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The practice of event-based surveillance: concept and methods

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ABSTRACT

Event-based surveillance (EBS) is the organised approach to the detection and reporting of 'signals,' defined as information that may represent events of public health importance, often through channels outside of routine surveillance systems. Signals can be designed to detect patterns of disease, such as clusters of similar illness in a community, or clusters of disease or death in animals. Signals can also include single cases of suspected high-priority events such a patient with viral haemorrhagic fever. EBS can be a key component of an effective early warning system, which enables countries to be better prepared for endemic and pandemic illness outbreaks. EBS uses an all-hazards approach that includes the principles of One Health. This review covers the concept and process of EBS, different sources for EBS data, and methods to obtain information from these sources. This overview will aid countries in implementing this important form of surveillance.

Introduction

In a world that is increasingly vulnerable to high-impact, fast-spreading outbreaks, including severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), Ebola virus disease (EVD) and Coronavirus Disease 2019 (COVID-19), sensitive early warning systems that can rapidly detect potential public health threats before they become large and uncontainable are imperative. Countries with effective early warning and response capacity may be able to detect threats while they are still emerging, leading to prompt public health responses. This in turn can limit spread of disease and minimise human and economic loss.

Surveillance strategies can be broadly grouped into two broad categories or approaches: event-based surveillance (EBS) and indicator-based surveillance (IBS). Both strategies are fundamental to a comprehensive surveillance system and each has different goals with some overlaps. EBSs primary goal is the early detection of outbreaks or other public health threats. This goal is accomplished through an organised approach to the detection of signals that may represent events of public health importance. Signals are detected through the monitoring and reporting of primarily unstructured, ad hoc information from a wide variety of sources, including information that may not be primarily established for the purpose of surveillance. (WHO, 2017) IBS, in contrast, is a surveillance approach that routinely collects and analyzes data from well-defined sources, usually health care delivery facilities, using pre-defined case definitions. Because it is usually facility-based and occurs often only at a limited number of sentinel sites, IBS is generally more useful in defining transmission patterns, such as seasonality, risk groups, and disease burden. (Balajee et al., 2016). They overlap when, for example, alert thresholds are defined in IBS data – essentially defining a signal that represents the occurrence of an event such as the onset of an seasonal epidemic – or when EBS data are tracked over time to give an indication of background rates of small localised outbreaks. When a country uses IBS and EBS together, they can form a comprehensive surveillance strategy to monitor emerging and ongoing threats to public health.

In 2014, the World Health Organisation (WHO) published an interim document that detailed the concepts of EBS and IBS. (WHO, 2017) More recently, WHO published benchmarks to help Member States

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understand the steps they can take to reach capacity levels as defined in the International Health Regulations (IHR), including a functional EBS capacity. (WHO, 2019) Despite the crucial nature of EBS capacity for a country's preparedness and early warning system, and the availability of these guides, countries still struggle to sustainably and effectively implement EBS. (Fall et al., 2019) One of the reasons for sub-optimal implementation of EBS capacities may be a lack of understanding of the key principles of EBS and how to implement EBS at the country level. In this manuscript, we provide a practical primer for EBS that may result in improved practice of this important surveillance strategy.

Event-based surveillance: the concept

In the context of public health, an event is any occurrence that may represent a threat to public health that needs urgent attention, such as an emerging outbreak. An event can be thought of conceptually as 'something that happens' and requires an action in response. In the broader context, events could also include natural or man-made disasters, and reporting of these have been included in some EBS systems. Events of public health importance vary widely in scope and can include outbreaks of infectious disease, reappearance of diseases that have been eliminated from a community, outbreaks of human disease related to food contamination, chemical spills, radiation leaks, or outbreaks of disease in animals that threaten human health.

