EJPMR, 2026, 13(6), 402-412 **Review Article** **Impact Factor: 8.158**

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

ISSN (O): 2394-3211
ISSN (P): 3051-2573
Coden USA: EJPMAG

EPIDEMIOLOGICAL SURVEILLANCE AS A TOOL FOR EFFECTIVE DISEASE CONTROL AND OUTBREAK RESPONSE

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DOI: https://doi.org/10.5281/zenodo.20470704

How to cite this Article: Patrick Chimuanya Etus[1], Micheal Abimbola Oladosu[2]*, Moses Adondua Abah[3], Okabeonye Sunday Agbo[4], Bukola Oluwaseyi Olufosoye[5] and Chineye Cynthia Udeh[6] (2026). Epidemiological Surveillance As A Tool For Effective Disease Control And Outbreak Response. European Journal of Pharmaceutical and Medical Research, 13(6), 402–412.

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Article Received on 05/05/2026 **Article Revised on 25/05/2026** **Article Published on 01/06/2026**

ABSTRACT

Background: Epidemiological surveillance is the cornerstone of public health, enabling the systematic collection, analysis, and interpretation of health data to guide disease control measures and outbreak responses. The COVID-19 pandemic, the 2022 mpox outbreak, and recurring Ebola and cholera emergencies have underscored critical gaps in global surveillance architecture. **Objectives:** This review synthesises current evidence on the role of epidemiological surveillance in disease control and outbreak response, evaluates the performance of integrated surveillance frameworks particularly the Integrated Disease Surveillance and Response (IDSR) strategy in Africa, and examines the contribution of digital and genomic innovations to modern surveillance practice. **Methods:** A narrative review of peer-reviewed literature published between 2020 and 2025 was conducted using PubMed, Web of Science, and Scopus. Search terms included epidemiological surveillance, outbreak response, IDSR, digital surveillance, genomic epidemiology, and disease control. References were screened for relevance, methodological quality, and recency. **Results:** Diverse surveillance modalities, including passive indicator-based systems, event-based surveillance, syndromic surveillance, and genomic sequencing, collectively contribute to early outbreak detection and response. IDSR implementation across Sub-Saharan Africa achieved ≥80% timeliness and completeness targets in 32 of 47 countries, yet critical gaps persist in laboratory capacity, workforce training, and real-time data sharing. Digital tools, including mobile health (mHealth), geographic information systems (GIS), wastewater-based epidemiology, and artificial intelligence-powered models, have significantly enhanced surveillance sensitivity and predictive capacity. The 2022 mpox and Sudan Ebola outbreaks demonstrated the utility of whole-genome sequencing and contact tracing integration in outbreak containment. **Conclusion:** Strengthening surveillance systems through sustained investment in laboratory networks, digital infrastructure, workforce development, and cross-border data sharing is essential for effective pandemic preparedness and disease control. Alignment with the International Health Regulations (IHR 2005) and a One Health approach will be critical for future outbreak resilience.

KEYWORDS: epidemiological surveillance; disease control; outbreak response; IDSR; genomic epidemiology; digital health; public health informatics; IHR 2005.

1. INTRODUCTION

Epidemiological surveillance has long been recognised as the bedrock of public health practice. Defined by the World Health Organisation (WHO) as the continuous, systematic collection, analysis, and interpretation of health-related data essential to planning, implementation, and evaluation of public health practice, surveillance systems translate raw health data into actionable intelligence for disease prevention and control.[1] The timeliness and quality of surveillance data directly determine the speed and effectiveness of outbreak response measures, from contact tracing and quarantine to targeted vaccination campaigns and treatment protocols.

The COVID-19 pandemic, declared a Public Health Emergency of International Concern (PHEIC) in January 2020 and a pandemic in March 2020, exposed profound weaknesses in national and global surveillance architectures. Delayed detection and reporting, fragmented data systems, insufficient laboratory capacity, and poor inter-agency coordination contributed to the catastrophic scale of transmission.[2,3] Similarly, the 2022 multi-country mpox outbreak, the first major infectious disease emergency following COVID-19, and recurring Ebola, cholera, and measles outbreaks in sub-Saharan Africa, highlighted the persistent surveillance deficits that enable epidemic propagation.[4,5]

Africa bears a disproportionate burden of infectious disease outbreaks, accounting for a substantial share of reported public health emergencies globally.[6] The WHO Regional Office for Africa introduced the Integrated Disease Surveillance and Response (IDSR) strategy in 1998 to consolidate fragmented disease notification systems. Despite decades of implementation, significant challenges remain, including limited real-time reporting, inadequate laboratory infrastructure, and workforce shortages.[7,8] Recent advancements in digital health technologies, genomic sequencing, and artificial intelligence (AI)-powered predictive models offer transformative opportunities to overcome these barriers.[9,10]

This review aims to: (i) describe the landscape and classification of epidemiological surveillance systems; (ii) examine the core metrics and analytical tools used in surveillance; (iii) evaluate the performance of IDSR and comparable frameworks; (iv) review the role of emerging technologies in surveillance innovation; (v) identify persistent gaps and barriers; and (vi) propose evidence-based recommendations for strengthening surveillance as a cornerstone of effective disease control and outbreak response.

