Enhancing global health security in Thailand: Strengths and challenges of initiating a One Health approach to avian influenza surveillance

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ARTICLE INFO

Keywords:
One Health
Avian influenza
Zoonoses
Thailand
Surveillance
Global health security

ABSTRACT

Infectious disease surveillance systems support early warning, promote preparedness, and inform public health response. Pathogens that have human, animal, and environmental reservoirs should be monitored through systems that incorporate a One Health approach. In 2016, Thailand’s federal government piloted an avian influenza (AI) surveillance system that integrates stakeholders from human, animal, and environmental sectors, at the central level and in four provinces to monitor influenza A viruses within human, waterfowl, and poultry populations. This research aims to describe and evaluate Thailand’s piloted AI surveillance system to inform strategies for strengthening and building surveillance systems relevant to One Health. We assessed this surveillance system using the United States Centers for Disease Control and Prevention’s (U.S. CDC) “Guidelines for Evaluating Public Health Surveillance Systems” and added three novel metrics: transparency, interoperability, and security. In-depth key informant interviews were conducted with representatives among six Thai federal agencies and departments, the One Health coordinating unit, a corporate poultry producer, and the Thai Ministry of Public Health-U.S. CDC Collaborating Unit. Thailand’s AI surveillance system demonstrated strengths in acceptability, simplicity, representativeness, and flexibility, and exhibited challenges in data quality, stability, security, interoperability, and transparency. System efforts may be strengthened through increasing laboratory integration, improving pathogen detection capabilities, implementing interoperable systems, and incorporating sustainable capacity building mechanisms. This innovative piloted surveillance system provides a strategic framework that can be used to develop, integrate, and bolster One Health surveillance approaches to combat emerging global pathogen threats and enhance global health security.

1. Background

Infectious disease surveillance is a fundamental global health security tool that aids in the detection and containment of diseases locally, nationally, and globally. Robust surveillance systems support efforts to disrupt infectious disease transmission through early warning signals, disease control activities information, and contextual basis for contact tracing investigation [1,2]. Further, successful surveillance systems

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https://doi.org/10.1016/j.onehlt.2022.100397
Received 2 December 2021; Received in revised form 6 May 2022; Accepted 6 May 2022
Available online 11 May 2022
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benefit from strong collaborations between the laboratory and epidemiology sectors to ensure effective and rapid sample collection, pathogen identification, and the quantification of disease in a population [3–5]. Beyond the laboratory-epidemiology partnership, multidisciplinary disease surveillance systems are critical to address emerging infectious diseases, which threaten global health security [6].

Approximately 75% of emerging infectious diseases are zoonotic [7]; consequently, One Health approaches may be used to predict [8], detect [9], prevent [10], and control [11] zoonoses. However, many emerging infectious disease surveillance activities are fragmented into separate exposure routes (foodborne, respiratory, healthcare associated) or divided by pathogen (e.g., influenza, coronaviruses). Humans and animal disease surveillance systems are often separated, as well; human surveillance systems are dedicated to human disease detection, while animal disease surveillance systems focus on animal disease detection [12]. Alternatively, One Health infectious disease surveillance systems rely on human, animal, and environmental health organizations to form communication and information networks or tertiary systems that harmonize all One Health domains [13]. Surveillance systems may leverage independent components and resources; however, agencies could benefit through unification of data, reporting, and response efforts. For example, surveillance activities among livestock and wildlife serve as important sentinels for human disease and may be used to identify, monitor, and respond to early indicators of known and novel biologic threats [14,15]. Additionally, the emergence of zoonotic diseases, including influenza subtypes of pandemic potential [10], Ebola [7], Zika [16], and MERS [17,18] have heightened awareness for necessity and utility of One Health [19–21].

Governments and international health organizations [22] have started to adopt One Health surveillance approaches to tackle global health security threats and support pandemic preparedness efforts. Such systems vary in geographic location and size, pathogens of interest, stakeholder coordination, and One Health capabilities. Several public health entities have implemented and maintained multi-sectoral surveillance systems that integrate human and animal disease detection. Among them, summarized by Bordier et al. [13], northern Italy has initiated a One Health surveillance system for West Nile Virus [23], Mongolia for multiple zoonotic pathogens [24], and Taiwan for zoonotic influenza [25].

