A SYSTEMS APPROACH FOR DESIGNING AN INTEGRATED ANIMAL HEALTH SURVEILLANCE SYSTEM IN TANZANIA

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A THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE MOROGORO, TANZANIA.

2022

EXTENDED ABSTRACT

Animal health surveillance plays a vital role in ensuring public health, animal welfare, and sustainable food production by monitoring disease trends, early detecting (new) hazards, facilitating disease control, and providing data for risk analysis. However, Tanzania's animal health surveillance system is currently not adequately equipped to address ever-increasing infectious diseases particularly emerging and re-emerging ones due to several inefficiencies, including fragmented data sources and their processing, delays in detection and underreporting. Lack of an efficient animal health surveillance system prevents the country from effective prevention and control of potential outbreaks and the spread of infectious livestock diseases resulting in high disease burden to the livestock keepers and the national economy. One of the solutions to such limitations could be to develop an integrated animal health surveillance system that is cost-effective by leveraging the existing technologies. The aim of the study was to develop integrative solutions for improving animal health system in Tanzania using a systems approach.

The thesis integrates multiple research methods that give perspectives on various aspects of animal health surveillance systems. The study involved systematic review, extensive field investigation, and systems integration. The systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA-P) 2015 checklist. Peer-reviewed articles obtained from five databases and eligible articles were assessed for quality using QualSyst Tool. The final list of articles was then synthesized thematically. Field investigations were organized into two phases: Phase I was conducted in Ngorongoro, Kibaha and Kongwa districts, focusing on the situational analysis of the existing animal health and related systems and process evaluation of the current national animal health surveillance system. Phase II involved Kilombero, Sikonge and

Sumbawanga districts focusing on subnational level stakeholder mapping for the animal health surveillance system. Various data collection techniques were deployed during field data collection, including documentary reviews, cross-sectional surveys, key informants' interviews, non-participant observation, and stakeholders' workshops.

The final part of the research was the development of a prototype of an interoperable animal health surveillance system in Tanzania. It was developed using Hypertext Processor (PHP) version 7.4 (Laravel framework), Python version 3.8.0 and MySQL database. Three animal health information systems: FAO EMPRES Global Animal Disease Information System (EMPRES-i), Sistema Informativo di Laboratorio (SILAB) and AfyaData were linked to the central data repository through Application Programming Interfaces (APIs).

The findings of the study are presented in five scientific papers. The first three papers in this thesis focus on gaining an in-depth understanding of the appropriate integration mechanisms in health surveillance systems, animal health surveillance situation, and contextual factors that influence the performance of the systems. The last two papers focus on operationalizing the integrated animal health surveillance system in Tanzania by looking into stakeholders' collaboration and prototype of the proposed integration.

A systematic review (Paper 1) reveals that integration in health surveillance systems is a relatively new concept which picked pace in the 2010s. There were very few integrated systems in animal health surveillance compared to human health. The common integration mechanisms were interoperability and semantic consistency. The results in paper 2 shows a lot of commonalities in the data sources in terms of relevant surveillance variables and area coverage but diverse in quality. However, despite the richness of the data sources for animal health surveillance, very few of them were being used actively and are fragmented. Paper 3 confirms that the performance of animal health surveillance is attributed to several interconnected factors which need to be analyzed and addressed holistically. More specifically, it reveals deviations in the implementation of surveillance from core principles and guidelines. Most identified challenges were systemic hence need systemic solutions and very little financial commitment to surveillance activities and its effect spilt over every component.

Paper 4 demonstrates the importance of animal health stakeholder mapping, especially at the sub-national level, and how stakeholders' collaboration can be leveraged to improve the efficiency of the system in early disease detection and response. The study established that community-level stakeholders had the strongest relationship with government animal health practitioners compared to other stakeholder categories. Meanwhile, the private sector had more resource-based influential stakeholders, while political leaders had more non-resource-based influence. Paper 5 presents a generic prototype of an interoperable animal health surveillance system in Tanzania, the ***Wanyama*** he**A**lth su**R**veilla**N**ce (WARN). The prototype has demonstrated the possibility of having an integrated multi-data source animal health surveillance system through the interoperability of existing animal health information systems.

This research confirms the complexities of the animal health surveillance systems and that their analyses require systems lens and integrative solutions. The final output of this thesis is the prototype. Its generic and flexible architectural features make it adaptable hence can be used beyond Tanzania with provision for data integration from other surveillance systems. Therefore this should be considered in the future to experiment on how we can move from single- to multi-sectoral health surveillance systems in the direction of One Health approach.

DECLARATION

I, JANETH GEORGE, do hereby declare to the Senate of Sokoine University of Agriculture that, this thesis is my own original work and that it has neither been submitted nor concurrently submitted for a degree award in any other institution.

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(Supervisor)

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ACKNOWLEDGEMENTS

Doing research in animal health surveillance systems has helped me understand even better how important animal health is to the humankind, so does my contribution. Therefore, working with others in this research has been invaluable undertaking and inspiring and finally I am here to express my sincere gratitude to everyone who make this a reality but above all My Almighty God for His grace and mercy.

First of all, I would like to express my gratitude to the Government of United Republic of Tanzania and the World Bank for financing my study [WB-ACE II Grant PAD1436) through SACIDS Africa Centre of Excellence for Infectious Diseases of Humans and Animals in East and Southern Africa. I also thank Royal Veterinary College, University of London, UK for hosting during my two-month visiting studentship and supported me with all the necessary facilities including office space, library, ICT resources, accommodation and serene study environment.

Completion of this study would not have been possible without great supervision team who provided both technical and moral support throughout the journey. Their guidance and professional advice kept me going even at the times when I felt I couldn't do it anymore. In particular, I would like to thank my primary supervisor Prof. Sharadhuli I. Kimera for accepting me when I was stranded and provided all the support I needed to make sure I finish on time, you are my winning team. Dear Dr. Barbara Häsler you have been more than a supervisor to me, always there to listen even on trivial things and sometimes a girl-to-girl talks which I needed to keep me going. Wherever I go, will always cherish your self-less kind and repay back by supporting others to be great selves. To Prof James ED Mlangwa and Prof. Mark Rweyemamu, I couldn't have done this PhD without your fatherly talk and encouragement that “You can do it”. You trusted and believed in me before I could trust myself; your wisdom, vision and endless support have taken me this far, and in tears of joy, I am saying *Ahsante sana!* I owe gratitude to Prof. Erick Komba and Dr. Calvin Sindato for their guidance, mentorship and encouragement.

This study also benefited from critical review from Dr. Leonard Mboera who held my hands and helped taking baby steps towards publishing, Prof. Dominic Kambarage who has been steering great discussions during my seminar presentations and Prof. Tandi Lwoga who supported me when I was doing systematic review. SACIDS-One Health Sciences Community of Practice under the leadership of Prof. Esron Karimuribo has been very instrumental in providing mentorship and peer-to-peer support.

I would like express my appreciation to the staff of the Ministry of livestock and fisheries for their generous support in all stages of this research, especially: Prof. Hezron Nonga (Director of Veterinary Services), Dr. Selemani Makungu, Dr. Svetlana Ranga. Dr. Benezeth Lutege, Dr. Gibonce Kayuni and Dr. Zacharia Makondo. I also extend my sincere thanks to the Food and Agriculture Organization of the United Nations (United Republic of Tanzania Country office), particularly Prof. Folorunso Fasina and Dr. Moses Ole-Neselle for the technical guidance. Fieldwork couldn’t have been easy without coordination and support from staff of Ngorongoro, Kibaha, Kongwa, Sumbawanga, Sikonge and Kilombero districts and willingness of respondents to participate in the study, therefore I owe them very much.

I will never forget COVID-19 pandemic for the rest of my life for the disruption it has caused but through these difficult times I also discovered great virtual community full of great people. For the past one year, PhD Forum (virtual writing room) pioneered by Dr. Donnah Peach has been a home to me. I met one big family who volunteered to be accountability partners, writing buddies, cheerleaders to each other despite our differences in time zone, backgrounds and nationalities. Special thanks to Will Francis (Los Angeles) who made sure I wake up and join the room every single day. I am grateful for the support from fellow students; Dr. Neema Opiyo, Gaspary Mwanyika, Rogers Azabo, and Irene Mremi who despite their struggle, they could still make sure I remain sane and focused.

I wish to acknowledge and thank my technical backstopping team-Reinfred Ngolongolo, Angelina Bululu, Dorothy Mtatifikolo, and Mpoki Mwabukusi and research assistants-Neema Salali, Ramadhani Muhala, Elly Ahimidiwe Kimaro, and Simon Kabendela for working with me tirelessly. I also thank SACIDS secretariat for their support in administration and logistics issues. I thank my former employer, NIRAS Tanzania Limited for allowing me to use the office facilities whenever I needed.

In special way, I am grateful to my parents and my immediate family and friends for their love, prayer and support throughout this PhD journey, they kept me going- my parents, Nyakorema and George; my son, Wilhelm-Prince; my sister Julieth; my brothers Steven and Browlin. I also express my thanks to my great friend Elly Ahimidiwe and sisters by choice, Lina, Agnes, Happy, Ntuli, Betty, Queen, Elizabeth, and Angelina for their moral support throughout my study. As it may not be possible to mention everyone, every contribution to this work is highly appreciated.

DEDICATION

To everyone who believed I could. I have done it and made you proud. To my son Wilhelm-Prince. If I did this, you can also be whoever you want to be in life. Just trust the process. To Prof. Mark Rweyemamu, the little girl you blessed with words" You are the little shining star" is about to get a PhD. I am forever grateful.

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Paper II: *Published as:* **George, J.,** Häsler, B., Komba, E., Sindato, C., Rweyemamu, M. and Mlangwa, J. (2021). Towards an integrated animal health surveillance system in Tanzania: making better use of existing and potential data sources for early warning surveillance. *BMC veterinary research*, *17*(1): 1-18. https://doi.org/10.1186/s12917-021-02789-x.

Paper III: *Published as*: **George, J.,** Häsler, B., Komba, E. V., Rweyemamu, M., Kimera, S. I. and Mlangwa, J. E. (2021). Mechanisms and Contextual Factors Affecting the Implementation of Animal Health Surveillance in Tanzania: A Process Evaluation. *Frontiers in Veterinary Science*, *8*:1-16 DOI: 10.3389/fvets.2021.790035

Paper IV: *Published as***: George J**, Häsler B, Komba EVG, Sindato C, Rweyemamu M, Kimera SI and Mlangwa JED (2021) Leveraging Sub-national Collaboration and Influence for Improving Animal Health Surveillance and Response: A Stakeholder Mapping in Tanzania. *Frontiers in Veterinary Science,* 8:1-13 DOI: 10.3389/fvets.2021.738888.

Paper V: *Submitted as:* **Janeth George**, Renfrid Ngolongo, Barbara Häsler, Calvin Sindato, Mark Rweyemamu, James ED Mlangwa and Sharadhuli I Kimera. WARN: A prototype of an interoperable animal health surveillance system for early disease detection in Tanzania. *Submitted to One Health Outlook.*

LIST OF ABBREVIATIONS AND SYMBOLS

API	Application Programming Interfaces
AMR	Antimicrobial Resistance
ARDS	Agricultural Routine Data System
AU-IBAR	African Union Interafrican Bureau for Animal Resources
CDC	Centre for Disease Control
DVO	District Veterinary Officer
DVS	Director of Veterinary Services
EMA-i	Event Mobile Application
EMPRES-i	EMPRES Global Animal Disease Information System
GIS	Geographic Information System
JEE	Joint External Evaluation
MoLF	Ministry of Livestock and Fisheries
IHR	International Health Regulation
ODK	Open Data Kit
OIE	Office International des Epizooties (World Organisation for Animal Health)
PHP	Hypertext Processor
PRISMAP	Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols
SET	Surveillance Evaluation Tool
SILAB	Sistema Informativo di Laboratorio
TANAPA	Tanzania National Parks
TANLITS	Tanzania National Livestock Identification and Traceability System
TAWIRI	Tanzania Wildlife Research Institute

TVLA	Tanzania Veterinary Laboratory Agency
URT	The United Republic of Tanzania
USA	United States of America
WARN	***W****anyama* he**A**lth su**R**veilla**N**ce
WHO	World Health Organization
ZVC	Zonal Veterinary Centre

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Background

Surveillance plays an important role in both human and animal health. In public health, the Centre for Disease Control (CDC) defines it as the continuous scrutiny of the occurrence of diseases and health-related events to enable prompt intervention for the control of diseases (Buehler *et al.,* 2004). The RISKSUR [1]consortium defined surveillance as the systematic, continuous or repeated, measurement, collection, collation, analysis, interpretation and timely dissemination of animal health and welfare-related data from defined populations (Hoinville *et al.,* 2011). The World Health Organization (WHO) defined surveillance as the ongoing and systematic collection, analysis, and interpretation of health data in describing and monitoring a health event to support the planning, implementation and evaluation of public health interventions and programmes (WHO, 1997). From the three definitions, the key described features of surveillance are systematic data collection, analysis and interpretation of data, defined population(s), communication and intervention. Surveillance helps decision-makers to manage disease prevention and control more effectively by providing timely and useful information for targeted action (Nsubuga *et al.,* 2006).