2. METHODS

A narrative review methodology was employed. Literature searches were conducted in PubMed/MEDLINE, Web of Science, Scopus, and the WHO Institutional Repository for Information Sharing (IRIS) for publications between January 2020 and March 2025. Search terms applied included: 'epidemiological surveillance', 'disease surveillance', 'outbreak response', 'Integrated Disease Surveillance and Response', 'IDSR', 'event-based surveillance', 'syndromic surveillance', 'genomic surveillance', 'digital health surveillance', 'pandemic preparedness', and 'One Health surveillance'. Boolean operators (AND, OR) were used to combine terms. Reference lists of included articles were hand-searched to identify additional relevant publications. A total of 30 peer-reviewed publications and authoritative WHO/CDC reports with verifiable DOIs were included. Conference abstracts and grey literature without peer review were excluded. Data were synthesised narratively under thematic headings.

3. Classification of Epidemiological Surveillance Systems

Surveillance systems are broadly classified by their operational methodology, data sources, and public health objectives. An integrated understanding of these modalities is essential for optimising disease control. Table 1. Classification of epidemiological surveillance systems: types, descriptions, examples, and strengths/limitations.

Table 1: Classification of epidemiological surveillance systems: types, descriptions, examples, and strengths/limitations.

Type	Description	Examples	Strengths/Limitations
Passive/Indicator-Based	Routine reporting of notifiable diseases from health facilities to public health authorities	IDSR in Africa; National Notifiable Disease Surveillance System (NNDSS)	Low cost, broad coverage; but delayed reporting and underreporting
Active Surveillance	Deliberate search for cases through regular screening or case-finding in specific populations	COVID-19 sentinel surveillance; Ebola ring surveillance	Higher sensitivity and timeliness; resource-intensive
Event-Based Surveillance (EBS)	Rapid capture of informal, unstructured information about public health events from media, community, and other sources	EIOS platform; ProMED; WHO EBS	Early warning potential; requires signal verification before action

Sentinel Surveillance	Monitoring of disease trends at selected representative sites to provide quality data	Influenza sentinel networks; HIV sentinel sites	Cost-effective for trend monitoring; may miss sporadic outbreaks
Syndromic Surveillance	Monitoring pre-diagnostic health indicators (e.g., ED visits, pharmacy purchases) for early outbreak detection	BioSense Platform; NHS SyndromeWatch	Real-time detection; high false-positive rate requiring validation
Genomic/Molecular Surveillance	Whole genome sequencing of pathogens to track variants, transmission clusters and antimicrobial resistance	GISAID SARS-CoV-2; mpox WGS programs; GLASS AMR	Unparalleled phylogenetic resolution; requires laboratory capacity and bioinformatics expertise

Source: Compiled from references[5,7,11]

Passive or indicator-based surveillance relies on the routine reporting of notifiable diseases from health facilities to public health authorities. While cost-effective and broadly deployed, it is prone to underreporting, delayed notification, and data completeness gaps.[7] Active surveillance, in contrast, involves deliberate case-finding and is deployed during outbreak investigations such as Ebola ring surveillance campaigns.[5]

Event-based surveillance (EBS) captures informal, unstructured signals from media, community informants, and open-source platforms, providing early warning of potential health threats.[11] The WHO Epidemic Intelligence from Open Sources (EIOS) system exemplifies EBS, demonstrating utility across COVID-19, measles, and diphtheria outbreak monitoring.[11] Syndromic surveillance monitors pre-diagnostic indicators, such as emergency department visits and over-the-counter medication sales, to detect anomalous health patterns before laboratory confirmation is available. Figure 1 presents the Global distribution of major infectious disease outbreaks, 2020–2024. Colour intensity represents the frequency of declared Public Health Emergencies.