Other than Taiwan, few other governments have adopted influenza surveillance systems that monitor animal reservoirs side-by-side with human cases [26]. Surveillance systems that monitor influenza, a disease that experts have projected to be a leading zoonotic pathogen to cause future pandemics [27–29], should incorporate a One Health approach due to the pathogen’s capacity to infect many animal species, demonstrated spillover, and potential for significant morbidity and mortality [30]. Establishing a robust One Health surveillance system for influenza may be most critical in regions where human spillover has been documented, such as in Southeast Asia [28].

Thailand, a country which reported its first H5N1 avian influenza (AI) human infection in 2004 [31], has exhibited both substantial human [32] and economic losses in the form of trade and tourism due to avian influenza [33,34]. Although Thailand has not reported a human case since 2004, AI poses a constant threat [35,36]. Therefore, Thailand has recognized the necessity to establish a One Health surveillance system to monitor AI in wild birds and poultry and detect disease spillover into the human population [37]. In 2016, stakeholders piloted a surveillance approach to AI surveillance in four provinces, which integrates the animal, human, and environmental sectors among government agencies, academia, and the private sector. Thailand’s AI surveillance system has neither been studied nor evaluated comprehensively. This research aims to describe its structure, map the network of stakeholders involved, and illustrate the strengths and challenges of the system’s activities. Further, this study strives to inform recommendations for future surveillance systems in Thailand and elsewhere to detect and monitor other zoonotic and high consequence diseases to enhance global health security.

2. Methods

2.1. One Health surveillance stakeholder interviews

Thailand’s AI One Health surveillance structure and activities were investigated through semi-structured, in-depth key informant interviews with partners who have implemented, participated in, and supported AI surveillance efforts. Key informants were identified by a roundtable discussion with experts from Thailand’s Ministry of Public Health (MoPH) to ensure representation from all One Health and technical surveillance entities. The interviewees represented three divisions of the MoPH’s Department of Disease Control (DDC), the Public Health Laboratory (PHL) at the National Institute of Health (NIH), the National Institute of Animal Health (NIAH) Laboratory, the Department of Livestock Development (DLD), the Department of National Parks Wildlife and Plant Conservation (DNP), a collaborating private poultry corporation, and the MoPH-U.S. CDC Collaboration (TUC). Within the MoPH DDC, the Division of Epidemiology (DoE), the Office of International Cooperation (OIC), and the Coordinating Unit for One Health (CUOH) were interviewed. One leader involved with the surveillance system from each agency was interviewed.

The semi-structured interview format ensured consistent surveying while also maintaining flexibility to gather unanticipated information and allow for follow-up questions. An interview guide was developed to assess critical surveillance system components and to evaluate the flow of data, communication, and public health response. Key informant interviews were planned for 60–90 min and were held on audio/video web-based software. For consistency, the same interviewer introduced the goals of the project and led the interview; however, three researchers were involved in every call to help facilitate, add thoughts, and troubleshoot any technical difficulties. Every interview was recorded for data extraction purposes, and each participant was verbally consented beforehand. After interviews, the interviewer emailed participants follow-up questions if particular subjects necessitated further clarification or to close knowledge gaps. The study was determined to be exempt from human subjects research approval by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board (IRB#12894).

