Data collection and sharing for pathogen surveillance
Making sense of a fragmented global system

Sarah Parkinson, Jessica Dawney, Avery Adams, Ben Senator
Preface

Pathogen surveillance is important in informing public health decision making around infectious diseases. There are many initiatives across the globe that collect and share data relating to surveillance of infectious diseases and antimicrobial resistance. However, few studies take an overview of the wider pathogen surveillance space and the stakeholders involved, or break down common challenges these initiatives face, along with their strengths and weaknesses.

In this context, RAND Europe was commissioned by the Novo Nordisk Foundation to conduct a study on pathogen surveillance and current initiatives. This study aims to provide an overview of the pathogen surveillance space internationally and the stakeholders involved, as well as to understand the strengths and weaknesses of different initiatives, the challenges of pathogen surveillance and how they have been addressed, and how data has been used to inform public health decision making. To do this, a scoping review of pathogen surveillance initiatives was conducted and ten case studies were developed, selected for further review following a workshop attended by the Novo Nordisk Foundation and RAND Europe study team. Interviews were conducted with individuals involved in pathogen surveillance initiatives to gather additional information to develop case studies, and expert interviews addressed gaps in the pathogen surveillance space and models that would be helpful in filling these gaps.

The study team would like to thank the Novo Nordisk Foundation for their engagement and support. Dr Nick Fahy and Dr Katherine Morley provided internal RAND Europe Quality Assurance.
Summary

Focus and aims

RAND Europe was commissioned by the Novo Nordisk Foundation to conduct a study of pathogen surveillance initiatives targeting infectious diseases and antimicrobial resistance (AMR). The aim of this study is to identify initiatives and the stakeholders involved, to understand challenges that have been faced and how they have been overcome, to assess the strengths and weaknesses of different approaches, and to understand how insights have been used to inform public health decision making. It also aims to provide an overview of gaps in the pathogen surveillance space and to identify how such gaps might be addressed.

Methods

This study comprises a scoping review of academic journal articles, grey literature and websites about pathogen surveillance initiatives. Ten priority initiatives were selected to be case studies, and additional desk research and interviews (n=5, across three initiatives, plus an additional consultation via email) were conducted to support case study development. Lastly, experts in different aspects of pathogen surveillance were also interviewed (n=8).

Findings

The study identifies 64 different initiatives relating to pathogen surveillance. They most often focus on multiple different pathogens within a single initiative (25 out of 64, or 39%), and those that focus more narrowly most often cover influenza, Covid-19 and AMR (each covered by 7 out of 64 initiatives, or 11%). 16 (25%) of the initiatives are international, covering countries in multiple continents, while the rest are national or regional, focusing on one or more countries within Africa (11, or 17%), Asia (12, or 19%), Europe (7, or 11%), North and South America (14, or 22%), and Oceania (4, or 6%).

The initiatives include a variety of stakeholders, including national and regional Centres for Disease Control (CDCs), the World Health Organization (WHO), national governments and other public sector stakeholders, and large charities, foundations and other third sector organisations (e.g. the Bill & Melinda Gates Foundation and Wellcome).

By looking across these initiatives and gathering expert insights, this study identifies a number of challenges and gaps in pathogen surveillance:

• **Capacity constraints and logistical challenges, particularly in low-resource settings, limit the amount, type and quality of data available for surveillance.** Healthcare and clinical data is also limited by the lack of diagnostics and electronic health records in some regions as well as limited reporting of relevant data to surveillance systems. There is a need to build distributed and sustainable capacity for surveillance, particularly in genomic surveillance, and to support the use of diagnostics and electronic health records across settings.

• **The ability to conduct integrated and real-time surveillance is critical to public health decision making, but is currently lacking.** Insufficient metadata and varying
case definitions, methodologies and data formats make it difficult to link and analyse data. Additionally, a lack of interoperability contributes to siloed data streams.

- **Several factors complicate data sharing.** For instance, logistical challenges such as a lack of interoperability between data platforms can make it difficult to share data between relevant stakeholders, and data-related regulations (e.g. GDPR) also need to be considered prior to sharing. Internationally, political pressure can result in a reluctance to share data or under-reporting of cases, due to concerns over reputation and tourism revenue. There are additional sensitivities when transporting physical samples and genetic data across borders.

- **Wastewater surveillance provides a promising way to understand population-level health** at a lower cost, and avoids some of the challenges involved in collecting and sharing individual-level data. Similarly, genomic surveillance is key, particularly in relation to AMR, and is increasingly being used. However, data science is needed to understand how new and emerging data sources, such as wastewater surveillance and genomic data, should be incorporated into surveillance activities and what actions should be triggered by signals in different data types.

- **The pathogen surveillance space is highly fragmented,** with poor coordination between efforts, varying approaches and methodologies, and a lack of clarity in how data flows. There is a need to bring stakeholders together to agree on priorities and approaches.

To address these challenges and gaps, and to help improve how insights from pathogen surveillance are used to inform public health activities, several broad categories of action are needed:

- **While direct funding, operational support and supplies can help address capacity constraints, more sustainable solutions are needed** that go beyond grant cycles and short-term funding mechanisms. Hub and spoke models have been used to build capacity, and can help improve harmonisation, while also allowing a degree of autonomy and local adaptation. Long-term support and training are also needed to build capacity, particularly in low- and middle-income countries (LMICs) and in relation to genomic surveillance. Technological solutions that allow for data collection, analysis and sharing in low-resource settings are also helpful.

- **To improve integration between data streams, more harmonised approaches and methods to collect and record data are needed,** along with technological solutions to increase interoperability and reduce siloed data.

- **There is potential to use artificial intelligence (AI) to help analyse integrated data** and to use data science techniques to clarify which data streams are important in integrated surveillance. This may highlight potential for efficiencies (e.g. integrating less resource-intensive techniques such as wastewater surveillance), and refine priorities around integrated surveillance.

- **Convening is an important role in the pathogen surveillance space,** to bring together experts to agree on priorities and common approaches, improve interoperability and increase harmonisation between the many different stakeholders and initiatives involved in pathogen surveillance.
• **Common approaches for pathogen surveillance would need to account for differing capacities across contexts and locations,** and would need to balance being simple enough to implement across settings, while also being sophisticated enough to capture granular and complex information. Step-wise approaches to building capacity in a coordinated way, allowing for interoperability and harmonisation, may be helpful in achieving this balance.

**Conclusion**

To improve surveillance systems for infectious diseases and AMR, there is a need to address long-standing capacity constraints. At the same time, there is also a need to improve the ability to conduct real-time and integrated surveillance, including through advances in genomic surveillance, wastewater surveillance, and AI and data science. In addition, more coordination is needed to harmonise approaches, agree on priorities and encourage collaboration between the many different actors involved in pathogen surveillance. Strengthening capacity to conduct pathogen surveillance and improving the ability to detect and respond to threats is critical in improving public health decision making and population-level health. Long-term funding is needed, along with coordination to ensure that current and future surveillance efforts improve preparedness.
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Abbreviations

ACEGID  African Centre of Excellence for Genomics of Infectious Diseases
AMR  Antimicrobial Resistance
APHF  African Public Health Foundation
CC  Collaborating Centre
CDC  Centre for Disease Control
CGPS  Centre for Genomic Pathogen Surveillance
CMP  Chinese Microbiome Project
COG-UK  Covid-19 Genomics Consortium
DP-EAB  Data Protection & Ethics Advisory Board
DVA  Detection, Verification and Assessment
ECDC  European Centre for Disease Prevention and Control
ECHO  European Civil Protection and Humanitarian Aid Operations
EHR  Electronic Health Record
EI  Epidemic Intelligence
EMS  Event Management System
ERLs  Essential Regulatory Laboratories
EU4S  EU Sewage Sentinel System for SARS-CoV-2
EWARS  Early Warning, Alert and Response System
FAO  Food and Agriculture Organization
GDPR  General Data Protection Regulation
GISAID  Global Initiative on Sharing All Influenza Data
GISRS  Global Influenza Surveillance and Response System
GOARN  Global Outbreak and Response Network
HaDEA  Health and Digital Executive Agency
HERA  Health Emergency Preparedness and Response Authority
HIM  Health Emergency Information and Risk Assessment
IANPHI  International Association of National Public Health Institutes
<table>
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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>JRC</td>
<td>Joint Research Centre</td>
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<tr>
<td>LMIC</td>
<td>Low- and Middle-Income Country</td>
</tr>
<tr>
<td>NAAT</td>
<td>Nucleic Acid Amplification Test</td>
</tr>
<tr>
<td>NHC</td>
<td>National Health Commission</td>
</tr>
<tr>
<td>NIC</td>
<td>National Influenza Centre</td>
</tr>
<tr>
<td>NIHR</td>
<td>National Institute for Health and Care Research</td>
</tr>
<tr>
<td>OFDA</td>
<td>Office of Foreign Disaster Assistance</td>
</tr>
<tr>
<td>PAHO</td>
<td>Pan American Health Organization</td>
</tr>
<tr>
<td>PHES-ODM</td>
<td>Public Health Environmental Surveillance Open Data Model</td>
</tr>
<tr>
<td>PIN</td>
<td>Pathogen Identification Network</td>
</tr>
<tr>
<td>PIP FW</td>
<td>Pandemic Influenza Preparedness Framework</td>
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<tr>
<td>RSV</td>
<td>Respiratory Syncytial Virus</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
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<tr>
<td>unCoVer</td>
<td>Unravelling data for rapid evidence-based response to Covid-19</td>
</tr>
<tr>
<td>WASH</td>
<td>Water, Sanitation and Hygiene</td>
</tr>
<tr>
<td>WBE</td>
<td>Wastewater-Based Epidemiology</td>
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<td>WHO</td>
<td>World Health Organization</td>
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Chapter 1. Scope and aims of study

Box 1: Summary of Chapter 1

This study looks across initiatives that conduct pathogen surveillance activities for infectious diseases and AMR internationally. The aim is to understand the challenges that initiatives have faced and how they have been overcome, the strengths and weaknesses of different approaches, and how surveillance data has been used in public health decision making.

This study also aims to understand the gaps in the pathogen surveillance space, and inform decisions about addressing these gaps.

This study was conducted independently by RAND Europe, and commissioned by the Novo Nordisk Foundation.

1.1. Background information about pathogen surveillance

Pathogen surveillance for infectious diseases and antimicrobial resistance (AMR) is an important tool to understand how illnesses spread across populations, measure disease burdens, quickly identify outbreaks and inform public health decision making and action. For instance, data from pathogen surveillance activities has been used to decide when public health teams need to be deployed to respond to outbreaks, what vaccines to use and how to distribute them across populations, and whether to implement measures to slow the spread of infectious diseases, such as masks and social distancing measures. Surveillance activities can also alert stakeholders when new pathogens, mutations or viral strains emerge, which can enable further investigations and rapid response, helping to prevent further spread and public health-related harms.

There is a wide range of data collection and sharing initiatives and platforms for pathogen surveillance across the globe, from small regional or local initiatives to national surveillance programmes and large systems that collect or collate data worldwide. Many different types of stakeholders are involved, including large supranational bodies (such as the World Health Organization (WHO)), national and regional centres for disease control (CDCs), national public health authorities and health ministries, non-governmental organisations (NGOs), and universities. Academic researchers, clinicians and private companies also have a stake in pathogen surveillance efforts, and are often involved in data collection, analysis and sharing. Although there are initiatives that coordinate across a large number of stakeholders, there is still fragmentation that affects how pathogen surveillance is conducted at an international level.

Pathogen surveillance relies on different types of data, including, for example, individual- or case-level data (e.g. clinical data or data from electronic health records (EHRs) that record diagnoses, treatments, symptoms and health outcomes), laboratory results, genomic data of individuals and pathogens, and aggregate-level data from wastewater surveillance efforts. Furthermore, there is also data that is collected...
at an individual-level, and then shared at an aggregate level. There are different challenges associated with each, and good pathogen surveillance depends on access to multiple sources and types of data. For instance, some data is collected for the specific purpose of pathogen surveillance, while other data, such as routine healthcare data, is repurposed for public health surveillance. These varied data sources have different trade-offs in relation to cost of data acquisition, capacity for harmonisation, and privacy and data governance restrictions. During the Covid-19 pandemic, a spotlight was shone on pathogen surveillance, infectious disease control and public health more broadly. Key gaps in pathogen surveillance were revealed, including limited capacity in some countries and regions to conduct surveillance, challenges related to data sharing, and delays in analysing data and using it to inform public health decision making. These gaps have led to additional investment in pathogen surveillance [1] to help build capacity to collect, integrate, analyse and use data.

1.2. Scope and aims of this study

In this context, the Novo Nordisk Foundation commissioned RAND Europe to conduct an independent study on pathogen surveillance efforts. This study looks across pathogen surveillance initiatives and the different stakeholders involved, and aims to understand the strengths and weaknesses of different initiatives, challenges in pathogen surveillance and how they have been addressed, and how data has been used to inform public health decision making. It focuses on the following research questions:

1. What initiatives exist to collect and share data relevant to pathogen surveillance for infectious diseases and AMR?
2. What are the challenges these initiatives have encountered in relation to data collection and sharing, and how were they overcome?
3. What stakeholders are involved in these initiatives?
4. What are the strengths and weaknesses of these initiatives?
5. How has pathogen surveillance data been used to support national and/or international public health activities?

This study focuses on both individual- and aggregate-level data. It is international in scope, and has taken a global approach when searching for and selecting initiatives, aiming to ensure that the study achieves appropriate geographic coverage (including low- and middle-income countries). It also focuses both on data collected for surveillance and public health purposes, and secondary data that is collated and repurposed for public health purposes.
Chapter 2. Methods

Box 2: Summary of Chapter 2

The study team conducted a scoping review of academic journal articles, grey literature and websites to identify initiatives involved in pathogen surveillance for infectious diseases and AMR (at a national scale or larger), and gather information about the challenges initiatives have faced, how such challenges were overcome, the strength and weakness of different approaches, and how data has been used to inform public health decision making.

Ten initiatives were selected to develop more in-depth case studies, and desk research and interviews were conducted with individuals involved in these initiatives (n=5, across three initiatives, plus an additional written exchange with an individual involved in a fourth initiative).

Interviews were conducted with eight experts in different aspects of pathogen surveillance to better understand gaps in surveillance and what is needed to fill these gaps, and to identify models for building capacity and improving harmonisation.

2.1. Overview of methods

Following an inception meeting with the Novo Nordisk Foundation in February 2023, the study team conducted a scoping review to find information about pathogen surveillance initiatives. A prioritisation exercise involving the Novo Nordisk Foundation in March 2023 saw the long list of initiatives identified in the scoping review narrowed down to a selection of ten case studies for further investigation. For each of these initiatives, further desk research was undertaken and, where possible, interviews conducted, to gather additional information. Experts in different aspects of pathogen surveillance were also interviewed. These activities are described in further detail below.

2.2. Scoping review

The study team conducted a scoping review using key website searches, grey literature searches, and academic literature searches to identify evidence relating to pathogen surveillance initiatives. This review consisted of several steps: searching for relevant sources of evidence, screening these results, extracting information from included sources, and analysing and synthesising information.

Searching for relevant sources

The study team looked for relevant sources using three different search strategies: a targeted website search, a grey literature search and an academic literature search. First, the study team reviewed websites of public health authorities, supranational organisations and major collaborations focused on public health to look for initiatives of national scale or greater that collected or shared data relevant to pathogen surveillance of infectious diseases and AMR. These included the websites of the WHO, the International Association of National Public Health Institutes (IANPHI), the European Centre for Disease Control (ECDC), the US Centre for Disease Control (US CDC), the
Central Asia CDC, the China CDC and the Africa CDC, among others (see Annex D for full list of websites). This search of a limited list of websites was conducted between 15 February and 8 March 2023, and was supplemented by further academic and grey literature searches, described below. This targeted website search identified 60 initiatives for screening.

Searches were then conducted for relevant initiatives using PubMed (see Annex D for search string) on 21 February 2023. Results were limited to articles published within the last five years (i.e. 2018 or later). This search generated 828 results for further screening.

Lastly, a grey literature search was conducted using Google on 1 March 2023, and the first 50 results were reviewed. The search string for the grey literature search is provided in Annex D. Using this strategy, ten additional results were selected for further screening. Sources were not included for further screening if they had already been identified through the targeted website search.

### Screening

All academic articles identified using the search strategy described above were screened for eligibility. For the website and grey literature searches, any sources of evidence about initiatives that were at least national in scale and that shared or collected data about pathogens were considered potentially relevant, and were included for further in-depth review and screening. The sources that were identified using this strategy were systematically screened using pre-specified inclusion and exclusion criteria (see Table 1 below).

### Table 1: Inclusion and exclusion criteria

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<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
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<tbody>
<tr>
<td>Initiatives of at least national scale</td>
<td>Small-scale, local or regional initiatives, and descriptions of hypothetical initiatives</td>
</tr>
<tr>
<td>Descriptions of initiatives that collect or share data about pathogens associated with infectious diseases or relating to AMR</td>
<td>Broader descriptions of pathogen surveillance that do not mention specific initiatives (e.g. about the need for surveillance, how surveillance should be structured, general challenges relating to data collection/sharing)</td>
</tr>
<tr>
<td>Initiatives with some link to public health or human health</td>
<td>Initiatives focused on animal health with no links to public health or human health</td>
</tr>
<tr>
<td>Initiatives that collect, collate or share data for public health purposes, including both primary data and secondary data (e.g. from routine healthcare) that is repurposed for public health</td>
<td>Initiatives that are not related to public health</td>
</tr>
<tr>
<td>Any type of data (individual or aggregate data)</td>
<td>No exclusion based on type of data</td>
</tr>
</tbody>
</table>
These inclusion and exclusion criteria were first applied to 20 sources in a pilot screening exercise in which the entire research team reviewed the same 20 articles. The results of this exercise were then discussed, to ensure alignment across reviewers. Where there was disagreement, this was discussed and the inclusion/exclusion criteria were refined for clarity as needed.

After the pilot, single title and abstract screening was conducted by three reviewers, with uncertainties discussed across the team, and with a fourth researcher where needed. After screening, 44 academic and grey literature articles were identified for full text review, of which 36 were taken forward for extraction, in addition to the 60 initiatives/sources that were identified through website searches. In total, 96 sources were extracted.

**Extraction**

All 96 sources from the website, grey and academic searches were extracted using a template, which was organised according to the research questions for this study. The extraction template included columns to record basic information about the initiative (name, brief description, aim, geographic coverage, stakeholders involved), funding information, challenges to data collection/sharing/governance and how these were mitigated, strengths and weaknesses, and how data has been used to inform public health decisions.

2.3. Prioritisation exercise and selection of ten case studies

Using the results from the scoping review, a table of all the identified initiatives was developed (see Annex A). This was shared with the Novo Nordisk Foundation, along with a long list of initiatives that would provide a varied sample for case study development. Reflections on what each case study would provide in terms of understanding the challenges involved in data collection, strengths and weaknesses, and gaps in the pathogen surveillance space were also provided. The sampling strategy for this long list was designed to provide geographic coverage across the globe, and to offer diversity as to the types of data collected (e.g. wastewater surveillance data, individual clinical data, genomic data), the scale of the initiative, and the pathogens covered.

To select the final list of ten case studies, the study team organised and facilitated a virtual workshop involving six members of Novo Nordisk Foundation in March 2023. At this workshop, the study team presented the preliminary findings from the scoping review and summarised a selection of initiatives. The discussion considered which initiatives should be prioritised for further review, what can be learned from each initiative, and the research questions that Novo Nordisk Foundation wanted to answer to inform pathogen surveillance activities. During the workshop, it was decided that the prioritised initiatives would be selected based on how they share data and how insights are used for public health decision making. After the workshop, the study team confirmed the final list of ten case studies in consultation with the Novo Nordisk Foundation:

- **Case study A**: African Centre of Excellence for Genomics of Infectious Diseases (ACEGID) – Sentinel project
- **Case study B**: Centre for Genomic Pathogen Surveillance (CGPS)
- **Case study C**: EpiPulse
- **Case study D**: EU Sewage Sentinel System for SARS-CoV-2 (EU4S) and the Digital European Exchange Platform (EU4S-DEEP)
• **Case study E**: Global Influenza Surveillance and Response System (GISRS)

• **Case study F**: Global Outbreak and Response Network (GOARN) and the Early Warning, Alert and Response System (EWARS)

• **Case study G**: Pan American Health Organisation (PAHO) Epidemic Intelligence (EI)

• **Case study H**: Chinese Pathogen Identification Network (PIN)

• **Case study I**: Unravelling data for rapid evidence-based response to Covid-19 (unCoVer)

• **Case study J**: EU4Health (funding programme of the European Commission).

### 2.4. Development of case studies

#### Further desk research

The ten initiatives selected for prioritisation were then further explored through additional desk research. This included online searches, for example on initiative and funder websites, as well as any material that has been published by the initiatives themselves or external stakeholders.

#### Case study interviews

For the ten prioritised initiatives, the study team sought to collect data directly from key stakeholders through interviews. Potential interviewees were identified through online searches and using publicly available information and personal networks, and by asking interviewees that had declined to participate for recommendations about colleagues that would be better placed to engage in the study. To provide more options to participants and encourage engagement, we also offered to send a short questionnaire over email, for the respondent to answer at their convenience.

An interview protocol was created, which asked participants about: their professional background; the initiative they were involved in; challenges and how they were mitigated; strengths and weaknesses of the initiatives; gaps in the pathogen surveillance space; and lessons for other surveillance efforts (see **Annex E**). Interviews were semi-structured to allow interviewers to ask follow-up questions, and to tailor the interview based on each interviewee’s expertise.

Prior to the interview, participants were provided with a privacy notice detailing how their data would be used and were asked to complete a consent form. All interviewees consented to their data being collected and used for this evaluation, although one interviewee did not consent for the interview to be audio and video recorded for note-taking purposes.

In total, five interviews were conducted across three initiatives, plus one additional consultation through email with an individual involved in a fourth initiative. Interviews lasted approximately 45–60 minutes, and were conducted remotely. Notes were taken during the interviews where possible, and recordings (if consented to) were written up. Along with information from written exchanges with participants, this data was then integrated into the case studies.

Throughout the report these interviews and consultation are referenced using anonymous codes (Int 1–5, and Consultation 1). Table 2 provides information about the participants; to encourage them to respond openly, their names are not given.
Table 2: Interviews and consultation conducted in relation to case studies

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<tr>
<th>Interview code</th>
<th>Initiative</th>
<th>General description of individual</th>
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</thead>
<tbody>
<tr>
<td>Int 1</td>
<td>Case Study A: ACEGID</td>
<td>Expert in biology and genomics, with senior role in Sentinel initiative</td>
</tr>
<tr>
<td>Int 2</td>
<td>Case Study A: ACEGID</td>
<td>Individual with senior role in Sentinel initiative</td>
</tr>
<tr>
<td>Int 3</td>
<td>Case study B: CGPS</td>
<td>Strategy expert who is involved with CGPS</td>
</tr>
<tr>
<td>Int 4</td>
<td>Case study J: EU4Health</td>
<td>Senior HERA staff involved in funding through the EU4Health programme</td>
</tr>
<tr>
<td>Int 5</td>
<td>Case study J: EU4Health</td>
<td>Senior individual involved in United4Surveillance, a programme funded through EU4Health</td>
</tr>
<tr>
<td>Consultation 1*</td>
<td>Case study I: unCoVer</td>
<td>Epidemiologist with senior role in unCoVer</td>
</tr>
</tbody>
</table>

*Written consultation conducted via email exchange

2.5. Expert interviews

Due to relatively low engagement rates in the initial round of interviews, further interviews were conducted with experts in the pathogen surveillance space, to better understand challenges and gaps and how these can be overcome. Interviewees were identified through online searches, and contacted via email to participate using the same process described above.

As with the case study interviews, expert interviewees were provided with a privacy notice detailing how their data would be held and used, and were asked to complete a consent form prior to the interview. All interviewees consented to their data being collected and used for the study, and for the interview to be audio and video recorded for the purpose of note-taking.

The interview protocol used for the expert interviews is provided in Annex F. Interviews were semi-structured to allow for follow-up questions, and to allow the interviewer to tailor the focus of the interview towards the participant’s area of expertise. Interviews lasted approximately 45–60 minutes and were conducted remotely. Notes were written during the interview or based on the recording.

Eight experts, detailed in Table 3, were interviewed, and their insights are referenced throughout this report (Expert 1–8).
Table 3: Expert interviewees

<table>
<thead>
<tr>
<th>Interviewee name</th>
<th>Role and description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr Amesh Adalja</td>
<td>Senior Scholar with John Hopkins Center for Health Security; Adjunct Assistant Professor with John Hopkins Bloomberg School for Public Health; Affiliate of Johns Hopkins Center for Global Health</td>
</tr>
<tr>
<td>Megan Diamond</td>
<td>Director at the Rockefeller Foundation; led wastewater surveillance portfolio with Covid-19 Response and Recovery team; former Assistant Director of the Harvard Global Health Institute</td>
</tr>
<tr>
<td>Josie Golding</td>
<td>Head of Epidemics and Epidemiology, Wellcome</td>
</tr>
<tr>
<td>Dr Tim Jinks</td>
<td>Head of Interventions, Infectious Disease team, Wellcome</td>
</tr>
<tr>
<td>Aparna Keshaviah</td>
<td>Principle Researcher, Mathematica; focuses on wastewater-based epidemiology</td>
</tr>
<tr>
<td>Dr Cassidy Nelson</td>
<td>Head of Biosecurity Policy at the Centre for Long-Term Resilience; expertise in biosecurity, pathology and epidemiology in relation to novel pathogen outbreaks</td>
</tr>
<tr>
<td>Dr Samuel Scarpino</td>
<td>Affiliate Assistant Professor in the Department of Physics and holds appointments in the Network Science Institute, Institute for Experiential AI, Global Resilience Institute, and Roux Institute at Northeastern University, Former Vice President of Pathogen Surveillance, Rockefeller Foundation</td>
</tr>
<tr>
<td>Dr Barbara Tornimbene</td>
<td>Consultant for Research and Development for Public Health Surveillance and Pandemic Intelligence, and AMR expert working with WHO</td>
</tr>
<tr>
<td>Kenneth Yeh</td>
<td>Biodefense, biotechnology, and global health security expert with MRIGlobal</td>
</tr>
</tbody>
</table>

2.6. Synthesis and reporting

Once the scoping review was complete, the study team held an analysis meeting to discuss its findings. A list of themes was developed at this meeting, and results were written up under these themes. These findings are presented in this report, supported by insights from the data extraction.

Case studies were then developed for the ten initiatives that were prioritised for further review. These case studies followed a standardised template, which was adapted as needed. Four case studies were based on information from desk research and interviews/consultations, while six were based solely on desk research.

In the following chapter (Chapter 3), the overall findings of the scoping review are presented. The subsequent chapter (Chapter 4) details the ten case studies. Chapter 5 presents the findings from the expert interviews regarding gaps in the pathogen surveillance space and ways to address these gaps. The final chapter (Chapter 6) synthesises these findings and provides reflections on gaps in the pathogen surveillance space.

2.7. Strengths and limitations of this study

This study provides an overview of pathogen surveillance efforts, and evidence around common challenges, strengths and
weaknesses of different approaches to pathogen surveillance. By connecting lessons from individual initiatives, which operate in different settings and which deal with different types of pathogen surveillance data, gaps in the pathogen surveillance space can be better understood.

However, this study is subject to several limitations. Firstly, it relies largely on publicly available sources of evidence, such as initiative websites and academic publications. It is likely that initiatives have faced challenges that are not described in publicly available sources, since they have an interest in presenting their efforts in a positive light to attract further support and funding. Furthermore, although this study was not limited to initiatives that were successful, there is less information available that describes unsuccessful projects or efforts that were discontinued after a short period. Thus, if a challenge was so significant that it led to an initiative ending prematurely, the study may not have been able to identify it. Similarly, although attempts are made to quantify the number of initiatives reported to have faced particular challenges or to have implemented specific mitigation strategies, these counts are an underestimation, and only reflect initiatives that happened to have information in the public domain, rather than the true number.

Secondly, although the study team attempted to identify initiatives through several means (targeted web searches, grey literature searches and academic literature searches), some initiatives may still have been missed. Initiatives were only included that were national scale or greater, and so those that were smaller in scale, or were set up in the context of a time-limited study rather than for public health reasons, are excluded. Additionally, the search strategy employed for the scoping review was limited to the past five years (i.e. since 2018). This time frame means that the searches may have yielded a higher proportion of initiatives focusing on Covid-19.

Lastly, this study was conducted over a relatively short period, which affected the level of engagement from interviewees. The study team attempted to interview at least one individual involved in each of the ten case studies, and encouraged engagement by providing different options to contribute information through email exchanges. However, interviews were only conducted with five representatives from three initiatives, in addition to one written consultation with an individual from a fourth initiative, to support the development of case studies. Furthermore, those that agreed to participate in interviews for this study may have different views than those that did not respond.
Chapter 3. Scoping review findings

In this chapter, the findings from the scoping review are described. First, an overview of the surveillance initiatives identified is provided, including the pathogens and geographies that they cover, and the stakeholders involved. Then, the challenges initiatives have faced related to data collection, sharing and analysis, and how these were addressed, are summarised, followed by an assessment of the strengths and weaknesses of the initiatives. Lastly, there is a discussion of how data has been used to inform public health decision making and action.

This chapter looks across the initiatives identified in the scoping review, and is descriptive and broad in nature. The following chapter (Chapter 4) provides depth through ten case studies of pathogen surveillance efforts, and Chapter 5 summarises findings from expert interviews.

Box 3: Summary of Chapter 3

The scoping review identified sources describing 64 different pathogen surveillance initiatives, which covered a wide variety of pathogens and geographies. Most initiatives focused on more than one pathogen, and those that focused on a single pathogen or group of pathogens most often covered influenza, Covid-19 and AMR. While there are large, coordinated efforts such as those organised by the WHO, the pathogen surveillance space is fragmented, with many different stakeholders involved and a lack of coordination between initiatives.

Initiatives that conduct pathogen surveillance face capacity constraints such as limited physical and digital infrastructure, a lack of laboratory capacity (especially for genomic sequencing and in relation to AMR), and limited access to skilled staff, particularly in low-resource settings. To help build capacity, some initiatives have directly provided supplies and logistical support. Strategies to build distributed capacity in a more sustainable way have included hub and spoke models and the provision of training. Tools that aid data collection and analysis (e.g. web-based tools that automate parts of analysis, mobile data collection for low-connectivity settings) have also been used to increase capacity and help encourage the use of data to inform local decision making.

Where metadata and contextual data is lacking, it is difficult to link data collected in different contexts and settings, which limits the analysis that can be conducted. Varying case definitions and data formats and a lack of interoperability also make it difficult to share and link data and conduct integrated surveillance. Developing standardised guidance and operating procedures helps encourage more harmonised data collection and the collection of metadata.

The success of pathogen surveillance initiatives depends on many different factors, including sustainable funding, structures for collecting data (e.g. mandated reporting, incentives and motivations of stakeholders to participate), the speed at which data can be analysed and outbreaks can be identified, and the ability to link between different types of data and data collected in different locations and contexts. Integrated and real-time surveillance is critical to being able to inform public health decisions and activities.
Throughout this chapter, attempts are made to provide specific examples from sources that the study team reviewed, and to quantify (to the extent possible) the number of initiatives that faced particular challenges. However, it is important to note that figures given are likely to be underestimates – the study can only report the number of initiatives where challenges were reported in sources within the public domain, and it is likely that many more initiatives faced challenges but did not report them in the sources that were included in this scoping review.

3.1. Overview of pathogen surveillance initiatives

This study identified 64 initiatives relating to pathogen surveillance. However, some of these initiatives were interconnected. For instance, some sat under a larger umbrella initiative, but these were counted as two separate initiatives for the purpose of this study. For example, the National Outbreak Reporting System, managed by the US CDC, receives data from other initiatives coordinated by US CDC identified in this study including the Foodborne Disease Outbreak Surveillance System, the Waterborne Disease and Outbreak Surveillance System, PulseNet and CaliciNet. These are each counted as separate initiatives in this study.

A table detailing the initiatives that were identified in this study is provided in Annex A. An excerpt from this table is provided below (Table 2), with rows relating to the ten case studies that are described in Chapter 4 of this report.

Pathogens

The initiatives identified in the scoping review covered a wide variety of pathogens, and most often focused on multiple pathogens within a single initiative (n=27). As presented in Figure 1 below, initiatives that focused on smaller groups of pathogens or single pathogens covered influenza (n=8, two of which were primarily focused on influenza but had been expanded to also include Covid-19), Covid-19 (n=8, not including the two which were primarily focused on influenza), foodborne illnesses (n=5), polio (n=3), enteroviruses (n=2), enteric diseases (n=1), SARS (n=1) and noroviruses (n=1). There were also eight initiatives that did not involve particular pathogens, but instead focused on surveillance of antimicrobial resistance (AMR).

Figure 1: Pathogens and illnesses covered by initiatives identified in the scoping review (number of initiatives)

<table>
<thead>
<tr>
<th>Pathogen / Illness</th>
<th>Number of Initiatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influenza</td>
<td>8</td>
</tr>
<tr>
<td>Covid-19</td>
<td>8</td>
</tr>
<tr>
<td>Foodborne illnesses</td>
<td>5</td>
</tr>
<tr>
<td>Polio</td>
<td>3</td>
</tr>
<tr>
<td>Enteroviruses</td>
<td>2</td>
</tr>
<tr>
<td>Enteric diseases</td>
<td>1</td>
</tr>
<tr>
<td>SARS</td>
<td>1</td>
</tr>
<tr>
<td>Noroviruses</td>
<td>1</td>
</tr>
<tr>
<td>AMR</td>
<td>8</td>
</tr>
</tbody>
</table>

Initiatives not focused on particular pathogens, groups of pathogens or AMR (n=27) are not included in this graphic.
The initiatives covered many different regions globally. In total, 16 initiatives were international, covering countries in multiple continents; these were often coordinated by the WHO, with nine directly managed by the WHO or its regional offices and many more sending data to the WHO (see Annex B for a list of initiatives that the WHO coordinated). Other initiatives focused within single continents or countries – 11 focused on one or more African countries, 12 focused on one or more Asian countries, 7 focused on one or more European countries, 14 focused on one or more countries in North or South America, and 4 focused on one more countries in Oceania (see Figure 2 above). Please see Annex A for a full list of regions and countries covered by each initiative.

