Establishing a One Health Surveillance Platform for Electronic Integrated Disease Surveillance and Response (eIDSR) in Malawi: Lessons in Building a Resilient Digital Health System

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Abstract

Background: Facing the threats of emerging and re-emerging health issues requires the One Health surveillance systems to provide information for integral responses. The One Health approach emphasises inter-sectoral and multidisciplinary collaboration across human, animal, and environmental health and offers promising avenues for strengthening public health management and emergency preparedness. Digital solutions are critical components of One Health surveillance. However, evidence of successful implementation and experience in establishing a resilient digital One Health surveillance system are scarce.

Objective: This study aims to describe the establishment of the One Health Surveillance Platform (OHSP) in Malawi and assess its contribution to strengthening the resilience of the country's digital health surveillance system before and during the COVID-19 pandemic.

Methods: The establishment of Malawi's OHSP was based on the action design research (ADR) methodology. The core team synthesised an analytic tool to assess OHSP's establishment and resilience amidst the COVID-19 pandemic.

Results: The OHSP core team applied ADR methodology, leveraging lessons from previous electronic integrated diseases surveillance and response (eIDSR) pilots, and developed digital solutions in 2019, right before the COVID-19 pandemic. The initial establishment was to cover 48.3% of the country's health districts. Pivoting from the initial plan as the COVID-19 pandemic emerged, the core team swiftly adapted for OHSP to scale up nationwide and assisted the health system in resiliently responding to the pandemic.
Strong government leadership and coordinated implementation ensured financial and organisational sustainability, enabling rapid nationwide scale-up. The OHSP/DHIS2 products proved highly adaptable and robust for emergency response.
The resilience analysis indicated that OHSP enhanced Malawi's surveillance capabilities in the anticipation and preparation phases during the COVID-19 pandemic. The established One Health stakeholder ecosystem, awareness mechanisms, and adaptive resilience of the OHSP were critical success factors in attaining eIDSR goals. OHSP was proven to be resilient in

responding pandemic, but gaps remain in community-level surveillance and inadequate infrastructure to fully support the eIDSR functionality in the country.

Conclusions: The establishment of OHSP significantly bolstered the resilience of Malawi's health system and partially supported the eIDSR function. Government leadership and good coordination were keys to success. Continuous capacity building, adaptable technical infrastructure, and enhanced community-level surveillance are essential for long-term sustainability. Malawi's experience may apply to other countries with demonstrated value of resilient, government-led digital health interventions. Future efforts should focus on improving interoperability with other One Health domains and investing in infrastructure upgrades to prepare for future emergencies. Clinical Trial: Not applicable.

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Strong government leadership and coordinated implementation ensured financial and organisational sustainability, enabling rapid nationwide scale-up. The OHSP/DHIS2 products proved highly adaptable and robust for emergency response.

The resilience analysis indicated that OHSP enhanced Malawi's surveillance capabilities in the anticipation and preparation phases during the COVID-19 pandemic. The established One Health stakeholder ecosystem, awareness mechanisms, and adaptive resilience of the OHSP were critical success factors in attaining eIDSR goals. OHSP was proven to be resilient in responding pandemic, but gaps remain in community-level surveillance and inadequate infrastructure to fully support the eIDSR functionality in the country.

Conclusions: The establishment of OHSP significantly bolstered the resilience of Malawi's health system and partially supported the eIDSR function. Government leadership and good coordination were keys to success. Continuous capacity building, adaptable technical infrastructure, and enhanced community-level surveillance are essential for long-term sustainability. Malawi's experience may apply to other countries with demonstrated value of resilient, government-led digital health interventions. Future efforts should focus on improving interoperability with other One Health domains and investing in infrastructure upgrades to prepare for future emergencies.

Keywords

One Health, One Health surveillance, IDSR, eIDSR, DHIS2, resilient digital health system, pandemic preparedness

Introduction

Emerging and re-emerging health threats, coupled with the complexity of modern health systems, underscore the need for an integrated approach to health surveillance and response, known as the One Health (OH) approach [1-3]. Leveraging the OH approach, the One Health Surveillance (OHS) system emphasises inter-sectoral and multidisciplinary collaboration integrated surveillance of human, animal, and environmental health, which offers promising avenues for strengthening public health management and pandemic preparedness [2, 3]. The recent Coronavirus disease 2019 (COVID-19) pandemic highlights the critical need to adopt and realise OH approach-aided surveillance systems to foster the health system's resilience and reduce disease risks [1, 3]. However, by the nature of the broad spectrum of OH, a proper implementation model and monitoring and evaluation frameworks scrutinising OHS and resilient health systems are still yet to be fully developed [1, 4].

One Health Surveillance

In strengthening health system resilience, surveillance is essential for enhancing the health system's governance function during the shock onset, alert and impact management stage [5]. Considering the most recent health system resilience study, having effective information and communication systems empowered surveillance can aid the health authorities during the anticipation, preparation and response phases with awareness ability and monitoring tools [6]. Meanwhile, the 'One Health surveillance' is considered a collaborative surveillance system that provides systematic collection, validation, analysis, interpretation of data and dissemination of information collected on humans, animals and the environment to inform decisions for more effective, evidence-and system-based health interventions. [2, 7]. By linking surveillance data from different sectors, OHS can help address the full spectrum of disease or outbreak detection, emergency preparedness, response, management, and global health security and health system resilience [4].

However, there were documented challenges in realising and implementing OHS. Findings showed that the absence of a clear vision for the future of One Health is a barrier to interdisciplinary collaboration and that siloed approaches by different sectors restrict the ability of professionals to work collaboratively across disciplines [7, 8]. Also, political will and legal basis are essential for integrating surveillance systems [7, 8]. Establishing a formal governance body with representatives from each sector could assist in overcoming long-standing barriers of privacy and distrust, and these socio-political factors were considered as organisational attributes contributing to establishing a One Health surveillance system [2, 7-9]. The Johnson et al. study also indicated that the requirements for a successful One Health surveillance system should include understanding disease transmission and the importance of domain experts' knowledge [8].

Digital Health System Resilience for One Health Surveillance

Health system resilience is the ability of the system to prepare for and respond to sudden shocks and everyday challenges and its capacity to absorb deteriorations, adapt, and transform the health system to cope with them [5, 10]. Similar challenges were observed concerning building health surveillance system resilience. It requires strong leadership, political will, a collaborated and coordinated governance structure, and robust surveillance systems to detect shocks and their impact in a timely manner [5, 6]. Most of the literature focuses on concepts and principles of health system resilience, yet it is critical to understand how to realise them in the real world [10], especially in surveillance using OH approaches.

A sound design and functioning surveillance in a health system can contribute to the awareness function in an ideal resilience health system, and a powerful information system is necessary for an aware health system as a complex adaptive system [6]. Utilising digital health technologies shall have the ability to early detect, analyse and share information, including weak change signals from various internal and external parts of the health system, to form an aware health system as a complex adaptive system leading to sensemaking [4, 6]. A resilient digital health system can continue to provide essential health services, data management, and communication, even in disruptions or adverse conditions. Effective propagation of information plays a crucial role in ensuring emergency-management resilience; hence, the technological systems responsible for information management must be resilient to be relied upon during an emergency [11].

In response to the challenges posed by various health threats and the need for a comprehensive approach to public health, Malawi has recognised the importance of adopting a One Health approach and leveraging digital tools for surveillance and health emergency preparedness and response [12]. The Ministry of Health (MoH) was aware of the importance of establishing a fully integrated and functional surveillance system for One Health and the utilisation of electronic systems to strengthen the integrated disease surveillance and response (IDSR) system as a starting point for human health domain in Malawi [13, 14]. Hence, the MoH decided to establish a digital One Health Surveillance Platform (OHSP) instead of a single digital solution for One Health surveillance to accommodate the needs. Malawi was able to utilise the OHSP as one of the digital health innovations bounced forward resiliently during the recent COVID-19 pandemic [15]. This paper aims to describe the establishment of the OHSP in Malawi and assess its contribution to strengthening the resilience of the country's digital health surveillance system before and during the COVID-19 pandemic.

Methods

The establishment of Malawi's One Health Surveillance Platform (OHSP) was based on the action design research (ADR) methodology [16]. The ADR method has four stages: (1) Problem Formulation, (2) Building, Intervention, and Evaluation (BIE), (3). Reflection and Learning, and (4) Formalization of Learning [16]. We chose this method to ensure that practical insights and stakeholder feedback were continually incorporated into the platform's development. The first author, TSJW, led the action design of the OHSP as a technical advisor and participant observer. In this section, we provide information on the contextual background that necessitated the establishment of an OHSP in Malawi. We also detail the composition of the OHSP team, the material used for analysis, and the methods employed to assess the resilience of the OHSP.