2.2. Surveillance system evaluation metrics

Semi-structured interview questions were developed to collect data on the strengths and challenges of Thailand’s piloted AI surveillance system using the United States Centers for Disease Control’s (U.S. CDC) updated “Guidelines for Evaluating Public Health Surveillance Systems” (henceforth, “U.S. CDC Evaluation Guidelines”) framework [38]. The U.S. CDC Evaluation Guidelines has been used and validated in studies to evaluate surveillance programs across the world, including Brazil [39], Ghana [40], Jordan [41], Yemen [42], and others [43]. The U.S. CDC Evaluation Guidelines considers nine metrics: i) simplicity, ii) flexibility, iii) data quality, iv) acceptability, v) sensitivity, vi) predictive value positivity, vii) representativeness, viii) timelines, and ix) stability. Three additional metrics developed by the authorship team and used to evaluate the surveillance system: x) transparency, xi) interoperability, and xii) security (Table 1). Surveillance systems evolve in parallel to public health threats and technologies, and these three new metrics facilitate assessing emerging surveillance system components that are critical to digital data collection, storage, and communication [44]. Taken together, these 12 metrics provided a basis from which to evaluate the strengths and challenges of the piloted AI surveillance system in Thailand.

Table 1: Surveillance System Evaluation Metrics

| Metric | Criteria |
|--------|----------|
| Simplicity | How easy is it to use? |
| Flexibility | How adaptable is the system to new situations? |
| Data Quality | How accurate is the data collected? |
| Acceptability | How acceptable is the system to users? |
| Sensitivity | How sensitive is the system to detect new threats? |
| Predictive Value Positivity | How likely is it that true positives are detected? |
| Representativeness | How representative is the surveillance system? |
| Timeliness | How quickly does the system provide information? |
| Stability | How consistent is the system over time? |
| Transparency | How transparent is the system’s data collection and analysis? |
| Interoperability | How well does the system integrate with other systems? |
| Security | How secure is the system against unauthorized access? |
Table 1 Surveillance system evaluation metrics and associated strengths and challenges of Thailand’s One Health Avian influenza surveillance system.

| Metric                        | Strengths                                                                 | Challenges                                                                 |
|-------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Simplicity                    | Intuitive structure of surveillance system and ease of operation          |                                                                           |
|                               | • Three government agencies (MoPH, DLD, and DNP) lead system with a coordinating unit (CU/OH) acting as a monitoring and engagement hub |                                                                           |
|                               | • Integration exists within data collection, emergency response, and training activities |                                                                           |
|                               | • Informal and formal mechanisms exist to share data (e.g. social media applications, phone calls, and official hardcopy reports) |                                                                           |
|                               | • One Health approach describes events in human and avian populations     |                                                                           |
|                               | • Active and passive system components aim to increase the representativeness of human populations (e.g. obtaining data from urban and rural areas; using both private and public hospitals in the sentinel network) |                                                                           |
|                               | • Adaptable case definitions that have been changed to increase sensitivity and adapt to local situations |                                                                           |
|                               | • Human resource surge capacity plans exist (and tested during COVID-19 pandemic) |                                                                           |
|                               | • Data can enter the surveillance system through multiple formal and informal sources: official report, phone call, mobile phone application reports, sentinel sources, and event-based triggers |                                                                           |
|                               | • Strong acceptability for a One Health approach at the central, national government level |                                                                           |
|                               | • District and Provincial-level governments have been willing to contribute and provide human resources |                                                                           |
|                               | • International organizations are willing to contribute funding and technical assistance such as the U.S. CDC, WHO, and FAO |                                                                           |
|                               | • Private poultry industry has been engaged                                |                                                                           |
|                               | • Paper records are digitized in formal spreadsheets                       |                                                                           |
|                               | • Multiple sources of data for informed situational awareness such as case reports, epidemiologic |                                                                           |
|                               | • Multiple formal and informal data sources for multiple species enter the system |                                                                           |
|                               | • Lacking an integrated, interoperable data system                         |                                                                           |
|                               | • Low level of integration of laboratories, non-human resources, and data  |                                                                           |
|                               | • Effort and time to manage and disseminate samples and data are high      |                                                                           |
|                               | • Environmental sampling of water sources and of high-risk transmission environments are currently not conducted |                                                                           |
|                               | • Swine species are not monitored or surveyed                              |                                                                           |
|                               | • Only public hospitals conduct sentinel surveillance                      |                                                                           |
|                               | • Human and animal laboratory networks encounter resource obstacles in surge situations (e.g. epidemics and pandemics) |                                                                           |
|                               | • Laboratory structure is currently vertically based upon pathogen type and species |                                                                           |
|                               | • Lack of political will at the local level in other provinces without pre-existing collaborations |                                                                           |
|                               | • Lacking integrated database(s) which hinders data sharing                |                                                                           |
|                               | • Data from mobile application not automatically                           |                                                                           |
|                               | • System designed to capture multiple case definitions                     |                                                                           |
|                               | • Systems aims to differentiate between seasonal, pandemic, and novel influenza viruses |                                                                           |
|                               | • Established timeliness targets:                                          |                                                                           |
|                               | o <24 h from abnormal event to sample collection                           |                                                                           |
|                               | o 6 h between sample collection and submission to regional laboratory      |                                                                           |
|                               | o <48 h from sample collection and regional laboratory result or referral to central laboratory |                                                                           |
|                               | o Post-laboratory result suspected avian influenza are reported within 24 h |                                                                           |
|                               | • Hospital human resources are supplemented by public health volunteers at the village/district levels |                                                                           |
|                               | • Situational Awareness Teams (SAT) comprised of multidisciplinary staff are able to deploy to high risk situations |                                                                           |
|                               | • Multiple IT technicians operate and repair the system                     |                                                                           |
|                               | • Potential expansion to other provinces                                    |                                                                           |
|                               | • Designated servers with access restrictions exist to store some surveillance data sources |                                                                           |
|                               | • Human resources are limited at the laboratory level                       |                                                                           |
|                               | • Sample cold chain not always reliable across surveillance network        |                                                                           |
|                               | • System lacking surge capacity, highlighted by the COVID-19 pandemic      |                                                                           |
|                               | • Relies on external funding cycles                                        |                                                                           |
|                               | • Paper data sources used for some system components                       |                                                                           |
|                               | • Hardcopy data can be easily compromised                                  |                                                                           |
|                               | • Electronic systems do not have multiple layers of security               |                                                                           |
|                               | • Surveillance data systems are not yet interoperable between species, geographic units, and pathogens |                                                                           |
|                               | • Multiple applications and programs exist both within agencies (from epidemiology to laboratory to administrative) and between agencies |                                                                           |
|                               | • No consistent formal communication technologies and pathways             |                                                                           |
|                               | • Most information dissemination is paper based                           |                                                                           |
|                               | • Existence of three surveillance-related pathways                          |                                                                           |