### Stakeholders

A wide variety of organisations and stakeholders was involved in pathogen surveillance initiatives. WHO is one of the largest stakeholders in this space, often playing a coordinating role by collating data from multiple regional initiatives to analyse and share data at a global level. Public sector stakeholders were also frequently involved in pathogen surveillance, for instance national public health authorities, health ministries or multi-national stakeholders (such as the Africa Centre for Disease Control). Large charities, foundations and other types of third sector organisations, such as the Bill & Melinda Gates Foundation and Wellcome were also involved in pathogen surveillance initiatives, along with smaller non-governmental organisations that helped coordinated efforts at a local level. Most initiatives involved multiple types of stakeholders – academic researchers and clinicians were often connected with pathogen surveillance efforts, and some initiatives were public-private partnerships.

In Annex B, a list of major stakeholders in pathogen surveillance, and a list of the primary initiatives that they are involved in is provided. This is not an exhaustive list of all stakeholders or initiatives, but provides information about key stakeholders and their main initiatives. For the full list of initiatives identified, and their key stakeholders, please see Annex A.
<table>
<thead>
<tr>
<th>Case study</th>
<th>Initiative name</th>
<th>Brief description of the initiative</th>
<th>Aim of initiative</th>
<th>Pathogens</th>
<th>Region</th>
<th>Geographic coverage</th>
<th>Key stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ACEGID/ Broad Institute: Sentinel project</td>
<td>Sentinel: an early-warning system to detect viral threats in real time and help stop them before they spread, use a three-part approach to detect viruses, connect data systems and empower the healthcare community. Point-of-care tests can facilitate identification of high priority viruses within an hour, any known human virus within a day, and previously unknown viruses within a week</td>
<td>To get ahead of pandemic outbreaks and facilitate the detection of viral threats in real time</td>
<td>Multiple pathogens</td>
<td>Africa</td>
<td>West Africa and Central Africa with eventual global roll-out planned</td>
<td>ACEGID, The Broad Institute of MIT and Harvard manage implementation Dimagi, Fathom and MassDesign support data analytics, healthcare technology and data visualisation Funding provided by Audacious Project (initiative of TED)</td>
</tr>
<tr>
<td>B</td>
<td>Centre for Genomic Pathogen Surveillance</td>
<td>Organisation that builds capacity relating to genomic pathogen surveillance by providing access to expertise, data and tools</td>
<td>To provide universal surveillance strategies at scale, facilitating rapid analysis and enabling the training of experts worldwide</td>
<td>Multiple AMR-relevant pathogens</td>
<td>International</td>
<td>Global</td>
<td>Funders include multiple CDCs, ECDC, FAO, multiple National Institutes for Health, NIHR, WHO Links to Big Data Institute, University of Oxford, and Wellcome</td>
</tr>
<tr>
<td>Case study</td>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
<td>Region</td>
<td>Geographic coverage</td>
<td>Key stakeholders</td>
</tr>
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</tr>
</tbody>
</table>
| C          | EpiPulse       | Online portal for European public health authorities and partners to collect, analyse, share and discuss infectious disease data for surveillance activities. Established in June 2021, integrating previously independent systems (the European Surveillance System (TESSy), the five Epidemic Intelligence Information System (EPIS) platforms and the Threat Tracking Tool (TTT)). Facilitates collection, analysis and dissemination of indicator- and event-based surveillance data, including global epidemic intelligence, whole-genome sequencing, and health determinants | To strengthen infectious disease prevention and control, and to support better preparedness and management of threats, by enhancing early threat detection and assessment and enabling real-time monitoring | Multiple pathogens | Europe | EU and EEA Member States | ECDC coordinates platform
EU/EEA Member States, partner countries and institutions, and appointed experts can access portal to report and analyse data |
| D          | EU4S-DEEP (EU Sewage Sentinel System for SARS-CoV-2 Digital European Exchange Platform) | Platform to support investigations into Covid-19 and water. Focuses on gathering and sharing best practices, collecting results from wastewater surveillance activities, publishing sampling and analysis methods, gathering experts in wastewater surveillance, and fostering collaboration. Includes data dashboard, partially open to the general public | To ensure that the results of the wastewater surveillance are promptly shared and used | Covid-19 | Europe | EU and EEA Member States | Stakeholders in health and the environment at supra-national, national, regional and local levels (e.g. Croatian Institute of Public Health, State General Laboratory MoH in Cyprus)
Private and commercial contributors from various economic sectors including water utilities; researchers and academics; NGOs |
<table>
<thead>
<tr>
<th>Case study</th>
<th>Initiative name</th>
<th>Brief description of the initiative</th>
<th>Aim of initiative</th>
<th>Pathogens</th>
<th>Region</th>
<th>Geographic coverage</th>
<th>Key stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>WHO: Global Influenza Surveillance and Response System (GISRS)</td>
<td>Global influenza surveillance and preparedness in 125 states via monitoring, alerts and surveillance. National Influenza Centres (NICs) collect virus specimens in their country and perform preliminary analysis before shipping clinical specimens and isolated viruses to collaborative centres (WHO CCs) for advanced antigenic and genetic analysis. The results form the basis of WHO recommendations on the composition of the influenza vaccine and relevant risk-assessment activities</td>
<td>To foster global confidence and trust through collaboration and sharing of data, viruses and benefits based on global health model</td>
<td>Seasonal, pandemic and zoonotic influenza, and some non-influenza emergencies such as Covid-19</td>
<td>International</td>
<td>125 WHO member states</td>
<td>125 WHO member states; National Influenza Centres at national level; WHO Collaborating Centres; H5 Reference Laboratories (in relation to H5N1) and Essential Regulatory Laboratories (ERLs).</td>
</tr>
<tr>
<td>F</td>
<td>WHO: Early Warning, Alert and Response System (EWARS)</td>
<td>Initiative to support pathogen surveillance in low resource and emergency settings, including ‘EWARS in a box’, which includes everything needed to do surveillance in the field (e.g. phones, a laptop, a datahub storage device, solar chargers, etc.)</td>
<td>To improve early warning, alert and responses to public health emergencies</td>
<td>Multiple pathogens</td>
<td>International</td>
<td>Global</td>
<td>WHO provides equipment Country-level stakeholders conduct surveillance</td>
</tr>
<tr>
<td>Case study</td>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
<td>Region</td>
<td>Geographic coverage</td>
<td>Key stakeholders</td>
</tr>
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</tr>
<tr>
<td>G</td>
<td>Pan American Health Organization (PAHO): Epidemic Intelligence</td>
<td>Regional WHO initiative to support epidemic intelligence activities (cycle of organised and systematic collection, analysis and interpretation)</td>
<td>To support the detection, verification and response to potential health risks</td>
<td>Multiple pathogens (e.g. cholera, diphtheria, measles, yellow fever, polio, dengue, Chikungunya, Covid-19, avian influenza, etc.)</td>
<td>North/ South America</td>
<td>Americas</td>
<td>WHO, PAHO, public health authorities, Ministries of Health, WHO collaborating centres, NGOs</td>
</tr>
<tr>
<td>H</td>
<td>China CDC: Pathogen Identification Net (PIN)</td>
<td>National laboratory-based surveillance network for bacterial pathogens. Collects bioanalysis data of bacterial pathogens from network laboratories. Analysis includes pathogen identification, bio typing, antimicrobial resistance detection, molecular typing, and whole genome sequencing. Combining epidemiological data and laboratory data, network laboratories can detect clusters of pathogens and suggest possible cases to initiate investigation for detection of potential outbreaks or spread.</td>
<td>To support early detection and tracing of infectious diseases</td>
<td>Multiple pathogens, AMR</td>
<td>Asia</td>
<td>China</td>
<td>Under management of the China National Health Commission, with involvement from Regional CDC labs and Provincial and Municipal Health Commissions. CDC labs at various levels execute laboratory analysis</td>
</tr>
<tr>
<td>Case study</td>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
<td>Region</td>
<td>Geographic coverage</td>
<td>Key stakeholders</td>
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<tr>
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</tr>
<tr>
<td>I</td>
<td>Unravelling data for rapid evidence-based response to Covid-19 (unCoVer)</td>
<td>Network that brings together experts (e.g. in medicine, research, data management, statistical modelling, research ethics) to support the better use of real-world data and routine healthcare data to better understand Covid-19</td>
<td>To provide a research platform for the use of real-world data by bringing together data, medical and scientific expertise to address the questions about the determinants of Covid-19 prognosis to inform more effective medical and public health strategies</td>
<td>Covid-19</td>
<td>International</td>
<td>29 partners from 25 institutions in the EU and 4 non-EU partners representing 18 countries (Belgium, Bosnia and Herzegovina, Brazil, Colombia, Croatia, Greece, Ireland, Italy, Luxembourg, Norway, Portugal, Romania, Slovakia, South Korea, Spain, Turkey, UK, US)</td>
<td>Clinical partners, epidemiologists and external advisory boards</td>
</tr>
<tr>
<td>J</td>
<td>HERA surveillance activities (funded through EU4Health)</td>
<td>HERA collects intelligence on health threats (including infectious diseases, but also communicable diseases, chemical and environmental threats) and medical countermeasures against these threats to better prepare for and respond to health emergencies. Activities include coordination with ECDC and supporting national wastewater surveillance activities</td>
<td>To protect the EU from serious cross-border threats to health and strengthen the responsiveness of health systems and coordination among Member States to cope with serious cross-border threats to health</td>
<td>Multiple pathogens (with high pandemic potential, mainly respiratory RNA viral families)</td>
<td>Europe</td>
<td>EU countries, and third countries associated with the EU4Health programme, including Norway, Iceland, Ukraine and Moldova</td>
<td>EU/EEA Member States and third countries associated with the EU4Health programme European Commission and other EU-level stakeholders (coordination with ECDC and DG SANTE regarding health threats, EMA regarding medical countermeasures) European Parliament</td>
</tr>
</tbody>
</table>
3.2. Challenges related to data collection across the identified initiatives

Initiatives faced challenges in relation to both the quantity and quality of data collected, as described in the sections below. In some cases, challenges related to data collection affect the quantity of data, making it difficult to conduct robust analyses that accurately reflect how pathogens spread. Issues around data collection also have the potential to affect data quality, causing inaccurate or imprecise results, along with less efficient processes related to quality control and data cleaning. It is important for initiatives to understand the quality of the data they are collecting as this impacts how it can be used and interpreted.

It can be challenging to collect good data due to capacity constraints, low testing coverage and poor reporting

Many of the initiatives identified through this study identified resource constraints as a key weakness that limited what they were able to accomplish. Challenges related to resource constraints occurred when initiatives lacked the human, structural or financial resources necessary for data collection – this included access to staff to collect data from the field and manually input data to centralised systems [2], laboratory capacity for sequencing and bioinformatics [3], and skilled microbiologists, virologists and epidemiologists to undertake laboratory testing, analysis and interpretation of data [4, 5]. There were also challenges in terms of pathogen surveillance initiatives not having access to clinical samples [6], particularly during the pandemic when telemedicine decreased the number of patients physically going to healthcare settings where clinical samples could be collected and fed into sentinel surveillance systems [7]. Initiatives also reported issues with staff turnover and skills, which cause particular challenges in resource-limited settings and in times of conflict [2]. Initiatives that are dependent on others to submit data (e.g. health departments, hospitals, labs) have reported struggles with low levels of reporting due to a lack of training or knowledge and a lack of staff capacity to submit data, among other challenges in local settings [4, 8–11].

In some areas, and in relation to particular diseases, low testing coverage or low capacity affects the ability to collect sufficient data required to support public health actions [12, 13]. For example, there are particular challenges relating to AMR surveillance, with labs sometimes lacking sufficient resources to test for susceptibility to all relevant antimicrobials [9]. Issues also arise related to data entry and reporting for AMR surveillance due to a lack of training in clinical settings around AMR, which in some cases can lead to poor understanding of the sensitivity of pathogens to first-line microbials [4, 9]. Initiatives that use genome sequencing for pathogen surveillance also struggle with capacity constraints [14], since specialised skills are required to collect and analyse genomic data, although the situation is improving as genomic sequencing technology becomes more accessible.

Along with funding for specific initiatives, there are also challenges around public sector investment and general interest in public health in the long term. Political buy-in and strong commitment from relevant stakeholders help initiatives secure sufficient resources, and also help them succeed in times when financial resources are limited. Strong buy-in and commitment was mentioned, for example, as a strength in sources describing the Influenza-Monitoring Vaccine Effectiveness in Europe (I-MOVE) initiative and the cooperative agreement between the US CDC and the Chinese National Influenza Center (CNIC) [5].
However, when this support is not sustained, initiatives that conduct pathogen surveillance can struggle to secure long-term resources. The Covid-19 pandemic, for example, led to increased funding for pathogen surveillance, with many of the initiatives identified through the scoping review focusing on the pandemic or adapting to cover Covid-19. However, it is not clear how long this will be sustained, as governments can deprioritise the surveillance of certain diseases when there are health emergencies perceived to be more urgent [11, 15]. Competing priorities and a lack of government support were mentioned as factors limiting the expansion of environmental surveillance, which affected data collection for the WHO’s Polio Information System, to provide one example [16]. Initiatives that received increased funding because of the Covid-19 pandemic may struggle with sustainability in the long term.

Logistical issues such as a lack of connectivity, poor infrastructure and disrupted supply chains can cause challenges in collecting data

At least six initiatives’ experienced technical challenges relating to the lack of 24-hour electricity supply and internet connections at the point of data collection, based on reporting in the available literature [2, 5, 17–20], including the Global Outbreak and Response Network (GOARN), which is described in Case Study F. However, it is likely that more initiatives have experienced issues related to connectivity at data collection sites.

In settings with poor internet connectivity it may be necessary to use data collection tools that allow data to be entered into a centralised system at a later time. To fit the needs of settings with poor connectivity, tools allow for systematic offline data collection using standardised forms, automatic data upload once connectivity is restored, and alternative ways to upload data without internet connectivity, such as by mobile phone. However, suitable tools are not always available or used [12, 21–23]. In the absence of suitable tools, some initiatives used less systematic tools, such as spreadsheets or paper-based tools [17], which can contribute to delays and human error when inputting data into the main system.

Physical infrastructure and transport is another challenge in terms of collecting data from hard-to-reach areas or areas that present security or safety challenges, including in LMICs [2, 15]. For example, physically transporting samples, particularly from rural or remote areas [7, 22, 23] or across national borders [11, 24], has been challenging due to long shipping timelines and a lack of infrastructure to support transport of biological samples. Along with causing bottlenecks in pathogen surveillance efforts, these types of challenges lead to difficulty tracking specimens from the field to the laboratory [15], causing issues around accurate metadata and data quality. From the sources reviewed, at least 14 initiatives were reported to have experienced challenges with infrastructure-related issues or else highlighted the importance of having sufficient infrastructure.

Supply chains also present obstacles. For example, a lack of laboratory reagents and kits [11], or shortages of consumables such as personal protective equipment (PPE), swabs and testing kits can sometimes be an issue, particularly during outbreaks when supply chains are stretched [7], contributing to a

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1 EWARS; Disease Early Warning System in Yemen; Regional Action through Data (RAD); Cooperative Agreement of CNIC and US CDC (2004–2014); CHINA CDC: Pathogen Identification Net (PIN); Global Ebola Laboratory Data Collection and Reporting System.
lack of timely data and poor coverage across geographies and settings.

**Some initiatives struggle to collect additional data and metadata to conduct pathogen surveillance for public health decision making**

In some instances, initiatives struggled to collect sufficient additional data alongside data about pathogens (e.g. data on the person or place where a pathogen was found, as well as risk factors, demographics, age) to conduct analyses to inform public health decision making. Although electronic health records may contain this information, they are not consistently used in pathogen surveillance across locations and different healthcare settings. Where initiatives have incomplete data, supplementation may be possible with sources such as web surveys, phone advice lines and search engine queries to further understand how pathogens are spreading and how symptoms are experienced at a population level. However, not all initiatives make full use of these types of supplementary data.

Metadata, or data that provides contextual information about data, is important in pathogen surveillance. For instance, this can include information about where samples come from, when they were collected, what labs they were processed in and who entered data into the surveillance system. Along with providing valuable information to make pathogen surveillance efforts more transparent and accountable, this metadata can be key in allowing data to be linked to other sources for more comprehensive surveillance. When good metadata is not collected, this limits how data can be used. For example, in the foodborne illness context, a national effort in the US received data that did not have information about the food that samples were taken from. Because of this, researchers sometimes had to assume that different outbreaks were associated with a single food source, without being able to confirm that this was the case.

**Challenges related to collecting standardised data using consistent methods can limit data quantity and quality**

There are also challenges relating to the use of standardised and consistent methods for pathogen surveillance. From the sources reviewed, at least six report challenges around standardisation. Differences in data collection methods create difficulties comparing data across regions and countries, which limits how data from separate initiatives can be collated to understand global trends. For example, efforts to monitor invasive pneumococcal disease in Australia differ between regions in terms of whether electronic health records are available and used for surveillance and whether data on vaccine history is collected, which makes it difficult to use data to inform vaccine strategies nationally. Some initiatives also lack a systematic means of tracing and detecting outbreaks in that they rely on ad hoc data collection and analysis (rather than data that is routinely collected and analysed), which leads to issues in data quantity and quality.

Even where data is available across regions and over time, changes in case definition or surveillance systems over time could present challenges in generating reliable, compatible and comparable data. Along with making data linkages more difficult, this means that additional resources are then required to clean and merge datasets.

**Environmental surveillance strategies face unique challenges**

Wastewater surveillance uses samples collected from sewage treatment sites or other settings to test for the presence of pathogens at a population level (corresponding to the catchment area of the wastewater site). Where
pathogens are present, this can inform public health strategies directly, or inform testing strategies by which individual-level data is collected. Although this type of surveillance can help address some challenges such as capacity constraints and data privacy concerns, the data generated has its own challenges.

For instance, some environmental surveillance programmes struggle to account for factors that vary between surveillance sites [15], including variation caused by rainfall and turnaround time [33, 34]. While wastewater surveillance is useful in settings with centralised sewage systems (e.g. airplanes, some hospitals, and other settings where a limited number of people are using one sewage system), they have limited application in terms of understanding the spread of pathogens in settings without centralised systems; while they can be used to understand population-level health, they cannot provide data at a more granular level than the catchment area of wastewater sites [35].

Although environmental surveillance has potential to provide useful information about a particular catchment area or region, it is typically not possible to reliably predict the number of infected individuals in a community from environmental data alone [35], and so additional data collection activities are needed alongside wastewater surveillance. With the Covid-19 pandemic, this type of surveillance has increasingly been applied in the area of pathogen surveillance, and best practices are still being formulated.

3.3. Challenges related to data sharing and data governance across the identified initiatives

Many of the challenges discussed above also affect how data can be analysed, shared and used for public health decision making. Here, the challenges identified in the scoping review that specifically relate to data sharing and use are discussed.

The pathogen surveillance space is fragmented – although many initiatives identified in this study fed into global or regional surveillance systems (e.g. at least 12 fed data into systems coordinated by WHO, likely with more sending data without this being explicitly stated), many did not seem to share data with one another. For instance, initiatives undertaken by public and private entities may not link to one another [36], and efforts undertaken in different regions are not always linked [25].

Storing, managing and analysing data can be challenging, particularly in locations with limited capacity

Many initiatives (at least 11)² experienced challenges related to storing, managing, analysing and sharing data. For instance, initiatives such as the Early Warning, Alert and Response System and the Global Polio Eradication Initiative experienced technical difficulties related to the lack of an electronic data management system, or constraints related to technical capability or infrastructure to analyse and disseminate data [5, 8, 17, 18, 22, 23]. Some systems for pathogen surveillance are more difficult to maintain than others – one article discussing challenges relating to an integrated pathogen surveillance

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² GOARN, EWARS, Global Polio Eradication Initiative; Regional Action through Data (RAD); Global Ebola Laboratory Data Collection and Reporting System; National Wastewater Surveillance System; Global Initiative on Sharing All Influenza Data; Vigilancia Integrada Comunitaria (ViCo); Integrated Disease Surveillance and Response Strategy; National Influenza Surveillance System (Australia); National Influenza Surveillance Network (NISN).
system in Guatemala, for example, cited the size and complexity of the system (in terms of the number of different data items collected and the number of stakeholders involved in data management) as a factor that made the system more difficult to manage [31]. This indicates that although more complicated systems can provide more comprehensive surveillance, there is a need to ensure that there is sufficient capacity to manage the data.

There are data privacy and governance concerns that need to be addressed before data can be collected and shared.

The scoping review identified a range of challenges related to data privacy and governance, which were reported as challenges by at least eight initiatives [3, 9, 16, 18, 38, 41, 44, 45]. These included considerations around who can use data for research, publication rights, and intellectual property rights [3, 24], along with informed consent [37] and how personal identifiable data can be anonymised or pseudonymised for privacy [37–39]. The transfer of and use of data, such as through online networks, may also require security measures like encryption and decryption, to ensure that individuals only have access to data which they are authorised to use [37, 39, 40]. Many initiatives will also need to account for differences in the kinds of data that are being collected, for example by establishing different data protection and governance practices related to clinical data, hospital records and personal data [37].

Depending on the jurisdiction or country in which they operate, initiatives also need to take account of different data protection regulations, such as GDPR in the EU [37]. Where initiatives operate in more than one jurisdiction (e.g. in both EU and non-EU countries), this creates additional challenges in terms of establishing practices that meet the requirements of different regulatory regimes.

Data sharing also often requires formalised arrangements, and the creation of specific frameworks for sharing and analysis [3, 41].

### 3.4. Overcoming challenges related to data collection and sharing across the identified initiatives

Providing equipment, improving infrastructure and offering direct operational support can help address logistical issues.

To overcome the logistical challenges of collecting data described above (e.g. capacity constraints, lack of resources, poor infrastructure), initiatives have taken several approaches. Some focus on solving issues locally – for example, to support the Global Influenza Surveillance and Response System, the WHO has organised the Shipping Fund Project and other logistics activities to aid in shipping virus samples, reagents, laboratory supplies and biological material from national influenza centres. These support mechanisms provide funds to pay for shipping, guidance on the safe and legal shipping of biological materials, support with monitoring and tracking samples throughout the shipping process and workshops to train participating sites in logistics and safe shipping. Along with solving logistics issues, these activities help ensure that stakeholders involved in collecting and sharing data are safe when handling potentially hazardous material [24]. The Global Polio Laboratory Network also works to support local capacity by assigning the production and distribution of reagents to specialised labs with a clear quality-assurance procedure to help resolve supply chain issues for reagents [22, 23].

Other initiatives provide supplies directly to data collection sites to help address challenges related to logistical issues and resource
constraints (as discussed in Section 3.2). From the sources reviewed, at least four described providing supplies to sites. For example, several provide low-cost tests to be used for the rapid genetic identification of diseases at the point-of-care, such as paper strips for use in remote areas which do not require healthcare providers to have specialised skills related to epidemiology or infectious diseases [21, 29, 30]. Another initiative, the Early Warning, Alert and Response System, provided boxes of equipment for pathogen surveillance in emergency settings with limited electricity and internet connection, which included mobile phones to upload data and printed questionnaires to support data collection in resource-limited settings [17].

Support at a local level can create more distributed capacity to support pathogen surveillance

One way to resolve logistical challenges, capacity constraints and skills gaps (see Section 3.2) is to build capacity locally, closer to where data is being collected. For example, the Global Polio Eradication Initiative reduced the time required to ship specimens by building capacity in local laboratories to conduct specific molecular tests [22, 23]. Another initiative, the GenRe-Mekong platform, integrated their data collection processes within existing workflows in healthcare settings, to avoid placing undue strain on testing capacity [41].

Other initiatives seek to resolve logistical challenges by implementing certain data collection models. Hub and spoke models and other models that help build distributed capacity are one way to do this. For example, prior to Covid-19, surveillance for influenza vaccine monitoring in Europe typically relied on sending samples to reference laboratories. However, during the pandemic, this system was repurposed for Covid-19, and additional capacity was needed to keep up with testing demand. To provide more capacity, countries adopted a more decentralised model to test samples locally, rather than shipping all samples to reference laboratories, which helped speed up the testing process and prevent long travel times for samples [7].

Where initiatives are able to provide support to partner laboratories and other stakeholders, this has the potential to improve data quality and consistency [5, 31, 42]. Initiatives such as the EU Sewage Sentinel System and the Global Antimicrobial Resistance and Use Surveillance System provide training material, guidance on best practice, protocols and workflow guidelines to data collection sites [6, 12, 42, 43]. Along with improving data quality, standardised tools can improve the efficiency of pathogen surveillance initiatives, and prevent the need for each individual site to create their own standards and templates [12]. This also helps mitigate challenges around fragmentation by establishing standardised ways of collecting and recording data, and thus helping with the process of collating and analysing data collected in different contexts and settings.

Since wastewater surveillance is an emerging technique, initiatives often provided training in this area (at least 7) [4, 15, 18, 22, 23, 33, 34].

Web-based tools can help increase capacity to analyse data locally and support public health actions at a local level, as well as improve data consistency and quality

Supporting and building capacity to analyse and interpret data locally helps to support the use of data to inform public health decision making at a local level. For example, a China–US collaboration that supported improving surveillance systems and developing expertise/capacity (Cooperative Agreement of CNIC and US CDC) provided web-based platforms that could be used to store, manipulate, analyse and
visualise data by the people that were involved in collecting it [5]. Similar tools have also been developed by the Centre for Genomic Pathogen Surveillance (see Case Study B: Centre for Genomic Pathogen Surveillance (CGPS)) and the unCoVer initiative (see Case Study I), which have developed their own databases to facilitate collection, analysis and sharing of genomic data and real-world data, respectively. While the CGPS has developed its own tools for data storage and analysis with input from programmers, epidemiologists and other experts, unCoVer drew from existing open source software to allow users to store and analyse data locally.

Websites that integrate many different functions into one site can be particularly helpful in supporting transparency, use and impact [42]. Good platforms also tend to be intuitive to use, and are customisable depending on what parameters users would like to explore [40]. Descriptions of these tools tended to focus on ease-of-use, internet accessibility [2, 5, 15, 42], searchability, flexibility and real-time access to data [20].

**Good data governance procedures need to take data protection, privacy and ethics into account, while also facilitating data sharing**

The value of cohesive and clear internal policies, practices and governance procedures was often mentioned in the literature as a way to address challenges relating to data sharing, privacy and governance (see Section 3.3). Some initiatives published data sharing frameworks or protocols – for example, GenRe-Mekong has published a governance framework to protect patient privacy and AusTrakka has published a framework formalising the recommendation that all regions in Australia rapidly upload data to the platform [3, 41]. Some specific measures taken to limit risks relating to data privacy include disclosing age in intervals and only providing geographical information for regions with certain population sizes (referred to as statistical disclosure control) [38]. Data encryption and user authentication procedures are also used to regulate access to private or sensitive data [37]. At least eight initiatives reported challenges around data privacy and governance [3, 9, 16, 18, 38, 41, 44, 45].

Three initiatives were reported to have used an external advisory board to support decision making on data protection, privacy, ethics and governance, namely GenRe-Mekong, unCoVer and the Canadian Covid-19 Genomics Network [37, 38, 41]. However, more initiatives may have used similar governance structures. These groups assisted with risk mitigation, informed thinking on specific ethical and data protection challenges, and supported the creation of assessment checklists to determine how different kinds of data should be handled [37, 38]. Other initiatives reporting using other forms of engagement – for example, to help inform their governance decisions, the West Africa Health Organisation conducted a survey of those involved with health data governance (e.g. IT, finance, project management, programme implementation) to identify gaps in data governance at a national level [18].

Although there are many legal and ethical issues that must be addressed, there is also a large potential benefit to society from conducting pathogen surveillance activities. Risk management strategies must trade off the potential risks and benefits of pathogen surveillance efforts, and mitigate potential disbenefits [37].

There are also more general guidelines and principles that can help guide data management, governance and ethics, in order to support data re-use and open science. For example, Box 4 below describes the FAIR and CARE principles.
Box 4: FAIR and CARE principles

**FAIR principles**

- The FAIR Guiding Principles for scientific data management and stewardship were published in 2016 as a guideline for those wishing to enhance the reusability of data. They emphasize enhancing the ability of machines to source and use data, and attempt to address challenges and obstacles to finding and reusing data.

- The 4 key principles are for data to be: Findable, Accessible, Interoperable and Reusable.

**CARE principles**

- The CARE Principles were developed as a complement to the FAIR principles by the Global Indigenous Data Alliance in 2019, following comments that progress towards open data and open science did not fully engage with Indigenous Peoples’ rights and interests.

- The principles complement the four FAIR principles. They are: Collective benefit, Authority to control, Responsibility and Ethics.

### 3.5. Strengths and weaknesses of the identified initiatives

The scoping review found that resource levels can constrain initiatives, and determine what pathogen surveillance activities are able to be undertaken. Large-scale initiatives tended to have funding from multiple sources [5, 40, 45–47], including international organisations such as the WHO, national governments and large foundations and charities. For some, funding source and level varies over time [48], and many initiatives have a limited funding period [37]. Sustained funding is important and necessary for the success of an initiative, but this may in some cases be difficult to secure and maintain once the immediate threat presented by a pathogen passes. The Covid-19 pandemic, for example, led to additional investment in pathogen surveillance, which may in the future leave gaps as political commitment wanes in the long term.

Many initiatives rely on voluntary submission of data, which can present both strengths and weaknesses when compared to mandated data sharing.

Some initiatives identified in this study have regulatory backing, for example the German Antimicrobial Resistance Strategy (developed by the Federal Ministry of Health, the Federal Ministry of Food and Agriculture, and the Federal Ministry of Education and Research in Germany), the System for Enteric Disease Response, Investigation, and Coordination (coordinated by the US CDC and used by CDC partners), and other efforts involving public health departments and national CDCs (see Annex A for full list of stakeholders and initiatives) [49, 50]. A small number of these initiatives have mandatory requirements around data submission, such as the WHO Global Influenza Surveillance and Response System (described in Case Study E) under which National Influenza Centres are required.

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3 The FAIR Guiding Principles for scientific data management and stewardship | Scientific Data ([https://www.nature.com/](https://www.nature.com/))

to submit data. However, it is more common for initiatives to be based on voluntary data collection and sharing. For example, several initiatives at the EU level, despite involving public sector stakeholders and national governments, rely on voluntary data submission (e.g. EpiPulse, EU4S-DEEP).

At least one initiative identified voluntary reporting as a potential weakness, describing a struggle to create mechanisms or incentives to encourage local partners to collect and report data [11]. This can occur even when initiatives are coordinated by national health ministries or public health authorities.

The speed at which data can be collected and shared is important in terms of the usefulness of initiatives to public health decision making

Speed is a key factor in detecting and responding to outbreaks of infectious diseases to prevent further transmission. Where initiatives are able to collate and analyse data in real or near real time, this information can be critical to responding to the spread of pathogens and preventing further harms to public health.

Hub and spoke models, where the collection of data is distributed across a variety of settings or contexts and then fed into a centralised database, is one approach that can help increase the speed of analysis, especially in contexts where data is collected in a standardised format that requires less processing and cleaning prior to analysis. This approach was taken by the Sentinel project (see Case Study A). Some of the tools provided by the Centre for Genomic Pathogen Surveillance (see Case Study B) also support capacity for quick analysis.

However, at least 13 initiatives were reported to be limited by a lack of timely collection and sharing, including large international initiatives such as the Global Polio Laboratory Network and AusTrakka, along with national systems in Guatemala and Yemen [2, 3, 23, 31]. For example, the system in Yemen relied on manual data entry and analysis [2], which can cause delays in tracking diseases, along with errors in data entry. Delays once data have been collected are also present, for example when integrating data into centralised systems, as was reported with the AusTrakka system [3]. Where this occurs, it inhibits timely and rigorous analysis of pathogen and disease trends, and limits how data is used to inform public health decision making.

The degree to which initiatives were able to link pathogen-level data to other sources of data was often mentioned as a factor that influenced success

When initiatives were able to combine both clinical data and laboratory data, this was cited as a strength. For example, an initiative under the US CDC worked to capture rich data by performing both laboratory-based and case-based pathogen surveillance, including symptoms and when they started, demographic information and risk factors (e.g. travel, food consumption) [35].

Some initiatives were also able to combine case- and lab-based surveillance with other sources of information. The ‘One Health’ approach to infectious diseases, which recognises the interconnections between human health, animal health and the environment, informed data linkages. For instance, a surveillance effort in Greece was able to connect data on enterovirus to environmental surveillance [13]. This additional surveillance supported pathogen tracking efforts in the region and the early warning system for, in this example, poliovirus. Another initiative was able to connect genomic sequencing data to environmental surveillance data [51], which in turn provided
information about variants in circulation at a population level.

Where surveillance efforts do not collect sufficient case-based data, this limits the usefulness of pathogen data. For example, an investigation into a Malaysian influenza surveillance initiative found that a lack of granularity in case-based data (e.g. age, gender, risk conditions) likely limited scientific research around influenza and the ability to respond to active outbreaks [25]. An Indian initiative around AMR similarly suffered from an inability to connect laboratory information systems and hospital information systems, creating challenges in correlating AMR to clinical outcomes.