Context of Establishing a One Health Surveillance Platform in Malawi

Malawi is responding to numerous health disasters continously, including floods, droughts, and disease outbreaks. The country adopted the integrated disease surveillance and response (IDSR) system as its national surveillance system for human health and recognised the need for improvements through advanced information technologies [13]. IDSR is a widely adopted surveillance system for human health across Africa. The latest technical guidelines highlight the importance of utilising electronic and digital tools to strengthen its function since paper-based tools often lead to delays[17]. Countries are urged to implement electronic tools to expedite data transmission and enable a swift response to public health threats. The critical workforce for IDSR includes staff across all health system levels, with the OH approach including all sectors, data management personnel, disease-specific program personnel, and decision-makers at the national

level. Based on the most updated IDSR technical guidelines, countries must aim for an interoperable approach to fortify electronic integrated disease surveillance and response (eIDSR) by creating systematic linkages and information-sharing platforms by formalising agreements between various health units [17].

In 2014, the Ministry of Health (MoH) sought to enhance the nation's health emergency preparedness plan and piloted an in-house developed eIDSR system for the first time [18]. After the World Bank-funded eIDSR pilot project, the Public Health Institute of Malawi (PHIM) of the MoH carried out another pilot by using a Short Message Service (SMS) technology, namely ARGUS, to aid periodic reporting requirement of the IDSR system [19]. However, these two pilots could not be sustained and scaled up. Nonetheless, they provided valuable lessons for the subsequent establishment of the OHSP.

After Cyclone Idai in 2019, the post-disaster needs assessment revealed the dire need for strengthening and sustaining epidemiological surveillance and emergency preparedness, including developing strategies to improve financing, accessibility, and adherence to health standards for overall health system resilience [20]. The idea of OHSP originated amidst the pilots of eIDSR and the post-disaster period, where the MoH chose the District Health Information System 2 (DHIS2) to be the main digital solution to the OHSP. Malawi has been using the DHIS2 for its health management information system with a successful nationwide scale-up [12, 21]; hence, the team was encouraged to utilise the same technology to build the solutions for eIDSR to strengthen IDSR functions in providing One Health surveillance functions and ultimately becoming a core digital solution of the OHSP to assist the MoH in achieving One Health surveillance goals.

Constitution of the OHSP team

The OHSP core team (N=12) comprises the two government officials responsible for the nation's IDSR system, three epidemiology unit and institution leaders at the PHIM, five digital health and information technology staff from the Digital Health Division (DHD) and Information Communication Technology Division of the MoH, a coordination officer and a technical advisor. TSJW, the first author and technical advisor who was involved in the previous eIDSR pilots, provides technical inputs and guidance on developing the OHSP. The extended OHSP team consists of government technical officers from different sectors, by their role as the International Health Regulation (IHR) focal person in the respective departments. The OHSP core team applied an inductive social networking approach to constitute the extended OHSP team and include all relevant stakeholders. The OHSP core team inherited technical officers supported by partners and sustained the institutional memories within the government from the previous eIDSR pilot projects by transcending them to the OHSP core team and started working on establishing the OHSP in 2019.

Research materials and analysis methods

Our analysis centred around various documents, including policies, meeting minutes, field notes, technical documentation, and digital health products used in establishing the OHSP. The primary investigator actively participated in the building of OHSP digital health products, leveraging ADR methodology and applying an inductive method. Since the OHSP is an ongoing development in the country being applied during the COVID-19 pandemic [15], we aim to summarise the findings from the current establishment to fill the existing knowledge gaps of the implementation process in developing a digitalised One Health surveillance platform.

We conducted the OHSP resilience analysis corresponding to the anticipation, preparedness, shock onset, and alert phases based on the resilience phases and stages of the shock cycle of the Foroughi et al. and Thomas et al. studies [5, 6]. The phases were explicitly chosen to assess the establishment of the OHSP before the COVID-19 pandemic.

Reflection and Learning Analytic Tool and Domains

In order to reflect on the OHSP establishment, an analytic tool against the resilience framework was synthesised from the available literature. The selection of literature covered the One Health surveillance systems establishment, attributes of engineering resilient information systems for emergency response, strengthening health systems resilience and known challenges of implementing DHIS2 [2, 5, 6, 8, 9, 11, 22]. Based on the synthesised findings, we first defined five analysis domains, namely (1) One health surveillance characteristics, (2) Addressing known DHIS2 challenges, (3) Health system resilience phases, (4) Health system resilience attributes, (5) Health system resilience tools [2, 5, 6, 22]. We then identified thematic areas [2, 5, 6, 11, 22] and their corresponding establishment level of a One Health surveillance system, namely policy, institutional and operational levels, based on the Bordier et al. study [2]. Key attributes and challenges were identified from the reviewed literature [1, 2, 5, 6, 8, 9, 11, 22-24]. We selected the relevant strategies and principles applied to the thematic areas and finally picked up attributes for our analysis. The high-level analytic tool is shown in Table 1, and indicators are detailed in Appendix 1.

Table 1. High level analytic tool for reflection and learning of the OHSP establishment

Domain	Thematic Area	Establishment Levels	Attributes/Challenges
One health surveillance characteristic	• Policy and governance • Sustainability • Data integration • Technical infrastructure	• Policy level • Institutional level • Operational level	• Policies, legal and operational framework • Funding and scalability • Data exchange across domains • Hardware, software and communication infrastructures
Addressing known dhis2 implementation challenges	• Political, cultural, social and structural infrastructure • Appropriate data • Workforce • Education and training	• Institutional level • Operational level	• Political challenges • Stability • Integrity of the health system/fragmentation • Structural infrastructure • Sufficient and qualified data • Data quality • Adequate technical support • Comprehensive training programs
Health system resilience phases	• Anticipation • Preparation	• Policy level • Institutional level • Operational level	• Early detection and risk analysis • Scenario planning • Resource mobilisation
Health system resilience attributes	• Stakeholder Ecosystem • Awareness • Adaptive resilience • Robustness	• Policy level • Institutional level • Operational level	• Stakeholder engagement • Sectoral interaction • Situation awareness • Operational environment • Adaptive structures • Interoperability • Coping strategies • Withstanding challenges • Capacity to handle increased demand • Mobilisation of essential resources
Health system resilience	• Institutionalisation	• Policy level • Institutional	• Capacity building • System and infrastructure enhancement

tools		level • Operational level	

In the One Heath Surveillance Characteristics domain, we focused on analysing the OHS-related policies, legal instruments, governance, and leadership in Malawi, reflecting on the known characteristics of setting up and sustaining an OHS [2, 8, 9]. We further analysed the stakeholders' engagement processes and strategy for data integration. After that, we analysed the technical infrastructure of OHSP to see if it fulfils the OHS need in this domain [2, 9].

The DHIS2 was chosen as the main digital solution for OHSP; hence, we applied the Addressing Known DHIS2 Implementation Challenges domain for analysis[22]. Among the 11 themes, we selected four relevant themes, focusing on analysing the infrastructure issues, data pipeline, and the workforce to provide technical support, as well as education and training to implement the OHSP/DHIS2, and synthesised the rest in other domains.

Concerning OHSP resilience, we identified three domains: Health System Resilience Phases, Health System Resilience Attributes and Health System Resilience Tools for analysis. In the HSRP, the focus was on the MoH's ability to anticipate and prepare by using the OHSP [5, 6]. In the Health System Resilience Attributes domain, we applied four themes with various functional attributes of a resilient digital health information system from engineering and health system perspectives for assessing the OHSP design and establishment, including:

- Stakeholder ecosystem: to analyse the stakeholder ecosystem, which refers to the coordination and collaboration network of individuals, groups, organisations, and institutions that have an interest or role in the OHS [5, 6, 11].
- Awareness: to assess OHSP's ability to continuously monitor, detect, and interpret changes in the health environment by recognising early warning signs, understanding ongoing health trends, and maintaining an informed perspective for decision-making and modification of the solutions to emerging needs [1, 5, 6, 11].
- Adaptive resilience: to assess the ability of the OHSP and core team to swiftly adjust to immediate challenges with flexibility while continuously evolving and improving based on past experiences and new information. Resilient digital health systems shall be designed to adapt and maintain functionality, as well as smooth recovery and reintegration to changing circumstances. They can adjust and reconfigure themselves, or swiftly by the technicians, to accommodate new requirements, emerging threats, or evolving user needs. The practice of adaptability includes integrating new business requirements and new technologies, scaling up or down as necessary, and supporting interoperability with other systems [1, 9, 23, 24].
- Robustness: to analyse the OHSP's design and establishment to ensure its stability, security, and reliability with redundancy for its operations so it can withstand technical glitches, hardware or software failures, and other challenges without significant interruptions in service delivery, including security measures [1, 5, 6, 11, 22].

