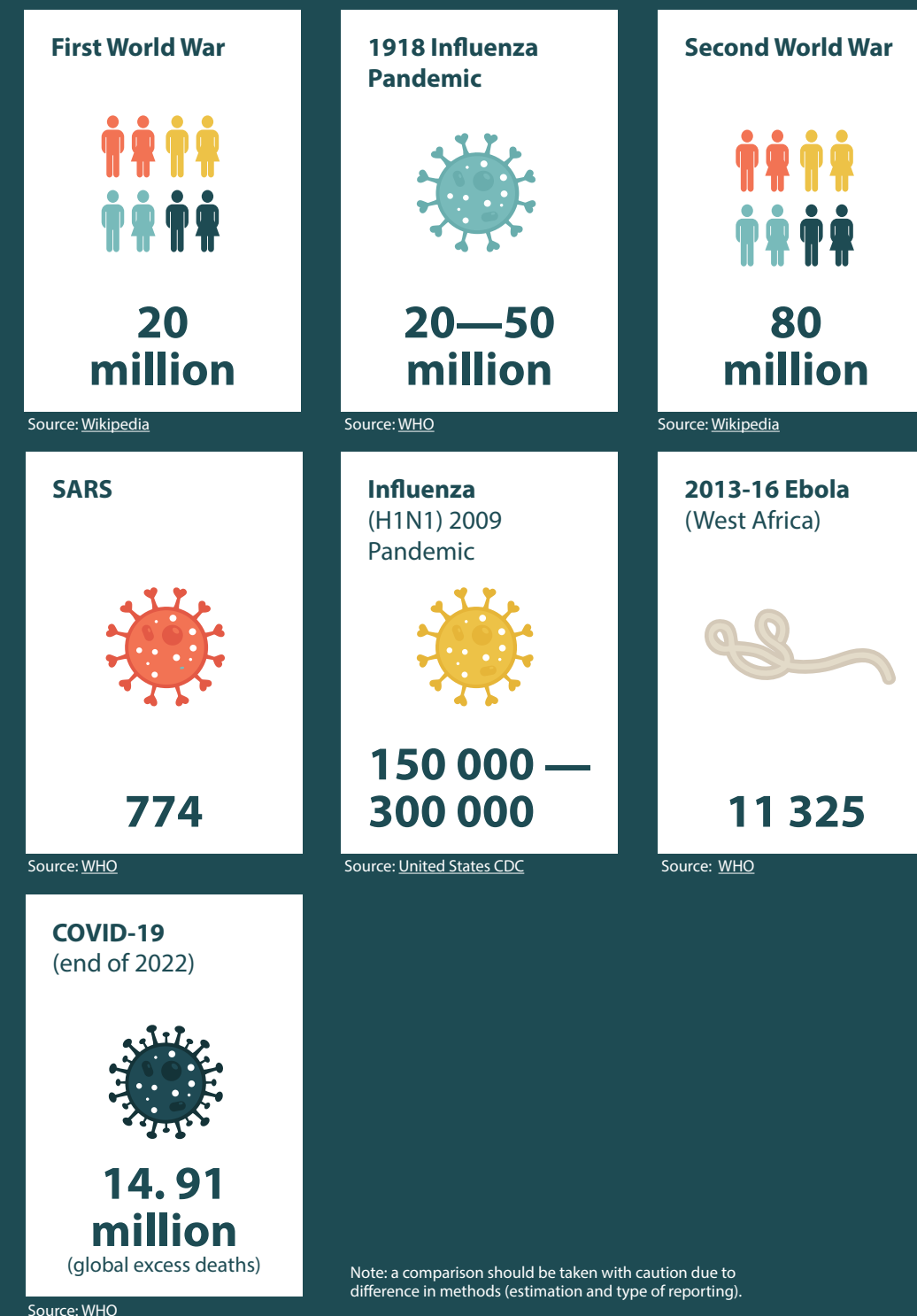
811 million

persons worldwide were undernourished amid accelerating rates of extreme poverty (80).



Urbanization and densification are also accelerating, with over half of the global population currently living in urban areas (81). Rapid urban growth will only continue, with increasing numbers of persons living in rapidly expanding, and increasingly high-density, cities across Asia and Africa. As COVID-19 has shown, during epidemics and pandemics dense urban centres become major sites of disease transmission. As the global population urbanizes, development of mass transit networks has surged to connect dense urban centres. These are favourable conditions for both emergence of infectious diseases and acceleration of disease transmission beyond borders, since major urban centers are also transit hubs (Fig. 8). Current demographic trends and shifts call for attention to ensure that surveillance in the future covers all age groups and populations.

Fig. 8. Mortality comparison of major events



Chapter 4. Opportunities

4.1 Participatory surveillance

Epidemics and pandemics begin and end in communities. Creating a people-centered, culturally and socially appropriate response requires community-based, participatory approaches that supplement more traditional indicator- and facility-based disease surveillance approaches (such as notifiable disease categories, laboratory testing).

Participatory surveillance engages members of the affected community for health reporting, monitoring and responding (82, 83). Individuals can report through a mobile app, a hotline or interaction with a community health worker. Influenzanet is a participatory system for the syndromic surveillance of influenza-like illness (ILI) in Europe. Through standardized online surveys, the system collects detailed profile information and self-reported symptoms volunteered by participants residing in Influenzanet countries (84).



Established in 2009, influenzanet now represents **36% of the 28 Member States** in Europe and more than half (58%) of the population in the European Union (85).

Other participatory surveillance systems have been established for ILI including Flu Tracking in Australia, Reporta in Mexico, Flu Near You in the United States, as well as for other diseases including Dengue na Web in Brazil (86, 87). Recently conducted landscape mapping on One Health identified 60 ongoing participatory surveillance systems spanning five continents (83).

Notably, the COVID-19 pandemic has provided opportunities for developing participatory surveillance approaches. Rapid diagnostic tests have been distributed in communities at an unprecedented scale during the pandemic, and widespread use of self-testing has offered the potential for disease-specific participatory surveillance, as opposed to a purely syndromic approach. Harnessing the power of digital technologies for participatory surveillance requires enhanced telecommunications infrastructure to ensure that even remote communities can participate. For participatory surveillance to be effective, especially when using digital technologies, human rights and privacies must be upheld and protected (88).

4.2 Community-based surveillance

Community-based surveillance is the systematic detection and reporting of events of public health significance within a community, by community members.

One example is the Red Cross and Red Crescent Movement, a network of 17 million active volunteers worldwide. By making tools available, the Movement enables community volunteers to report on health risks and other unusual events contributing to early warning, early action and lives saved (89).

Box 2. Community event-based surveillance system (CEBS) in Tiruvallur district, Tamil Nadu, India

In 2017, a pilot project to develop a community event-based surveillance system (CEBS) was conducted in the Tiruvallur district of Tamil Nadu, India (90). The project was a collaboration between the National Institute of Epidemiology (NIE), the Tamil Nadu State Public Health Department, and the United States Centers for Disease Control and Prevention (CDC). The aim was to create a mechanism for community volunteers to report unusual disease signals to public health authorities.

Through consultations and stakeholder meetings, priority diseases were identified, signals for reporting were defined, criteria for volunteers established, and training materials (training guide, pocket cards, posters, etc.) and an SMS communication system for reporting were developed.

Training was then rolled out using a cascade training plan for district, block and community levels. Village health nurses were trained and in turn provided training to community volunteers. A total of 385 health workers and 8,214 volunteers were trained.

During April–December 2017 and February–December 2019, a total of 144 signals were reported. The most common signals were fever with rash, cluster of similar illness and death of three or more animals or birds in one week. Among the 25 events requiring action, 16 were not reported from existing surveillance systems. Events included chickenpox, dengue, undiagnosed fever, acute diarrhoeal disease, goatpox and hand, foot and mouth disease (HFMD). Volunteers were primarily homemakers, with 60 homemakers reporting events.

Box 3. Integrated Outbreak Analytics in the Democratic Republic of the Congo

The Integrated Analytics Cell (CAI) is an operational research unit in the Democratic Republic of the Congo that supports the Ministry of Health and other public health actors by providing rapid analyses and evidence to support decision-making in response to outbreaks and other public health emergencies.

