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How to reach the poor? Surveillance in low-income countries, lessons from experiences in Cambodia and Madagascar

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ABSTRACT

Surveillance of animal diseases in developing countries faces many constraints. Innovative tools and methods to enhance surveillance in remote and neglected areas should be defined, assessed and applied in close connection with local farmers, national stakeholders and international agencies. The authors performed a narrative synthesis of their own publications about surveillance in Madagascar and Cambodia. They analysed the data in light of their fieldwork experiences in the two countries' very challenging environments. The burden of animal and zoonotic diseases (e.g. avian influenza, African swine fever, Newcastle disease, Rift Valley fever) is huge in both countries which are among the poorest in the world. Being poor countries implies a lack of human and financial means to ensure effective surveillance of emerging and endemic diseases. Several recent projects have shown that new approaches can be proposed and tested in the field. Several advanced participatory approaches are promising and could be part of an innovative method for improving the dialogue among different actors in a surveillance system. Thus, participatory modelling, developed for natural resources management involving local stakeholders, could be applied to health management, including surveillance. Data transmission could benefit from the large mobile-phone coverage in these countries. Ecological studies and advances in the field of livestock surveillance should guide methods for enhancing wildlife monitoring and surveillance. Under the umbrella of the One Health paradigm, and in the framework of a risk-based surveillance concept, a combination of participatory methods and modern technologies could help to overcome the constraints present in low-income countries. These unconventional approaches should be merged in order to optimise surveillance of emerging and endemic diseases in challenging environments.

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1. Introduction

In 2010 the World Bank estimated that 21% of the population in developing countries, representing approximately 1.21 billion people, were extremely poor (making a living on less than $1.25 per day) (World Bank, 2014). Seventy five percent of these people live in rural areas and depend on agriculture and livestock for their livelihoods (Otte et al., 2012). Even with the acceleration of urbanisation in developing countries, this situation is expected to remain unchanged in the coming decades, with the majority of the poor continuing to live in rural areas (United Nations, 2012). In Asia and Sub-Saharan Africa, the two poorest regions in the world, farm animals play a major role in food security by providing access to high quality food, better crop production (with manure and traction) and an important store of wealth and insurance in case of crop failure or sickness (Smith et al., 2013). In these regions, farming systems aim to ensure subsistence; that is they produce low and unpredictable profits but require minimal external inputs. Poor rural farmers typically live in areas that lack infrastructure and have limited access to markets. For these farmers, a household's livelihood strategy cannot rely on a single source of income and farmers often prefer to keep multispecies herds in order to manage potential risks (Perry and Grace, 2009). Lack of disease control strategies and poor husbandry practices are common and result in a high prevalence of endemic production diseases, making herds and flocks more susceptible to epidemic diseases with high morbidity or mortality (Herrero et al., 2013). A significant number of these infectious diseases are zoonoses that can be transmitted to humans through direct or indirect contact. In low income countries, zoonotic diseases are responsible for 12% of human sickness and mortality (Grace et al., 2012) with the poorest populations being the most commonly affected.

Death of any livestock in a poor household will have an impact on the livelihood of the entire family, as poor households own fewer animals and rely almost exclusively on them for food, transport and farm work (Bordier and Roger, 2013). The impact will be even greater during disease epidemics, where there may be sudden and rapid mortality of animals and often a significant decrease in market demand due to the fear of diseases, depriving the poorest families of critical assets and increasing their vulnerability (Perry et al., 2002). In this context surveillance and response systems are essential for the control of animal diseases. An effective surveillance system will have the capacity to rapidly detect the presence of the disease, process information and provide appropriate responses to decision makers and stakeholders (Grosbois et al., 2015). The main objective of surveillance is to minimise the economic impact and the public health hazards resulting from epidemics, especially on the most vulnerable sectors of the population. However, the main difficulty of disease surveillance in many poor regions is the dearth of basic means to collect and transmit veterinary and public health data and samples from small farms and backyard livestock. Despite the capacity-efforts undertaken by OIE, with the use of the Performance of Veterinary Services (PVS) tool (OIE, 2014a), and the numerous projects implemented by agencies (e.g. FAO to control the H5N1 epizootic), the human resources needed for sustainable surveillance and rapid response – official services, public and private veterinarians, technicians – are often insufficient. Furthermore, when implemented, surveillance systems often suffer from a lack of coverage and fail to reach the poorest populations (Randolph et al., 2007). Data reports are often delayed, incomplete or biased. Several factors have been identified that contribute to disease underreporting: low density of health facilities with poor communication systems, poor awareness of disease by livestock owners, risk of penalty or stigmatisation, distrust of governmental authorities and lack of qualified staff (Halliday et al., 2012). As a result, poorest farmers often rely on traditional "know-how" for animal disease management and do not perceive a priori how their participation in surveillance systems could contribute to improving their livelihoods.

The French Research Centre for International Development (CIRAD) is a research institution specialised in working in tropical areas. Its mission is to support the rural development of developing countries through research and training actions and by exchanging technical and scientific knowledge (http://www.cirad.fr/en). Over the years, CIRAD has been actively involved in the development of research projects in tropical countries. One recent research focus was the development of new and original tools for the design and evaluation of surveillance and control systems for animal diseases in order to support the most vulnerable populations in rural settings. Cambodia and Madagascar are among the poorest countries in the world, belonging to the 36 low-income economies (countries with $1,035 or less of Gross National Income per capita). Significant percentages of the populations of Madagascar (82.4%) and Cambodia (53%) live below the poverty line (earning less than $1.25/day), representing the 4th and 38th poorest countries in the world, respectively (World Bank, 2013).

The ministries of agriculture and the veterinary services of Madagascar and Cambodia are long-standing partners of CIRAD, with well-established research collaborations that will continue into the future with the development of research platforms and regional networks. The research and development activities in these countries were set up to support the management of transboundary and emerging diseases through collaborative research. In these two geographic areas, researchers have primarily focused on developing a better understanding of the epidemiology and risk factors of priority diseases (e.g. African swine fever and Rift Valley fever in Madagascar; foot-and-mouth disease and Japanese encephalitis in Cambodia) in order to develop more effective surveillance and control strategies (Vigier, 2011). More recently, researchers have worked on the design of more adapted evaluation frameworks for surveillance in developing countries and on the conception of innovative tools to assess the epidemiological and socioeconomic performance of surveillance in challenging countries (Cappelle et al., 2013). After more than a decade of collaboration within each country, we felt it was important before proposing new research projects, to compare and analyse the research conducted by CIRAD into methods and tools to evaluate and improve the animal disease surveillance and control systems in Madagascar and Cambodia.