Lastly, we analysed the institutionalisation of the OHSP, including the capacity-building plan and system and infrastructure enhancement, in order to cope with future crises [1, 5, 6].

Results

The OHSP establishment and implementation are reflected as follows.

Problem Formulation

The establishment of OHSP to support the eIDSR function was inspired by surveillance practices in the country and international recommendations. As stated in the introduction, the MoH aimed to enhance the nation's health emergency preparedness, which aligned with the 3rd edition of the IHR 2005 (IHR-2005) from the World Health Organization (WHO) [25]. Two eIDSR pilots were conducted from 2015 to 2018.

The first pilot was supported by the World Bank for the post-Ebola era *"in preparedness for emerging infectious diseases (EIDs) outbreak and strengthening Malawi's national disease surveillance system"* with the aim to utilise the WHO recommended strategy and customise with the local setting and developments to develop and implement an electronic Integrated Disease Surveillance and Response (eIDSR) system at all levels of the health system in 2015. Two arms of the eIDSR pilot, namely (1) Comprehensive eIDSR system architecture and system logical design and (2) eIDSR system deployment and field support. During the eIDSR pilot, we managed to develop the eIDSR architecture design, establish a border health fever screening system deployed to two main international airports, and develop the IDSR immediate notifiable disease reporting and syndromic reporting automated functions in the outpatient module of a partner-funded electronic medical record system (EMRS). The eIDSR architecture design used the organisation architecture level to guide respective information product developments and information flow; at the same time, the dashboard was designed to enable monitoring of the diseases and syndromic patterns of the outpatient visits together with a geographic information system and global health news RSS feeds function, as shown in Figure 1.

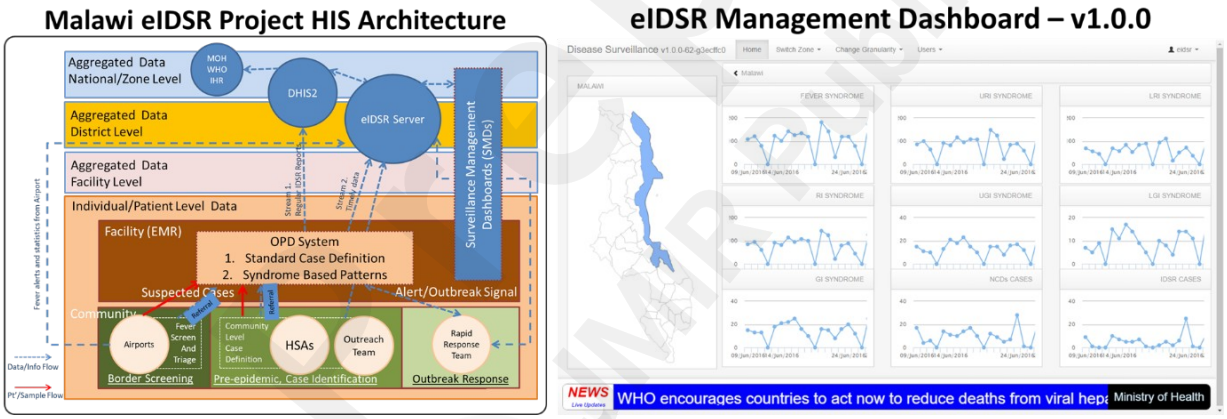

Figure 1. eIDSR Architecture and Dashboard Concept of the Pilot

Despite the substantial success of the eIDSR pilot [18], we still noticed two key problems:

1. Sustainability: Most of the project team members were dismissed after the project left minimum capacity within the MoH to maintain the developed systems. The management dashboard and eIDSR central database were designed in-house without the full transition of the source codes to the ministry, and the eIDSR functions in the EMRS were removed after the pilot due to a lack of funding for continuous support.
2. Technical infrastructure: The eIDSR pilot at the facility level was implemented in 59 health facilities with EMRS; however, it only covered only 3.2% (59/1849) of the total public health facilities in the country at that time. By the time the pilot ended, the eIDSR pilot also did not cover the whole country for the needed periodic IDSR reporting (weekly and monthly) and community-level case detection.

In order to continue the eIDSR enhancement, the MoH obtained support from UNICEF "*to pilot the WHO-Argus solution and facilitate system integration for the country*" in mid-2017. In January 2015, Malawi experienced one of the worst floods in its history caused by extreme weather [26]. By late 2015, Malawi had been experiencing outbreaks of cholera and its worst food insecurity in over a decade [27]. The support from UNICEF was to address the need for a timely weekly IDSR report using the technology. The solution was successfully built and deployed to 220 healthcare workers at the facility level for weekly IDSR reporting. However, we still faced sustainability and technical infrastructure challenges, no subsequent financial resources and inadequate coverage of the facilities. During the Argus pilot, additional need was identified to have interoperability between the WHO-Argus solution and the nation's health management information systems (HMIS)/DHIS2. Although these two pilots could not be sustained and scaled up, they provided valuable lessons for the subsequent establishment of the OHSP.

While the OHSP core team was searching for a resource to sustain and enhance the previous eIDSR pilots' accomplishments, Malawi successfully prevented a hippopotamus original anthrax outbreak from transmitting to the human population in late 2018 [28]. In early 2019, Malawi faced a significant anthrax outbreak primarily affecting wildlife in the Liwonde National Park, where at least 48 hippopotamuses died from the disease. This outbreak posed a severe risk of transmission to humans and domestic animals. The Malawi Government, through the MoH and PHIM, collaborated with various stakeholders to prevent human infection by using the One Health approach [28]. The success of preventing potential anthrax outbreak inspired the MoH to decide *"to build a suitable digital system to accommodate the OHS needs as a component of the eIDSR system".*

Building, Intervention and Evaluation (BIE) process of OHSP establishment

The OHSP establishment formally started in September 2019. Based on the pilot experience, the OHSP core team identified sustainability and technical infrastructure as the two key problems to be addressed in the coming OHSP, as summarised in Table 2. In addition, two of the OHSP core team members conducted a study to assess current implementation gaps for the IDSR system in the country. Key challenges in relation to technology for timely reporting, inadequate training and resource constraints were also taken into consideration when the team started the OHSP establishment [13]. Findings from adults' acute respiratory illness health-seeking behaviour also stimulated the team on the community-level surveillance needs [29].

Table 2. Problems with previous eIDSR pilots

Problems	Challenges encountered during eIDSR pilots
Sustainability	• Organisational sustainability: o Lack of coordination leading to duplication efforts o Lack of engagement from key personnel o Unavailability of Key MoH Staff o Coordination issues for systems deployment o Conflicting project schedules with some implementing partners • Human resource sustainability: o User non-compliance with systems usage o Technical staff were dismissed without a full transition o Inadequate technical personnel in MoH to continue the development and

	maintenance • Financial sustainability o Unforeseen communication expenses o Cash flow issues delaying hardware procurement o Lack of financial resources for scale-up and sustain
Technical Infrastructure	• Incomplete functionality for full IDSR system needs • Low coverage of the solution • Extended power outages affecting deployment • Connectivity issues affecting system functionality • Labor-intensive setup process for the terminal device (smartphone) • Congestion and delivery failures of SMS service

The OHSP core team initiated the BIE stage by addressing organisational sustainability issues, aiming to build a resilient digital system to accommodate OHS needs and enhance the eIDSR system. The appropriate legal instrument and governance framework are keys to ease collaboration across sectors [2]. Hence, the core team started reviewing the organisational structure across One Health domains, government documents (policy, strategic plan, technical guidelines, and tools in use) and literature to inform the design of the OHSP organisational architecture. Addressing the coordination and leadership issue was the first step. The core team conducted several technical meetings with the MoH leadership and learnt that during the anthrax response, a One Health task force was formed. The task force comprises cross-ministerial officials, implementing partners and development partners. Through these meetings, we affirmed the ownership and leadership of the OHSP, which is the PHIM at MoH, as the chair of the OH task force. PHIM's leadership led the core team to further engage with stakeholders to contribute to the architecture design of the OHSP. The stakeholders from the animal health domain were well consulted, while for the environmental domain, due to its vast fields, the core team decided to engage further and consult in the next phase of the OHSP implementation. After several technical meetings, focused group discussions, key informant interviews and literature review results, the core team developed a high-level business process architecture of the One Health Surveillance Platform (Figure 2) and the OHSP alignment with the eIDSR information flow in Malawi. The core team agreed to focus on establishing the main data repository to enable facility-level weekly, monthly, and quarterly IDSR reporting and be prepared to integrate the animal and environmental health surveillance data pipelines in the next phase. In order to secure human resources and financial sustainability, the core team developed a strategy to advocate and lobby future surveillance-related investment in the country, which shall anchor and align the OHS architecture and existing solutions. At the beginning of the OHSP establishment, UNICEF supported the initial OHSP development and committed to the initial implementation to cover 48.3% (14/29) of the country's health districts.