The CAI applies an Integrated Outbreak Analytics (IOA) approach to better understand health trends and outbreak dynamics by bringing together multiple types and sources of data to fully understand the factors that might be causing a particular trend in an outbreak or health situation and the impact of the situation and its response on communities. Integrated analyses of data from multiple sources and methods provide a more holistic understanding of outbreak and health dynamics, drivers, enablers and impacts of both the disease and its subsequent effect on communities. Data sources include:

1. epidemiologic and surveillance data;
2. programme data from different actors;
3. health service use data;
4. information on perceptions and health-seeking behaviors of communities;
5. knowledge and practices of healthcare workers;
6. key events that may have had an influence on access to service or risk of a disease;
7. price changes in markets;
8. transportation or services that may affect access to health care or prevention measures;
9. pre-existing social and gender norms contributing to behaviours.

The CAI operates on three core principles:

1. partnership, collaboration and sharing
2. capacity building (community, local and national)
3. monitoring the use of evidence over time, location and public health concern.

By applying an IOA approach based on these principles, the CAI supports better programming, planning and budgeting towards an efficient and relevant community health response.

Source: [IOA](#)



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4.3 Proxy monitoring

Opportunities are also provided using big data and/or open online data sources and computer algorithms for disease surveillance and monitoring. Digital disease detection can uncover signals of potential outbreaks and disease trends by scouring web-based media reports, examining aggregated search queries and analysing social media posts.

For example, the start of an influenza season can be detected when internet search engine key words [influenza], [flu], [antipyretics] are typed in increasing numbers, or when consumption of antipyretics and other flu symptom relievers start to increase earlier than the national outpatient sentinel surveillance picks it up. This approach may also be beneficial where people's health-seeking behaviours include places outside the health system (for example in pharmacies or with traditional health practitioners) or where sentinel sites do not fully represent the population.

Within the health system, monitoring of ICU bed occupancy and other hospital-based indicators can also expose the pressure exerted by epidemics on hospitals. Rapid turnaround all-cause mortality monitoring can serve as an alert for a severe health event, especially when deaths are not clustering or are occurring outside of health facilities. Detection of targeted pathogens in wastewater suggests community circulation of a given pathogen. Crowdsourcing can provide data from non-health sectors such as climate, traffic, transportation and trade that are driving factors of disease spread.



Although big data can be useful to improve the capacity for surveillance, caution and attention are always required. Data access, cleaning, management and security remain a challenge.

The convincing power of numbers can also give a false sense of robustness. Numbers – e.g., compilation of “**confirmed case counts**” for COVID-19 – might suggest impact and may be helpful to **see trends** if interpreted correctly, but this depends on **testing strategies** or simply **access to testing**.

Once a virus is rapidly spreading, or when determining the total case count is no longer feasible, we can switch from quantitative to qualitative indicators or direct to indirect parameters for monitoring (for example intensity of transmission, stress to health systems, workplace and/or school absenteeism etc.) This type of surveillance improves timeliness and geographical participation and therefore is more appropriate for real-time situation and impact.

4.4 Benefits from open and freely available software

As noted above, digitalization and electronic transmission of data have enabled rapid collation of local and national data to compose a global picture of infectious diseases. These data also inform analysis and modeling of local transmission trends, which can be used for projection of near-future forecasting.

However, an abundance of data requires sophisticated software for cleaning, analysis and visualization. Historically, software capable of these functions has been proprietary, making it challenging for low-resource settings to obtain software licenses. To address this gap, in recent years there has been an influx of powerful free software or open-source software with supportive communities to help learners apply tools in context and troubleshoot problems, maximizing local information gain. These applications, such as R and QGIS among others, have revolutionized the way we interact with data. Developing and sharing online code repositories supports the harmonization of complex analyses, as well as more advanced visualizations and data presentation. This approach can support insights into comparable disease activity and burden and enable local actors to extend analyses to the country setting.

While free software for statistical or mapping applications dominate the digital landscape, there are also a wide range of emerging software innovations to enhance understanding of infectious diseases. For example, advances in satellite technologies allow for more precise and widely accessible climate and geographical information on a large scale. Also, more detailed, localized information is available, thanks to higher resolution, accuracy and precision of satellite imaging/GIS.

A better **view of our world** and its ecosystems is particularly useful when **monitoring waterborne and vector-borne diseases** with a view to:

- anticipate future risks
- support preparedness
- ensure early detection.



4.5 Advances in diagnostic technologies

Substantial advances in diagnostic technologies, regarding not only technical performance but also operability and cost-performance, have changed the landscape of surveillance and have the potential to drastically enhance future surveillance capacity. Multiplex tests devised on a syndromic basis can be deployed on a wider basis.

The COVID-19 pandemic spurred around-the-clock development and mass production of rapid diagnostic kits at a global scale. Point-of-care diagnostics provide opportunities for early detection, early reporting and timely clinical and public health interventions. They reduce delays caused by processing samples for transportation to specialized laboratories, thereby reducing overall costs and labor incurred for confirmatory tests.

While there are **concerns** that **self-testing decreases data flow** necessary for sound surveillance, adding novel digital health technologies to self-testing and other point-of-care tests may provide a solution to data capture, allowing the **best of both worlds** – tests in the hands of individuals and health workers for rapid actionable diagnosis (test-and-treat) also feed into **centralized reporting systems** for understanding infection at the population level.

The **quick turn-round times** associated with **rapid diagnostic kits** also facilitate contact tracing and interrupting disease transmission.



Serologic analyses to detect pathogen-specific antibodies are invaluable in assessing transmission patterns as well as infection attack rates and immunity in populations while they may not be so useful in early diagnosis of cases. Conventional methods used so far are time and labour intensive, usually carried out in well-equipped specialized laboratories with trained staff, hence accessibility is limited particularly in LMICs. Rapid antibody assays remain challenged by their relative non-specificity and lack of universally agreed standards.

The COVID-19 pandemic nevertheless provided an opportunity to accelerate development of many rapid immunological assays. Varying performances are reported, and further improvement is imperative, but these technologies may enable more accurate assessment of protective immunity of individuals and populations. Furthermore, application of novel technologies such as AI and machine learning, CRISPR, nanotechnologies and wearable diagnostics appear to be on the near horizon, with the potential to fundamentally change the landscape of diagnosis and surveillance.

4.6 Legally binding international instruments

In light of the impact of the COVID-19 pandemic, in December 2021, WHO Member States established a process to draft and negotiate a new convention, agreement or other international instrument (referred to as an accord) on pandemic preparedness and response. The work on the new accord aims to be coherent with and complement the IHR (2005).

The new accord would be expected to establish principles, priorities and targets for pandemic preparedness and response with the following aims.

- 1 To build resilience to pandemics.
- 2 To ensure equitable access to pandemic countermeasures.
- 3 To support prevention, detection and responses to outbreaks with pandemic potential.
- 4 To support global coordination through a stronger and more accountable WHO.



A new accord could promote **political commitment at the highest level** by ensuring an all-of-government and whole-of-society approach within countries and sustained and sufficient political and financial investment within and among countries.

Among other things, the new accord could address gaps that have been highlighted by the COVID-19 pandemic, including the following key areas for action.

- 1 Global preparedness and response arrangements, including at the human-animal interface, to help anticipate and prevent future pandemics and address them more effectively when they do arise.
- 2 Sustained and predictable funding for health emergency preparedness and response, including from domestic budgets to support preparedness measures and help ensure that the world is prepared and can respond to the emergence of dangerous pathogens.
- 3 Governance and oversight mechanisms to increase trust, ensure accountability and foster transparency.

The IHR (2005) are also under a process of potential targeted amendments. Proposed amendments address notification, verification, information sharing, risk assessment, determination of a public health emergency of international concern (PHEIC) and intermediate levels of alert. COVID-19 and Mpox highlighted the importance of protecting reporting Member States from stigmatization and economic sanctions such as travel and trade restrictions.

Fulfillment of **IHR (2005)-defined core capacities**, including surveillance and response, **are evaluated by Joint External Evaluation (JEE)**. Of evaluations completed in **117 countries by the end of 2022**, more than **50% were rated as not achieving the standard**. A new accord may help expedite core capacity development in these countries (91, 92).