We believe that comparison of experiences and cross analysis of the research implemented in these two challenging environments could assist in development of new approaches and sustainable solutions for these low socioeconomic environments. Moreover, this approach will help us to prepare the phase of impact evaluation that will be launched by the management of CIRAD in 2015/2016 for several case-studies including surveillance methods and systems. Our objective was to produce an overview of surveillance methods and tools currently developed or implemented by CIRAD researchers in Madagascar and Cambodia, and to critically analyse and review their field feasibilities in order to determine their benefits, and to strategically provide effective, targeted recommendations.

2. Materials and methods

The methodology consisted of a systematic review of papers related to surveillance in Madagascar and Cambodia, followed by the use of narrative synthesis to compare and analyse the results of the systematic review. In order to meet our objectives, we limited our study to papers that have been published under projects implemented in whole or in part by CIRAD and by the authors of this paper who have an in-depth knowledge of the challenging environments of these countries.

2.1. Sources of information

We searched the period 2004 to April 2014 in Scopus for papers in English or French using the following key words AFFIL (CIRAD) AND ALL ("Madagascar OR Cambodia") AND ALL ("Surveillance OR monitoring OR information system") and Google Scholar™ with the following key words, "CIRAD" AND "Madagascar OR Cambodia" AND "Surveillance OR monitoring OR information system" AND "animal diseases". Additional searches were performed using CIRAD's database, AGRITROP, and project websites (FSP project [GRIPAVI 2006–26] funded by the French Ministry of Foreign and European Affairs (MAEE) http://gripavi.cirad.fr/en/, and DGAL funded project [FRIA-08-009 REVASIA] http://revasia.cirad.fr/en/). All documents retrieved were screened to exclude papers that were not written by authors from CIRAD (homonyms or presence of the word CIRAD in the article or in the reference list of the paper), that were not about infectious animal diseases and from which no recommendation about surveillance systems could arise. Two reviewers conducted the appraisal and authors of selected studies were consulted in order to assess the contents and validity of the findings.

2.2. Narrative synthesis

The choice of a narrative synthesis method was driven by the large variability of research protocols described in the papers retrieved by the review and by the qualitative nature of our results. This method allows the aggregation of qualitative data in order to produce a comprehensive analysis and synthesis of the results of a systematic review, using a textual approach (Popay et al., 2006).

The narrative synthesis method has been mainly developed for systematic review of intervention studies (Arai et al., 2007). The process usually follows four elements (development of a theoretical model, preliminary synthesis, assessing relationships in the findings, and validation of the synthesis).

The studies included in our review are different from intervention studies and are of various types (observational and descriptive studies, analytical studies, qualitative studies), therefore we developed a modified process for our narrative synthesis involving: (1) a description of the background of the studies that we want to compare (country profile), (2) synthesis with textual description of each study, grouping of the studies, tabulation of results across studies, (3) comparisons between studies and visualisation of the connection among findings with the use of radar charts and spider diagrams, and (4) testing the validity of interpretations by consulting primary authors of the studies.

The main objectives of this synthesis were to list and critically review surveillance tools and methods developed in Madagascar and Cambodia in order to draw recommendations for future research in similar contexts. To be able to do that, we needed to first describe the socio-economic contexts of the two countries, the main diseases under surveillance with their epidemiological contexts and the tools and methods used by CIRAD researchers. Therefore the following data were extracted from each study in the form of textual description: details about the country in which the study was implemented, epidemiological and ecological conditions of the diseases (or health events) targeted in the study, type of surveillance described or mentioned (passive, active, risk-based, participatory, etc.), population included in the surveillance, method or tool tested during the study, limitations and advantages of these methods or tools and recommendations for surveillance and control systems. Data that describe the current situations in Madagascar and Cambodia were completed with additional literature research and compiled under a "country profile". Selected data were retrieved from the papers and grouped according to geographic area and disease or health event targeted by the study before being tabulated. The tools or methods implemented or described within the papers have been included in the tables and a qualitative assessment of their limitations and advantages was completed, using the attributes listed in the OIE guidelines for surveillance (OIE, 2014b) and the expertise of the authors of the reviewed papers.

3. Results

3.1. Flow diagram and data description

A total of 148 papers were identified from Scopus and 63 from Google Scholar™. After exclusion and verification of duplicates, 22 papers remained: 21 research articles (Baron et al., 2013; Bellet et al., 2012; Calba et al., 2014; Chevalier et al., 2011; Collineau et al., 2013; Conan et al., 2013; Costard et al., 2009; Desvaux et al., 2006; Domenech et al., 2006; Fournié et al., 2012;Guerrini et al., 2014; Netrabukkana et al., 2014; Peyre et al., 2011;

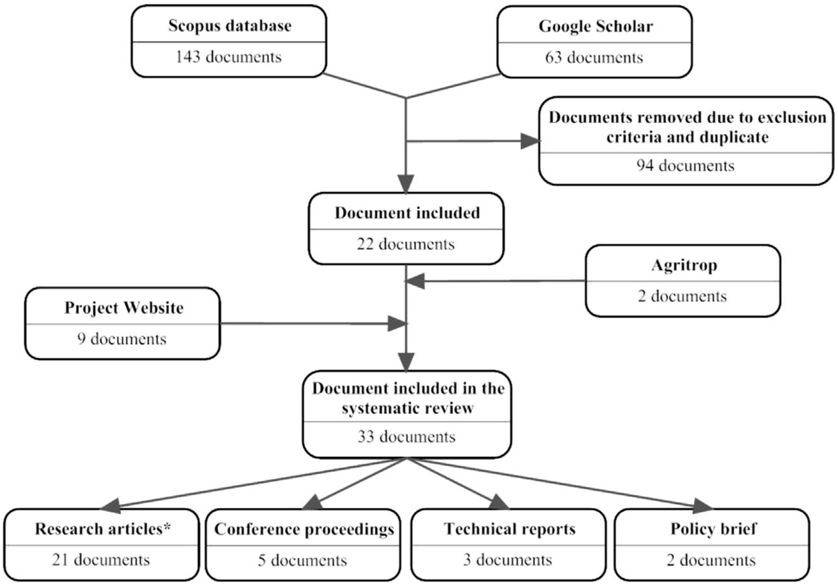

Fig. 1. Flow diagram of the selection process for the systematic review of CIRAD research papers on surveillance in Madagascar and Cambodia. *One document was a thesis manuscript.