(continued on next page)
3. Results

3.1. Surveillance system stakeholder roles and network

Thailand has adopted a “trans-professional” approach through a partnership with governmental agencies, academic institutions, and the private sector. On the central government level, the surveillance system partnership is comprised of the MoPH (human focused), the DLD (livestock focused), the DNP (wildlife focused), and their respective laboratory entities (Fig. 2). Within NIH, PHL and the regional laboratory network analyze suspected AI samples collected from humans. The NIAH Laboratory analyzes suspected AI samples from animals including domestic and wild birds (livestock and wildlife sectors collaborate and use the same laboratory facilities). Multiple AI surveillance stakeholders work under the MoPH’s DDC, the central public health department responsible for infectious disease epidemiology, surveillance, and control, such as the DoE, OIC, and the CUOH. The DoE is responsible for surveillance and epidemiology, and the OIC tackles activities related to cross-border and internal surveillance. Thailand also founded the CUOH, located within the MoPH, which coordinates staff, research,

Table 1 (continued)

| Metric          | Strengths                                                                 | Challenges                                                                 |
|-----------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Transparency    | Extent to which information can be and is shared across member agencies   | • Data shared during bi/triannual stakeholder meetings                     |
|                 |                                                                           | • Data shared immediately between partners when high consequence influenza samples are identified |
|                 |                                                                           | • Public and private sector surveillance partnerships                      |
|                 |                                                                           | • Data is not consistently shared in real-time or on a scheduled basis apart from low frequency meetings |