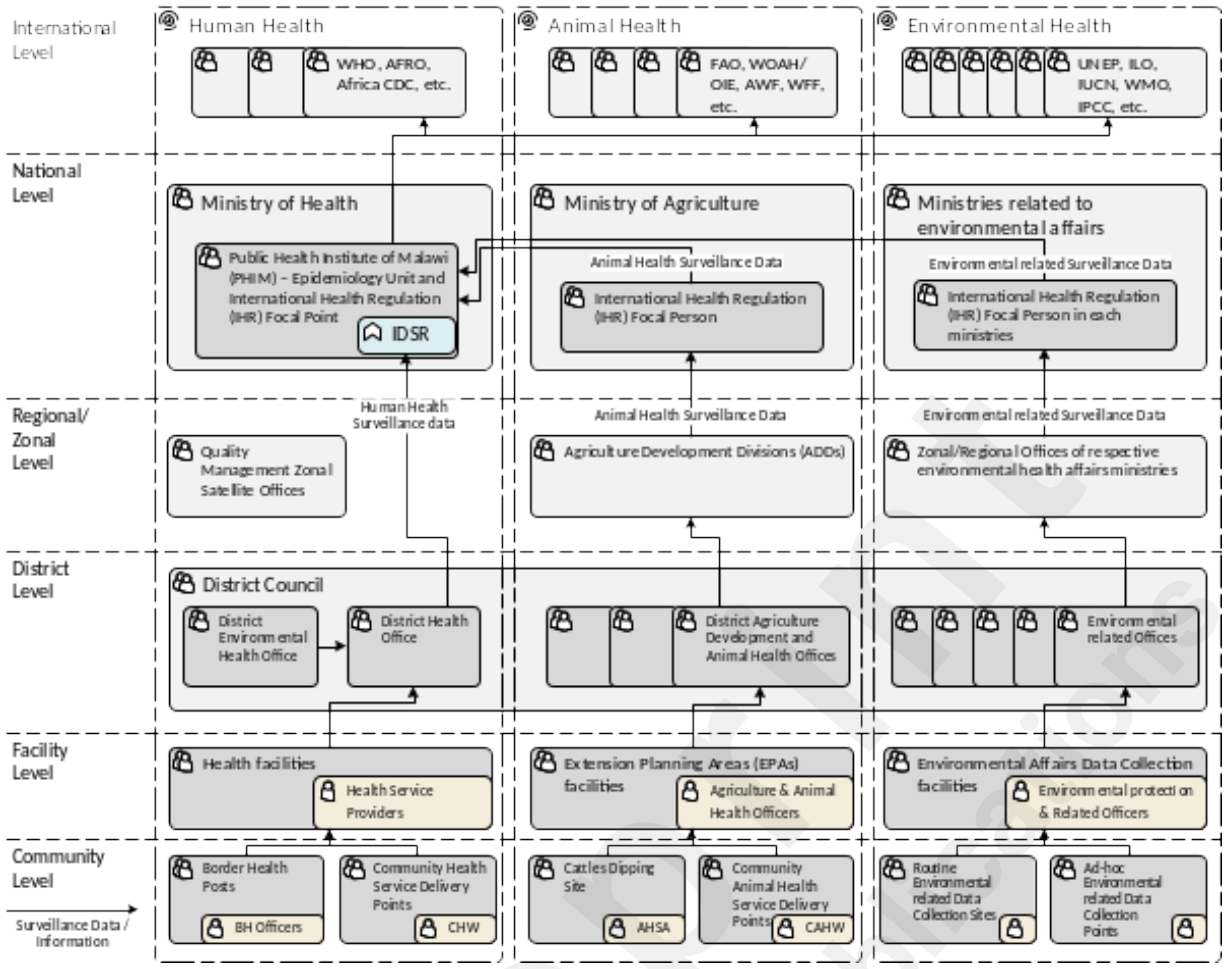

Figure 2. High-level Business Process Architecture of the One Health Surveillance Platform (OHSP) in Malawi, 2019

Once the relevant organisation and information architectures were designed, the core team started working on the technical infrastructure to support the establishment of OHSP. Technical factors are considered to favour collaboration and integration of data from different domains, and the most common one is the availability of a joint database or the ease of data exchange with compatible sectoral information systems [2]. DHIS2 was selected as the technological solution for the OHSP because it can address the different needs of HMIS and IDSR within the existing national DHIS2-enabled digital health infrastructure [13].

The core team started developing the OHSP/DHIS2 solutions in November 2019. The technical staff were responsible for software development, server and device configuration, and connectivity. The technical advisor worked as a mediator in fostering communication and discussion between different stakeholders, translating the requirements and limitations from different disciplines to the technical staff. He translated the business process flow, information flow, and available information tools into programmable technical requirements for the development team. After the technical execution, the core team designed the technical architecture for OHSP software developments, as shown in Figure 3.