Rasamoelina-Andriamanivo et al., 2011; Ravaomanana et al., 2011; Reynes et al., 2005; Rith et al., 2013; Roger et al., 2004; Tarantola et al., 2014; Trevennec et al., 2011; Vergne et al., 2012), one policy brief (Roger, 2012) and one conference proceeding paper (Cappelle et al., 2013). The additional search in AGRITROP and CIRAD's projects' websites identified 11 new documents: 1 policy brief (Figuié et al., 2013), 3 technical reports (Antoine-Moussiaux et al., 2011; CIRAD, 2009; Thonnat, 2005), 4 conference proceeding papers (Desvaux and Figuié, 2011; Figuié, 2013; Figuié and Peyre, 2013; Roger et al., 2008), 1 thesis manuscript (Rasamoelina-Andriamanivo, 2014) and 1 research paper (Renard, 2010). A total of 33 documents were used for this synthesis. The literature selection process is illustrated in Fig. 1.

3.2. Data description

These data are represented in three different tables according to the country or geographic areas targeted (Table 1 for Cambodia; Table 2 for Madagascar; Table 3 for regional research activities). A summary of the main qualities of the tools and methods was displayed in radar chart form (Fig. 2). The main limitations were the lack of representativeness, specificity, sustainability and simplicity. The main advantages were the sensitivity, the ownership, the usefulness and the flexibility. Qualitative case descriptions were used to compare data between countries in order to: (1) identify similarities and differences in the epidemiological situations of the main transboundary, emerging and zoonotic diseases; (2) identify methods and tools for data collection and data transmission that would be interesting to share between countries and; (3) understand the variability between the efficacies of the surveillance methods or tools within different population compartments, to inform the implementation of improved surveillance.

3.3. Country profiles

As the purpose of our article is to provide generic recommendations for improving surveillance methods in a context of resource poor settings, we started by analysing the epidemiological situations in Cambodia and Madagascar.

3.3.1. Madagascar

Madagascar is one of the poorest countries in the world, the life expectancy is 64 years and 67% of the people live in rural areas (World Bank, 2013). The agriculture sector accounts for 27.3% of national GDP, with the majority of people raising livestock. The total bovine population is estimated at 10 million head. Common cattle endemic diseases are bovine tuberculosis (Rasolofo Razanamparany et al., 2006), anthrax (Blancou, 1968), blackleg (Rajaonarison, 2001), tick-borne diseases (Stachurski et al., 2013) and internal parasitism. In 2008–2009, Madagascar was severely affected by Rift Valley fever (RVF) (Andriamandimby et al., 2010). Besides the direct economic losses affecting farmers, with high mortality of young stock and high abortion rates in females, outbreaks of disease also damaged commercial trade of both live animals and farmed products. Similarly, the poultry industry plays an essential role in the Madagascar economy and livelihood. The Food and Agriculture Organization of the United Nations estimates the domestic poultry population at 34.4 million birds (FAOSTAT database 2011: http://faostat.fao.org/). Small-scale commercial farms and backyard farms account for two thirds of the poultry production system (Ocean-Consultant, 2004). Therefore, avian disease outbreaks can lead to major consequences for household economies. Newcastle disease (ND) is the most prevalent poultry disease, accounting for 44% of poultry mortalities in the suburban area of the capital

Table 1
Description of the papers retrieved for Cambodia via the review: by disease, species, type of tools described, limitation/advantage of the tools*, recommendation and current surveillance implemented. *We used the list of attributes published in the OIE guidelines for surveillance (OIE, 2014b). We limited the attributes of limitations and advantages to the most significant ones for each paper.

Cambodia and regional studies including Cambodia						
Reference	Disease(s) or surveyed events	Species	*Current surveillance in the country (2013–2014)*	Tools and/or methods mentioned or described	*Limitations* **Advantages**	Recommendations for surveillance implementation
Conan et al. (2013)	Poultry diseases	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*	Epidemiological studies	*Representativness* **Sensibility and Simplicity**	Design of risk-based surveillance. Needs for targeted surveillance at farm level and sero-monitoring at abattoir. Design of One Health Surveillance.
Fournié et al. (2012)	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*			
Netrabukkana et al. (2014)	Swine influenza	Pig	*Farmers declaration*			
Trevennec et al. (2011)	Swine influenza	Pig	*Farmers declaration*			
Rith et al. (2013)	Swine influenza	Pig	*Farmers declaration*	Laboratory based surveillance	*Sustainability and Representativness* **Sensibility**	Design of systematic surveillance of influenza viruses on farms. Design of One Health Surveillance.
Reynes et al. (2005)	Nipah	Human Bats	*Syndromic surveillance (human)* *Repeated surveys (bats)*			
Cappelle et al. (2013)	Zoonoses	Multispecies	*Farmers declaration* *Repeated surveys*	Review	*Sustainability* **Flexibility**	Design of One Health Surveillance
Roger et al. (2008)	Zoonoses Animal diseases	Multispecies	*Farmers declaration* *Repeated surveys*			
Antoine-Moussiaux et al. (2011)	Animal diseases	Multispecies	*Farmers declaration* *Repeated surveys*	Assessment and evaluation tools	*Representativness and Simplicity* **Usefulness and Flexibility**	Implement economic evaluation. Systematic assessment and evaluation.
Peyre et al. (2011)	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*			
Vergne et al. (2012)	Foot and mouth disease	Cattle	*Farmers declaration*			
Bellet et al. (2012)	Foot and mouth disease	Cattle	*Farmers declaration*	Participatory surveillance	*Specificity and Sustainability* **Ownership**	Development of participatory approaches. Systematic assessment and evaluation.
Desvaux et al. (2006)	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*			
Calba et al. (2014)	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*			
Desvaux and Figuié (2011)	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*	Non conventional surveillance	*Specificity* **Ownership**	Need for various systems (informal, private) to be integrated
Figuié et al., 2013	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*			
Collineau et al. (2013)	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*	Epidemiological modelling	*Simplicity* **Flexibility**	Use modelling to improve surveillance design
Figuié (2013)	Avian influenza (H5N1 HPAI)	Poultry	*Farmers declaration* *Serosurveillance at live-bird markets*	Governance	*Simplicity* **Usefulness**	Insertion in the local context
Baron et al. (2013)	Side-effect of vaccination	Human	*No surveillance*	Mobile phone-based surveillance	*Sustainability* **Timeliness**	Develop tailored systems of SMS-reporting for developing countries
Tarantola et al. (2014)	Zoonotic encephalitis (JE, rabies)	Human Animal	*Syndromic surveillance (human)* *Farmers declaration (dogs)*	Syndromic surveillance	*Sensitivity* **Flexibility**	Design of human syndromic surveillance for zoonoses