4.7 Funding

Dealing effectively with the complex and multidimensional infectious threats of the 21st century requires a strengthened and agile approach to the way we prepare for and respond to health emergencies.

Where previously there has been chronic neglect and underinvestment in national capacities, we need to make smart, evidence-based investments that deliver the best possible return in terms of lives saved, within the context of sustainable development, global economic stability and long-term growth. This means recognizing that strengthening global health emergency preparedness, response and resilience (HEPR) architecture must be part of the broader effort toward the 2030 Sustainable Development Goals (93, 94).

To achieve a stronger global health architecture, three priority points were proposed by the Indonesia G20 presidency in 2022.

- 1 Increasing global health resilience.
- 2 Aligning global health protocol standards.
- 3 Redistributing global manufacturing centers and research centers to reduce future health vulnerabilities.

The importance of promoting the role of the private sector in the collaboration of global health sector financing is also highlighted.



Fig. 9. Economic impact of major infectious disease outbreaks



A persistent gap in the global health architecture has been availability of long-term and sustainable Prevention, Preparedness, and Response (PPR) financing.

The PIP framework successfully raised US\$ 252 million from private sector as partnership contributions since its onset in 2011 by the end of 2022, approximately 40% of which has been allocated to strengthen surveillance and diagnostic capacity in LMICs. The progress made with the support of the PIP partner contributions, had a positive impact on the COVID-19 response.

Seventy-six countries integrated COVID-19 surveillance into their influenza surveillance systems, influenza/GISRS platforms were used by countries for sample and data sharing for COVID-19, and more than 90% of the National Influenza Centres served as national COVID-19 reference laboratories. These achievements have contributed greatly to the COVID-19 response and highlight the need for similar and more sustainable funding mechanisms.

Another global mechanism, the World Bank's Pandemic Emergency Funding Facility (PEF) was established in May 2016, reflecting lessons learned from the EVD outbreak in West Africa. It aimed to help epidemic and pandemic response, using an innovative bond mechanism in addition to contributions from several donor countries. The PEF was released for the 2019 EVD outbreak in the Democratic Republic of the Congo (US\$ 50 million) and for COVID-19 (US\$ 195 million for 64 International Development Association-eligible countries) in April 2020 (95) (See Fig. 9 for full economic impacts). But historically the funds have been released only in response to epidemics and the COVID-19 pandemic based on pre-determined criteria, limiting its availability. The PEF was closed in 2021 (96).

In 2015 the WHO **Contingency Funds for Emergencies (CFE)** was established, supported by Member States' contributions, and allocated **US\$ 217 million between 2015 - 2021**. The CFE has proven its usefulness in supporting **early response** and control because it can be **released in 24 hours or less**.

The CFE provides WHO with the resources to respond rapidly to disease outbreaks and health emergencies. The CFE also allows WHO the flexibility to scale up operations in response to an escalation in a health emergency and provide funding to ensure the continuity of critical, life-saving operations. The CFE has also been used to support preparedness and readiness activities (97).

When it comes to preparedness for product purchasing, there have been several innovative funding mechanisms such as Advance Purchase Commitment (APC) created by Gavi, International Finance Facility for Immunization (IFFI) for childhood vaccines in LMICs, and COVAX and ACT Accelerator for COVID-19. The aforementioned PIP framework includes Standard Material Transfer Agreement with industries to secure pandemic response products such as vaccines, diagnostic kits and therapeutics.

Beyond these mechanisms, there were no other dedicated pooled international funding sources for pandemic preparedness except for existing or ongoing bilateral agreements. However, to address these shortcomings, in June 2022, the Financial Intermediary Fund (FIF) for PPR (now known as the Pandemic Fund) was established (98). The Pandemic Fund provides dedicated and long-term financing to strengthen PPR in LMICs and to address gaps through both investment and technical support from the national to the global level (99). The first call for proposals for the Pandemic Fund was issued in early 2023 (100).



Chapter 5. Shaping the future: collaborative surveillance

5.1 The vision

Lessons from the COVID-19 pandemic and other emergencies, coupled with the opportunities and possibilities described above, challenge us to conceive of a vision for more robust, resilient and coordinated future surveillance that aligns traditional processes with new initiatives and methodologies. As the cornerstone of efforts to recognize tomorrow's threats and prevent their escalation, future surveillance must be grounded in a set of foundational public health tasks that address key aspects associated with the causes and spread of infectious disease.

Detection	Identify unusual or alert signals for early warning, followed by laboratory confirmation of emergence or re-emergence of a pathogen of concern.
Characterization	Determine the pathogen's clinical presentation, severity, transmissibility, natural history, risk for infection, risk for severe clinical outcomes and full genomic characterization, as well as ensure open reporting of the pathogen sequence.
Understanding dynamics	Elucidate transmission and incidence to indicate the possible scale of an outbreak.
Impact measurement	Assess the burden on the health care and public health systems and on socioeconomic disturbance.
Monitoring and evaluation	Track and adjust efforts through ongoing monitoring and evaluation, including for public health and social measures and medical and pharmacological interventions.

Underpinned by this intelligence and recognizing the documented gaps in surveillance infrastructure and methods, future surveillance for epidemic and pandemic diseases can be envisioned as encompassing nine main attributes.

The vision: future surveillance for epidemic and pandemic diseases

1 Tailored to address public health issues in a given context , contributing to decision-making for action.	2 Builds on strengthened existing surveillance mechanisms for known risks.	3 Involves people and communities .
4 Leverages new technologies and innovative approaches.	5 Grounded in effective healthcare delivery services .	6 Links local, sub-national, national, regional and global surveillance efforts.
7 Based on a clear and consensus framework for sharing data ethically .	8 Stands on sustainable and scalable financing and trained human resources .	9 Coordinated and overseen by a strengthened and empowered NPHI .

5.2 The way forward

Achieving the vision of future surveillance for epidemic and pandemic diseases will require united efforts that leverage both learnings from the COVID-19 pandemic as well as the success of investments to advance surveillance as a core capacity of the IHR (2005) to develop a robust global architecture and implement innovative approaches now and looking towards a 2030 horizon. Each of the attributes of the vision suggests actions toward a more connected and response-ready global community.

Tailor surveillance to address public health issues in a given context, contributing to decision-making for action

Countries are confronted with challenges to achieving efficient and timely surveillance for detecting, monitoring and responding to emergencies caused by infectious hazards. Examples of these challenges include varying capabilities, siloed non-scalable surveillance systems and limited resources. In 10 proposals to build a safer world together — Strengthening the Global Health Architecture for Health Emergency Preparedness, Response and Resilience: draft for consultation, WHO proposed five core subsystems for strengthening the global architecture for health emergency preparedness, response and resilience, including what was termed collaborative surveillance (93). Interconnected capabilities for the generation and linkage of relevant data and the application of intelligence at all levels of decision-making can revolutionize our ability to detect emerging events, communicate information quickly, rapidly initiate responses and continue to inform actions throughout emergency cycles. This vision has motivated the inclusion of the collaborative surveillance concept as a core component of the framework for strengthening global architecture for HEPR. The concept emphasizes collaboration itself as a key capability (101,102). This new vision for future surveillance has four main components:

1. integration through consolidation of surveillance systems to address multiple hazards;
2. data and information sharing across systems and dimensions and linked to decision making;
3. integration of capacities to ensure that resources strengthen surveillance beyond individual disease objectives and can be leveraged to address emerging threats;
4. open communication of surveillance findings at all levels, with systems and feedback loops to enable to exchange of intelligence generated by others.

Through an intentional focus on and commitment to collaboration, this approach aims to strengthen how we generate, communicate, and apply timely and high-quality data and information on hazards, populations affected and their contexts to make informed public health decisions for the prevention and control of public health emergencies. It builds on foundations of robust public health, health systems and laboratory surveillance, harnessing contemporary data sources and advanced data and analytical approaches to enable the generation of contextualized insights on risks.