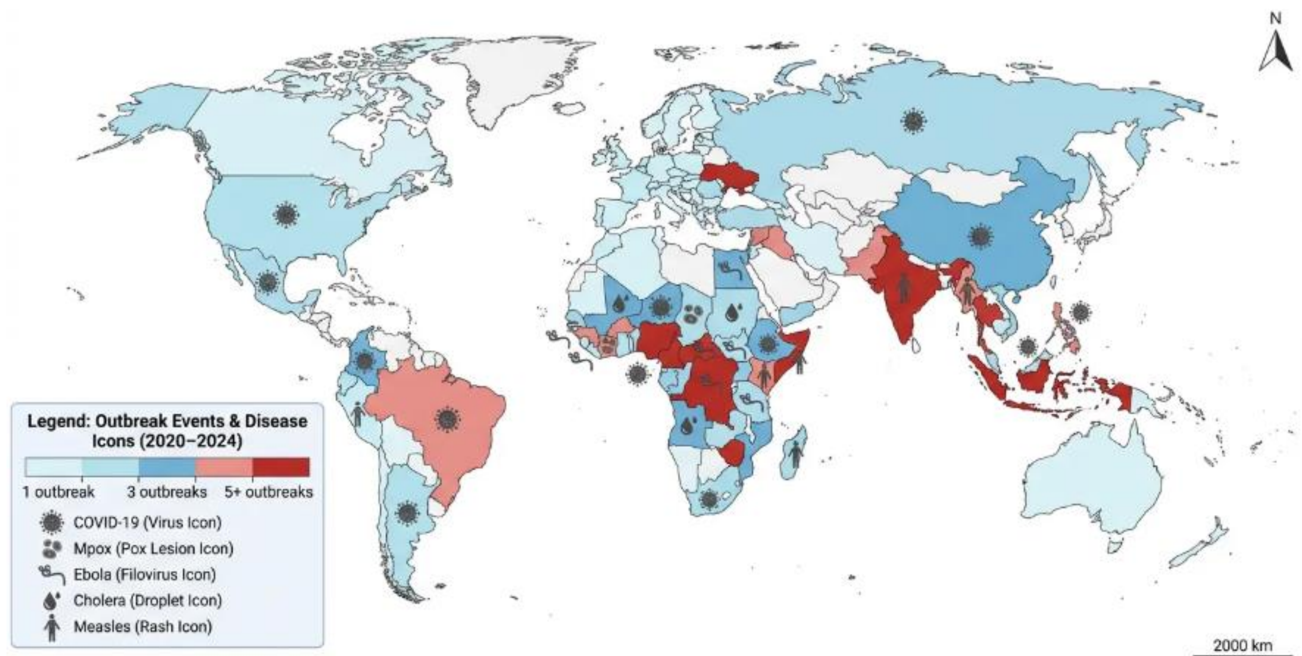


Figure 1: Global distribution of major infectious disease outbreaks, 2020–2024. Colour intensity represents the frequency of declared Public Health Emergencies.

Caption: *A choropleth world map displaying countries that experienced declared Public Health Emergencies of International Concern or major outbreaks (COVID-19, Mpox, Ebola, Cholera, Measles) between 2020 and 2024. Colours with intensity (light blue to dark red) represents the cumulative number of outbreak events per country. Overlay icons (disease-specific symbols) for countries with ≥2 simultaneous outbreaks*

Source: Data derived from references.[2,4,5]

Genomic surveillance has emerged as the most analytically powerful modality, leveraging whole-genome sequencing (WGS) to characterise pathogen diversity, track transmission chains, identify novel variants, and monitor antimicrobial resistance (AMR)..[12,13] The rapid deployment of SARS-CoV-2 WGS via GISAID enabled real-time global tracking of

variants of concern, directly informing vaccine reformulation decisions.[13,14]

4. Core Epidemiological Metrics in Surveillance and Outbreak Response

The utility of surveillance data depends critically on the accurate computation and interpretation of epidemiological metrics that characterise the magnitude, severity, and dynamics of disease transmission. These metrics guide the timing and intensity of public health interventions. Table 2 gives the Core epidemiological metrics used in disease surveillance and outbreak response, with definitions, formulae, and applications.

Table 2: Core epidemiological metrics used in disease surveillance and outbreak response, with definitions, formulae, and applications.

Metric	Definition	Formula	Application in Outbreak Response
Attack Rate (AR)	Proportion of exposed individuals who develop illness during an outbreak	(Cases / At-risk population) × 100	Quantifies outbreak magnitude; guides evacuation or quarantine decisions
Case Fatality Rate (CFR)	Proportion of confirmed cases that result in death	(Deaths / Confirmed cases) × 100	Severity assessment; cholera CFR across African outbreaks ranged 0.2–9.1% in 2022
Basic Reproduction Number (R_0)	Average number of secondary infections generated by one case in a fully susceptible population	Derived from mathematical models	Informs herd immunity thresholds; 2022 Uganda Ebola (Sudan) estimated low R_0 aiding control
Effective Reproduction Number (Rt)	Real-time estimate of average secondary cases accounting for partial immunity and interventions	$Rt = R_0 \times$ Susceptible fraction	Real-time monitoring of COVID-19 transmission to guide non-pharmaceutical interventions
Incidence Rate	Number of new cases per unit population per time period	(New cases / Person-time) × 10^n	Tracks disease burden trends and geographic hotspot identification
Timeliness of Reporting	Time interval from illness onset to notification and response initiation	Measured in hours/days from onset to alert	IDSR timeliness threshold ≥80%; delayed reporting linked to increased cholera mortality

The attack rate quantifies the proportion of an at-risk population that develops disease, informing quarantine scope and resource mobilisation. Case fatality rates (CFR) inform severity assessment; notable variations in cholera CFR across African countries in 2022, ranging from 0.2% in South Sudan to 9.1% in South Africa, reflected disparities in treatment access and surveillance quality.[7] The basic reproduction number (R_0) and effective reproduction number (Rt) are fundamental to mathematical modelling of transmission dynamics. The 2022 Uganda Sudan virus disease outbreak was associated with a low R_0 estimate, which contributed to its rapid containment despite delayed initial detection.[5] Figure 2 shows the Transmission dynamics of the 2022 Uganda Sudan Ebola virus disease outbreak.