EBS is the process of monitoring and reporting of potential events from information sources not specifically designed for this purpose (i.e., surveillance). This process starts with the detection of *signals*, or observations that alert the public health community that an *event* may be occurring in a population. The source of signals can include a variety of information sources such as community informants, educational institutions, public and private hospitals, the animal health sector, news outlets, and social media. These signals are designed to indicate potential high-priority events of concern. Signals can be designed to detect patterns of disease, such as clusters of similar illness in a community, or clusters of disease or death in animals. Signals can also include single cases of a suspected high-priority events such as a child with acute flaccid paralysis or a patient with viral haemorrhagic fever in a country at risk for EVD.

One of the primary challenges to establishing and sustaining an EBS system is designing a system with an optimal balance of sensitivity and specificity, so as to not overload the surveillance infrastructure while maintaining the ability to detect high-threat events very early. Since not all signals represent true events, EBS can generate a lot of signal 'noise.' For example, in order to detect a single case of suspect cholera, a recent pilot EBS project used the signal definition of 'anyone who has three abundant liquid stools during the day'; this resulted in 1,500 signals in a single district in a year. Following subsequent verification and investigation, zero cases of cholera were found. Here, the signal was too broad, as it likely captured every single case of diarrhoea due to any pathogen occurring in a community. (Clara et al., 2020) More specific definitions of cholera signals have been used in other studies – examples include 'acute watery diarrhea with severe dehydration or death in any person 5 years of age or older'" –. (Clara et al., 2018) Achieving the right balance of sensitivity, specificity, utility, and practicality may require piloting and revision of signal definitions before they are finalised.

Because of the informal nature of signal sources, once detected, the process of triage and verification must be used to evaluate the likelihood that the signal truly represents an event. The process of triage involves the sorting of data and information to discard duplicates and to exclude disinformation, irrelevant information, and false information to identify real events. Once triaged, the verification step confirms the authenticity of the signal and stimulates the collection of additional information. Once the signal has been triaged and verified, it becomes an event (Figure 1). As much as feasible, EBS reporting should be integrated into existing disease reporting system, such as the Integrated Disease Surveillance and Response (IDSR) system in the WHO African Region, (WHO AFRO, 2010) for appropriate response and recording.

After verification, events need to be assessed to determine the level of risk to human health or other impacts, such as economic or food security. (WHO, 2012).Once a risk level is assigned, the appropriate level of investigation, response and control measures can be determined. This activity will depend in large part on several factors, including whether or not the event is resulting in severe cases or deaths, the size of the event, the point in the arc of the event when it is discovered, and whether or not the event is thought to represent a novel occurrence, such as disease caused by a new pathogen or incidence in a new geographical area or population. Use of decision trees can help public health units at the district or equivalent level to determine which events need urgent high-level response (e.g, events that suggest the presence of cholera or viral haemorrhagic disease) and those that can be investigated and handled at a lower level (e.g, a localised cluster of mild food-borne illness).

In the initial development of an EBS, countries should start with prioritisation of the list of events that will be detected through the EBS system. Prioritisation
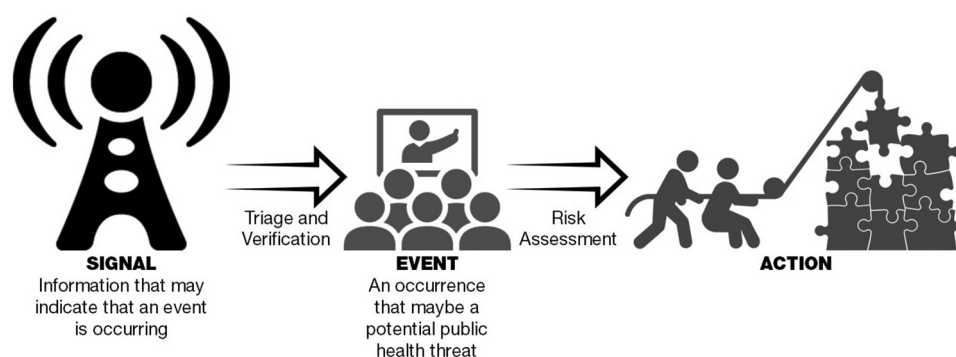
Figure 1. Illustration of the process of EBS. EBS starts with the detection of a signal. The signal has to be triaged and verified to be categorised as an event. An event requires an action; determining the specific type of action requires a risk assesment step.