Geographic coverage can strengthen or weaken initiatives, and it is important that initiatives cover a wide enough area to support public health responses

The initiatives identified in this study cover different geographic areas – some were national or international in scale, while some covered smaller geographic areas across different countries. It is important for the geographic coverage of an initiative to be fit-for-purpose in terms of matching with how public health decisions are made and how responses are coordinated.

For instance, national-level programmes should ensure sufficient coverage across areas within the country to be informative for public health decision making. This can be challenging where infrastructure for surveillance is not evenly distributed, or where some areas are much less populated. For instance, one of the weaknesses of foodborne illness surveillance in the United States is that, despite being a national system, it only covers 15% of the population (although the reason for this low coverage is not clear) [52]. Similarly, US efforts around norovirus surveillance are limited in that only 29 (out of 50) states and one district (Columbia) have laboratories that have been certified to directly participate in surveillance initiatives – the other states therefore need to rely on resources elsewhere [39].

3.6. Use of pathogen surveillance data in public health

Pathogen surveillance data has been used to inform policy [42, 53] and often does so through alerts and reports accessed by policy makers [54]. For some initiatives, data is reported to larger national reporting systems [35, 55, 56], often coordinated by national health authorities such as CDCs [26]. For example, the National Outbreak Reporting System, managed by the US CDC, receives data from other initiatives coordinated by the US CDC including the Foodborne Disease Outbreak Surveillance System, the Waterborne Disease and Outbreak Surveillance System, PulseNet and CaliciNet. Additionally, the Sentinel project (see Case Study A) sends data to the Africa CDC.

Many initiatives directly include policy makers or regulators themselves, which promotes the use of data in policy making and helps ensure that results are actionable and reach decision makers. For example the unCoV er initiative included national institutes of health and public research institutions, alongside academics and universities [37]. Where initiatives bring together varied stakeholders, this supports development of appropriate tactics and responses to public health outbreaks, for example in the context of foodborne illness outbreaks that involve health, agricultural and food-related authorities [57].

Pathogen surveillance efforts are often used to inform the response to public health threats, and how resources are deployed [53, 57]. For example, many of the initiatives identified in the scoping review inform public health action at an international level, and are directly connected to how responses are coordinated.
Surveillance efforts by the WHO, ECDC and national CDCs have been used to inform responses to pandemics, including vaccination strategies, deployments of public health staff to affected areas and distribution of PPE and other equipment. Within the EU, the ECDC coordinates some of the collaboration between countries, although countries also may share data or feed into surveillance activities as part of bilateral or multilateral agreements.

Data from pathogen surveillance initiatives have also been used in secondary or additional analysis, including for academic publications [10, 55]. For example, data may be used for clinical studies on drug efficacy, evaluation of interventions, and for further epidemiological investigations [41]. Data can also be used to understand inequalities and risk factors, including age-related risk and ethnic disparities [52].

Overall, pathogen surveillance data can be used in varying ways to inform public health. The data has potential to inform response efforts, further understanding of specific pathogens, support additional analysis, and inform policy development. Further information about how pathogen surveillance data is used in public health is discussed in the next chapter, where ten case study examples of pathogen surveillance initiatives are explored, each with their own contributions to public health.

**Improving the use of surveillance data in public health**

The interviews conducted for this study (see Chapters 4 and 5) offer insights relevant to improving the use of surveillance data in public health. Often, public health decisions are made by local stakeholders and national governments, rather than by international organisations that conduct large coordinated surveillance efforts (although stakeholders such as the ECDC and WHO also have an important role in providing guidance and responding to outbreaks). Therefore, securing buy-in from local and national stakeholders helps ensure that surveillance activities feed into public health decision making. For instance, getting local NGOs and other organisations involved in surveillance activities, providing tools that help local stakeholders analyse and interpret data themselves, and encouraging local ownership of data and analysis is important in making sure that surveillance influences local decision making (Int 1, Int 2, Expert 9) (see **Case Study A** for an example of how this has been done). Similarly, liaising with national governments around what information they need to inform decisions helps align data being collected with information needs of key stakeholders (Int 1, 2), rather than collecting data and then looking for a suitable audience (Expert 6).

Real-time surveillance is crucial to decision making, as intervening early during outbreaks can help limit the exponential spread of pathogens (Expert 1, 2, 3, 4, 5, 6, 8). Using aggregated data, such as data from wastewater surveillance, helps overcome some of the lags and limitations of individual-level data, particularly in identifying outbreaks (Expert 1, 2, 9), the emergence of pathogens in particular locations and new variants (see **Case Study D** for an example of wastewater surveillance in the EU). However, there are still questions around how best to interpret this type of data alongside other data streams in integrated surveillance systems, and what types of actions should be triggered by signals found in wastewater surveillance (Expert 5, 7). For more information on these gaps, see **Section 5.1.3**.
Chapter 4. Case studies

Ten initiatives identified in the scoping review for this study were prioritised for further data collection and the development of case studies. The case studies are intended to provide information about how initiatives were structured; how they collected, analysed and shared data; challenges that they faced; and the strengths and weaknesses of each initiative. They also provide information on how the intelligence from pathogen surveillance informs public health decision making. Whilst the case studies follow a general structure, they vary slightly in some cases to account for the different focus and structure of the initiatives. The case studies are based on additional desk research as well as interviews, to the extent that this was possible.

For additional information about the prioritised initiatives, see Annex C.

Box 5: Summary of Chapter 4

• **Case Study A** (Sentinel project) provides an example of a hub and spoke model that aims to build sustainable capacity, and engages closely with local areas collecting and analysing data.

• **Case Study B** (Centre for Genomic Pathogen Surveillance) is an example of an initiative that provides overarching support to genomic surveillance, along with specific tools to help build capacity for this key type of surveillance.

• **Case Study C** (EpiPulse) describes a voluntary system headed by the ECDC to share data across countries.

• **Case Study D** (EU4S) describes an effort to create a community and share best practices around wastewater surveillance, an emerging and promising area within pathogen surveillance.

• **Case Study E** (Global Influenza Surveillance and Response System) describes a WHO-led, established surveillance system, and sheds light on some of the basic challenges that affect how data is collected at a local level.

• **Case Study F** (Global Outbreak and Response Network and the Early Warning, Alert and Response System) describes a WHO-led effort to improve surveillance in low-resource settings.

• **Case Study G** (PAHO Epidemic Intelligence) provides an example of a regional WHO initiative that conducts continuous monitoring and builds integrated surveillance systems.

• **Case Study H** (China PIN) describes the national laboratory-based surveillance network for bacterial diseases in China (although limited information was available).

• **Case Study I** (unCoVer) provides an example of an initiative looking at how real-world data can be used for surveillance, and describes some of the strengths and weaknesses of federated structures.

• **Case Study J** (EU4Health) describes an EU funding mechanism, and how it has supported pathogen surveillance.
4.1. Case study A: African Centre of Excellence for Genomics of Infectious Diseases (ACEGID) – Sentinel project

The African Centre of Excellence for Genomics of Infectious Diseases (ACEGID; associated with Redeemer’s University in Nigeria) and the Broad Institute (associated with MIT and Harvard in the US) collaborate to deliver the Sentinel project, a pathogen surveillance initiative for early warning and response that builds capacity to collect and analyse samples across different countries in Africa [59]. The initiative aims to support the detection of all viral diseases by detecting pathogens using affordable point-of-care tests, developing regional capacity in local hospitals for the identification of viruses, and supporting the genomic sequencing of novel viruses [29, 30, 60]. The initiative focuses on enabling rapid responses to outbreaks and prevention measures through the identification of pathogens and collaboratively building capacity for surveillance across Africa rather than being dependent upon shipping samples abroad [29, 30, 60].

Collecting data

The Sentinel project supports local data collection through a hub and spoke model. Interviewees reported extensive capacity building activities delivered to local communities that collect data, for example through training, provision of standardised procedures and tools, and infrastructure support.

At a local level, data is collected through clinical samples from patients presenting to health clinics, often in rural settings. To help collect data as efficiently as possible, the programme has implemented a system whereby samples are first tested locally, and then escalated to higher levels if this testing does not provide a clear diagnosis.

In the first instance, data that is collected locally is tested locally for a range of pathogens that are present in that location. The Sentinel project has developed a specific new technology – a CRISPR-based paper strip test called SHERLOCK, which is used to detect viruses or bacteria in clinical samples of urine, blood or saliva within minutes [61] – to support diagnosis at the point of care, which both supports clinical care locally (which encourages use of the technology) and supports data collection for pathogen surveillance. At present, this tool is approved for the detection of Lassa fever, Ebola and Covid-19 in a single test, with plans to expand to other viruses and diseases in future (Int 1) [30, 62]. This local approach ensures that high-priority pathogens are promptly identified, both to inform the patient’s care and to take local public health action where needed.

If the SHERLOCK test is inconclusive or cannot identify the pathogen, a further blood sample will be taken at a primary care facility and sent to a local hospital to be tested with CARMEN, a technology that can test for and diagnose hundreds of known viruses simultaneously [29, 30]. This requires additional resources and infrastructure beyond what is present at local data collection sites, and so this is only undertaken where the local point of care test is inconclusive.

If the CARMEN test fails to provide a result, the sample will then be sent to a regional sequencing centre for metagenomic sequencing to identify the pathogen (Int 1). This combination of measures for detection ensures that high-priority viruses can be detected within the hour, known human viruses within twenty-four hours, and previously
unknown viruses within a week, ensuring a rapid response to any outbreak [29, 30]. Interviewees explained that where samples are escalated, this information also feeds into the technology development activity of Sentinel, to consider whether the SHERLOCK or CARMEN technologies need to test for additional pathogens at the point of care.

Test results, data on symptoms and metadata about the sample are transferred digitally via cloud-based databases and mobile applications designed to function in low-connectivity environments. For example, the CommCare app developed by Sentinel partner Dimagi enables frontline workers to share symptoms and diagnostic data from clinics, and still functions in areas of intermittent and unreliable internet connectivity [60]. The initiative acknowledges resource constraints where it operates, and consequently designs its tools for those with limited computational experience or resource access [60].

**Analysing and sharing data**

Basic analysis is conducted at the point of care using SHERLOCK, in regional hospitals using CARMEN, and in national genomic reference labs which conduct genomic sequencing and work with national public health agencies to identify pathogens [60]. The use of cloud-based technologies such as Terra and DNANexus makes analysis pipelines available via a web-accessible interface in settings with limited computing resources, while also providing integrated visualisation tools and datasets [29, 60]. This enables those collecting data locally to explore it themselves and conduct their own analyses, which interviewees explained both promotes engagement and encourages the use of data to inform local decision making.

Data is also analysed centrally within the Sentinel project. Current analysis is focused on identifying the variant, transmission dynamics and mutations of a virus but there are also plans to enable prediction of whether a virus is likely to be more or less virulent over time (Int 2).

Data collected through the Sentinel project is shared with national Ministries of Health and with the Africa CDC, so that it can be used to inform public health actions such as further testing and vaccination programmes (Int 1). In the future, ACEGID and the Broad Institute intend to link to other databases on the continent and develop a region-specific cloud-based dashboard to improve the connection and integration of data from a variety of data sources (Int 1).

**Governance and funding**

The Sentinel project is run collaboratively by ACEGID, based at Redeemer’s University, Ede, Nigeria; and the Broad Institute, a US philanthropic medical research organisation focusing on infectious diseases, cancer, cardiovascular disease and genomics [59, 63]. It received funding in 2020 through the Audacious project, a TED initiative [64] that received support from large partners such as the Skoll Foundation and the Bill & Melinda Gates Foundation. Alongside this funding and financial support from the Broad Institute, the initiative also receives funding from the Nigeria CDC, Africa CDC and regional WHO offices across Africa [60]. Private sector collaborators, including Dimagi, Fathom and MassDesign, provide support with technological and app development, while other organisations have donated technology such as solar panels and inverter batteries to ACEGID to ensure a 24/7 power supply [29, 30] (Int 2).

Sentinel is managed by Co-Directors from ACEGID and the Broad Institute, with a Science Advisory Board providing oversight of the programme as a whole. While ACEGID is based in Nigeria and provides significant expertise in genomic pathogen surveillance and capacity building within the African continent, the
Broad Institute provides support from the United States with the development of apps and programmes used for data capture and analytics, and with genomic sequencing and quality control (Int 1, 2).

Although funding for Sentinel is secured for the present, the future funding of the initiative represents a challenge, with the organisation needing to attract funders in the long term or else find different streams of revenue (Int 1, 2).

**Strengths of the initiative**

The Sentinel project has been able to integrate a range of different testing options into a coherent system, which creates cost efficiencies and supports local care while also not restricting testing to only known pathogens [29, 60]. The speed of the network is also facilitated by the use of a hub and spoke model, which makes information available at the point of care for a targeted response [30, 60] (Int 1). During the Covid-19 outbreak in 2020, the Sentinel project was able to sequence the whole genome of the virus within 48-hours of receiving the first sample and it developed the first rapid diagnostic test in Africa (Int 1).

Sentinel seems to make the most of data by using it for both clinical care and pathogen surveillance, as well as for technology development. For example, their use of sequencing data to support the development of point-of-care diagnostics has been a strength, which can support future pathogen surveillance efforts and clinical care. Sentinel data is being used to develop a CRISPR database (genomic sequencing data from pathogens to inform the development of CRISPR-based technologies to edit genomes) which is currently undergoing validation (Int 2). The tools developed through Sentinel are designed to be scaled and flexible for use in different geographical settings [29, 60]. This includes cloud-based analysis tools, which eliminate the need for intensive computing power, and apps that facilitate offline use that automatically upload data once there is an internet signal (Int 1). Finally, SHERLOCK tools are free for use in research worldwide and the licensing framework adopted aims to ensure that tests will be accessible in low- and middle-income countries [62].

Sentinel’s strategy places a strong focus on capacity building and establishing trust and good relationships, with the initiative training more than 1,300 local health workers and scientists to use its diagnostic and surveillance tools in 42 different countries according to interviewees (Int 1, 2). Efforts to improve the capacity for genomic analysis through regional hubs also ensure a much faster turn-around time and the use of data in public health decision making, facilitating rapid responses to outbreaks before they start (Int 2). Interviewees from the Sentinel project emphasised the importance of relationship building and trust – rather than being perceived as a stakeholder that only goes to local areas to extract data, the initiative hopes to contribute locally and build true collaborations with local healthcare providers and scientists.

**Weaknesses of initiative and challenges faced**

The Sentinel project has faced a range of challenges related to operating in low- and middle-income countries, including limited internet connectivity and hardware access [60]. While the installation of back-up batteries and solar panels at ACEGID has ameliorated some of these issues, regular power failures at storage points can still mean that processed samples generate fewer viable results (Int 2). The initiative has also struggled with the acquisition of reagents and consumables for laboratory work, which may be required on an urgent basis to conduct tests for specific
pathogens during outbreaks (Int 2). This is being addressed by working with public health institutions like Africa CDC and partners such as Illumina (developer of a sequencing platform) to facilitate regular access to reagents and consumables (Int 2).

The Sentinel project focuses heavily on capacity building, and has also faced challenges relating to the lack of knowledge and awareness among healthcare workers and the general population around infectious diseases [60]. ACEGID and the Broad Institute have responded to these challenges by doing community engagement work, such as establishing a diagnostic centre for Lassa in an area where the virus is endemic. Extensive training has also been conducted with healthcare workers and laboratory scientists on sample collection, storage, what type of samples to collect, and so on (Int 2). Helping to set up regional laboratory facilities as part of this training has also ensured buy-in and trust, as workers and scientists can see that there is long-term investment in the initiative (Int 1). Scientists from public health institutions in the Central African Republic, the Democratic Republic of the Congo, Cameroon and Nigeria (where monkeypox is endemic) were also recently invited to bring suspected samples of the virus for hands-on training. This data could then be inputted into relevant databases (e.g. those coordinated by national public health authorities). This model of hands-on training has also been implemented for other diseases (Int 2).

Sentinel has experienced some challenges in relation to data protection, with genomic sequence data prior to the Ebola virus epidemic of 2013–2016 predominantly being siloed within individual organisations due to these challenges. While the situation has improved in recent years, with ACEGID promoting the public use of data, interviewees reported that there has also been some use of sequence data without proper approval or recognition (e.g. in academic papers). The project intends to develop more in-depth data-sharing protocols for infectious diseases in the future, similar to those developed by the H3Africa consortium [65] (Int 1, 2).

The project may face some potential challenges in relation to technology in the longer term, including the need for enhancements to increase scale, cost and sensitivity of testing, the ability to test for more viruses, and the need to keep abreast of rapid changes in the field of diagnostics [60]. To account for this, the tests that have been developed are designed to be adaptable to an array of different pathogens, and the Sentinel project serves as a hub for innovation that will allow other technologies to be developed in future [60].

Finally, the Sentinel project has experienced challenges relating to the nature of public health in Africa, where projects are often pursued in isolation and funding only granted in the short term (Int 1). To address these issues, the initiative has been focusing on meeting its goals to attract long-term funders, having other sources of income available to ensure long-term sustainability, and collaborating with national public health institutions (Int 1, 2).

Use of data and analyses in public health activities and decision making

The Sentinel project has been extensively involved in the response to Covid-19 in Africa, including in Nigeria, Senegal, Sierra Leone and Liberia [59]. This has included the development of the SHERLOCK diagnostic test and sequencing for Covid-19, as well as notification to public health authorities about potential outbreaks in order to inform responses (Int 2). Sentinel has facilitated the rapid identification of viruses with similar presentations, such as in 2018 when an outbreak of yellow fever was identified. Local hospitals and the Nigeria
CDC were alerted rapidly to this outbreak, and organised vaccinations in the community to help prevent further spread (Int 2).

The initiative also makes information about virus outbreaks available to staff at the point of care (to inform clinical care) and policy makers such as individuals within national public health authorities and health ministries (to inform public health decision making). While this information was previously provided separately by ACEGID, an interviewee reported that it is now in the process of being integrated directly into a digital platform that will allow users to visualise how variants spread across populations (Int 1).

Conclusions

The ACEGID/Broad Sentinel project is a valuable case study of a leading pathogen surveillance initiative which has been highly adaptable, preventative and focused on building long-term capacity for pathogen surveillance.

The participatory nature of the project means that it is highly dependent on the engagement of communities, individual healthcare workers and national health institutions, with tens of thousands needing to be trained if Sentinel is to achieve its goals (Int 1). The engagement and training that Sentinel provides are crucial both in terms of collecting data for this individual initiative, as well as increasing capacity for pathogen surveillance in African countries more broadly. The hub and spoke model of Sentinel helps to create distributed capacity for data collection and analysis, which can provide lessons for other initiatives working in this space looking to increase capacity in low-resource settings.

The programme is also looking in the long term towards animal health, climate change and other factors with a view to bringing these under the same umbrella and recognising their role in human diseases (Int 1). Funding which is not tied to specific outbreaks is needed to support these efforts around data integration and capacity building, which in turn helps support preventative actions in public health (Int 1).

4.2. Case study B: Centre for Genomic Pathogen Surveillance (CGPS)

The Centre for Genomic Pathogen Surveillance (CGPS) is an initiative supporting genomic pathogen surveillance globally. Although CGPS is involved in several projects that conduct pathogen surveillance, it primarily focuses on building capacity rather than conducting actual pathogen surveillance. The initiative aims to: make expertise in genomic pathogen surveillance available to those working in the field; build capacity in genome sequencing, data collection and analysis; provide surveillance strategies to experts and organisations, at scale; facilitate rapid analysis; and train public health practitioners and connect them with expertise [46]. For example, CGPS helps to connect experts in epidemiology to people collecting genetic data on the ground, and provides tools that can be used to support genomic pathogen surveillance at scale. A large proportion of its work relates to AMR [46] although CGPS also supports genomic pathogen surveillance more widely. The key partner involved with CGPS is the Big Data Institute at the University of Oxford.

CGPS designs and develops mobile and web-based tools and applications that are made available online for free. They also have a non-profit arm which supports installation

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6 Centre for Genomic Pathogen Surveillance (https://www.pathogensurveillance.net/)
of tools locally and their implementation in secure environments (Int 3). For example, CGPS tools include EpiCollect (to gather data via mobile and the web), Data-Flo (for data integration), Microreact (to link and interactively visualise data) and the MetaData Uploader; together these help collect, process, upload and interpret genomic data without the need for in-depth programming skills. CGPS has also helped developed web applications for Pangolin, which is used to assign lineages to Covid-19 sequences [66]. Another CGPS development, Pathogenwatch, is a platform that provides a way to conduct genomic analysis (e.g. clustering, predicting resistance) and deliver insight into pathogen risk that is suitable for non-informatics specialists [67].

A long-term goal of CGPS is to provide evidence on the associations between genomics and resistance phenotypes to help improve society’s understanding of AMR, support decision makers to quickly identify the biggest threats related to AMR, and contribute towards more targeted antimicrobial therapies, better diagnostics, vaccines and overall antimicrobial R&D efforts. CGPS’s contribution towards this long-term goal consists of supporting a more systematic process for genomic surveillance and integrating genomic information with other types of data (e.g. geo-temporal, epidemiological, clinical) which are key to inform public health action (Int 3).

**Tools for collecting, analysing and sharing data**

CGPS has a variety of modular tools available for public use to support the collection of pathogen surveillance data, which are designed to integrate with one another. The tools that CGPS provides can be used to upload genomic data to a database, and compare uploaded genomic sequence data to publicly available sequences to identify mutations or genes known to be associated with risk. When users upload data using these tools, they can create a ‘private room’ so only they and their team have access to it (Int 3). CGPS tools are designed to be agnostic of use cases, meaning they can be used for many different types of data (Int 3).

EpiCollect allows users to collect different types of data via mobile devices or the web (e.g. from the field, forums or questionnaires, photos, videos, audios and barcodes), both online or offline, with automatic collection of certain types of metadata such as geo-tagged data with location and time of data collection [68]. This enables monitoring of results in real time and visualisation of the data collected (e.g. on a map with markers to view at scale or a single entry) [69]. Data-flo, another web-based tool provided by CGPS, can then be used to import, transform and export data, which can be useful in integrating data collected from different sources. For instance, Data-flo can be used to provide open access workflows to transform and convert data to standardised formats, such as those used for international surveillance by the WHO. It can also be adapted to fit the needs of individual projects looking at pathogen surveillance data, to provide more customised workflows for processing and transforming data into the formats needed for integration and analysis [70].

One of the key tools that CGPS provides is Pathogenwatch, which is a platform for genomic surveillance that functions as both a database and a platform for data processing and analysis. When users upload data to Pathogenwatch, the platform automatically identifies the pathogen, conducts analytics (e.g. clustering and comparison to known genomes, and prediction of risks such as AMR), and contextualises data in terms of where it sits in comparison with data that are publicly available. Users uploading data can choose whether the data is public, meaning that it will be available to anyone online, or
private. CGPS curates and quality checks all data from the public archives before incorporating it in Pathogenwatch, to ensure that only high-quality data remains in the system. As of November 2020, it included 4,389 public genomes from 26 published articles, and covered 77 different countries [71]. Results from Pathogenwatch-facilitated analyses can then be downloaded or shared with others via the web. This can help monitor the emergence and spread of resistance, and facilitate collaboration by allowing genomic surveillance results to be rapidly shared. It also increases capacity for genomic surveillance in that it enables more stakeholders, including those with less formal training and skills in genomics or bioinformatics such as public health practitioners and researchers, to directly analyse data and use it to inform decision making (Int 3).

CGPS also provides tools for reporting data and sharing results, which enables genomic surveillance data to be used to inform public health decision making. For example, the Microreact tool helps users (with or without programming skills) to map and visualise data over space and time, and allows them to create bespoke visualisations based on their analysis and information needs. Visualisations produced by Microreact have been used in academic publications (e.g. articles about the spread of carbapenem-resistant *Klebsiella pneumoniae*, and the resistance dynamics of *Streptococcus pneumoniae*), as well as by the Covid-19 Genomics Consortium (COG-UK), which provides regularly updated visualisations of the global and UK-wide distribution of SARS-CoV-2 [72]. Along with facilitating the use of genomic surveillance data in public health decision making, this tool facilitates data sharing and the creation of data visualisations, increasing capacity to analyse, interpret and share data.

**Governance and funding**

CGPS has various funders and partners who help sponsor and develop tools. For example, CGPS has partnered or received funding from multiple institutions, such as national CDCs, the ECDC, the FAO, NIHR, and the WHO [46]. CGPS is also a partner within the COG-UK consortium, which helped track the spread of Covid-19 in real time by using genomic sequencing data [66]. CGPS is also in the process of working with the WHO, with aims to integrate genomics into international AMR surveillance efforts such as GLASS-AMR (Int 3). CGPS has established a charitable or not-for-profit organisation that sits alongside the main centre, in order to scale implementation and training globally and provide other forms of support to the pathogen surveillance space (Int 3).

CGPS has also partnered with public health institutions in specific countries, including the Philippines, India, Nigeria and Colombia, to build genomics and bioinformatics capacity for surveillance as part of the NIHR Global Health Research Unit for Genomic Surveillance of Antimicrobial Resistance. These partnerships have aimed to expand capacity for genomic surveillance, and are now focused on epidemiological data linkages, interpretation and sharing of data for AMR surveillance and public health decision making (Int 3).

Notably, there is no financial return from CGPS as an academic centre, although it provides a service that is valuable to pathogen surveillance efforts. Whilst CGPS has funding from a number of large donors, it has noted that the recurring grant model is not a sustainable model for them to scale up (Int 3). One option would be to create a subsidised model through the non-profit arm of CGPS, with high-income countries paying for services, which will then subsidise costs for low- and middle-income countries. Public-private
partnerships are also a possibility, since NGOs and private companies could potentially benefit from the surveillance that CGPS enables, for example in developing targeted vaccines, therapeutics or diagnostics for infectious diseases (Int 3).

**Strengths of the initiative**

CGPS provides valuable resources to increase capacity to conduct genomic pathogen surveillance. Several aspects of these tools make them impactful in terms of supporting the use of genomic data in pathogen surveillance and public health decision-making. CGPS tools are open-access and free to use, making them accessible to different types of stakeholders who are interested in conducting pathogen surveillance using genomic data, from large national health institutes to smaller organisations collecting data at a local level. Some tools, such as EpiCollect and Microreact, allow data to be collected and visualised without internet access, which supports surveillance efforts in LMIC regions and other areas with limited digital infrastructure [73] and in locations without bioinformatic expertise. Using CGPS tools also does not require in-depth knowledge of web programming or particularly technical knowledge of epidemiology, which helps increase capacity in settings where this type of expertise is in short supply. Where specific knowledge or know-how is required, CGPS also provides training modules for using their tools (Int 3) and supports external training to build knowledge and skills for sequencing and analysis [73].

Genomic surveillance requires access to publicly available sequencing data, to help identify pathogens, assess potential for resistance and contextualise data. Tools provided by CGPS provide access to such data, while also contributing to the body of publicly available information by allowing users to upload certain types of data (excluding identifiable full genomic sequencing data, private metadata and confidential data such as patient records) to publicly available databases [66, 73]. This provides a data privacy framework that attempts to balance the risks associated with sharing personal and identifiable data, with the need for publicly available data to conduct genomic surveillance activities. Lastly, the ability of the tools that CGPS provides to automatically create metadata, and to store private metadata that is relevant within specific organisations or projects, is also a strength. This improves how metadata are collected and used, and in turn enhances data quality, improves the ability to integrate genomic data with other sources of data, and allows researchers to conduct more customised analyses using private metadata [66].

**Weaknesses of the initiative and challenges faced**

Genomic data surveillance presents unique challenges in terms of data privacy and data security, which CGPS must consider in the tools it provides and the activities it conducts (Int 3). There are additional challenges relating to the legal and regulatory requirements for genomic data, which vary between countries (Int 3). To help address this challenge, CGPS provides ‘private rooms’ for data, so that information is available to those collecting and analysing data and to relevant partner organisations, but not more widely. CGPS has also installed tools locally behind firewalls or within secure cloud-based technologies in order to ensure health information is protected in a manner which meets IT security requirements (Int 3).

However, there remain challenges around the representativeness of genomic data, in part due to the varying capacity of countries in terms of genomic facilities and adequately trained staff. Pathogenwatch, for example, sees significant variation between high-income
countries and LMICs in terms of the number of genomes included in public databases and uploaded to Pathogenwatch [71]. CGPS can help address this challenge by building capacity to generate data in settings which are currently underrepresented, although this challenge requires significant global support beyond CGPS to overcome.

Additionally, as genomic surveillance is a relatively new field, there is not always agreement on best practices (e.g. in terms of data pipelines). In some cases, CGPS plays a coordinating role in bringing experts and stakeholders together to create best practice guidelines, and to communicate these standards throughout relevant networks (Int 3). However, these standards subsequently need to be endorsed by global public health authorities (e.g. the WHO) in order to be perceived as authoritative (Int 3), which requires coordination and buy-in from stakeholders beyond CGPS.

Another challenge faced by CGPS is meeting the needs of many different types of stakeholders, ranging from lab scientists to epidemiological experts to national health ministries, which each have different needs and interests. For example, each stakeholder will often want to look at data at different levels of granularity, and so CGPS tools must be adaptable to allow for this (Int 3). There is also high demand for the service that CGPS is providing, which can be hard to fulfil and meet. For example, the initiative receives a high number of requests for local versions of the tools they provide, along with a high number of queries, reports of bugs in the system and suggestions for additional features. While this feeds into the development process for its tools, CGPS is not always able to keep up with demand. However, it reports that the recently established non-profit arm should help build capacity to respond to such requests and help the initiative scale up (Int 3).

Use of data and analysis in public health activities and decision making

CGPS has contributed to public health activities and decision making in a number of ways. For example, CGPS supported public health action through its contributions to Covid-19 surveillance, including by providing highly visual means of communicating the results of genomic surveillance to decision makers [66] (Int 3).

Various stakeholders use CGPS’s resources to improve their surveillance efforts. For example, the ECDC’s EpiPulse system (Case Study C) uses EpiCollect technology and other CGPS tools, providing national health ministries with the ability to analyse their own data and create data visualisations (7). CGPS’s networks and partnerships with relevant stakeholders also help encourage the use of genomic data in pathogen surveillance – for example, it has developed a framework to conduct surveillance across a number of partner countries through the NIHR-funded Global Health Research Unit for Genomic Surveillance of AMR, which has informed the surveillance strategies of the Philippines, India, Nigeria and Colombia (Int 3).

Along with supporting public health decision making, CGPS also provides tools that are useful in the development of medical countermeasures against infectious diseases and AMR, such as vaccines and therapeutics [71]. For example, the tools provided by CGPS can be used to understand the need for these products, to collect sequencing data which can be helpful in identifying drug targets and other relevant aspects of product development, and to monitor the impact of interventions.

Conclusions

CGPS offers an example of how initiatives can provide overarching support to help build global capacity for pathogen surveillance, in this case through supporting the collection, analysis and
integration of genomic data alongside other sources of data about infectious diseases and AMR. By focusing on capacity building, CGPS addresses some of the challenges that would be difficult and costly for single, small-scale, local initiatives to address alone, such as developing customisable tools for data collection, processing and analysis.

CGPS innovation and pilot projects have been funded by multiple governmental and charitable institutions. However, the future sustainability of CGPS will rely on establishing a long-term funding model, possibly related to the further development of the non-profit operational arm of CGPS. Establishing this model will likely require consideration of the monetary and economic value of genomic surveillance in pathogen surveillance efforts and public health activities, alongside the resources required to run these types of initiatives. Relationships are also a key aspect to what CGPS is able to achieve, and scaling the initiative would require additional connections with national health ministries and demonstrations of value to support the integration of genomic data into national surveillance activities (Int 3).

4.3. Case study C: EpiPulse

EpiPulse is an online portal to facilitate the collection, analysis, sharing and discussion of infectious disease data between European public health authorities and partner organisations. It was launched in June 2021 and sits within the European Centre for Disease Prevention and Control (ECDC). It is a voluntary system, and works alongside the ECDC’s Early Warning and Response System (EWRS), which is restricted to public health authorities in EU/EEA states responsible for mandated reporting of infectious diseases. By enhancing the ability of EpiPulse users to detect and assess the threat level of infectious diseases, and providing rapid access to surveillance data, the portal aims to strengthen the ability of its users to prevent and control infectious diseases across EU and EEA Member States and partner institutions.

Although EpiPulse is a relatively recent development, it is the result of integrating of a number of previously independent European pathogen surveillance systems: the European Surveillance System (TESSy); the Epidemic Intelligence Information System (EPIS) platforms; and the Threat Tracking Tool (TTT) [74].

Collecting data

EpiPulse collates a range of indicator- and event-based infectious disease surveillance data, including data on outbreaks and epidemics, whole-genome sequencing (WGS) data, information about health determinants, and other forms of pathogen data [74]. The portal also allows users to upload other information, such as documents, protocols and surveillance guidelines [75]. The portal is structured into disease areas [76, 77] under three categories: cases, events and documents, and molecular typing.

EU and EEA Member States and partner institutions are strongly encouraged by the ECDC to share relevant data through EpiPulse to facilitate rapid access and sharing, [75, 78]. For example, the ECDC has invited DG SANTE, the European Food Safety Authority, nominated experts in Member States, and public health authorities to contribute to EpiPulse. However, data and information sharing is ultimately voluntary, with no legal or binding framework mandating data submission and reporting.

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Analysing and sharing data

To share data about particular events of interest, EpiPulse uses event codes, allowing for all data and information relating to a public health risk to be stored and accessed within the portal [79]. These event codes can be shared with EpiPulse users to invite them to submit information or data to an event. For example, during the Covid-19 pandemic, the ECDC invited particular EU and EEA Member State institutions to submit data on variants of SARS-CoV-2 [80]. Data and information stored on EpiPulse is confidential [80], with only those authorised to access data (through event codes) able to see it. The ECDC, national public health institutions and other authorised users are able to access data associated with an event to inform pathogen surveillance activities.