Fig. 1. Map of Thailand’s avian and human influenza surveillance system laboratory network. Thailand’s avian influenza One Health surveillance system is located in Chiang Rai, Ubon Ratchathani, Nakthon Phanom, and Mukdahan provinces and represented by the blue color. The yellow color represents the national, species-focused surveillance system. Types of species sampled are denoted by the figure within each point. The central laboratories, which test either human and animal specimen are located in Bangkok, denoted by the purple point and the target-like symbol. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
conferences, training, and public health response across One Health-related government agencies. This coordinating-unit maintains an interagency communication channel and facilitates cross-governmental implementation of One Health activities. The TUC coordinates and supports AI surveillance efforts in border provinces. Unlike traditional surveillance systems, Thailand has integrated both academic and private institutions into its surveillance network. These non-governmental entities lead active and passive AI surveillance activities independently and have been engaged by the CUOH to initiate results-sharing and joint training with the One Health surveillance network (Fig. 2 illustrates a network diagram).

3.2. Mapping Thailand’s One Health Avian Influenza surveillance system and steps

In 2016, Thailand’s MoPH and DLD piloted a One Health AI surveillance system in four provinces: Chiang Rai, Ubon Ratchathani, Nakhon Phanom, and Mukdahan Province (Fig. 1). Provinces were selected based upon their poultry production density, live bird markets, migratory bird flyways, and local government acceptability of the One Health surveillance network. Interagency surveillance stakeholders aimed to integrate AI detection, coordination, and training activities using a One Health approach. Historically, influenza surveillance in humans and animals had been executed separately [45]. However, this One Health-based system aimed to facilitate communication, data collection and transfer, and response pathways by linking human, animal, and environmental health agencies at all levels: central, provincial, and district.

Thailand’s AI surveillance system structure can be further divided into five sequential components that monitor, analyze and respond to potential AI threats: 1) surveillance triggering events, 2) sample collection, 3) laboratory analysis, 4) data interpretation and sharing, and 5) communication and response activities (Fig. 2). Each component is a critical step for both surveillance and public health response activities, possessing active and passive components. Active AI surveillance includes the surveillance of poultry at live bird markets and poultry farms each month and the targeted surveillance of wild birds twice per year. Sample collection is performed by district and provincial level DLD staff, who collaborate and communicate regularly with the public health office of the human domain. Resources for active surveillance are also mobilized during suspected human and animal influenza cases. Passive AI surveillance is conducted through telephone alerts, in-person informants, and mobile phone applications that are used to document abnormal events in humans and birds. Three mobile phone applications (apps)—an academic-initiated FODD app [46], the CUOH’s app, and a DLD app developed for farmers—are publicly available to report potential influenza-related abnormal events. Abnormal event reports can be initiated by local community members and farmers or individuals operating in the formal surveillance structure such as One Health volunteers, veterinarians, and physicians.

A suspected AI case or abnormal event in humans or animals triggers a cascade of public health actions. First, sample collection is initiated and performed by the district or provincial office, which is dependent upon the species which triggered the event: the public health office for humans and the livestock office for animals. However, the lead entity coordinates with the non-triggered office to maintain open One Health

Fig. 2. Thailand’s avian influenza One Health surveillance system stakeholder network and surveillance system structure among governmental agencies, which represents Chiang Rai, Ubon Ratchathani, Nakhon Phanom, and Mukdahan provinces. Each stakeholder is denoted by blue or grey labeled cylinders connected by links that indicate information sharing across each of the five sequential surveillance components: triggering events, sample collection, laboratory analysis, data interpretation/sharing, and communication/response. Horizontal links between stakeholders represent One Health collaborations among different species sectors. Governmental entities may be present at several layers, which illustrates their broad role in the One Health Surveillance System. CDC, United States Centers for Disease Control and Prevention; DLD, Division of Livestock Development; DNP, Department of National Parks Wildlife and Plant Conservation; MoPH, Ministry of Public Health; NIH, National Institutes of Health; NIAH, National Institute of Animal Health; OHCU, One Health Coordinating Unit. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
communication channels. After collection, the sample is shipped to the regional laboratory network—a subset of laboratories forming a geographically dispersed network to reduce sample travel time and burden on the central laboratory—for RT-PCR confirmatory testing. Samples with either positive or inconclusive results are then shipped to the central laboratory for subsequent analyses.