of events of concern should be done in consultation with all the EBS stakeholders including those involved with wildlife, livestock and other domestic animals, agriculture, border/quarantine, and other relevant sectors in the government such as community health. It is helpful at this stage to establish a multi-sectoral technical working group of representatives from different sectors. Criteria for high-priority events include those that are likely to have high impact on the community, have the propensity to spread, represent diseases slated for eradication such as polio or measles, have a high risk of importation, and have the potential to affect large numbers of people. Another criterion to consider when designing an EBS system is whether or not early detection can help ameliorate the impact or facilitate containment and control. Additionally, early in the design of the EBS system a decision should be made whether or not to include non-infectious events such as food contamination or chemical spills into the environment. It is important to note that the process of selection of events and signals should be dynamic and readily amenable to additions or deletions as the need arises.

Source of signals and methods of event-based surveillance

Signals can come from multiple sources. Systematically identifying potential sources and the characteristics that set each apart is likely to be useful. The following section defines some of the common sources of EBS signals and how to implement EBS for each data source.

Signal source: community

Community-based surveillance (CBS) and EBS are often used interchangeably, but the two are not synonymous. According to a recent consensus publication by WHO, CBS is the 'systematic detection and reporting of events

of public health significance within a community by community members.' (Guerra et al., 2019) CBS can be a source of signals for EBS, but can also be used to routinely monitor health (acute flaccid paralysis) and non-health-related characteristics of a community such as births, deaths, prevalence of malnutrition, deaths, and rates of non-communicable disease as part of IBS. The importance of the CBS platform in EBS lies in its ability to detect events before they spread and are detected by health care providers, as it is more likely that members of the community will more quickly recognise the relatedness of affected individuals (clusters) than health care providers, particularly when multiple providers are present in the community and health care facilities are not readily accessible.

EBS at the community level can be conducted by community health workers (CHWs), community health volunteers (CHVs), or a local level public health office working through key informants in the community. The use of key informants as the primary source of signals in a community, rather than universal reporting by all members of the community, is a critical step to limiting signal noise while maintaining sensitivity. Key informants are community members who are connected to networks within their communities and can include traditional healers, village leaders, leaders of women's groups or agricultural unions, shop owners, educators, barbers, and religious leaders. In urban areas, it is important to more broadly define a 'community,' beyond just a geographic area and include key informants from high-risk communities such as sex workers, intravenous drug users, and ethnic or religious communities.

The primary advantage of key informants is that they can be targeted for training and provide a ready source of public health intelligence for CHWs. Even for these trained individuals, however, signals need to be simply worded without technical jargon, as informants

Table 1. Example list of signals for community, health facility, laboratory, animal health sector.

Signals for the Community
• Any child less than 15 years old: ○ with sudden weakness of limb(s)   ○ fever and skin rash   • A single case *severe enough to require admission to hospital or causing death* of any of the following: ○ 3 or more rice watery stools in 24 hours with dehydration (fatigue, thirst, or sunken eyes)   ○ A respiratory infection with fever in someone who has been travelling abroad in the last 14 days   ○ Illness that occurs after contact with sick or dead animals   ○ Illness with fever, watery diarrhoea, and unexplained bleeding (gums, skin, or eyes, stool or urine)   • Two or more hospitalised cases and/or death with similar type of symptoms occurring in the same community, school, workplace in the same 7-day period, especially: ○ with high fever, stiff neck   ○ with high fever, yellow eyes or skin   • Unexpected large numbers of: ○ Animal deaths (including both domestic animals and wildlife)   ○ Children absent from school due to the same illness in the same 7-day period   • Any event that poses a risk to public health, including natural disasters, or symptoms/diseases rarely seen in the community
Signals for Health Facilities
• Severe illness requiring hospital admission in health care workers after caring for patients with similar symptoms.   • Large, unexpected, sudden increases in admissions for any illness of the same type, including patients in intensive care units.   • Severe, unusual, unexplainable illness including failure to respond to standard treatment.   • All immediately notifiable diseases, especially those to be reported immediately and any event that poses a public health risk.
Signals for Laboratories
• Detection of a pathogen that has not been detected for a long time in that country or a new pathogen.   • Large/sudden unexpected increase in numbers of specimens with the same testing request, or positive for the same pathogen (including pathogens that are resistant to multiple antibiotics).   • Any pathogen on the immediately notifiable list.   • Unsubtypeable or new influenza strain from a patient with severe acute respiratory infection.
Signals for the Animal Health Sector
• Severe illness in veterinarian, wildlife staff, or community members after contact (culling, feeding, treating, vaccinating) a sick or dead animal.   • Large, unexpected, sudden increases in disease or death of animals.   • Sudden increase in abortions in animals.   • All immediately notifiable zoonoses.

