



# Evaluation of Ebola virus disease surveillance system capability to promptly detect a new outbreak in Liberia

Fulton Quincy Shannon, II <sup>1,2</sup>, Luke L Bawo,<sup>2</sup> John A Crump <sup>1</sup>, Katrina Sharples,<sup>3</sup> Richard Egan,<sup>4</sup> Philip C Hill<sup>1</sup>

**To cite:** Shannon, II FQ, Bawo LL, Crump JA, *et al.* Evaluation of Ebola virus disease surveillance system capability to promptly detect a new outbreak in Liberia. *BMJ Glob Health* 2023;**8**:e012369. doi:10.1136/bmjgh-2023-012369

**Handling editor** Seye Abimbola

► Additional supplemental material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/bmjgh-2023-012369>).

Received 22 March 2023  
Accepted 9 July 2023



© Author(s) (or their employer(s)) 2023. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

<sup>1</sup>Centre for International Health, University of Otago, Dunedin, New Zealand

<sup>2</sup>Planning Research and Development, Republic of Liberia Ministry of Health, Monrovia, Liberia

<sup>3</sup>Mathematics and Statistics, University of Otago, Dunedin, New Zealand

<sup>4</sup>Preventive and Social Medicine, University of Otago, Dunedin, New Zealand

## Correspondence to

Fulton Quincy Shannon, II; [fqshannon@gmail.com](mailto:fqshannon@gmail.com)

## ABSTRACT

**Introduction** Liberia was heavily affected by the 2014–2016 Ebola virus disease (EVD) outbreak. With substantial investments in interventions to combat future outbreaks, it is hoped that Liberia is well prepared for a new incursion. We assessed the performance of the current EVD surveillance system in Liberia, focusing on its ability to promptly detect a new EVD outbreak.

**Methods** We integrated WHO and US Centers for Disease Control and Prevention guidelines for public health surveillance system evaluation and used standardised indicators to measure system performance. We conducted 23 key informant interviews, 150 health facility assessment surveys and a standardised patient (SP) study (19 visits) from January 2020 to January 2021. Data were summarised and a gap analysis conducted.

**Results** We found basic competencies of case detection and reporting necessary for a functional surveillance system were in place. At the higher (national, county and district) levels, we found performance gaps in 2 of 6 indicators relating to surveillance system structure, 3 of 14 indicators related to core functions, 1 of 5 quality indicators and 2 of 8 indicators related to support functions. The health facility assessment found performance gaps in 9 of 10 indicators related to core functions, 5 of 6 indicators related to support functions and 3 of 7 indicators related to quality. The SP simulations revealed large gaps between expected and actual practice in managing a patient warranting investigation for EVD. Major challenges affecting the system's operations across all levels included limited access to resources to support surveillance activities, persistent stock out of sample collection materials and attrition of trained staff.

**Conclusion** The EVD surveillance system in Liberia may fail to promptly detect a new EVD outbreak. Specific improvements are required, and regular evaluations recommended. SP studies could be crucial in evaluating surveillance systems for rarely occurring diseases that are important to detect early.

## INTRODUCTION

The West Africa Ebola virus disease (EVD) epidemic 2014–2016, caused by Ebolavirus

## WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Ebola virus disease (EVD) surveillance systems in sub-Saharan Africa have been challenged with delays in detecting new outbreaks.
- ⇒ The most severe manifestation of delayed outbreak detection was the 2014–2016 EVD epidemic in West Africa.
- ⇒ Issues with EVD surveillance include limited laboratory capacity, inadequately trained staff, limited information technology resources and poor health-seeking behaviour.
- ⇒ Since the 2014–2016 EVD epidemic, multiple organisations have collaborated to improve EVD surveillance, but formal evaluations of their ability to promptly detect a new outbreak are limited.

Zaire, was the largest ever recorded.<sup>1</sup> Liberia was one of the three most affected countries,<sup>2</sup> with 10 675 suspected, probable and confirmed cases and 4810 deaths.<sup>3</sup> According to the United Nations Office for the Coordination of Humanitarian Affairs, US\$1.07 billion were mobilised in 2014 to support the Liberian response and preparedness interventions through 47 institutions. In addition, US\$3.9 million were received towards surveillance, preparedness and response interventions by 2016.<sup>4</sup>

Liberia's Integrated Disease Surveillance and Response (IDSR) strategy was revised to include specific provisions for EVD, reporting tools and standard operating protocols (SOPs) in 2016. Healthcare workers at all levels were trained on surveillance and response competencies.<sup>5</sup> At health facilities, healthcare workers received training on providing safe and quality services. Specific provisions include EVD surveillance, clinical emergency and management, and infection prevention and control (IPC) tools.

### WHAT THIS STUDY ADDS

- ⇒ Ebola virus disease (EVD) surveillance systems in sub-Saharan Africa have been challenged with delays in detecting new outbreaks.
- ⇒ The most severe manifestation of delayed outbreak detection was the 2014–2016 EVD epidemic in West Africa.
- ⇒ Issues with EVD surveillance include limited laboratory capacity, inadequately trained staff, limited information technology resources and poor health-seeking behaviour.
- ⇒ Since the 2014–2016 EVD epidemic, multiple organisations have collaborated to improve EVD surveillance, but formal evaluations of their ability to promptly detect a new outbreak are limited.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ The study presents detailed surveillance system-wide performance measures for policy-makers and those running health facilities, to inform the development of specific interventions to close performance gaps.
- ⇒ Future evaluations of surveillance for rarely occurring but severe diseases, which need to be detected early, could incorporate SP studies as part of the assessment process.

Furthermore, laboratory diagnostic capacity for priority diseases, including EVD, was improved.<sup>5</sup>

As a result of these initiatives, it is hoped that Liberia is well placed to detect and respond promptly to a new EVD outbreak,<sup>6</sup> fulfilling its obligations under the 2005 International Health Regulations to prevent local and international spread of the disease.<sup>7</sup> However, given the number of activities and external agencies involved,<sup>8</sup> optimal alignment of all resources and parties leading to achievement of this goal should not be assumed. Therefore, we aimed to assess the performance of Liberia's EVD surveillance system 5 years after the epidemic, focusing on its ability to detect and respond effectively to a potential new outbreak.

## METHODS

### Setting

This project was linked to a World Bank funded One Health project (EERP: 02/2016 TA; Crossover Diseases: Animal to Human Surveillance) in Liberia. It was a collaboration between researchers from the Ministry of Health, Liberia and the University of Otago, New Zealand (online supplemental file 1).

Liberia is a West African country with a population of approximately 5 million people. It is divided into 15 counties, subdivided into 93 health districts. The Ministry of Health and the National Public Health Institute oversee operations nationwide. Each county has a 'county health team', while districts have district health teams. Liberia implements a three-tier health system: the primary healthcare level includes clinics and community health programmes; the secondary level consists of health centres and county hospitals; and the tertiary level consists of two health referral hospitals.<sup>9</sup> In Liberia, EVD surveillance is implemented under the IDSR strategy,

which categorises EVD as an 'immediately reportable epidemic-prone disease'. An alert threshold is triggered if one case is suspected. An action or epidemic threshold is activated if the case is confirmed by laboratory testing.<sup>5</sup>

### Conceptual framework

We primarily based this evaluation on the WHO framework for evaluating surveillance systems because of its applicability to low-resource countries,<sup>10</sup> which implement EVD surveillance through the IDSR strategy.<sup>5</sup> WHO developed a framework with a list of indicators in 2004<sup>11</sup> and an accompanying manual in 2006.<sup>12</sup> It includes four components: structure, core functions, support functions and surveillance quality and has been used to assess specific components of surveillance systems<sup>13</sup> and the usefulness of the IDSR strategy.<sup>14</sup> The surveillance system structure includes surveillance legislation, surveillance strategies, coordination, networking and partnership. The core functions include case detection and reporting, registration and confirmation, and routinely analysing and interpreting data captured.<sup>13</sup> Other core functions are epidemic preparedness and response and feedback. The support functions include standards and guidelines, training and supervision and resources. Surveillance system quality involves the system's usefulness and attributes (stability, flexibility, simplicity, acceptability, representativeness and completeness).<sup>13</sup>