The focus is on collaboration across diseases and threats, sectors, geographies and event lifecycles, ultimately interconnecting with response capacity at all levels where decisions are made to inform action. Efforts to foster collaborative surveillance can be supported by having a common guidance for surveillance developed by WHO and partners. This guidance can set standards for surveillance and include an array of components including systems (for example digitalization and electronic platforms, use of AI and other innovative approaches), governance and implementation roadmaps for building and achieving coordinated, collaborative and integrated data collection and analysis where appropriate. Ensuring that guidance is followed will enable countries and their leadership to champion and coordinate surveillance and drive towards greater data sharing to enhance the detection and control of infectious hazards.

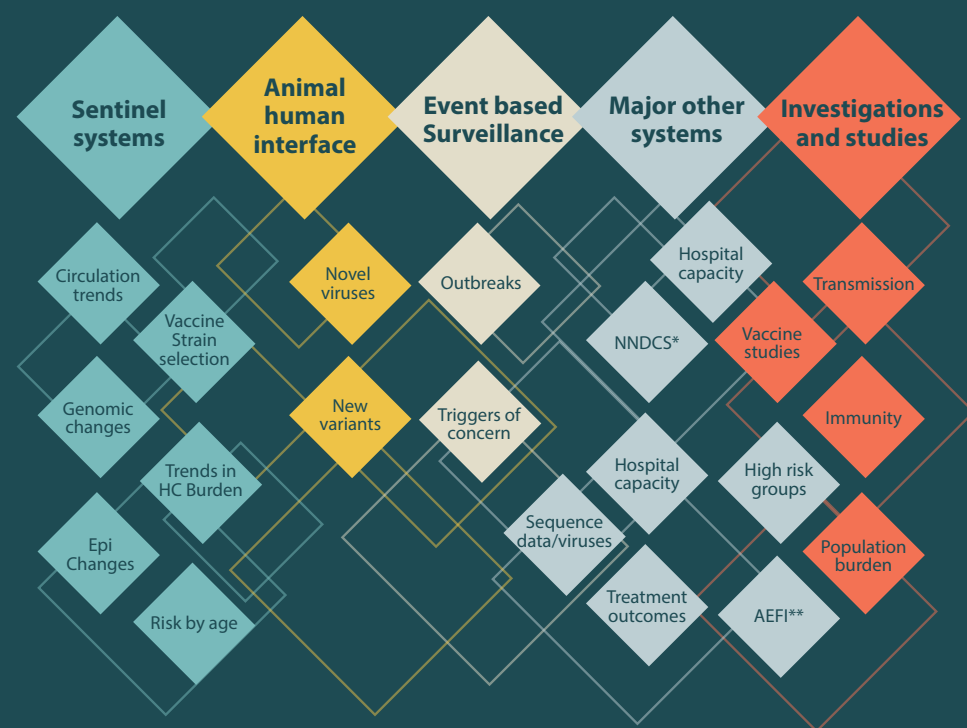
Build on strengthened existing surveillance mechanisms for known risks

Collaborative surveillance recognizes the need for continued investment in existing surveillance programmes while increasing their ability to respond to new or expanded needs. The model recognizes that a single surveillance modality cannot provide all the information needed to make sound decisions. It requires combining several surveillance approaches to capture the various dimensions of a disease and its impact.

Given the ongoing risk of newly emerging respiratory pathogens with pandemic potential, a focus on coordinated surveillance for respiratory diseases of pandemic potential is critical. WHO has proposed a framework for coordinated global respiratory disease surveillance (Crafting the Mosaic) aimed at supporting decision-making by collecting information from multiple sources and complemented by new ways to generate data.

This initiative expands on the capabilities of the Global Influenza Surveillance and Response System (GISRS) and other existing surveillance approaches (for example pneumonia, lower respiratory infections) to include other respiratory pathogens, with an understanding that new platforms for vaccines and therapeutics may have different data requirements in the future.

Fig. 10. Landscape of Mosaic Respiratory Surveillance Framework
Source: WHO Mosaic Respiratory Surveillance Framework



*National notifiable disease/condition reporting clinical networks, targeted special pop surveillance, administrative and electronic health care data etc.
** Adverse event following immunization (AEFI)

Developing an approach for coordinating the mosaic of systems is a multi-step process. First, an evaluation is needed of the landscape of current systems, for example laboratory networks, sentinel networks, event-based approaches (Fig. 10), applying principles of equity, inclusivity and coherence, as outlined in *10 proposals to build a safer world together* (103).

Potential partners include early warning and outbreak response partners, for example, Field Epidemiology Training Program (FETP), influenza and COVID-19 programme partners, Essential Programme for Immunization (EPI), nationally notifiable disease systems, TB programmes and groups working to reduce the childhood pneumonia burden, particularly in LMICs. Community-based surveillance or special studies are needed to monitor trends in special groups, those not captured by the health system due to their limited accessibility to health care or health care-seeking behavior (including older adults in LMICs), or those who belong to so-called hard-to-reach groups such as migrant workers and persons living in urban slums or rural areas.

It is important to **view the mosaic** of surveillance systems through the **lens of decision-makers in countries**. Recommendations for these systems must be **user-centered, outcome-driven, evidence-based** and **focused on the questions** and data needed for leadership to **make critical decisions** throughout a public health response to an infectious hazard.



Importantly, WHO and stakeholders need to develop a strategy to expand global surveillance networks at the sub-regional level, including ways to fund collaborating centers in LMICs to support surveillance systems that contribute to the global mosaic of systems. This should include the potential for identifying locations where laboratory testing and targeted surveillance can be supported and built upon to improve detection of emerging infectious hazards.

Involve and benefit people and communities

As noted previously, participatory surveillance is one of many emerging approaches to detect and monitor disease threats in addition to traditional surveillance approaches such as indicator- and facility-based surveillance. These systems support the public to actively provide data that can be aggregated and analysed for a variety of purposes, for example to monitor disease trends, identify risk factors, detect outbreaks and track attitudes about and adherence to public health and social measures. Participatory surveillance can also potentially expand coverage of populations and age groups that are inappropriately or not at all captured by existing surveillance systems.

A key group to capture is the growing working-age population that is highly mobile, socially active and a main driver of disease spread, while at the same time active in digital communication. Indeed, advances in digital technologies and the ubiquity of digital platforms can support the application of and scale up of participatory surveillance platforms.

Participatory surveillance can also be used to monitor health events in both humans and animals in rural areas where surveillance resources are often limited (102). In LMICs in particular, where traditional disease surveillance systems (including laboratory capacity) may be limited by financial and human resources, participatory surveillance approaches can serve as a low-cost method for routine monitoring and detection of early signals. The main limitation is that participatory surveillance may not be representative of the general population as people self-select into the system and participation tends to decrease over time. Thus, part of a research agenda should consider how to sustain both the system and encourage greater involvement in participatory surveillance over time.

WHO and its partners are committed to promoting the role of communities in detecting and reporting unusual disease events. Ensuring better participation and engagement, however, requires providing tools and building capacities, particularly among hard-to-reach groups. Another key to successful community-based participatory surveillance is addressing incentives and disincentives to reporting. System design, data collection and data analysis and use should be guided by principles of equity, ethics and human rights and should leverage local community surveillance assets (82, 83). Confidentiality and de-identification of data should be well sought.

Not only should future surveillance **involve people and communities** but it must also **provide benefits in return**. In many cases, central bodies collect large amounts of data with **little or no analysis** of that data or **use of the information** that they provide.

The surveillance system then becomes driven by the need to collect and move data, with little attention to the use of information by each level of the health service for decision-making. Instead, the surveillance system should be tailored to address public health questions in a given context, contributing to decision-making for local action.



Importantly, the system must reflect the stage of the epidemic or pandemic, for example contact tracing in the early stage and assessing the magnitude of transmission and strain on health care in later stages.

Leverage new technologies and innovative approaches

Clearly, technological advances continue to bring new opportunities for surveillance. Future surveillance will benefit from machine learning (ML) of online searches for establishing disease baselines and alerts. Other technologies that offer potential benefits to surveillance include:

1. digital technologies, including data capture and analysis, high-performance processing, autonomous systems, other AI, ML and Internet of Things (IoT);
2. point-of-care or near-patient diagnostics linked to mobile devices (or wearables) for reporting and use of telemedicine (consultation and prescriptions) or human-computer interaction using smart sensors and AI devices, collectively known as Zero UI;
3. free software enabling user-friendly, customized and cost-saving analyses;
4. satellite information;
5. drones;
6. crowdsourcing facilitated by mobile phones and connectivity.