Table 2

Description of the papers retrieved for Madagascar via the review: by disease, species, type of tools described, limitation/advantage of the tools*, recommendation and current surveillance implemented. *We used the list of attributes published in the OIE guidelines for surveillance (OIE, 2014b). We limited the attributes of limitations and advantages to the most significant ones for each paper.

Madagascar and regional studies including Madagascar						
Reference	Disease(s) or surveyed events	Species	*Current surveillance in the country (2013–2014)*	Tools and/or methods mentioned or described	*Limitations/Constraints* **Opportunities**	Recommendations for surveillance implementation
Guerrini et al. (2014)	Avian influenza Newcastle disease	Poultry	*Farmers declaration* *Repeated surveys*	Epidemiological studies	*Representativness* **Sensitivity, specificity and flexibility**	Identification of risk factors Design of risk-based surveillance (risk mapping) Design tailored-surveillance for wildlife
Chevalier et al. (2011)	Rift valley fever	Cattle	*Farmers declaration (cattle)* *Hospital-based (homme)*			
Ravaomanana et al. (2011)	Swine fevers	Wild pig	*Farmers and hunters declaration*			
Costard et al. (2009)	Swine fevers	Pig	*Farmers declaration*			
Rasamoelina-Andriamanivo (2011)	Avian influenza Newcastle disease	Poultry	*Farmers declaration* *Repeated surveys*	Participatory surveillance	*Specificity and sensitivity* *Ownership*	Development of participatory approaches Training of village animal health workers for surveillance
Thonnat (2005)	Zoonoses Animal diseases	Multispecies	*Farmers declaration* *Repeated surveys*			
Roger et al. (2004)	Zoonoses Animal diseases	Multispecies	*Farmers declaration* *Repeated surveys*	Non conventional surveillance	*Flexibility* **Sustainability**	Need for various systems (informal, private) to be integrated
Rasamoelina-Andriamanivo et al. (2014)	Avian influenza Newcastle disease	Poultry	*Farmers declaration* *Repeated surveys*	Epidemiological modelling	*Simplicity* **Specificity**	Design of risk-based surveillance (risk mapping)

Table 3
Description of the papers about regional researches retrieved via the review: by disease, species, type of tools described and recommendation.

Global: Africa and SE Asia				
Reference	Disease(s) or surveyed events	Species	Tools and/or methods mentioned or described	Recommendations for surveillance implementation
CIRAD (2009)	Avian influenza Newcastle disease	Poultry and wildbirds	Epidemiological studies	Design of Risk-based surveillance. Development of participatory approaches
Domenech et al. (2006)	Zoonoses Animal diseases	Multispecies	Governance	Linking regional and international surveillance.
Figuié and Peyre (2013)	Avian influenza (SRAS)	Poultry, human		Design of One Health Surveillance
Renard (2010)	Avian influenza	Poultry	Evaluation	Design of risk based-surveillance (markets)
Roger (2012)	Zoonoses	Multispecies	Participatory surveillance	Design of One Health Surveillance

Antananarivo (Maminiaina et al., 2007). With 1.38 million animals (FAOSTAT database 2011: http://faostat.fao.org/), the pig production sector is also significant, despite the devastating consequences that recurring outbreaks of African swine fever (ASF) (Roger et al., 2000) and classical swine fever (CSF) (Paton and Greiser-Wilke, 2003) have had on the livelihood of smallholders.

3.3.2. Cambodia

In 2012, the population of Cambodia was 14.86 million people, with 80% living in rural areas. Despite increasing economic growth, 2.8 million people are still considered very poor (earning less than $1.25 per day). Life expectancy is 71 years, and 40% of children under the age of 5 are malnourished (World Bank, 2013). The agriculture sector accounts for 30% of national GDP, and the livestock sector is the third most important subsector contributing about 5% of the GDP. The total bovine population is estimated at 3.68 million animals (MAFF, 2012). The annual mortality due to bovine diseases is estimated at 10%. Smallholders face numerous threats, including annual outbreaks of foot-and-mouth disease (FMD), endemic in Cambodia, and the presence of haemorrhagic septicaemia and internal parasites (Nampanya et al., 2012). Eighty five percent of rural households own pigs and raise them in traditional farming systems, with small herds. It is not unusual to find only one animal in the poorest families. The annual pig mortality due to diseases is very high, 46%, with the endemic circulation of various infectious diseases (FMD, CSF, porcine reproductive and respiratory syndrome) (Shankar et al., 2012). Backyard poultry are present in almost every household, and the Ministry of Agriculture, Forestry and Fisheries of