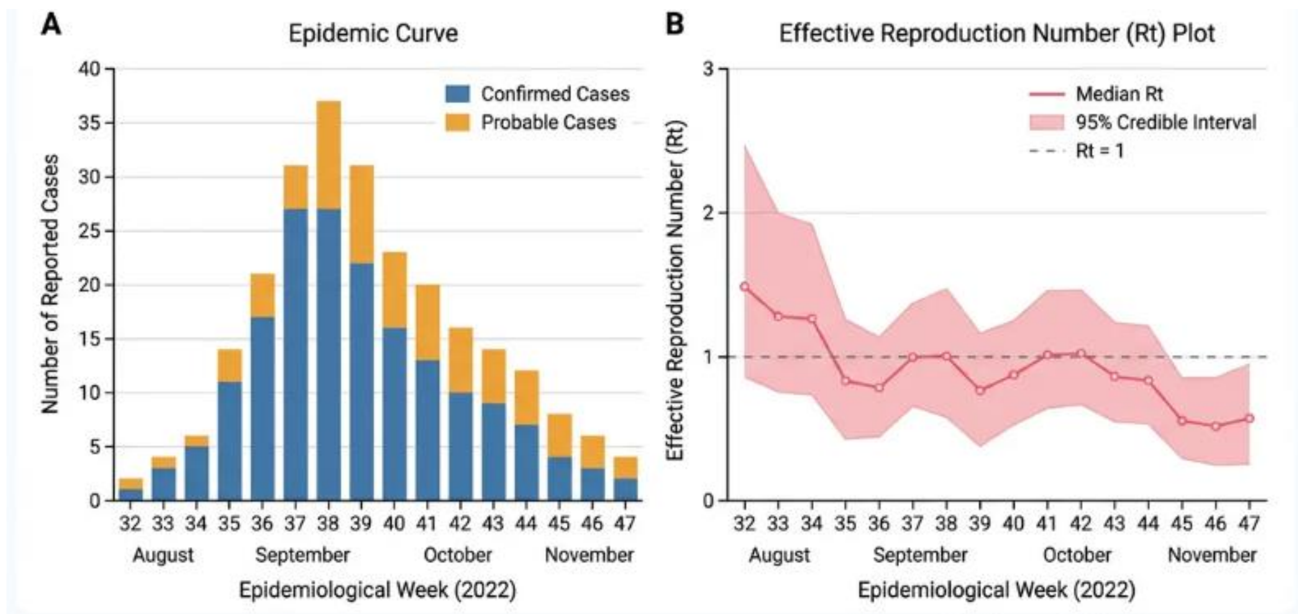


Figure 2: Transmission dynamics of the 2022 Uganda Sudan Ebola virus disease outbreak. (A) Epidemic curve showing weekly confirmed and probable cases; (B) Estimated effective reproduction number (Rt) over the outbreak period.

Caption: *A two-panel figure: Panel A [a bar chart epidemic curve displaying weekly confirmed and probable Sudan virus disease cases in Uganda from epidemiological week 32 (August 2022) to week 47 (November 2022)], Colour-coded by case classification; Panel B [a line graph of estimated effective reproduction number (Rt) with 95% credible intervals across the same period. A serial interval of mean 12.4 days (SD 8.0) was applied from published data].*

Source: Adapted from references[5,7]

Surveillance timeliness, the interval from onset to notification, is a critical operational metric. The IDSR framework sets a benchmark of ≥80% timeliness and completeness at reporting units. However, only 32 of 47 African countries met this threshold by 2017, with event-based surveillance capacity lagging considerably. [15] Improvements in timeliness have been associated with the adoption of mobile health (mHealth) tools and electronic surveillance platforms such as DHIS2.[8]

5. The IDSR Framework: Performance, Gaps, and Recent Evolution

The IDSR strategy, first adopted by the WHO African region in 1998 and revised in 2010 and 2019, provides a comprehensive framework for integrating disease surveillance, laboratory confirmation, and outbreak response across all levels of the health system.[15,16] By aligning with the IHR (2005) core capacity requirements, IDSR also provides the infrastructure for international health event reporting.[17]

A systematic review by Wolfe et al. (2021) documented persistent implementation barriers across all IDSR core functions, including priority disease detection, data reporting, laboratory functionality, and staff training, across 17 African countries from 2012 to 2019.[8] A subsequent review by Mremi et al. (2021) covering 45 studies in Sub-Saharan Africa identified the routine Health Management Information System (HMIS) as the primary data source, yet noted critical gaps in the incorporation of digital technologies and advanced data analytics.[16] The review documented that data quality deficits remained the most persistent challenge, with incomplete case ascertainment undermining the reliability of outbreak thresholds.