Along with sharing data through the system, information about infectious diseases can be shared using the EpiPulse system in the form of signals, events and threats. Where needed, events can be shared with relevant international stakeholders such as the WHO. EpiPulse users can also message through the platform to communicate about infectious diseases and public health responses [81].

For instance, relevant international health agencies were informed of outbreaks of Salmonella Bovismorbificans ST142 and monophasic Salmonella Typhimurium ST34 in part through the online portal [82]. These forms of instant communication have been noted to facilitate development of risk management strategies [83].

Governance and funding

The ECDC receives funding from the EU budget, and works closely with the European Commission, its DGs (particularly DG SANTE) and other EU Agencies such as European Food Safety Agency (EFSA), European Medicines Agency (EMA) and EEA. The ECDC is responsible for the governance of EpiPulse, which does not fall under regulation in the same way that other initiatives do (such as the EWRS, under which EU/EEA countries are required to report surveillance [84]).

Access to EpiPulse is controlled by the ECDC, and can be granted for all domains, or for specific events and threats. For example, access has been granted to the European Food Safety Agency, DG SANTE, the WHO and national public health authorities. National governments are responsible for appointing experts within their countries to access EpiPulse [74].

Strengths of the initiative

One of the main strengths of EpiPulse is its ability to link different types of data to events of interest, with EU and EEA Member States able to see all available data relating to a public health risk at once and in real time. The ability of the system to create alerts and prompt communication about specific events also facilitates rapid communication about public health responses and facilitates coordination among relevant stakeholders.

Speed is another key strength that allows near real-time cross-border data sharing. For example, rapid sharing of genomic data through EpiPulse has been credited as an important factor in detecting and reporting on the monkeypox outbreak in Europe, with relevant information disseminated quickly to partners in Europe and internationally [85]. Similarly, EpiPulse’s real-time data visualisation functions were helpful in detecting and subsequently limiting the impact of Campylobacter gastrointestinal illnesses [86].

Another strength of EpiPulse is the diversity of data that can be uploaded to the system. Being able to link epidemiological data, case-based reports, surveillance guidance documents, and genomic sequencing data also allows
for more comprehensive surveillance. For example, the portal allows for the integration of genomic surveillance, which has been helpful in detecting disease outbreaks. Another example can be seen in the case of a study looking at Hepatitis A virus amongst the Irish Traveller community which highlighted the importance of genomic surveillance and sharing sequences for robust investigation and control of outbreaks [87].

Weaknesses of the initiative and challenges faced

The voluntary nature of data and information sharing on EpiPulse is a potential weakness of the platform. However, given its status as a key centralised surveillance tool in Europe, and the legitimacy of the ECDC as an institution, this voluntary submission of data may not be such a challenge.

EpiPulse is a somewhat restricted tool in that only European public health authorities and global partners can collect, analyse and share the infectious disease data [84]. EpiPulse has restricted access (with specific nominated users), whereas other tools enable wider public access and contributions. As such, this could limit the amount of data inputted into the system, but equally ensures that what is provided is of good quality and reputable.

Use of data in public health activities and decision making

Despite only being launched in mid-2021, the platform has been used to detect outbreaks of infectious diseases across multiple countries. The most notable use of EpiPulse data and information in informing public health activities can be seen in outbreak reports and recommendations from the ECDC, in which data from EpiPulse is a primary source of information.

For example, reporting about a recent multi-country outbreak of Salmonella Virchow ST16, linked to chicken meat [81], relied on data submitted by EU Member States, the United Kingdom and the United States to EpiPulse to identify the common strain. This then triggered a joint Rapid Outbreak Assessment by the ECDC in collaboration with the European Food Safety Authority (EFSA), which helped trace outbreaks, identify sources and inform public health actions. A similar example can be seen in the case of Shigella sonnei in the EU/EEA, United Kingdom and United States amongst travellers returning from Cabo Verde [79], whereby data submitted to EpiPulse led to a Rapid Risk Assessment, which informed recommendations to educate healthcare professionals on risks amongst travellers; and to interview travellers with confirmed cases to identify high-risk areas.

Conclusions

EpiPulse allows for rapid cross-border sharing of relevant data about public health events amongst international stakeholders, public health authorities and other authorised users. While mandated reporting of infectious diseases takes place through another ECDC platform, EpiPulse is an important initiative that supports pathogen surveillance at the EU level. It provides an example of how voluntary systems can facilitate rapid data access, to help make sure analyses are quickly fed into public health decision making.

Rather than only provide a data-sharing platform, the EpiPulse initiative also supports public health action by helping relevant stakeholders to coordinate outbreak response. For example, the organisation of surveillance data into events, the ability to share access through event codes and the communication and alert system facilitated through the EpiPulse platform can help public health authorities coordinate public health actions.
4.4. Case study D: EU Sewage Sentinel System for SARS-CoV-2 (EU4S) and the Digital European Exchange Platform (EU4S-DEEP)

The EU Sewage Sentinel System for SARS-CoV-2 (EU4S) is a wastewater surveillance consortium (commenced 2021) that was established by the European Commission following a feasibility report published by the Joint Research Centre (JRC) in mid-2021 [88, 89]. EU4S was founded on the grounds that wastewater surveillance can complement other forms of pathogen surveillance and provide insight into the prevalence of pathogen variants by analysing raw sewage and wastewater [90, 91].

EU Member States have been strongly encouraged to develop strategies to use wastewater monitoring for their national surveillance strategy for SARS-CoV-2 in guidance published on 1 October 2021 [91]. This guidance included information on the design and management of wastewater surveillance systems to detect SARS-CoV-2, and methods for sampling, testing and analysing wastewater data [91]. Through EU4S, relevant stakeholders are encouraged to share data through the Digital European Exchange Platform.

The Digital European Exchange Platform (EU4S-DEEP) was established to collect harmonised data and display data gathered through EU4S [90]. It is designed to support the prompt sharing of wastewater surveillance data, and promote the use of this data to inform public health decision making. EU4S-DEEP focuses on five objectives: gathering and sharing best practices; collecting results from wastewater surveillance activities; publishing and regularly updating sampling and analysis methods; creating a voluntary list of experts involved in wastewater surveillance; and facilitating collaboration [90].

Collecting data in Member States

EU4S provides guidelines and suggestions for Member States around data collection for wastewater surveillance. For example, Member States are encouraged to ensure that their wastewater surveillance system covers a significant part of the total population and that sampling strategies adhere to certain minimum expectations regarding frequency and adaptability [91]. Specifically, the system should cover large cities with populations over 150,000, with other sites established on a case-by-case basis to ensure coverage of the population and specific vulnerable communities of interest such as retirement centres, transport hubs, education centres and hospitals. According to the guidance, sampling should occur no less than twice a week, although it also states that this should be scaled up or down depending on the pathogen spread in the country [91]. The guidance also provides Member States with details and guidance on sampling; for example, that samples are taken over a period of 24 hours and during specific weather conditions to minimise the influence of meteorological events [91].

In terms of data harmonisation, EU4S encourages members to contribute to and use the Public Health Environmental Surveillance Open Data Model (PHES-ODM, which originated in Canada) which includes structures for open data sharing for wastewater surveillance. For example, this model sets out mandatory fields for data collection and analysis, report

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8 EU4S (https://wastewater-observatory.jrc.ec.europa.eu/)
9 https://docs.phes-odm.org/
templates, data dictionaries and GitHub-based resources for coding and metadata to support analysis [92].

**Process of analysing data within Member States and sharing data via EU4S-DEEP**

Analysis of wastewater data takes place within Member States themselves, and results are then reported via EU4S-DEEP. Member States are encouraged to analyse the samples they have collected for the presence of SARS-CoV-2 twice a month [91]. These analyses should be carried out in proficiency-tested labs with RT-PCR methodological approaches, in accordance with all relevant standards for such methods, and variants should be detected by gene sequencing. The European Commission provides several tools via EU4S to help Member States carry out analyses — for example, they provide a tool to aid nucleic acid amplification testing (NAAT) and reference material for analytical quality control [93].

Wastewater surveillance is meant to complement other forms of pathogen surveillance. For example, Member States are encouraged to develop national-level structures, in partnership with relevant authorities, to ensure that datasets from wastewater surveillance are appropriately merged and linked with other types of surveillance data [91].

EU4S also provides access to documents about wastewater surveillance and water-cycle epidemiology in the EU and technical reports detailing the results of wastewater surveillance in Member States. The data submitted via EU4S-DEEP is also visualised on a dashboard available via the web, which brings together national, regional and local data. Although national dashboards (owned and operated by national public health authorities) and some regional dashboards are available, a European dashboard which brings together all data submitted to the system is still under development. Stakeholders involved in EU4S are also directed to resources published by the Covid-19 Wastewater-based Epidemiology (WBE) Collaborative, which also provides data visualisations that link international data sources.

**Funding and governance**

EU4S is an initiative of the European Commission that is managed by the Joint Research Centre (JRC). The JRC is responsible for providing independent, evidence-based knowledge and science to support EU policies, and is funded through the EU budget. National health authorities are responsible for analysing and providing access to data visualisations from their own national wastewater surveillance activities, which are then linked to on the EU4S website. Regional, municipal and local initiatives can also provide links to data visualisations, as can smaller initiatives (e.g. pilot programmes and individual studies) that undertake wastewater surveillance projects. A current list of partners and contributors is available on the EU4S-DEEP website [94].

Member States are responsible for their own wastewater surveillance strategies, and are able to draw on guidance and resources provided by the European Commission [91]. The Commission specifically encourages members to comply with the principles of ethical surveillance for public health activities laid out by the WHO [95].

**Strengths of the initiative**

Although submitting data to EU4S-DEEP is voluntary, its use has been strongly recommended by the European Commission [47], which provides legitimacy and encourages uptake. For example, EU grants supporting wastewater surveillance require data to be uploaded to EU4S-DEEP [96]. EU4S-DEEP has a range of partners and contributors [94] and has held town hall meetings to encourage further
engagement between experts, decision makers and non-state actors [97].

EU4S-DEEP allows wastewater surveillance data to be shared internationally, which helps coordinate responses to the pandemic. For example, the ability of the platform to support detection of variants of SARS-CoV-2 (e.g. through genomic sequencing data) has allowed multiple variants to be identified and tracked internationally [98]. EU4S’s international scope also influences how data is used to inform public health decision making. Data can be shared with EU/EEA countries and non-EU countries, which is particularly useful for countries that do not have access to strong wastewater surveillance information. The initiative also maintains strong connections with the WHO and other relevant institutions that provide support for implementing wastewater surveillance systems and conducting pathogen surveillance [91].

Along with providing a platform to share data and information, EU4S also shares best practice information, such as tools for analytical quality control and method implementation [93]. This encourages the uptake of rigorous and efficient processes for wastewater surveillance, and helps harmonise wastewater surveillance practices internationally. More harmonised data will be useful in developing larger-scale dashboards where information can be views across countries, as is currently being developed for European-wide data visualisation, to be hosted on the EU4S website [99].

**Weaknesses of the initiative and challenges faced**

Wastewater surveillance for monitoring infectious diseases and wastewater-based epidemiology is an emerging area which received increased attention during the Covid-19 pandemic. As such, the EU4S initiative has faced the challenge of helping to establish and share best practice in a space that is rapidly developing. To help accomplish this, the initiative has linked with stakeholders in wastewater surveillance, both within and outside of public health. EU4S also aims to share best practice guidance, and host events to discuss wastewater surveillance with relevant stakeholders.

Submitting data to EU4S-DEEP is strongly encouraged by the European Commission, but not mandatory. This has also created challenges in terms of data availability. At the time of writing, out of the 30 EU/EEA countries, national data dashboards were not available for Bulgaria, Croatia, Estonia, Finland, Greece, Malta, Poland, Portugal or Romania.

**Use of data and analysis in public health activities and decision making**

The harmonised data in EU4S-DEEP allows users to follow SARS-CoV-2 trends across the EU, which is particularly useful for variant tracking. For example, researchers in Italy used wastewater surveillance data from 737 sewage samples from Italy to ascertain prevalence estimates of SARS-CoV-2, and were able to identify how the Omicron variant spread through the Italian population [100]. At the international scale, data gathered under the EU4S-DEEP initiative has been used to compare SARS-CoV-2 mutation profiles across variants known in the EU, and give an overview of the variants in circulation at the time in 54 European cities [98].

There could also be potential for the EU4S-DEEP system to be used for other wastewater surveillance initiatives. For example, wastewater surveillance can be used to track other pathogens, such as polio, influenza and hepatitis A, as well as the use of pharmaceuticals and illicit drugs. It may also be used in areas outside of public health, such as to inform policies about agriculture, energy, climate and the environment. The Knowledge
Hub for Water (another European Commission initiative managed by the JRC) includes more information about how the European Commission intends to use wastewater surveillance [101].

Conclusions

The EU4S initiative has worked to establish a stronger community of practice for wastewater surveillance for SARS-CoV-2 across the EU. This provides an example of how initiatives can help establish and share best practices, and support capacity in an emerging area of public health surveillance.

Wastewater surveillance will likely become increasingly used in the areas of public health and infectious disease surveillance in the future, and is helpful in overcoming capacity constraints in certain settings. As this type of data is integrated with other types of surveillance data and used to inform public health decision making, EU4S and other initiatives focusing on wastewater surveillance may become more central to pathogen surveillance internationally.

4.5. Case study E: The Global Influenza Surveillance and Response System (GISRS)

The Global Influenza Surveillance and Response System (GISRS) is a WHO initiative founded in 1952. Its mission is to protect people from the threat of influenza through surveillance, preparedness and response; to provide a global platform for monitoring; and to issue global alerts for novel viruses and other respiratory pathogens [24]. GISRS is a large-scale initiative, and tests approximately 1 million clinical samples per year and reports several hundred thousand influenza-positive results to the WHO [102].

GISRS is part of routine influenza surveillance, which supports knowledge and understanding of seasonality and the start and end of influenza season, vaccine production, and the evolution of viruses. Data from the GISRS system is also used to monitor high-risk groups, assess severity, estimate disease burden, monitor antiviral susceptibility, and detect unusual or unexpected events and outbreaks [103].

GISRS works across 125 WHO Member States through monitoring alerts and surveillance. It works with National Influenza Centres (NICs) which collect virus specimens in their country and perform preliminary analysis before shipping specimens to WHO Collaborating Centres (CCs) for further advanced analysis [24]. These results then form the basis of WHO recommendations for influenza vaccines and response [24]. FluNet, which is part of GISRS and allows laboratories to upload laboratory and epidemiological data, was launched in 1997 [102].

This initiative covers seasonal, pandemic and zoonotic influenza and also some non-influenza emergencies such as Covid-19 and respiratory syncytial virus (RSV) [24]. It is also linked with other WHO-run efforts, such as the Pandemic Influenza Preparedness Framework (PIP FW), a formal agreement between WHO member states to promote and improve pandemic preparedness and response [104].

Collecting data

GISRS works with various organisations and centres to support the process of collecting influenza surveillance data. This includes a network of NICs in WHO Member States, WHO
Collaborating Centres (CCs), H5 Reference Laboratories (H5N1) and Essential Regulatory Laboratories (ERLs) [24].

NICs are one of the key stakeholders that collect data and escalate samples for further analysis where necessary. The NICs collect virus specimens in their country and perform preliminary analysis before shipping specimens and isolated viruses to WHO Collaborating Centres for advanced antigenic and genetic analysis where needed [24]. NICs act as national reference points, serving as the ‘backbone’ for sample collection and testing, procuring and providing vaccine strains for use amongst their population, and coordinating surveillance activities and outbreak response. They are required to send and submit laboratory and epidemiological data to FluNet and FluID databases [105]. Country-level data is updated and available weekly, with results presented in various formats such as tables, maps and graphs [106].

WHO CCs work one level above NICs within GISRS. They are laboratories located across the globe, and are responsible for maintaining national and international surveillance data, conducting advanced viral antigenic and genetic characterisation, selecting vaccine strains based on available surveillance data, maintaining a repository of vaccine isolates, and providing resources to other partner laboratories. H5 Reference Laboratories provide specific support relating to avian influenza, and ERLs support surveillance by standardising protocols, producing reagents, and engaging in other essential supportive activities.

Analysing and sharing data

The WHO shares results from pathogen surveillance by publishing data that has been uploaded to FluNet on a weekly basis. The data collected through GISRS also informs the WHO’s guidelines and recommendations, which are made available as needed to inform outbreak response strategies and other public health activities.

The EpiFlu database, which is coordinated by the Global Initiative for Sharing All Influenza Data (GISAID), is the data-sharing platform used by GISRS [107]. Database Access Agreements govern each individual’s access to and use of data in the EpiFlu database and define a code of conduct between providers and users of the data. EpiFlu is designed to meet the needs of influenza research and public health communities, and to provide a ‘one stop’ search for available influenza virus sequences which can be sorted using a variety of search criteria [108]. The database includes FluServer, which is a tool to interpret the impact of certain mutations of influenza, and NextFlu, which provides open access to regularly updated analyses of the latest data [104].

Governance and funding

GISRS is undertaken by the WHO, and the initiative covers 125 WHO Member States [24]. There are 144 NICs in 144 countries, 60% of which are WHO Member States [104]. GISAID has been an important partner of GISRS [24].

Strengths of the initiative

GISRS is a large-scale initiative that has been used over time to understand influenza and other related illnesses. It now has more than 100 countries conducting surveillance and contributing to the programme, which has been facilitated by the WHO’s place as a key actor within the global pathogen surveillance space [109]. Overall, the initiative is able to test more than 2 million respiratory specimens from 114 countries annually, which represents around 91% of the world’s population [110]. This large and distributed capacity is a strength of the initiative, allowing for meaningful surveillance on a global level.
The initiative is also highly adaptable; for example, it was adapted during the pandemic to include surveillance for Covid-19 [103]. It has also been adapted to include RSV, which can support national policy makers in responding to RSV outbreaks [110]. Combining influenza and RSV in one surveillance system provides benefits in terms of understanding co-infections and improving the certainty of vaccine effectiveness estimates for influenza [110].

**Weaknesses of the initiative and challenges faced**

While GISRS is a large-scale, well-resourced and longstanding surveillance system, it faces several challenges. For example, the physical handling and transport of biological material, including tracing and tracking samples, can be difficult. To help address these challenges, GISRS works with logistics services who provide advice, guidance and assistance in relation to shipping, provision of supplies and interaction with the relevant civil aviation authorities [24]. The WHO Shipping Fund Project also provides shipping services for NICs, covering the cost of shipping specimens from national labs to WHO CCs or H5 Reference Laboratories. Along with addressing logistical challenges involved in shipping, providing these services centrally also simplifies processes and improves efficiency [106].

As mentioned above, GISRS has expanded to include Covid-19 and RSV, and as such may face challenges around maintaining meaningful influenza surveillance while also expanding in scope [103]. For example, there have been challenges relating to surges in demand for testing, causing significant disruptions to data reporting, along with resource challenges [103]. There are also wider resource-related challenges within GISRS, particularly around workforce and skills, and a lack of suitable laboratory space, equipment, re-agents and other consumables [105, 109]. These issues tend to vary by country, as some locations (such as LMICs) face workforce and funding constraints and low government commitment [105]. The situation in some larger countries, for example in India where there is a single NIC serving a large population, is also sub-optimal [105]. More than 70 countries do not have a designated NIC, which affects the ability of the programme to achieve global coverage [105].

There are also specific challenges relating to RSV surveillance in terms of case definitions and lack of understanding around RSV seasonality. In some locations, GISRS sampling is confined to the specific influenza seasons, and as such may miss data that is relevant to RSV [110].

**Use of data and analysis in public health activities and decision making**

Data and analyses from GISRS have been widely used to support public health activities. For example, GISRS reporting systems became the primary platforms for sharing Covid-19 data at regional and global levels [103]. NIC-collected specimens and analyses also form the basis of WHO recommendations for influenza vaccines and response globally [24], which influences what actions WHO Member States and other international actors take to support public health and preparedness (e.g. vaccine strategies).

**Conclusions**

GISRS provides an example of a large-scale and long-term global initiative supporting influenza surveillance and response. It shows how individual national systems can be used to collate data at an international level, to support a more harmonised global surveillance system that tracks pathogens across international boundaries. This case study also speaks to some of the basic challenges in pathogen surveillance in terms of different capacities to collect and analyse data at a local level,
Data collection and sharing for pathogen surveillance particularly in LMICs. While GISRS provides support for lower-resource settings, and direct support in transporting samples, there are still challenges that affect coverage at a global level.

The WHO is expected to make several improvements to GISRS in the future, and is currently developing a roadmap for GISRS+. This will be an advanced network built upon existing influenza infrastructure, to achieve further integrated surveillance and response systems for influenza and a range of other respiratory viruses that have epidemic or pandemic potential [111].

4.6. Case study F: Global Outbreak and Response Network (GOARN) and the Early Warning, Alert and Response System (EWARS)

The Global Outbreak and Response Network (GOARN)\(^\text{11}\) was established by the WHO in 2000 to bring together research institutes, universities, international health organisations and technical networks to contribute to outbreak preparedness and response to infectious disease outbreaks of international importance [112–114]. By 2014, the network involved 153 institutions, with 37 additional networks integrated into it (which encompass 355 further members) [112].

GOARN supports two initiatives: Rapid Response Mobile Laboratories, which provide lab resources on location in different settings, and the Early Warning, Alert and Response System (EWARS),\(^\text{12}\) which offers a rapidly configurable field surveillance solution in a box, including phones, laptop, datahub storage device and solar chargers [17, 115]. This case study focuses on GOARN’s EWARS activities to support data collection and analysis in resource-limited and emergency settings.

**Collecting data**

EWARS provides equipment in low-resource and emergency settings to collect pathogen surveillance data in the field, without internet access. For both EWARS and its Rapid Response Mobile Laboratories, GOARN uses Go.Data, a mobile software tool that collects data on cases and contacts in real time. Using an app, users such as field epidemiologists, healthcare workers, contract tracers and laboratory staff, can register cases, contacts and data including laboratory samples and data on hospitalisations [116]. Go.Data allows for data to be stored within the software application, which can be accessed by other users that have been assigned roles and granted permission to access it [117]. EWARS also provides training to relevant stakeholders, such as local partners of national health ministries, to help them collect data.

EWARS collects data through standardised forms, which ask about daily consultations for certain symptoms and outcomes (e.g. acute watery diarrhoea, acute flaccid paralysis, acute fever and rash, outbreaks of unexplained illnesses and unexplained death, acute fevers with cough, prolonged fever and bloody diarrhoea). It also asks about tests that have been performed for certain infectious diseases such as malaria. This system is meant to be flexible to different types of situations, rapid to implement, and low cost, while still allowing public health decision makers to rapidly detect and respond to potential threats.

The process for data collection depends on where it is being collected from. For example, in some cases it may involve contact tracing

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11 [GOARN](https://goarn.who.int/)
12 [EWARS](https://www.who.int/emergencies/surveillance/early-warning-alert-and-response-system-ewars)
teams using phones to collect data from individuals or clinicians, who then feed into provincial centres, and eventually central systems hosted in national ministries of health or public health institutes [116].

**Analysing and sharing data**

The information inputted into the Go.Data tool can be used to generate analytics in real time. For example, the platform can be used to view the relationships between cases, contacts and exposure events, and to generate outputs that are useful in outbreak responses such as contact follow-up lists and chains of transmission, which can directly facilitate contact-tracing and outbreak response to health threats [116].

For EWARS, a basic weekly systematic analysis plan is provided, which includes processes for data cleaning; identifying the coverage, completeness and timeliness of reporting; calculating weekly case totals, and cumulative totals; visualising trends in cases over time; calculating the number of alerts triggered; and assessing outcomes. It is recommended that local teams implementing EWARS meet daily to review data and discuss suspected cases, suspected deaths, hospitalised cases, new alerts and mapping of affected (and newly affected) geographic areas [118].

EWARS also supports users in creating a dissemination plan, to share information with governments, partners, healthcare providers and communities. For instance, the EWARS user guide includes an indicative dissemination plan, with weekly dissemination using dashboards, presentations and reports to stakeholders such as national public health authorities, NGOs, health facilities and others [117].

**Governance and funding**

GOARN is organised by a steering committee consisting of representatives from network partners including the Eastern Mediterranean Public Health Network, the UN Children’s Fund, Institut Pasteur de Dakar, the National University of Singapore and the Public Health Agency of Canada [113]. The steering committee oversees implementation, planning and evaluation [112, 113]. GOARN is supported by the WHO, with WHO regional offices facilitating the deployment of GOARN teams [112]. EWARS also has a technical working group and sub-groups to share learning and review modules [118].

EWARS surveillance is conducted by national public health authorities using the equipment and networks supplied by GOARN and EWARS, with support from the WHO [17, 118]. The funding for GOARN comes from a range of organisations including the European Civil Protection and Humanitarian Aid Operations (ECHO), the Office of US Foreign Aid Disaster (OFDA) and the German government [17].

**Strengths of the initiative**

GOARN’s focus on providing modular technologies through EWARS that help account for site-specific capacity issues such as a lack of stable internet connection, power supply or computing power, ensure that GOARN is able to facilitate outbreak response in a variety of different settings. Both EWARS and Go.Data are adaptable for use by skilled and unskilled users, and support is also provided through the WHO to help train local users on how to use the tool [116, 118, 119]. For example, individuals are deployed to assist with rollout at national public institutes, and to brief and train staff in how to use and configure the tool for local use. This is also complemented by open-access training content for users to study in their own time.

EWARS has been found to be effective in identifying and helping inform response to outbreaks in the field in multiple different settings, including following natural disasters [17, 112, 116, 120]. The programme has also
been found to be flexible, and relatively low cost, with 50 surveillance kits costing $15,000 and facilitating surveillance for approximately 500,000 people [17]. In Nigeria, EWARS was integral to the early detection of outbreaks of measles in 2016–2019, cholera in 2018 and several other diseases [17].

Field laboratories used by GOARN are designed to meet the requirements of use, with training and capacity building provided by the WHO to ensure readiness for use. This enhances both the technical and human resource capacity for disease identification and monitoring, such as during the Ebola outbreak in Uganda where the CDC used such laboratories to diagnose suspected infections in patients [112, 115].

**Weaknesses of the initiative and challenges faced**

Although EWARS is designed to increase capacity for data collection and rapid, action-oriented analysis in low-resource settings, there are still gaps around capacity and skills that affect pathogen surveillance efforts in these settings. For example, there are capacity gaps around language skills, and the capacity to provide leadership and response coordination in these settings [112]. Other capacity-related challenges include potential lack of staff motivation, training, and supervision to engage with the initiative and contribute to its work [115, 118, 120]. There are also issues around local partners not understanding the boundaries of the data (e.g. which symptoms to report, along with location and geographical limit of the programme) that should be collected through EWARS [118]. Furthermore, in some cases, EWARS used an ad hoc Excel-based system and had no standardised information tools due to remote field settings with reduced access to resources [17, 121], limiting reproducibility and data-sharing opportunities. As a response, GOARN partners and the WHO have developed training programmes to support skills in international outbreak response leadership [112].

Although an internet connection is not required, a mobile cellular service is needed, and the initiative is limited by lack of availability of mobile networks and functional telecommunication systems in some remote areas [17, 120, 121]. One example described how staff ran out of mobile phone credit, which led to delays in reporting and variation in data quality [120]. In response to these infrastructure challenges, the performance of EWARS is regularly monitored to identify where support is needed at 3- to 6-month intervals [122] (4).

Wider contextual events present further challenges too, including the rapidity and regularity of refugee movements and displacement in LMICs, for example. This poses significant barriers to data collection, and surveillance strategies must also seek to capture both ‘undocumented’ and established populations [123]. EWARS has reportedly experienced challenges related to cross-border monitoring, as there are inconsistencies in timeliness and method of reporting [123]. There may also be issues related to EWARS in terms duplication of efforts with other activities and surveillance partners [17]. To help resolve these issues, it would be helpful to support more connection and integration with other initiatives that support rapid responses to outbreaks of infectious diseases [115]. Wider geographic coverage would also be helpful in terms of making sure that EWARS and GOARN are able to identify and enable response to outbreaks at a global level [112].

The initiative also faces particular challenges with certain diseases and pathogens. For example, early detection of outbreaks of diseases such as Zika and Chikungunya pose a challenge as there are no universally accepted sets of indicators for early warning [124]. As
such, the tools provided by GOARN and EWARS may not be comprehensive enough to identify risks associated with these illnesses, which contributes to fragmentation in the reporting and collection of data for these pathogens [17].

Use of data and analysis in public health activities and decision making

Since 2000, GOARN partners have responded to major outbreaks of conditions including cholera, dengue, encephalitis, influenza, meningitis and yellow fever [112]. Data suggests that, as of 2014, this covered 137 missions and 31,629 person days across 79 countries [112]. The primary aim has been to provide rapid support, and deployments also support the development of local, national and international capacities to respond to outbreaks [112].

In some particular regions, including South Sudan in 2016, the initiative has developed additional components to EWARS to help track cases of specific pathogens and conditions [17]. This has since led to a more targeted response to cholera outbreaks in South Sudan, and plans to implement oral cholera vaccines in local community centres where outbreaks are expected [17].

In Bangladesh during the Rohingya refugee crisis, 151 health facilities run by 23 humanitarian organisations were enrolled and trained as EWARS reporting sites, serving around 700,000 refugees [125]. In this example, EWARS played an important role in informing public health action. For example, it helped to create mapping alerts related to measles and identify the affected age groups to target vaccination campaigns [125]. It also led to alerts for acute jaundice cases which facilitated a team from the Bangladeshi Institute of Epidemiology, Disease Control and Research to collect samples and identify outbreaks [125].

Conclusions

This case study provides an example of an initiative which aims to strengthen capacity in low-resource settings to collect data and conduct simple analyses that help public health decision makers rapidly identify and respond to outbreaks. This gives an insight into how international stakeholders such as the WHO can support public health decision making and action, even where data is patchy and not always able to be integrated into wider national and international surveillance activities due to issues around standardisation and data quality.

There could be opportunities to improve how data collected through GOARN and EWARS is integrated into international surveillance efforts, for example by standardising how data is collected and inputted into central databases. However, efforts to support this must also balance the need to enable data collection by low-skilled staff, and ensure sufficient capacity to implement any improvements to the system.

4.7. Case study G: The Pan American Health Organization (PAHO) Epidemic Intelligence (EI)

The Pan American Health Organization (PAHO)\textsuperscript{13} is a Regional Office of the WHO, and is in charge of international health cooperation in the Americas. Much of its work is related to infectious diseases, with departments working on: Communicable Disease Prevention, Control, and Elimination; Health Emergencies; and Evidence and Intelligence for Health Action (EIH).

\textsuperscript{13} PAHO/WHO (https://www.paho.org/en)
PAHO’s Epidemic Intelligence (EI) programme is delivered by the Health Emergency Information and Risk Assessment (HIM) Unit at the Health Emergencies Department. EI is a cycle of organised and systematic data collection, analysis and interpretation which aims to support the detection, verification and response to potential health risks [126]. The initiative covers a variety of pathogens and diseases including cholera, diphtheria, measles, yellow fever, polio, dengue, Chikungunya, Covid-19 and avian influenza [126].

PAHO’s EI activity also links to the Epidemic Intelligence from Open Sources (EIOS) initiative within the WHO Hub for Pandemic and Epidemic Intelligence (Berlin). EIOS is an international collaboration of public health stakeholders to support the early detection, verification, assessment and communication of public health threats [127]; it encourages the formation of communities of practice and collaboration amongst its members, along with providing guidance, a technology platform for sharing and accessing information, and training. This initiative has been implemented by some Member States in the WHO Americas region (Argentina, Brazil, Dominica, Saint Lucia, Guatemala, Haiti) but not all [126, 127].

Collecting data
PAHO collects data on a range of pathogens, and also collates information from the WHO, public health authorities and other stakeholders such as laboratories, academic institutes and NGOs [126]. The data submitted to PAHO is continuously analysed and monitored through PAHO’s EI system (see below). Where a potential health risk is found, the data is then reviewed further, and action is taken if necessary (e.g. generating alerts or communications, further research, outbreak response mechanisms). Approximately 24,000 signals (per year) of potential health events (primarily related to infectious diseases) are screened annually by PAHO, with 5,000 further analysed and 160 leading to further action (on average three per week) [126].

The EIOS initiative aims to support standardised public health intelligence systems across organisations in order to create a unified approach to the detection, verification and communication of public health threats using the range of publicly available data [127]. Through the EIOS system, data is collated from thousands of sources (including online media, news, blogs, other initiatives) and automatically processed [128]. As discussed, this has been implemented in several countries across the Americas and supports PAHO’s EI initiative.

Analysis and sharing data
As described by PAHO, EI is a resource-intensive activity taking place 24/7, 365 days a year, and requires highly qualified staff to conduct analyses. PAHO screens and analyses all signals that come through the EI system to detect, assess, characterise, monitor and respond to threats – signals can comprise any type of data received indicating a potential outbreak, including laboratory results and clinical data. Risk assessments are a large portion of the analysis, aiming to understand the potential impact of infectious disease events, the risk of spread, and the resource implications of mitigation. Once a public health risk has been detected, information about the event is managed through the WHO’s Event Management System (EMS), which records details, WHO assessments and analyses, and official communications and decisions that have been made about a threat [126].

Data and insights from EI are shared through several formats. For example, there are publicly available data dashboards, weekly updates on certain pathogens such as Covid-19, and regular communication between PAHO, public health authorities and other relevant stakeholders that coordinate pandemic
responses. Data from EI is shared, in part, by the PAHO Mapping team within HIM, which systemically collects and visualises EI data using Geographic Information Systems (GIS) to generate maps and interactive dashboards which are made publicly available [126]. The PAHO Data, Verification and Risk Assessment (DVA) team within HIM is also responsible for assessing risks and managing information about outbreaks. This team coordinates with other WHO offices and the WHO headquarters to disseminate information and implement early warning systems.