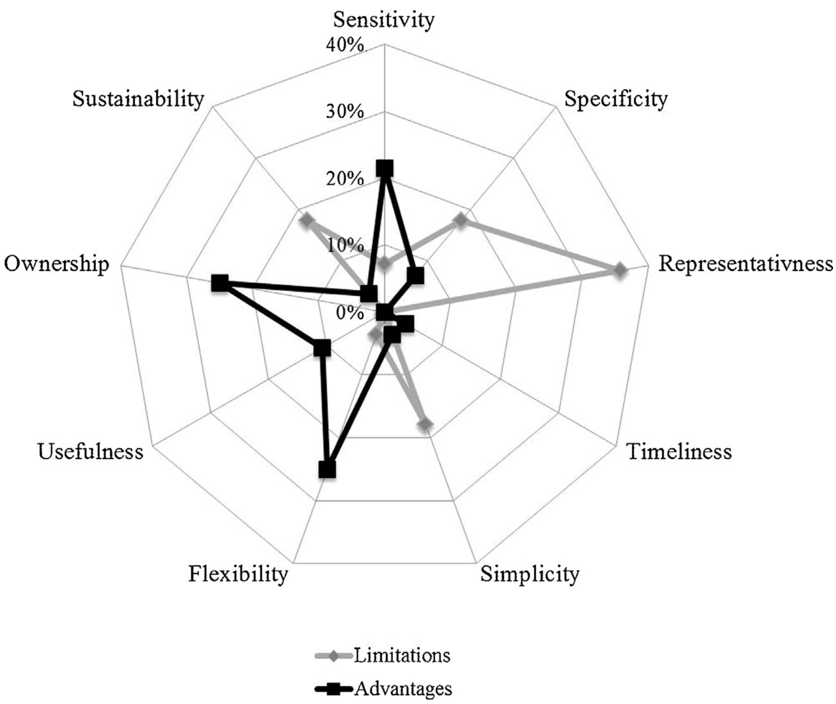

Fig. 2. Radar chart of the proportion of studies included in the systematic review of CIRAD research papers that developed surveillance tools with the following attributes as advantages and as limitations ($n = 28$).

Cambodia (MAFF) estimated the total population of birds at 15 million. Production is characterised by low biosecurity, with high risk of contagious diseases (ND, fowl cholera) and a high level of mortality (between 30% to 60% annual mortality from diseases) (Zilberman et al., 2012). Highly pathogenic avian influenza (HPAI) H5N1 virus has been present in Cambodia since 2004, with regular outbreaks in the poultry sector. The disease, with a mortality rate above 50% within affected flocks in 1 to 3 days, had a dramatic effect on farmers' livelihoods, exacerbated by the national policy of culling without compensation, causing extreme financial losses for poor small-scale breeders (Zilberman et al., 2012). To date, 42 avian outbreaks and 56 human cases have been identified, with a very high human case fatality rate of 66% (WHO, 2014).

3.4. Comparative analysis of the epidemiological and ecological situations of the main animal diseases

The two countries have numerous transboundary (TADs), emerging (EIDs)and neglected tropical (NTDs) infectious diseases, affecting or threatening their livestock sectors. Regarding TADs, African swine fever (ASF) is endemic in Madagascar (Ravaomanana et al., 2011), which is also at risk for foot-and-mouth disease (FMD) due to its proximity to endemic areas (e.g. Mozambique). In Cambodia the situation is reversed, FMD is endemic (Bellet et al., 2012) and ASF absent. Nevertheless, ASF is prevalent in Africa and more recently in Russia, thus the increase of international trade and the high density of wild boars in Eurasia amplify the risk of ASF virus introduction in Southeast Asia and China, where the pork industry is growing strongly (Verbeke and Liu, 2014). HPAI H5N1, initially viewed as an EID in Southeast Asia, is now considered to be endemic in Cambodia. In Madagascar, HPAI viruses have not been reported but the ecosystem favours the potential emergence and spread of influenza, as drivers like rice paddies and the mixing of poultry and pig species prevail (Paul et al., 2014). The virus could potentially be introduced by migratory wild birds through the East Africa-West Asia flyway (Olsen et al., 2006). Newcastle disease is highly prevalent in Asia (Miller et al., 2015) and Africa, including Madagascar (Miguel et al., 2013). Its clinical and epidemiological similarity to HPAI H5N1 drove the development of joint avian pests surveillance systems, mainly in Africa, including Madagascar (Rasamoelina-Andriamanivo, 2011).

Rift Valley fever (RVF) is a recurrent issue in Madagascar (Nicolas et al., 2013). The virus was first isolated in 1979, from mosquitoes trapped in the Perinet forest (Moramanga District), without any reported human or animal clinical cases (Fontenille et al., 1987; Morvan et al., 1991). The first recorded outbreak occurred during the rainy season of 1990–1991 (Morvan et al., 1992) in both human and animal populations. Outbreaks were last recorded in 2008–2009, during two consecutive rainy seasons, affecting the whole country (Andriamandimby et al., 2010). Numerous cases in humans (418 reported cases of which 59 were laboratory-confirmed) and ruminants were reported. Cambodia, like the rest of the tropical and subtropical areas of South East Asia and China, may be considered at risk of RVF, although in this region it is still an exotic disease. Japanese encephalitis (JE) is responsible for 10,000 to 15,000 human deaths per year in the world (Tarantola et al., 2014). It occurs in Southeast Asia but is not currently in the Indian Ocean countries. In Cambodia the JE annual incidence rate was estimated to be 10.6 per 100,000 children aged under 15 years (Touch et al., 2009). Because of international trade and the presence of potential mosquito vectors for both RVF and JE in both continents, RVF and JE may be exported and cause new outbreaks in areas currently disease-free.

Most NTDs mentioned in the papers that we analysed are zoonoses. Rabies is highly prevalent in both countries but its incidence is widely underestimated and only the tip of the iceberg is revealed by human post-exposure treatments in the capital cities, i.e. Antananarivo (Andriamandimby et al., 2013) and Phnom Penh (Ponsich et al., 2012). Bovine tuberculosis (bTB) is quite well described in Madagascar (Marcotty et al., 2009) but insufficiently documented in Southeast Asia, including Cambodia (Bordier and Roger, 2013).

3.5. Comparison of data collection and transmission methods used in both countries

HPAI H5N1surveillance in poultry in Cambodia relied mainly on the passive reporting by farmers, with occasional active surveillance components funded by external donors (Desvaux et al., 2006; Calba et al., 2014). When HPAI H5N1 outbreaks are confirmed, the current policy in Cambodia is culling of poultry in the affected village, without economic compensation. Thus control measure lead to under-reporting and under-detection of H5N1 (Burgos et al., 2008), which often means that the discovery of HPAI H5N1 in a region is first detected by a human case (Leboeuf, 2009). Pilot surveillance systems on highly pathogenic poultry diseases have been set up by non-governmental organisations (NGO), FOFIFA (Madagascan National Centre of Applied Research for Rural Development) and CIRAD in the Lake Alaotra region. The results showed that a combination of participatory and event-based surveillance allowed benefits to accrue from the advantages of each: the high sensitivity of the participatory approach and the high specificity of event-based surveillance (Rasamoelina-Andriamanivo, 2011).