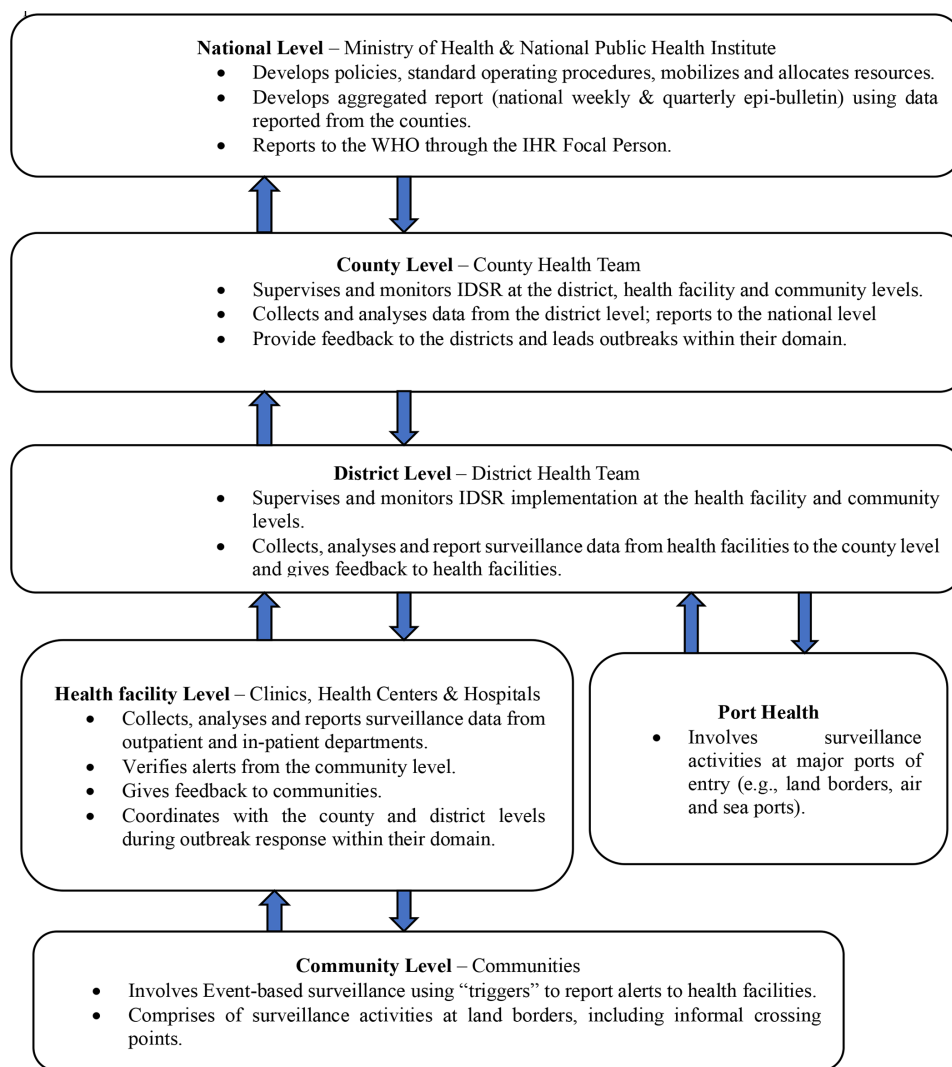
In addition, the framework provides a basis for identifying challenges in implementing IDSR.<sup>10–15</sup> We used the 2001 update of the US Centers for Disease Control and Prevention (US CDC) guidelines for the evaluation of surveillance systems to assess the surveillance system's quality component.<sup>16</sup> This framework was designed to evaluate surveillance systems that monitor emerging threats from bioterrorism and imminent disease outbreaks.<sup>17</sup>

### Study design and data collection

Using a mixed methods approach, we assessed system performance across the national, county, district and health facility levels (figure 1). Following a desk review to characterise Liberia's surveillance system and finalise the evaluation design, we employed three main data collection methods: key informant interviews, a health facility survey and standardised patient (SP) visitation to health facilities. Data collection was implemented between January 2020 and December 2021.

### Key informant interviews

We conducted 23 semistructured interviews with 22 key informants (online supplemental table 1). We purposively selected seven key informants at the national level. Five counties were selected based on the case count of EVD during the 2014–2016 EVD outbreak—classified as either high, medium or low. Surveillance activities during the 2014–2016 epidemic, including data collection and EVD confirmation, were standardised across the country. The top



**Figure 1** Flow diagram of Integrated Disease Surveillance and Response (IDSR) implementation at each level, Liberia, 2020–2021. IHR, International Health Regulations.

two counties for total case count were selected from the high and medium categories, while the county with the lowest case count was selected from the list of ‘low’ burden counties. We randomly selected two health districts from each of the five counties to interview district surveillance officers. We adapted generic questionnaires from the WHO and US CDC surveillance evaluation frameworks<sup>16 18</sup> to develop the study interview guide. Questions were aligned with performance indicators related to each component. We asked key informants questions related to indicators aligned with their specific level of operations (online supplemental table 2). We employed both face-to-face (n=13) and telephone (n=10; due to COVID-19 restrictions) interviews, which were digitally recorded and transcribed. The key informant interviews were conducted between 25 January and 30 April 2020.

### Health facility assessment

Using trained data collectors, we administered a survey to surveillance focal persons (SFPs) at 150

health facilities across all 15 counties to provide a nationally representative evaluation<sup>19</sup> of the core and support functions and the quality of the surveillance system. We developed the assessment tool using the WHO Service Availability and Readiness Assessment,<sup>19</sup> and data quality review toolkit,<sup>20</sup> and the US CDC tools.<sup>16</sup> We excluded specialised health facilities, such as those for tuberculosis and mental health, and randomly selected health facilities from each of three strata: clinics, health centres and hospitals. Additionally, the interviewer made a physical walk through of each health facility to observe key items directly. We implemented the questionnaire in the Census and Survey Processing System (CSPro) software application (US Census Bureau, USA),<sup>21 22</sup> and interviewers collected data on Android mobile devices. Forms were checked for completeness and transmitted to the online CSPro database at the end of each day. The health facility assessment was conducted between 1 June and 31 August 2020.

## SP study

We conducted an unannounced SP study during a period of heightened EVD risk (1 December 2020–31 January 2021) when there were two EVD outbreaks in The Democratic Republic of Congo (1 August 2018–25 June 2020) and Guinea (14 February 2021). Using stratified random sampling, we selected 20 health facilities in Bong and Montserrado counties—5 hospitals, 5 health centres and 10 clinics. SPs were purposively recruited after engaging communities around health facilities selected for the study and considering their age, educational level, occupation and gender. We developed three clinical scenarios (online supplemental table 3) portraying early symptoms of EVD, consistent with the national criteria for a suspected EVD case.<sup>23</sup> We trained SPs by educating them about EVD and using role plays to depict ‘real-life’ manifestations of the clinical symptoms and presentation. We coached them on potential biohazards in health facilities, strategies to avoid infection and approaches to decline invasive medical procedures.<sup>24</sup> We evaluated SPs clinically<sup>25</sup> as part of the selection process to limit and minimise alternative diagnoses. We conducted postvisit interviews with the clinical staff that screened the SPs and with the SPs. These evaluated healthcare workers’ screening practices for EVD related to the visits and documented their practices from the SPs’ perspective. Due to the COVID-19 pandemic, we enrolled fewer SPs than planned and assessed half of the sample of health facilities.

## Performance measurements

We adapted indicators informed by the WHO and US CDC guidelines. We set indicator targets to represent reasonable performance expectations consistent with Liberia’s IDSR strategy. Regarding the surveillance system’s structure, we assessed indicators linked to surveillance legislation, strategies, coordination, networking and partnership. Regarding core functions, we assessed indicators related to case detection and reporting, registration, confirmation, analysis and interpretation of data routinely captured by the system. We also measured the level of preparedness at each level of the system regarding. Furthermore, we assessed the provision of and described mechanisms for feedback. Regarding support functions, indicators evaluated covered the existence of standards and procedures, the proportion of trained staff with core competencies and supervision. Additionally, we determined the proportion of surveillance units with evidence of appropriate budgetary allocation. For surveillance system quality, we assessed indicators related to simplicity, acceptability, representativeness, stability, flexibility, data completeness and usefulness for evidence-based decision-making.

## Data management and analysis

All quantitative data were imported to Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) and cleaned to eliminate inconsistencies and correct

typographical errors where necessary. Each dataset was stored in an Excel comma-separated value file format. The transcripts from digital recordings of the key informant interviews were cleaned and stored as separate Microsoft Word (Microsoft Corporation) documents. For quantitative data, we conducted descriptive analyses and summarised the data into frequencies and proportions. All statistical analyses were done using STATA (V.16.1) (StataCorp LLC, Texas, USA). We used weighted percentage scores, which took into account the relative numbers of the different types of facility across Liberia, to measure each indicator. For the SP study, we directly compared health facility assessment findings with their associated results from the field evaluation. We described the associations between the system’s expected performance and the actual performance in the field. For the qualitative analysis, we analysed transcripts and interview notes using NVivo V.1.5 (QSR International, Melbourne, Australia) according to the performance indicators. We conducted a gap analysis comparing the observed results to a standard predetermined target. These predetermined targets were based on WHO’s standard benchmarks for surveillance and response indicators, focusing on an overall goal of a high-performing, but not perfect, system and taking the single disease focus into account (online supplemental table 2).

## RESULTS

### Key informant interviews

With respect to the key informants, 90% (n=20) were male. Their median (range) age was 41.5 (32–60) years. Eleven had completed a Master’s degree in public health or a related field, while five had completed a Bachelor’s degree (one in Public Health). The interviews lasted a median (range) of 24.8 (15–50) min (online supplemental table 1).