In animal health, surveillance serves four main objectives, namely demonstration of disease freedom, early detection of disease, case finding and measuring the level of disease (Cameron, 2012). Surveillance is categorized into active, passive and sentinel (WHO, 2020). Types of surveillance may also be categorized to include early warning,

[1] https://www.fp7-risksur.eu/ The RISKSUR project, an EU FP7 funded project running from 2012 to 2015, was aimed to develop decision support tools for the design of cost-effective risk-based surveillance systems that integrate the most recent advances in epidemiological methodologies, based on an interdisciplinary approach and tailored to the needs of individual EU Members States

indicator-based, hazard-specific, general surveillance, and syndromic, event-based, risk-based, enhanced passive and participatory surveillance (Hoinville *et al.*, 2011).

In recent years, there have been increased concerns about the spread of animal infectious diseases due to their overwhelming impact on animal welfare, international trade, public health, ecosystem health and economic well-being of people who depend on animals as a source of livelihood. Current world trade and travel patterns favour the rapid movement of people, animals (livestock, fish, pets, and wildlife), and their products around the world, which result in more frequent introductions of new diseases into naïve human and animal populations (Berezowski, 2010). Additionally, the trend in livestock production is toward larger herds and flocks with greater animal density and increased risk of rapid propagation from natural and intentional agroterrorism-related disease events (McCluskey, 2007). These overwhelming challenges highlight the need for (more) effective and efficient surveillance systems. By having robust animal health surveillance systems in place, the detection and control of animal diseases, including zoonoses, becomes more likely (Bisdorff *et al.*, 2017). They will also ensure smooth international trading of live animals and their products, protect the public from zoonotic and foodborne diseases, improve animal welfare, and protect the economic well-being of the producers and other stakeholders in livestock food systems (Lees and Prince, 2017).

However, surveillance is an ever-evolving activity that needs to be backed up by the best available scientific evidence and methodology (Willeberg, 2012). Research and development generate novel approaches and initiatives for strengthening surveillance systems at national and international levels for early detection and response to control disease outbreaks at source. That includes exploring innovative surveillance approaches such as participatory and syndromic surveillance (Way *et al.*, 2010; Dórea *et al.*, 2011;

Queenan *et al.,* 2017) and integrating data across the systems (Hardstaff *et al.,* 2012; Muellner *et al.,* 2015). Animal health surveillance also benefits from technological advancements such as mobile technologies (Mwabukusi *et al.,* 2014; Karimuribo *et al.,* 2017) to improve data capture, transmission, analysis, and visualization efficiency. The majority of the surveillance systems have surpassed the initial emphasis on infectious diseases only to include monitoring and forecasting of a broad range of health determinants (Cameron, 2012). Generally, the modern concept of surveillance has been shaped by a rapid evolution in informatics and digitalization, particularly in public health. The literature indicates that new innovations in animal health surveillance are few compared to public health (Scotch *et al.,* 2009; Lee and Brumme, 2013). Halliday *et al.* (2011) emphasized the importance of evaluating the utility of these innovations and how they can complement rather than replace the existing classical epidemiological approaches.

1.2. Value of animal health surveillance in strengthening global health security

Animal health surveillance has demonstrated its value in global health security and is now recognized as a key element in predicting public health risks linked to animal populations or pathogens transmitted between animals, people and their shared environments. Surveillance of animal populations can provide important early warnings of emerging threats to human populations from bioterrorism or naturally occurring infectious disease epidemics (Meidenbauer, 2017; Neo and Tan, 2017). There is scientific evidence on how animals, through sentinel surveillance, can predict human risks such as food contamination, infectious diseases, and bioterrorism, enabling early intervention to reduce the risk for people (Gubernot *et al.,* 2008; Schmidt, 2009; Hilborn and Beasley, 2015).

For example, given the increased human-animal interaction, animal-based surveillance data have been useful in mapping areas affected by zoonotic disease agents and model the epidemic spread by looking at the spatial and temporal patterns of animal host distribution (Childs *et al.,* 2007; Rotejanaprasert *et al.,* 2018). Day *et al.* (2012) justified the need for surveillance of companion animals as a means for controlling ever-evolving influenza viruses, and while the COVID-19 pandemic underscored the importance of veterinarians in early detection at the human-animal interface (Bhatia, 2020) through a survey of animal reservoirs, intentional sentinels and linkage and analysis of surveillance data from animals and human helps to reduce human risks of contracting diseases (Scotch *et al.,* 2009). Animal health-related surveillance has also been used in addressing food safety issues and control of antimicrobial resistance challenges (Boeckel *et al.,* 2019). The mentioned examples are regarded as global health threats because their occurrence may lead to pandemics with long-standing impact, destabilize governments, pose overall security and economic risk, and threaten food security and global economies (GHSA, 2019). The overwhelming evidence on the value of animal health surveillance in addressing global health threats emphasizes the importance of having a stronger animal health surveillance system at national, regional, and international levels.

1.3. Economics of animal health surveillance

Animal health surveillance, if well implemented, generates both monetary and non-monetary benefits. One of the rationales of the animal health surveillance is to protect the interest of the producers and economy at large and comply with international trade rules (Ahmadi, 2014), design and evaluate interventions and guide decisions their implementation (Häsler *et al.,* 2017) and inform cost-effective control of diseases hence improve productivity and food security (Calba *et al.*, 2014). Other economic values of animal health surveillance include minimizing the economic impact of livestock diseases through early detection and priority setting for resource allocation in animal health interventions. However, to realize the benefits of surveillance, it is important to link to disease and interventions. Surveillance and intervention are regarded as technical substitutes since the reduction of one increases the level of the other to reach the same benefits (Häsler *et al.,* 2017).

Investing in animal health and veterinary services of which surveillance is an integral part can have a measurable impact on the health of people and the environment (Huntington *et al.,* 2021). However, direct value of surveillance may be difficult to measure as it has to be linked with right intervention. The degree of public funding depends on nature of disease and its associated economic impact (Ahmadi, 2014) but how to reach to such decision is not clear. Drewe *et al.* (2014) argued that in order to understand the benefits of surveillance, one must first clarify who pays the costs and who gains. On the other hand, we are living in the globalized world where the disease impacts are assessed at the interface of economic, social, scientific and political forces. Magnitude of such impacts warrant the inclusion of science-based international standards and investment in robust animal disease surveillance systems (Evans, 2006).

To decide which surveillance system to go for, economic criteria are paramount in decision-making given the resource constraints, but animal health surveillance systems are rarely subjected to rigorous economic appraisal (Häsler *et al.,* 2016). The most used economic evaluation methods are cost-benefit-analysis (CBA) and cost-effectiveness-analysis (CEA). The former uses monetary units to quantify the cost and outcomes of the intervention used to justify a defined strategy or assess the impact of the past programme (Martins and Rushton, 2014). On the other hand, cost-effectiveness analysis compares costs (in monetary units) and consequences (in natural units) of the two or more alternatives. It is mainly used when competing for alternatives to produce a common health consequence or find the alternative with the greatest outcome per input. Pinior *et al.* (2014) have discussed the advantages and limitations of each method as summarized in Table 1.1.

Table 1.1: The strengths and the weaknesses of the methods for the economic evaluation of animal diseases

Method	Strengths	Weaknesses
Cost-benefit analysis	Different preventive- or intervention measures can be compared directly because costs/benefits are expressed in monetary units	Intangible costs and benefits cannot be considered directly
Cost-effectiveness analysis	An aid in order to consider parameters in the assessment, which are monetarily difficult to assess	Subjective nature of the assessment with respect to the effectiveness of measures;
Linear programming	Can be used in the veterinary area to identify the least cost set of preventive- or intervention measures with the constraint that a certain level of animal disease control is achieved	Can only be used if there is a guarantee that the variables are independent from each other
Partial budgeting	Estimates the direct effects of the change in consideration of supply and demand behaviour on market; Focuses attention on the issues that are of interest	No clear time horizon can be specified No comparison can be made with alternative investments

1.4. Innovations in animal health surveillance

Limited infrastructures and other resources, especially in low-income countries, have stimulated a number of innovative approaches and tools for improving animal health surveillance. Countries are now departing from traditional surveillance to other novel approaches such as syndromic and participatory surveillance, which are more flexible, timely and relatively inexpensive (Mariner *et al.,* 2011). Participatory animal disease surveillance has been recognized as a panacea to the existing high level of animal disease underreporting in low-income countries (Babalobil, 2011), while syndromic surveillance also offers opportunities that go beyond early detection of diseases providing information to aid planning and policy development (Dórea *et al.,* 2011).

There has been evolution in animal health surveillance seeking to exploit the advancement of Geographic Information System (GIS), information and technology and communication (Davies *et al.,* 2007) for improving data accuracy and timeliness. Mobile technologies advancement is regarded as an alternative route for fast-tracking disease surveillance activities and addresses some paper-based challenges, as pointed out by (Mwabukusi *et al.,* 2009). Given the wide distribution of cellphone users and the increase in network coverage even in resource-limited countries, mobile phone technology can provide capacity for two-way communication and feedback of data to participants in surveillance, which is a critical element of system effectiveness and sustainability. Through technology, the world is becoming more disease intelligent as there is a great move from many countries to establish epidemic intelligence by integrating disease reporting systems with other animal information components such as laboratory data (Dórea *et al.,* 2011), livestock movement records (Gates *et al.,* 2015), private veterinary clinics data (Muellner *et al.,* 2016), production records (Hutchison *et al.,* 2019), and abattoir data (Vial and Reist, 2014). Nevertheless, most of these innovative approaches are still in the infancy stages, with lower uptake in animal health than public health. Hence, they need more data-driven evidence and investment to influence their utility.

1.5. Theoretical support for systems approaches to surveillance systems analysis and improvement

The outcomes of a surveillance system on reducing the disease and its impact are a combination of complex interactions between surveillance processes, enablers and context on which the systems operate. Therefore, when evaluating the performance of the system, it is important to focus beyond the surveillance processes and look into the contextual and structural factors and their relations to the system. In order to do that, one must use systems thinking approaches that aim at understanding why a system works the way it does (system synthesis) instead of how a system works (system analysis) (Pourdehnad *et al.*, 2011).

Hitchins (2008) defined systems thinking as thinking scientifically about phenomena, events, situations, etc. from a systems perspective, i.e. using systems methods, systems theory and systems tools, while Best *et al.* (2007) defined it as an approach for studying and managing complex feedback systems, such as one finds in business and other social systems. Systems thinking theories propose an understanding of a system by holistically examining the linkages and interactions between the elements that compose the entire system (Chen, 2016). Best and Holmes (2010) pointed out theoretical underpinnings to systems approaches as follow: systems are dynamic and constantly changing; systems themselves exist within other, interdependent systems (e.g. individual, organizations, and community); changes in one part of the system can have unexpected changes in other parts of the system. In health settings, systems thinking has been used in various interventions related to control of tobacco use, obesity and tuberculosis (Best *et al.*, 2007; De Savigny and Adam, 2009) and conceptualization of Eco-health and One Health approaches (Zinsstag *et al.*, 2009). In the surveillance context, it can take into account the role of government, data sources and technology as grits that make up the system wholly.

Berezowski *et al.* (2019) applied the complex adaptive system theory to demonstrate how animal health surveillance can be analyzed holistically through a systems lens. However, despite its usefulness, the authors acknowledge the untapped potential application of the approach in designing and evaluating health interventions.