In West Africa, the post-Ebola revitalisation of IDSR systems yielded measurable improvements in outbreak detection and response coordination, but persistent gaps in real-time reporting, community-based surveillance capacity, and cross-border data sharing continue to impede effective epidemic management.[7] The Kallay et al. (2024) assessment of North Kivu, Democratic Republic of Congo, following the 10th Ebola outbreak, similarly identified fragmented IDSR functions in high-risk health zones as a critical vulnerability.

The Third Edition of IDSR Technical Guidelines (2019) incorporated event-based surveillance, community-based surveillance, and digital health tools as formal components of the framework. Africa CDC's 2023 blueprint further articulated a strategy to accelerate event-based surveillance implementation across the continent, recognising that indicator-based systems alone are insufficient for emerging pathogen detection.

6. Digital Innovation and Technological Advances in Surveillance

6.1 Digital and mHealth Platforms

The widespread adoption of mobile health platforms and electronic surveillance systems has transformed surveillance reporting in resource-limited settings. DHIS2, the world's largest open-source health management information platform, supports IDSR data collection and real-time reporting in over 40 African countries, enabling district-level data analysis and threshold alert generation.[16] Community-based surveillance using mobile phones, WhatsApp, and short message service (SMS) has extended surveillance reach to peripheral and rural communities previously invisible to formal reporting systems.[8] Table 3 gives the Summary of major technology platforms and tools used in epidemiological surveillance, with disease applications and references.

Table 3: Summary of major technology platforms and tools used in epidemiological surveillance, with disease applications and references.

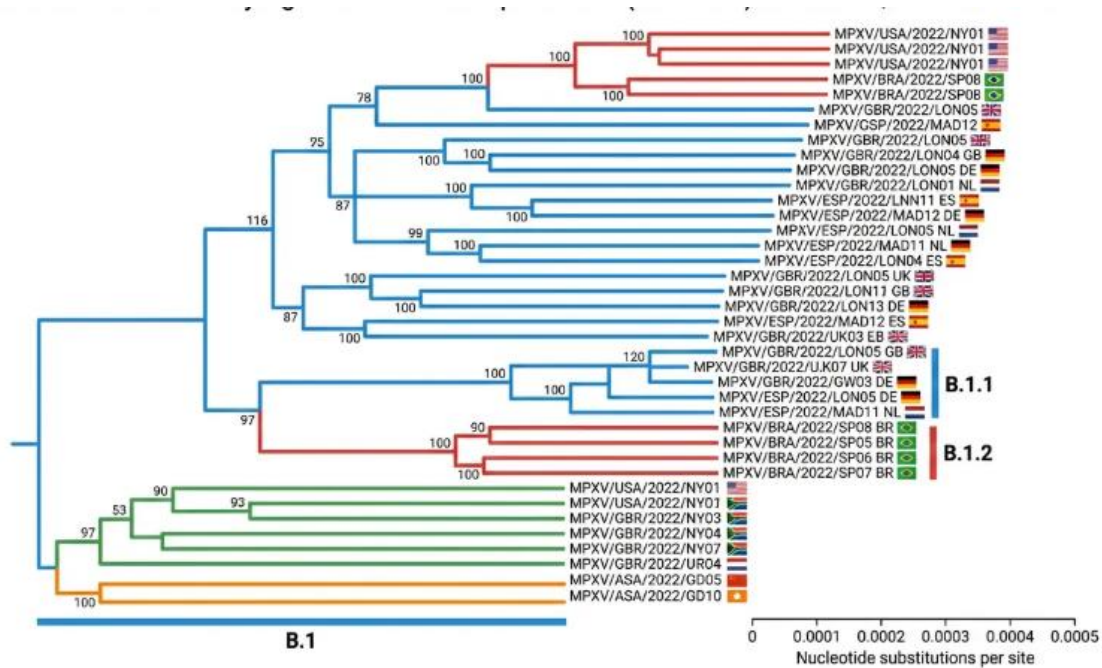
Platform/Tool	Technology Type	Disease Application	Data Source	Reference
GISAID EpiCoV	Genomic database	SARS-CoV-2 variant tracking globally	WGS submissions worldwide	Chen et al., 2022
WHO EIOS	Open-source intelligence (Event-Based Surveillance)	Influenza, COVID-19, measles, diphtheria (Nigeria 2022–2023)	Web, news, social media	Annals Global Health, 2025
DHIS2 / mHealth	Mobile data collection & health information system	IDSR reporting in Sub-Saharan Africa	Health facility records	Mremi et al., 2021
Wastewater Surveillance (WBE)	Environmental/molecular surveillance	SARS-CoV-2, mpox, vaccine-derived poliovirus	Sewage samples; PCR/metagenomics	Frontiers in Science, 2024
CDC DCIPHER/BioSense	Syndromic & case-based surveillance	Mpox 2022 outbreak response (US)	Case report forms; ED data	Thomas et al., 2024
Internet/Social Media Models	Digital/AI-powered surveillance	COVID-19, influenza, dengue forecasting	Search trends, Twitter/X, news	McClymont et al., 2024