Participatory methods were also used and validated for data collection on FMD in Cambodia (Bellet et al., 2012). These approaches could be implemented for the surveillance of other TADs including ASF in light of similarities in the farming system characteristics and stakeholder behaviours (Costard et al., 2009).

National public and veterinary health services conduct clinical surveillance for RVF in Madagascar using a specific definition, e.g. a set of symptoms including haemorrhagic fever in humans and abortions in animals (Balenghien et al., 2013). The occurrence of RVF is usually signified by the sudden onset of abortions at all stages of pregnancy, with deaths of young animals following an acute febrile disease, associated with liver damage in most cases. However, severity of clinical symptoms depends on the species, and ranges from acute mortality to a mild febrile syndrome. As described in many African countries, the virus may circulate silently at a very low level, either without or with few clinical signs. This cryptic transmission during inter-epidemic phases is extremely difficult to detect (FAO, 2003). Only sero- and/or viro-surveillance would be effective for early detection, but these procedures require considerable resources.

The number of mobile phones per capita is lower in Madagascar than in Cambodia (World Bank, 2013, http://data.worldbank.org/indicator/IT.CEL.SETS.P2). However, the low cost and ease of disease notification using a mobile surveillance pilot system was demonstrated in Cambodia (Baron et al., 2013) making it an interesting option for the Malagasy context. Indeed, in both countries networks of community-based workers (Village Animal Health Workers in Cambodia; Community Animal Health Workers in Madagascar) have been created and have increased the sensitivity of disease detection (CelAgrid, 2007; Rasamoelina-Andriamanivo et al., 2014). Actors in these networks could be equipped and trained to report suspicion of diseases through mobile phone messages. However, late and underreporting still prevails, with problems of lack of compensation for outbreak responses in outreach areas, the burden of extra duties, and the economic penalties for farmers when reporting is followed by mass culling of infected animals (Burgos et al., 2008).

3.6. Comparison of cross-sector surveillance in both countries

Outputs from field surveys of bats in Cambodia (Reynes et al., 2005) and to rodents (Olive et al., 2013) and bushpigs (Rouillé et al., 2014) in Madagascar could be translated into surveillance and monitoring protocols in both countries. Few risk-based surveillance programmes have been designed for wildlife. However, methods combining environmental monitoring (through remote sensing for example) and ecological monitoring of wild species (such as regular censuses of different species and populations) could allow the implementation of real time risk mapping and the adaptation of an active surveillance programs to seasonal changes (Cappelle et al., 2010). In Cambodia, monitoring of the population dynamics of *Pteropus lylei* allowed researchers to implement targeted monitoring of Nipah virus circulation and could be used as a permanent, cost-effective surveillance system (Cappelle et al., 2014).

International agencies have developed specific veterinary public health surveillance activities in Cambodia in response to the HPAI H5N1 crisis. Serological surveillance of duck sentinel flocks and virological surveillance in market places for the detection of HPAI H5N1 (Horm et al., 2013) have been implemented. Monitoring has also been developed as a research tool in pig abattoirs to detect the circulation of the pandemic strain (H1N1) of influenza virus (Rith et al., 2013). These methods have successfully demonstrated the presence of the virus, but are too expensive to be maintained by the national authorities, especially with the current decline in regular funding. However, the recent circulation in China of a new influenza virus, H7N9 which has low pathogenicity for poultry but is highly pathogenic for humans, has placed the need for joint surveillance of influenza in animals and humans in the spotlight (Wu et al., 2015).

4. Discussion

A systematic review of previously published information and recent CIRAD researchers' experiences in Cambodia and Madagascar were used to analyse similarities, gaps and potential cross-cutting lessons for animal disease surveillance systems. To overcome extensive deficiencies in surveillance systems, diverse methods or tools have been tested with varying degrees of success (Fig. 3). Some of these methods (e.g. participatory surveillance) have proved their effectiveness in practice in both countries and could be replicated in other settings. Other methods have shown potential for success (e.g. SMS data transmission) but they will need a certain amount of modification or adaptation to be really effective in these settings. Success could be achieved through dialogue and sharing of experiences among researchers working in Cambodia, in Madagascar and in other developing regions. Finally, methods such as syndromic surveillance appear too complex to be implemented as classically defined and applied in developed countries, highlighting the need to develop new approaches tailored to resource poor situations. On the basis of these results, highlighting trends in the epidemiological situations and surveillance systems for TADs, EIDs and NTDs in Madagascar and Cambodia and trends regarding surveillance methods (data collection and transmission, One Health collaboration), we propose recommendations for improvement of data collection and transmission, stakeholders' involvement and rationale for risk management.

4.1. Alternative data collection approaches

We have highlighted that in the resource poor settings context of the studies implemented in Cambodia and Madagascar, participatory disease surveillance is a very relevant alternative for data collection. It explores community-based information networks and uses a range of methods and tools (semi-structured interviews with key informants, scoring and visualising techniques) to enable communities to share their traditional knowledge about the clinical and epidemiological features of local diseases and to understand disease patterns leading to control decisions (Jost et al., 2007). The basis of participatory surveillance is to identify a community-specific case-definition of threats (which can be evaluated using laboratory diagnostics) and to conduct risk-based surveillance. This approach allows for rapid and effective collection of data with limited use of resources. However it is more adapted to diseases with clearly recognisable clinical signs.