### Surveillance system structure

At the national, county and district levels, all (100%) of the surveillance units had a copy of the roles and responsibilities of stakeholders, while 89% (n=17) reported having a strategic plan of action. Four (one per quarter) intersectoral meetings, and one cross-border collaborative initiative, were held at the national level over the year before the assessment (table 1).

### Core functions

At the national, county and district levels, all (100%) of the surveillance units had the standard case definitions for EVD, and all (100%) of the surveillance managers and officers displayed correct knowledge of them. All of the surveillance officers used the required case-based form, and the one recent suspected EVD case was referred for confirmation within 24 hours. Of the 40 samples from suspected EVD patients at the National Reference Laboratory, 98% (n=39) were tested, and all results were disseminated within 72 hours. Meanwhile, 73% (n=11) of 15 surveillance units reported no stockout of EVD sample

**Table 1** Performance of surveillance system structure at national, county and district levels, 2020–2021

System parameters	Indicator	Denominator	Expected performance	Observed n (%)
Surveillance legislation (laws and regulations)				
Existence of national legislative support for surveillance and response to EVD	Laws related to EVD surveillance and response recalled across surveillance managers	1	100%	1 (100%)
	Surveillance units with a copy of the National Public Health Law	19 surveillance units	80%	2 (10.5%)
Surveillance strategy and coordination				
Presence of plan of action for EVD surveillance and response	Surveillance units with a strategic plan of action for Ebola surveillance and response	19 surveillance units	100%	17 (89.5%)
Existence of documented roles and responsibilities for EVD surveillance and response at all levels of the surveillance system	Surveillance units with a copy of roles and responsibilities of stakeholders of the EVD surveillance and response system	19 surveillance units	80%	19 (100%)
Networking and partnership				
Evidence of intersectoral collaboration, networking and partnership	Intersectoral collaboration, networking and partnership meetings held at the national level in the past 1 year	NA	4	4
Cross-border collaborations	Cross-border collaboration activities implemented at the national level in the past 1 year	NA	1	1
EVD, Ebola virus disease; N/A, not applicable (indicators characterised as 'number' observed..., for example, number of case-based forms).				

collection supplies in the previous 3 months. However, only one unit reported that they had adequate funds (table 2).

### Support functions

All of the surveillance managers and officers at the national, county and district levels reported having training in IDSR and field epidemiology. Similarly, there were technical guidelines and SOPs relating to EVD surveillance and response, including sample collection, across all surveillance units. However, only 1 of the 12 surveillance units with budgetary functions showed evidence of a budget for implementing surveillance activities related to EVD (table 2).

### Surveillance system quality

All of the surveillance units at the national, county and district levels produced weekly and quarterly reports and bulletins (table 2; usefulness). There was one standardised form for reporting suspected EVD cases and two channels for reporting (simplicity). The EVD surveillance system is interoperable with other subsystems (eg, Lassa fever, Marburg, Yellow fever) (flexibility). Approximately, 85% of stakeholders actively participated in EVD surveillance activities at least 3 months before the assessment (table 3).

### Health facility assessment

Of 150 assessments, data were adequate for analysis from 149 facilities, representing 18% (149) of the country's

828 facilities. Of these, 88% (n=119) were clinics, 4% (n=11) were hospitals and 7% (n=19) were health centres. Additionally, 80% (n=117) were government-managed public facilities. More than 60% (n=101) of the 149 SFPs interviewed were nurses, while about 20% (n=27) were midwives, 4 were nurse aides and 7 were trained in other professions.

### Core functions

At the health facility level, 84% (n=126) of SFPs displayed correct knowledge of the standard EVD case definitions. Furthermore, 70% (n=104) of 149 health facilities had a stock of case-based EVD reporting forms. In addition, 36% (n=53) of 149 SFPs portrayed correct knowledge of collecting and packaging EVD samples. Approximately 56% (n=85) of 149 health facilities reported no stockout of EVD sample collection kits at least 3 months before the assessment (figure 2A).

### Support functions

Approximately 89% (n=133) of 149 health facilities reported no stockout of case-based reporting forms at least 3 months before the assessment; 71% (n=106) reported having necessary technical guidelines; and 69% (n=103) reported having training in surveillance competencies. In addition, 24% (n=36) of 149 health facilities reported having a functional designated mobile phone for reporting suspected EVD cases (figure 2B).

**Table 2** Performance of core and support functions at national, county and district levels, Liberia, 2020–2021

System parameters	Indicator	Denominator	Expected performance	Observed n (%)
<b>Core functions</b>				
Case detections				
Mechanism for outbreak detection	Standard case definitions for EVD on file	19 surveillance units	100%	19 (100%)
	Knowledge of a standard case definition for a suspected case of EVD at the county and district levels	15 surveillance officers	100%	15 (100%)
	Knowledge on standard case definition for a suspected case of EVD at national level	7 surveillance officers	100%	7 (100%)
	Using standard case definitions to validate suspected cases of EVD at county and district levels	15 surveillance officers	100%	15 (100%)
Case registration				
Mechanisms to record suspected cases	Line list/databases of suspected EVD cases	19 surveillance units	100%	19 (100%)
Case reporting				
Case-based reporting	Reporting the use of case-based forms to report suspected EVD cases	Total number of suspected case report observed during the recall period	1	1 (100%)
Case confirmation				
Confirmation of EVD	Samples tested with results available within 72 hours of reception	Total number of suspected case report observed during the recall period	80%	13 (92.8%)
	Samples referred from county and district levels within 24 hours	Total number of suspected case report observed during the recall period	100%	1 (100%)
Supplies for EVD specimen collection and transportation	Reporting no stockout of supplies for EVD specimen collection	15 surveillance units	80%	11 (73.3%)
Data analysis and interpretation				
EVD surveillance data analysis and interpretation	Evidence of descriptive analysis of EVD data	19 surveillance units	80%	18 (95%)
Epidemic preparedness, response and control				
Epidemic preparedness plan	Evidence of an epidemic preparedness plan for EVD	19 surveillance units	100%	18 (95%)
Emergency funds	Existing adequate funds for emergency response	17 surveillance units	80%	1 (5.9%)
Feedback				
Existence of regular feedback	Received lab results for suspected EVD samples	Total number of sample referred for confirmation during the recall period	100%	1 (100%)
	Reporting feedback from the next higher level	15 surveillance unit	100%	15 (100%)
<b>Support functions</b>				
Standards and guidelines				
Availability of surveillance guidelines	Copy of technical guidelines (2016) for EVD	19 surveillance units	80%	19 (100%)
Standard operating procedures for collection, packaging and transportation of Ebola specimen	Standard operating protocols for EVD specimen collection, packaging and transport	19 surveillance units	80%	19 (100%)

Continued

**Table 2** Continued

System parameters	Indicator	Denominator	Expected performance	Observed n (%)
Training				
Trained on Integrated Disease Surveillance and Response	Surveillance managers at national level reporting training in Integrated Disease Surveillance and Response	7 officers/managers	80%	7 (100%)
Trained field epidemiologist	Surveillance managers at national level reporting training in field epidemiology	7 officers/managers	80%	7 (100%)
	Surveillance officers at county and district levels reporting training in field epidemiology	15 surveillance officers	80%	15 (100%)
Supervision				
Conduct of supervisions	Conducted supervision(s) to immediate lower level	15 surveillance units	80%	11 (73.3%)
Resources				
Evidence of budget	Evidence of budget for surveillance activities	12 surveillance units	80%	1 (8.3%)

EVD, Ebola virus disease.

### Surveillance system quality

All SFPs identified one standardised suspected EVD case reporting form and three unambiguous channels for reporting to the higher levels (simplicity) (table 3). All (100%) of the health facilities sent regular reports, including ‘zero reporting’, to the higher levels (representativeness). About 87% (n=129) of SFPs accepted EVD surveillance as their responsibility (acceptability). Only 40% (n=60) of 149 health facilities had a designated phone, access to a mobile cellular network, daily internet service and uninterrupted electricity during operational hours (stability) and only 13% (n=20) showed evidence of an EVD line list meeting expected standards (completeness) (figure 2C).

### SP study

In total, 9 SPs made 19 visits to 10 health facilities (hospitals, health centres and clinics). Overall, 60% (n=6) of health facilities were in urban areas and 90% (n=9) were publicly owned or managed. Overall, 56% (n=5) of the 9 SPs were male, and the median (range) age was 20 (5–32) years.

### Expected performance in the SP study versus actual performance

The health facility assessment showed 92% (n=13) and 80% (n=29) of SFPs in Bong and Montserrado counties were recently trained in disease surveillance competencies (table 4). All had displayed ‘correct’ knowledge of the standard clinical case definition for a suspected EVD case. In addition, 85% (n=12) and 91% (n=33) had responsive supervision. However, no SP was suspected of being an EVD case. Therefore, the sensitivity was 0%, and the timeliness of the EVD surveillance system was not estimated. Furthermore, healthcare workers infrequently probed SPs for contact with animals, 15% (n=3), similar symptoms in close contacts, 15% (n=3), or travel history, 10% (n=2) (table 4).