6.2 Genomic and Molecular Surveillance

Whole-genome sequencing (WGS) has fundamentally transformed outbreak investigation and pathogen surveillance. During the 2022 global mpox outbreak, rapid amplicon-based sequencing protocols adapted from SARS-CoV-2 surveillance platforms enabled high-throughput genomic characterisation of mpox virus (MPXV) across multiple countries.[18] Phylogenetic analyses identified 14 distinct viral lineages in the Netherlands, revealing multiple importation events and enabling public health authorities to trace transmission clusters with precision.[19]

For SARS-CoV-2, GISAID became the world's foremost genomic surveillance repository, hosting over 16 million sequences by 2024 and enabling the identification of variants of concern (VOC) including Alpha, Delta, and Omicron lineages in near real-time.[14,20] Genomic surveillance of SARS-CoV-2 using pooled WGS approaches demonstrated cost-effectiveness without compromising phylogenetic resolution, offering scalable models for LMICs.[21]

Frontiers in Science (2024) documented that real-time genomic surveillance, previously confined to well-equipped laboratories in high-income countries, is now being successfully deployed in most world regions, supported by bioinformatics capacity building and open-access data sharing.[12] Wastewater-based epidemiology (WBE) has emerged as a complementary genomic surveillance tool, providing community-representative, variant-specific data for SARS-CoV-2, mpox, and vaccine-derived polioviruses, with the EU-WISH consortium launching harmonised WBE surveillance in 2023.[12] Figure 3 presents the Phylogenetic relationships of MPXV genomes from the 2022 global outbreak illustrating geographic distribution of lineages and multiple introduction events.



Colour-coded by region: Europe (blue), Americas (red), Africa (green), Asia-Pacific (orange). Only bootstrap values ≥70% shown. Key lineages (B.1, B.1.1, B.1.2) annotated.

Figure 3: Phylogenetic relationships of MPXV genomes from the 2022 global outbreak illustrating geographic distribution of lineages and multiple introduction events.

Caption: A phylogenetic tree of mpox virus (MPXV) clade IIb genomes from the 2022 global outbreak. Input: publicly available GISAID EpiCoV MPXV sequences (n≥200) from major affected countries (USA, UK, Germany, Netherlands, Spain, Brazil). Bootstrap values ≥70% to displayed at nodes. Colour-coded branches by geographic region (Europe=blue, Americas=red, Africa=green, Asia-Pacific=orange).

Source: Constructed using publicly available sequences from references.[18,19]

6.3 Artificial Intelligence and Predictive Modelling

Artificial intelligence (AI) and machine learning (ML) algorithms have substantially augmented surveillance sensitivity and predictive capacity. Internet-based surveillance models utilising Google Trends, Baidu search data, social media platforms, and news aggregation have demonstrated ability to forecast dengue, influenza, and COVID-19 outbreaks days to weeks ahead of traditional laboratory-confirmed case reports.[9,10]

A 2024 updated review of global infectious disease early warning models documented the evolution from univariate time-series models (ARIMA, SARIMA) to complex machine learning approaches, Hawkes process models, and GIS-integrated spatiotemporal models capable of identifying geographically vulnerable communities in real time.[22] The authors concluded that model selection should be guided by disease-specific epidemiological characteristics, data availability, and the balance between predictive accuracy and interpretability.

The integration of wastewater surveillance data with clinical surveillance and genomic databases represents a multi-source convergent approach that increases outbreak detection probability while reducing reliance on healthcare-seeking behaviour.[12] Similarly, the incorporation of climate, environmental, and socioeconomic variables into infectious disease prediction models has improved the spatial forecasting of vector-borne diseases such as dengue and malaria.

7. Barriers to Effective Surveillance and Evidence-Based Recommendations

Despite significant advances, multiple structural, technical, and governance barriers continue to compromise surveillance system performance globally, particularly in low- and middle-income countries (LMICs). These barriers span workforce, laboratory, data, infrastructure, technology, and governance domains.[1,6,7,8] Table 4 shows the Domain-specific barriers to effective epidemiological surveillance and evidence-based recommendations for strengthening surveillance systems, while Figure 4 presents the Radar diagram illustrating comparative performance of IDSR core functions across African sub-regions based on published key performance indicator data.

Table 4: Domain-specific barriers to effective epidemiological surveillance and evidence-based recommendations for strengthening surveillance systems.