This study conceptualized animal health surveillance as a complex adaptive system that operates in open system principles (Figure 1.1). The system comprises a set of interrelated agents (inputs, enablers and outcomes) that interact with each other and the environment where the system operates (political will, legal framework and international guidelines). The agents are also sub-systems with their own interactions while forming part of the larger system. The adaptive nature of the system is due to dynamic interactions between the agents and interaction between the agents and their external environment (Berezowski *et al.*, 2019) and can evolve in response to the needs of its surroundings (Sturmberg and Bircher, 2019). Understanding animal health surveillance using a systems lens helps to identify critical and leverage points for system performance.

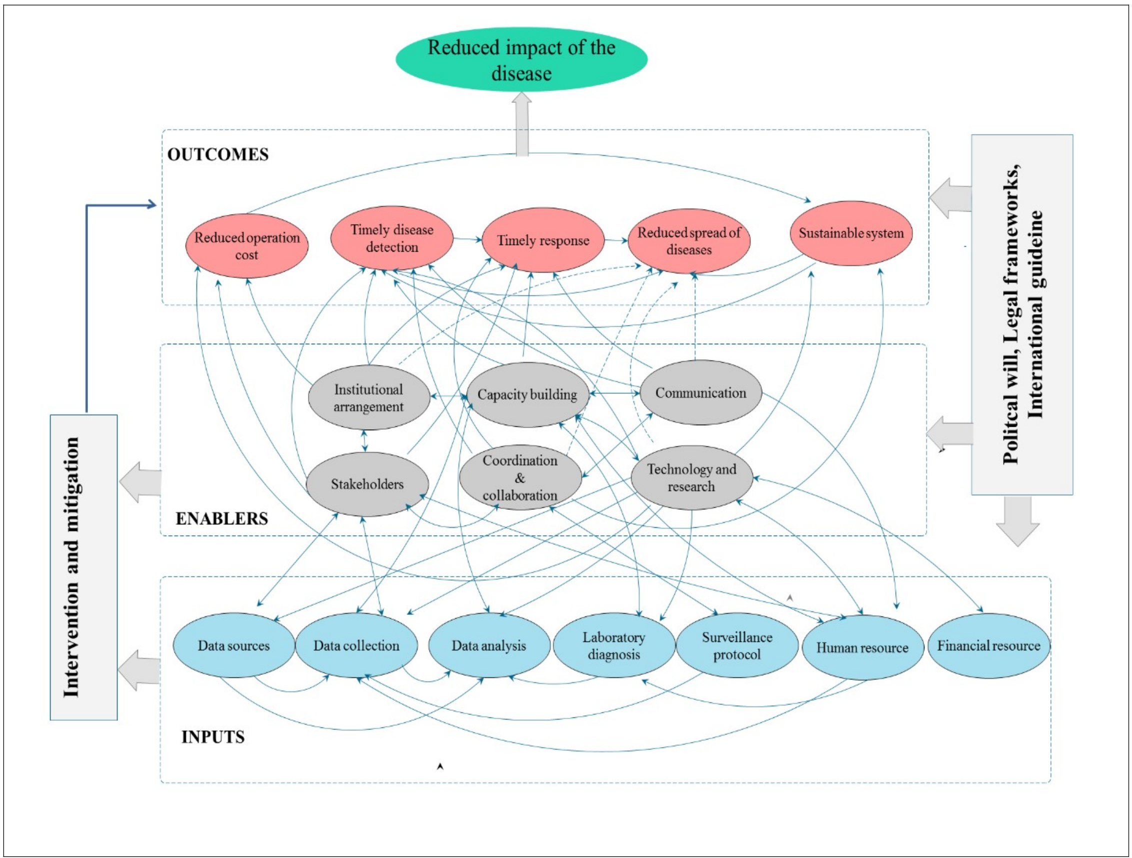

Figure 1.1: Animal health surveillance system as a complex adaptive system

The system is made up of three main agents (inputs [blue boxes], enablers [grey boxes] and outcomes [salmon boxes]), which are interrelated and interact with each other and its external environment (political will, legal frameworks, and international guidelines). With appropriate intervention, the interactions ultimately lead to the achievement of the overall impact (reduced impact of the disease).

1.6. Problem statement and justification

1.6.1. Problem statement

Tanzania has an estimated population of 32.23million cattle, 21.29 million goats, 5.65 million sheep, 79.1 million chicken, 2.14million pigs and 657 389 donkeys, among other species. In 2019/2020, the value of live animals and skins sold amounted to 1.6 trillion

TZS and 23.9 billion TZS, respectively, while the government earned 10.7 bilions TZS from various levies (URT, 2020a). In 2019, the livestock sector grew by 5%, contributing 7.2% of the GDP. Despite these great economic resources, the livestock sector growth and its contribution to the national Gross Domestic Product (GDP) are still low. Diseases including Transboundary animal diseases (TADs), zoonotic disease and vector-borne diseases are the major constraint to the growth of the livestock sector in Tanzania (URT, 2019). Between 2018 and 2020, a total of 1562 cases were reported affecting 1 358 902 livestock (cattle, sheep and goats) including 538,494 deaths (URT, 2020a). The ten-year spatial-temporal analysis on priority diseases in Tanzania also revealed the increase in disease outbreaks for the past five years (URT, 2020b). Despite the increased occurrence of livestock diseases, the Ministry of Livestock and Fisheries (MoLF) has inadequately prevented and controlled outbreak and spread of livestock diseases partly as a result of inadequate surveillance system (URT, 2020).

Several evaluations conducted between 2008 and 2017 indicated the limited capacity of the national animal health surveillance system to detect and respond to disease outbreaks. Tanzania's animal health surveillance system has been evaluated using various standard tools, namely the OIE Performance of Veterinary Services (PVS) evaluation in 2008 and 2016, PVS Gap analysis in 2009 and the FAO Surveillance Evaluation Tool (SET) in 2017. The system was also subjected to a Joint External Evaluation (JEE) in 2016. The second PVS evaluation of 2016 pointed out technical strengths and weaknesses of the surveillance, among other components. It showed that the technical authorities and capacities had not changed since the 2008 evaluation. The underreporting was still high with more than 90% of the reports were based on symptomatology, the system was manned by limited number of veterinary paraprofessionals and was also characterized by inadequacy in-service trainings on surveillance and disease control, insufficient funding and an unclear communication chain (OIE, 2016). The Surveillance Evaluation Tool (SET, 2017) report highlighted strengths in the analytical aspects of laboratory, epidemiology workforce management, training, and internal communication. It also pointed out areas that needed improvement, including unclear roles and responsibilities of partners in the surveillance system, limited supervision, partial harmonization of surveillance activities at the field level, low inter-sectoral collaboration and limited integration between laboratory and surveillance system (URT, 2017). The identified weaknesses pose a major challenge for the country to implement effective surveillance programmes for disease control.

1.6.2. Justification of the research

Timely information about infectious disease events is among the fundamental aspects of any health surveillance system for prompt actions. However, Tanzania's animal health surveillance system is currently not adequately equipped to address ever-increasing infectious diseases particularly emerging and re-emerging ones due to several inefficiencies, including fragmented data sources and their processing, delays in detection and underreporting. Lack of an efficient animal health surveillance system prevents the country from effective prevention and control of potential outbreaks and the spread of infectious livestock diseases resulting on negative implications on livelihoods of resource-poor livestock keepers and the national economy. The persisting challenges indicate the complex interrelationships between the performance of the surveillance system and its processes, political and institutional frameworks at all levels. One of the solutions to the identified limitations could be to develop an integrated animal health surveillance system that is cost-effective by leveraging the existing technologies. Houe *et al.* (2019) argued that the complexity of the global animal health challenges and related issues requires integrating and coordinating information and data from different sources.

A well-integrated animal health surveillance system is a cornerstone in addressing various global health security threats such as zoonotic diseases (Halliday *et al.,* 2014), antimicrobial resistance and food safety (Acar and Moulin, 2013). Muellner *et al.* (2015) believed that the future of veterinary public health surveillance lies in developing truly integrated surveillance systems (multi-country, multispecies, epidemiological metadata combined with sequence data) with sufficient analytical and reporting/early-warning capacity. Several studies have demonstrated how integration can improve surveillance systems attributes (Napoli *et al.,* 2013; Toutant *et al.*, 2011; Wimberly *et al.*, 2017), early detection (Leal and Laupland, 2008) and help to tackle global health threats (Halliday *et al.,* 2011; Neo and Tan, 2017). Nevertheless, there are very few documented studies on the integration of animal health surveillance systems and their effect on performance. Therefore, further research is needed to explore integration options that fit the context, all facilitating factors, and potential barriers to operationalizing such systems.

In Tanzania, there have been several technological interventions to address animal health surveillance system challenges. Some of the interventions include the introduction of digital surveillance tools and web-based information systems such as FAO Event Mobile Application (EMA-i) Afyadata, Laboratory Information Management System (SILAB- Sistema Informativo di Laboratorio -LIMS) and Agricultural Routine Data System (ARDS). However, they are still at infancy stages with no integration and little coordination, which leads to the duplication of efforts. Therefore, this study hypothesized that the system could be improved through appropriate integration. It was envisaged that an integrated animal health surveillance system that considers social and technical aspects could improve early disease detection in both animals and humans. The study is in line with the National Livestock Research Agenda (2020-2025) thematic area III i.e animal health, disease management and public health and a 5-year (2019–2024) animal health surveillance strategy by contributing to the development of early warning systems and surveillance of animal diseases.

1.7. General aim and specific objectives

1.7.1. Aim

The aim of the study was to develop integrative solutions for improving animal health system in Tanzania using a systems approach.

1.7.2. Specific objectives

i. To document existing integration mechanisms in health surveillance systems and their contribution to strengthening surveillance attributes.

ii. To characterize existing animal health surveillance and other animal health information systems in Tanzania to identify leverage points for integration.

iii. To conduct a process evaluation of the current national animal health surveillance system.

iv. To develop a prototype of an integrated animal health surveillance system in Tanzania, including facilitating factors for its operationalization.

1.8. General methodology and thesis outline

This thesis details the systematic approach for the development of an integrated animal health surveillance system in Tanzania. The study involved extensive field investigation, systematic review and systems integration. Data were collected using various techniques, including systematic review, questionnaire administration, key informants' interviews, non-participant observation and stakeholders' workshops. Various analytical skills were applied to process, analyze and interpret data including thematic and content analyses, Microsoft™ Excel application, and programming.

This thesis is organized into three chapters. Chapter 1 gives the general introduction and sets the scene for the work. It is followed by chapter 2 that comprises five papers (paper 1-5) anchored in distinct research questions. Chapter 3 reiterates the research findings and main conclusions of the study. It starts by summarizing the key results of the four research questions and reflects on the proposed prototype of an integrated animal health surveillance system, its implication in disease surveillance in Tanzania and pre-conditions for it to be operational. This chapter also points out the limitation of this research, recommendations and areas for future research.

The performance of any animal health surveillance system is linked to many factors. Therefore, to design an appropriate integrated system, one requires an in-depth understanding of the current animal health surveillance situation and contextual factors that influence its performance. Furthermore, the selection of the integration options must consider its prerequisites and limitations; hence it is essential to learn from others' experiences. Finally, it is equally important to identify leverage points for the integrated system to be operational, impactful and sustainable. In this thesis, such linkage is described in Chapter 2 in the form of scientific papers. Each paper is centred on the key research question and its respective objective, as depicted in Figure 1.2.