Innovative syndromic approaches need to be developed and adapted to these resource poor settings and challenging field conditions; for instance monitoring volumes of veterinary medicine sales or trade prices for short-cycle animal species. These approaches could address the lack of flexibility of traditional systems and help poor countries

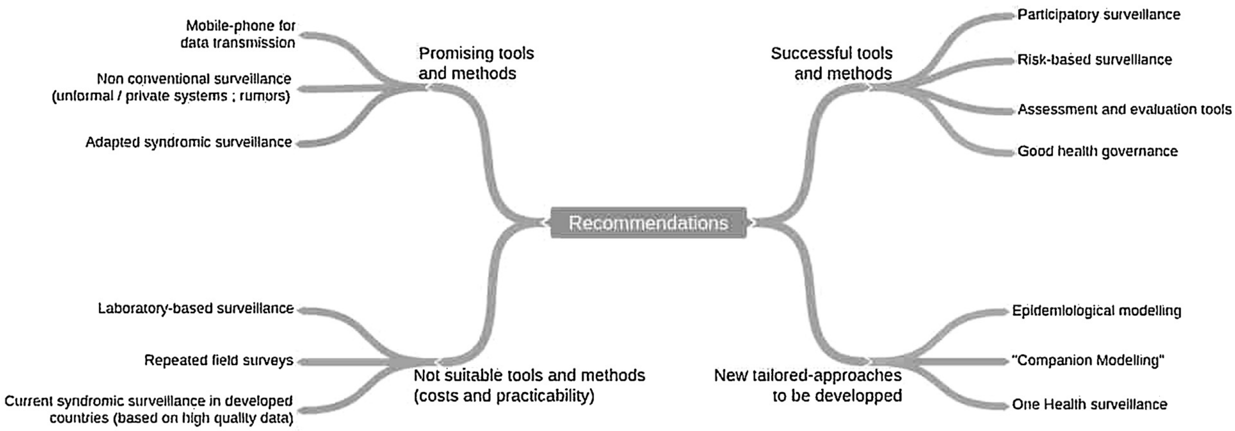

Fig. 3. Spider diagram summarising the variability of success of tools and methods and the main recommendations to improve surveillance in developing countries, drawn from the systematic review of CIRAD research papers ($n = 33$).

to set up early warning systems for unknown emerging diseases (OIE, 2014b).

We have also shown that "One Health", based on joint work with medical services, which generally have a greater field presence, could be very efficient for improving the design of surveillance systems, especially for zoonoses. In addition, incorporating wildlife and bushmeat monitoring into surveillance systems could help to monitor pathogens hazardous for livestock and/or human populations. Elaborate methods for monitoring and surveillance of domestic animals have been developed in the past decades, but ecological characteristics of wildlife species make it difficult to apply these methods to wild species (Ryser-Degiorgis, 2013). When direct observation is too challenging, indirect methods can be used to investigate disease ecology in wild animal populations. Non-invasive sampling methods can for example help to reach the required sample size. Nipah virus was first isolated in bats through urine collection on plastic sheets deployed under the trees of a flying-fox roost. No capture or handling of any bat was necessary (Chua et al., 2002). The same technique was successfully implemented in Cambodia to isolate Nipah virus for the first time (Reynes et al., 2005). The implementation of non-invasive methods for wildlife sampling and monitoring should be improved in the field. It would also be valuable to involve rural populations living at the edge of protected areas and close to wildlife (e.g. wild pigs, bats, rodents) in surveillance programs. Because of the livelihood dependence of local people on natural resources, i.e. wildlife hunting and natural resource gathering, villagers in these fringe areas could play an essential role in government veterinary and human health services, by providing eco-epidemiological information about priority mammalian species. The reinforcement of animal health surveillance policies could benefit from the engagement of local communities and the use of their ethno-veterinary knowledge in countries such as Cambodia and Madagascar. These alternative approaches are well suited for less-developed countries with poorly resourced veterinary services and in remote areas where formal data collection methods are difficult to implement. In such places the active participation of local populations and their knowledge has been acknowledged as a powerful aid for designing successful health surveillance. For example, local communities could inform regional and national authorities about unusual morbidity or mortality events in wildlife, as part of participatory syndromic surveillance. Their involvement could increase contact and trust with government agents and encourage transparency of epizootic disease management. Flexible management is still needed to ensure there is the ability to respond rapidly to data received from the field.

Nevertheless this raises the issue of implementing an effective One Health collaboration among environment and animal health sectors in national contexts mostly characterised by sectoral and "in silo" political management (Waage et al., 2010).

4.2. Adaptive data transmission

As emphasised in our synthesis, the widespread diffusion of mobile phone networks, even in the most remote areas, can enable the use of mobile communication devices (mobile health or mHealth), such as phones, tablet computers and personal digital assistants (PDA), to collect and share animal and human health data. A light but efficient surveillance system of targeted diseases or syndromes could then be established. As it has been noted by the NGO Colalife (http://www.colalife.org), "*Coca-Cola seems to get everywhere in developing countries, yet essential medicines don't. Why?*" Answers to this question could point to new ways to develop non-conventional channels for the transmission of surveillance samples and information in the resource poor settings and remote areas that have been targeted in our article. Remoteness or resource poor settings are not insurmountable obstacles as long as we are able to identify motivations and incentives that make sense for the stakeholders. A key question is to identify the right incentives.

4.3. Non-conventional stakeholders involvement

Our narrative synthesis clearly stated that collaboration and communication between government officers and local people in the framework of surveillance is difficult and raises a lot of issues. Among them, we have highlighted divergences in points of view regarding risk perception and disease management. We propose some action tools aimed at co-building and co-designing a shared representation of the epidemiological situation. All relevant stakeholders should be involved and key health information will be collected by identifying incentives (not only financial) for their participation at the community level. This rationale could contribute to elaborate, well-accepted data collection methods through effective collaboration between policy makers, veterinarians and civil society. Indeed, the various stakeholders concerned with animal health surveillance have their own rationales and practices in terms of risk perception and monitoring. These practices differ between the sectors (public health, veterinary services, environment, land planning, livestock trading, etc.) and action levels (government officers, international agencies representatives, traders, communities' representatives, etc.) involved. Furthermore, animal health crises can generate conflicts and stress at the level of the local community. Information diffusion and sharing during such crises is sensitive. Sensitive data and information (such as sudden death in poultry) are obviously better shared within small social groups with pre-existing trust relationships (Desvaux and Figuié, 2011). These social groups (involving different stakeholders such as experienced farmers, traders, drug sellers, village heads, etc. in the same community) implement non-conventional surveillance practices based on intensive social networking and information sharing. The knowledge and practical know-how of these stakeholders, in terms of animal health management and their social networking, could be valuable for the improvement of surveillance systems at the local community level. However, effective cooperation between these non-conventional networks and the official surveillance networks often appear to be insufficient (Figuié et al., 2013).