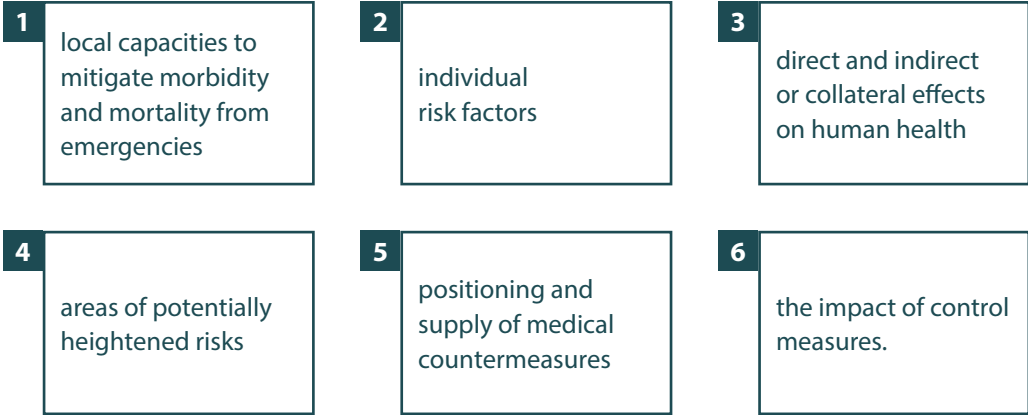
Although such simplified and user-friendly tools will facilitate timely risk assessment with benefits to communities, they also raise concerns. For example, data ownership will need consideration as data generated by mobile phones are currently owned by private companies. Datafication of everything around us, while providing unique opportunities for digital collection and analysis, also raises issues related to data justice and ethics that are imperative to advancing surveillance.

Ground surveillance in effective health care delivery services

Public health competencies and tools, including disease surveillance, rely on highly functioning healthcare systems; the capabilities and infrastructure of both systems are needed to ready communities and countries to prepare for and respond to infectious threats. As noted above, epidemic and pandemic disease surveillance often begins with recognition of suspicious disease activity or unusual illness of unknown aetiology by a clinician or other health worker, followed by specimen collection for laboratory testing. The system can then mobilize the appropriate public health actions to protect the community and the appropriate health services for the infected persons.

In particular, **health service capacity, access and usage monitoring** form a **critical complement to public health surveillance activities** for emergencies, providing a **dynamic picture** of health systems resilience. In many contexts, these data are **collected but not connected to public health authorities**. Surveillance systems must therefore be **interconnected** with public health response mechanisms, with the **flexibility to surge and adapt to all types of emergencies** and the capacity to **rapidly assess** the effect of major disasters on the availability of, and accessibility to, health services.

In addition to aiding routine patient and facility management and service provision, health systems surveillance can inform:



As digitization of health systems continues to grow in importance and evolve, there are also growing needs to harness the power of technologies, including electronic medical records and telehealth platforms, to complement and improve current surveillance and response systems. Digital tools such as geospatial and environmental sensors and personal health devices can also be applied to improving disease surveillance, population health and drivers of health in general. As noted above, however, gaps persist in how modernized health systems link to public health systems. Data sharing, interoperability and inclusivity are ongoing challenges. To ensure that unusual health events are identified and monitored, digitized surveillance systems and health systems must ensure interoperability and timely data sharing. Ensuring the availability of standardized datasets is important for interoperability. These data sets can be shared through integrated data repositories to strengthen the capacity of surveillance systems. Further, there is an opportunity to leverage existing administrative databases currently used to manage health (and other) data. These, when linked via deterministic or probabilistic algorithms, can complement and improve current surveillance and response systems.

As with other public health pursuits, **digital health** should be an **integral part of health priorities** and **benefit people** in a way that is:

- ethical
- safe
- secure
- liable
- equitable
- sustainable.

It should be **developed** with:

- principles of transparency
- accessibility
- scalability
- replicability
- interoperability
- privacy
- security
- confidentiality (66).



Link local, sub-national, national, regional and global surveillance efforts

Collaborative surveillance calls for efforts to connect horizontally (across sectors) and vertically (across levels – local, sub-national, regional, global) and to take a multi- and cross-sectoral approach to enable integration and collaboration.

By doing so, collaborative surveillance expands traditional surveillance approaches to capture epidemiological data, as well as intervention and effectiveness data from multiple information sources supported by multi-sectoral analysis and interpretation. This holistic approach facilitates achievement of more cost-effective, efficient and sustainable surveillance at all levels of the public health system.

Many countries have **developed surveillance activities** to monitor **high-burden diseases** of public health relevance, **detect outbreaks** of epidemic-prone diseases and **monitor progress** towards national or international control or eradication targets. In this sense, surveillance of infectious diseases is a **priority national function**. Surveillance activities within vertical programmes allow the surveillance function to **remain close to the control function**.



On the other hand, the overall surveillance function in a country can become disjointed and inefficient with field workers participating in multiple systems and using different surveillance methods, reporting forms and schedules. In addition, scarce expertise and laboratory facilities (for example in molecular diagnostics, virus isolation) may be needlessly duplicated. This entails extra costs and training requirements and often leads to work overload among health workers, resulting in deterioration of data quality or system collapse. The specimen(s) collected for surveillance on one disease may be more efficiently used for surveillance of multiple diseases causing the same disease syndrome.

Optimal modalities for integration and coordination to overcome these barriers include:

Coordination by mode of transmission (for example respiratory, vector-borne, waterborne, sexually transmitted, foodborne), and integration, as feasible, using a syndromic approach (for example acute respiratory, acute gastrointestinal, acute neurological, acute hemorrhagic, acute jaundice, acute fever and rash, acute flaccid paralysis (AFP)). Integrated Disease Surveillance and Response (IDSR) implemented by WHO Regional Office for Africa is one example; use of a multi-pathogen diagnostic approach with local priority pathogens is another.

Where feasible, **integration by sharing laboratory diagnostic capacity** (antigen detection and characterization, genetic analysis and genomic surveillance, serological surveys and seroprevalence studies) in line with the Immunization Agenda 2030 aiming to monitor achievement of immunization goals.

Coordination with and strengthening of existing surveillance systems including Global Influenza Surveillance and Response System (GSRIS), Vaccine-Preventable Diseases (VPD), Global Polio Eradication Initiative (GPEI) and systems for surveillance of AFP, environmental factors (including wastewater surveillance and genetic analysis and mapping of poliovirus), HIV, TB, malaria, neglected tropical diseases, AMR and NCDs.

Integration by sharing of health delivery systems and resources, for example primary health care centres; reference hospitals; health information systems; telemedicine programs; laboratories including antigen detection and genetic sequencing capacity; programmes including VPD/Essential Programme for Immunization, mother-child health, sexually transmitted infections; and human resources including community health workers, health providers, public health workers, midwives, laboratory workers, volunteers, community members, local actors, amongst others.

In the setting of an event, encouraging those doing clinical research to **collect data that would allow for better characterization** of the event and to make that data generally available as soon as possible.

Where appropriate (for example with potential zoonotic infections), **integration with animal and environmental health sectors** to carry out One Health investigations, including climate and vector intelligence.

Where feasible, **consideration of wastewater surveillance** that can integrate with surveillance for human health issues and also for other sectors, including animal health and environment as part of a One Health surveillance approach, as used for AMR surveillance.

Inclusion of data collected by UN agencies, including the quadripartite agencies (One Health approach), and **non-state actors**, (private sector, civil societies, non-profit and non-governmental organizations, academic and research institutions, community-led participatory surveillance), ranging from climate data and animal die-offs to goods consumption and mobility data.

Coordination of national and international funds to develop, integrate and maintain surveillance systems and analyse data to inform policy for action; funding sources should include bilateral, multilateral, public-private partnership (PPP), philanthropic, academic and research, development, security funds and gap-filling funds such as the World Bank-led Pandemic Fund.