### Performance gap analysis

At the national county and district levels, we recorded performance gaps in 22.2% (n=8) of 36 indicators related to the surveillance system structure, core and support functions and surveillance system quality. The highest performance gaps for surveillance units were in relation to the presence of an existing and adequate budget for emergency response (74.1%), evidence of budget for surveillance activities (71.7%) or having a copy of the National Public Health Law (69.5%) (figure 3A).

We recorded performance gaps in 68.2% (n=15) of 22 indicators assessed at the health facility level in core and support functions and surveillance system quality. The highest performance gaps were documented for data completeness (66.6%), SFP knowledge on the collection and packaging of EVD samples (64.1%), health facilities having a designated functional mobile phone for reporting (55.8%) and evidence of data analysis (45.3%) (figure 3B). The SP study identified a 100% gap in performance for the system’s sensitivity.

### DISCUSSION

In this study, we found the EVD surveillance system in Liberia has the basic competencies required for case detection and reporting necessary for a functional surveillance system were in place. However, at the higher (national, county and district) levels, we found performance gaps in 2 of 6 indicators relating to surveillance system structure, 3 of 14 indicators related to core functions, 1 of 5 quality indicators and 2 of 8 indicators related to support functions. Similarly, at the health facility level, we found performance gaps in 9 of 10 indicators related to core functions, 5 of 6 indicators related to support functions and 3 of 7 quality indicators. In the field evaluation, there was a large gap between expected and actual practice in managing a patient warranting investigation

**Table 3** Performance of surveillance system quality, Liberia, 2020–2021

Attributes	Indicators	Surveillance level	Denominator	Expected performance	Observed n (%)
Usefulness	Surveillance units that produced reports/bulletin for decision-making	National county and district	17 surveillance units	100%	17 (100%)
Simplicity	Case-based reporting forms required by the system for reporting suspected EVD	National county and district	NA	1	1
	Existing reporting channels required for reporting suspected cases of EVD	National county and district	NA	1	2
	Case-based reporting forms required by the system for reporting a suspected EVD case	Health facility	NA	1	1
	Existing reporting channels required for reporting suspected cases of EVD	Health facility	NA	1	3
Flexibility	Subsystems with which the EVD system is interoperable	National county and district	Total number of existing subsystems	80%	14 (100%)
	Changes made to EVD case detection and reporting	National county and district	NA	1	1 (100%)
Stability	Surveillance units reporting unscheduled electrical power outages that occurred	National county and district	17 surveillance units	0	17 (100%)
	Surveillance units reporting EVD surveillance activities unhindered by lack of funds	National county and district	17 surveillance units	100%	6 (35.3%)
Acceptability	Stakeholders actively participated in surveillance and response activities	National county and district	Total number of stakeholders required to participate in the system	80%	85%
Representativeness	Reporting sites that sent weekly surveillance reports (including zero reports) of suspected EVD	National county and district	Total number of reporting sites observed during the recall period	100%	15 (100%)

EVD, Ebola virus disease; N/A, not applicable (indicators characterised as ‘number’ observed..., eg, number of case-based forms).

for EVD. These findings suggest that while Liberia has made substantial progress in EVD surveillance, there are several areas for improvement if a future EVD outbreak is to be detected promptly.

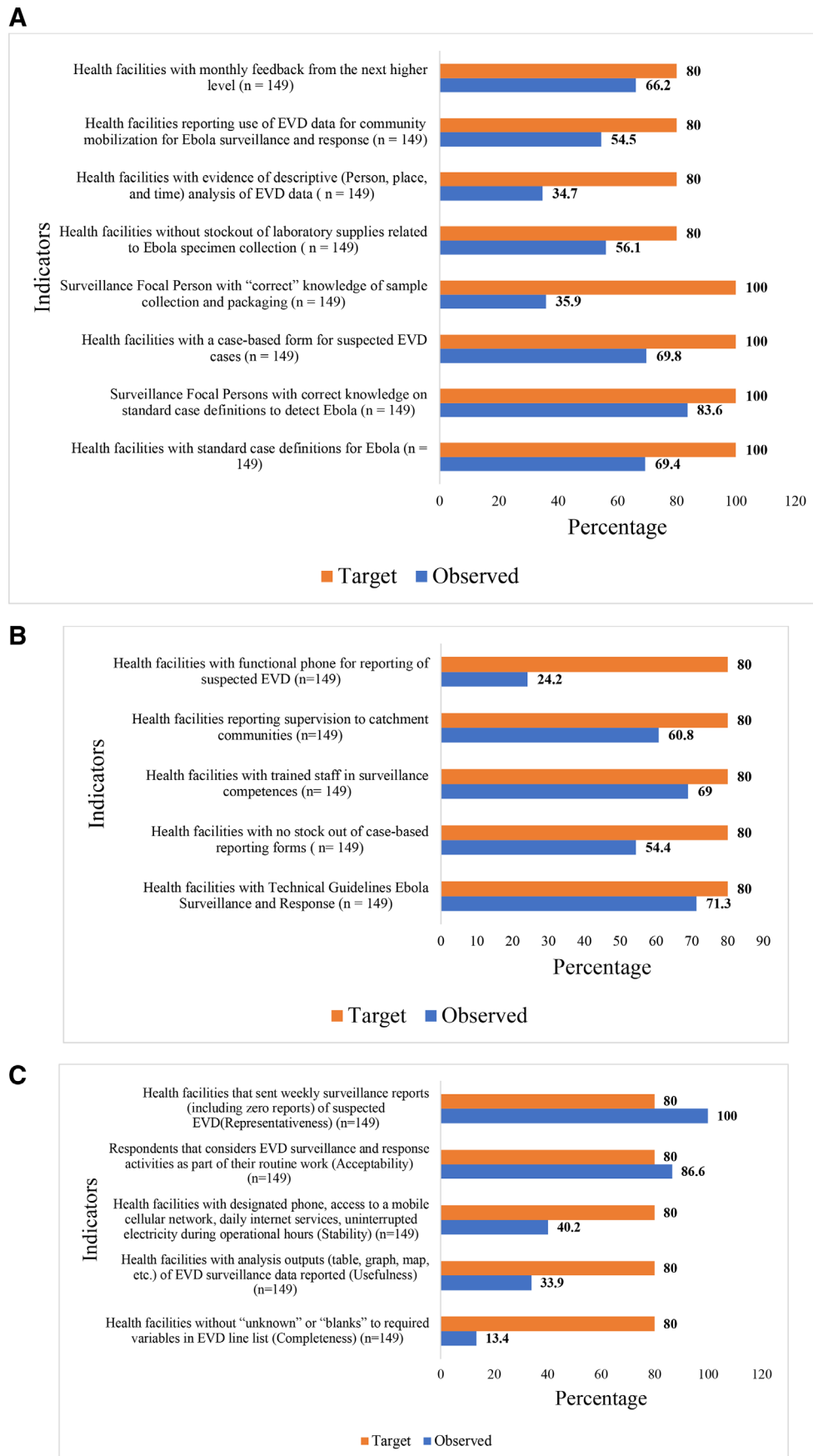
Concerning specific performance indicator findings, while no other studies have comprehensively evaluated EVD surveillance system performance, several studies have evaluated IDSR performance, within which EVD surveillance resides. Similar to our study, Nagbe *et al*<sup>5</sup> recorded inconsistencies when assessing the implementation of IDSR in Liberia. They found persistent stockouts of sample collection kits at health facilities and the need for correct knowledge of the packaging of EVD samples. Resources for surveillance were available at the national, county and district levels but not at the health facilities. Nagbe *et al* also found that data used for decision-making at the subnational levels were lacking.<sup>5 26</sup>

Similarly, Saleh *et al*<sup>27</sup> found limited capacity for sample collection due to regular stockouts at health

facilities when they assessed the core and support function of IDSR implementation in Zanzibar, Tanzania.<sup>27</sup> They also documented performance inconsistencies between the higher and lower levels of the surveillance system; case detection and reporting were poorest at the health facility level compared with the district and national. Support functions such as training opportunities and trained staff, regular supervision, coordination and communication and logistic support were frequently inadequate at health facilities.<sup>27</sup>

In contrast to our study, a study by Ilesanmi *et al* assessing the surveillance system attributes found the acceptability of the EVD surveillance system in Tonkolili District, Sierra Leone, to be poor, but its usefulness was good.<sup>28</sup> There was limited or no supervision of health facilities in Cameroon on evaluating the cholera surveillance.<sup>29</sup> Separate studies assessing IDSR implementation in Ethiopia and Ghana showed fewer health facilities with the standard case definitions of priority disease<sup>30</sup>; healthcare workers at health