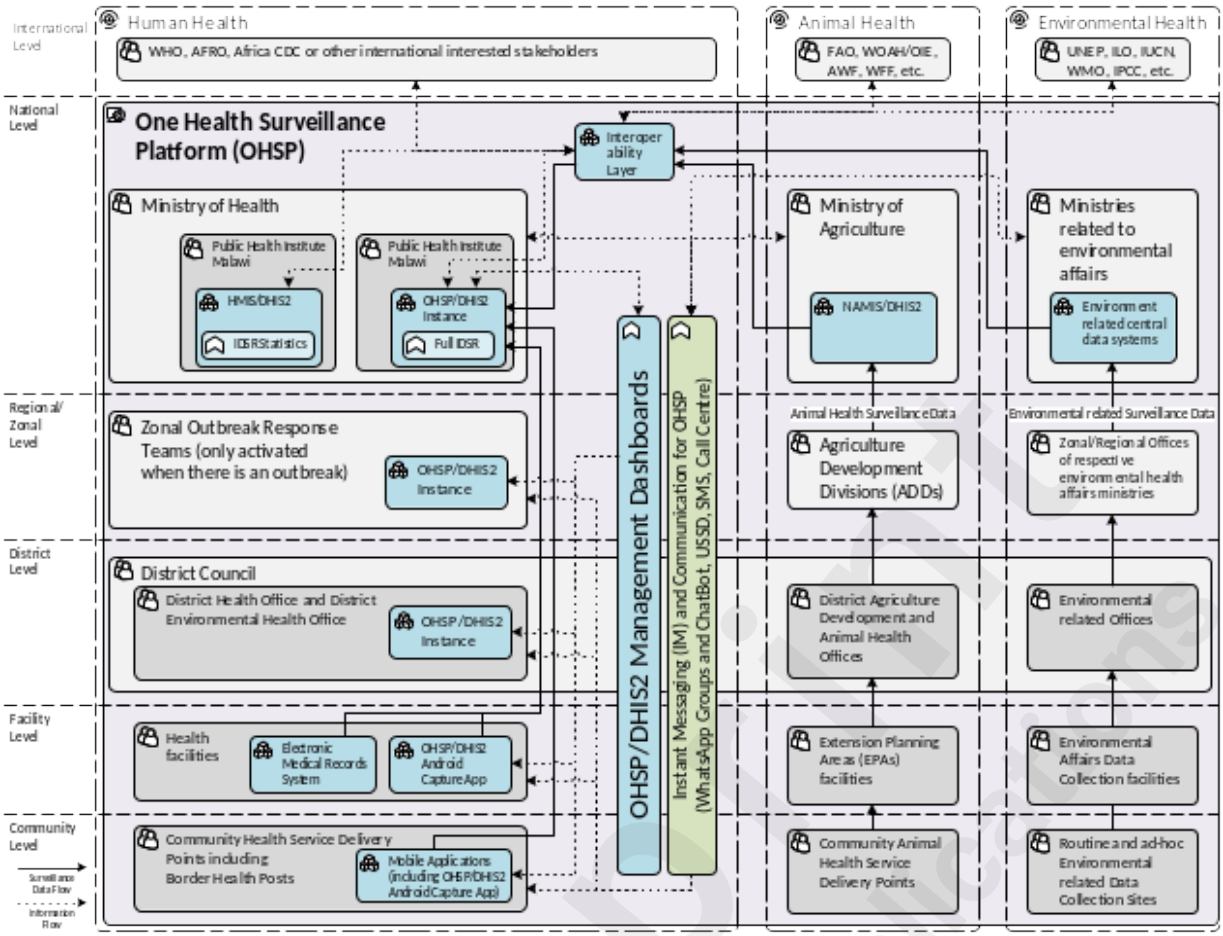

Figure 3. Technical Architecture of OHSP

Based on the architectural design, the core team technical staff applied the Agile method, executing Scrum sprints [30] to build the OHSP digital products, including (1) OHSP/DHIS2 instance, (2) OHSP/DHIS2 Android Capture App and (3) interoperability mediator between HMIS/DHIS2 and OHSP/DHIS2. The Instant Messaging and Communication for One Health Surveillance was already established during the 2018-2019 anthrax outbreak by using the WhatsApp One Health Forum chat group. Therefore, the team focused on leveraging available infrastructure resources from previous pilots to develop the three DHIS2-related digital products. The primary focus during January 2020 was setting up the main OHSP/DHIS2 instance, as well as the metadata design and implementation for weekly, monthly, and quarterly IDSR reporting requirements. In February, the team concentrated on ensuring HMIS-OHSP interoperability. The team cloned existing facility mappings and data element mapping identification from the existing HMIS/DHIS2 instance and registered OHSP as a client in the nation's Interoperability Layer (IL) so it can recognise OHSP/DHIS2 instance as a source. Simultaneously, The team worked on the integration and user interface design of the DHIS2 Android Capture App to interact with the OHSP/DHIS2 instance for data collection and reporting. The team also worked on obtaining additional public IP addresses with the government domain for OHSP to facilitate SSL acquisition. By March 2020, OHSP was tested by PHIM and fully ready for implementation to support Malawi's surveillance and response needs.

Right before the core team was ready to deploy the OHSP/DHIS2 products, new requests emerged as the country faced the impending threats from the COVID-19 pandemic. According to the original plan, the first release of the OHSP/DHIS2 products was to facilitate timely IDSR periodic aggregated data reports. However, with the emergency, the MoH and the national COVID-19 response team at the emergency operation centre raised various requests and digital health solutions needs, which

required additional functions, integration and interoperation between the OHSP/DHIS2 products. The core team swiftly responded to the requests and prioritised them according to the consensus and guidance from the COVID-19 emergency operation centre. The case-based surveillance form, capturing individual-level data, was quickly updated with COVID-19 conditions and added to the OHSP/DHIS2 products. The core team also applied the agreed strategy to advocate resources for the national scale-up of OHSP instead of only implementing it in 14 districts. Through the government leadership, multiple funders accepted the advocacy at the beginning of the COVID-19 epidemic, and the core team managed to deploy the OHSP/DHIS2 products countrywide, together with multiple implementing partners. After the deployment, the core team has constantly reflected on the needs and feedback from relevant stakeholders and maintained the key personnel within the MoH governance structure.

Reflections and learnings of OHSP establishment

Amidst the COVID-19 pandemic, the MoH evidently utilised the OHSP to mitigate the spread and impact of the pandemic [15]. The demonstrated resilience prompted us to reflect on the OHSP establishment experience with the synthesis analytic tool. The findings are detailed in respective domains and themes.

- **One health surveillance characteristics**
  - ***Policy and Governance***

The alignment of the national health policies and the establishment of a formal coordination body was essential for overcoming the One Health surveillance governance issue. On a global scale, the International Health Regulations (IHR) 2005 revision emphasises the need for a multidisciplinary and multisectoral approach to managing public health emergencies. While the IHR-2005 does not explicitly mention the One Health approach, its underlying principles align closely with this holistic perspective on managing public health emergencies, providing a framework for integrating One Health principles, which Malawi adopted. The IHR-2005 then was the main international legal instrument used to justify the OHS initiative in Malawi. Locally, the Public Health Act (1948) and the Control and Diseases of Animals Act (1967) provide legal frameworks for disease surveillance, reporting, and control in both human and animal health sectors in Malawi. These acts emphasise intersectoral collaboration and the prevention and control of zoonotic diseases. The Environment Management Act (2017) complements the OH approach by promoting environmental protection, monitoring, reporting, and public participation in decision-making processes. Malawi's health sector policies, such as the Health Sector Strategic Plan II (HSSP II), recognise the importance of a comprehensive and integrated approach to health. These plans emphasise using digital health solutions, data-driven decision-making, and multisectoral collaboration. The Joint External Evaluation (JEE) conducted in Malawi in 2019 highlighted the importance of operationalising and strengthening the One Health platform, improving surveillance systems, and enhancing data sharing. These policies and official plans provided the governance basis and an enabling environment for establishing the OHSP.

In regards to the coordination, the successful prevention of the Anthrax outbreak spreading to the human population using the OH approach in 2018-2019 was the direct trigger to affirm the leadership role of PHIM and solidify the commitment of the government to take the same OH approach for future health emergencies. Although the formal One Health technical working group was not established by then, a One Health forum WhatsApp group was created for all IHR focal persons from different ministries to collaborate on health emergency preparedness and responses

with the instant messaging (IM) technology for real-time communications. The Malawi government's commitment, supported by legal instruments and multisectoral collaborations, provides a solid foundation for developing the OHSP.

- ***Sustainability***

The affirmation of the One Health leadership and policy alignment secured the organisational sustainability of Malawi's OHS initiatives. To avoid district and facility healthcare workers conceiving the OHSP as an external system from MoH, the OHSP core team and MoH's implementing partners agreed to implement and deliver the OHSP digital products with the government officials at the forefront of leading the implementation.

Concerning financial sustainability, the strategy of advocating and lobbying future surveillance-related investment to anchor and align the OHS architecture proved to be a useful approach for the OHSP to scale up nationwide. The OHSP core team already has a preamble to lobby resources for scale-up, and the COVID-19 pandemic provided the MoH with an opportunity to align and direct investment to support it. The government-owned and government-led strategy was useful for communicating with all potential funders. In essence, funders could invest and align with the government's direction instead of funding another project initiated by a certain funder to be seen as "funding another donor's initiative". As a result, MoH drew the commitment and investment to scale up the OHSP implementation and needed infrastructure from UNICEF, CDC/PEPFAR, WHO, Gates Foundation, World Bank and Global Fund, covering the whole country. Government ownership and leadership avoid the potential interruption or hiccup of the funding availability. Because the OHSP is a government system, with or without extra financial support, all civil servants commit to making it work.

- ***Data Integration***

The developed holistic OHSP architecture guided the data and information integration between three OH domains. During the stakeholder consultation, the core team identified that the key issues for data integration are organisational units and the standardisation of the reporting tools.

Identifying the level of the organisational units is critical for defining the geographical location of the data collection, entry, analysis, and information usage. The hierarchy of the surveillance data org units is similar but still has differences at the sub-national level in three OH domains (Table 3). The mapping of the corresponding organisation units with the human health system hierarchy at each administrative level proved to be a complicated task. While the OHSP core team focused on the human health domain's eIDSR enhancement, the team considered this complexity to sensitise all stakeholders engaged in helping with the proper mapping of the units for future integration and development.

Table 3. Organisational units mapping between three One Health domains

Administrative Level	Human Health	Animal Health	Environmental Health
National level	Ministry of Health	Ministry of Agriculture	Ministries of Water and Sanitation, Natural Resources and Climate Change, Mining, Labour, Land
Sub-national level:	3 regions, 5 health	8 agricultural development	Different from each

Region/Zone/Division	zones	divisions (ADDs)	ministry
District level	29 health districts with district health offices (DHOs)	28 administrative districts with district agricultural development offices (DADOs)	28 administrative districts
Facility level	• Central hospitals • District hospitals • Rural and community hospitals • Health centres	Extension Planning Areas (EPAs) and Sections where Agriculture Extension Development Officers (AEDOs) work	Different from each ministry
Community level	• Health post • Village clinic • Outreach clinic • Village health committees - Operates by Community Health Workers (CHWs)	• Area Development Committees (ADCs) • Village Development Committees (VDCs) - Operates by Animal Health Surveillance Assistants (AHSAs)	Different from each ministry

Upon stakeholder engagement, we noticed that only the human health surveillance system had standardised reporting and data collection tools using IDSR technical guidelines. Animal health surveillance has a reporting structure, but the standardised reporting forms and tools have yet to be updated and made available. Environmental health surveillance encompasses an even larger degree of complexity, including at least climate change, weather forecasts, air and water quality monitoring, waste management, pollution incident surveillance, occupational hazard and risk surveillance. The OHSP core team applied the same approach to sensitise the stakeholders engaged to ensure the understanding of the importance of the data standards for future OHS data exchange and interoperability.