The PAHO Epidemiological Analytics team is also involved in EI activities. They collate data on a regular basis and provide epidemiological analyses when outbreaks occur to inform decision making. Much of this team’s analyses inform the WHO’s internal decisions, although they also provide support to countries to help them implement early warning and alert systems. Other dissemination activities this group undertakes include modelling for forecasting and nowcasting for Covid-19 and other pathogens.

Governance and funding

As described earlier in this section, PAHO is a WHO regional office. It is financed through quota contributions from its Member States, allocations of funding from the WHO, and voluntary contributions from governments, international organisations and the public and private sectors [129]. PAHO main governing bodies are the Pan American Sanitary Conference, the PAHO Directing Council and the Executive Committee [129].

EI activities are delivered by the HIM Unit at the Health Emergencies Department, in coordination with a range of regional stakeholders and individual countries. The HIM team within PAHO is the International Health Regulation (IHR) regional contact point for the Americas. This means that within WHO Member States, they are legally required to be accessible for communication about health threats and to coordinate with national focal points [130].

Strengths of the initiative

A strength of PAHO’s EI activities is their ability to screen a high number of signals annually (approximately 24,000) and collate data from a range of sources across countries. The initiative’s direct responsibility for coordinating public health actions internationally, and its connection with the WHO and regional and national focal points, is also a strength that helps make sure that data from the initiative is used to inform decision making.

Outputs from EI are made publicly available, in digestible user-friendly formats to increase understanding and awareness of updates and health events [131]. This includes maps and dashboards which can be explored by public health event, and also filtered by location, status and other aspects. The visualisations provided by PAHO, for example, allow relevant stakeholders to access information to inform public health activities.

Weaknesses of the initiative and challenges faced

PAHO’s capacity to provide actionable information to support global health security through their EI activities is dependent on timely reporting of information. Therefore, one potential limitation is the quantity and quality of data that is submitted to the system. Capacity to collect and supply information likely varies between countries, and is dependent on local reporting of cases and outbreaks. The capacity building and training activities that are provided by EIOS help mitigate this issue, although the initiative has limited engagement and does not address all capacity issues. Funding availability is also key to capacity, as some regions will
Data collection and sharing for pathogen surveillance

have substantial need but significantly lower funds or capacity to meet this need.

Since data is collected by different types of stakeholders and across different countries, there also may be challenges related to data harmonisation and collecting good metadata. The initiative does work with and support the EIOS collaboration, which has efforts in data standardisation. However, there were no mentions of these challenges related to EI in the sources reviewed to develop this case study.

Use of data and analyses in public health activities and decision making

EI informs and supports a range of public health activities and decision making through continuous data collection, analysis and sharing [126]. Once an event is recorded it is managed, monitored and assessed to determine whether additional support or response activities are needed. For example, the WHO EMS recorded over 2,000 events for the Americas region from 2001 to 2022 and supported subsequent action, where appropriate, many of which were assessed using data from PAHO's EI activities.

Conclusions

This case study offers an example of an initiative that provides continuous monitoring of infectious diseases through timely analysis and reporting. PAHO is a regional office for the WHO, and their EI activities are part of a large-scale coordinated effort to share information about health threats internationally. The approach employed by PAHO's EI system, with data continuously analysed and threats escalated to more central bodies where needed, provides one model of how data from disparate systems can be used to inform international action.

Another key takeaway from this initiative is how it integrates a range of sources from various data contributors with the hope of creating a unified system working towards early detection, verification, assessment and communication of public health threats. It also works with other ongoing established initiatives, such as the WHO's EIOS, in its work highlighting wider collaboration and cooperation.

4.8. Case study H: Chinese Pathogen Identification Network (PIN)

The Chinese Pathogen Identification Network (or China PIN) is the national laboratory-based surveillance network for bacterial diseases in China [19, 132]. The primary aim of the network is to support the early detection and tracing of bacterial diseases, such as cholera and typhoidal Salmonella, with a focus on antibiotic resistant strains [19, 132, 133]. PIN developed out of the national reporting system for bacterial disease in China, first established in 1959, and was integrated into the China CDC-established PulseNet International Network for foodborne diseases in 2004. While this was the first use of a computerised database for the reporting and recording of bacterial diseases in China, the database only stored clinical diagnoses and epidemiological records rather than the biological data of pathogens [19, 134]. In 2017, PulseNet China became China PIN, and began to collect bioanalysis data of bacterial pathogens from network laboratories within China, while continuing to feed into PulseNet [19].

Collecting data

The China PIN network collects data from network laboratories at five levels within China: sentinel, county, municipal, provincial and national [19, 132, 135]. At the sentinel level, clinical sentinel laboratories conduct basic data collection and cultures of samples. The
county CDC labs, at the second level, transfer the isolates to the municipal and provincial labs, who coordinate a field investigation, conduct lab work and data processing, and manage the system at a local and regional level respectively. Finally, the national China CDC lab coordinates management of the entire network, conducts data processing and prepares information for release throughout the network [135]. The data is uploaded through a web-based information system to a central server where it can be analysed, and is inputted into a database for comparative analysis of pathogens and tracing of pathogenicity [19].

Analysing and sharing

The analysis for China PIN is conducted by China CDC labs at the national, provincial and municipal levels [19, 135]. Once a case is identified and a sample has been cultured by a clinical sentinel lab, the pathogen is identified and sequenced genomically. From here, cluster detection is used to identify similar pathogens and inform protection measures [19]. By submitting a query in the system, network laboratories can use a combination of epidemiological data and laboratory analysis to show typing clusters of pathogens and inform investigations of spread [19].

The China PIN platform includes a Core/Whole Genome Multilocus Sequence Typing (CgMLST) pipeline, which provides a useful tool to identify outbreaks of certain pathogens such as *C. difficile* [136].

Governance and funding

The China PIN network is nationally funded and managed by the Chinese National Health Commission (NHC) which coordinates the management of the network through the central China CDC Lab [19, 135]. The network is managed at a regional level by Provincial CDC labs and at a local level by Municipal CDC labs, which are under the jurisdiction of Provincial and Municipal Health and Family Commissions respectively [135].

Strengths and weaknesses of the initiative

There is limited information about the strengths of the China PIN initiative due to a lack of available English-language sources. Nonetheless, the network has responded to more than 150 public health events and played a role in the detection, confirmation, tracking and risk assessment of diseases, which has informed the management of disease outbreaks [19, 137].

There was also limited information on the weaknesses or challenges faced by China PIN due to a lack of available English-language sources. Sources which were available indicated that network laboratories are in need of capacity support, and stressed the need for further synergy between the China CDC and medical institutions in China [19, 136].

Use of data and analysis in public health activities and decision making

As noted previously, China PIN has been involved in the response to more than 150 public health events, with the analysis of bacterial pathogens informing outbreak hypotheses, risk assessments and public health interventions [19]. Additionally, as of 2022, PIN has also been engaged in the Chinese Microbiome Project (CMP), conducting epidemiological surveys and collecting faecal samples from 239 healthy people in four cities to develop a greater understanding of the gut microbiome to inform understanding of and response to diseases [138].

Conclusions

Due to the limited English-language information available on China PIN, it is hard to make conclusive judgements about the potential
lessons to be learned from this case study. Additional data collection would be useful to understand the challenges that this system has faced, how they have been overcome, and how data from China PIN is fed into international surveillance strategies in the Asian continent and beyond.

4.9. Case study I: Unravelling data for rapid evidence-based response to Covid-19 (unCoVer)

The unravelling data for rapid evidence-based response to Covid-19 (unCoVer) initiative provided a research platform for real-world data about Covid-19. It aimed to facilitate access to otherwise scattered data sources and provide a harmonised, integrated repository of real-world data (e.g. from electronic health records and screening programmes). According to the protocol for unCoVer, it aimed to ‘exploit the full potential of routine healthcare data already collected from patients during the pandemic’ [37]. It arose in response to the Covid-19 pandemic – it was funded by the European Union’s Horizon 2020 Research and Innovation Programme from November 2020 to November 2022 [139], and ended after this time (Consultation 1).

unCoVer included 29 partners from 25 institutions across the European Union (EU) and 4 non-EU partners. In total, 18 countries were represented: Belgium, Bosnia and Herzegovina, Brazil, Colombia, Croatia, Greece, Ireland, Italy, Luxembourg, Norway, Portugal, Romania, Slovakia, South Korea, Spain, Turkey, the United Kingdom and the United States. Specific partner institutions included healthcare stakeholders, universities and public health institutes. In addition, the network included experts in data management, statistical modelling and research ethics. These partners provided data, along with scientific, research and medical expertise.

Collecting data

The unCoVer initiative collated real-world data that was already being collected (e.g. in healthcare settings or for research) from partners [140]. The platform integrated different types of data and databases, including electronic medical/health records, population screening databases, information on Covid-19 hospitalisation (e.g. admissions and discharges), demographics and clinical/epidemiological data (including data on onset, symptoms, comorbidities, laboratory results), and other types of data such as biospecimens, contact-tracing data and mental health data. Partners provided data to unCoVer from sources including frontline hospitals, national health agencies, registries and investigator-led observational studies [37]. Partners uploaded data to unCoVer’s centralised system through a portal. To ensure that data was harmonised, the initiative provided a common codebook with definitions, and data was inputted using a standardised format. The initiative used a federated data infrastructure (supported by Opal V.4.1, an open-source online server application), meaning that when individual-level data was uploaded by partners, it stayed within partner institutions. The centralised system only contained aggregates data, which was structured such that it could be analysed alongside other aggregate data uploaded to the system to create larger datasets for analysis.

Compliance with ethical and legal requirements (e.g. General Data Protection Regulation (GDPR) or equivalent) was checked when data was uploaded to unCoVer. Those that uploaded
data were required to complete a checklist to assess the risks involved in data processing, including questions on the nature of the data (e.g. whether it is personal data), informed consent, ethical approval data privacy and data processing. This information was then reviewed on a case-by-case basis by the ethics team and the initiatives’ Data Protection and Ethics Advisory Board [37].

Analysing and sharing data
The unCoVer initiative supported data sharing and analysis in several ways. Partners had access to aggregated data through the platform’s federated data infrastructure, and were able to conduct their own analyses on data that had been uploaded to the system. The network provided tools to aid in this analysis, which allowed analysis to be conducted without disclosing individual-level data and identifiable information to those analysing the data [37]. For example, a toolbox allowed unCoVer members to conduct pre-programmed analyses – which take into account uncertainty and prior evidence – to examine the distribution of disease prevalence [141–143].

The initiative had a dedicated work package for data analysis and outcomes, which was focused on maximising use of the data acquired for informing public health response. One of the priorities for this work package was to provide real-world evidence to inform decisions about how resources should be utilised during a pandemic [37]. There are not yet deliverables from this work package available on the unCoVer website, although a June 2022 publication noted that the data from unCoVer would likely be useful in informing burden of disease estimates at national and international levels [144].

Governance and funding
The unCoVer project was funded as part of the European Union’s Horizon 2020 Research and Innovation Programme, with a total cost of €3,045,573.50 [139] between late 2020 and late 2022. It was a Coordinating and Support Action to provide data infrastructure in response to the Covid-19 pandemic.

unCoVer was coordinated by the Prins Leopold Instituut voor Tropische Geneeskunde in Belgium (an institute focusing on innovative research, education and capacity strengthening across Africa, Asia and Latin America) [145], with 29 partners located across 18 countries worldwide [140]. There were also various advisory boards and committees for unCoVer who supported the network’s efforts and work. These included: (1) a Steering Committee with representatives from each partner; (2) the General Assembly who were responsible for the delivery of the project, comprising the project coordinator and work package leads; (3) a Management Support Team; (4) the Exploitation & Dissemination Committee, who were responsible for identifying potential areas for exploitation and providing scientific guidance; (5) the Data Protection & Ethics Advisory Board (DP-EAB); (6) the External Advisory Board, who supported work concerning the relevance of medical research and findings; and (7) the Societal and Regulatory Advisory Board for stakeholder involvement [140]. Partners were kept engaged and involved in the initiative through regular network-wide meetings, alongside dedicated meetings for each specific work stream (Consultation 1).

Due to the sensitive nature of health data and personal information, compliance with ethical and legal aspects was key to facilitating data sharing. UnCoVer employed a checklist for assessing the risks involved in data processing which considered the legal and regulatory
issues concerning data protection, privacy and information security. Every data provider within the network was required to complete the checklist, which was reviewed on an individual basis by the unCoVer ethics team and the DP-EAB. This assessment then informed risk mitigation strategies [140].

**Strengths of the initiative**

The unCoVer initiative created additional infrastructure and capacity to support Covid-19 surveillance using real-world data. One of its strengths was that it comprised many members that contributed data to the platform, analysed data and shared results, which resulted in larger datasets and additional capacity for the analysis and use of real-world data. The different expertise of unCoVer members helped ensure that they met best practices in terms of data collection, management and analysis for public health decision making. For example, one interviewee reported that the initiative was able to help standardise practice and enable data access based on their federated structure and the degree to which the initiative facilitated networking and the sharing of best practice (Consultation 1).

The quantity and diversity of data that the initiative was able to collect was also a strength – for example, the network facilitated access to several databases that hold electronic health records from hospitals across Europe among partners in the network (Consultation 1). This included various sources of patient data from electronic medical records in different countries and institutions, public health surveillance data and registers, observational research data sources, and screening data [37]. This was accomplished by collecting real-world data from members and providing a platform to integrate a wide array of different types of data (e.g. hospitalisation and epidemiological data). The initiative also took steps to harmonise data that was uploaded to the platform by providing clear case definitions and tools for standardising and validating data, which contributed to being able to analyse larger datasets to understand Covid-19 [37].

Initiatives working with real-world data must consider data protection and privacy, which was especially pressing during the Covid-19 pandemic when decisions were being made in the context of a public health emergency. The unCoVer initiative brought in experts in ethics, data protection and privacy to help inform its strategies, and included an ethics committee and regulatory advisory group [37].

**Weaknesses of the initiative and challenges faced**

UnCoVer handled highly sensitive data from electronic health records, which was not collected for research purposes. This presented challenges in terms of determining consent and ensuring robust data protection measures. The infrastructure of the data platform helped address some of these concerns. For example, users that uploaded data needed to demonstrate compliance with ethical standards, data protection and privacy legislation, which could then be verified by unCoVer. One of the main challenges unCoVer faced was establishing access to hospital data in a manner that is compliant with GDPR and other relevant national data protection legislation (Consultation 1).

The platform also used a federated data infrastructure, meaning that individual-level data did not leave host institutions. While this helped provide a secure platform for sharing data, setting up this infrastructure led to significant delays from an ethics perspective which also affected timelines for data analysis. This infrastructure required host institutions to set up legal and informatics aspects of the network, which required IT and data curation support (and therefore, additional resources,
funding and support for local partners such as hospitals) [146], which limited the countries that were able to participate in the platform. According to one interviewee, deploying this federated infrastructure was a major challenge, and there were gaps in hospital technical capacity that inhibited pathogen surveillance efforts more widely (Consultation 1).

Additionally, the use of real-world data for pathogen surveillance can be limited by how electronic health records are used across countries and across healthcare settings [147]. The unCoVer initiative focused on data that was already routinely collected and did not address this challenge.

Use of data and analysis in public health activities and decision making

UnCoVer’s key aims were to inform public health strategies for Covid-19 and reduce the impact of future pandemics by facilitating access to datasets [139]. Whilst there is clear application potential for estimating the burden of disease, understanding progression and treatment, and understanding the risk factors associated with severity [37, 146], it is unclear what studies have been conducted using unCoVer’s tools and data. The project ended in late 2022, so outputs may become publicly available in the future, although these could be difficult to track given the distributed nature of the analysis.

Outreach was a key aspect of unCoVer. For example, UnCoVer’s dissemination plans outlined that it would disseminate results through the initiative website, social media (e.g. Twitter and LinkedIn), and project newsletters sent to all partners and stakeholders. UnCoVer also partnered with other programmes doing work around the use of distributed infrastructure for public health (PHIRI), cohort data for infectious disease surveillance and public health (SYNCHROS, ORCHESTRA and ReCoDID), and Covid-19 and other health emergency response (HERoS), among others, to help create impact from their work. The unCoVer network was also highly involved with initiatives like the Cohorts Coordination Board (Consultation 1). The consultee for this initiative reported that although the initiative has ended, it is seeking to publish case studies of how real-world data has been used and is actively looking for opportunities to share the knowledge generated (Consultation 1). At the time of writing, these case studies were not available through unCoVer.

Conclusions

The unCoVer initiative provides an example of an international initiative collating a wide array of real-world data through a federated data infrastructure with many users. While this infrastructure was set up in response to the Covid-19 pandemic, similar structures may also be appropriate in other pathogen surveillance applications.

Additionally, now that the funding period has ended for the initiative, it is unclear how funding will be sustained or what will happen next in relation to this initiative (at least based on information that is available in the public domain). UnCoVer is reportedly hoping to keep developing some of its infrastructure for rapid access that was set up through the initiative, and is looking for opportunities to share the knowledge it has generated with further support from the European Commission (Consultation 1).

There are important lessons from unCoVer to improve surveillance in future pandemics. For example, the federated structure took time to set up, which delayed analysis undertaken by unCoVer members. If international systems were already in place to collate real-world data in a standardised format, this would mean routine health data could be used more quickly to inform responses to future public health emergencies.
4.10. Case study J: EU4Health

EU4Health\textsuperscript{15} is a long-standing programme of the European Commission; it is a funding programme rather than a pathogen surveillance programme specifically. EU4Health aims to generate knowledge and evidence, and works with EU Member States and third countries associated to the EU4Health programme, including Norway, Iceland, Ukraine and Moldova\textsuperscript{148}. In 2021, the new version of EU4Health was adapted, which responded to the fragilities in national health systems that were exposed during the Covid-19 pandemic in order to support crisis preparedness in the EU\textsuperscript{148}. The first EU4Health programme commenced in 2003, and the current version covers 2021–2027.

EU Regulation 2021/552 adapted the EU4Health Programme. It outlines actions and provides funding to better prepare for, prevent and control the spread of infectious diseases, including measures to support pathogen surveillance. The Health and Digital Executive Agency (HaDEA) implements the programme, with support from HERA,\textsuperscript{16} DG SANTE and other EU agencies. The programme also works with other EU programmes, including: Digital Europe and the Connecting Europe facility to develop digital infrastructure for health; Horizon Europe for health research; and the European Regional and Development Fund to improve regional health infrastructure\textsuperscript{148}.

Importantly, EU4Health is structured as a funding programme which supports various efforts across the EU related to health, including efforts on pathogen surveillance. As such, this case study follows a slightly different structure to account for the work that this initiative funds and works on.

Gaps in pathogen surveillance

During the Covid-19 pandemic, there were issues related to the existing surveillance systems in EU Member States, which many of the actions and funding in the new EU4Health programme aim to address. For example, during the Covid-19 pandemic, pathogen surveillance efforts faced delays in epidemiological data transmission from Member States to the Commission, and a lack of proficient information systems and digital surveillance systems in some countries or subregions. Furthermore, even where there was capacity for Member States to collect data, surveillance efforts were slowed by a lack of harmonisation between data from different countries and sources, and a lack of integration of methods to support epidemiological modelling, such as molecular and genomic typing\textsuperscript{96}. The Covid-19 pandemic also revealed gaps in pathogen surveillance outside the EU, particularly in low- and middle-income countries.

EU4Health support for pathogen surveillance

Whilst the EU4Health programme consists of funding for a range of public health areas, a major focus of the European Commission’s Work Plan in 2023\textsuperscript{96} has related to pathogen surveillance. Some of the actions that the EU4Health programme has supported are described below:

\textsuperscript{15} EU4Health (https://health.ec.europa.eu/funding/eu4health-programme-2021-2027-vision-healthier-european-union_en)
\textsuperscript{16} The Health Emergency Preparedness and Response Authority (HERA) was established in 2021 in response to the Covid-19 pandemic as a new Directorate-General (DG) of the European Commission, with a mission to prevent, detect and rapidly respond to health emergencies. HERA has identified three health threats to focus on: pathogens with high pandemic potential (primarily zoonotic diseases in the respiratory RNA viral family); chemical biological, radiological and nuclear threats; and AMR.
Support for HERA to improve health preparedness and response

The Health Emergency Preparedness and Response Authority (HERA) was established in 2021 in response to the Covid-19 pandemic as a new Directorate-General (DG) of the European Commission, with a mission to prevent, detect and rapidly respond to health emergencies (Int 4). HERA has identified three health threats to focus on: pathogens with high pandemic potential (primarily zoonotic diseases in the respiratory RNA viral family); chemical biological, radiological and nuclear threats; and AMR.

Many of EU4Health’s actions support HERA’s work in emergency preparedness and response at a national and EU level. For example, the programme provided €25 million in funding to DURABLE, a HERA network of 15 laboratories within the EU (Int 4). This network supports rapid, comprehensive pathogen surveillance data for the identification of pathogens and threats, and the development and purchase of medical countermeasures [149] (Int 4). Data and insights from network laboratories will be used to support HERA’s aim of improving emergency preparedness and response across the EU. The DURABLE network aims to have a global reach, providing researchers with connections to peers (Int 4).

Support and funding for the United4Surveillance programme

EU4Health also supports the United4Surveillance [17] programme, which focuses on strengthening national surveillance systems and supporting better preparedness for future health threats. The programme aims to support integration, interoperability and the digitisation of data sources. Part of increasing preparedness will consist of developing a roadmap to implementing integrated surveillance, which will outline gaps and needs, suggest ways to integrate national and international policies, identify and test promising approaches to integration, disseminate best practices, support capacity building and encourage sharing of experiences and knowledge.

An interviewee reported that United4Surveillance takes a bottom-up approach starting with national surveillance systems to see where gaps are, in order to create a sensible strategy to build capacity for integrated surveillance at a national and international level (Int 5). The work of United4Surveillance has three key pillars, focusing on outbreak detection, hospital surveillance, and One Health surveillance, and aims for integration across different data streams (Int 5).

Each Member State involved in United4Surveillance has its own dissemination plan, which identifies relevant stakeholders for each country, such as the relevant public health institute of that nation (Int 5).

Notably, while the United4Surveillance initiative provides a roadmap for integration and action, it will not be involved in implementing it. This would require further funding and follow-up actions within each country and potentially at an EU level, supported by EU4Health or others.

Strengthening national surveillance systems

The EU4Health programme also supports national surveillance systems more generally. For example, one Crisis Preparedness (CP) grant (CP-g-23-01) provides direct funding to strengthen national surveillance systems in EU Member States, with a budget of €97.3 million
This grant is in direct response to some of the shortcomings of national surveillance systems described above. It provides funding for: assessing the existing surveillance systems in EU Member States and identifying areas in need of (financial) support, including infrastructural support for information systems; building capacity in surveillance through training programmes; and piloting new integrated pathogen surveillance systems [96].

Support for building capacity in Member States was also provided through the EU4Health programme through a Joint Action on integrated surveillance (JA UNITED4Surveillance) [150]. There have also been measures in the EU4Health programme to encourage data sharing – for example through joint funding (€4 million) from HERA and the WHO to support access to and sharing of data through the WHO Hub for Pandemic and Epidemic Preparedness [151, 152]. This hub will facilitate global collaboration of partners from multiple sectors to support both countries and stakeholders to address future pandemic and epidemic risks through, for example, better access to data, stronger capabilities for analysis, and insights for decision making.

This funding is expected to improve the use of integrated data to conduct pathogen surveillance and strengthen early warning alert systems, and to help address fragmentation between existing pathogen surveillance systems (Int 4). It is also anticipated that the infrastructure improvements that this grant funds will help digitise surveillance systems, which will enable them to operate more rapidly and at larger scale.

Supporting wastewater surveillance
There are also actions within the EU4Health programme to support wastewater surveillance. For example, one grant (CP-g-23-18) aims to extend and consolidate wastewater surveillance for public health [96]. Funding can be used to share best practices of wastewater surveillance for SARS-CoV-2 and other pathogens, with a focus on supporting wastewater surveillance capacities in Member States that are currently lagging behind. The first activity that was funded through this grant related to defining wastewater surveillance, including identifying of priority pathogens, establishing surveillance objectives, and developing strategies to gather intelligence and integrate data into existing public health surveillance systems [96]. Further activities include defining the technical procedures of wastewater surveillance and harmonising wastewater surveillance methodologies across EU Member States.

The aim of this grant is to use wastewater surveillance, integrated with other types of data, to improve pandemic preparedness in the EU and provide EU Member States with a richer understanding of how infectious diseases spread across their populations [96].

Funding network of reference laboratories
Reference laboratories which collect data for EU-level surveillance also receive support through the EU4Health programme. Grant CP-g-23-05-01 provides funding to EU reference laboratories (EURLs) (operated by the ECDC in collaboration with the WHO and HERA) and national laboratories as part of the Diagnostics of Human Pathogens Network. Networks of laboratories support the sharing of best practice and technical information, including through guidance and protocols, quality assessment information, scientific and technical advice, training and outbreak response support [96].

It is hoped that providing funding for networks of laboratories will help improve pathogen surveillance by creating efficiencies in processing and analysing samples, and improving laboratories’ ability to detect
outbreaks by providing access to technical and scientific support.

Supporting surveillance in third countries
Some funding is also provided to third countries to support pathogen surveillance. Through grant CP-g-23-22, HERA and HaDEA will provide €6 million in funding to the African Public Health Foundation (APHF) and the African Society of Laboratory Medicine (ASLM), who were selected due to their position as leading actors in the field of pathogen surveillance in Africa and their capacity to deliver. This funding is based on the assessment that Africa is likely to continue to see outbreaks of Covid-19, but currently has limited (financial) capacity to implement continent-wide SARS-CoV-2 surveillance, share best practices, and respond to the pandemic [96]. The grant supports data management and data analysis platforms in Africa for the detection of SARS-CoV-2 and the implementation of next-generation methods in African pathogen surveillance systems. An additional €2 million in funding to support surveillance for Covid-19 and emerging pathogens was also provided under a joint initiative by HERA and the WHO under the EU4Health programme.

By supporting pathogen surveillance in Africa, the EU4Health programme aims to decrease the risk of cross-border health threats both within Africa and globally. Africa has the highest infectious disease burden in the world, and has faced threats from new zoonotic pathogens such monkeypox [153] – by increasing capacity around pathogen surveillance in this area, better data could be generated to help prevent future cross-border threats.

Strengths and weaknesses of the programme
EU4Health is a funding mechanism rather than a pathogen surveillance effort specifically. It provides additional resourcing for EU/EEA Member States to conduct public health activities, and encompasses a number of different support and funding structures to achieve this. Thus, one of the strengths of the programme has been in supporting cross-border health in the EU and in certain third countries. The EU4Health programme provides support to HERA, and allows HERA to fund procurement activities, grants, programme development, crisis preparedness activities and health resilience work (Int 4). Additionally, EU4Health has provided funding for the United4Surveillance and is one of the key enablers of the programme (Int 5).

However, the programme also faces a number of weaknesses. The funding provided through EU4Health is temporary, meaning that there can be concerns around the sustainability of the activities conducted. Additionally, while the programme provides funding and support, there is no obligation for EU/EEA countries to take advantage of this support. This means that the programme in part relies on capacity within countries to engage with the programme and conduct additional public health activities. Furthermore, support and funds provided are subject to procurement rules and limits, which often have fixed topic areas (Int 4), and which can limit the areas where EU4Health funding is used. Notably, however, during times of crisis and urgent need there is potential for flexibility (Int 4).

Another potential weakness of EU4Health is that although it attempts to address fragmentation in pathogen surveillance efforts in some ways, it provides separate pots of funding to separate initiatives and programmes. This fragmented funding causes additional challenges in terms of collaboration and coordination and consistency in sampling approaches and methods (Int 4). According to one interviewee, it would be beneficial to provide oversight across activities and
surveillance efforts to ensure there is no duplication of efforts, to reduce fragmentation, and to encourage coordination across EU4Health efforts (Int 5).

**Conclusions**

The EU4Health case study provides an example of a long-running health programme that has responded to gaps in pandemic preparedness and response that were revealed during the Covid-19 pandemic. A large part of this programme has consisted of supporting pathogen surveillance in Member States and more widely.

EU4Health grants focus on the sharing of best practices for pathogen surveillance, the harmonisation and integration of data and pathogen surveillance systems, and boosting infrastructure (e.g. digital infrastructure, laboratories). There is evidence that suggests these actions have been effective in supporting the EU’s ability to take public health action, such as declaring EU-level public health emergencies, coordinating medical responses to outbreaks, and adapting to health needs [154].

EU4Health has acted as a mechanism to direct large amounts of funding to pathogen surveillance in Europe, in part due to the lack of preparedness within the EU for the Covid-19 pandemic. During the pandemic, political will was strong in terms of willingness to support and fund public health initiatives. However, after the immediate pressures of the pandemic have ended (and after the current EU4Health programme ends in 2027), it is unclear whether this level of funding and support will be sustained. As such, it will be important for initiatives that are funded through EU4Health to consider how to build sustainable capacity, and how to fund surveillance efforts in the longer term.
Chapter 5. Expert interview findings

This chapter describes the findings of expert interviews that were conducted to further understand gaps in the pathogen surveillance space and approaches that could be used to help address them. This chapter also provides insights relevant to stakeholders who are looking to take action to improve pathogen surveillance, based on advice from experts in the space.

Many of these themes overlap with issues and mitigation strategies that were identified through the scoping review (Chapter 3) and the development of case studies (Chapter 4). This chapter complements these findings by providing a view of overarching priorities for pathogen surveillance, based on insights from topic experts.

Box 6: Summary of Chapter 5

Experts reflected that missing data and capacity constraints are a major challenge in pathogen surveillance. There are fundamental limitations to how much healthcare and clinical data is available for surveillance, along with capacity constraints, particularly in low-resource settings and in relation to genomic surveillance. While capacity building is needed, there are population-level surveillance techniques, such as wastewater surveillance, that can be used to overcome limitations in individual-level data.

Improving the ability to conduct integrated and real-time surveillance is also a priority within pathogen surveillance, and is critical in detecting outbreaks, the emergence of novel pathogens and intentional threats to human health. Reducing siloed data and improving interoperability can help encourage data sharing, and public health departments and other stakeholders may need training in using integrated data in decision making. More broadly, there is a need to understand how new data sources such as wastewater surveillance should be incorporated into surveillance activities, and what actions should be triggered by signals in different data types.

The pathogen surveillance space is highly fragmented and broadly defined, and experts reported that there is a need to bring stakeholders together to agree on priorities and approaches. Large organisations may be well-placed to act as convenors and should coordinate with one another to avoid duplication of effort and to create a more harmonised space.
5.1. Gaps in pathogen surveillance and how they can be addressed

5.1.1. Missing data and capacity constraints

Expert interviewees highlighted issues relating missing data, which ultimately contribute to a paucity of data for surveillance (Expert 1, 2, 3, 4, 5, 6, 8, 9). Primarily, they discussed this issue in relation to healthcare data. Firstly, many people who experience symptoms from infectious diseases do not seek help or go to healthcare settings, and even when they do, doctors do not always report infections consistently. As such, this means that healthcare data will always suffer from underreporting (or misreporting) and lags in some way (Expert 1, 2, 3, 4, 5, 6, 9). This issue is amplified in LMICs, as well as in systems where individuals need to pay for care themselves (Expert 3).

Diagnostic capacity is a key factor in the accessibility of data for surveillance (Expert 3, 5, 6, 8). Organisational structures which disincentivise the use of diagnostic tests, such as those in the United States where a flat rate is typically paid to hospitals regardless of how many diagnostic tests are performed, tends to limit the use of diagnostics and results in less data from this source (Expert 5). The use of electronic health records also affects how much clinical data is available (Expert 2, 6).

The quantity of data available for surveillance is also limited by capacity constraints, particularly in relation to laboratory capacity and data infrastructure for genomic surveillance (Expert 1, 2, 4) and wastewater surveillance (Expert 9). This issue limits the granularity of data available to assess variants and AMR (Expert 1). The supply of labour and equipment in LMICs is also a constraint; one interviewee mentioned that this was a challenge in the SPIDAAR programme, an initiative launched by Pfizer and Wellcome around AMR in sub-Saharan Africa [155].

To help overcome issues relating to missing data, expert interviewees highlighted several tools and models that can be used. Several potential solutions had to do with surveillance methods:

- **Aggregated surveillance strategies, which do not rely on individuals submitting data, including wastewater surveillance,** can be used to capture timely information on how pathogens are spreading across populations. Three expert interviewees reported that these systems can outperform other types of surveillance by providing access to information despite capacity constraints and issues around missing healthcare data (Expert 1, 2, 9). Similarly, interviewees stressed the importance of wastewater surveillance and the potential opportunities in this area due to its lower cost, cost effectiveness and ability to be implemented across settings globally (Expert 7, 9), and expressed that this type of surveillance should be expanded both geographically and with respect to pathogen coverage (Expert 9). However, interviewees also mentioned that there is a need to better understand the thresholds in this space in terms of what measurements should trigger different public health actions (e.g. finding polio in wastewater may trigger vaccination campaigns, while finding resistant genes may trigger further genomic research using wastewater to investigate the potential for AMR) (Expert 5, 9).

- **Syndromic surveillance, which tracks symptoms that individuals experience,** can be used to estimate pathogen spread in the absence of data about confirmed cases, and can be cheaper to implement (Expert 1, 3).
• **Event-based surveillance**, which attempts to detect the signals of unusual public health events using different types of data, can help overcome gaps in individual data streams (Expert 1).

• **Repeated population surveys** also add to understanding of risk groups, infections and symptoms at single time points, and can be used to assess how well surveillance systems have performed in retrospect (Expert 3, 6).

Experts also highlighted wider interventions and support that can help address issues around a lack of data and capacity constraints:

• **Automating as much data collection and analysis as possible** would make pathogen surveillance efforts more efficient, helping to achieve more despite limited resources (Expert 1, 3).

• **Support for health systems**, particularly in LMICs, in using diagnostics and electronic health records (Expert 6) and genomic surveillance (Expert 1) can help improve data availability.