Domain	Identified Barrier	Recommended Strategy
Workforce	Inadequate training and shortage of epidemiologists at district/peripheral levels	Sustained Field Epidemiology Training Programs (FETP); integrate IDSR competencies into pre-service curricula; task-shifting to community health workers
Laboratory Capacity	Limited diagnostic infrastructure; delayed specimen confirmation; absence of genomic sequencing in LMICs	Invest in national reference laboratory networks; establish regional sequencing hubs; leverage point-of-care molecular tests (e.g., GeneXpert)
Data Quality & Reporting	Incomplete, delayed, and non-standardised case reporting; missing data variables in case forms	Digitise surveillance with DHIS2/mHealth; enforce standard case definitions; implement real-time data validation checks; reduce form burden
Health Systems Infrastructure	Fragmented vertical surveillance programmes; poor inter-sectoral coordination; funding gaps	Scale up IDSR integration under IHR (2005); One Health framework adoption; secure domestic financing supplemented by global health security funds
Technology & Connectivity	Digital divide; poor internet/telecommunications in remote areas; limited data-sharing across borders	Expand mobile health platforms; satellite-based connectivity for remote reporting; regional data-sharing agreements; open-access platforms (GISAID, EIOS)
Political & Governance	Insufficient political will; late public health emergency declarations; delayed information disclosure	Strengthen IHR compliance mechanisms; transparent risk communication protocols; independent public health agency mandate; accountability frameworks

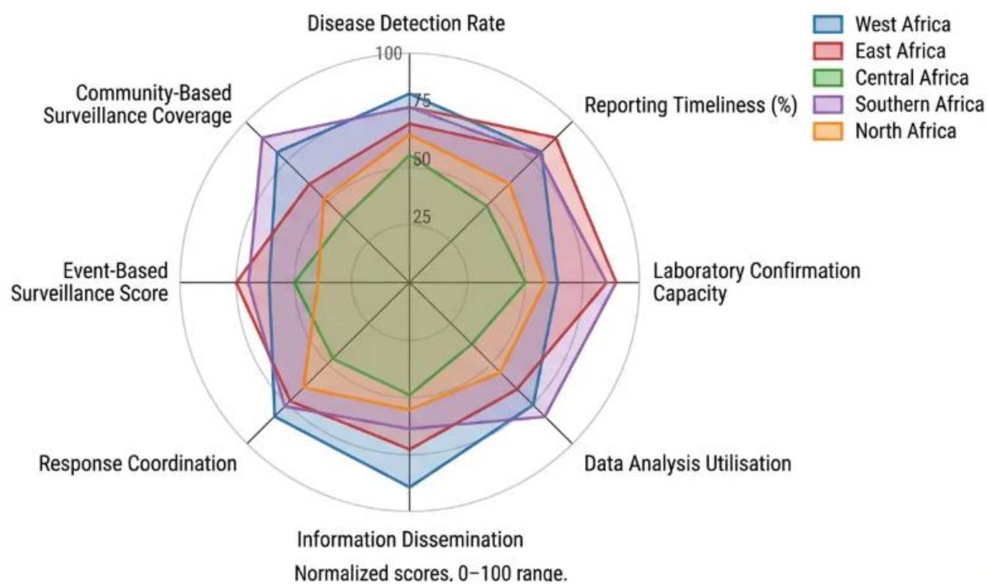


Figure 4: Radar diagram illustrating comparative performance of IDSR core functions across African sub-regions based on published key performance indicator data. Higher scores indicate better performance.

Caption: A radar diagram comparing IDSR core function performance across five African sub-regions (West, East, Central, Southern, and North Africa). Eight axes: (1) Disease Detection Rate, (2) Reporting Timeliness (%), (3) Laboratory Confirmation Capacity, (4) Data Analysis Utilisation, (5) Information Dissemination, (6) Response Coordination, (7) Event-Based Surveillance Score, and (8) Community-Based Surveillance Coverage. All scores were normalised to 0–100 scale

Source: Adapted from references.[15,16]

Workforce gaps represent the most pervasive challenge, with critical shortfalls of trained epidemiologists and laboratory scientists at peripheral health facility levels.[23] Evidence consistently demonstrates that facility-based health workers with inadequate IDSR training are associated with lower rates of case detection, delayed reporting, and poor data quality.[23] Field Epidemiology Training Programs (FETPs), championed by Africa CDC and CDC-AMED, offer a proven model for in-country capacity building.