typically do not have medical training (Table 1). CBS programmes need active, sustained engagement from the local public health unit responsible for CHWs to successfully maintain a network of key informants. Sustained involvement of key informants requires active engagement by the local public health unit responsible for CHWs; connections are further strengthened by regular feedback and engagement.

Signal source: health care facilities

Surveillance activities at health care facilities typically focus on specific disease(s) and take the form of routine, regular reporting of a specific list of notifiable diseases (via IBS). IBS may also include sentinel surveillance for

endemic diseases, such as influenza or dengue, and facilitates the understanding of the epidemiological characteristics of the disease and tracking trends over time. However, an additional type of *signal* using health facility data involves the definition of alert thresholds in these data, especially for common seasonal diseases. (WHO, 2014). When verified to meet specific predefined criteria, these signals can be used as alerts for events, such as the start of a season or an unusually severe disease season. (CDC, 2020). The detection and verification of these signals allows public health programs to alert health care providers of the need to monitor for these conditions in patients presenting for care and to initiate general public health control measures.

Individual cases of disease that are mandated for immediate reporting are also considered signals in an EBS system, particularly diseases that may signal a larger problem in the region that requires urgent response. These are typically diseases that may signal a larger problem in the region such as suspect EVD, cholera, MERS, or novel conditions. Defining signals for immediate reporting beyond a list of notifiable diseases, however, can improve the sensitivity of the early warning system. Examples of other signals include a sudden increase of hospital admissions of cases with similar signs and symptoms especially if the disease is not known or not in the list of notifiable diseases, a case with unusual presentation or clinical course, or a health care provider – or group of providers – who develop acute illness after caring for medical patients.

If facility-based EBS is to serve its respective purpose in an early warning system, every health facility in both public and private sectors should participate. For implementation of EBS in health care facilities, each facility should consider nominating a focal point in the facility to receive signal reports from the health care workers in that facility. Once a list of signals is defined for health facilities, all health care workers should be routinely sensitised to look for and immediately report anything unusual to their focal points using the available list of signals (Table). Every facility surveillance focal point in turn should participate in EBS training to support health care workers. Focal points are responsible for immediate reporting of signals to public health authorities through predefined reporting mechanisms.

Signal source: laboratories

Signals from laboratories include detection of pathogens that are immediately notifiable, such as the detection of Ebola virus from a clinical sample. Another example of a signal from a laboratory might be detection of an

unusual pattern, such as a laboratorian recognising a sudden increase in pathogen detection in a given time period; detection of a rare pathogen from body fluid (e. g. fungi from sterile body fluids); detection of multi-drug resistant pathogens; clusters of specific organisms; and unexpected increases in detections of organisms from unusual places. All laboratories, including public and private sector laboratories, should be engaged as part of the surveillance reporting network and communicate notifiable diseases and other signals to their public health authorities (Table 1).