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A research agenda on cost-effective, efficient and sustainable surveillance should also be developed.

In addition, it is important to develop a **business case that articulates the cost-effectiveness and benefits** of collaborative surveillance, by for example, introducing **point-of-care diagnostics** wherever possible, better technologies and other approaches such as **genomic surveillance and wastewater surveillance** (104-106).

Achieve a clear and consensus framework for sharing data ethically

As emphasized in previous sections of this report, there is a need for a clear and consensus framework on sharing data ethically. Currently, the lack of such a consensus inhibits advances in many areas of work, including leveraging big data for surveillance. The collaborative surveillance model must be based on a culture of trust and disposition towards the exchange of data, information and intelligence for mutual benefit.

All **data sharing** should **balance** and **protect** the **privacy of individuals** and the **dignity of communities**, while **acknowledging the imperative to improve public health** through the most productive use of data (107).



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It is important to maintain transparency and effectively communicate about data security strategies. The principal guiding values in research ethics are autonomy, privacy and confidentiality. By contrast, the ethics of public health surveillance focuses on the common good, solidarity, accountability, trust and balancing of individual rights with collective interests. Agencies or organizations that conduct public health surveillance should take into account community values, concerns and priorities in a transparent manner. Communities cannot be engaged if they have no means of knowing about the benefits and risks (or potential for harm) of surveillance. Active engagement of the community may involve meetings with community leaders, focus group discussions and other forums that provide an opportunity for members to clearly express their values and concerns. In whatever manner the community is engaged, it is critical that decision-making is transparent, fair and open to revision. Identifiable information like names and addresses are sometimes part of surveillance records. Using unique identifiers such as numbers instead of names is one way to prevent identities from being inadvertently disclosed. Another is geo-masking, which preserves vital information on the spatial distribution of cases but does not pinpoint the exact location of case clusters.

Assessing the legal protections for those who might be particularly susceptible to harm is another strategy for ensuring that, in advance of surveillance, broad social protections are in place. In many nations, laws requiring surveillance are paired not only with security protections but also with clear protections of economic, social and civil rights. In the context of emergency situations, rapid data sharing is imperative. It is also appropriate to share public health data for legitimate research purposes that have been approved by an ethics review committee. But data collected in the name of public health should never be shared for the purpose of acting against individuals or for uses unrelated to public health. Access to personal information by agencies responsible for national security, law enforcement or the allocation of social benefits should be allowed only after legal due process.

To preserve trust in public health surveillance systems, there should be a compelling justification for sharing identifiable data for non-public health uses. An engaged oversight body can help to identify ethical issues when they arise, consider new evidence or emerging best practices and deal with complex problems in an accountable and transparent manner. Decisions that may require ethical oversight include collecting data that reveal stigmatized behaviour, adopting new uses for existing surveillance data, such as for case management or contact tracing, or using public health surveillance data for commercial or security purposes. Oversight is also important to ensure active monitoring for harms and appropriate data sharing. Mechanisms for the ethical oversight can also help to ensure that countries meet their obligations to conduct surveillance responsibly (108).



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Whereas **surveillance data** are typically collected and stored in a database **owned by the respective public authority**, **open data** should also be an **important component** for future surveillance.

Non-state bodies, including academic institutions, **should be able to access national data** to facilitate insightful analyses.

To that end, an increasing number of **governments are launching open-data initiatives** with de-identification and **confidentiality protections**.

Stand on sustainable and scalable financing and trained human resources

Sustainable funding is needed to establish and maintain collaborative surveillance systems that can adjust to evolving priorities and technologies and cope with contingencies. There is a need to conduct analyses to make the case for action around financing future collaborative surveillance, including mobilization, allocation and use.

While every country **should step up domestic investments to achieve future surveillance**, **low-income countries** and **some lower middle-income countries** need **urgent international support**.



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WHO proposes to establish a coordinating platform for financing to promote domestic investment and direct existing and gap-filling international financing to where it is needed most (93). Countries and supporting partners should work closely to incorporate recommended elements of surveillance systems by collecting, applying and implementing funding within a certain time frame. International funding pools with dedicated and long-term financing for preparedness and response, such as the Pandemic Fund, must be promoted, and financial mechanisms for gap-filling funding support must be ensured. In doing so, involving, and achieving contributions from, the private sector should be considered following the PIP Framework model.

Future collaborative surveillance also requires an effective, highly skilled workforce focused on aspects of surveillance every day and a framework for scaling up during emergencies. This includes strong in-house capabilities and additional multidisciplinary collaboration mechanisms (shared capacity) across epidemiology, One Health, social sciences, data sciences, clinical sciences, laboratory sciences, systems engineering, and other disciplines. The surveillance workforce must be supported with continuous capacity development through cross-cutting and disease-specific learning and training opportunities, and other initiatives to encourage retention of skilled staff.

Provide coordination and oversight by strengthened and empowered NPHIs

Championing collaborative surveillance at the country level can be achieved by supporting countries to establish an NPHI (109, 110). Effective and empowered NPHIs are those that:

- 1

have a defined role (either through legislation or regulation)
- 2

operate based on a common analysis of gaps to address and clarify goals
- 3

integrate laboratory and epidemiology expertise
- 4

engage stakeholders through a whole-of-government and One Health approach
- 5

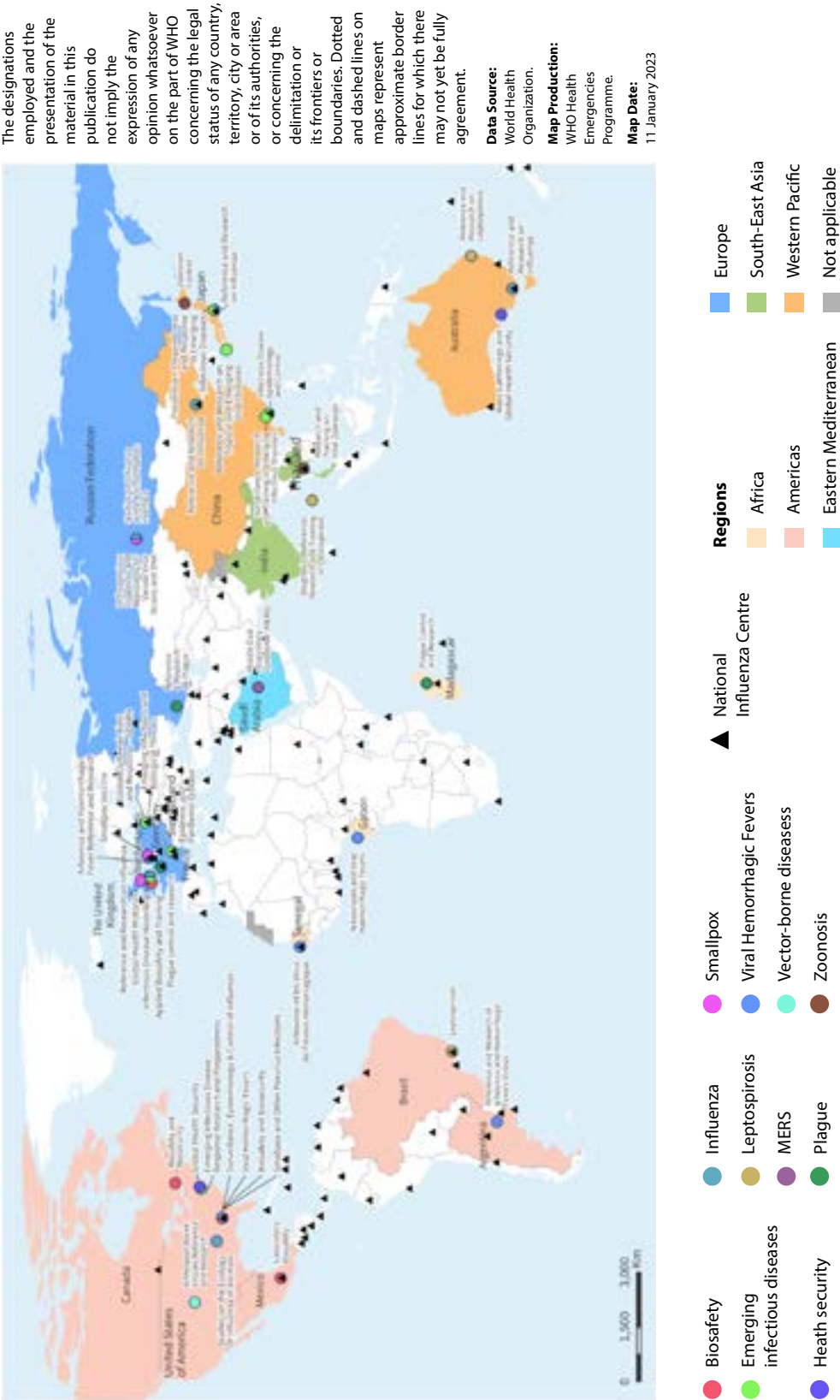
address essential administrative functions
- 6

are helmed by and support effective leadership.