- ***Technical Infrastructure:***

The reuse of the eIDSR pilots' hardware and available digital solutions (WhatsApp group, IL, DHIS2, telecommunication networks) provided adequate hardware, software, and communication infrastructure for the initial establishment of the OHSP. Close collaboration and communication between the core team and stakeholders secured access to additional technical infrastructure resources, especially the server, terminal devices (tablets) and reverse billing approach connectivity. The global DHIS2 and OpenHIE community provide technical advancement and long-term software sustainability for the OHSP via core team members.

• Addressing known DHIS2 implementation challenges

- ***Political, cultural, social and structural infrastructure***

The legal instruments and the MoH's leadership addressed potential political-related challenges by ensuring continuity and clear policy direction. Since the importance of surveillance system integrity and interoperability was already noted during the eIDSR pilots, the core team paid attention to building the OHSP into an integrated and interoperable digital platform. The HMIS/DHIS2 already has the IDSR periodic report, though it faces some implementation challenges [16]. The weekly and monthly IDSR reporting forms were replicated on OHSP/DHIS2 to match the ones on HMIS/DHIS2

to maintain data integrity. The integration was done by first matching the data element IDs, including the category option combo IDs and the data set IDs. The organisation unit IDs were already mapped since the ones on the HMIS instance were imported into the OHSP, aligning with national standards. When building the interoperability, initially, a script was created to directly transfer the IDSR data from the HMIS/DHIS2 instance into the OHSP/DHIS2. However, when running the script, there was a time-out due to the huge payload that was being sent from HMIS/DHIS2 to OHSP/DHIS2, hence the need to use IL to utilise the chunking functionality. Also, the IDSR periodic reporting was not standardised: some facilities reported in HMIS while some reported in OHSP. Later, through the MoH leadership, all surveillance data were entered in OHSP/DHIS2, both the HMIS and OHSP were upgraded, and the payload was channelled through the interoperability layer to utilise the chunking of the payload when sending it from OHSP/DHIS2 to HMIS/DHIS2. The known infrastrcture challenge was then addressed by system integration and interoperation.

- ***The need for the existence of appropriate data***

The IDSR periodic report and case-based surveillance form were standardised for use, providing available data for surveillance. In response to the urgent COVID-19 surveillance needs, the MoH updated the IDSR reporting forms, including developing additional forms for border health declaration and contact tracing. The validation rules for mandatory data entry were programmed in the OHSP/DHIS2 instance and capture app. The completeness and timeliness of IDSR periodic reports' data quality indicators were defined. The data quality monitoring dashboards were configured for online use and included in the weekly epidemiological bulletin. The MoH provides appropriate feedback on data quality issues through the dashboards, bulletins, and WhatsApp groups to reporting facilities to ensure data supplies.

- ***Workforce***

Malawi has a relatively adequate workforce for OHSP development and implementation. The core team consisted of government officials and technical support officers from the partners who were capable of programming the DHIS2 solutions on their own. The DHD provided additional support for IL development. Surveillance personnel and IDSR focal persons were identified at each reporting site to use the OHSP/DHIS2 products. During the national rollout, all partners followed the MoH leadership in jointly providing training. Follow-up supervision, refresh training and a centralised digital health helpdesk at DHD were provided to support OHSP.

- ***Education and Training***

Considering education is one of the most challenging issues in the implementation of DHIS2 [22], the training program for OHSP/DHIS2 products was designed and implemented comprehensively with user manuals, standardised presentations, deployment checklist and detailed schedules to cover computer literacy from the beginner level. The core team members also received further education and training to strengthen their DHIS2-related capacity through online and in-person participation in DHIS2 academies [31].

• Health system resilience phases

• *Anticipation*

The functional WhatsApp One Health forum chat group served as one of the digital solutions in OHSP. The usage of IM technology provided the function of timely sharing of information, discussion, and communication on potential health risks like COVID-19. This digital tool provided the alertness ability to the group members. The experts in the group already anticipated the virus would become a great threat to the nation's public health in mid-January 2020. Hence, the health system was prepared. Similar groups exist to facilitate IDSR coordination and collaboration and provide the health system with better anticipation ability. The later developed OHSP/DHIS2 dashboards provided functionality to monitor the epidemiological patterns of notifiable diseases routinely, so the anticipation ability was further enhanced.

• *Preparation*

During the COVID-19 response preparation phase, similarly, the WhatsApp group supported the planning for the emergency response with the OH concept. After the OHSP/DHIS2 products were developed, they were included in the new national emergency preparedness and response plans to support the health system in preparations.

• Health system resilience attributes

• *Stakeholder Ecosystem*

The existence and adequacy of policies, regulations, and legal frameworks supported the establishment of the OHSP. The data sharing, privacy and confidentiality, interoperability, and coordinated implementation across different sectors were taken into consideration as evidently collaborated and coordinated by the PHIM during the COVID-19 pandemic. A resilient stakeholder ecosystem is in place for future OHS enhancement.

• *Awareness:*

The OHSP's One Health forum WhatsApp chat group evidently provided its function for early awareness of the COVID-19 pandemic. This digital tool facilitated timely communication and information-sharing among the IHR focal persons across government sectors and stakeholders and enabled the health system to stay informed about both domestic and international health situations.

• *Adaptive Resilience*

The DHIS2 was designed for high adaptability, allowing various applications and digital systems to interact seamlessly through available APIs, IL, technical documentation, and local developer support. The adaptability enables the OHSP/DHIS2 to be adjusted according to specific needs, ensuring flexibility and local control, as proved by the last-minute requests due to the COVID-19 pandemic response needs. The browser-based nature of DHIS2, compatible with major web browsers, enhances accessibility and cross-browser functionality.

In order to ensure graceful degradation and seamless reintegration, the OHSP/DHIS2 instance includes features of PostgreSQL performance tuning, which manages kernel-shared memory and connection limits, and read-only replicas of the master database to enhance query performance and scalability. The MoH-owned Proxmox cluster through multiple web servers improves system scalability and availability, allowing the system to tolerate server downtime without affecting user access. Load balancing via Nginx distributes load evenly across server instances and detects any unavailable instances, rerouting traffic as needed. The use of "sticky sessions" helps maintain user session continuity by routing requests from the same client to the same server, thus enhancing performance and reliability during disruptions.

- ***Robustness***

The infrastructure hosting the OHSP/DHIS2 products was designed for resilience against attacks and failures through local control and load shedding. Daily data backups ensure data restoration capabilities. The system operates continuously with minimal downtime, supported by fire and water safety controls and a continuous power backup supply at the national digital health server room. However, the current server room does not meet the Tier-1 data centre standard, and the backup server is constantly running out of space for storage. The core team and DHD provide proactive maintenance and updates to the OHSP/DHIS2, IL and other related digital solutions. The OHSP/DHIS2 solutions employ password protection and controlled access. The MoH manages the WhatsApp groups; however, risks remain for intentional information leakage by group members. The OHSP/DHIS2 includes some redundancy, such as cluster servers and backup systems. However, the current infrastructure lacks comprehensive redundancy, making it vulnerable to failures due to resource constraints.

- **Health system resilience tools**

  - ***Institutionalisation***

In order to institutionalise OHSP effectively, the plan is in place to establish a dedicated technical working group to facilitate One Health Surveillance and ensure regular updates through an OH bulletin. A comprehensive capacity-building plan and system infrastructure enhancement are in place to gradually integrate animal health and environmental health data pipelines. Initially, the focus is on climate change's impacts on environmental health and key animal health issues such as rabies, antimicrobial resistance, and anthrax.

Summary of Key Findings and Implications for Future Development

The One Health Surveillance Platform (OHSP) was successfully integrated into Malawi's health system governance structures. Global and national policies, especially the IHR-2005, are the legal instruments that solidify the government-led coordination mechanism. The successful One Health approach during the 2018-2019 anthrax outbreak reinforced the government's commitment to OHSP's development. Coordinated implementation with government leadership and maintained continuity and OHSP ownership, ensuring financial and organisational sustainability. The high-level

architecture of the One Health Surveillance Platform and its alignment with IDSR support the enhancement of the eIDSR. Reusing eIDSR pilots' hardware and collaborating with stakeholders secured adequate technical infrastructure for OHSP. The OHSP/DHIS2 products are highly adaptable and robust, and they have adequate technical support. However, infrastructure challenges persist. These findings highlight the importance of strong policy frameworks, government-led coordinated stakeholder engagement, and robust technical infrastructure, which are the critical success factors in establishing and sustaining a resilient One Health Surveillance Platform.