Signal source: animal health sector

Many countries have animal health surveillance and response systems, inclusive of national reference laboratories as well as national and international reporting and notification requirements, that exist in parallel to the human health systems. (World Organisation for Animal Health [OIE], 2019). These parallel systems may also have a CBS component that collects information from the community through routine veterinary services or community animal health workers (CAHWs) and is informed by farmers, livestock and poultry producers, veterinary clinics, and wildlife and national park service staff, among others. (Community-Based Animal Health Workers [CAHWs], 2019, MEASURE, 2019, Bugeza et al., 2017) For the implementation of EBS, countries should design a list of signals for recognising shared health threats like zoonotic diseases and diseases passed between animals and humans – for reporting and cross-notification (Table 1). Once the list of signals is developed, both CAHWs and CHWs from the local to the

national level should be trained to cross notify signals between his/her respective animal health and human health counterparts (Figure 2). Additionally, there should be coordination mechanisms (FAO, OIE & WHO, 2019) in place at the national level and if resources allow at the sub-national level for immediate notification of these shared health events by both sectors. Such mechanisms should also support the deployment of joint responses.

Connections should be established between human and animal health actors at each administrative level within the country and across the different sources of signals in the EBS system. An example of this cross-sector collaborative, or coordinated, surveillance and reporting could be that a CHW is the first one in her community to be aware of a die-off in a backyard poultry flock, or an exposure to a rabid dog; the CHW should be trained to notify their animal health counterpart, and vice versa. Any diseases or patterns of illness in animals that might represent a threat to human health, especially zoonotic diseases, should be notified as events to public health authorities. Additional examples of animal health-related signals that should be reported to human health EBS counterparts include: unusually high rates of abortions in goats, the sudden death or appearance of haemorrhagic signs in domestic and wild hoof stock, and sudden die-offs in migratory bird flocks.

Signal source: media monitoring

Monitoring of information in the online environment has become an important source of public health intelligence. Media monitoring in the context
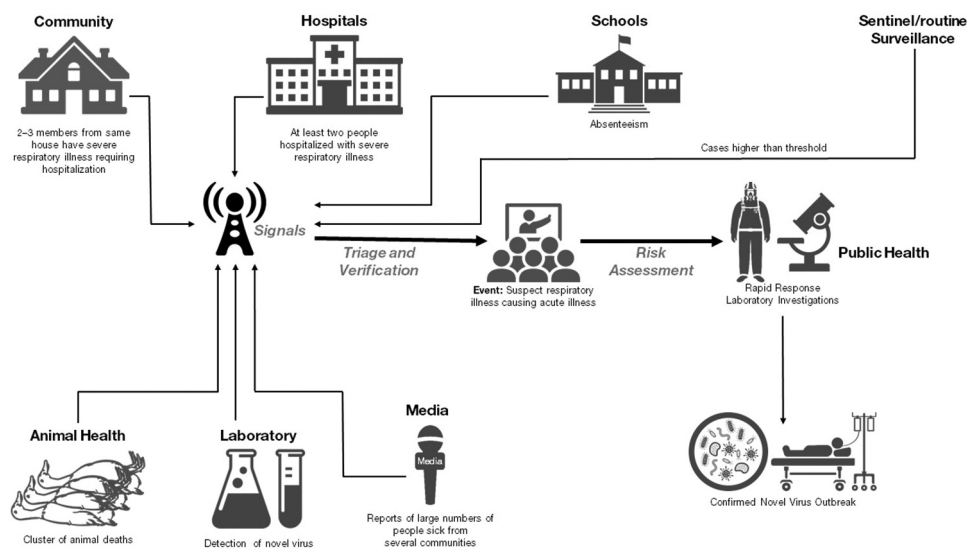

Figure 2. Illustration of how EBS can function as a One Health approach in a country that has optimal human, animal, and environmental health surveillance. Here, data sharing can occur at every level of a coordinated surveillance system.

of EBS is the process of tracking media coverage with the aim of early detection of signals with potential public health impact. It can be a useful supplement to the community, facility, district, and regional components of the EBS system, and is a useful tool to monitor the course of an event, especially for national and international offices with limited awareness of local-level events. Media sources can be either official (e.g. a ministry of health website) or unofficial (e.g. newspaper) and can also include social networks. The media monitoring team is an interdisciplinary group of analysts who perform scanning of open sources of information on the Web, triaging and verifying potential signals, and initial risk assessments of events.