Participatory approaches to mapping and modelling are potentially mediating tools that may support dialogue and data collection with different interest groups. They could be used to collect users' knowledge about socioeconomic and environmental factors at the scale of a local community or to improve institutional coordination. In addition, participatory approaches could help to better understand local behaviour rules and the principles of "collective action" (Sandler et al., 1992) for decision making when people involved in the same community are facing similar risks.

The impact of such knowledge sharing on the improvement of cross-sector dialogue has already been demonstrated in the framework of natural resource management with the "Companion Modelling" approach (ComMod association© ComMod 2010). This participatory modelling method was developed in the field of renewable resources management to tackle issues regarding decision processes, common property, and institutional coordination (Etienne, 2011). The final objective of this approach is for stakeholders to identify, through a consultation process, the issues for which they share joint interest, in order to obtain win–win solutions. Participatory modelling uses conceptual models, role-playing games, and agent-based modelling in an iterative way to search for acceptable collective solutions through scenario assessment.

Participatory modelling in surveillance and health risk management has been implemented in several research projects. Stakeholders (including researchers) learn together by creating, modifying, observing and assessing simulations. When different stakeholders have very divergent points of view about the same situation, a "Companion Modelling" approach using iterative focused group discussions, allows the co-design of a common representation of the situation. This co-built representation (initially a conceptual model) can then evolve towards agent-based models which allow scenario testing and role-playing games. Agent-based models are stochastic computer simulations used to investigate the interactions between "agents" – i.e. people, things and places – which are encoded to behave and interact with other agents and the environment. This modelling approach is relevant in the field of epidemiology (Galea et al., 2010).

The process enables discussion, communication, negotiation and knowledge sharing, and provides a strong basis for the common identification of socially acceptable solutions. Knowledge, perceptions, behaviours, and practices evolve throughout the process and can lead to the development of collective action plans and better stakeholder mobilisation to implement them.

A surveillance system involving official, private and non-conventional stakeholders, could be developed using participatory approaches. Simulations could be used as a collective decision making process involving various stakeholders (non-conventional stakeholders and officers from public health, veterinary services and environmental sectors for example). The purpose of the decision making would be improved management of health risks. Public health and veterinary public health would then be perceived as a common good (Ostrom, 2000) to be managed collectively.

4.4. Limitations of the study

Very little information or data is published about animal diseases surveillance methods and systems in the two studied countries. Publications about the health of animals in these two countries are available from different teams and institutions but they deal mainly with pathology, microbiology, and descriptive epidemiology. It was this lack of information that motivated us to perform a critical appraisal of our fieldwork focusing on publications of CIRAD and partner researchers. These researchers are either from the two countries or have worked for several years in the field. They have worked on research and development projects and provided training and education and for these reasons have in-depth knowledge of these challenging environments. Obviously, there is a degree of subjectivity that may bias the evaluation of this work. However, these studies have value as they may stimulate other assessments in similar contexts and promote further discussions on an international level with donors and policymakers.

4.5. Global recommendations

Surveillance systems may be improved by establishing routine communication processes. Such collaboration will be successful if information flow and data sharing improve from both sides (government officers and community members). Routine communication that goes beyond the relationships developed with farmers during outbreaks should be established. As researchers working in developing territories, we must move beyond the "surveillance of surveillance" so often emphasised. While networks of networks, including regional networks, are necessary, they do not usually tackle problems at the source i.e. at herd and farms levels. Health management in challenging environments needs innovative methods and tools that are built in close connection with rural populations and stakeholders. The integration of different disciplines (biology, ecology, social and modelling sciences) and sectors (veterinary, medical, environmental and rural development) is needed to address the challenges faced by surveillance system designers in resource-constrained settings.

In contexts such as Cambodia or Madagascar, where resources for surveillance are restricted and often dependent on uncertain and variable external funding, a priority should be placed on the use of cost-effective methods and tools. Participatory modelling and simulation can assist decision makers and local stakeholders to design such methods (Collineau et al., 2013; Duboz, 2013). In the same way, design of risk-based surveillance systems, using exposure and risk assessment methods, should be supported (Stärk et al., 2006). These approaches will help to identify surveillance needs, set priorities, select appropriate surveillance activities and allow for optimal allocation of resources.

It will be necessary to combine these diverse approaches in order to optimise surveillance for emerging and endemic diseases in these countries. Surveillance must be conducted as a partnership with various local and national stakeholders, and be consistent with the recommendations of international agencies (OIE, FAO, WHO). A combination of participatory approaches, companion modelling and modern information technology could enable weaknesses in surveillance systems to be better identified and help to overcome some of the constraints inherent in developing countries. Comparing experiences from a range of low-income countries allows the generation of new knowledge, supports development and fuels the debate among scientists and policy-makers on how to improve animal health surveillance through better collaboration.

5. Conclusion

This review allowed us to highlight the main limitations and advantages of the tools and methods developed and assessed in the field of animal diseases surveillance in Cambodia and Madagascar (Fig. 2). A lot of the methods were linked to the design of risk-based approaches enabling the surveillance to be more cost-effective at the expense of representativeness. However this drawback has little impact when the surveillance objective is the early detection of disease. Lack of simplicity and sustainability of the processes are directly connected to the field of research. Innovative tools, typically developed during time limited projects can at first be seen as complex, but they often appear simpler as they are used more and become endorsed by policy makers. Sustainability remains a great challenge. To overcome it researchers should improve interactions with governmental organisations, international agencies, and donors with respect to research outputs from innovative surveillance approaches. Flexibility and usefulness of the methods are critically important in resource poor countries. Ownership and sensitivity are linked and are often the main weaknesses of the surveillance systems in these countries.

Finally, this in-depth analysis of studies in Madagascar and Cambodia demonstrated that generally there is poor communication between farmers, various stakeholders and authorities. Information is often communicated to farmers when there is a confirmed case of a major disease. However communication of surveillance results for other diseases, to the rural populations most affected is commonly insufficient. In accordance with the international standards and recommendations of OIE, FAO, and WHO, research on innovative and creative methods and tools should be developed for adapting surveillance systems in poor countries largely at-risk and highly vulnerable to emerging and endemic animal and zoonotic diseases.

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