• **Capacity building, training and infrastructural support** to improve surveillance in LMICs is needed (Expert 1, 2, 5, 6, 8, 9), particularly for genomic surveillance (Expert 1, 2, 5, 8) and wastewater surveillance (Expert 9). In building capacity, local stakeholder buy-in is key to ensure that efforts are sustainable and owned by local communities (Expert 9). It may be possible to use capacity that was built in response to the Covid-19 pandemic for other surveillance activities ("pivoting"), as a way to build capacity (Expert 8, 9), since much of the infrastructure is identical (e.g. wastewater surveillance infrastructure is identical for Covid-19 and other pathogens, with the exception of an additional laboratory test) (Expert 9).

• **Specific models** mentioned by interviewees to build capacity include hub and spoke models, which provide a way to offer support, guidance and a degree of standardisation while also offering autonomy (Expert 2, 6), and federated approaches where data is held and analysed locally (Expert 3). However, one interviewee reflected that there are not yet good models for doing this at a large scale (Expert 6).

• **Taking a step-wise approach** to building surveillance capacity may be a way to support national surveillance systems. This approach may include guidance on different levels of maturity around diagnostics, epidemiology, governance, funding and policy. According to one interviewee, this would help to address the difficult balance between a simple data collection technique that is easy to use, and the complex and nuanced information that can improve surveillance (e.g. for AMR) (Expert 3). Auditing tools that help countries assess how they collect, analyse and share data may also be helpful (Expert 3), if coupled with support and tools for improvement.

• **Improving diagnostic technologies** is key to understanding infectious diseases better (Expert 3, 5, 6, 8), and is important from a biosecurity perspective (Expert 5). For example, in vitro diagnostics, point-of-care and tests in community settings, such as the lateral flow tests used during the Covid-19 pandemic, are a key technology (Expert 6, 8).

5.1.2. Data sharing and linking
Experts noted issues relating to data sharing and linking (Expert 1, 3, 4, 5, 7, 8, 9). Systems that are used to store and analyse surveillance data often do not connect with one another, and this lack of interoperability causes data
Data collection and sharing for pathogen surveillance

streams to be siloed (Expert 1, 3, 5, 7, 8). Often, systems are based on old technology which might not accommodate all types of data (Expert 1, 3, 5), and it can be difficult to switch to newer systems without disturbing existing surveillance activities (Expert 1). Even in high-resource settings, linking clinical data to other data streams can be difficult (Expert 1, 4, 5, 7) – for example, even hospitals in the same city may have different IT systems (Expert 5). According to one interviewee, difficulties linking data across different sources and geographies can be attributed to a lack of leadership and coordination in the pathogen surveillance space (Expert 9).

Interviewees also mentioned challenges related to data privacy and protection (Expert 3, 4) and setting up data sharing agreements (Expert 4). Lastly, two interviewees mentioned political pressure that countries may face to withhold data or to under-report cases, for example due to concern over reputational damage, embarrassment and lost revenue (e.g. from tourism) (Expert 4, 9). There are also particular sensitivities around transporting clinical samples across international borders (Expert 4).

Experts identified several strategies to help overcome issues related to data sharing and linking:

- **Efforts to encourage data sharing** at different levels are important (Expert 1, 3). This has included, for example, support in setting up data sharing agreements between organisations (Expert 3). Some systems also have mandatory data sharing systems, such as that between the EU and its Member States (Expert 3). Consortiums can be helpful in facilitating data sharing – for example, one interviewee mentioned the Covid-19 Genomics UK Consortium (COG-UK) as a positive example of a consortium that has encouraged data sharing amongst its members (Expert 1).

- **Encouraging (and incentivising) transparency at an international level** can help improve data sharing between countries (Expert 1, 9).

- **Event-based surveillance** helps to overcome structural issues in how data is reported in other surveillance activities in terms of siloed data streams (Expert 1).

### 5.1.3. Integrated and real-time surveillance systems

Integrated surveillance systems are important to detect threats early, and are currently lacking (Expert 1, 2, 3, 4, 5, 6, 8). Issues related to data linkages and siloed data streams make it difficult to conduct integrated surveillance (Expert 1, 3, 4, 5), and surveillance systems do not use all of the data streams available to them (Expert 1, 2, 3, 5). These factors contribute to challenges in conducting real-time surveillance.

Even where integrated data sets are created and where real-time data is available, there can be challenges in its analysis. According to one interviewee, small public health departments are often not accustomed to this type of data and using it to inform decision making continuously, and are more accustomed to reviewing data on a quarterly or yearly basis (Expert 5). Similarly, many public health departments are not informed on how to interpret and use wastewater surveillance data alongside other data streams, beyond looking at the presence or absence of a pathogen (Expert 9).

More broadly, there is also a need to work out which information is important when multiple data sources are being used to conduct integrated surveillance (Expert 5, 6, 8). According to interviewees, there is a lack of clarity around what actions should be taken in response to different indicators (Expert 6), for example, in relation to wastewater surveillance (Expert 5, 7) and genomic surveillance (Expert 8).
Experts highlighted several ways to improve integrated and real-time surveillance:

- **Improved IT systems and better interoperability** can make it easier to link data across different sources and locations (Expert 1, 3, 4, 5).

- **Incorporating additional data sources** can improve the ability to conduct surveillance and detect threats in real time. For example, experts mentioned the potential of Google searches (Expert 1), social media data (Expert 2), information about mobility and travel (Expert 2), school absenteeism (Expert 5), and prescription and sales data for cold and cough medicines (Expert 5). However, one interviewee mentioned that there are many false positives with this type of data (e.g. when external factors such as coupons influence sales) (Expert 5). Additionally, two interviewees mentioned the need to more carefully assess how well systems work, and how sensitive and complete different data sources and methods are (Expert 1, 5). Other interviewees mentioned that it can take time for new types of data to be accepted; for example, wastewater data took years to be taken seriously in infectious disease surveillance (Expert 2, 7).

- **Using AI to analyse data** from integrated surveillance efforts can make it easier to process large amounts of data (Expert 4, 5, 6, 7). For example, two interviewees mentioned BlueDot, a Canadian company that provides outbreak intelligence using AI to analyse many different data sources, which picked up a signal for an illness (later known to be Covid-19) over a week before the WHO (Expert 4, 5).

- **Automating analysis** to the extent possible would make improvements to the ability to process data (Expert 1, 3). For example, semantic analysis can be used to process unstructured data in electronic health records (Expert 3).

- **Data science** will be important in improving the ability to predict outbreaks, and in determining which data streams matter most (Expert 2, 5, 8). For example, by training AI with data from previous outbreaks, it is possible to learn more about which data is important in predicting outbreaks (Expert 5). One interviewee mentioned the WHO Hub for Pandemic and Epidemic Intelligence (see Box 7) as a key stakeholder the area of prediction (Expert 2).

- **Establishing triggers to indicate what actions should be taken** in response to surveillance would be useful in making sure insights are actionable, particularly in the area of wastewater surveillance (Expert 5, 6, 7, 9) and AMR genes in the environment (Expert 5, 7).

- **Developing combined metrics** for wastewater surveillance and other integrated data sources provides a way to make sense of multiple data streams for decision makers, including by demonstrating where data from different sources diverges or coalesces (Expert 9). Developing these metrics will require interdisciplinary expertise to understand the information needs of decision makers, the evidence-base for different data streams and wider factors (e.g. societal and environmental) that influence metrics (Expert 9).

Positive examples of integrated surveillance systems provided by experts include the UK’s early warning system, which uses data from ambulances, syndrome surveillance, and sentinel surveillance from general practitioners (with current efforts focused on incorporating wastewater surveillance) (Expert 1), and the Integrated Disease Surveillance and Response (IDSR) strategy in the WHO Africa region (Expert 1).
Box 7: WHO Hub for Pandemic and Epidemic Intelligence

The WHO Hub for Pandemic and Epidemic Intelligence was established in September 2021 through the WHO Health Emergencies Programme. It focuses on strengthening pandemic and epidemic intelligence through better data, better analytics and better decisions to manage public health emergencies.

The WHO Hub was established in response to weaknesses in identifying and understanding pathogens with pandemic and epidemic potential, limited and fragmented data, capacity constraints in analysing data and issues related to data sharing.

It adopts the WHO’s approach to ‘collaborative intelligence’:

- **Multidisciplinary collaboration**: Synthesizing different types of contextual information
- **Multidisciplinary decision making**: Interacting across different types of stakeholders who use intelligence outputs to respond to public health emergencies
- **Trust architecture**: Promoting greater data sharing through an architecture of global trust
- **Distributed information exchange**: Adaptively sharing information, using human and AI insights effectively.

The WHO Hub works with Member States and WHO regional and national offices, and has international reach.

The WHO Hub collaborates with various stakeholders, including HERA, the Robert Koch Institute and the US CDC’s Centre for Forecasting and Analysis. It also collaborates with the Joint Research Centre of the European Commission on EIOS (see Case Study G) and with GOARN (see Case Study F). It brings together the International Pathogen Surveillance Network (IPSN) to develop analytical tools and capabilities for genomic surveillance [152].

5.1.4. Novel pathogens

Novel pathogens are difficult to track, since surveillance systems need to look for something that they have not seen before (Expert 1, 2, 5). It is especially difficult to identify novel pathogens when symptoms are similar to existing illnesses (e.g. novel respiratory pathogens with symptoms similar to RSV or influenza), and when diagnostics are not used for illnesses, such as sepsis, that can be caused by multiple pathogens (Expert 5).

Several strategies to improve the ability to detect novel pathogens quickly were mentioned by interviewees:

- **Pathogen-agnostic techniques**, including those using metagenomics, can identify exponential increases in key indicators, which can be a signal of new outbreaks. Where exponential increases are detected, further research is then needed to identify novel pathogens (Expert 1). Measures to increase the use of metagenomics has been included within the UK Biological Security Strategy [156]. However, pathogen-agnostic, non-targeted techniques tend to be more resource intensive than targeted techniques, and surveillance strategies need to incorporate sensible measures to balance these two approaches (Expert 9).

- **Increased use of diagnostic tests**, for example to distinguish Covid-19 from RSV or influenza and to diagnose pathogens that cause sepsis, help identify where novel pathogens may have emerged (Expert 5).
• **Metrics and targets for identifying novel pathogens** such as 7-1-7 (detection within seven days of the emergent outbreak, notification to health authorities within one day, response within seven days) [157] are used as standards in the ability to detect novel pathogens. This 7-1-7 target was originally proposed by Resolve to Save Lives and is now being promoted by the Rockefeller Foundation (Expert 2).

5.1.5. Intentional threats

When asked about intentional threats, three expert interviewees reflected that intentional threats to human health, including bioengineered threats, generally rely on the same systems as naturally occurring threats, and that improving these systems will also improve the ability to detect intentional threats (Expert 1, 4, 5). One interviewee also commented that it can be difficult to determine whether naturally occurring pathogens were planted intentionally (Expert 5).

Interviewees mentioned several areas in which countries are attempting to improve their ability to detect intentional threats to human health:

• **The Defence Advanced Research Projects Agency (DARPA) in the US and the UK government** have invested in sensors to improve their ability to detect pathogens in transport settings (Expert 1, 4).

• **The US Department of Homeland Security’s BioWatch programme** was also mentioned (Expert 4).

5.1.6. Funding gaps

Experts described funding issues that contribute to issues in pathogen surveillance. Short-term funding models make it difficult to achieve goals and make efforts beholden to funder interests (Expert 2); one interviewee reflected that the model of foundations funding much of the work in pathogen space is not sustainable, as surveillance requires buy in, mandates and investment from federal government (Expert 9). Short-term funding also makes it necessary for initiatives to spend time and resources seeking additional funding, and may contribute to a reluctance in investing in efforts that will take time to achieve impacts (Expert 2). Similarly, two experts brought up a tendency to favour provision of funding for ‘hot’, novel or topical issues (Expert 3, 8). Another interviewee reflected that there is generally underfunding across the space (Expert 7).

Specific measures to address these funding gaps that were mentioned by experts include:

• **Providing larger, more long-term allocations of funding** may be more efficient, and such funding is needed to address some of the big issues facing pathogen surveillance today. Concurrently, there is a need to balance the tackling of old challenges, such as access to care and logistical capacity constraints, with investments in new areas, such as wastewater surveillance, increasing the use of AI and algorithms, and advanced data analytics (Expert 2, 7, 8).

• **Encouraging surveillance initiatives to secure long-term funding and local buy-in** can help ensure that the benefits of funded initiatives are sustainable, and that they are ‘owned’ by local stakeholders rather than dependent on far-off funders (Expert 8, 9).

5.2. Fragmentation and the role of convening

Overall, the experts consulted in this study reported that the surveillance space is fragmented (Expert 1, 2, 3, 6, 8, 9), which contributes to a lack of coordination, duplication of effort, missed opportunities and a lack of sharing of best practices (Expert
Data collection and sharing for pathogen surveillance

For example, there is a lack of standardised procedures to get comparable results across surveillance efforts, which would require agreement and buy in to establish (Expert 2, 3, 6, 9). In addition, research projects that conduct surveillance-related activities often do not coordinate with one another to share knowledge and establish common ways of working (Int 8). However, one interviewee reflected that, outside of single projects, standardisation is very difficult (Expert 3).

Interviewees noted several issues that make issues around fragmentation worse. Two interviewees said that organisations that provide funding in this area do not always incentivise coordination between initiatives (Expert 2, 8) or the uploading of data to common repositories (Expert 8). Although funding often comes from philanthropic organisations without commercial interests, this interviewee noted that funders still compete for reputation, prestige and other factors (Expert 2).

Furthermore, although pandemic preparedness is an important goal, it is a broadly defined area, which can make fragmentation worse (Expert 2, 5, 6, 8). This means that broad pandemic preparedness efforts may struggle to coordinate and galvanise around a common goal (Expert 2, 5, 8). Additionally, such efforts, according to one stakeholder, tend to focus on issues that affect high-income countries, rather than building general readiness for endemic diseases that tend to originate in LMICs (Expert 8).

In areas as broad as pandemic preparedness, and in spaces as fragmented as the pathogen surveillance space, convening and bringing stakeholders together to agree on priorities, data standards, actions and approaches is an important role (Expert 1, 2, 3, 6, 8, 9). One interviewee reflected that although the WHO would need to be involved in these efforts, its focus on Member States and limited reach at the local level would make it difficult for it to take on a convenor role (Expert 3). Another interviewee communicated the importance of leaders and convenors in this space taking an interdisciplinary approach, and focusing on decision making and practical applications for data to be used in policy, rather than concentrating exclusively on technical aspects of surveillance systems (Expert 9).

5.3. Insights for stakeholders looking to take action to improve pathogen surveillance

Experts also provided views on what makes efforts to improve pathogen surveillance successful and what would be helpful for stakeholders looking to take action in pathogen surveillance.

For example, experts explained the need to understand what the landscape is like and what other organisations are doing to build on success and not 'reinvent the wheel' (Expert 1, 2, 3, 8, 9). Additionally, understanding the space more completely can help navigate tensions between stakeholders that have been involved in surveillance and pandemic preparedness for a long time, and new entrants in this field (Expert 2, 3). When working in LMICs, it is important to be aware of power dynamics and histories of colonialism (Expert 2, 3, 8), and to recognise that small NGOs have extensive experience (and close relationships) working in resource-poor settings (Expert 5). Regardless of setting, experts mentioned that interpersonal relationships are important in surveillance (Expert 3, 4).

Thinking about scope is also key when creating initiatives in the pathogen surveillance space. Several interviewees mentioned the need to define scope narrowly, and to communicate and work towards specific goals and aims (Expert 1, 2, 5). For example, this can take the form of focusing on a particular disease area, which
has been an important factor in the success of efforts to address HIV, malaria, tuberculosis and polio (Expert 2, 5). However, another interviewee suggested that disease-specific surveillance approaches contribute to siloed data streams and inefficiencies (Expert 8).

In deciding what scope initiatives will have, several factors are important to consider. One interviewee commented that differentiation is important, given the crowded nature of the surveillance space, and reflected that wastewater surveillance is a field in which roles have not yet been clearly defined (Expert 2). It is also important to consider what information decision makers need to inform public health decisions – as one interviewee explained, this is a better approach than trying to find an audience for information (Expert 6). In considering scope, it is also important to identify the strengths of organisations leading and contributing to efforts (Expert 2).

Lastly, experts pointed to the importance of communicating the benefits of surveillance, as well as the importance of spending up-front to realise the long-term benefits of integrated surveillance and wastewater surveillance (Expert 1, 3, 9). Using plain language to explain the benefits of this type of surveillance is helpful in building buy-in, as is adopting an interdisciplinary lens and communicating the wide-ranging effects of infectious diseases beyond public health (e.g. in relation to mental health, the economy, education, bottom lines in the private sector) (Expert 9). This will become more important as interest in this area potentially wanes in the long-term aftermath of the Covid-19 pandemic (Expert 3). In thinking about benefits from surveillance, it is important to address both national and international information needs, along with local benefit to communities gathering data (Expert 8, 9).

Lastly, optimisation and practicality must be balanced, as decisions may benefit from timely, simple insight more than from nuanced, delayed insight (Expert 9).
Chapter 6. Discussion and conclusions

This study has provided an overview of the pathogen surveillance space, and has identified common challenges in conducting surveillance, as well as the strengths and weaknesses of different initiatives. It also offers insights into gaps in pathogen surveillance and how initiatives have approached challenges (see Chapter 3 and Annex G for a summary of challenges and mitigation strategies). Along with this broad insight, this study provides depth by focusing more closely on ten case study initiatives (see Chapter 4). Expert insights (see Chapter 5) provide additional evidence regarding the priorities in the pathogen surveillance space and opportunities to address these challenges.

This chapter presents reflections on the main findings from this study, and provides an overview of the gaps and priorities in pathogen surveillance.

Box 8: Summary of Chapter 6

By looking across different pathogen surveillance initiatives and gathering expert insight, this study has identified challenges and gaps in pathogen surveillance, and has explored ways in which these issues have been addressed as well as priorities for improving the ability to detect threats to human health from infectious diseases and AMR.

Capacity constraints, particularly in low-resources setting, limit the amount, type and quality of data that is available for surveillance. There is a need to build long-term, sustainable capacity, particularly in genomic surveillance, and to support the use of diagnostics and electronic health records across settings. There are also challenges in sharing data, both in terms of logistics (e.g. a lack of interoperability in data platforms) and in terms of political pressures around international data sharing and the transport of clinical samples across borders.

At the same time, there is a gap in the ability to conduct integrated and real-time surveillance at scale across settings, which is critical in informing public health action. There is a need to improve data infrastructure and interoperability to integrate siloed data streams, understand what actions should be taken in response to new data streams (e.g. wastewater surveillance), and use data science and AI to analyse what data matters in integrated surveillance.

Overall, the pathogen surveillance space is fragmented, with a variety of different efforts and stakeholders that do not always share data or coordinate with one another. There is a need to improve coordination between stakeholders, agree on priorities and common approaches, improve interoperability and increase harmonisation. Doing so would help make surveillance efforts more efficient, and may help improve the insights available by allowing data to be linked and analysed in new ways.
Challenges, gaps and opportunities in pathogen surveillance

Building capacity
There are fundamental capacity constraints that limit the amount, type and quality of data that is available for surveillance activities. For example, data collection is often limited by IT and physical infrastructure, supply chains, the availability of skilled workers and laboratory capacity, particularly in low-resource settings. Capacity to conduct genomic surveillance, which is critical to the tracking of AMR, is particularly lacking. Additionally, healthcare and clinical data is limited in that many people who experience symptoms do not seek medical care, and even when they do, there are gaps in the use of diagnostics and reporting, and data may not be available in a digitised form.

To help address these challenges, capacity building is needed. While direct funding, operational support and supplies can help address short-term issues, there is a wider need to build sustainable and distributed capacity. For example, GOARN and EWARS (see Case Study F) provide technological solutions and toolkits for data collection in low-resource settings, and the Sentinel project (see Case Study A) helped build distributed capacity through hub and spoke models, coupled with embedded support and training. Support for health systems in using diagnostics and electronic health records may also be helpful in increasing the amount of data available for surveillance activities, depending on how data flows.

Models that go beyond providing short-term resources can be helpful in building distributed, sustainable capacity that outlives grant cycles and short-term funding mechanisms. Relationship building with local partners is a key part of building this distributed capacity, and smaller stakeholders such as NGOs often have the types of relationships that are needed to create change in this area. Supporting local stakeholders in analysing data and drawing conclusions from surveillance data is important in making sure that data informs public health decision making at this level.

Drawing insights from integrated surveillance, real-time surveillance and wastewater surveillance
Integrated and real-time surveillance is critical in informing public health action, but capacity to do this type of surveillance at scale is lacking. There is variation in how data is collected and recorded that makes it difficult to link between data sources, and issues with databases and IT systems can limit interoperability. Although data from genomic surveillance and wastewater surveillance is increasingly being used to understand infectious diseases and AMR, there remain challenges in integrating such information with other sources of data and understanding what actions should be taken in response to particular signals. More broadly, there are also challenges in identifying what data is important in terms of predicting outbreaks.

In response to these challenges, initiatives have provided digital infrastructure and training to support integrated surveillance and the use of real-time data, including tools for analysing and sharing data between stakeholders (see Case Study C: Epipulse, Case Study G: PAHO EI and Case Study I: unCoVer). Bringing stakeholders together and providing general support and a forum to share best practice in key areas such as genomic surveillance (see Case Study B: CGPS) and wastewater surveillance (see Case Study D: EU4S) is also helpful in improving how data is used in integrated surveillance. Wastewater surveillance is an emerging space, and best practice and stakeholder roles are still being formed; additionally, the technique provides a way of conducting population-level...
surveillance, helping to overcome limitations in individual level data at a lower cost.

There is also potential to use more AI-based methods to analyse integrated data, and for data scientists to learn about what data streams matter in outbreak prediction. This approach takes advantage of the vast amount of data that is already being collected that could potentially be useful in pathogen surveillance. Additionally, improvements in this space have the potential to generate efficiencies, and insights may be used to inform priorities and guide capacity building efforts.

Convening and coordinating in a fragmented system

Overall, the pathogen surveillance space is complex and fragmented, and there is not a unified international system. There is a mix of larger and smaller stakeholders collecting and analysing surveillance data across the public, not-for-profit and private sectors. While many initiatives feed data into international surveillance mechanisms, such as those coordinated by the WHO, regional WHO offices and regional CDCs, there is a lack of coordination and harmonisation at an international level. Data is collected in many different formats, and systems are often not interoperable. Both logistical issues and political pressures limit the degree to which data is shared between relevant stakeholders, particularly internationally.

Creating an entirely unified system is not a realistic goal in pathogen surveillance. However, there is a need to bring stakeholders together to agree on priorities and common approaches, improve interoperability and increase harmonisation between the many different stakeholders and initiatives involved. Convening is an important role, and convenors would need to bring together stakeholders across many different locations, sectors and settings. Priority setting could include input from experts, insights from data science in terms of what data matters for prediction and information about what decision makers in public health need to improve preparedness and response systems.

Pathogen surveillance and pandemic preparedness are broadly defined areas with diverse stakeholders, which can make consensus building challenging. Experts suggested that having clear aims and limiting scope make it easier to bring stakeholders together around a common goal. Additionally, among the complexities of agreeing on priorities are differing capacities and contexts between locations, meaning that common systems need to be simple enough to implement across settings, while also being sophisticated enough to capture granular and complex information. Step-wise approaches to building capacity in a coordinated way that allows for interoperability and harmonisation may be helpful in achieving this balance.