As with other EBS strategies, signals for surveillance from media sources should be defined and, once reported, verified, triaged and assessed for potential risk. Several tools are available at no cost to support media monitoring and signal verification processes such as the Global Public Health Intelligence Network (GPHIN) and Epidemic Intelligence from Open Sources (EIOS). (Public Health Agency of Canada, 2019; WHO, 2020) In addition, there are several other aggregator systems that provide moderated content like ProMed and HealthMap that are useful for monitoring global events. MediSys, another system based on the European Media Monitor, is yet another available systemGPHIN, one of the earliest programs to automate media scanning, was developed by Health Canada in partnership with WHO in the late 1990s.

Most recently, WHO, in collaboration with the European Union and a number of organisations – created a community of practice and supporting 'system of systems' for public health intelligence: the EIOS initiative. The EIOS system pulls together many existing aggregator systems, incorporates additional sources, and is customised to meet the needs and priorities of individual users (i.e. country or organisation). The EIOS system allows for individual curation of the user interface to highlight personally relevant content based on breadth of disease and hazard categories, geographic locations, Boolean search combinations, and machine-learning approaches. Beyond the system, EIOS as an initiative is aimed at cultivating an international community of experts both in system development and field implementation to drive its ongoing evolution, ensuring linkages and developments that adapt to changing landscapes and meet the needs of the public health intelligence community.

Signal source: other sectors

Events can originate from other sectors, such as educational institutions, military hospitals, pharmacies, factories, other specific surveillance systems from the border and environmental health sectors. It is not necessary that these sectors share all of the information/data that they are collecting with the human health sector, only data or signals that may predict human health events. Some countries also implement EBS during mass gatherings; consideration should be given to how these experiences can improve EBS systems in the country after the mass gathering event. As with other sources described above, these sectors can share data/signals based on a predetermined list of signals

Use of hotlines and toll-free lines for signal reporting

Hotlines and toll-free lines can be employed for signal reporting in event-based surveillance. These mechanisms can be used by both members of the community and health care providers to report signals. In this approach, all received information should be recorded in a signal database for triaging and verification tracking. The public health team should be trained on a list of priority signals and the use of standard data collection tools, to ensure that minimum information needed for triage and verification is collected. Before launching this mechanism for use in EBS, several limitations need to be understood and addressed, including the tendency for callers to use this mechanisms to call in other information other than event reporting (e.g, as a complaint line by disgruntled clients of the health care system), difficulty in localising callers when calls are received at a central facility, and generating large amounts of 'signal noise' in the system due to over-reporting of unverified signals by the general public. These systems can also raise the expectations of the general public that some action will be taken as a result of the reporting, ultimately resulting in dissatisfaction when these expectations aren't not met. One method to address some of these issues is to limit use of these call-in lines to a select group of key informants and public health professionals.

Information management

EBS is an ongoing process that continues throughout the lifespan of an event. As an event evolves and, as new information becomes available, evaluation and risk assessment processes may need to be repeated to pro-