The human and animal agencies cooperate closely during surveillance alerts to collect samples and ship specimen to the laboratory for further analysis. Although the regional laboratory networks and central laboratories are species-specific and do not share resources or communicate findings, once sample results are reported to the fifth and final level of the system, information is shared with the relevant central agency such as the DOE at the DDC or the Bureau of Disease Control and Veterinary Services at DLD. Then, the DOE and the DLD initiate One Health communication, response, and data sharing efforts.

### 3.3. Surveillance system strengths

Thailand’s AI One Health surveillance system was evaluated with the nine U.S. CDC’s Surveillance System Evaluation Guidelines parameters and three additional metrics which we developed to adapt with technological advances. Along with the definition of each metric, Table 1 details surveillance system strengths and challenges. Thailand’s One Health surveillance system strengths were its acceptability, simplicity, representativeness, and flexibility. An effective component of the AI surveillance system was its ability to assemble supporters from all governmental levels. For example, a cadre of village health volunteers (VHVs) support Thailand’s surveillance system on location. VHVs are comprised of a trusted, self-reliant community member network who monitor and report to their respective jurisdictions for signs of influenza-like illness (human and avian). Surveillance stakeholders span the local, district, provincial, regional, and national level, which demonstrates its acceptability. The acceptability metric applies beyond a system’s ability to mobilize individuals. Thailand’s AI surveillance system, initially developed and founded by the COOH, DLD, DNP, and MoPH, has been promoted throughout the Thai government. Thai stakeholder involvement has expanded beyond the public sector and into the private poultry sector. International organizations have also accepted Thailand’s surveillance system evidenced by WHO, FAO, and U.S. CDC, which have all provided technical assistance and funding to support Thailand’s efforts.

Beyond its widespread acceptance, Thailand’s AI surveillance system framework forms a pyramidal structure, which demonstrates the system’s simplicity. The base tier comprises local tracking of abnormal events and conduct sample collection, while information and data are sent to the regional laboratory network, central laboratory, and finally to the central disease control unit at its apex. When uncommon and highly consequential strains of influenza are identified, the central disease control unit communicates with the provincial and district levels to initiate response activities. Governmental agencies involved in the One Health surveillance system (i.e. MoPH, DLD, and DNP) collaborate with the Coordinating Unit for One Health (CUOH) to disseminate findings, once sample results are reported to the fifth and final level of the system. Information is then shared with the relevant central agency such as the DOE at the DDC or the Bureau of Disease Control and Veterinary Services at DLD. Then, the DOE and the DLD initiate One Health communication, response, and data sharing efforts.

### 3.4. Surveillance system challenges

The system exhibited challenges in data quality, interoperability, security, and transparency. Each level of the surveillance system has opportunities to more effectively transition from triggering event recognition to sample collection and finally results dissemination. Data quality and efficiency could be optimized at multiple levels of data collection, which is further complicated by multiple data collection systems three mobile apps, email, phone, and verbal warnings without direct data entry into a common database system. The data collected from these widespread reporting mechanisms requires manual entry via paper-based form and transferred to electronic spreadsheets, exposing the process to constraints on human resources, the potential for errors, and possible data quality problems. Viral isolate integrity was also difficult to maintain due to the many steps during collection practices, contamination, travel time from collection point to laboratories, and maintenance of cold chain.