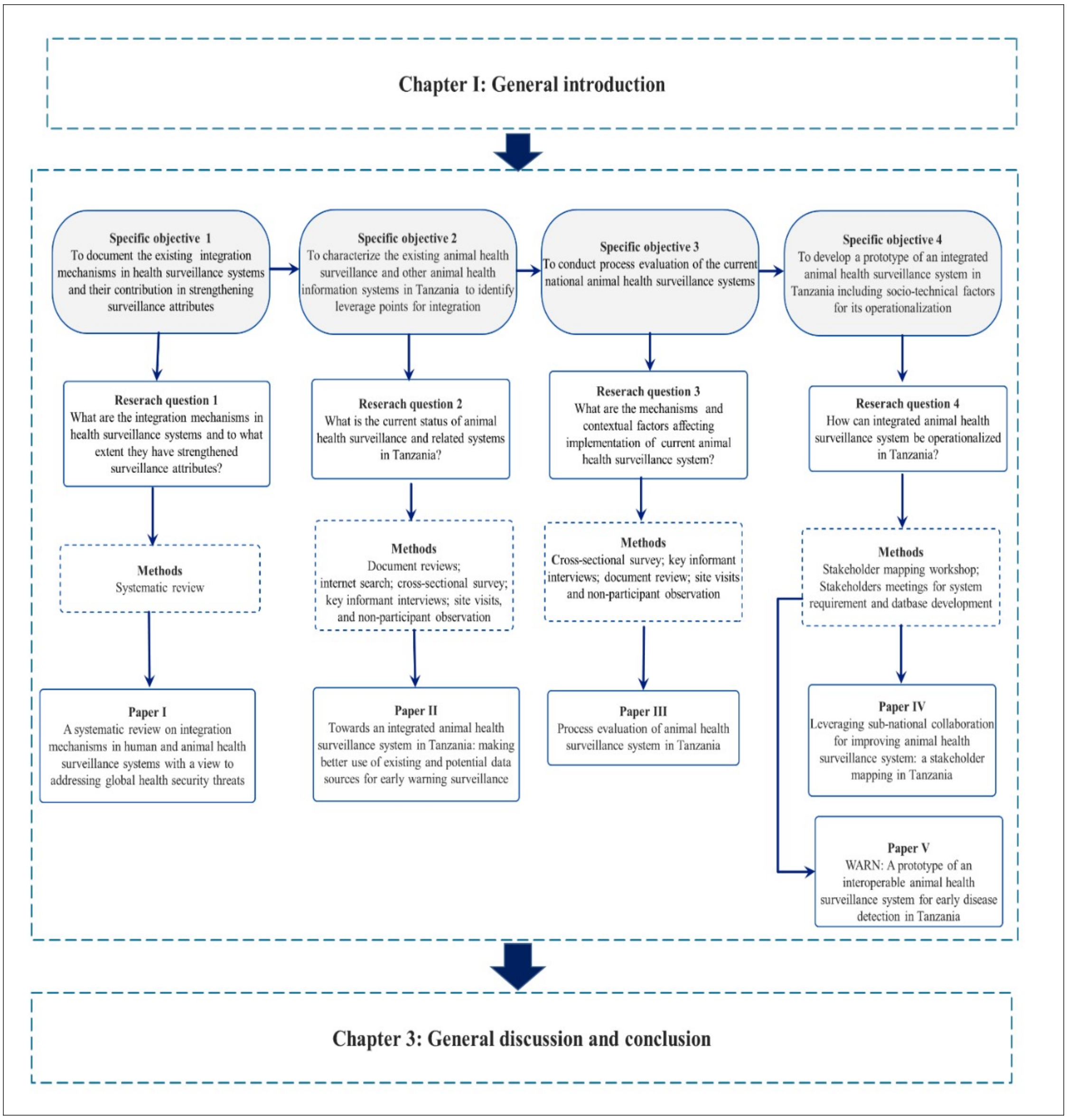

Figure 1.2: Schematic diagram detailing the research objectives and questions, methodology and development of scientific paper

Paper 1 (*A systematic review on integration mechanisms in human and animal health surveillance systems with a view to addressing global health security threats*) identifies and categorizes existing integration mechanisms, point out the value of integration in strengthening surveillance and key aspects to consider when integrating the systems.

The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA-P) 2015 checklist. Peer-reviewed articles were searched from PubMed, HINARI, Web of Science, Science Direct and advanced Google search engines. The search captured articles published in English from 1900 to 2018. The study selection considered all articles that used quantitative, qualitative or mixed research methods. Eligible articles were assessed independently for quality by two authors using the QualSyst Tool. Relevant information, including a year of publication, field, continent, addressed attributes and integration mechanism, were extracted. The findings from this review formed the basis for selection of the integration option for the prototype design and systems attributes to focus on when evaluating the performance of the integrated system.

As a response to research question 2 and its corresponding objective, paper 2 (*Towards an integrated animal health surveillance system in Tanzania: making better use of existing and potential data sources for early warning surveillance*) describes existing and potential data sources for enhancing early warning surveillance in Tanzania. It illustrates the flow and management of data from those sources to trace the integration level and proposes better ways of harnessing surveillance information from them. Using a mixed-method design, data were collected through document reviews, internet search, cross-sectional survey, key informant interviews, site visits, and non-participant observation to identify and assess the strength and weaknesses of each data source. Pre-defined criteria were used to assess the qualities of the data sources.

Paper 3 (*Mechanisms and contextual factors affecting the implementation of animal health surveillance in Tanzania: A process evaluation*) discusses how animal health surveillance is implemented vis-à-vis the national and international guidelines and mechanisms of impact and contextual factors influencing the implementation of surveillance activities. It also explores how the implementation processes are linked with surveillance outcomes. A process evaluation approach guided by a framework developed by Moore *et al.* (Moore *et al.,* 2015) was used to assess Tanzania's animal health surveillance system using the following attributes: fidelity, completeness, exposure, satisfaction, participation rate, recruitment and context. Quantitative and qualitative data were collected using a cross-sectional survey, key informant interviews, document review, site visits and non-participant observation. Data from questionnaires were downloaded, cleaned and analyzed using Microsoft™ Excel. Qualitative data were analyzed following deductive thematic analysis whereby data were reviewed, manually coded in MS Word and clustered to establish themes. Documents reviewed were analyzed by using content analysis method.

The operationalization of an integrated animal health surveillance system must consider both technical and social aspects, which are discussed in the last two papers. Paper 4 (*Leveraging sub-national collaboration and influence for improving animal health surveillance and response: a stakeholder mapping in Tanzania*) explores how sub-national animal health stakeholders' collaboration could be leveraged to strengthen national animal health surveillance system. A qualitative design was used involving consultative workshops with government animal health practitioners in Sumbawanga, Sikonge and Kilombero districts of Tanzania. Data were collected using an adapted USAID stakeholder collaboration mapping tool that with the following steps: (i) Define the objective (ii) Identify all stakeholders (iii) Take stock of the current relationships (iv) Determine resource-based influence (v) Determine non-resource-based influence and (vi) Review and revise the collaboration map.

Paper 5 (*WARN: A prototype of an interoperable animal health surveillance system for early disease detection in Tanzania*) describe the technical details of the developed system prototype. The system prototype was developed based on a Laravel framework, Python version 3.8.0, Hypertext Preprocessor (PHP) 7.4 programming languages, and MySQL database. Three systems: FAO EMPRES Global Animal Disease Information System (EMPRES-i), Sistema Informativo di Laboratorio (SILAB) and AfyaData were linked to the central data repository through Application Programming Interface (API).

CHAPTER TWO

Paper I

A systematic review on integration mechanisms in human and animal health surveillance systems with a view to addressing global health security threats

Paper II

Towards an integrated animal health surveillance system in Tanzania: making better use of existing and potential data sources for early warning surveillance

Paper III

Mechanisms and Contextual Factors Affecting the Implementation of Animal Health Surveillance in Tanzania: A Process Evaluation

Paper IV

Leveraging Sub-national Collaboration and Influence for Improving Animal Health Surveillance and Response: A Stakeholder Mapping in Tanzania

Paper V

WARN: A prototype of an interoperable animal health surveillance system for early disease detection in Tanzania

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Abstract

Timely information about disease events is a fundamental aspect of early warning surveillance system for aiding informed decisions and prompt actions. However, Tanzania's animal health surveillance system is currently not adequately equipped to address ever-increasing infectious diseases particularly emerging and re-emerging ones due to several inefficiencies, including fragmented data sources and their processing, delays in detection and underreporting. This study aimed to develop a prototype of an interoperable animal health surveillance system in Tanzania to improve early detection through utilization of data from complementary multiple sources ultimately enhancing timely response to disease outbreaks. In this paper, the ***Wanyama*** he**A**lth Su**R**veilla**N**ce (WARN) interoperable prototype is proposed. The WARN was developed using Hypertext Preprocessor (PHP) version 7.4 (Laravel framework), Python version 3.8.0 and MySQL database. This was demonstrated using data repository from three animal health information systems that are part of animal health surveillance in Tanzania: Emergency Prevention System Global Animal Disease Information System (EMPRES-i), *Sistema Informativo di Laboratorio*-Laboratory information management system (SILAB-LIMS) and AfyaData that were linked to the central data repository through Application Programming Interfaces (APIs). It gathers and integrates laboratory data, case-based event reports, data from field operation and syndromic data from the community and private veterinary facilities. The WARN was composed of three main components, which are: (a) Data acquisition, (b) data integration, and (c) data analysis and alert. It combined both case-based and syndromic surveillance indicators. Using sample records and dummy data pulled from SILAB and AfyaData repositories, the prototype was simulated and its outputs visualized on the unified interactive dashboard. Also while at the WARN dashboard, user was able to perform queries, access raw data in tabular forms and analyzed trends of the reported events. The initial simulation of the WARN using dummy data and archived records has demonstrated that an integrated animal health surveillance system in Tanzania could improve the sensitivity of the system in disease detection. The WARN is flexible to integrate large datasets hence the opportunity for disease trend analyses and predictions.

Keywords: Animal health, surveillance system, interoperability, Tanzania, prototype, WARN, EMPRESS-i, AfyaDATA.

Introduction

Tanzania is vulnerable to increased disease occurrence due to the nature of livestock production systems, which are characterized mainly by communal grazing and extensive livestock movements (1,2), informal livestock trading and unregulated movement of people and livestock along the borders with neighbouring countries (3). The high prevalence of livestock diseases in the country, such as transboundary, vector-borne, zoonotic and emerging infectious diseases present a significant challenge to improved livestock industry, animal welfare and public health (4). In this context, the country requires a robust animal health surveillance system for disease mitigation that allows promoting animal health and welfare, protecting human health, supporting efficient animal production, and enabling trade (5). Timely information about infectious disease events is among the fundamental aspects of any health surveillance system for prompt actions. However, Tanzania's animal health surveillance system is currently not adequately equipped to address ever-increasing infectious diseases particularly emerging and re-emerging ones due to several inefficiencies, including fragmented data sources and their processing, delays in detection and underreporting. Lack of an efficient animal health surveillance system prevents the country from effective prevention and control of potential outbreaks and the spread of infectious livestock diseases resulting in high disease burden to the livestock keepers and the national economy.

The current surveillance system still heavily relies on passive hard copies of reports from livestock farmers and animal health staff from their routine activities through clinical diagnoses and reporting of suspected cases (6) which is not efficient as underreporting of animal health events is high- estimated at 90% (7). Lack of adequate laboratory services and underutilization of the existing data sources also impede the efficiency of the system for early detection of infectious diseases, monitoring of slow burning production diseases and timely response to outbreaks. About ninety-five percent (95%) of the data reporting is still paper-based, which comes with high submission costs and poor data quality (7).

In recent years, surveillance system integrations have been promoted as strategies for improving disease detection, reporting and response capabilities (8). Integration in health surveillance systems may include merging health records databases with surveillance systems, sharing databases with heterogeneous data to form common indicators, or merging surveillance activities and processes (8). An integrated surveillance system can provide continous, comprehensive information more effectively and economically (9). Integration also enhances consistency in data collection, analysis and information dissemination, and data credibility for decision-making (10). Several studies have reported the value of integration in improving systems attributes such as sensitivity(11–13), data quality (14,15), timeliness (16,17) and flexibility (18,19). However, there are very few documented studies in the integration of animal health surveillance systems.

Globally, there have been several initiatives to develop integrated early warning systems at national, regional and international levels to keep up with the increased global health security threats due to zoonotic diseases, bioterrorism and antimicrobial resistance, among many others. Examples of global level integrated surveillance systems include Program for Monitoring Emerging Diseases (ProMED-mail) (20) and Global Early Warning and Response System (GLEWS) (21). Countries are also pursuing to improve systems efficiency in disease detection through the integration of syndromic data into surveillance systems (22–24) and integration of animal disease reporting platforms (25, 26) among others. The use of mobile technology for disease surveillance and reporting offers the opportunity to develop improved integrated systems that are both time-efficient and cost-effective and provide comprehensive geographic coverage (27,28). Moreover, the development of web-based data management platforms has been proposed as a critical strategy for strengthening surveillance by automating significant data processing steps, enabling data access, implementing outbreak alerts, and integrating surveillance data with other relevant sources of information (29).

In Tanzania, several digital surveillance and web-based information systems have been introduced recently such as Event Mobile Application (EMA-i)/ EMPRES-i, AfyaData, SILAB-LIMS (Sistema Informativo di Laboratorio, Laboratory Information Management System) and Agricultural Routine Data System (ARDS). However, many of these tools are still at the infancy stages and operate in silos with little coordination. In this paper, a prototype of an interoperable animal health surveillance system in Tanzania branded '*Wanyama* heAlth SuRveillaNce (WARN)' is proposed. *Wanyama* is a Swahili term which means animals.