vide a longitudinal understanding of the development and trajectory of the event. Effective EBS systems have multiple sources of information available and a capacity to coordinate and synthesise the data coming from all of them. It may be useful to establish a public health intelligence hub(s) nationally and sub-nationally with the capacity to receive, interpret, and visualise all surveillance data from a variety of sources and in multiple formats. Optimally, structured data collected through IBS systems, verified events from EBS systems, animal events significant to public health from the animal health sector, data from immunisation registries, environmental sectors and other sectors, and media and scientific publications should be received at this hub in order to quickly identify any event which might become a public health concern (Figure 3). In these data hubs, data streams should be integrated and displayed on dashboards using automated routine analyses to improve accessibility and utility of the surveillance data. Many countries now have Public Health Emergency Operation Centres that can serve as data hubs for epidemic intelligence. (Balajee et al., 2017)
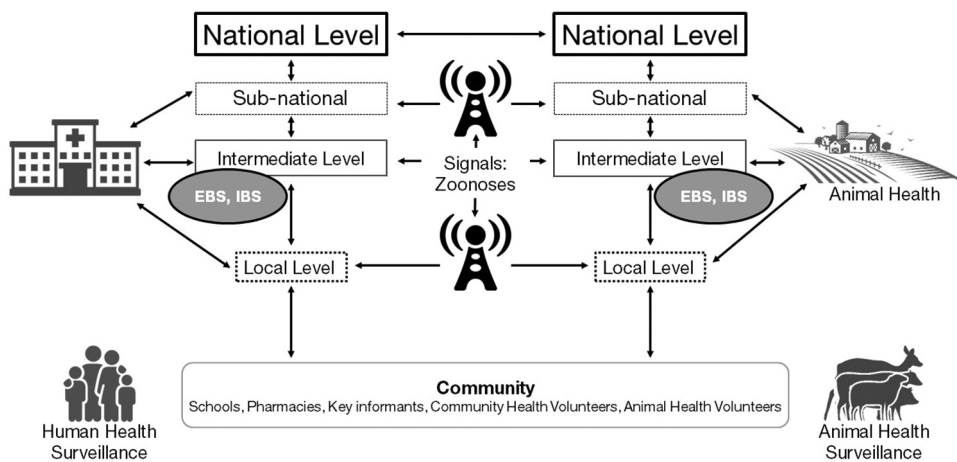
Figure 3. An optimal EBS system will have the capacity to collect information from diverse sources: points of entry and human, animal, and environmental health surveillance. A central epidmic intelligence hub capacity to receive, interpret, and visualise surveillance data from multiple sources and in multiple formats will be important to ensure prompt action for an event.

Figure 4. Hypothetical scenario where signals for an event of a cluster of cases due to a novel respiratory virus are detected through different sources.

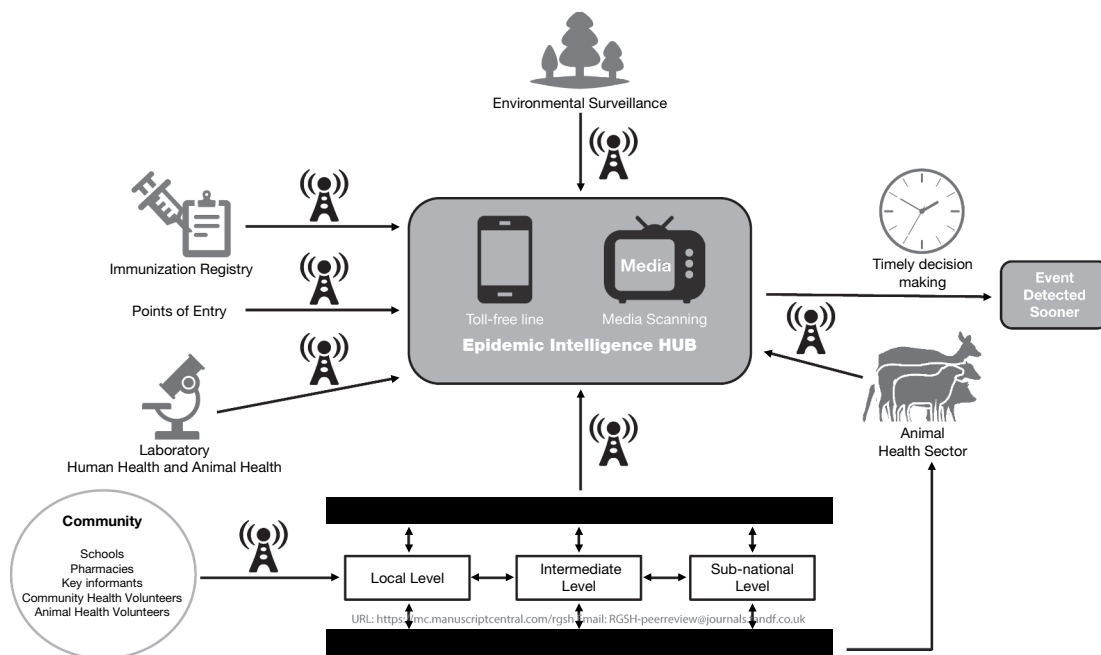Collating all data facilitates the work of trained analysts who evaluate and synthesise the data that can be provided to decision makers and responders.