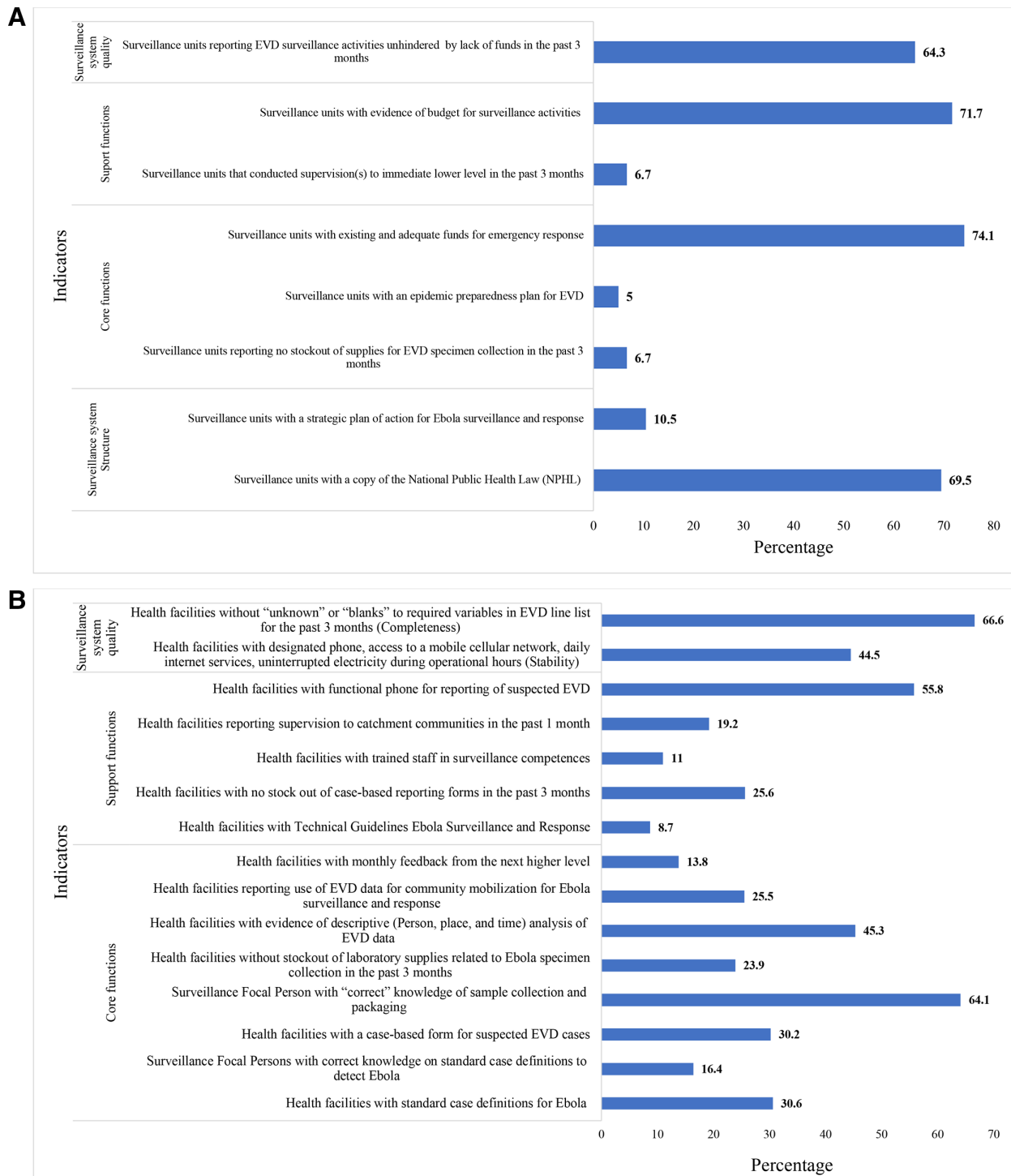




**Figure 2** Performance of core and support functions and surveillance system quality of Ebola virus disease (EVD) surveillance and response system at health facilities, Liberia, 2020–2021. (A) Core functions. (B) Support functions. (C) Surveillance system quality.

**Table 4** EVD surveillance system performance versus outcomes in practice, SP study, Bong and Montserrado counties, Liberia, 2020–2021

Surveillance component	Indicators	Performance		Expected practice	Actual practice
		Bong county	Montserrado county		
Case detection	Health facilities with standard case definitions for Ebola posted on wall of screening room	78.6%	36.1%	Healthcare workers in Montserrado county may lack quick access to references for suspected EVD case detection Healthcare workers in Bong county have quick access to references for suspected EVD case detection	Zero case (SP) detected during the study
	Surveillance focal persons with knowledge on standard case definitions to detect Ebola	100%	100%	Healthcare workers possess the knowledge to detect suspected EVD	Zero case (SP) detected during the study
Feedback	Health facilities with feedback during supervision	85.7%	91.7%	Healthcare workers have opportunities for personal and professional mentorship in: detecting suspected EVD Infection prevention and control (eg, proper use of gloves) screening patients for risk factors associated with EVD infection (eg, contact with infected wild animals)	Zero cases (SP) were detected during the study Gloves used during 31.6% of SP visits Gloves disposed of after use during 15.8% of SP visits Probed for risk factors: travel history (10.5%) contact with animals (15.8%) similar symptoms in family/relatives (15.8%)
	Standards and Guidelines	Health facilities with Technical Guidelines (2016) Ebola Surveillance and Response	21.4%	80.6%	Healthcare workers in Bong county may lack quick access to references for suspected EVD case detection Healthcare workers in Montserrado county have quick access to references for suspected EVD case detection
Training	Health facilities with trained staff in surveillance competences	92.8%	80.6%	Healthcare workers are expected to: detect a suspected case of EVD infection prevention and control (eg, proper use gloves during screening of patient) screen patients for travel history, ask about similar symptoms in family and closed relative history of contact with wild animals	Zero cases (SP) detected during the study Gloves used during 31.6% of SP visits Gloves disposed after use during 15.8% of SP visits Probe for risk factors: travel history (10.5%) contact with animals (15.8%) similar symptoms in family/relatives (15.8%)
	EVD, Ebola virus disease; SP, standardised patient.				



**Figure 3** Performance gaps in EVD surveillance and response implementation at national county, district and health facility levels, Liberia, 2020–2021. (A) Gaps at national, county and district levels. (B) Gaps at health facility level.

facilities displayed poor knowledge of the case definition of a suspected EVD case, focusing only on bleeding manifestations.<sup>14</sup>

In the health facility survey, we found that a high proportion of healthcare workers had correct knowledge of the standard case definition of suspected EVD and training in IDSR. Health facilities had the required screening aids for EVD available to healthcare workers. However, these did not translate into practices or

behaviours consistent with the existing competencies in the health facilities. Our SP detection sensitivity was zero, which implies poor application of the standard case definition to identify the early symptoms of EVD. Healthcare workers probed less for EVD risk factors, including contact with wild animals, travel history or close relative(s) with similar symptoms. In addition, their practice of universal compliance with IPC was poor. Similar to our study, Daniels *et al* in 2017 found

that no possible cases were detected when assessing the quality of care relating to asthma, tuberculosis, childhood diarrhoea and unstable angina in Nairobi, Kenya.<sup>24</sup>

In contrast, healthcare workers in the simulation exercises related to EVD case detection and response in Liberia<sup>31 32</sup> and South Sudan<sup>33</sup> showed a good understanding of the spectrum of EVD symptoms, with detection at 100%. However, the simulation exercises involved informing the healthcare workers of the scenarios before implementation, limiting the ability to assess real-life practice. Another study that evaluated hospital interventions in China showed good adherence to IPC standards overall when screening SPs presenting as people living with HIV,<sup>34</sup> contrary to our finding. This could possibly be explained by the perceived risks of HIV infection while working in an HIV clinic.

Our study has several strengths. First, integrating the WHO and US CDC frameworks and an indicator-based approach allowed us to measure the whole system's performance based on expected and achieved outcomes. Second, this evaluation was conducted in the context of IDSR, with EVD surveillance being a part of the integrated surveillance strategy. Hence, our results could be relevant to diseases similar to EVD and settings similar to Liberia. Third, the SP study assessed gaps between what healthcare workers were expected to do from the indicator measurements and what they did in practice.

Our study has some limitations. Purposive sampling may introduce sampling bias, although it is best suited to identify the most knowledgeable individuals. There was a male predominance of the respondents, although this did reflect the gender balance of the employees under study. We did not investigate the costs of operating the surveillance system, but we explored access to financial resources. We did not assess the Community Event-Based Surveillance (CEBS) system, but we confirmed the existence of CEBS in catchment communities of health facilities we assessed. We did not complete the SP study as planned due to circumstances related to the COVID-19 pandemic. Its relatively small sample size may have limited our ability to make precise estimates of system performance against indicators. Finally, being a cross-sectional study, we did not assess changes in system performance over time.