Interoperability is a critical metric for a One Health surveillance system as human, animal, and environmental data must be integrated at a consistent level to inform and execute public health action. The measure of a surveillance system’s interoperability can be evaluated by multiple characteristics such as the interoperability of data from different sentinel hospitals collecting influenza data, stakeholders such as the government and private industry, and species such as humans and poultry. Thailand’s AI surveillance system faced data interoperability challenges at the local, provincial, and national levels. Technical capabilities to alleviate these challenges related to data interoperability between species have been difficult to build. AI has different human and zoonotic case definitions, investigation triggers, and laboratory protocols. Surveillance stakeholders also cited interoperability challenges related to communication and reporting channels connecting OH stakeholders, given that many informal and formal mechanisms exist and are not integrated. Interoperability challenges also arose with respect to suspected event reporting. For example, three different mobile apps are utilized to report abnormal events related to AI, and other One Health pathogens of interest, and currently these applications are unable to share data, integrated into the same data structure, or communicate with one another. A One Health challenge that emerged related to data quality and interoperability was its security. AI, like other zoonotic emerging infectious diseases, is of critical importance and it may be...
stigmatizing to report due to potential downstream control mechanisms such as flock culling and trade reporting. Transparency is a difficult metric to maintain in infectious disease surveillance. Data sharing channels for real-time situational awareness do not exist for immediate results sharing between One Health stakeholders. AI surveillance data is often shared at high-level stakeholder meetings dispersed across time. The stakeholder agencies, government, academic, and private, also maintain their own separate databases that are not synced or integrated to facilitate surveillance data transparency.

4. Discussion

Thailand has implemented a One Health surveillance system in four provinces to monitor AI in wild birds, poultry, and humans to strengthen country-wide and global health security. This system has engaged diverse surveillance partners from the Thai government to local villages, and the private poultry industry effectively. Public-private partnerships is again highlighted as an asset to this surveillance system, which has demonstrated success in other surveillance systems and disease control programs across the world [47–49]. The integrated approach of this AI surveillance system has initiated the removal of the metaphorical walls between different health sectors and the sharing of critical disease surveillance data. The mapping of the system and evaluation of the system’s metrics has allowed for the strategic identification of strengths and challenges to further improve the current and future integrated surveillance systems. We have identified that strengths of this piloted surveillance system are simplicity, flexibility, and acceptability. The system faces challenges related to transparency, interoperability, data quality, and security.

Thailand’s AI surveillance system evaluation results were synthesized into recommendations with five areas of focus and specific aims for system strengthening (Table 2). The focus areas include: 1) strengthening surveillance reporting and communication, 2) increasing laboratory integration between human and animal sectors, 3) improving pathogen detection capabilities and flexibility, 4) implementing interoperable systems, and 5) incorporating these recommendations through sustainable capacity building mechanisms.

Surveillance data, reports, and communications from the local levels, such as villages, districts, and provinces, should be integrated up to the national level to maintain surveillance situational awareness. This unification of data and information could be achieved through a common data management system with clear corresponding guidance and quality standards. Thailand’s One Health AI surveillance system could be further strengthened by increasing the integration between human and animal laboratory staff, resources, and spaces. Samples often travel long distances and human and animal health laboratories are distributed differently across the country. Laboratory collaboration or the repurposing of laboratories for integrated-animal, human, and environment pathogen monitoring, could assist in the strategic allocation of resources, decrease sample travel times, and bridge gaps between siloed staff. Another recommendation area focuses on strengthening pathogen detection capabilities, flexibility, and resilience. This surveillance system could benefit from integrating rapid and multiplexed pathogen detection technologies to improve timeliness and remain flexible to other pathogen threats apart from AI. Next-generation sequencing (NGS) platforms, especially field-able technologies, could also be used to detect influenza viruses and potentially novel viruses, in One Health surveillance sampling activities, especially in targeted hotspot locations such as live bird markets [50]. The system also currently focuses on domestic and wild avian species and humans, and it is recommended to expand influenza surveillance to swine [51,52] and potential environmental monitoring sources such as wastewater or water sources near high-risk human-animal interfaces [53]. Expanding the system will also require increased capacity and streamlined data flows. The implementation of an interoperable data system could address these needs while also improving data quality, timeliness, and transparency.