Illustration of event-based surveillance

Figure 4 illustrates how a novel respiratory virus can be detected through a comprehensive EBS. In this hypothetical scenario, the early warning can come through several sources:

(1) A CHW or a key informant receiving information about three residents of the same neighbourhood who are severely ill, with two of them rushed to a hospital with severe respiratory illness
(2) A hospital receiving two severely ill patients from the same household in the emergency unit
(3) The animal health sector sharing reports of sudden sickness and deaths of poultry in a community and in an animal market
(4) The national public health laboratory detecting an unsubtypeable influenza virus from hospitalised patients
(5) Media reporting of increasing public anxiety over a number of hospitalised cases from one municipality
(6) A school reporting several children absent with severe respiratory illness
(7) Surveillance experts finding an increase in the number of cases of suspected dengue over the alert threshold

A signal entering the public health system through any of the sources should initiate immediate triage and verification. Once the event is verified as a suspect cluster of severe respiratory illness, response mechanisms will swing into place with coordination across sectors and quick intervention to save lives.

Conclusion

A functional EBS system is a critical component of a country's preparedness and early warning system. However, it is important to understand several key concepts of EBS. Ideally, an EBS system will: 1) support country preparedness for endemics and pandemics; 2) complement and enhance other surveillance and reporting systems; 3) use an all-hazards approach including principles of One Health; and 4) provide opportunities for multi-sectoral collaboration and communication including public and private sectors.

Building and sustaining EBS often does not require new resources. Rather, it relies on the country's ability to review existing surveillance and information structures and adapt, connect, and extend some of these structures, and to raise awareness of the need to detect and report among critical members of the public health community. By engaging the community and health care workers to look and report a 2–3 signals rather than a list of case definitions, which may require clinical knowledge, EBS may be a more nimble platform, especially in low-resource settings and existing surveillance systems may already be weak. Most countries have informal systems that serve as platforms for rumour reporting. For EBS, these rumour-reporting platforms become formalised by creation of a community signal list and training for communities to detect and report signals. Countries that already have animal health surveillance systems need to improve capacities at various administrative levels and the national level for cross-notification of shared health threats like zoonotic events.

Taking the steps to clearly prioritise events of concern, define signals that can detect events without being overly sensitive, and having a broad source of signals that includes communities, health care facilities, laboratories, and news media can provide a level of detection capacity that will facilitate early response when events are still small.

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Disclosure statement

Notes on contributors

Dr. S. Arunmozhi Balajee is currently the Associate Director, Global Health Sciences in the Division of Viral Diseases, National Center for Immunization and Respiratory Diseases, Centers for Disease Control and Prevention. She and her team implement event-based surveillance in several countries, developed extensive training materials for implementation and provide training to country partners in this important surveillance platform.

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Dr. Anthony W. Mounts trained in clinical medicine with specialization in Pediatrics, Internal Medicine, and adult Infectious Diseases. Since October 2018, he has been working at USAID as a Senior Advisor on Immunization to the Child Health and Immunization team. Dr. Mounts has led a polio eradication program in Pakistan, guided the development of influenza projects and capacity building around the world and has served as the Technical Lead for the WHO response to a novel coronavirus in the Middle East (later named MERS) until moving to Vietnam where he serves as the CDC Country Director.

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