Liberia's EVD surveillance and response system may not be able to detect and respond to a new EVD outbreak as effectively or promptly as desired. Surveillance systems may especially fail to meet their objectives when one or more system components at each level perform poorly, as we found in this study. In addition to the Liberian Ministry of Health's implementation of a dissemination plan related to this study's findings, opportunities for changes to improve the system include enhancing capacity for timely reporting at health facilities, training and retaining healthcare workers at all levels, optimising

surveillance competencies, preventing stockout of key sample collection kits and regularising supervision and mentorship at the subnational levels. Further studies could focus on possible variations in level of preparedness per region, system challenges and potential reasons for performance gaps, along with options for filling them. It is important to assure the government and the people of Liberia that a widespread outbreak of this devastating disease will not happen again. Therefore, regular evaluations are advised. These should include using SP studies, which may be important to incorporate in surveillance system evaluations for all infectious diseases that rarely occur but are crucial to detect early to save thousands of lives.

**Acknowledgements** We also acknowledge the data collectors' and study participants' contributions to this study.

**Contributors** The success of this research project is attributed to the hard work and effective coordination of expertise from the research team. FQSII, the corresponding author, led the design and field investigations for the study. He was solely responsible for conducting the key informant interviews. He led the training exercises for hired data collectors involved with the health facility assessments and the standardised patients (SPs) study. He supervised (directly and remotely) the field activities for the health facility assessments and the SP study. In addition, he was responsible for spearheading the data analysis (with support from KS) and report writing and synthesising the reports into this research article. PCH served as a coauthor. He supported the study design, implementation and report writing. JAC served as coauthor. He also assisted in the study design and the writing of reports. KS assisted in the study design, data analysis and report writing. RE specifically supported the qualitative aspect of this paper, including the data analysis and report writing. LLB supervised field implementation and contributed to the report writing. FQSII is the guarantor.

**Funding** This study came out of an academic (Doctor of Philosophy) work funded through a University of Otago Scholarship and Foundation Trust.

**Competing interests** None declared.

**Patient and public involvement** Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

**Patient consent for publication** Not applicable.

**Ethics approval** This study involves human participants and was approved by The University of Liberia Institutional Review Board (UL-IRB) (Ref. #: 20-01-196). The Human Ethics Committee (Health), University of Otago (Ref. #: H19/155 (Health facility assessment); H19/145) (Assessment at National County and District levels); H20/001 (Standardised Patient Study). Participants gave informed consent to participate in the study before taking part.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available upon reasonable request. All data (delinked) and tools will be made available based on a reasonable request to the Centers for International Health, University of Otago.

**Supplemental material** This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

**Open access** This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

## ORCID iDs

Fulton Quincy Shannon, II <http://orcid.org/0009-0002-6280-9473>  
 John A Crump <http://orcid.org/0000-0002-4529-102X>

## REFERENCES

- Kalra S, Kelkar D, Galwankar SC, *et al*. The emergence of Ebola as a global health security threat: from 'lessons learned' to coordinated multilateral containment efforts. *J Glob Infect Dis* 2014;6:164–77.
- Coltart CEM, Lindsey B, Ghinai I, *et al*. The Ebola outbreak, 2013–2016: old lessons for new epidemics. *Philos Trans R Soc Lond B Biol Sci* 2017;372:20160297.
- Wagenaar BH, Augusto O, Beste J, *et al*. The 2014–2015 Ebola virus disease outbreak and primary healthcare delivery in Liberia: time-series analyses for 2010–2016. *PLoS Med* 2018;15:e1002508.
- United Nations Office for the Coordination of Humanitarian Affairs. Ebola virus outbreak - overview of needs and requirements. Liberia | financial tracking service; 2015.
- Nagbe T, Naiene JD, Rude JM, *et al*. The implementation of integrated disease surveillance and response in Liberia after Ebola virus disease outbreak 2015–2017. *Pan Afr Med J* 2019;33:3.
- Kiggundu T, Ario AR, Kadobera D, *et al*. Notes from the field: outbreak of Ebola virus disease caused by Sudan ebolavirus - Uganda, August–October 2022. *MMWR Morb Mortal Wkly Rep* 2022;71:1457–9.
- World Health Organization. 2008. International health regulations (2005)
- World Bank. The economic impact of the 2014 Ebola epidemic: Short- and medium-term estimates for West Africa; 2014.
- Kesselly RY, Kwenah NK, Gonyon E. The status of health services in the 15 counties of Liberia. *SEEJPH* 2018.
- Sahal N, Reintjes R, Aro AR. Review article: communicable diseases surveillance lessons learned from developed and developing countries: literature review. *Scand J Public Health* 2009;37:187–200.
- World Health Organization. Overview of the WHO framework for monitoring and evaluating surveillance and response systems for communicable diseases. *Wkly Epidemiol Rec* 2004;79:322–6.
- World Health Organization. Communicable disease surveillance and response systems: guide to monitoring and evaluating. 2006. Available: [https://www.who.int/csr/resources/publications/surveillance.WHO\\_CDS\\_EPR\\_LYO\\_2006\\_2.pdf](https://www.who.int/csr/resources/publications/surveillance.WHO_CDS_EPR_LYO_2006_2.pdf) [Accessed 08 Apr 2020].
- Phalkey RK, Shukla S, Shardul S, *et al*. Assessment of the core and support functions of the integrated disease surveillance system in Maharashtra, India. *BMC Public Health* 2013;13:575.
- Issah K, Nartey K, Amoah R, *et al*. Assessment of the usefulness of integrated disease surveillance and response on suspected Ebola cases in the Brong Ahafo region, Ghana. *Infect Dis Poverty* 2015;4:17.
- Phalkey RK, Yamamoto S, Awate P, *et al*. Challenges with the implementation of an integrated disease surveillance and response (IDSR) system: systematic review of the lessons learned. *Health Policy Plan* 2015;30:131–43.
- German RR, Lee LM, Horan JM, *et al*. Updated guidelines for evaluating public health surveillance systems recommendations from the guidelines working group. *MMWR Recomm Rep* 2001;50:1–35.
- Buehler JW, Hopkins RS, Overhage JM, *et al*. Framework for evaluating public health surveillance systems for early detection of outbreaks: recommendations from the CDC working group. *MMWR Recomm Rep* 2004;53:1–11.
- World Health Organization. Communicable disease surveillance and response systems: guide to monitoring and evaluating. 2006. Available: <https://apps.who.int/iris/handle/10665/69331> [accessed [Accessed 13 Aug 2019].
- World Health Organization. Service availability and readiness assessment (SARA). 2013. Available: <https://www.who.int/healthinfo/systems> [Accessed 13 Aug 2019].
- World Health Organization. Data quality review: module 1: framework and Metrics; 2017.
- The United States Census Bureau. CSPro software. Available: <https://www.census.gov/data/software/cspro.html> [Accessed 16 Jul 2021].
- Roque JD, Lapitan P, Pipon D. *Massive open online courses for building statistical capacity in computer-assisted surveys*. : Asian Development Bank. 2020.
- Ministry of Health, Republic of Liberia. 2016. National technical guidelines for integrated disease surveillance & response
- Daniels B, Dolinger A, Bedoya G, *et al*. Use of standardised patients to assess quality of healthcare in Nairobi, Kenya: a pilot, cross-sectional study with international comparisons. *BMJ Glob Health* 2017;2:e000333.
- World Health Organization. *Optimized supportive care for Ebola virus disease: standard clinical management procedures*. 2019.
- Nagbe T, Yealue K, Yeabah T, *et al*. Integrated disease surveillance and response implementation in Liberia, findings from a data quality audit, 2017. *Pan Afr Med J* 2019;33:10.
- Saleh F, Kitau J, Konradsen F, *et al*. Assessment of the core and support functions of the integrated disease surveillance and response system in Zanzibar, Tanzania. *BMC Public Health* 2021;21:748.
- Ilesanmi OS, Fawole O, Nguku P, *et al*. Evaluation of Ebola virus disease surveillance system in Tonkolili district, Sierra Leone. *Pan Afr Med J* 2019;32:2.
- Ngwa MC, Liang S, Mbam LM, *et al*. Cholera public health surveillance in the republic of cameroon-opportunities and challenges. *Pan Afr Med J* 2016;24:222.
- Begashaw B, Tesfaye T. Assessment of integrated disease surveillance and response implementation in special health facilities of Dawuro zone. *J Anesthesiol* 2016;4:11.
- Ministry of Health, Republic of Liberia. County simulation final report Monrovia Ministry of Health; 2019.
- Ministry of Health, Republic of Liberia. District-level simulation report Monrovia Ministry of Health; 2019.
- Centers for Disease Control and Prevention. Simulation exercise in South Sudan. 2022. Available: <https://www.cdc.gov/globalhealth/stories/2019/simulation-exercise-in-south-sudan.html> [Accessed 09 May 2022].
- Li L, Lin C, Guan J. Using standardized patients to evaluate hospital-based intervention outcomes. *Int J Epidemiol* 2014;43:897–903.