Electronic data integration and management would reduce the stress on workforces who hand enter and send data and would also reduce human errors. The system could also provide more real-time situational awareness to surveillance partners who would normally share data at designated meetings throughout the year. Lastly, to address challenges, grow the piloted system, and implement recommendations sustainable funding mechanisms, technology integration, and capacity building are needed. Workforce development and surveillance partnership

| Focus Area | Metrics | Recommendations |
|------------|---------|----------------|
| Integrate surveillance reporting and communication from the local (village, district, and province) to national levels | Acceptability Flexibility Interoperability Simplicity Transparency | • Adopt a unified One Health data management and surveillance system that integrates human, animal, and environmental health domains |
| Increase integration between human and animal laboratories | Acceptability Flexibility Interoperability Security Stability Simplicity Timeliness Transparency | • Integrate laboratory resources and stakeholders through a One Health approach to build collaborations; optimize laboratory space, protocols, and equipment |
| Strengthen pathogen detection capabilities, flexibility, and resilience | Data Quality Flexibility Sensitivity | • Build partnerships between animal, human, and environmental laboratories |
| Implement an interoperable data management system | Data Quality Flexibility Interoperability Sensitivity Timeliness Transparency | • Adopt a reliable, easily accessible data integration and management system to improve data repositories and interoperability of One Health surveillance data |
| Sustainability and capacity building | Interoperability Security Transparency | • Allow for system to be implemented in all related sectors, including government, private, intergovernmental, non-profit, and academic stakeholders |

Electronic data integration and management would reduce the stress on workforces who hand enter and send data and would also reduce human errors. The system could also provide more real-time situational awareness to surveillance partners who would normally share data at designated meetings throughout the year. Lastly, to address challenges, grow the piloted system, and implement recommendations sustainable funding mechanisms, technology integration, and capacity building are needed. Workforce development and surveillance partnership
engagement at all levels are critical surveillance strengthening elements. Thailand’s pilot One Health AI surveillance system innovatively integrates pathogen detection, public health, and multidisciplinary collaboration. The system can grow its impact on global health security by maintaining the system’s strengths and addressing challenges. The limitations of the study are rooted in stakeholder sample, metric tools, and potential responder biases. The key informants that participated in semi-structured interviews were only recruited from the central level. Local provincial and district levels were not included in this sample and consequently, the local surveillance officer perspective was not included in metrics and evaluations. Another limitation derived from the lack of quantitative data for availability for sensitivity and specificity estimates. The evaluations metrics analysis also did not calculate quantitative scores as these metrics were utilized as a data collection guide and tool to identify strengths and challenges. Potential biases may have also been introduced from responder bias during stakeholder interviews, however, surveillance system components, strengths, and challenges were evaluated from a diverse stakeholder group from all involved agencies.

5. Conclusions

Thailand has integrated a One Health approach to public health through the establishment of a coordinating unit, surveillance activities, integrated trainings, and research conferences. Thailand’s piloted AI surveillance system exhibits similarities to other One Health systems, such as it has focused on one priority pathogen, integrates human, livestock, and wildlife health agencies, and aims to increase degrees of collaboration across surveillance system components. However, Thailand has innovatively established a One Health specific government unit, the CUOH, within its central government structure, which is a characteristic not yet largely adopted globally. Already a global leader in its One Health advancements, Thailand’s AI surveillance system may benefit from improving several focus areas, including further local level engagement, increased laboratory integration between the human and animal facets, and higher degrees of system interoperability among species and departments. Transformatives technologies paired with capacity building activities can be integrated into Thailand’s existing strong One Health stakeholder network to improve data interoperability, pathogen detection potential, and downstream public health actions. This One Health approach should also be expanded to enhance surveillance of other critical zoonotic pathogens, especially those with pandemic potential to strengthen global health security, and may also serve as an example for other centralized surveillance systems. Overall, Thailand’s One Health AI surveillance system provides a strategic framework that can be used to develop, integrate, or bolster integrated surveillance systems—a necessary public health tool to combat global, zoonotic pathogen threats.

CRediT authorship contribution statement

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Declaration of Competing Interest

None.

Acknowledgements

We gratefully thank all of the stakeholder participants from Thailand’s AI One Health System who were willing to dedicate time to speak about their professions, their daily work, the surveillance system and challenges. We are very grateful for Johns Hopkins Alliance for a Healthier World for funding this work through their Health Equity Launchpad grant.

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