Methods

Settings

Animal health surveillance in Tanzania involves passive collection of data by the livestock field officers (LFOs), which are then submitted to the national epidemiology unit through district veterinary officers (DVOs) and zonal veterinary centres (ZVCs). The primary sources of information for surveillance systems include livestock farmers, zoosanitary border posts and checkpoints, slaughter facilities and livestock markets. Data are captured using designated animal disease surveillance forms and abattoir forms. Depending on the category of the disease, reporting is either within 24hours if notifiable disease or weekly for others.

Selection of the animal health information systems for integration

In developing WARN the following animal health information systems were integrated with the prototype: EMPRES-i, SILAB-LIMS and AfyaData. The systems were identified and explored through key informants' interviews and consultation with experts working in animal health surveillance in Tanzania. They were selected because they were operating and contain potential interoperability features.

SILAB-LIMS: This web-based laboratory information management system tracks the samples from the point of collection to the results using unique identification numbers (ID). It automates the generation of test reports and monitors outbreaks through data interrogation functions. That way it eliminates multiple registrations of the same data on paper records. The system is installed and links the entire veterinary laboratory network in the country which consist of 11 veterinary laboratories located in eight zones.

EMPRES-i: FAO EMPRES Global Animal Disease Information System (EMPRES-i) is a web-based application that collects and processes animal disease outbreak information to support analysis, risk assessment and early warning activities. EMPRES-i platform serves as a tool for data analysis through charts, tables and maps. The system is linked to an Event-mobile application (EMA-i) which enables data collection and real-time reporting of geo-referenced animal disease information.

AfyaData: A system which is made up of two sets of applications; a mobile Android-based client and a Web-based app acting as a server. It is designed to collect data using a mobile application which has an offline feature that allows to store data offline in case of network unavailability, and data can be synchronized back up when there is network/internet connectivity. It enables the collection of syndromic data in both humans and animals from the community level, and data transmission is in real-time. The application has GPS embedded features for capturing geo-referenced data.

Selection of the data sources and their link to the prototype

Data sources were identified from the review of animal health surveillance documents obtained through personal communication with officials of the MoLF, TVLA, FAO, websites, grey literature search as well as interviews with experts on the subject matter and individuals from institutions working on animal health surveillance. The details on the identification and assessment of data sources have been published by George *et al.* (6). The following categories of data sources were selected and integrated into prototype design: (a) laboratory data, (b) case-based event reports, (c) data from field operations and (d) Syndromic data from the community and private veterinary facilities. Table 2.1 describe the selected data sources, variables in each source, data capture method and link to the prototype. The selection criteria included data content, spatial coverage, accessibility of data source and cost of data generation and capture.

Table 2.1: Description of the selected data sources and their link to the WARN prototype

Data source	Description	Variables	Data capture	Link to the prototype
Laboratory data	Sample processing data from network of veterinary laboratories, universities and research institutions	Laboratory ID, client ID, sample ID, test conducted, results and the test date	Sample data entered into SILAB web-interface accessible via computer connected to Local area network (LAN)	Data are entered into the SILAB system which is linked to prototype
Case-based event reports	Event reports from District veterinary officer (DVO) or livestock field officer (LFO)	Observation date, reporting date, location ID, animal species and status (confirmed/suspected), clinical signs, diagnosis source, population at risk and number of deaths	Digitized event-based surveillance form installed in EMA-i	data are sent to EMPRES-i database which is linked to prototype
Data from field operations	Reports from livestock markets, slaughter facilities, dip sites, and zoo-sanitary checkpoints	Location ID, date of inspection, origin of animals, owner, animal species, suspected/confirmed disease, signs observed, and number of infected animals, including their age and sex	Digitized movement permits, abattoir and dipping forms installed in AfyaData mobile application	Data are sent to AfyaData server which is linked to prototype
Syndromic data from the community and private veterinary facilities	Reports from community health reporters (CHRs), farmers, commercial farms, private veterinary clinics and veterinary	Location ID, animal species, syndromes, number of animals affected, number of deaths, number of treated animals and medication	Digitized syndromic surveillance form installed in AfyaData mobile application	Data are sent to AfyaData server which is linked to prototype

	shops			

Prototype building

The WARN was built using Laravel, a PHP framework that is cost and time-efficient (30) Python version 3.8.0 and MySQL database. The three systems were linked to the central data repository through Application Programming Interfaces (APIs). It utilized the Leaflet technology and OpenStreetMap Libraries to display maps and visualize data as an interactive map (31). WARN is custom-built and supported by dashboard that helps the data analyzer to visualize data from the repository (32).

Initial prototype testing

Using archived records and dummy data pulled from integrated systems repositories, the prototype was simulated and visualizing outputs on the unified dashboard. The development of the prototype assumed data sources are actively used and data flow reliably.

Results

WARN prototype overview

The WARN integrated laboratory data, case reports, field operations and reported syndromes from communities and private practitioners. Figure 2.1 presents the general prototype architecture. It is composed of three main components, which are: (a) data acquisition, (b) data integration and (c) data analysis and alert. The WARN combines both case-based and syndromic surveillance indicators. Data acquired from various sources are captured using mobile applications (EMA-i or AfyaData) or web interface on desktop PC and sent to the respective databases (SILAB or EMPRES-i or AfyaData). The three databases are linked to the central data repository (WARN) through the Application programming interfaces (APIs), which allow applications to access data and interact with external software components. From the WARN, data are processed and displayed on the dashboard. This component displays tables, charts and maps of the reported disease events from various data sources in real-time. Data analyzers may use the dashboard interface that provides an option to visualize and analyze reported cases and syndromic data for outbreak detection. Data can be downloaded and exported to preferred software for further management and analysis. Interactive maps allow visualization of the locations of the reported disease events and spread status.

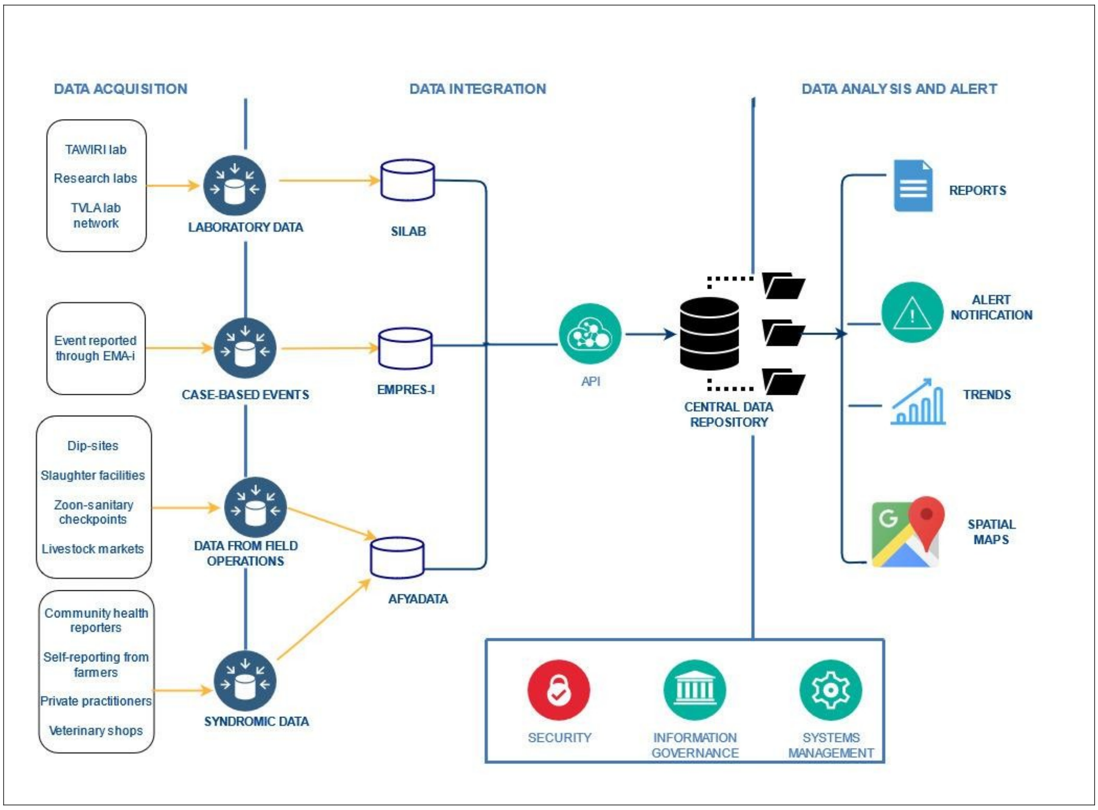


Figure 2.1: Schematic presentation of the general architecture of the WARN

To ensure data security, constant and consistent flow of information and sustainability, the security, information governance and systems management are cross-cutting aspects of the integrated system.

All systems that communicate with the prototype through APIs will take advantage of reliable messaging, transactional integrity, and secure authenticated communications. To achieve this all messages (data) exchanged between systems will be signed using digital signatures to prevent third party systems from tampering the message or impersonation. The prototype is using both authentication and authorization to protect its resources. In order for system users to use the prototype they will have to be authenticated by providing their given username and password to prove their identity, if the credentials don’t match those registered in the prototype, that user won't be allowed to access any resource in the prototype. For cases when users can prove their identity but have not been authorized to access that particular resource they will still be denied access.

WARN data flow and outbreak detection

The flow and notification in the system is as follow (illustrated in Figure 2.2):

a) User interface

The administrator creates users and assign roles to the users and access level depending on their roles in the animal health surveillance. Data access level will be granted according to the areas of jurisdictions to support surveillance officials in decision making. The administrator will also set disease threshold values which will be defined by the authority responsible for animal health surveillance in the country and updated whenever necessary. Users can log in/out, change credentials and access notifications and alerts. Alerts can be accessed via dashboard but can also be shared through other mechanisms such as SMS/emails. Users can also view and list data and export them for further analysis and command reports. The reports can be extracted in comma-separated values (CSV), excel, pdf or picture format.

b) Central data repository

Through APIs, WARN is able to pull data from different complementary sources. Data attributes are defined for the system to store data systematically. This enables all data from the different sources to be stored in the same database.

c) Alert reporting and outbreak detection

The prototype allows the user to set the list of notifiable diseases of interest and keep updating it whenever need be. The system has the function to compare the disease list set by the user with the data reported. Depending on the defined alert mechanism the system provides the notification on the dashboard and alerts the user. The system can also alert the user when the number of similar cases for the specific disease or syndrome exceed the set threshold.

The system also has the function for comparing laboratory results with reported data from other sources. For the positive results, the system checks for the ID/location; if similar to the data reported, it provides the notification to the user**.** If similar cases reported from different locations, it also provides notification to the user. For the negative results, the system checks if the ID/location is similar to the reported data. It will suggest further investigation if several locations submitted the same case.