Discussion and Conclusion

Malawi successfully established a digital tools-aided One Health Surveillance Platform right before the COVID-19 Pandemic. The notion of OHSP in Malawi aimed to build a resilient surveillance system with the One Health approach, which is composed of actors, standards, processes, digital solutions and governance structure corresponding to the characteristics of OH surveillance systems [1, 2].

The result demonstrated that Malawi's OHSP is a resilient system that supports the surveillance goals during the COVID-19 pandemic [15]. As known challenges, strong policy frameworks and governance structures are essential for the success of an integrated One Health surveillance system [2, 7, 8]. The OHSP core team managed consistently to build effective governance with strong government leadership to provide clear policy directions, which are essential for building resilient health systems [1, 4]. The government's strong leadership in the establishment of the OHSP paved the way for OHSP digital health solutions to be developed with resilience and rapidly scaled nationwide, which echoed the conclusions for Africa's digital transformation [32]. The established OHSP addressed Malawi's JEE report by operationalising and strengthening the One Health platform [14]. The OHSP is now institutionalised in Malawi, as clearly stated in Malawi's Health Sector Strategic Plan III [33].

The HSSP III specifically highlights the adoption of the One Health approach, the integration of digital health systems, and the strengthening of data sharing and accessibility. It recognises the interconnectedness of human, animal, and environmental health, particularly in areas of AMR and climate change. As argued by Bordier et al., if data is collected and analysed by a single sector and does not support interventions to improve the health situation in another sector, this approach should not be considered as OH, as no added value emerges from inter-sectoral collaboration [2]. The established OHSP provides the opportunity for all sectors to report, analyse data and share information with others. The OHSP enhancements plan and HSSP III will guide the gradual integration of animal health and environmental health data pipelines, starting with climate change impacts and key animal health issues [33].

The OHSP/DHIS2 addressed some identified challenges to support the IDSR system [13]; however, the current functionality of the OHSP/DHIS2 has yet to address the community-level surveillance gaps fully [29]. Event-based surveillance (EBS) is one of the recommended surveillance methods to support community-level surveillance, as stated in the recent IDSR technical guidelines [17]. Other countries' EBS implementation experience and practice encountered some challenges, including the trade-off between sensitivity and specificity, low awareness of EBS and inadequate infrastructure [34, 35]. The role of middle-layer actors in participating in community-level surveillance, community engagement and additional digital solutions shall be taken into consideration as we enhance the OHSP to support the EBS in the country, not only human health but also one's health as

a whole [1, 29, 35]. The core team shall engage with stakeholders using existing coordination mechanisms and apply the participatory approach for future OHSP enhancement [36].

Most of the OH surveillance systems in action are focused on zoonotic diseases [37, 38]. The established OHSP can swiftly connect with animal health surveillance data. In fact, the recent development of the National Agriculture Management Information System (NAMIS) also uses the same DHIS2 technology to support the Ministry of Agriculture in improving livestock production, enhancing herd health, and addressing transboundary animal diseases [39]. The OHSP/DHIS2 provides its affordance to interoperate with NAMIS for surveillance needs. Environmental health, by the nature of its vast domain, has more work to do. The OHSP enhancement strategy focuses on climate change in alignment with HSSP III and can be supported by the same DHIS2 solutions [40]. However, as per our findings, the standardisation of organisation units to cover the needs of human, animal, and environmental surveillance systems will be one key issue that needs to be addressed. It will be useful to have a similar master health facility registry for animal and environmental surveillance sites.

The reuse of existing digital solutions and infrastructure, such as DHIS2 and WhatsApp groups, facilitated the rapid deployment of OHSP. Digital health tools have proven instrumental in improving resilience and maintaining essential health services during crises [15]. Government-owned and led digital health interventions offer an opportunity to strengthen health systems and attain health-related goals on the continent [32]. However, the challenges noted in the infrastructure, particularly the lack of comprehensive redundancy and the limitations of the server room, point to the need for continuous investment and upgrades. The engineering resilience literature also supports the importance of robust technical infrastructure to ensure system scalability and reliability [11].

Nevertheless, the OHSP establishment faced several challenges that were addressed through strategic planning and implementation. Political, cultural, social, and structural infrastructure issues were tackled, data quality and integration were improved, and workforce and training challenges were met. However, continuous capacity building, training, supervision and retaining skilled personnel are essential to maintaining and enhancing the system to be resilient, similar to the challenge that Tanznia encountered [41].

The characteristics and analysis methods of the resilience of health systems were developed [5, 6]. Similar frameworks and assessment tools are also available but limited to emergency management and healthcare systems, and none for the One Health surveillance system [11, 42, 43]. The synthesis tool we developed for the OHSP establishment analysis can be utilised in similar settings in the future. However, the tool is limited to analysing the One Health surveillance system establishment stage. Adaptability was evident in the rapid response to COVID-19, with adjustments made to the system based on emerging needs. This finding echoes the recent organisational resilience studies during COVID-19 about adaptation, innovation, capabilities and the use of new technology [44]. The Agile software development method, skilled and committed core team and affordable digital tools made the success possible.

Malawi's health emergency awareness ability was enhanced through real-time communication facilitated by digital tools, ensuring timely information sharing and decision-making, responding to the Riyadh Declaration and applying the One Health approach to get better preparedness and response to the future pandemic [45]. The experience from Malawi can provide practical guidance to other countries regarding their development toward integrating the One Health approach to strengthen their health system and improve disease surveillance and control.

The establishment of the OHSP in Malawi has significantly bolstered the resilience of the country's health system. The success of the system establishment highlights the importance of government leadership and coordination in ensuring financial and organisational sustainability, coinciding with the important attributes of organisational resilience during COVID-19 [44]. Key findings emphasise the need for continuous capacity building, adaptable technical infrastructure, and enhanced community-level surveillance in the long run. As global health systems continue to face emerging threats, Malawi's experience demonstrates that a well-integrated, government-led digital One Health Surveillance Platform can enhance resilience and preparedness. Future investments in interoperability, infrastructure, and community engagement will be essential for maximising the impact of OHSP and similar initiatives worldwide.

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Conflicts of Interest

The authors declare that they have no competing interests.

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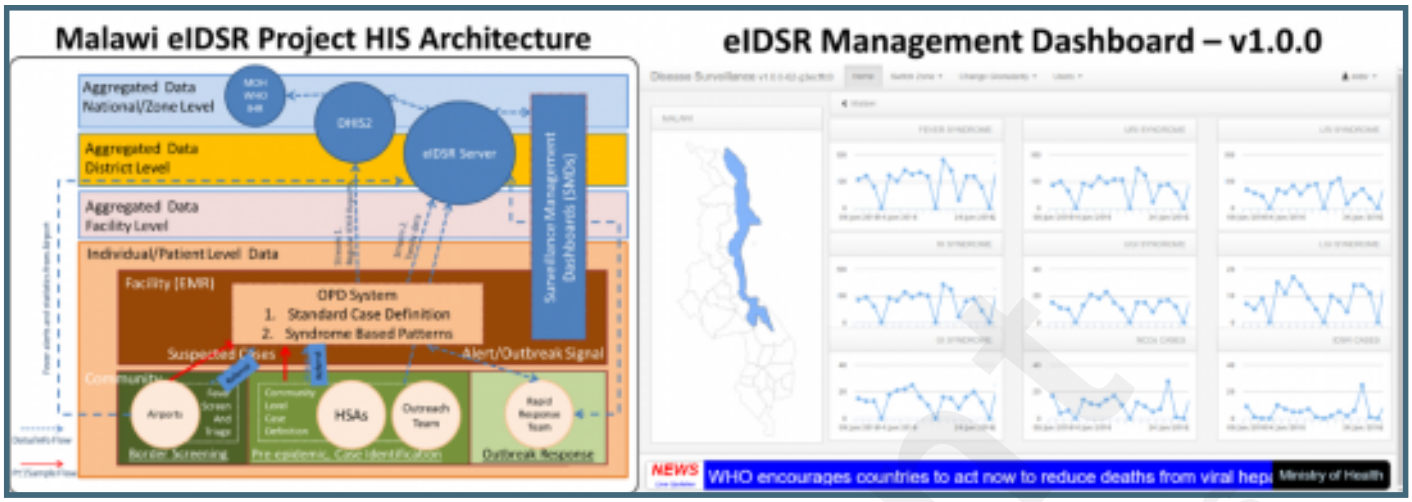
Abbreviations