Political and governance dimensions are equally consequential. Delayed public health emergency declarations, reluctance to share outbreak information due to economic consequences, and inadequate domestic financing of surveillance systems remain critical obstacles.[6] A 2024 analysis of epidemic preparedness and response capacities across 186 countries demonstrated a strong gradient in preparedness scores correlated with national income levels, highlighting the need for global solidarity mechanisms to bridge preparedness inequities.[6]

8. Lessons from Recent Outbreak Responses

8.1 COVID-19 Pandemic (2020–2023)

The COVID-19 pandemic remains the defining test of global surveillance architecture in recent history. The identification of a novel pneumonia cluster in Wuhan, China, through China's National Notifiable Disease Reporting System in December 2019 triggered subsequent WHO notifications under IHR mechanisms. However, delays in transparent reporting, initial diagnostic uncertainty, and fragmented global surveillance contributed to the unchecked international spread.[2,3] The subsequent deployment of genomic surveillance via GISAID, wastewater-based epidemiology, and digital surveillance tools enabled unprecedented real-time tracking of variant emergence and geographic spread.[13,14]

8.2 2022 Mpox Global Outbreak

The 2022 multi-country mpox outbreak, declared a PHEIC on 23 July 2022, presented unique surveillance challenges due to atypical clinical presentation, primarily affecting men who have sex with men, limited pre-existing awareness among clinicians, and the concurrent strain of COVID-19 response operations.[4,24] Surveillance responses included rapid adaptation of case definitions, establishment of multisite case-based surveillance networks such as the US National Emergency Department Registry for Mpox, and rapid deployment of amplicon-based WGS platforms.[18,24] Phylogenomic analyses revealed that the outbreak originated from a single introduction of MPXV clade IIb into the MSM community with rapid subsequent global dissemination.[19]

A retrospective analysis of mpox surveillance implementation in Tennessee demonstrated that clear case definitions, streamlined laboratory testing algorithms, and dedicated surveillance staffing were critical determinants of surveillance system performance during the acute response phase.[25]

8.3 2022 Uganda Sudan Ebola Virus Disease Outbreak

The Sudan virus disease outbreak in Uganda (August–November 2022) resulted in 164 cases and was contained within approximately four months, despite the absence of an approved vaccine.[5] Key surveillance contributions to containment included systematic field investigation using structured case investigation forms entered into the Go. Data platform, rapid contact tracing and follow-up, and the integration of retrospective medical records review with prospective case ascertainment.[5] The outbreak underscored the critical importance of laboratory confirmation capacity, as IDSR-trained field epidemiologists required access to functional PCR platforms for real-time case classification.

9. One Health and the Future of Epidemiological Surveillance

The One Health framework, which recognises the interdependence of human, animal, and environmental health, is increasingly integral to surveillance system design. The majority of emerging infectious diseases are zoonotic in origin, necessitating surveillance architectures that span the human-animal-environment interface.[1,26] The COVID-19 pandemic, mpox, Ebola, and the ongoing H5N1 avian influenza situation all exemplify zoonotic spillover events requiring multi-sectoral surveillance coordination.

Integration of veterinary, wildlife, and environmental surveillance data with human disease notification systems remains underdeveloped in most LMICs. Strengthening One Health surveillance platforms, including linking livestock disease reporting with human illness clusters and environmental monitoring such as wastewater-based epidemiology, offers substantial gains in early warning sensitivity for novel pathogen detection.[12,26]

The IHR (2005) Amendment adopted in 2024 expanded the scope of PHEIC criteria and strengthened equity provisions, requiring WHO to support LMICs in developing national surveillance capacities. This creates a legal and governance framework that, if effectively implemented, could catalyse the sustained investment in surveillance infrastructure that LMICs require.

10. CONCLUSION

Epidemiological surveillance is an indispensable pillar of effective disease control and outbreak response. This review has demonstrated that the integration of diverse surveillance modalities, passive indicator-based systems, event-based surveillance, syndromic surveillance,

genomic sequencing, and digital AI-powered tools provides a multi-layered defence against epidemic threats. The IDSR framework, while representing a significant achievement in systematising surveillance across Africa, faces persistent implementation challenges that require sustained political commitment, domestic financing, workforce investment, and technological modernisation.

The COVID-19 pandemic, 2022 mpox outbreak, and Uganda Ebola response have provided critical real-world evidence of both the power and the limitations of current surveillance systems. Genomic surveillance, in particular, has demonstrated transformative potential, enabling near real-time pathogen tracking, variant characterisation, and transmission cluster identification at a global scale. Wastewater-based epidemiology and AI-driven predictive models offer complementary capabilities that enhance outbreak detection before clinical case counts emerge.

Future investment priorities must include the expansion of genomic sequencing capacity in LMICs, the standardisation and interoperability of digital surveillance platforms, the strengthening of cross-border data sharing mechanisms under IHR, and the integration of animal and environmental health surveillance under a One Health paradigm. Equity in surveillance capacity is not merely a technical imperative but a global security necessity; a chain of disease reporting is only as strong as its weakest national link.

Declarations

Funding
This research received no specific funding from any agency in the public, commercial, or not-for-profit sectors.

Conflicts of Interest
The authors declare no conflicts of interest.

Ethics Statement
Not applicable (this is a review article involving no primary data collection).

Author Contributions
All authors contributed to conceptualisation, literature search, drafting, and critical revision of the manuscript.

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