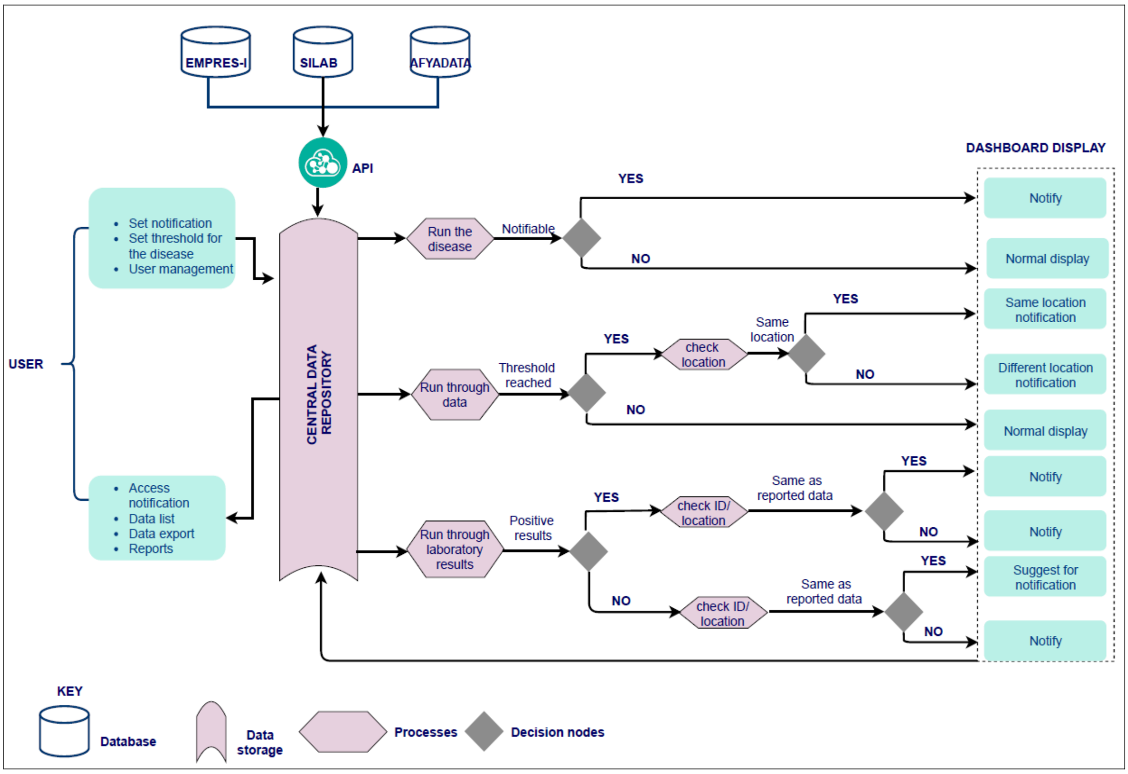


Figure 2.2: Description of the WARN data flow and notification mechanisms

d) The Dashboard

A unified dashboard provides a comprehensive view of the surveillance system by displaying data from various sources in real-time. The user granted with credentials can log into the system and access the dashboard (Figure 2.3). The system administrator will generate the access credentials; therefore, the user won't register.

Figure 2.3: Login page of the WARN

On the landing page of the dashboard, the default view is the dashboard menu, and summary which displays the event reported map, graphical charts and recent disease reports (Figure 2.4). The dashboard menu is composed of tabs for summary, event sources (events), interactive map of reported events (map), a summary of reported syndromes (syndromes), animal disease surveillance report (surveillance), human reported syndromes (human events) and animal reported syndromes (animal events).

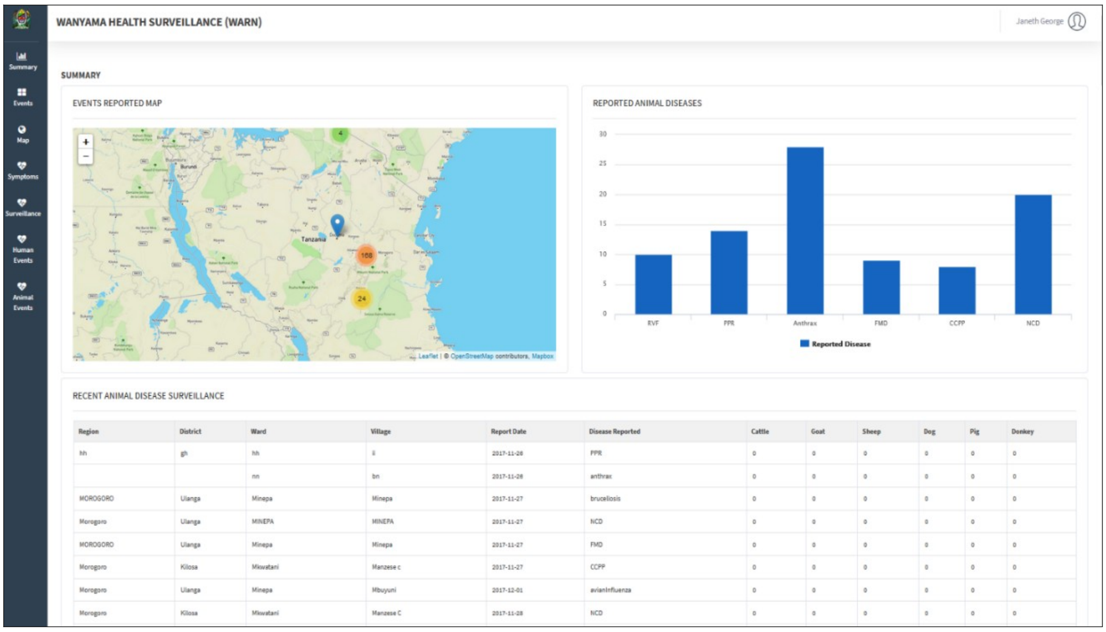
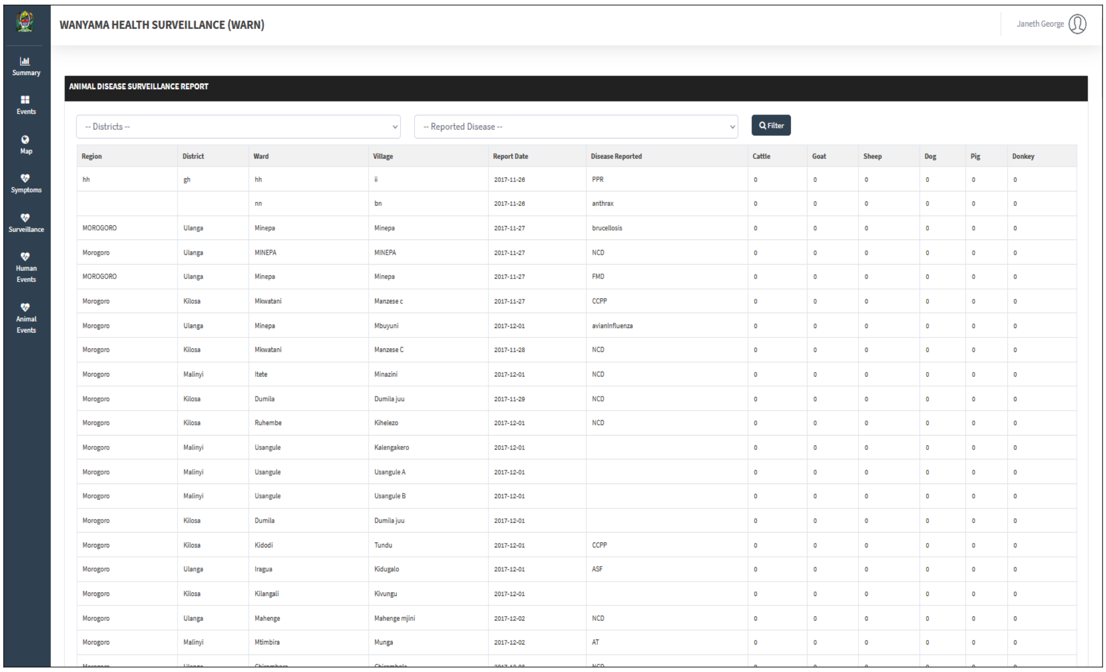


Figure 2.4: The dashboard landing page

The default view of the landing page displays dashboard menu (left margin) and summary of events. The summary displays event report map (top left), graphical charts on the reported diseases (top right) and recently reported events in tabular format (bottom)

The user can perform a query for the aggregated data or individual raw data from the sources. While on the dashboard, the user can interactively access raw data in tabular forms (Figure 2.5 and 2.6) and graphs and maps. The dashboard also displays the trend charts of the reported events by month (Figure 2.7).


WANYAMA HEALTH SURVEILLANCE (WARN)

Janeth George

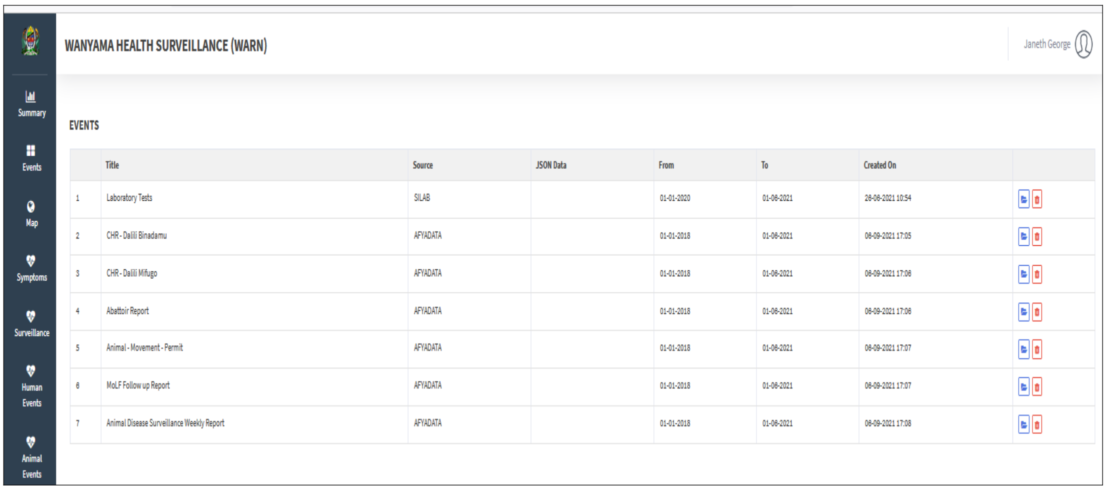
Summary
Events
Map
Symptoms
Surveillance
Human Events
Animal Events

ANIMAL DISEASE SURVEILLANCE REPORT

-- Districts -- | -- Reported Disease -- | Filter

Region	District	Ward	Village	Report Date	Disease Reported	Cattle	Goat	Sheep	Dog	Pig	Donkey
hh	gh	hh	ii	2017-11-26	PPR	0	0	0	0	0	0
		nn	bn	2017-11-26	anthrax	0	0	0	0	0	0
MOROGORO	Ulanga	Minepa	Minepa	2017-11-27	brucellosis	0	0	0	0	0	0
Morogoro	Ulanga	MINEPA	MINEPA	2017-11-27	NCD	0	0	0	0	0	0
MOROGORO	Ulanga	Minepa	Minepa	2017-11-27	FMD	0	0	0	0	0	0
Morogoro	Kilosa	Mkwatani	Manzese c	2017-11-27	CCPP	0	0	0	0	0	0
Morogoro	Ulanga	Minepa	Mbuyuni	2017-12-01	avianInfluenza	0	0	0	0	0	0
Morogoro	Kilosa	Mkwatani	Manzese C	2017-11-28	NCD	0	0	0	0	0	0
Morogoro	Malinyi	Itete	Minazini	2017-12-01	NCD	0	0	0	0	0	0
Morogoro	Kilosa	Dumila	Dumila juu	2017-11-29	NCD	0	0	0	0	0	0
Morogoro	Kilosa	Ruhembe	Kihelezo	2017-12-01	NCD	0	0	0	0	0	0
Morogoro	Malinyi	Usangule	Kalengakero	2017-12-01		0	0	0	0	0	0
Morogoro	Malinyi	Usangule	Usangule A	2017-12-01		0	0	0	0	0	0
Morogoro	Malinyi	Usangule	Usangule B	2017-12-01		0	0	0	0	0	0
Morogoro	Kilosa	Dumila	Dumila juu	2017-12-01		0	0	0	0	0	0
Morogoro	Kilosa	Kidodi	Tundu	2017-12-01	CCPP	0	0	0	0	0	0
Morogoro	Ulanga	Iragua	Kidugalo	2017-12-01	ASF	0	0	0	0	0	0
Morogoro	Kilosa	Kilangali	Kivungu	2017-12-01		0	0	0	0	0	0
Morogoro	Ulanga	Mahenge	Mahenge mjini	2017-12-02	NCD	0	0	0	0	0	0
Morogoro	Malinyi	Mtimbira	Munga	2017-12-02	AT	0	0	0	0	0	0

Figure 2.5: Details of the reported events. Data can be filtered by location and reported disease.