By hosting Centres of Excellence, an NPHI can serve as a knowledge hub and mothership for field epidemiologists, laboratory workers and multidisciplinary Rapid Investigation/Response Teams, providing technical support and overseeing the quality of processes and deliverables. These teams should be trained and equipped to investigate signals of unusual disease outbreaks that remain undiagnosed, identify outbreaks of undiagnosed illnesses and make referrals to more expert national or regional centers as appropriate.

An NPHI can be established by expanding and strengthening an existing NRL or national public health laboratory, which often build on national influenza centres that as of January 2023 have been established in 125 countries (111) (Fig. 11). Coordinated and led by the NRL, a national network connecting local laboratories with diagnostic capacity can be built. Maintaining sustainable local diagnostic laboratories is key for successful future epidemic and pandemic surveillance. Increased networking of NPHIs and Emergency Operations Centers (EOCs) is expected to enable greater engagement among countries and contribute to regional and global data sharing.

Fig. 11. Map of WHO Collaborating Centres and National Influenza Centres (as of December 2023)



5.3 Summary of strategies for future surveillance of epidemics and pandemics

To ensure a more response-ready world, the HEPR architecture calls for a new vision for future surveillance, termed collaborative surveillance. The aim is to strengthen capacities and combat fragmentation through enhanced strategies for coordination, collaboration and innovation among a range of traditional and new partners. Achieving such a collaborative surveillance approach will require sustainable investments and commitments at all levels to move from the status quo of siloed and deficient surveillance systems toward better management of health threats. WHO has identified the following strategies as those most essential for achieving future surveillance.

- 1 Foster collaborative surveillance and related tools and platforms to enhance integration of various systems both horizontally (across sectors) and vertically (across levels -- local, national, regional, global).
- 2 Identify sentinel surveillance sites in strategic locations, particularly in LMICs, that can be strengthened to provide comprehensive and holistic surveillance insights and enable partners to rapidly collect specimens, analyse genomic information and interpret and share results.
- 3 Connect institutions involved in surveillance to function as interconnected nodes that link partners from the local to the global level and including both LMICs and high-income countries.
- 4 Strengthen data generation, access and sharing to ensure that mechanisms, resources and technologies are in place so that the objectives of surveillance are achieved at local and national levels, while useful insights are also generated and shared to inform regional and global risk assessment and decision-making.
- 5 Enhance and expand partnerships, building on existing partnerships and forging new partnerships including civil society and the private sector.

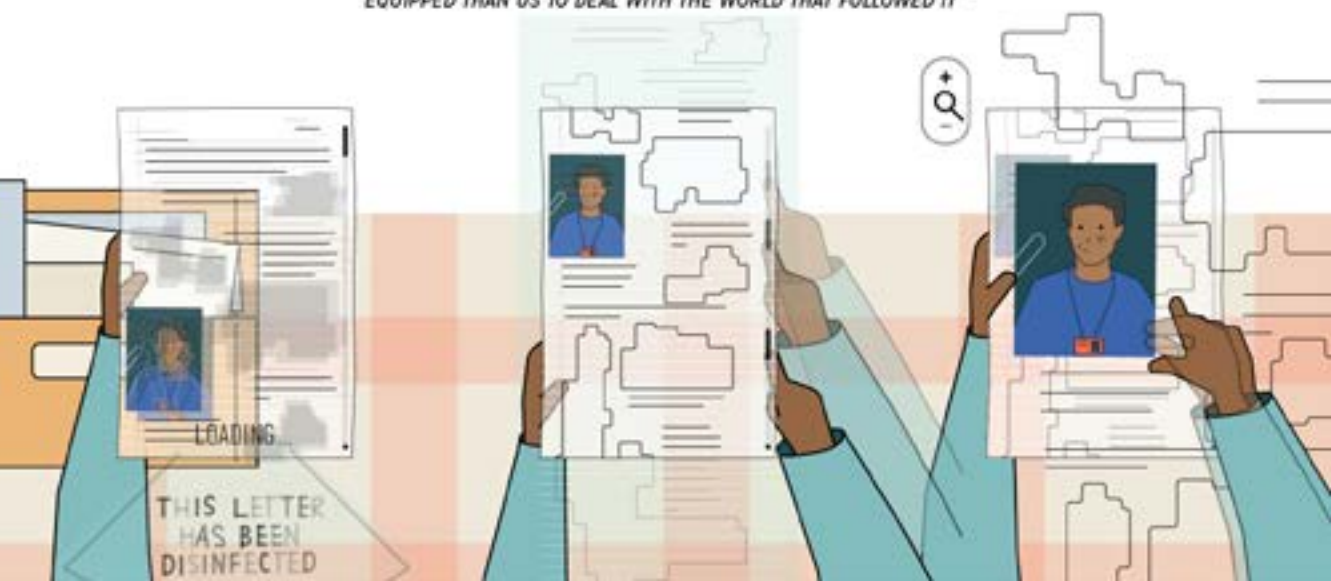
- 6 Adopt the Crafting the Mosaic approach to inform decision-making across sectors by collecting information from multiple sources and instituting new ways to generate data from the local to the global.
- 7 Introduce and support innovative surveillance approaches, including efficient and cost-saving novel approaches that draw on One Health as well as non-traditional partnerships and community engagement and multi-sectoral data sources, including environmental sources.
- 8 Harness digital technologies to develop innovative and open-source databases and tools for timely and insightful analysis and interpretation that strengthen public health fundamentals, meet surveillance needs in communities and support decision-making across levels.
- 9 Champion ethics and equity by using ethical surveillance approaches and processes, protecting privacy and upholding economic, social and civil rights, while also addressing gaps in access to digital surveillance technologies.
- 10 Develop an operational research agenda that brings together a wide range of surveillance partners to create a unified and strategic roadmap to guide the advancement of surveillance approaches, methods, tools and practices.
- 11 Commit to adequate, long-term and dependable funding for surveillance at all levels, with monitoring and evaluation of its allocation and use.
- 12 Ensure coordination, collaboration and oversight, and, based on the IHR (2005), support WHO to carry out its coordinating role between and across surveillance partners.

Meet Marcus, one of Nala's ex-students, as he travels the world as an epidemiologist in 2028, working alongside communities to improve pandemic surveillance.





LUCKILY, MANY OF THOSE CHILDREN THAT HAD GROWN UP WITH THAT CHAOS WERE BETTER EQUIPPED THAN US TO DEAL WITH THE WORLD THAT FOLLOWED IT



Nov, 2028

Dear Miss Nala,

All those years ago, when you taught us about the different countries of the world - but we were stuck at home taking classes on zoom - I never dared dream I'd get to visit as many of them as I have...

...but of course my journey to becoming an epidemiologist started in much less glamorous ways...



...for a start I never knew I'd spend so much time sampling sewage water! But it turns out to be one of the very best ways we can keep track of emerging viruses.

I guess you can call what I do surveillance, a term that understandably makes a lot of people nervous...



...but the reality is a lot of the time, I'm not surveilling humans at all.



In reality, what we're really watching and tracking are the pathogens themselves.



When you realise that, you also realise that means going to places where there's a lot less people...

In reality, what we're really
watching and tracking are
the viruses themselves.

When you realise that, you also realise that means going to places where
there's a lot less people...