Conclusions

To improve surveillance systems for infectious diseases and AMR, there is a need to address long-standing capacity constraints that limit the amount, type and quality of data available by building distributed, sustainable capacity. At the same time, there is also a need to improve the ability to conduct real-time and integrated surveillance, including through advances in genomic surveillance, wastewater surveillance and AI and data science. Some advances in this area help overcome challenges related to capacity constraints by using diverse data sources. Across both of these broad areas, more coordination is needed. Convening roles within this space are highly valuable, and according to experts, needed to help coordinate, prioritise and focus. Convenors should be positioned to bring diverse stakeholders together, define clear aims and navigate complex spaces and systems.
Strengthening the capacity to conduct pathogen surveillance and the ability to detect and respond to threats has the potential to improve public health decision making and population-level health. Long-term funding is needed in this area, along with coordination to ensure that current and future surveillance efforts improve preparedness.
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Annex A. **Table of initiatives identified in this study**
<table>
<thead>
<tr>
<th>Initiative name</th>
<th>Brief description of the initiative</th>
<th>Aim of initiative</th>
<th>Pathogens</th>
<th>Region</th>
<th>Geographic coverage</th>
<th>Key stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa CDC: Regional Integrated Surveillance and Laboratory Network (RISLNET)</td>
<td>Established by the Africa Centres for Disease Control and Prevention to coordinate and integrate laboratory, surveillance and emergency response assets. Facilitates close networking between national public health institutes, academic institutions, private and public laboratories, centres of excellence, etc.</td>
<td>To support the detection of diseases in Africa and integrate regional laboratories and experts to facilitate responses to disease threats</td>
<td>Multiple pathogens</td>
<td>Africa</td>
<td>Africa; sub-groups for Northern, Western, Central, Southern and Eastern Africa</td>
<td>Africa CDC, Africa CDC Regional Collaborating Centres (RCCs), National Public Health Institutes, private and public laboratories, veterinary networks, etc. Operations integrated into Regional Collaborating Centres (RCCs) run by Africa CDC</td>
</tr>
<tr>
<td>Integrated Disease Surveillance and Response Strategy (IDSR)</td>
<td>IDSR has been implemented in Ghana with environmental surveillance for priority diseases, conditions and events since 2002. Recent focus on polio (2016 onwards) and Covid-19. Now 14 environmental surveillance sites for polio in 7 regions; criteria for selection includes: sewer network availability, areas of high risk for transmission, absence of industrial waste. Covid-19 surveillance being trialled in 2021. Expanding to other pathogens like cholera and Salmonella Typhi</td>
<td>To support the monitoring and management of diseases (specifically polio and Covid-19) in Ghana</td>
<td>Multiple pathogens (e.g. polio, Covid-19)</td>
<td>Africa</td>
<td>Ghana</td>
<td>Ghana Health Service, Training Research and Networking for Development (TREND), Water Research Institute (Ghana) and the Emory University Centre for Global Safe Water, Sanitation, and Hygiene</td>
</tr>
<tr>
<td>Africa CDC: Digital Disease Surveillance</td>
<td>Aggregation and analysis of data from the internet, search engines, social media and mobile phones. Pilot programme aims to develop indicators and online disease dashboards</td>
<td>To strengthen disease surveillance in Africa and improve the timeliness and depth of surveillance information</td>
<td>Multiple pathogens</td>
<td>Africa</td>
<td>Ghana, Liberia, Madagascar, Nigeria, Sierra Leone, South Africa</td>
<td>Funding: Bill &amp; Melinda Gates Foundation Implementation: Fogarty International Centre at the US National Institutes of Health, Boston Children’s Hospital, Harvard Medical School, Roskilde University, Salzburg University, Georgia State University</td>
</tr>
<tr>
<td>Global Ebola Laboratory Data Collection and Reporting System</td>
<td>Initiative to develop a data reporting and collection system containing all laboratory data from three countries during the 2013–2016 Ebola outbreak in Liberia, Sierra Leone and Guinea in West Africa</td>
<td>To support surveillance of and response to the 2013–2016 Ebola outbreak</td>
<td>Ebola</td>
<td>Africa</td>
<td>Guinea, Liberia, Sierra Leone</td>
<td>Health teams in Guinea, Liberia and Sierra Leone collect data and enter it into the Global Ebola Laboratory database</td>
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<tr>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
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<td>Geographic coverage</td>
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<tr>
<td>H3Africa: Genomic Characterization and Surveillance of Microbial Threats in West Africa</td>
<td>Enabling rapid, accurate diagnosis of patient samples in West Africa with robust and cost-effective field diagnostics and modern genomic technologies</td>
<td>To develop innovative genomic tools and strategies that will reduce the impact of viral diseases on West African populations</td>
<td>Multiple pathogens (Ebola, Lassa fever, yellow fever, dengue)</td>
<td>Africa</td>
<td>Nigeria, Senegal, Sierra Leone</td>
<td>Funding: US National Institutes of Health (NIH) Office of the Director (OD), National Institute of Allergy and Infectious Diseases (NIAID) and the National Human Genome Research Institute (NHGRI) Project sites: Redeemers’ University and Irrua Specialist Teaching Hospital (Nigeria), Université Cheikh Anta Diop (Senegal), Kenema Government Hospital (Sierra Leone); supported by ACEGID</td>
</tr>
<tr>
<td>US CDC: South Africa Regional Global Disease Detection Centre (SARGDDC)</td>
<td>Enhancing capacity to detect and respond to threats through surveillance, workforce development and research and response; includes surveillance of influenza and zoonotic diseases. Using sentinel surveillance in animals as early warning systems to detect outbreaks of arboviral diseases in humans</td>
<td>To support monitoring and response to infectious diseases in South Africa and thereby contribute to global health security</td>
<td>Multiple pathogens (influenza, West Nile virus, Shuni virus, Middelburg virus, other zoonotic diseases)</td>
<td>Africa</td>
<td>South Africa</td>
<td>South African National Department of Health, National Institute for Communicable Diseases (NICD), University of Pretoria, US Defense Threat Reduction Agency (DTRA) Cooperative Biological Engagement Program, CDC’s Division of Global HIV/AIDS Future collaboration planned with US CDC and the Robert Koch Institute to detect and respond to emerging diseases</td>
</tr>
<tr>
<td>South African Collaborative Covid-19 Environmental Surveillance System (SACCESS)</td>
<td>SACCESS network developed out of WHO recommendations for environmental surveillance of polio, beginning with regular sampling of 18 sites; emerging interest for use in relation to Covid-19 in 2020. SACCESS network comprises 8 laboratories which test 87 wastewater treatment plants every week across South Africa</td>
<td>To support the monitoring and management of Covid-19 in South Africa</td>
<td>Covid-19</td>
<td>Africa</td>
<td>South Africa</td>
<td>Funding from Bill &amp; Melinda Gates Foundation, with analysis and practical support from other stakeholders South Africa: National Institute for Communicable Diseases, Praecautio, South African Medical Research Council, Waterlab, Lumegen Laboratories</td>
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<tr>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
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<td>Key stakeholders</td>
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<tr>
<td>Regional Action through Data (RAD)</td>
<td>Partnership facilitated by the US Agency for International Development (USAID) providing support to technical experts to identify health needs and fill gaps in data provision to support the development of policies and public health practices in sub-Saharan Africa</td>
<td>To address the issue of limited data to drive performance in healthcare service delivery in sub-Saharan Africa by changing how and why data is collected, analysed and used</td>
<td>Covid-19 and other pathogens</td>
<td>Africa</td>
<td>Sub-Saharan Africa</td>
<td>BroadReach, West African Health Organisation (WAHO), the Intergovernmental Authority on Development (IGAD), Duke University Global Health Centre, Jembi Health Systems South Africa, USAID Member states and regions are responsible for implementation</td>
</tr>
<tr>
<td>GLASS-Uganda</td>
<td>The Global Antimicrobial Resistance and Use Surveillance System (GLASS) in Uganda. Supported by Uganda’s national laboratories and the National Action Plan (NAP) for antimicrobial resistance (AMR) in Uganda</td>
<td>To enable monitoring of AMR at the country level and inform clinical decision making</td>
<td>Multiple AMR-relevant pathogens</td>
<td>Africa</td>
<td>Uganda</td>
<td>WHO, US CDC, Ugandan government, Central Public Health Laboratories</td>
</tr>
<tr>
<td>JWARG: Surveillance, Detection, Risks and Consequences of Severe Infectious Disease in West Africa</td>
<td>African Centre for Excellence for Genomics of Infectious Diseases (ACEGID) and Joint West Africa Research Group (JWARG) collaboration to establish coordinated systems to detect and respond to human pathogens</td>
<td>To prepare for and prevent future infectious disease epidemics in West Africa</td>
<td>Multiple pathogens</td>
<td>Africa</td>
<td>West Africa</td>
<td>ACEGID responsible for research administration, study planning and laboratory testing JWARG and Walter Reed Army Institute of Research are also involved</td>
</tr>
<tr>
<td>ACEGID/Broad Institute: Sentinel project (2020–2025)</td>
<td>Sentinel: an early-warning system which will detect viral threats in real time and help stop them before they spread, use a three-part approach to detect viruses, connect data systems and empower the healthcare community. Point-of-care tests can facilitate identification of high priority viruses within an hour, any known human virus within a day, and previously unknown viruses within a week</td>
<td>To get ahead of pandemic outbreaks and facilitate the detection of viral threats in real time</td>
<td>Multiple pathogens</td>
<td>Africa</td>
<td>West Africa and Central Africa with eventual global roll-out planned</td>
<td>ACEGID, The Broad Institute of MIT and Harvard manage implementation Dimagi, Fathom and MassDesign support data analytics, healthcare technology and data visualisation Funding provided by Audacious Project (initiative of TED)</td>
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<tr>
<td>Asia-Pacific Network for Enterovirus Surveillance</td>
<td>Network established between academic institutions and hospitals in Cambodia, Malaysia, Vietnam and Taiwan to ensure harmonised laboratory diagnosis and estimating disease burden of different enterovirus serotypes to accelerate development of vaccines</td>
<td>To estimate disease burden, understand enterovirus evolution and facilitate vaccine development through harmonising laboratory diagnosis and data collection</td>
<td>Enteroviruses</td>
<td>Asia</td>
<td>Cambodia, Malaysia, Vietnam, Taiwan</td>
<td>Institut Pasteur du Cambodge (IPC, Cambodia), University of Malaya Universiti Malaysia Sarawak, Children's Hospital No. 1, Pasteur Institute of Ho Chi Minh City (Vietnam) and National Health Research Institutes (NHRI) in Taiwan</td>
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<tr>
<td>GenRe-Mekong</td>
<td>Platform for genetic surveillance of malaria in the Greater Mekong; dry blood spot samples processed by SpotMalaria which produces a set of genotypes comprising resistance, species and genomic markers. Produces a genetic report card or compendium of genotypes and phenotype predictions used to map prevalence and/or resistance to multiple drugs</td>
<td>To support genomic surveillance of malaria in the Mekong sub-region with primary focus on drug resistance</td>
<td>Malaria (expansion expected)</td>
<td>Asia</td>
<td>Cambodia, Vietnam, Laos, Thailand, Bangladesh (continued in Vietnam and Laos)</td>
<td>Over-arching surveillance studies coordinated and run by Oxford University Clinical Research Unit in collaboration with national health bodies and research/technical partners</td>
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<tr>
<td>China CDC: Pathogen Identification Net (PIN)</td>
<td>National laboratory-based surveillance network for bacterial pathogens. Collects bioanalysis data of bacterial pathogens from network laboratories. Analysis includes pathogen identification, bio typing, antimicrobial resistance detection, molecular typing, and whole genome sequencing. Combining epidemiological data and laboratory data, network laboratories can detect clusters of pathogens and suggest possible cases to initiate investigation for detection of potential outbreaks or spread.</td>
<td>To support early detection and tracing of infectious diseases</td>
<td>Multiple pathogens, AMR</td>
<td>Asia</td>
<td>China</td>
<td>Under management of the China National Health Commission, with involvement from Regional CDC labs and Provincial and Municipal Health Commissions</td>
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<td>CDC labs at various levels execute the laboratory analysis: clinical sentinel labs conduct basic data collection, data upload and sample culture/detection; county labs conduct field investigations, and collect/transfer data; municipal labs conduct training, lab work, data upload, and provide QA/QC and local management; provincial labs conduct training, lab work, data upload, and provide regional management; the central CDC lab provides management and organisation, data processing, information release in network, training, QA/QC</td>
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<tr>
<td>China: National Influenza Surveillance Network (NISN)</td>
<td>Initiative for the surveillance of influenza in China</td>
<td>To monitor the spread of influenza</td>
<td>Influenza</td>
<td>Asia</td>
<td>China</td>
<td>WHO, Chinese National Influenza Centre, National Health Commission and Centre of Prevention and Disease Control Ministries of health orchestrate delivery, laboratory surveillance conducted by WHO CC and NICs and sentinel laboratories</td>
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<tr>
<td>Cooperative Agreement of CNIC and US CDC (2004–2014)</td>
<td>Programme that builds upon relationship between Chinese National Influenza Centre (CNIC) and US CDC through Cooperative Agreement signed in 2007 focusing on emerging infectious diseases. US CDC provides technical support to China to develop additional virology and epidemiology expertise, improve the influenza surveillance programme in China and strengthen analysis, utilisation of data and early response to threats</td>
<td>1) to improve and expand the influenza surveillance system in China; and 2) to build capacity for early detection and response to seasonal influenza, avian influenza and other influenza viruses with pandemic potential</td>
<td>Influenza, and influenza-like illnesses</td>
<td>Asia</td>
<td>China</td>
<td>US CDC, CNIC</td>
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<tr>
<td>Antimicrobial Resistance Surveillance &amp; Research Network (AMRSN) (India)</td>
<td>Network established by the Indian Council of Medical Research (ICMR) to bring together antimicrobial resistance (AMR) expertise. Network laboratories conduct routine AMR surveillance using standard operating procedures, and are part of the quality assurance scheme set up by the Indian Association of Medical Microbiologists collaborating centres. Data collected by the network is used to monitor resistance and measure the impact of future interventions to combat AMR</td>
<td>To understand the extent and pattern of AMR and use this evidence to inform public health decision making around AMR. Specific aims include: (i) establish network of hospitals to monitor trends in the antimicrobial susceptibility profile of clinically important bacteria and fungi limited to human health; (ii) include comprehensive molecular studies for identifying the clonality of drug-resistant pathogens and their transmission dynamics to enable a better understanding of AMR in the Indian context and develop suitable interventions; (iii) disseminate information on AMR in pathogenic organisms to stakeholders to promote interventions that reduce AMR; and (iv) create a data management system for data collection and analysis</td>
<td>Multiple AMR-relevant pathogens</td>
<td>Asia</td>
<td>India</td>
<td>Nodal centres for pathogenic groups (in tertiary hospitals), ICMR, regional labs</td>
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<td>Japan Nosocomial Infections Surveillance (JANIS)</td>
<td>National surveillance program organised by Ministry of Health, Labour and Welfare (MHLW) to track nosocomial infections (in hospital setting) and spread of antimicrobial resistant bacteria in Japanese medical settings. Started in 2000 as a voluntary surveillance system for healthcare-associated infections, and now focuses more broadly on AMR-relevant pathogens detected in clinical specimens. Publishes aggregate data collected from participating hospitals, who upload data on a monthly basis.</td>
<td>To track and monitor spread of nosocomial infections and antimicrobial-resistant bacteria</td>
<td>Multiple pathogens (E. coli, staph infections, Klebsiella pneumoniae, E. faecalis, Candida albicans, etc.)</td>
<td>Asia</td>
<td>Japan</td>
<td>JANIS - clinical laboratory registers, tests, converts data, stores data, and produces reports Participating sites (e.g. hospitals, clinical laboratories, intensive care units) submit data to JANIS-CL voluntarily</td>
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<tr>
<td>National Epidemiological Surveillance of Infectious Diseases (NESID)</td>
<td>Physicians are required to submit data about infectious diseases to public health authorities through NESID, which is accessed through a web-based system. Surveillance data are then published at a national level weekly on the National Institute of Infectious Diseases (NIID) website.</td>
<td>To collect local data on infectious diseases and publish information at a national level</td>
<td>Multiple pathogens (113 reportable infectious diseases)</td>
<td>Asia</td>
<td>Japan</td>
<td>Physicians submit data to health centre, which then reports data to local public health authorities (usually at prefecture level) NIID collates, analyses and publishes data</td>
</tr>
<tr>
<td>US CDC in Central Asia: Digital Case Notification Register (DCNR)</td>
<td>US CDC-led effort to create Digital Case Notification Register (DCNR), a web-based portal for infectious disease surveillance.</td>
<td>To monitor notifiable infectious diseases</td>
<td>Multiple pathogens</td>
<td>Asia</td>
<td>Kyrgyzstan</td>
<td>US CDC</td>
</tr>
<tr>
<td>Malaysia -- Influenza network</td>
<td>Initiative for the surveillance of influenza in Malaysia</td>
<td>To monitor the spread of influenza</td>
<td>Influenza</td>
<td>Asia</td>
<td>Malaysia</td>
<td>WHO, Ministry of Health Malaysia, MKAK Sungai Buloh, Virology Unit of Institute of Medical Research. Ministries of Health deliver initiative, while laboratory surveillance is conducted by WHO CC and NICs and sentinel laboratories</td>
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<td>Kor-GLASS</td>
<td>Variant of GLASS (Global Antimicrobial Resistance and Use Surveillance System) established in South Korea. Clinical isolates are collected in sentinel hospitals and then sent to an analysis centre.</td>
<td>To address antimicrobial resistance in South Korea</td>
<td>AMR-relevant pathogens, (S. aureus, strep pneumonia, E. faecalis, E. faecium, E. coli, Klebsiella pneumoniae, Shigella, Salmonella, etc.)</td>
<td>Asia</td>
<td>South Korea</td>
<td>Ministry of Health and Welfare manages all aspects of Kor-GLASS, operational and advisory committee supporting with design and decision making</td>
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<tr>
<td>Disease Early Warning System in Yemen (eDEWS)</td>
<td>Conflict in Yemen has collapsed essential life services, prompted temporary settings with high population densities, unsafe water, poor sanitation, and lack of basic health services. eDEWS intended to strengthen the routine disease surveillance system in Yemen and ensure rapid detection and response to diseases using electronic tools and platform for data collection, management, analysis and visualisation.</td>
<td>To supplement the existing disease surveillance systems in Yemen during humanitarian crisis and ensure rapid surveillance and response to diseases</td>
<td>Multiple pathogens (31 communicable diseases)</td>
<td>Asia</td>
<td>Yemen (all 333 districts, 1982 health facilities)</td>
<td>Regional health facilities</td>
</tr>
<tr>
<td>Country-level acute flaccid paralysis (AFP) surveillance systems</td>
<td>Ten different country-level acute flaccid paralysis (AFP) surveillance systems linked to the WHO Regional Reference Laboratory at the Istituto Superiore di Sanità (Italy)</td>
<td>To monitor enteroviruses (including polio), including isolation, identification and typing according to WHO protocols</td>
<td>Enteroviruses (including polio)</td>
<td>Europe</td>
<td>Italy, Serbia, Bosnia and Herzegovina, Montenegro, Bulgaria, Kosovo, Albania, North Macedonia, Malta, Greece</td>
<td>WHO regional reference laboratory collects data Respective Ministries of Health organise polio response at national level</td>
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<td><strong>EpiPulse</strong></td>
<td>Online portal for European public health authorities and partners to collect, analyse, share and discuss infectious disease data for surveillance activities. Established in June 2021, integrating previously independent systems (the European Surveillance System (TESSy), the five Epidemic Intelligence Information System (EPIS) platforms and the Threat Tracking Tool (TTT)). Facilitates collection, analysis and dissemination of indicator- and event-based surveillance data, including global epidemic intelligence, whole-genome sequencing and health determinants.</td>
<td>To strengthen infectious disease prevention and control, and to support better preparedness and management of threats, by enhancing early threat detection and assessment and enabling real-time monitoring</td>
<td>Multiple pathogens</td>
<td>Europe</td>
<td>EU and EEA Member States</td>
<td>ECDC coordinates platform EU/EEA Member States, partner countries and institutions, and appointed experts can access portal to report and analyse data</td>
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<tr>
<td><strong>EU4S-DEEP</strong>   (EU Sewage Sentinel System for SARS-CoV-2 Digital European Exchange Platform)</td>
<td>Platform to support investigations into Covid-19 and water. Focuses on gathering and sharing best practices, collecting results from wastewater surveillance activities, publishing sampling and analysis methods, gathering experts in wastewater surveillance, and fostering collaboration. Includes data dashboard, partially open to the general public.</td>
<td>To ensure that the results of the wastewater surveillance are promptly shared and used</td>
<td>Covid-19</td>
<td>Europe</td>
<td>EU and EEA Member States</td>
<td>Stakeholders in health and the environment at supra-national, national, regional and local levels (e.g. Croatian Institute of Public Health, State General Laboratory MoH in Cyprus) Private and commercial contributors from various economic sectors including water utilities; researchers and academics; NGOs</td>
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<tr>
<td><strong>ELIXIR – Compute Platform</strong></td>
<td>EU effort to provide infrastructure for life scientists to access, share and analyse data across different sources – in Europe – includes services related to authentication and authorisation, storage and data transfer, and cloud and computing resources</td>
<td>To support secure, cloud-based data storage, access, management and computation for the life-science research community</td>
<td>Initiative not specifically focused on pathogen surveillance</td>
<td>Europe</td>
<td>EU and EEA Member States (22) and UK</td>
<td>Hub-and-node model ELIXIR Hub: Wellcome Genome Campus (UK) ELIXIR Nodes: Network of organisations in each Member State, led by one organisation that coordinates local ELIXIR activities (e.g., Dutch Techcentre for Life Sciences, Utrecht, oversees Dutch node of ELIXIR Netherlands)</td>
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<td>HERA surveillance activities (funded through EU4Health)</td>
<td>The EU4Health programme established the HERA MCMI IT platform in 2023. HERA collects intelligence on health threats (including infectious diseases, but also communicable diseases, chemical and environmental threats) and medical countermeasures against these threats to better prepare for and respond to health emergencies. Activities include coordination with ECDC and supporting national wastewater surveillance activities.</td>
<td>To protect the EU from serious cross-border threats to health and strengthen the responsiveness of health systems and coordination among Member States to cope with serious cross-border threats to health</td>
<td>Multiple pathogens with high pandemic potential (mainly respiratory RNA viral families)</td>
<td>Europe</td>
<td>EU countries, and third countries associated with the EU4Health programme, including Norway, Iceland, Ukraine and Moldova</td>
<td>EU/EEA Member States and third countries associated with the EU4Health programme, European Commission and other EU-level stakeholders (coordination with ECDC and DG SANTE regarding health threats, EMA regarding medical countermeasures), European Parliament</td>
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<tr>
<td>AMR Data Hub</td>
<td>Online infrastructure created by the EU H2020-funded COMPARE Consortium for storing and sharing genomic data and phenotypic AMR data. Can be used by stakeholders that collect relevant data, such as public health and clinical laboratories, food safety agencies and veterinary institutes.</td>
<td>To provide a system for public health, food and veterinary institutes, clinical laboratories and researchers to share their genomic and related data</td>
<td>Multiple AMR-relevant pathogens</td>
<td>Europe</td>
<td>Europe</td>
<td>European Nucleotide Archive created open repository for sequencing and related data that the Data Hub is built on, European COMPARE Consortium, Public health and clinical laboratories, food safety agencies and veterinary institutes</td>
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<tr>
<td>Influenza-Monitoring Vaccine Effectiveness in Europe (I-MOVE)</td>
<td>Established in 2007 to share information and estimate influenza vaccine effectiveness across primary and secondary care. Sentinel PCRs collect specimens from a sample of patients who present with influenza-like illness or acute respiratory infection. Samples are tested at regional laboratories. Network was expanded to include Covid-19 to strengthen surveillance systems.</td>
<td>To share information and estimate influenza vaccine effectiveness in both primary and secondary care</td>
<td>Influenza (both type A and B), Covid-19</td>
<td>Europe</td>
<td>Six sentinel sites in the European Union (France, Ireland, Netherlands, Portugal, Spain, Sweden) and two sites in the UK (England and Scotland)</td>
<td>I-MOVE network coordinates surveillance, Regional surveillance networks in Spain, Netherlands, France, England, Scotland, Portugal and Sweden</td>
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<tr>
<td>Pan American Health Organization (PAHO): Epidemic Intelligence</td>
<td>Regional WHO initiative to support epidemic intelligence activities (cycle of organised and systematic collection, analysis and interpretation)</td>
<td>To support the detection, verification and response to potential health risks</td>
<td>Multiple pathogens (cholera, diphtheria, measles, yellow fever, polio, dengue, Chikungunya, Covid-19, avian influenza, etc.)</td>
<td>North/South America</td>
<td>Americas</td>
<td>WHO, PAHO, public health authorities, Ministries of Health, WHO collaborating centres, NGOs</td>
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<td>Canadian Covid-19 Genomics Network (CanCOGeN)</td>
<td>Initiative consists of two–sub-groups -- CanCOGeN-HostSeq and CanCO–N-VirusSeq -- to address topics specific to the individual and viral genomic data sharing respectively</td>
<td>To coordinate and upscale existing genomics-based Covid-19 research and surveillance efforts to better track viral introductions, inform the public health response, and explore the relationship of viral and human genomes</td>
<td>Covid-19</td>
<td>North/South America</td>
<td>Canada</td>
<td>Genome Canada</td>
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<tr>
<td>Vigilancia Integrada Comunitaria (ViCo)</td>
<td>Integrated syndromic community surveillance in Guatemala set up in 2007</td>
<td>To generate high-quality data among a network of sentinel reporting sites, identify research needs, facilitate planning and warn of infections</td>
<td>Multiple pathogens (dengue, norovirus, rotavirus, Campylobacter, Salmonella, influenza, group A Streptococcus)</td>
<td>North/South America</td>
<td>Guatemala</td>
<td>Universidad del Valle de Guatemala (UVG) runs surveillance programme</td>
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<td>Guatemala Ministry of Public Health and Social Assistance (MSPAS) and US CDC provide support</td>
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<tr>
<td>Coordinated Outbreak Response and Evaluation (CORE) Network</td>
<td>Responds to instances of foodborne illness outbreaks in the US, with multidisciplinary expertise such as epidemiologists, microbiologists, environmental health officers, consumer safety officers, veterinary medical officers, chemists, health communication specialists, and scientific writers. Sits under the FDA in the US</td>
<td>To achieve the public health goal of a safer food supply, and to manage outbreak surveillance, response, and post-response activities related to incidents involving multiple illnesses linked to FDA-regulated human food, dietary supplements, and cosmetic products</td>
<td>Foodborne illnesses</td>
<td>North/South America</td>
<td>United States</td>
<td>Teams within CORE: Signals and Surveillance Team (SST), CORE Response Teams (CRTs), Outbreak Evaluation Team (OET), Outbreak Analytics Team (OAT), CORE Communications Team</td>
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<td>FDA (ORA Divisions and Laboratories, CFSAN Program Offices, Office of the Commissioner)</td>
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<td>CDC (Outbreak Response and Prevention Branch)</td>
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<td>State partners and rapid response teams (RRTs) provide state-specific insight, information, and jurisdictional authority, responsibilities, and actions</td>
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<td>USDA FSIS</td>
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<td>Industry stakeholders and trade organisations</td>
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<td>Foodborne Disease Outbreak Surveillance System (FDOSS)</td>
<td>US CDC system to collect information about foodborne disease outbreaks</td>
<td>To better understand the germs, foods, settings and contributing factors (e.g. food not kept at the right temperature) involved in outbreaks, and to identify emerging foodborne disease threats to inform outbreak prevention measures</td>
<td>Foodborne illnesses (e.g. C. perfringens, Campylobacter, E. coli, norovirus and Salmonella)</td>
<td>North/ South America</td>
<td>United States</td>
<td>CDC State, local and territorial public health departments</td>
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<tr>
<td>FoodNet</td>
<td>US CDC-led food safety programme, which includes active laboratory surveillance of foodborne illnesses</td>
<td>To determine burden of foodborne illness in the United States, monitor trends in the burden of specific foodborne illness over time, attribute the burden of foodborne illness to specific foods and settings, and disseminate information that can lead to improvements in public health practice and the development of interventions to reduce the burden of foodborne illness</td>
<td>Multiple pathogens (including Campylobacter, Cyclospora, Listeria, Salmonella, shiga toxin-producing E. coli (STEC) O157 and non-O157, Shigella, Vibrio, and Yersinia infections diagnosed by laboratory testing of samples from patients)</td>
<td>North/ South America</td>
<td>United States</td>
<td>US CDC Collaborating partners: US Department of Agriculture's Food Safety and Inspection Service (USDA-FSIS) and the Food and Drug Administration (FDA) FoodNet personnel located at state health departments State clinical laboratories</td>
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<tr>
<td>National Electronic Norovirus Outbreak Network (CaliciNet)</td>
<td>US norovirus outbreak surveillance network of federal, state and local public health laboratories (launched in 2009). Public health laboratories electronically submit data (e.g. genetic sequence data, epidemiology data), and strains are then compared with other norovirus strains in the database, helping CDC link outbreaks to a common source, monitor norovirus strains, and identify new strains</td>
<td>To help public health professionals better understand noroviruses and develop interventions to prevent them from spreading</td>
<td>Noroviruses</td>
<td>North/ South America</td>
<td>United States</td>
<td>US CDC State health departments identify norovirus exposure and collect epidemiological data and specimens, and, if outbreak occurs, upload outbreak and sequence data into CaliciNet CaliciNet-participating labs test specimens and sequence them to identify strains, and publish data alongside the CDC</td>
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| National Outbreak Reporting System (NORS) | Web-based platform for health departments to report data to US CDC – supports outbreak reporting by partners in state, local and territorial public health agencies | To support outbreak reporting and response | Multiple pathogens (enteric disease outbreaks caused by bacterial, viral, parasitic, chemical, toxin, and unknown agents, as well as foodborne and waterborne outbreaks of non-enteric disease, certain fungal disease outbreaks) | North/ South America | United States | US CDC
|                  |                                   |                  |          |                    |                  | Health/public health departments across the US report outbreaks
|                  |                                   |                  |          |                    |                  | Coordinates with the Council of State and Territorial Epidemiologists, United States Environmental Protection Agency, the US FDA, and US Department of Agriculture |
| National Surveillance of Bacterial Foodborne Illnesses | US CDC system to analyse and disseminate national surveillance data on bacterial foodborne illnesses. Includes LEDS system (Laboratory-based Enteric Disease Surveillance) for Salmonella, Shigella, and Shiga toxin-producing E. coli (STEC), and a case-based surveillance system for botulism, cholera and other Vibrio illnesses (including V. parahaemolyticus and V. vulnificus infections), Listeria infections, and typhoid and paratyphoid fever infections | To decrease the burden of acute bacterial enteric illnesses in the United States | Multiple foodborne pathogens (including Listeria monocytogenes, Salmonella spp, Shiga toxin-producing E. coli (STEC), Shigella spp, Vibrio spp, Clostridium botulinum) | North/ South America | United States | Clinical diagnostic labs
|                  |                                   |                  |          |                    |                  | State and territorial public health labs/departments
|                  |                                   |                  |          |                    |                  | CDC National Reference Labs (e.g. Enteric Diseases Laboratory Branch)
|                  |                                   |                  |          |                    |                  | Data storage and management departments within the CDC (e.g. Division of Foodborne, Waterborne, and Environmental Diseases (DFWED)) |
| National Wastewater Surveillance System (NWSS) | US CDC-led response to the Covid-19 pandemic (launched September 2020) to monitor wastewater. Samples are collected by local partners (e.g. water treatment plants), and sent to environmental or public health laboratories for SARS-CoV-2 testing. Health departments then submit data to the US CDC through the online NWSS Data Collation and Integration for Public Health Event Response (DCIPHER) portal. Data is analysed and reported to the health department to inform Covid-19 responses, and made publicly available through CDC’s Covid Data Tracker | To coordinate and build the nation's capacity to track the presence of SARS-CoV-2, the virus that causes Covid-19, in wastewater, so communities can act quickly to prevent the spread of Covid-19 | Covid-19 | North/ South America | United States | State local, tribal and territorial health departments; wastewater treatment plants; public health, environmental, academic and private laboratories collect and test samples
<p>|                  |                                   |                  |          |                    |                  | US CDC provides guidance and technical support and manages system |</p>
<table>
<thead>
<tr>
<th>Initiative name</th>
<th>Brief description of the initiative</th>
<th>Aim of initiative</th>
<th>Pathogens</th>
<th>Region</th>
<th>Geographic coverage</th>
<th>Key stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Center for Biotechnology Information (NCBI) Pathogen Detection system</td>
<td>US-based centralised system that integrates data and analysis for pathogens. Provides access to relevant data (e.g. genomic data, metadata) through a web-based platform, and features to automate analysis (e.g. by automatically screening genome sequences for genes associated with AMR, stress response and virulence)</td>
<td>To identify closely or clonally related isolates to aid in outbreak investigation and to facilitate active, real-time surveillance of pathogens</td>
<td>Multiple pathogens (foodborne, hospital-acquired, etc.), AMR-relevant pathogens</td>
<td>North/ South America</td>
<td>United States</td>
<td>US CDC (CDC Advanced Molecular Detection, and CDC Foodborne Outbreak) FDA (FDA Whole Genome Sequencing Program, FDA GenomeTrakr, the National Antimicrobial Resistance Monitoring System) US Department of Agriculture (Food Safety Inspection Service – FSIS, Molecular Subtyping) PHE (PHE Whole Genome Sequencing Other associations of Public Health Laboratories (APHL) Longer list of contributors: <a href="https://www.ncbi.nlm.nih.gov/pathogens/contributors/">https://www.ncbi.nlm.nih.gov/pathogens/contributors/</a></td>
</tr>
<tr>
<td>PulseNet</td>
<td>US-based network of local, state and federal public health laboratories that can analyse genomic data (DNA fingerprints and whole genome sequences) related to foodborne illnesses</td>
<td>To provide real-time surveillance of bacterial foodborne diseases, assist epidemiologists in investigating outbreaks, and to provide a rapid and effective means of communication between public health laboratories</td>
<td>Multiple pathogens (E. coli, Campylobacter, Listeria monocytogenes, Salmonella, Shigella, Vibrio cholerae, Vibrio parahaemolyticus, Cronobacter, etc.)</td>
<td>North/ South America</td>
<td>United States</td>
<td>CDC; State, local and federal labs; Public health microbiologists</td>
</tr>
<tr>
<td>System for Enteric Disease Response, Investigation and Coordination (SEDRIC)</td>
<td>Cloud-based platform for foodborne and animal contact outbreak investigations in the US. Includes features to help integrate data sources in real time (including data from other systems such as PulseNet, National AMR Monitoring System, NORS), visualise outbreak data, share data with partners, and manage historical surveillance and outbreak data</td>
<td>To streamline and coordinate outbreak investigations by combining epidemiologic, laboratory and traceback data in real time, to facilitate more effective responses to outbreaks</td>
<td>Enteric diseases</td>
<td>North/ South America</td>
<td>United States</td>
<td>SEDRIC team in the CDC and partners: state and local health departments, CDC, FDA, Food Safety and Inspection Service (FSIS), Animal and Plant Health Inspection Service (APHIS)</td>
</tr>
<tr>
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<tr>
<td>Waterborne Disease and Outbreak Surveillance System (WBDOSS)</td>
<td>US system to collect data on waterborne disease and outbreaks associated with recreational water, drinking water, and environmental and other water sources. Data collected includes: the number of outbreak-associated illnesses, hospitalisations and deaths; implicated types of water, settings and water systems; information on single cases of waterborne illnesses; characteristics of the outbreak (e.g. number of cases, timing of outbreak and location); results from epidemiologic and environmental health investigations; results from clinical specimen and environmental water sample testing</td>
<td>To provide information that can help prevent future disease and outbreaks</td>
<td>Multiple pathogens associated with waterborne illnesses</td>
<td>North/South America</td>
<td>United States</td>
<td>Local public health agencies, state and territorial health authorities, CDC</td>
</tr>
<tr>
<td>Pacific Public Health Surveillance Network (PPHSN)</td>
<td>Voluntary network of countries and organisations in the Pacific developing surveillance and responses to the health challenges of 22 Pacific Island countries and territories. Developed Pacific Syndromic Surveillance System (PSSS) as an early warning tool which collects and reports on surveillance data</td>
<td>To improve public health surveillance and response in the Pacific Islands</td>
<td>Multiple pathogens (e.g. dengue, measles, rubella, influenza, leptospirosis, typhoid fever, cholera and HIV/STIs)</td>
<td>Oceania</td>
<td>22 Pacific Island countries and territories</td>
<td>Core members: American Samoa, Cook Islands, Federated States of Micronesia, Nauru, New Caledonia, Palau, Papua New Guinea, Tonga, Tuvalu and Vanuatu, Allies members: US CDC, Fiji National University, Institute of Environmental Science and Research, Pacific Community (SPC), Pacific Island Health Officers Association (PIHOA), WHO</td>
</tr>
<tr>
<td>Enhanced Invasive Pneumococcal Disease (IPD) Surveillance Program</td>
<td>System in Australia to report cases of pneumococcal disease through passive surveillance</td>
<td>To record cases of IPD and collect detailed information on each case occurring in Australia, and to measure impact of conjugate pneumococcal vaccination on the rates and types of pneumococcal disease, the prevalence of circulating pneumococcal serotypes as well as levels of antibiotic resistance</td>
<td>Invasive pneumococcal disease (IPD), caused by respiratory pathogen Streptococcus pneumoniae</td>
<td>Oceania</td>
<td>All Australian jurisdictions</td>
<td>Enhanced Invasive Pneumococcal Disease Surveillance Working Group (EIPDSWG) coordinates programme (subcommittee of the Communicable Diseases Network Australia (CDNA)); Australian Technical Advisory Group on Immunisation (ATAGI); Australian Minister for Health; physicians; Commonwealth, state and territory health departments; public and private labs; researchers and academics</td>
</tr>
<tr>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
<td>Region</td>
<td>Geographic coverage</td>
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<tr>
<td>Australia: NISS (National Influenza Surveillance System)</td>
<td>Initiative for the surveillance of influenza in Australia</td>
<td>To monitor the spread of influenza</td>
<td>Influenza</td>
<td>Oceania</td>
<td>Australia</td>
<td>WHO, WHO NICs and National Notifiable Diseases Surveillance System, Networks of general practitioners, Sentinel sites, Department of Health</td>
</tr>
<tr>
<td>AusTrakka</td>
<td>Pathogen genomics platform initially proposed in 2015 and fast-tracked during Covid; collects data from all public health laboratories in Australia (and some in New Zealand) and allows sequences to be viewed in national context</td>
<td>To facilitate genomic surveillance through sharing of data and analysis</td>
<td>Covid-19 (potential for expansion)</td>
<td>Oceania</td>
<td>Australia and New Zealand</td>
<td>Communicable Diseases Genomics Network (CDGN), all public health laboratories; Australian Health Protection Principal Committee (AHPPC)</td>
</tr>
<tr>
<td>WHO: Global Antimicrobial Resistance and Use Surveillance System (GLASS)</td>
<td>Provides a standardised approach to the collection, analysis and sharing of antimicrobial resistance (AMR) data, and collects AMR data for priority pathogens through case-based surveillance that combines clinical, microbiological and epidemiological data</td>
<td>To collect valid AMR data for use in AMR trend and burden monitoring, and the development of local and national guidelines around AMR</td>
<td>Multiple AMR-relevant pathogens</td>
<td>International</td>
<td>Global. 109 countries enrolled in GLASS-AMR, 87 country-territory-areas provided details on AMR rates during 2020</td>
<td>Surveillance, Evidence and Laboratory Strengthening Unit of the Department of Surveillance, Prevention and Control of the WHO Antimicrobial Resistance Division; Central Asian and European Surveillance of Antimicrobial Resistance (CAESAR) network, European Antimicrobial Resistance Surveillance Network (EARS-Net), ReLAVRA (Latin American Network for AMR Surveillance), Western Pacific Regional Antimicrobial Surveillance System (WPRACSS), Euro AMC Network, WHO AMR Surveillance Collaborating Centres Network</td>
</tr>
<tr>
<td>WHO: Global Antimicrobial Resistance and Use Surveillance System (GLASS)-FUNGI</td>
<td>Part of GLASS (previous initiative). GLASS-FUNGI supports surveillance of invasive bloodstream infections caused by Candida spp.</td>
<td>To collect, analyse, and report species distribution of Candida and the antifungal resistance patterns, and support setting up and strengthening national fungal AMR surveillance systems</td>
<td>AMR-relevant pathogens, Candida spp.</td>
<td>International</td>
<td>Global</td>
<td>As above</td>
</tr>
<tr>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
<td>Region</td>
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<tr>
<td>WHO: Global Influenza Surveillance and Response System (GISRS)</td>
<td>Global influenza surveillance and preparedness in 125 states via monitoring, alerts and surveillance. National Influenza Centres (NICs) collect virus specimens in their country and perform preliminary analysis before shipping clinical specimens and isolated viruses to collaborative centres (WHO CCs) for advanced antigenic and genetic analysis. The results form the basis of WHO recommendations on the composition of the influenza vaccine and relevant risk-assessment activities.</td>
<td>To foster global confidence and trust through collaboration and sharing of data, viruses and benefits based on global health model.</td>
<td>Seasonal, pandemic and zoonotic influenza, some non-influenza emergencies such as Covid-19</td>
<td>International</td>
<td>125 WHO member states</td>
<td>125 WHO member states; National Influenza Centres at national level; WHO Collaborating Centres; H5 Reference Laboratories (in relation to H5N1) and Essential Regulatory Laboratories (ERLs)</td>
</tr>
<tr>
<td>Central Asian and European Surveillance of Antimicrobial Resistance (CAESAR) network</td>
<td>Central Asian and European network that includes all countries in European region that are not part of EARS-Net</td>
<td>To detect and monitor antimicrobial resistance (AMR)</td>
<td>Multiple AMR-relevant pathogens</td>
<td>International</td>
<td>19 countries (Albania, Moldova, Russia, Serbia, Turkey, and others); 7 countries have submitted national surveillance information to the database</td>
<td>Joint initiative by WHO Regional Office for Europe, the European Society of Clinical Microbiology and Infectious Diseases (ESCMID) and the Dutch National Institute for Public Health and the Environment</td>
</tr>
<tr>
<td>WHO FluNet and EMFLU</td>
<td>WHO FluNet (global influenza surveillance platform) and EMFLU (Eastern Mediterranean Flu): 19 out of 22 Eastern Mediterranean countries with functioning surveillance systems report to WHO through EMFLU. Data are collected from countries by using either case-based data entered online from sentinel sites or collected data by Ministry of Health teams. There are 18 National Influenza Centres (NICs) and 3 National Influenza Laboratories in the Eastern Mediterranean region who coordinate with the WHO laboratory team.</td>
<td>To collect data on influenza viruses in the Eastern Mediterranean region, including genetic characterisation, to reduce the intensity and severity of potential epidemics.</td>
<td>Influenza</td>
<td>International</td>
<td>22 countries in the Eastern Mediterranean (only 19 have functioning surveillance systems, 18–19 reporting cases in 2017–2020 with only 11 reporting in 2021)</td>
<td>WHO and WHO Regional Offices; WHO National Influenza Centres conduct testing; National Ministries of Health collect and upload data</td>
</tr>
<tr>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
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<td>Pathogens</td>
<td>Region</td>
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<tr>
<td><strong>Unravelling data for rapid evidence-based response to Covid-19 (unCoVer)</strong></td>
<td>Network that brings together experts (e.g. in medicine, research, data management, statistical modelling, research ethics) to support the better use of real-world data and routine healthcare data to better understand Covid-19</td>
<td>To provide a research platform for the use of real-world data by bringing together data, medical and scientific expertise to address questions about the determinants of Covid-19 prognosis to inform more effective medical and public health strategies</td>
<td>Covid-19</td>
<td>International</td>
<td>29 partners from 25 institutions in the EU and 4 non-EU partners representing 18 countries (Belgium, Bosnia and Herzegovina, Brazil, Colombia, Croatia, Greece, Ireland, Italy, Luxembourg, Norway, Portugal, Romania, Slovakia, South Korea, Spain, Turkey, UK, US)</td>
<td>Clinical partners and epidemiologists, external advisory boards</td>
</tr>
<tr>
<td><strong>Global Polio Laboratory Network</strong></td>
<td>Established in 1990, consists of 146 WHO-accredited laboratories in 92 countries following recommended procedures for detecting and characterising polio viruses from stool and sewage samples collected from acute flaccid paralysis (AFP) cases and the environment</td>
<td>To support the detection of polio across the world and distinguish poliovirus as a cause of AFP from AFP caused by other diseases</td>
<td>Poliovirus</td>
<td>International</td>
<td>92 countries</td>
<td>Global Polio Eradication Initiative Agency partners include: Rotary International, US Centers for Disease Control, UNICEF, Bill &amp; Melinda Gates Foundation and Gavi, the Vaccine Alliance; country-level Polio laboratories</td>
</tr>
<tr>
<td><strong>WHO: Polio Information System</strong></td>
<td>System which collects all polio-related data shared at the global level, processes and performs quality checks and generates analyses across acute flaccid paralysis (AFP) and environmental surveillance, laboratory data and supplemental immunisation activities (SIAs)</td>
<td>To support the detection and eradication of polio</td>
<td>Poliovirus</td>
<td>International</td>
<td>All six WHO regions</td>
<td>Global Polio Eradication Initiative Agency partners include: Rotary International, US Centers for Disease Control, UNICEF, Bill &amp; Melinda Gates Foundation and Gavi, the Vaccine Alliance</td>
</tr>
<tr>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
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<tr>
<td>Global Alliance for Genomics and Health</td>
<td>Not pathogen surveillance specific – an initiative to accelerate biomedical advances by enabling responsible sharing of clinical and genomic data. Has established secure, interoperable technical standards and policy frameworks.</td>
<td>To support biomedical advances by enabling responsible sharing of clinical and genomic data</td>
<td>Not specified</td>
<td>International</td>
<td>Global</td>
<td>Strategic alignments with organisations such as Public Health Alliance for Genomic Epidemiology (PHA4GE), the International Covid-19 Data Alliance (ICODA) and the European Covid19 data portal Researchers in genomics</td>
</tr>
<tr>
<td>Global Initiative on Sharing All Influenza Data (GISAID)</td>
<td>Data sharing initiative to support research into how viruses evolve and spread. Promotes the rapid sharing of genetic sequence data and related clinical and epidemiological data associated with human viruses, and data associated with avian and other animal viruses.</td>
<td>To promote the rapid sharing of data from all influenza viruses and the coronavirus causing Covid-19</td>
<td>Influenza and Covid-19, avian and animal viruses</td>
<td>International</td>
<td>Global</td>
<td>Public-private partnerships and technical partners (including Brazilian Ministry of Health, Federal Republic of Germany, A*STAR, US CDC, Sanofi foundation, Seqirus) Technical partners – Bioinformatics Institute, Institut Pasteur, a7digital Previously funded by US Department of Health and Human Services, Swiss Federation, Max-Planck-Foundation, Association of Public Health Laboratories, European Commission Current funding through the Rockefeller Foundation (2021–2024, awarded grant)</td>
</tr>
<tr>
<td>Global Outbreak Alert and Response Network (GOARN)</td>
<td>Network coordinates identification, confirmation and response to outbreaks of international importance</td>
<td>To detect, confirm and respond to outbreaks of international importance</td>
<td>Multiple pathogens (deployments have included cholera, hepatitis, dengue, Ebola, H5N1, meningitis, rift valley fever, yellow fever)</td>
<td>International</td>
<td>Global</td>
<td>WHO</td>
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<td>Steering committee has representatives from 21 partner institutions including: African Field Epidemiology Network (AFENET), China CDC, European CDC, International Centre for Diarrhoeal Disease Research, and others</td>
</tr>
<tr>
<td>Initiative name</td>
<td>Brief description of the initiative</td>
<td>Aim of initiative</td>
<td>Pathogens</td>
<td>Region</td>
<td>Geographic coverage</td>
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<tr>
<td>Global Polio Eradication Initiative (GPEI): Field Surveillance</td>
<td>GPEI conducts three kinds of surveillance: of cases among individuals with acute flaccid paralysis (AFP), environmental surveillance (ES) in sewage and wastewater, and surveillance among individuals with primary immunodeficiency disorders (PIDs) referred to as immunodeficiency-associated vaccine-derived poliovirus (iVDPV) surveillance. iVDPV surveillance being established as of 2022</td>
<td>To support the detection and eradication of polio</td>
<td>Poliovirus</td>
<td>International</td>
<td>Global</td>
<td>Global Polio Eradication Initiative Agency partners include: Rotary International, US Centers for Disease Control, UNICEF, Bill &amp; Melinda Gates Foundation and Gavi, the Vaccine Alliance</td>
</tr>
<tr>
<td>International Severe Acute Respiratory and emerging Infection Consortium (ISARIC)</td>
<td>Develops protocols around characterising pathogens</td>
<td>To prevent illness and deaths from infectious diseases outbreaks</td>
<td>Infectious diseases</td>
<td>International</td>
<td>Global</td>
<td>Funding from Wellcome; Foreign, Commonwealth, and Development Office (UK), Bill &amp; Melinda Gates Foundation ISARIC members and associates Global Support Centre through the University of Oxford</td>
</tr>
<tr>
<td>Centre for Genomic Pathogen Surveillance</td>
<td>Organisation that builds capacity relating to genomic pathogen surveillance by providing access to expertise, data and tools</td>
<td>To provide universal surveillance strategies at scale, facilitating rapid analysis and enabling the training of experts worldwide</td>
<td>Multiple AMR-relevant pathogens</td>
<td>International</td>
<td>Global</td>
<td>Funders include multiple CDCs, ECDC, FAO, multiple National Institutes for Health, NIHR, WHO Links to Big Data Institute, University of Oxford, Wellcome</td>
</tr>
<tr>
<td>WHO: Early Warning, Alert and Response System (EWARS)</td>
<td>Initiative to support pathogen surveillance in low-resource and emergency settings, including ‘EWARS in a box’, which includes everything needed to do surveillance in the field (e.g. phones, a laptop, a datahub storage device, solar chargers, etc.)</td>
<td>To improve early warning, alert and responses to public health emergencies</td>
<td>Multiple pathogens</td>
<td>International</td>
<td>Global</td>
<td>WHO provides equipment Country-level stakeholders conduct surveillance</td>
</tr>
<tr>
<td>NORMAN/SCORE SARS-CoV-2 (SC2S)</td>
<td>Open-access database for wastewater pathogen surveillance, where data can be accessed and shared for Covid-19</td>
<td>To enable and facilitate the rapid sharing and critical evaluation of multiple wastewater metadata sets, and to engage public health authorities around wastewater surveillance for public health</td>
<td>Covid-19</td>
<td>International</td>
<td>Global – but current data uploaded (as of 2021) have been mostly European/Scandinavian, as well as from Saudi Arabia and Cyprus</td>
<td>NORMAN</td>
</tr>
</tbody>
</table>
Annex B. **Major stakeholders in pathogen surveillance and associated initiatives**