## Supplementary Materials

**Table 1: Distribution of key informant interviews by Institution, Liberia, 2020**

Institution/Organization	Number of Key informants	Position/Role
Ministry of Health	1	Director/Health Management Information System
National Public Health Institute	5	Surveillance Coordinator/Division of Infectious Disease and Epidemiology; Epidemic Preparedness and Response Coordinator/ Division of Infectious Disease and Epidemiology; Data Manager/ Division of Infectious Disease and Epidemiology; Director/Monitoring and Evaluation; Director/National Reference Laboratory
World Health Organization	1	Technical Assistant/Surveillance and Response
County Health Team (Montserrado, Lofa, Grand Bassa, Bomi & Rivercess counties)	5	County Surveillance Officers
District Health Team (Montserrado, Lofa, Grand Bassa, Bomi & Rivercess counties)	10	District Surveillance Officers

**Table 2: Performance indicators for the assessment of Ebola Virus Disease surveillance in Liberia**

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
<b>Surveillance System Structure</b>						
<b>Surveillance Legislation (laws &amp; regulations)</b>						
Existence of National legislative support for surveillance and response to EVD	Laws related to EVD surveillance and response recalled across surveillance managers	Total number of existing laws	Percentage	100%	Key Informants (KI)	Percent aggregate across all surveillance units
	Surveillance units with a copy of the National Public Health Law (NPHL)	19 Surveillance Units	Percentage	80%	Paper and electronic documents	Percent aggregate across all surveillance units
<b>Surveillance strategy and coordination</b>						
Presence of plan of action (POA) for EVD Surveillance and Response	Surveillance units with a strategic plan of action for Ebola surveillance and response	19 Surveillance Units	Percentage	100%	Paper and electronic documents	Percent aggregate across all surveillance units through document review
Existence of documented roles and responsibilities for EVD surveillance and response at all levels of the surveillance system	Surveillance units with a copy of roles and responsibilities of stakeholders of the EVD	19 Surveillance Units	Percentage	80%	Paper and electronic documents	Percent aggregate across all surveillance units through document review

<b>System parameters</b>	<b>Indicator</b>	<b>Denominator/Total sample</b>	<b>Unit of measurement</b>	<b>Target</b>	<b>Data source</b>	<b>Measurement method(s)</b>
	surveillance and response system					
<b>Networking and partnership</b>						
Evidence of intersectoral collaboration, networking, and partnership	Intersectoral collaboration, networking, and partnership meetings held at the national level in the past one year	NA	Number	At least 1/quarter/year	Paper and electronic documents	Summary count of observations through document review
Cross-border collaborations	Cross-border collaboration activities implemented at the national level in the past one year	NA	Number	At least 1/quarter/year	Paper and electronic documents	Summary count of observations through document review
<b>Core functions</b>						
<b>National County and District levels</b>						
<b>Case detections</b>						
Mechanism for outbreak detection at managerial levels of the surveillance and response system	Surveillance units with standard case definitions for EVD on file	19 Surveillance Units	Percentage	100%	Paper and electronic documents	Percent aggregate across all surveillance units through document review



<b>System parameters</b>	<b>Indicator</b>	<b>Denominator/Total sample</b>	<b>Unit of measurement</b>	<b>Target</b>	<b>Data source</b>	<b>Measurement method(s)</b>
	Surveillance officers at county and district levels with knowledge on a standard case definition for a suspected case of EVD (6)	15 Surveillance Officers	Percentage	100%	KI	Percent aggregate across 3 levels
	Surveillance manager at national level with knowledge on standard case definition for a suspected case of EVD	7 Surveillance Officers	Percentage	100%	KI	Percent aggregate across surveillance at national level
	Surveillance officers at county and district levels using standard case definitions to validate suspected cases of EVD	15 Surveillance Officers	Percentage	100%	KI	Percent aggregate across 3 levels
<b>Case registration</b>						
Mechanisms to record suspected EVD cases at the managerial levels of the surveillance and response system	Surveillance units with line list/databases of suspected EVD cases	19 Surveillance Units	Percentage	100%	Paper and electronic databases	Percent aggregate across 3 levels through database review

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
<b>Case reporting</b>						
Case-based reporting of suspected EVD cases	Surveillance Officers reporting the use of case-based form to report suspected EVD cases	Total # of suspected case report observed during the recall period	Percentage	100%	Paper and electronic documents	Percent aggregate across 3 levels through document review
<b>Case Confirmation</b>						
Confirmation of epidemic prone disease, including EVD	Samples tested in the past 3 months with results available within 72 hours of reception	Total # of sample tested during the recall period	Percentage	80%	Paper and Electronic Laboratory database	Percent aggregate across 3 levels through database review

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
	EVD samples referred from county and district levels within 24 hours in the past 3 months	Total # of sample referred during the recall period	Percentage	100%	Specimen logbook	Percent aggregate across county and district levels through document review
Supplies for EVD specimen collection and transportation	Surveillance units reporting no stockout of supplies for EVD specimen collection in the past 3 months	15 Surveillance Units	Percentage	80%	Inventory logs	Percent aggregate across appropriate units through document review
<b>Data analysis and interpretation</b>						
EVD surveillance data analysis and interpretation	Surveillance units with evidence of descriptive (Person, place and time) analysis of EVD data	19 Surveillance Units	Percentage	80%	Bulletin boards, walls, electronic documents	Percent aggregate across 3 levels through document review
<b>Epidemic Preparedness, Response and Control</b>						
Epidemic preparedness plan for Ebola	Surveillance units with an epidemic preparedness plan for EVD	19 Surveillance Units	Percentage	100%	Paper and electronic documents	Percent aggregate across 3 levels through document review
Emergency funds	Surveillance units with existing and adequate	17 Surveillance Units	Percentage	80%	Paper and electronic documents	Percent aggregate across 3 levels

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
	funds for emergency response					through document review
<b>Feedback</b>						
Existence of regular feedback	Surveillance Officers who received lab results for suspected EVD samples	Total # of sample referred for confirmation during the recall period	Percentage	100%	Paper and Electronic Laboratory database	Total average percentage score
	Surveillance units reporting to have received feedback (bulletins/reports) received from the next higher level in the past 3 months	15 Surveillance Units	Percentage	100%	Paper and electronic documents	Percent aggregate across 3 levels through document review
<b>Health facility level</b>						
<b>Case detection</b>						
Mechanism for outbreak detection within health facilities	Health facilities with standard case definitions for Ebola	149 health facilities	Percentage	100%	Paper documents	Weighted percentage through direct observation
	Surveillance Focal Persons with correct knowledge on standard	149 Surveillance Focal Persons	Percentage	100%	Surveillance Focal Person	Weighted percentage through survey interviews

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
	case definitions to detect Ebola					
<b>Case reporting</b>						
Case-based reporting of suspected EVD cases	Health facilities with a case-based form for suspected EVD cases	149 health facilities	Percentage	100%	Paper documents	Weighted percentage through direct observation
<b>Case confirmation</b>						
Capacity for sample collection and referrals	Surveillance Focal Person with “correct” knowledge of sample collection and packaging	149 health facilities	Percentage	100%	Surveillance Focal Person	Weighted percentage through survey interviews
Supplies for Ebola specimen collection and transportation	Health facilities without stockout of laboratory supplies related to Ebola specimen collection in the past 3 months	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
<b>Data analysis and interpretation</b>						

<b>System parameters</b>	<b>Indicator</b>	<b>Denominator/Total sample</b>	<b>Unit of measurement</b>	<b>Target</b>	<b>Data source</b>	<b>Measurement method(s)</b>
EVD surveillance data analysis and interpretation	Health facilities with evidence of descriptive (Person, place, and time) analysis of EVD data	149 health facilities	Percentage	80%	Paper documents	Weighted percentage through direct observation
<b>Epidemic Preparedness and Control</b>						
Availability of IEC strategy for surveillance and response to Ebola	Health facilities reporting use of EVD data for community mobilization for Ebola surveillance and response	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
<b>Feedback</b>						
Existence of regular feedback	Health facilities with feedback during supervision	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
	Health facilities with monthly feedback from the next higher level	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
<b>Support functions</b>						
<b>National County &amp; District levels</b>						
<b>Standards and guidelines</b>						

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
Availability of surveillance guidelines	Surveillance units with a copy of technical guidelines (2016) for EVD	19 Surveillance Units	Percentage	80%	Paper and electronic documents	Percent aggregate across 3 levels through document review
Standard operating procedures for collection, packaging and transportation of Ebola specimen	Surveillance units with SOPs for EVD specimen collection, packaging and transport	19 Surveillance Units	Percentage	80%	Paper and electronic documents	Percent aggregate across 3 levels through document review
<b>Training</b>						
Staff trained on integrated disease surveillance and response	Surveillance managers at national level reporting training in IDSR	7 managers	Percentage	80%	KI	Percent aggregate across surveillance at national level
	Surveillance officers at county and district levels reporting training in IDSR	15 Surveillance officers	Percentage	80%	KI	Percent aggregate across 3 levels
Surveillance units with trained Field Epidemiologist	Surveillance managers at national level reporting training in Field Epidemiology	7 Officers/managers	Percentage	80%	KI	Percent aggregate across surveillance at national level
	Surveillance officers at county and district	15 Surveillance officers	Percentage	80%	KI	Percent aggregate across 3 levels