...because sometimes you need to go further
afield to find the roots and causes.

At first people were
sceptical everywhere we
go, but when we explain
we are there to help them
watch for disease
symptoms and keep their
communities safe, they
start to become pleased to
see us.



And oh, Miss Nala! You were always
such an inspiration to me - but I never
imagined I'd be back in the classroom!

And oh, Miss Nala! You were always
such an inspiration to me - but I never
imagined I'd be back in the classroom!

And I thank you not only for what
you taught me, but how - its
because of you that I know how to
be kind and
patient with
my 'students'



...and how important it is
to listen to them.

It's only then you realise that even as you teach others...



...you're always still a student yourself...

...because there's always so
much more to learn.

Epilogue

To become a more future-ready organization, WHO conducted the first foresight project on pandemics and epidemics during the ongoing COVID-19 pandemic in 2021 — 2022. The exercise taught us the power of imagining the future and encouraged us toward a forward-looking mindset, shifting from a reactive to a proactive approach and moving beyond lessons learned. With the esprit of future thinking, we launched a new series of annual reports on Epidemic and Pandemic Preparedness and Response, starting with the first and principal pillar of disease prevention and control – surveillance.

Surveillance is a fitting topic for this inaugural report. Central to our efforts to identify, detect and manage infectious hazards, it plays a key role at every step of preventing, mitigating and controlling epidemics and pandemics that threaten health and global security. The report is the product of a collaborative effort across WHO, partners, networks and Collaborating Centres, with key advice and support from STAG-IH, WHO's Strategic and Technical Advisory Group for Infectious Hazards with Pandemic and Epidemic Potential. The creation of this report has been a great journey of mutual learning – advanced by the role of STAG-IH in bringing groups together and creating a space for cross-fertilization of ideas. The report was enriched by the ongoing Organization-wide Health Emergency Preparedness and Response architecture (HEPR) discussions that have been unprecedented in depth, inclusive and intense on the five subsystems – surveillance, community protection, clinical management, access to countermeasures and coordination.

What future can we hand over to generations to come? Imagining future surveillance means imagining a vision of surveillance for tomorrow, with all of the implications associated with the benefits and challenges of rapidly advancing technologies. As I write this, Open-AI powered applications are transforming the way we work and communicate. Technology has the power to increase equity, efficiency and help us realize a healthier and fairer world for all. Whether and how we use innovations to reach ambitious global goals is up to us. While some places seem to be already living in a vision of the future – with widespread access to and routine use of technology to build health and well-being – others are left behind and continue to struggle to meet their basic needs. The digital divide persists and mirrors the deep inequities that we must work together to resolve. The question remains: will technological advancements contribute to polarization or drive us towards unity?

Each of us has a role in turning visions into realities. Through the collaborative process of creating this report, we have achieved a clear vision of future surveillance. Our journey now is to continue to imagine the future through collaborative action. We hope that this Annual Report provides a glimpse into future surveillance and in doing so sparks your own ideas and action on how to build a safer, healthier, more equitable and prosperous future.

Nahoko Shindo MD PhD

Secretariat in Charge

Epidemic and Pandemic Preparedness and Prevention
WHO Health Emergencies Programme

STAG-IH members and Secretariat at WHO Headquarters, October 2022



Welcome to Nala's home in 2050 – just one future out of countless possibilities - where high-tech gadgets and community sharing of data combine to create private, safe and effective health and pandemic monitoring.



AIR VENT FILTERS

SMART FILTERS ON AIR CONDITIONING AND HEATING VENTS CAN DETECT VIRUSES AS WELL AS FILTERING THEM FROM CIRCULATING AIR

SMART TOILET

SMART TOILETS MONITOR HUMAN WASTE TO PROVIDE EARLY WARNINGS OF INFECTION, AS WELL AS KEEPING TRACK OF OTHER MEDICAL CONDITIONS, DIET AND GENERAL HEALTH

TABLE TOP DRUG PRINTER

SOPHISTICATED 3D PRINTERS CAN PRINT ANTIVIRAL DRUGS AND SOME VACCINES DIRECTLY IN THE HOME

ZERO UI

TRADITIONAL TOUCHSCREEN INTERFACES ARE REPLACED WITH A ZERO UI ENVIRONMENT, WHERE VOICE, MOVEMENTS, GLANCES, AND GESTURES ARE READ BY TECHNOLOGIES AND APPS

SMART NOTIFICATIONS

NETWORKED HEALTH APPS GIVE UPDATES ON CHANGING PANDEMIC STATUS, AS WELL AS REMINDING USERS TO TAKE TESTS OR MEDICATION AND LOG THEIR SYMPTOMS

LONG RANGE DELIVERY DRONE

LONG RANGE DRONES ARE USED TO DELIVER TESTS, VACCINES AND OTHER SUPPLIES TO REMOTE COMMUNITIES

POP-UP PHARMA FACTORY

AUTOMATED, FLEXIBLE PHARMACEUTICAL FACTORIES IN DISUSED SPACES CAN INSTANTLY RESPOND TO PANDEMIC NEEDS OF LOCAL POPULATIONS

BILLBOARD

MEDIA WORKS WITH INSTEAD OF AGAINST COMMUNITIES, HELPING TO REASSURE CITIZENS AND PROVIDE ACCURATE, HELPFUL INFORMATION

SHORT RANGE DELIVERY DRONE

SMALL DRONES - PART OF A HYPER-EFFICIENT TAILORED SUPPLY CHAIN - CAN BE USED TO DELIVER DRUGS, TESTS, VACCINES AND OTHER SUPPLIES TO THOSE SELF-ISOLATING

COMPOSTABLE TESTING KIT

INSTEAD OF USING PLASTIC, TESTING KITS ARE MADE FROM BIODEGRADABLE MATERIALS THAT CAN BE RECYCLED ALONG WITH FOOD WASTE

BIOENGINEERED ORGAN

WEARABLE TECH - AND EVEN BIOENGINEERED ORGANS - THAT CAN MONITOR BIO-DATA FOR VIRUSES ARE AVAILABLE TO THOSE WHO WANT THEM

NETWORKED FOOD ANALYZER

USES MICRO-PROBES TO CHECK FOOD FOR PATHOGENS AND CONTAGIONS AGAINST A SHARED COMMUNITY DATABASE. ALSO PROVIDES ACCURATE NUTRITIONAL DATA

TRANSPARENT MASK

COMPLETELY CLEAR MEDICAL GRADE FACE MASK, THAT IS MADE FROM UNIQUE NANO-MATERIAL THAT BLOCKS PARTICULATES AND VIRUSES BUT ALLOWS NEAR PERFECT AIRFLOW WHILE NOT OBSCURING THE FACE

UV HAND WASHER

HIGH TECH HANDWASHING SOLUTION - USES HIGH POWER ULTRA VIOLET LIGHT BURSTS TO DISINFECT HANDS

WASTE WATER SAMPLING

SAMPLING AND TESTING HUMAN WASTEWATER CONTINUES TO BE AN EFFICIENT WAY OF MEASURING INFECTION AT A COMMUNITY LEVEL

SMART WINDOWS

VOICE CONTROLLED WINDOWS ALSO DOUBLE UP AS INFORMATION DISPLAYS, SHOWING NEWS REPORTS, ALERTS, NOTIFICATIONS, AND UPDATES FROM SMART FILTERS, TOILETS, AND OTHER DEVICES IN THE HOME

VR HEADSET

TECHNOLOGIES ALLOW PEOPLE TO WORK, SOCIALISE AND HAVE OTHER EXPERIENCES WHEN ISOLATING AT HOME

TELEHEALTH BOOTH

AUTOMATED TELEHEALTH BOOTHS ALLOW ANYONE TO GET AN INSTANT AND PRIVATE HEALTH CHECK UP! WITH RESULTS INSTANTLY AND SECURELY AVAILABLE, WHILE ALSO ANONYMOUSLY MONITORING COMMUNITY INFECTION RATES

SNIFFER DOG

ANOTHER EARLY WARNING DEVICE - EVEN OUR PETS - CAN BE TRAINED TO IDENTIFY THE SCENT OF AN INFECTED PATIENT

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