**Table 6: Major stakeholders and associated initiatives**

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Primary initiatives</th>
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</table>
| **WHO**                         | Coordinates or helps coordinate:  
                                   | Global Influenza Surveillance and Response System (GISRS)  
                                   | National Influenza Surveillance Network (NISN)  
                                   | FluNet  
                                   | Global Outbreak and Response Network (GOARN)  
                                   | Early Warning, Alert and Response System (EWARS)  
                                   | Global Polio Laboratory Network  
                                   | Polio Information System and Global Polio Eradication Initiative  
                                   | GLASS (AMR)  
                                   | WHO Regional office activities:  
                                   | PAHO Epidemic Intelligence  
                                   | Central Asian and European Surveillance of Antimicrobial Resistance (CAESAR)  
                                   | Pacific Public Health Surveillance Network  
                                   | Receives data from or collaborates with:  
                                   | African Centre of Excellence for Genomics of Infectious Diseases – Sentinel project  
                                   | Centre for Genomic Pathogen Surveillance  
                                   | National influenza networks and surveillance programmes (e.g. Chinese National Influenza Surveillance Network, Malaysian Influenza Network, Australia National Influenza Surveillance System) |
| **Bill & Melinda Gates Foundation** | Collaborates with or provides funding for:  
                                   | Africa CDC’s Digital Disease Surveillance programme  
                                   | South African Collaborative Covid-19 Environmental Surveillance System  
                                   | Global Polio Laboratory Network  
                                   | WHO Polio Information Centre and Global Polio Eradication Initiative  
                                   | African Centre of Excellence for Genomics of Infectious Diseases – Sentinel project |
| **Wellcome**                    | Coordinates:  
                                   | ELIXIR  
<pre><code>                               | Previously helped coordinate the Centre for Genomic Pathogen Surveillance (CGPS) |
</code></pre>
<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Primary initiatives</th>
</tr>
</thead>
</table>
| US CDC       | Coordinates: National Outbreak Reporting System (NORS)  
National Surveillance of Bacterial Foodborne Illnesses  
National Wastewater Surveillance System (NWSS)  
Waterborne Disease and Outbreak Surveillance System (WBDOSS)  
Foodborne Disease Outbreak Surveillance System (FDOSS)  
FoodNet  
National Electronic Norovirus Outbreak Network (CaliciNet)  
PulseNet  
Collaborates with or provides funding for:  
Pacific Public Health Surveillance Network (PPHSN)  
Vigilancia Integrada Comunitaria (ViCo)  
GLASS (AMR)  
Global Initiative on Sharing All Influenza Data (GISAID) |
| ECDC         | Coordinates EpiPulse  
Provides funding for Centre for Genomic Pathogen Surveillance (CGPS)                                                                                   |
| Africa CDC   | Coordinates:  
Regional Integrated Surveillance and Laboratory Network (RISLNET)  
Digital Disease Surveillance  
Receives data from different pathogen surveillance initiatives in Africa, including from ACEGID |
Annex C. **Additional details on prioritised initiatives**

### Table 7: Case Study A additional details

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<tr>
<th>African Centre of Excellence for Genomics of Infectious Diseases (ACEGID) – Sentinel project</th>
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<tr>
<td><strong>Date</strong></td>
<td>2020–2025</td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
<td>West and Central Africa. Future plans for wider expansion in Africa</td>
</tr>
</tbody>
</table>
| **Tools produced** | SHERLOCK – CRISPR-based paper strip test used to detect viruses or bacteria in clinical samples within minutes (used at point of care)  
CARMEN – Blood test for use in hospitals to test for hundreds of known viruses simultaneously (used in regional hospitals)  
CommCare (developed by Dimagi) – Tool for frontline workers to report symptoms and diagnostic data from clinics in low-connectivity environments |
| **Data source** | Health clinics, local hospitals or regional sequencing centres (hub and spoke model, with samples escalated if local level cannot determine pathogen) |
| **Data sharing** | Data uploaded to central Sentinel project for analysis (also analysed locally)  
Data and analysis shared with national Ministries of Health and with the Africa CDC |
| **Submission type (voluntary/mandatory)** | Voluntary |
| **Database/platform** | Initiative makes use of cloud-based technologies, such as Terra and DNANexus |
| **Access type** | Unclear |
| **Funding model** | Funded through the Audacious project (a TED initiative)  
Receives funding from Nigeria CDC, Africa CDC and WHO offices |
| **Relation to other initiatives** | Part of the Audacious project  
Works alongside WHO offices |
| **Key collaborators** | ACEGID  
Broad Institute  
Partners include: Dimagi, Fathom and MassDesign |
| **Pathogen focus** | All viral diseases |
| **Centre for Genomic Pathogen Surveillance (CGPS)** |
|------------------|------------------|
| **Date**         | 2015–ongoing     |
| **Geographic coverage** | Global          |
| **Tools produced** |                  |
| EpiCollect – Tool to gather data via mobile phone or web |
| Microreact – tool to help users map and visualise data |
| Data-Flo – tool for data integration |
| MetaData Uploader – tool to help collect, process, upload and interpret data |
| Web applications for Pangolin – Tool to assign lineages to Covid-19 sequences |
| **Data source** | N/A (Capacity building initiative for use of genomic data) |
| **Data sharing** | N/A              |
| **Submission type (voluntary/mandatory)** | N/A              |
| **Database/platform** | Pathogenwatch – platform to store, process and analysis data for genomic surveillance |
| **Access type** | Dependent on tool and user preference, e.g. space for ‘private rooms’ for users to keep secure within teams |
| **Funding model** | Funders include national CDCs, ECDC, FAPO, NIHR, WHO |
| **Long-term model for funding is unclear** |
| **Relation to other initiatives** | Other initiatives use CGPS’ tools, e.g. EpiPulse uses EpiCollect |
| **Key collaborators** | Big Data Institute at the University of Oxford |
| | Wellcome (previously) |
| | Partnered with public health institutions, e.g. through the NIHR Global Health Research Unit for Genomic Surveillance of Antimicrobial Resistance |
| **Pathogen focus** | Not pathogen-specific |
Table 9: Case Study C additional details

<table>
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<tr>
<th><strong>EpiPulse</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
</tr>
<tr>
<td>Launched in 2021</td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
</tr>
<tr>
<td>EU and EEA Member States and partner institutions</td>
</tr>
<tr>
<td><strong>Tools produced</strong></td>
</tr>
<tr>
<td>N/A</td>
</tr>
<tr>
<td><strong>Data source</strong></td>
</tr>
<tr>
<td>Collates a range of indicator- and event-based infectious disease surveillance data from Member States and partner institutions</td>
</tr>
<tr>
<td><strong>Data sharing</strong></td>
</tr>
<tr>
<td>Data shared with other users using event codes</td>
</tr>
<tr>
<td>Data and insights shared with relevant international stakeholders such as national governments, WHO and other EU bodies and agencies</td>
</tr>
<tr>
<td><strong>Submission type (voluntary/mandatory)</strong></td>
</tr>
<tr>
<td>Voluntary (strongly encouraged by ECDC)</td>
</tr>
<tr>
<td><strong>Database/platform</strong></td>
</tr>
<tr>
<td>EpiPulse database uses EpiCollect technology</td>
</tr>
<tr>
<td><strong>Access type</strong></td>
</tr>
<tr>
<td>Accessible for authorised users in EU/EEA Member States and partner institutions</td>
</tr>
<tr>
<td><strong>Funding model</strong></td>
</tr>
<tr>
<td>EU budget</td>
</tr>
<tr>
<td><strong>Relation to other initiatives</strong></td>
</tr>
<tr>
<td>Sits alongside ECDC’s Early Warning and Response System (EWARS)</td>
</tr>
<tr>
<td>Integrates several previous systems (including TESSy, EPIS, TTT)</td>
</tr>
<tr>
<td><strong>Key collaborators</strong></td>
</tr>
<tr>
<td>ECDC</td>
</tr>
<tr>
<td>Works closely with the European Commission and its DGs and other EU agencies (e.g. EFSA, EMA, EEA)</td>
</tr>
<tr>
<td><strong>Pathogen focus</strong></td>
</tr>
<tr>
<td>Infectious diseases</td>
</tr>
<tr>
<td><strong>EU4S</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Date</strong></td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
</tr>
<tr>
<td><strong>Tools produced</strong></td>
</tr>
<tr>
<td><strong>Data source</strong></td>
</tr>
<tr>
<td><strong>Data sharing</strong></td>
</tr>
<tr>
<td><strong>Submission type (voluntary/mandatory)</strong></td>
</tr>
<tr>
<td><strong>Database/platform</strong></td>
</tr>
<tr>
<td><strong>Access type</strong></td>
</tr>
<tr>
<td><strong>Funding model</strong></td>
</tr>
<tr>
<td><strong>Relation to other initiatives</strong></td>
</tr>
<tr>
<td><strong>Key collaborators</strong></td>
</tr>
<tr>
<td><strong>Pathogen focus</strong></td>
</tr>
</tbody>
</table>
### Table 11: Case Study E additional details

<table>
<thead>
<tr>
<th>Global Influenza Surveillance and Response System (GISRS)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td>Founded 1952</td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
<td>Global</td>
</tr>
<tr>
<td><strong>Tools produced</strong></td>
<td>FluServer – Tool to interpret impact of certain mutations (part of EpiFlu database coordinated by GISAID)</td>
</tr>
<tr>
<td><strong>Data source</strong></td>
<td>Data uploaded by National Influenza Centres, WHO Member States, WHO Collaborating Centres, laboratories and other stakeholders</td>
</tr>
<tr>
<td><strong>Data sharing</strong></td>
<td>WHO shares results from analysis of FluNet data on a weekly basis</td>
</tr>
<tr>
<td><strong>Submission type (voluntary/mandatory)</strong></td>
<td>National Influenza Centres are required to upload data</td>
</tr>
</tbody>
</table>
| **Database/platform**                                    | FluNet, FluID databases to collect data  
EpiFlu for data sharing (coordinated by GISAID) |
| **Access type**                                          | Designed access (governed by Database Access Agreements)  
Access provided through NextFlu |
| **Funding model**                                        | Funded by WHO |
| **Relation to other initiatives**                         | Undertaken by WHO and linked to other initiatives (including Pandemic Influenza Preparedness Framework) |
| **Key collaborators**                                    | WHO  
GISAID  
National Influenza Centres, Collaborating Centres and other stakeholders |
| **Pathogen focus**                                       | Respiratory pathogens (particularly influenza) |
### Table 12: Case Study F additional details

<table>
<thead>
<tr>
<th><strong>Global Outbreak and Response Network (GOARN) and the Early Warning, Alert and Response System (EWARS)</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td>Started in 2000</td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
<td>Global</td>
</tr>
</tbody>
</table>
| **Tools produced** | GOARN uses Go.Data – Mobile software tool to collect data and contacts, and analyse data  
Kits to collect data in low-resource settings |
| **Data source** | EWARS collects data through standardised forms, which ask about daily consultations for certain symptoms and outcomes |
| **Data sharing** | Real-time through Go.Data  
For EWARS data collected through standardised forms, a weekly analysis plan is provided and the results of this are shared |
| **Submission type (voluntary/mandatory)** | Voluntary |
| **Database/platform** | Go.Data |
| **Access type** | Unclear |
| **Funding model** | Range of funders, including ECHO, OFDA and the German government  
Support from WHO |
| **Relation to other initiatives** | GOARN also supports the Rapid Response Mobile Laboratories |
| **Key collaborators** | WHO  
Network partners include the Eastern Mediterranean Public Health Network, UN Children's Fund, Institut Pasteur de Dakar, National University of Singapore and the Public Health Agency of Canada |
| **Pathogen focus** | Infectious diseases |
Table 13: Case Study G additional details

<table>
<thead>
<tr>
<th>The Pan American Health Organisation (PAHO) Epidemic Intelligence (EI)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td>PAHO has existed since the early 20th century</td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
<td>Americas</td>
</tr>
<tr>
<td><strong>Tools produced</strong></td>
<td>Epidemic Intelligence from Open Sources (EIOS) – Initiative that helps automate collation and processing of data from thousands of sources (including online media, news, blogs, other initiatives)</td>
</tr>
<tr>
<td><strong>Data source</strong></td>
<td>Range of sources (including WHO, public health authorities, laboratories, academic institutions and NGOs)</td>
</tr>
<tr>
<td><strong>Data sharing</strong></td>
<td>Publicly available dashboards, weekly updates for certain pathogens, communication direct with stakeholders</td>
</tr>
<tr>
<td><strong>Submission type (voluntary/mandatory)</strong></td>
<td>Mixed</td>
</tr>
<tr>
<td><strong>Database/platform</strong></td>
<td>WHO EMS</td>
</tr>
<tr>
<td><strong>Access type</strong></td>
<td>Unclear</td>
</tr>
<tr>
<td></td>
<td>Encourages open access through EIOS initiative</td>
</tr>
<tr>
<td><strong>Funding model</strong></td>
<td>Financed through quota contributions from its Member States, WHO funding, and voluntary contributions (e.g. from governments, public and private sector)</td>
</tr>
<tr>
<td><strong>Relation to other initiatives</strong></td>
<td>PAHO is a WHO regional office</td>
</tr>
<tr>
<td></td>
<td>Links to EIOS initiative</td>
</tr>
<tr>
<td><strong>Key collaborators</strong></td>
<td>HIM Unit at Health Emergencies Department within WHO</td>
</tr>
<tr>
<td></td>
<td>Public health authorities, laboratories, academic institutions and NGOs</td>
</tr>
<tr>
<td><strong>Pathogen focus</strong></td>
<td>Infectious diseases</td>
</tr>
</tbody>
</table>
### Table 14: Case Study H additional details

<table>
<thead>
<tr>
<th><strong>Chinese Pathogen Identification Network (PIN)</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td>1959, and integrated into another network in 2004, and established as China PIN in 2017</td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
<td>China</td>
</tr>
<tr>
<td><strong>Tools produced</strong></td>
<td>Unclear</td>
</tr>
<tr>
<td><strong>Data source</strong></td>
<td>Laboratories (at clinical to country level)</td>
</tr>
<tr>
<td><strong>Data sharing</strong></td>
<td>Data shared within initiative network</td>
</tr>
<tr>
<td><strong>Submission type (voluntary/mandatory)</strong></td>
<td>Unclear</td>
</tr>
<tr>
<td><strong>Database/platform</strong></td>
<td>Unclear</td>
</tr>
<tr>
<td><strong>Access type</strong></td>
<td>Unclear</td>
</tr>
<tr>
<td><strong>Funding model</strong></td>
<td>Funded by the Chinese National Health Commission</td>
</tr>
<tr>
<td><strong>Relation to other initiatives</strong></td>
<td>Feeds into PulseNet initiative (an international network for foodborne diseases)</td>
</tr>
<tr>
<td><strong>Key collaborators</strong></td>
<td>China CDC</td>
</tr>
<tr>
<td><strong>Pathogen focus</strong></td>
<td>Bacterial diseases, with a focus on AMR</td>
</tr>
</tbody>
</table>
Table 15: Case Study I additional details

<table>
<thead>
<tr>
<th>Unravelling data for rapid evidence-based response to Covid-19 (unCoVer)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
</tr>
<tr>
<td><strong>Tools produced</strong></td>
</tr>
<tr>
<td><strong>Data source</strong></td>
</tr>
<tr>
<td><strong>Data sharing</strong></td>
</tr>
<tr>
<td><strong>Submission type (voluntary/mandatory)</strong></td>
</tr>
<tr>
<td><strong>Database/platform</strong></td>
</tr>
<tr>
<td><strong>Access type</strong></td>
</tr>
<tr>
<td><strong>Funding model</strong></td>
</tr>
<tr>
<td><strong>Relation to other initiatives</strong></td>
</tr>
<tr>
<td><strong>Key collaborators</strong></td>
</tr>
<tr>
<td><strong>Pathogen focus</strong></td>
</tr>
</tbody>
</table>
### EU4Health

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date</strong></td>
<td>EU funding mechanism – First commenced in 2003, current version is for 2021–2027</td>
</tr>
<tr>
<td><strong>Geographic coverage</strong></td>
<td>EU/EEA Member States and associated third countries</td>
</tr>
<tr>
<td><strong>Funding model</strong></td>
<td>EU4Health is a programme of the European Commission, which provides funding</td>
</tr>
<tr>
<td><strong>Relation to other initiatives</strong></td>
<td>Works with other EU programmes (e.g. Digital Europe and Connecting Europe)</td>
</tr>
<tr>
<td><strong>Key collaborators</strong></td>
<td>Works with EU Member State countries and third countries associated to the EU4Health programme HaDEA, HERA, DG SANTE and other EU agencies</td>
</tr>
<tr>
<td><strong>Pathogen focus</strong></td>
<td>Broad focus on health (not specific to infectious diseases)</td>
</tr>
</tbody>
</table>
## Annex D. Search strategy details

### Table 17: Search strings for grey and academic literature searches

<table>
<thead>
<tr>
<th>Search</th>
<th>Database</th>
<th>Search string</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targeted website search</td>
<td>Websites of: World Health Organisation (WHO); United Nations (UN), the International Association of National Public Health Institutes (IANPHI); European Centre for Disease Control (ECDC); Health Emergency Preparedness and Response Authority (HERA); Science Europe; Public Health England; US Centre for Disease Control (US CDC); Central Asia CDC, China CDC, and Africa CDC</td>
<td>(pathogen* OR disease* OR pandemic* OR outbreak* OR &quot;antimicrobial resistance&quot; OR AMR OR &quot;antibiotic resistance&quot;) AND (surveillance OR monitoring) AND ((data AROUND(5) sharing) OR (data AROUND(5) share) OR (data AROUND(5) collection) OR (data AROUND(5) collect)) AND (platform* OR network OR initiative* OR framework* OR system* OR collaboration* OR technolog* OR mechanism* OR governance)</td>
</tr>
</tbody>
</table>
Annex E. Interview protocol (case study interviews)

An indicative interview protocol is presented in this Annex, with a caveat that the interview protocol was adapted for each interview to reflect desk research and findings on the relevant initiative and perspective of the interviewee.

**Introduction**

1. Can you briefly introduce yourself and describe your role in [INITIATIVE]?

**Information about initiative**

2. We have done desk research around [INITIATIVE], and so we have a basic understanding of it based on information available in the public domain. However, for the purposes of this interview, how would you describe the initiative? *Prompt only if not covered by desk research:*
   a. What are the main aims of the initiative?
   b. What types of data are included in the initiative?
   c. From what sources does the initiative collect or collate data?
   d. Is there any processing that occurs after you receive data?
   e. Who does the initiative share data with, and how is data shared?
   f. How long has the initiative been running?
   g. Which stakeholders are involved in the initiative and what is the role of each stakeholder? Who funds the initiative?
   h. Who uses data from the initiative, and how is data used for public health activities?

3. What problem was the initiative designed to solve?
   a. Has the purpose of the initiative changed over time?

4. Can you describe how the initiative was initially funded, and whether there have been any changes over time to the funding structure?
   a. Is there any information on costs associated with this initiative that you’d be able to provide?

**Challenges in data collection and sharing**

5. What have been the main challenges involved in collecting and sharing data for the initiative? These can be challenges that arose at earlier points in the initiative, along with challenges that are ongoing. *Prompts:*
   a. Capacity constraints (e.g. laboratory capacity)
   b. Data or IT infrastructure and interoperability
   c. Data quality or standardisation
   d. Privacy, ethics and confidentiality
   e. Regulations and policy
   f. Governance concerns
   g. [Check against challenges identified in desk research]

6. [For each challenge] What is the implication of this challenge in terms of the ability
to collect data, share data, and produce data that can be useful to public health activities?

7. [For each challenge] Can you describe whether [INITIATIVE] has been able to overcome or mitigate against these challenges, and if so how?

8. Were any additional resources, skills or capacities needed to help overcome this issue (or that would be helpful in overcoming this issue, if it hasn’t already been resolved)?

Strengths of initiative and impact of initiative

9. What are some of the main strengths of [INITIATIVE]?

10. What have been some of the key factors that have facilitated [INITIATIVE] and made it possible to achieve a positive impact in the area of public health?

11. What are some of the main weaknesses of [INITIATIVE]?

12. Can you provide some examples of how data from [INITIATIVE] has been used to inform public health activities?

Overarching questions

13. Based on the experience of [INITIATIVE], and with the benefit of hindsight, what are some of the key lessons for other (pathogen surveillance) initiatives?

14. Are there any wider gaps in pathogen surveillance that you are aware of? For example, gaps that any single initiative working in pathogen surveillance would have a difficult time addressing, but that would improve the ability to conduct pathogen surveillance?

15. There are many different initiatives focused on data collection and sharing for pathogen surveillance efforts. What types of additional resources, activities or skills are needed to facilitate connections between these initiatives and move closer towards an effective global surveillance system?

Concluding questions

16. Are you aware of any documents or sources of evidence about [INITIATIVE] that would be helpful for us to review for this study?

17. Is there anything we haven’t gotten the chance to speak about yet that you think would be important for us to be aware of for this study?
Annex F. Interview protocol (expert interviews)

Introduction
RAND Europe was commissioned by the Novo Nordisk Foundation to conduct an independent study looking at pathogen surveillance initiatives that collect and share data about infectious diseases and AMR. The aim of this study was to identify initiatives and the stakeholders involved in them, look at challenges that initiatives faced and how these were overcome, review the strengths and weaknesses of different initiatives and understand how data from initiatives were used to support public health activities. The study also aimed to identify gaps in the pathogen surveillance space. The Novo Nordisk Foundation is currently assessing its potential role in pathogen surveillance, and will use the results of this study to inform decisions about how to engage in this space.

We have already conducted desk research for this study, and developed case studies about specific pathogen surveillance initiatives, informed by interviews with stakeholders involved in these initiatives. We are now interviewing experts in different aspects of pathogen surveillance, to better understand gaps in the pathogen surveillance space. You have been contacted to participate in these interviews based on your expertise and experience in this area. During the interview, we will ask about your experience in this field, challenges in pathogen surveillance, gaps in the pathogen surveillance space, and how these gaps can potentially be addressed.

The results from this study will be delivered to the Novo Nordisk Foundation, and will also be made publicly available in a report on the RAND Europe website. In the report, we will acknowledge the experts that were interviewed for this study by name and organisation. However, results will be reported in aggregate, meaning that readers of the report will not be able to attribute specific views to you.

If you feel you are unable to answer a question, this is not a problem. If this happens, please let me know and I can move onto the next question.

Before we start, do you have any questions about the interview or study?

Do you mind if we record this interview for internal note-taking purposes?

[Start recording if interviewee consents]

Introduction
1. Can you briefly introduce yourself and describe your experience in pathogen surveillance?

Challenges in pathogen surveillance
2. Overall, what are some of the main challenges in pathogen surveillance that you’ve observed that affect how information from pathogen surveillance can be used to inform decision making? Prompt as needed:
   a. Data collection challenges, including in resource-limited settings
   b. Data availability and quality
   c. Sharing data between stakeholders
   d. Data linkages/a lack of standardisation or harmonisation
   e. Analysing data/data modelling
   f. Communicating results and using results for public health decision making
3. What are some of the major gaps you’ve noticed in the pathogen surveillance space? Prompts:
   a. Coverage in terms of pathogens or illnesses
   b. Geographic coverage
   c. Types of data used and data linkages
   d. Ability to identify intentional, as opposed to naturally occurring threats

Addressing challenges and filling gaps

4. What do you think is needed to overcome some of these challenges? Prompts:
   a. Capacity and skills building
   b. Resources and funding
   c. Coordination and collaboration
   d. Infrastructural improvements
   e. Methods and data standards
   f. Tools for data collection and analysis
   g. Dynamic geographical coverage – adjusting resources for pathogen surveillance in a given area based on current situation/surveillance needs

5. What would be needed to create a more harmonised pathogen surveillance space, in terms of being able to link between different types of data and data collected in different locations and settings?

6. Have you observed any initiatives that have done a good job at addressing some of the challenges and gaps in pathogen surveillance? If so, what made them work well?

7. When initiatives attempt to address these challenges and fail, what has usually gone wrong?

8. What models work well for building capacity in pathogen surveillance? Prompt: For example, hub and spoke models, train the trainer
   a. In terms of creating a more global system for pathogen surveillance, do you think that it is more valuable to create a large initiative that operates as a cohesive unit, or to collate data from local initiatives into a centralised hub?

9. What types of stakeholders and organisations would be well-placed to address some of the gaps in pathogen surveillance?
   a. What puts them in a good position to address these gaps?
   b. What role do you think foundations and charities should have in addressing these gaps?

10. For stakeholders wanting to contribute to improving pathogen surveillance efforts, do you think it’s best to contribute to existing initiatives or create new ones?
    a. [If they say it’s best to contribute to an existing one] Are there any particular initiatives where you think additional support can be especially impactful?

Concluding questions

11. Based on your experience of pathogen surveillance, what do you think are the top priorities in terms of issues or challenges in pathogen surveillance that need to be addressed to protect against future health threats?

12. Is there anything we haven’t gotten the chance to speak about yet that you think would be important for us to be aware of for this study?

Thank you
Annex G. **Summary of challenges and mitigation strategies**

This study identified many different challenges that pathogen surveillance efforts face, and multiple approaches that have been used to address these challenges. Table 18 below provides a summary of these challenges and mitigation strategies.
### Table 18: Summary of challenges and mitigation strategies

<table>
<thead>
<tr>
<th>Challenge area</th>
<th>Specific challenge</th>
<th>Mitigations</th>
<th>Examples of initiatives that address challenge area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data quantity</td>
<td>Capacity constraints and logistical issues</td>
<td></td>
<td>Global Influenza Surveillance and Response System, Global Polio Laboratory Network, GOARN, EWARS, Global Polio Eradication Initiative, GenRe-Mekong Platform, EU Sewage Sentinel System, EU4S DEEP</td>
</tr>
<tr>
<td></td>
<td>Low use of diagnostics and testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor reporting of data (e.g. by doctors)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of digital tools and connectivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data quality</td>
<td>Lack of metadata</td>
<td></td>
<td>EU Sewage Sentinel System, GOARN, Sentinel project, Global Polio Eradication Initiative, Global Antimicrobial Resistance and Use Surveillance System</td>
</tr>
<tr>
<td></td>
<td>Lack of standardisation and consistent methods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Challenge area</td>
<td>Specific challenge</td>
<td>Direct support and funding</td>
<td>Building distributed capacity (e.g., hub and spoke models, training)</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------------------------</td>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------</td>
</tr>
<tr>
<td>Data sharing</td>
<td>Infrastructure for data storage and sharing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data privacy and governance concerns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reluctance to share data internationally</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fragmentation and use of data</td>
<td>Interpretability of data for decision makers</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of coordination between initiatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analysis capabilities in local communities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>