ADR	Action design research
BIE	Building, Intervention, and Evaluation
COVID-19	Coronavirus disease 2019
DHIS2	District Health Information Software 2
eIDSR	electronic Integrated Diseases Surveillance and Response
EMRS	Electronic medical record system
HMIS	Health Management Information Systems
HSSP	Health Sector Strategic Plan
IDSR	Integrated disease surveillance and response
IHR	International Health Regulation
IL	Interoperability Layer
JEE	Joint External Evaluation
MoH	Ministry of Health
OH	One Health
OHS	One Health Surveillance
OHSP	One Health Surveillance Platform
PHIM	Public Health Institute of Malawi
RSS	Really Simple Syndication
UNICEF	United Nations International Children's Emergency Fund

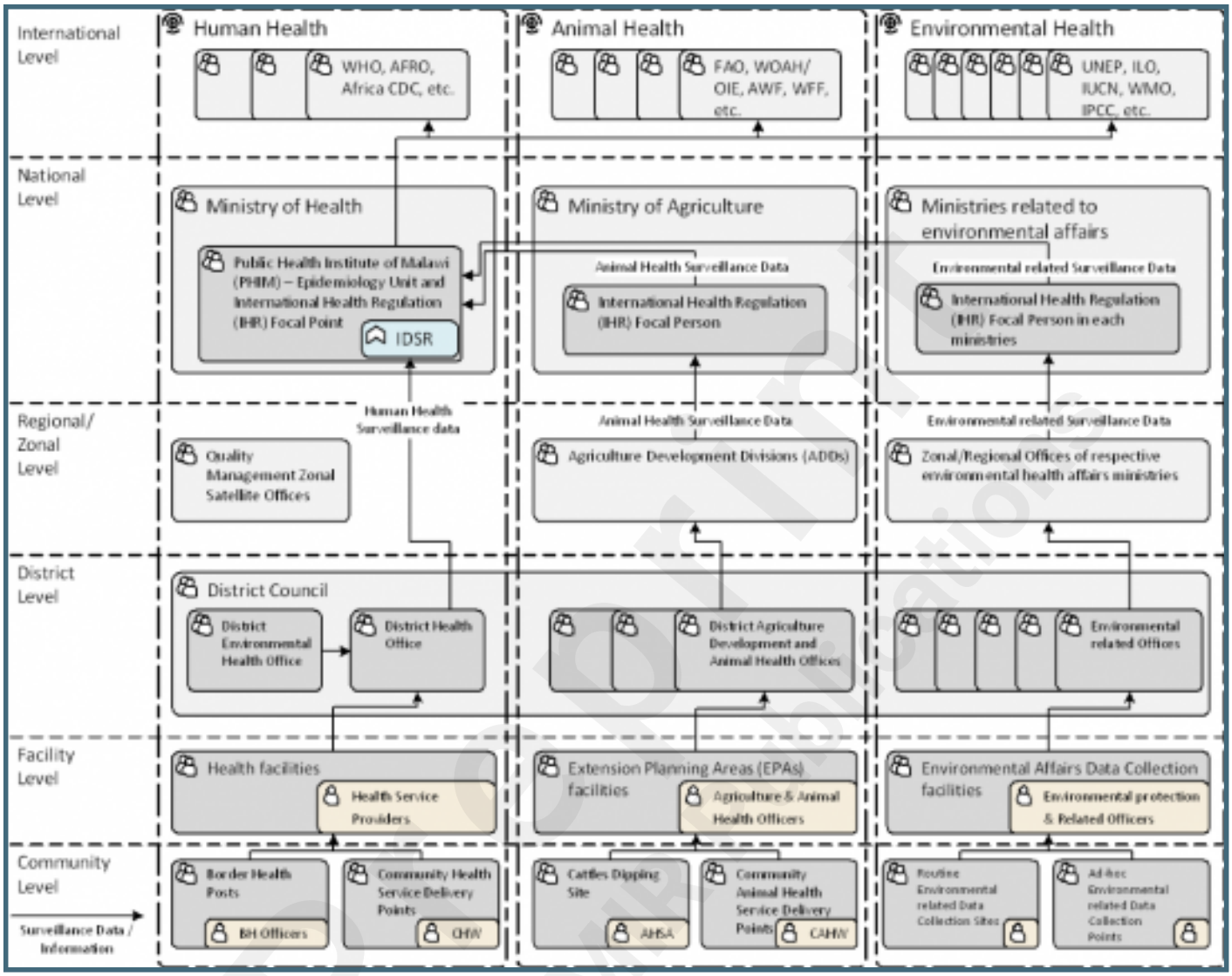
Supplementary Files

Figures

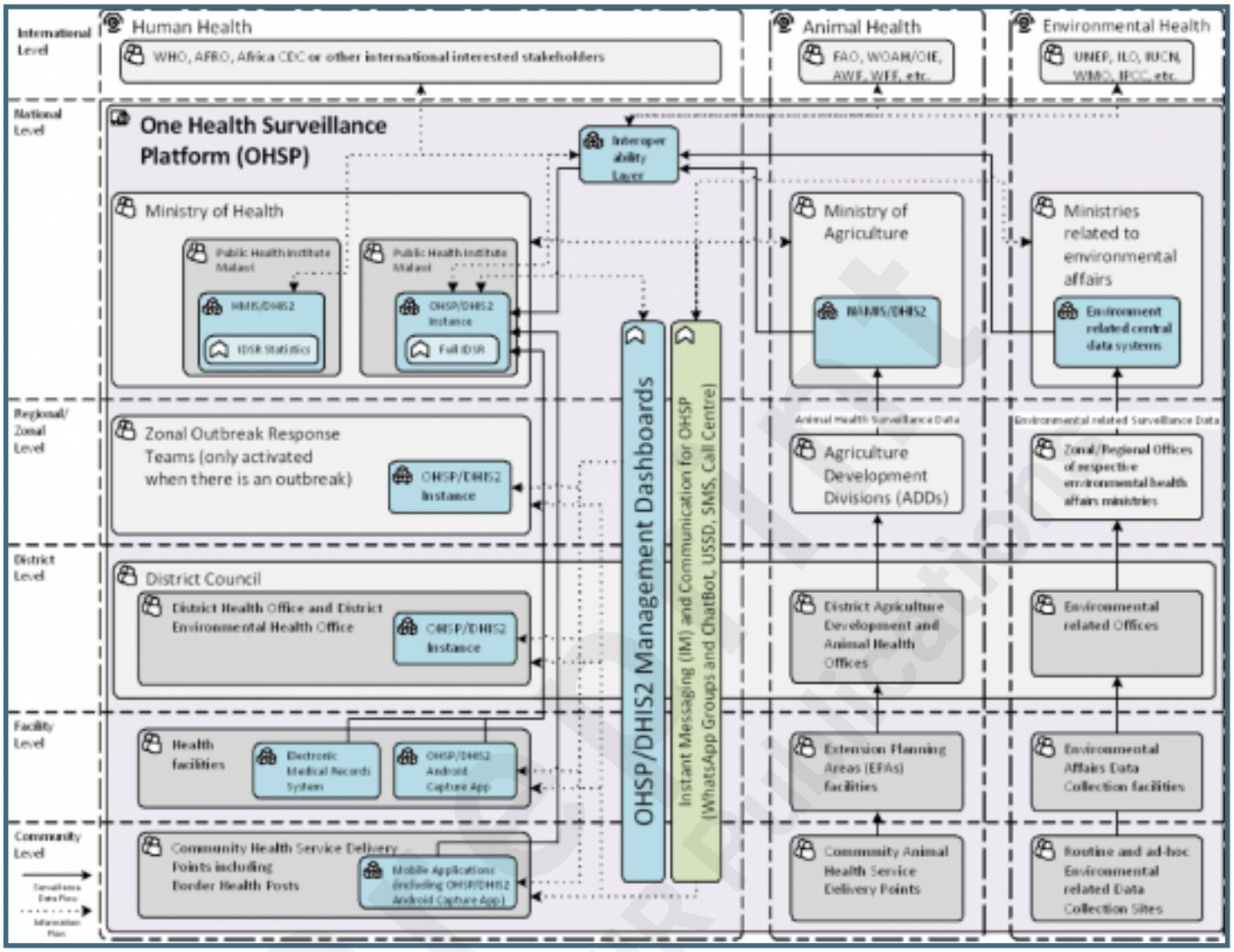
eIDSR Architecture and Dashboard Concept of the Pilot.



High-level Business Process Architecture of the One Health Surveillance Platform (OHSP) in Malawi, 2019.



Technical architecture of OHSP.



Multimedia Appendixes

Deatailed analytic tool for reflection and learning of the OHSP establishment.
URL: http://asset.jmir.pub/assets/d3a7e02a6dbbeb1fa209c41f6ba22d32.xlsx