WANYAMA HEALTH SURVEILLANCE (WARN)

Janeth George

Summary
Events
Map
Symptoms
Surveillance
Human Events
Animal Events

EVENTS

	Title	Source	JSON Data	From	To	Created On	
1	Laboratory Tests	SILAB		01-01-2020	01-06-2021	26-06-2021 10:54	
2	CHR - Dalili Binadamu	AFYADATA		01-01-2018	01-06-2021	06-09-2021 17:05	
3	CHR - Dalili Mifugo	AFYADATA		01-01-2018	01-06-2021	06-09-2021 17:06	
4	Abattoir Report	AFYADATA		01-01-2018	01-06-2021	06-09-2021 17:06	
5	Animal - Movement - Permit	AFYADATA		01-01-2018	01-06-2021	06-09-2021 17:07	
6	MoLF Follow up Report	AFYADATA		01-01-2018	01-06-2021	06-09-2021 17:07	
7	Animal Disease Surveillance Weekly Report	AFYADATA		01-01-2018	01-06-2021	06-09-2021 17:08	

Figure 2.6: Reported events from individual data sources

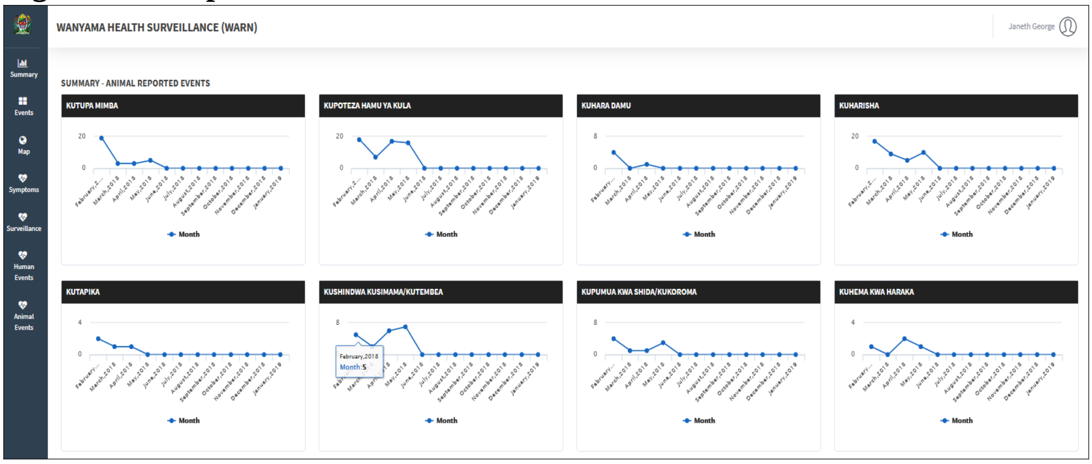


Figure 2.7: The trend of the reported syndromes per month

Issues from the initial prototype testing

The prototype was tested using archived records pulled from SILAB and AfyaData and dummy data for animal movement permits and abattoir forms. The user was able to visualize outputs on the unified dashboard in real time. Linking laboratory results with data from other sources was a challenge due to lack of universally unique IDs across the system.

Discussion

This study focused on designing a generic prototype of an integrated animal health surveillance system in Tanzania (WARN). Unlike the conventional existing surveillance system, primarily paper based with physical data transmission and case-based, WARN integrated data from various complementary data sources by taking advantage of technology and existing animal health information systems.

The WARN prototype has got the following advantageous features: First, it was built on Laravel, a PHP framework that is cost-effective, easy to use with advanced security features that enhance the security and protect sites from cyber-attacks (33,34). Second, systems enhance sharing of data through APIs without affecting their normal operations. The APIs link the systems, allow them to access and extract data from each other (35) but require strong communication among the participating institutions for quickly resolving issues and system improvement. Third, the prototype uses MySQL database for storing data from integrated systems. MySQL is an open source database that facilitates effective data management. Fourth, a web-based real-time GIS feature allows the spatial analysis and visualization of epidemiological data, which enhance decisions and timely response in case of emergency. Fifth, the notification function of the system enables the signaling of aberrations based on the set threshold and their review for decision making.

Without compromising the current legal reporting structure of animal health surveillance or increasing reporting burden, the WARN brings in a syndromic surveillance component that increases the system's sensitivity. Despite its low population coverage and relatively lower timeliness than other sources, laboratory data could still complement the existing system through laboratory confirmation. The volume of sample submission could be analyzed to provide a clue on the disease pattern in the population (36). George *et al.* (6) demonstrated how an integrated animal health surveillance system could benefit from multiple data sources through complementarity as they all have strengths and weaknesses. It should be noted that the designing of this prototype assumed the ideal situation whereby all sources are actively used and information flow as proposed. Therefore, for this system to be operational, both technical and socio-anthropological aspects must be considered.

Strengthening animal health surveillance is more important than ever due to the increased burden of diseases in animal and public health. Surveillance systems that can gather, store, and process information from communities to national levels in a centralized, widely accessible system that allows tailoring surveillance and intervention efforts (37). WARN has showcased how Tanzania can build a multi-data source integrated animal health surveillance system through interoperability of the existing animal health information systems and digital surveillance tools and improve its performance in early disease detection. The proposed prototype comes when there is high advocacy on information and surveillance data sharing through digital systems nationally (7, 38) and globally (20, 39) for strengthening global health security. Recently, there has also been greater emphasis on using other novel surveillance approaches such as syndromic surveillance (40) and participatory epidemiology (41) to complement traditional approaches. Nonetheless, there is a growing discussion towards integration between animal and human health surveillance systems and less on the integration of animal health surveillance. Therefore, this paper echoes the importance of strengthening animal health surveillance systems as an important sub-system to the global One Health surveillance systems.

The focus of the WARN design was on the web application architecture of the system, including data acquisition, interoperability, data management, analysis and visualization and interface. However, its operationalization requires elaborated organizational architecture such as the definition of processes, policies, information governance and resource commitment. The system entails reinforcement measures and revitalization of some of the following aspects: First, strengthening community-level reporting by raising awareness on the importance of disease reporting, designing incentivizing mechanisms, and timely responding to disease events. Second, sub-national animal health staff should be facilitated transport and tools, capacitated through surveillance refresher training, supervision and peer-to-peer support and motivated to ensure data flow from the stated sources. Third, active engagement of private sector and non-government institutions may reduce the cost of surveillance through collaboration and integration of animal health services. Fourth, there must be a memorandum of understanding on data sharing between the MoLF and institutions hosting the integrated systems. Finally, a direct chain of command between sub-national level animal health staff and parent ministry, MoLF has to be revitalized for more assertive communication, accountability and timely response to emergencies.

The initial simulation of the WARN using dummy data and archived records has demonstrated that an integrated system could improve the sensitivity of the system in disease detection. However, the prototype is still under development to integrate EMPRES-i, set alert mechanisms and user privileges. Designing and digitizing forms for dip-sites, veterinary shops and self-reporting are ongoing. It was still a challenge to link laboratory results and surveillance data from other sources due to lack of universally unique identifiers across the systems. There is an ongoing discussion on the possibility of reviving the Tanzania National Livestock Identification and Traceability System (TANLITS), which generates unique IDs and keeps a register of all livestock in the country for identification and tracking.

Conclusion

WARN has demonstrated the possibility of having an integrated multi-data source animal health surveillance system through the interoperability of existing animal health information systems. The prototype was built based on a well-known, cost-effective and flexible framework, which is easy to navigate and maintain. The flexibility of the system allows integration of large datasets; hence may benefit from big data analytics for early detection and prediction of infectious diseases. This is a step closer to Tanzania's goal of developing a One Health surveillance platform that will integrate animal, human and environment health systems. The operationalization of the proposed prototype must consider both technical and social aspects of the surveillance system. Therefore the next step is pilot testing to see the acceptability and usability of the system to the targeted surveillance actors.

Acknowledgments

Authors would like to thank staff of the Ministry of Livestock and Fisheries, Tanzania Veterinary Laboratory Agency and The United Nations Food and Agriculture Organization (FAO-Tanzania) for the generous support in this study. We also thank Ms. Angelina Bululu and Ms. Dorothy Mtatifikolo for their critical review on the earlier versions of the manuscript.

List of Abbreviations

APIs- Application Programming Interfaces; *DVO*-District veterinary officer; EMPRES-i-Emergency Prevention System Global Animal Disease Information System; LFO-Livestock field officer*;* PHP- Hypertext Preprocessor; SILAB-LIMS- *Sistema Informativo di Laboratorio*-Laboratory information management system*; WARN-Wanyama* heAlth SuRveillaNce

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

Contact the authors for any additional information

Competing interests

The authors have no conflict of interest to declare

Funding

JG received research fund for the development of a prototype for cost-effective integration of animal health surveillance systems in Tanzania supported by the Government of Tanzania and World Bank, grant no. PAD 1436 through SACIDS African Centre of Excellence (ACE II). The funder had no role in the design of the study, data collection, analysis and interpretation or preparation of this manuscript.

Authors' contributions

JG was the major contributor to the conception of the study with discussions and critical inputs from BH, SIK, JM, CS and MR. JG, RN and BH developed the methodology for prototype design. JG and RN developed and tested the prototype under supervision of BH, SIK, JM, CS and MR. JG wrote the first draft of the manuscript. BH, CS, SIK, JM and MR substantively revised the first draft of the manuscript and subsequent modifications. All authors read and approved the final version of the manuscript.

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CHAPTER THREE

GENERAL DISCUSSION

3 Introduction

The research aimed to develop integrative solutions for improving animal health system in Tanzania using a systems approach. It was hypothesized that an integrated animal health surveillance system would enhance early detection of infectious diseases including emerging and re-emerging ones. That will ultimately reduce the impact of the diseases by improving timeliness, sensitivity, data quality and usefulness in making decisions. The overarching question was: How and under what conditions can integration improve Tanzania's animal health surveillance system for early detection of infectious diseases?

To achieve that, the study specifically focused on answering the following questions: (i) what are the integration mechanisms in health surveillance systems and to what extent they have strengthened surveillance attributes? (ii) What is the current status of animal health surveillance and related systems in Tanzania? (iii) What are the mechanisms and contextual factors affecting the implementation of the current animal health surveillance system? and (iv) how can integrated animal health surveillance system be operationalized in Tanzania? The research questions were answered by conducting a systematic review of the existing integration mechanisms in animal and human health surveillance systems, situational analysis and process evaluation on the animal health surveillance systems, stakeholders mapping and designing and testing the prototype of an interoperable animal health surveillance system.

This chapter synthesizes the response to the overarching research question, which was investigated and analyzed through four specific questions. It starts by highlighting the key findings from each research question reflecting on the processes for integrating the animal health surveillance system and their implication (section 3.2). Theoretical contributions of the study to the integration of animal health surveillance systems and connection to the existing literature are presented in section 3.3. Limitations of the research methodological choices are discussed in section 3.4. The last part of this chapter (section 3.5) concludes the thesis and states recommendations for further research on operationalizing integrated animal health surveillance systems in Tanzania and beyond.

3.1 Summary of thesis findings and practical implications

Specific research objectives and their questions were addressed in five papers of this thesis. The findings from paper I-IV had informed the designing of the integrated animal health surveillance prototype (WARN). Table 3.1 presents the principle findings of this research with respective to specific objectives.

The findings of this study have got some practical implications and societal relevance for Tanzania and beyond. Specifically, the research has made innovative contributions in several areas:

First, the overall output of the research is the prototype of an interoperable animal health surveillance system for Tanzania (WARN) which can be adapted and developed further into a national surveillance system while considering other proposed aspects. WARN provides a unified digital surveillance system from community to national level. It complements the government efforts to strengthen the animal health surveillance system by promoting real-time technology, as clearly mentioned on the 5-year (2019-

2024) national animal health surveillance strategy (URT, 2019). It is also a step closer to Tanzania's goal of developing a One Health surveillance platform that will integrate animal, human and environmental health. It will provide a digital link with all animal disease surveillance of zoonotic potential to the public health surveillance.

Second, subnational-level stakeholder mapping complements national high-level stakeholder analysis. The findings suggest that collaboration is contextual and socially constructed. They also demonstrated a new perspective on collaborative stakeholder mapping, especially at sub-national levels, involving government field staff. Through this kind of analysis, national animal health surveillance may benefit from resource and non-resource influence and stakeholder interactions.

Third, process evaluation showed that the contextual factors are interconnected and interactively affect the implementation of surveillance activities. This may somehow explain the little progress on the uptake of recommendations from the previous evaluations. This shed light on the need for understanding the system as a whole, its key drivers and boundaries that will enhance the identification of leverage points that will trigger chain-reaction into the desired outcomes.

Fourth, field investigation revealed that very few data sources are actively used in reporting. The study identified potential data sources that were fragmented. Through recommendations made in paper II, they can be used complementarily to improve animal health surveillance systems.