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
	levels reporting training in Field Epidemiology					
<b>Supervision</b>						
Conduct of Supervisions	Surveillance units that conducted supervision(s) to immediate lower level in the past 3 months	15 Surveillance Units	Percentage	80%	Paper and electronic documents	Percent aggregate across 3 levels through document review
Availability of budget for surveillance activities	Proportion of surveillance units with evidence of budget for surveillance activities	19 Surveillance Units	Percentage	80%	KI	Percent aggregate across 3 levels
<b>Health facility level</b>						
<b>Standards and guidelines</b>						
Technical Guidelines for Ebola Surveillance and Response	Health facilities with Technical Guidelines Ebola Surveillance and Response	149 health facilities	Percentage	80%	Paper documents	Weighted percentage through direct observation
Availability of case-based reporting forms at all levels of the surveillance system	Health facilities with no stock out of case-based	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews



System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
	reporting forms in the past 3 months					
<b>Training</b>						
Staff trained on surveillance	Health facilities with trained staff in surveillance competences	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
<b>Supervision &amp; Communication</b>						
Mechanism for Supervisions	Health facilities reporting supervision from the higher level in the past 3 months	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
	Health facilities reporting supervision to catchment communities in the past 1 month	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
Availability of communication at health facilities	Health facilities with functional phone for reporting of suspected EVD	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews and direct observation

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
<b>Surveillance system quality</b>						
<b>National County and District levels</b>						
Usefulness	Surveillance units that produced reports/bulletin for decision-making in the past 3 months	17 Surveillance Units	Percentage	100%	Paper and electronic documents	Percent aggregate across 3 levels
Simplicity	Case-based reporting forms required by the system for reporting suspected EVD	NA	Number	1	KI	Summary count of observations through KI interviews
	Existing reporting channels required for reporting suspected cases of EVD	NA	Number	1	KI	Summary count of observations through KI interviews
Flexibility	Sub-systems with which the EVD system is interoperable	Total # of existing sub-systems	Percentage	80%	KI	Total average percentage score
	Changes made to EVD case detection and reporting in the past 1 year	NA	Frequency	At least 1 per year	KI	Summary count of observations through KI interviews

<b>System parameters</b>	<b>Indicator</b>	<b>Denominator/Total sample</b>	<b>Unit of measurement</b>	<b>Target</b>	<b>Data source</b>	<b>Measurement method(s)</b>
Stability	Surveillance units reporting unscheduled electrical power outages that occurred in the past 3 months	17 Surveillance Units	Percentage	0	KI	Percent aggregate across 3 levels
	Surveillance units reporting EVD surveillance activities unhindered by lack of funds in the past 3 months	17 Surveillance Units	Percentage	100%	KI	Percent aggregate across 3 levels
Acceptability	Stakeholders actively participated in surveillance and response activities in the past 3 months	Total # of stakeholders required to participate in the system	Percentage	80%	KI	Percent aggregate across 3 levels
Representativeness	Reporting sites that sent weekly surveillance reports (including zero reports) of suspected EVD in the past 3 months	Total # of reporting sites observed during the recall period	Percentage	100%	Paper and electronic documents	Percent aggregate across 3 levels
<b>Health facility level</b>						

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
Usefulness	Health facilities with analysis outputs (table, graph, map, etc.) of EVD surveillance data reported	149 health facilities	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews
Simplicity	Case-based reporting forms required by the system for reporting a suspected EVD case	NA	Number	1	Surveillance Focal Person	Weighted percentage through survey interviews
	Existing reporting channels required for reporting suspected cases of EVD	NA	Number	1	Surveillance Focal Person	Weighted percentage through survey interviews
Stability	Health facilities with designated phone, access to a mobile cellular network, daily internet services, uninterrupted electricity during operational hours	149 health facilities	Percentage	85%	Surveillance Focal Person	Weighted percentage through survey interviews
Acceptability	Respondents that considers EVD surveillance and response activities as part of their routine work	149 Surveillance Focal Persons	Percentage	80%	Surveillance Focal Person	Weighted percentage through survey interviews

<b>System parameters</b>	<b>Indicator</b>	<b>Denominator/Total sample</b>	<b>Unit of measurement</b>	<b>Target</b>	<b>Data source</b>	<b>Measurement method(s)</b>
Representativeness	Health facilities that sent weekly surveillance reports (including zero reports) of suspected EVD in the past 3 months	149 health facilities	Percentage	100%	Paper documents	Percent aggregate based on survey interviews and document review
Completeness	Health facilities without “unknown” or “blanks” to required variables in EVD line list for the past 3 months	149 health facilities	Percentage	80%	Paper documents	Percent aggregate based on survey interviews and document review
Sensitivity	Suspected EVD cases detected by the surveillance system	Number of suspected EVD cases detected	Percentage	100%	Healthcare workers interview, IDSR register	Percent aggregate based on follow up interviews with healthcare workers and document review
Timeliness	Suspect EVD cases reported to the next higher level immediately/within 24 hours of detection	Number of suspected EVD cases reported	Percentage	100%	Healthcare workers interview, IDSR register at health facility and district levels	Percent aggregate based on follow up interviews with healthcare workers

System parameters	Indicator	Denominator/Total sample	Unit of measurement	Target	Data source	Measurement method(s)
	Suspected EVD cases investigated within 48 hours	Number of suspected EVD cases reported	Percentage	100%	Healthcare workers interview, IDSR register at health facility and district levels	Percent aggregate based on follow up interviews with healthcare workers

**Table 3: Description of Standardised Patients Scenarios, Liberia, 2020**

Case	Presentation	Preferred management
A 5-year old child accompanied by mother/caregiver	Visit the health facility and report a history of intermittent fever, unexplained crying, vomiting, and diarrhoea with blood over four days. Have self-medicated with anti-malaria and antibiotics but symptoms persist.	<p>Enhance Standard (IPC) precautions at all times.</p> <p>Align patient symptoms with standard case definitions for suspected EVD.</p> <p>Probe for risks factors like travel history, contact with someone with similar symptoms and wild/bush animal.</p> <p>Request and collect specimen to confirm EVD; and isolate patient.</p> <p>Report case information immediately (via phone or text) to the appropriate level.</p>
A female 18 years and older	Visit the health facility and report a history of loss of appetite, nausea, fever, joint pains, and lower abdominal pains. She also complains of seeing her menses (unexpectedly) for longer than usual. These symptoms have lasted for about a week. Have self-medicated with anti-malaria and pain tablets, but symptoms persist.	
A male 18 years and older	Visit the health facility and report weakness, headache, muscles, joint pains, vomiting, watery diarrhoea with blood, and with history of fever. These symptoms have lasted for up to 5 days. Have self-medicated with anti-malaria and antibiotics, but symptoms persist.	

## Reflexibility Statement

This study provides evidence for policy decision-making regarding Ebola Virus Disease (EVD) surveillance and response system strengthening, aligned with Liberia's Investment Plan for Building a Resilient Health System (2015 – 2021).

The local researcher played the leading role in the study design.

The funding supported field operations (e.g., data collection and daily substance allowance).

We acknowledged the data collectors for their contributions to the study in this manuscript. All members of the research partnership have unlimited access to the study data. With support from a Biostatistician (a team member), the local staff led the data analysis for the entire project. This engagement provided an opportunity to improve data analytic skills locally.

Through a concerted effort, every team member contributed to writing the original study report and this manuscript.

The (local) research partner was regularly mentored and supported in enhancing their writing skills with comments and discussions while developing the study protocols and report writing. A copy of the original report for this project has been shared with the Coordinator for Monitoring and Evaluation, Research and Health Statistics at the Ministry of Health, Liberia. We have developed a result dissemination plan to deliver at least an oral presentation to policymakers at the National Public Health Institute and the Ministry of Health in Liberia.

Undoubtedly, the LMIC researchers have played a leadership role, made immense contributions and are the sole owner of this work. The corresponding author is an LMIC researcher. As an early researcher, the Corresponding author was guided to gain practical experience in conducting a surveillance system evaluation, working in a multidisciplinary team, including a social scientist, biostatistician and infectious disease experts. This exposure provided an enhanced understanding of evaluation methodologies and valuable networking opportunities. The gender ratio was five males to one female. The gender disparity did not happen intentionally but instead was based on availability and interest from team members. The only female on the project played a pivotal role as the Biostatistician.

This manuscript was written from a PhD scholarship for an LMIC researcher.

The research findings clearly described Liberia's surveillance infrastructure and made recommendations suggesting improving the local infrastructure.

We acquired multiple authorisations for this study from the health system's national, county and district levels. The study protocol was reviewed by a local Institutional Review Board (IRB) to ensure protection for study participants.