Table 3.1: Summary of the thesis findings

Specific objective	Principle findings
To document existing integration mechanisms in health surveillance systems and their contribution to strengthening surveillance attributes. (Paper I)	• Integration in health surveillance systems is a relatively new concept which picked pace in the 2010s • Very few integrated systems in animal health surveillance compared to human health. • Integration has shown value in improving health surveillance systems, especially on timeliness, sensitivity and data quality • Evaluation mostly focused on the operational and short-term outcomes of the system improvement than sustainability
To characterize existing animal health surveillance and other animal health information systems to identify leverage points for integration. (Paper II)	• A lot of commonalities in the data sources in terms of relevant surveillance variables and area coverage but diverse in quality • Very few data sources were actively used for reporting • Limited integration and lack of coordination on the data flow from various sources, leading to reduced data quality and delayed decision-making and actions
To conduct a process evaluation of the current national animal health surveillance system. (Paper III)	• Performance of animal health surveillance is attributed to several interconnected factors which need to be analyzed and addressed holistically • There were deviations in the implementation of surveillance from core principles and guidelines • Most identified challenges were systemic hence need systemic solutions • Financial resource is at the centre stage of the animal health surveillance, but very little was committed to surveillance activities and its effect spilt-over every component.
To develop a prototype of an integrated animal health surveillance system in Tanzania, including facilitating factors for its operationalization (Paper IV and V)	• Community-level stakeholders had strongest relationship with government animal health practitioners compared to other stakeholder categories • Private sector had a relatively higher number of resource-based influential stakeholders, while political leaders had more non-resource-based influence • The WARN prototype has demonstrated the possibility of having an integrated multi-data source animal health surveillance system • The proposed integration design has flexible features that allow animal health surveillance to transition into early warning and epidemic intelligent systems

3.2 Scientific contribution

3.2.1 Contribution of health surveillance systems integration to global health security

For the past two decades, there has been greater emphasis on integration and coordination of health surveillance activities to keep up with increased pressure of infectious disease, bioterrorism and antimicrobial resistance, among many other hazards *(*Giannopoulou *et al.,* 2007; Hulebak and Rodricks, 2013; Albiger *et al.,* 2018). The recent COVID-19 pandemic has exposed the vulnerability of the countries to such global health threats which require collective actions beyond individual organizations and countries (GHSA 2020). There was a global call to strengthen health surveillance systems (WHO, 2007; FAO, OIE and WHO, 2010) and the countries deliberated to depart from traditional reactive surveillance to novel proactive approaches, including integration of the systems (Shuai *et al.*, 2006; Wahl *et al*., 2012; Lwin *et al.,* 2014). The efforts manifested in the increase of surveillance system integration initiatives globally within the same period. However, the overarching questions were, how much integration is optimal in terms of cost and effectiveness, what to integrate, how to integrate and what factors to consider when integrating systems? Therefore through systematic review, this thesis has been able to find answers to these questions.

First, the review categorized integration into four mechanisms based on definitions adopted from Myerson (2001) and pointed out the most common among the integrated health surveillance systems (George *et al.*, 2020). The research suggests that integration among health surveillance systems is progressive, but integration of animal health systems takes a slower pace than public health and One Health. The rise of One Health systems coincides with the global initiatives such as the adoption of One Health approaches (Rweyemamu *et al.,* 2013; Gibbs, 2014), global health security agenda

(GHSA, 2019) and International Health Regulation (WHO, 2007) which strongly embrace the concept of resource sharing and multi-sectoral collaboration. Meanwhile, animal health surveillance despite being recognized as the key element in predicting public health risks related to zoonotic diseases (Meidenbauer, 2017), does not receive as much attention as public health or One Health surveillance. This was confirmed in this study which revealed out of 102 reviewed articles, only 6.9% focused on animal health surveillance systems. This may weaken the efforts to strengthen global health security, given that more than 70% of the emerging infectious diseases are of animal origin.

Second, the value of systems integration in improving health surveillance performance was evident but not enough to make a firm conclusion. Health surveillance systems are evaluated using several attributes that are linked and influenced each other (Calba *et al.*, 2013). This study found that majority of the evaluations focused on effectiveness attributes such as sensitive and timeliness than functional attributes of the systems like acceptability, data quality and stability. This leaves little evidence on the sustainability of the integration outcomes. On the other hand, there were a limited number of quantitative evaluations to back up the impact of integration as it may not be a cure for inadequate resources (Waddington and Egger, 2008). This raises questions on the operationalization and sustainability of the integrated systems as no single study evaluated sustainability attributes. In light of that, it is important that future evaluations consider a comprehensive list of attributes, even if some may not primarily target the integration. This will guide the choice of integration mechanism and projection of the outcomes.

Lastly, the review pinpointed salient issues and facilitating factors for the system integrations. The role of information technology as a facilitator of integration came out vividly in temporal and spatial patterns of publications. It was found that the number of articles published between 2011 and 2018 accounted for 62% of the total publications, which coincide with the rise of health information technology (Xierali *et al.,* 2013; Lee and Choi, 2018). On the other hand, 59 out 102 published articles focused on Europe and North America. Such technological disparities between low and high-income countries is an area that needs special attention as we are pacing towards meeting global health security targets.

3.2.2 Moving towards multi-data source animal health surveillance systems

Effective animal health surveillance systems depend on reliable and fit-for-purpose data sources, among other factors. The increased demand for data for decision making to address various health risks such as emerging infectious disease, bioterrorism and antimicrobial resistance has prompted various stakeholders in adapting new surveillance techniques. These novel approaches aim at achieving good surveillance coverage of a population by making better use of existing data sources of data, whilst minimizing costs and maintaining flexibility (Halliday *et al.*, 2011). However, the major concern regarding these data sources for surveillance activities is about the effectiveness and validity of their usage for illness pattern detection. Also, if they are not well-coordinated, may lead to double counting due to multiple reports of the same case. This thesis established criteria for systematically assessing the quality of data sources for animal health surveillance and propose a better way of making use of them for enhancing early warning.

3.2.3 Integrative approaches to evaluation of animal health surveillance systems

The value of animal health surveillance in the control and prevention of disease of both animal and public health importance is indisputable. In the current era where humans are confronted with multiple threats and public health systems are overwhelmed, having adequate animal health surveillance systems is compulsory. In light of that, the performance of the systems has to be in constant checks through regular evaluations (Drewe *et al.*, 2015) to ensure they are capable of providing timely and reliable information for planning and decision making in a resource-efficient manner (Peyre *et al.*, 2019).

There are several evaluation tools for health surveillance systems. Still, very few are for animal health surveillance (Drewe *et al.*, 2012), and they were mainly focusing on technical aspects of the system using few attributes and were highly quantitative. Peyre *et al.* (2019) developed a tool for integrated evaluation of animal health surveillance systems, including economic evaluation, which combines technical, processes and value/impact aspects. The findings from this thesis complement such ongoing efforts towards integrative approaches to animal health surveillance systems evaluation. Through the process evaluation approach, the study pointed out the interconnectedness between systems outcomes and processes. It also showed close interactions among mechanisms and/or contextual factors themselves, and they may affect the system collectively or individually; hence, their analyses require a systems lens. To the best of my knowledge, the adapted process evaluation framework (Moore *et al.*, 2015) has never been used to evaluate health surveillance systems. However, this study has demonstrated its applicability beyond health intervention as it embraces the systems thinking principles that are very important for evaluating our current systems.

3.2.4 Bringing stakeholders into animal health surveillance

A functional and efficient surveillance system requires collaborative efforts from relevant stakeholders working towards a common goal with a sense of shared responsibility. An understanding of relevant stakeholders, their interests and their power can facilitate such collaboration. There are substantial studies and documentation on stakeholder analysis and mapping (Skarlatidou *et al.,* 2019; Teklewold *et al.*, 2019). This study adopted the least conventional approach by conducting stakeholder mapping from the animal health practitioner's perspective. It enabled practitioners to reflect on the stakeholders they interact with in their day-to-day activities and how they affect/influence their implementations (an inside-out approach). Although the approach may seem subjective, Aligica (2006) argued that mapping is a cognitive process, and the best map is the one that helps to orient the social action. The mapping exercise demonstrated that the system could benefit from diverse interaction and influence of various stakeholders, such as resource mobilization and expanding the horizon of the surveillance data source.

3.2.5 Moving towards interoperable animal health surveillance systems for early disease outbreak detection

The world is heading towards big data and artificial intelligence for finding solutions for ever-pressing human challenges, including human and animal disease detection and prediction. Data are becoming the most crucial resource in human life. (Wong *et al.*, 2019) argued that with reliable data management platforms, artificial intelligence methods will enable analysis of massive infectious diseases and surveillance data to support response to diseases in the future. On the other hand, big data analytics are used to understand health risks and minimize the impact of adverse animal health issues through identifying high-risk populations, combining data or processes acting at multiple scales. Epidemiological modelling approaches and high-velocity data help to monitor animal health trends and detect emerging health threats (VanderWaal *et al*., 2017). These futuristic innovations can also benefit animal health surveillance if there are appropriate systems and collaborations among stakeholders. The WARN as one of the outputs in this thesis can be considered a significant step forward in early warning and surveillance systems for animal health. Although this research has proposed potential data sources that Tanzania can leverage for strengthening its animal health surveillance system, the interoperability features of the prototype allow more than that. With mobile application support, data transmission and analysis can be done in real-time or near real-time, while GIS features enable spatial analysis of events.

3.3 Limitation of the research

This research focused on designing integrated solutions for animal health surveillance in Tanzania and specific objectives were deliberated to address that. Due to limited resources there was little attention on other surveillance systems which would have given a One Health perspective and their linkage to animal health. The designing of prototype focused on domestic and wildlife health only but exploring aquaculture surveillance is equally important.

The systematic review included articles in English only; hence, due to that limitation, important experiences from other non-English speaking countries, especially Latin America and Asia, might have been missed. The review focused on animal and human health surveillance systems only and did not exclusively include environmental health surveillance systems essential for One Health. However, it did capture One Health surveillance systems which are essential components of One Health approaches in dealing with multi-source health risk events.

Field investigations were conducted in six districts of Tanzania, which were purposefully selected, but the sample size may not have sufficed to make statistical inference for generalizability for the entire country. The respondents were mainly government employees because they are the implementers of surveillance activities. The choice practitioner’s approach may suffer from respondents’ bias as a result of their experience and interactions with animal health surveillance system. The study could be enriched through other categories of respondents such as communities and the private sector.

The designing of the WARN prototype required endorsements from institutions hosting the selected systems in order to be granted APIs and expertise. Due to such bureaucratic processes, initial testing of the prototype was done using AfyaData and SILAB-LIMS archive data while working on the integration of EMPRES-i. Owing to limited time and financial resources, simulation of the WARN under field conditions couldn't be materialized. That would allow to ascertain the flow of data from the proposed sources in presence of other social factors. A next step could be to pilot testing it to see the acceptability of the systems to the users while observing other economic and anthropological aspects.

3.4 Conclusion and Recommendations for Future Research

3.4.1 Conclusion

Throughout this thesis, I have argued and demonstrated that animal health surveillance challenges entail both technical and social aspects which are interconnected. The study confirmed the complexities of the animal health surveillance systems and that their analyses require systems lens and integrative solutions. The value of integrations and salient issues to consider in improving health surveillance has been discussed. From the review it can be concluded that no integration fits all; therefore, it is very important to consider contexts and intrinsic values of the chosen integration mechanism.

People matter in animal health surveillance but understanding who can do what is fundamental. This research challenged the conventional approaches to identification and analysis of stakeholders by putting government animal health practitioners at the epicentre of the stakeholder mapping. From the findings it can concluded that stakeholder collaboration and interaction particularly in animal health is contextual and socially constructed. Therefore, for the animal health surveillance to benefit from such interactions, in-depth understanding of stakeholder interest and priorities is very important.

The final output of this thesis was the prototype of an interoperable animal health surveillance system in Tanzania branded as ***Wanyama*** he**A**lth su**R**veilla**N**ce (WARN). The novelty of this innovation lies on its interoperability features and flexibility to integrate more data for infectious disease intelligence. Although the design of the WARN considered Tanzanian context, its flexible features provide opportunity for adaptation beyond the country. It is a step closer towards One Health surveillance which integrates animal, human and environment systems. Nevertheless, its operationalization must consider socio-anthropological aspects in addition to technical functionalities for sustainable outcomes.

3.4.2 Recommendations for further research

Although the developed prototype has demonstrated the possibility of improving the animal health surveillance system by integrating animal health information systems and other data sources, some areas have still not been addressed in this research. Thus, future research is recommended toward the following critical areas:

i. Explore technical, organizational and socioeconomic requirements that will support the operationalization of an integrated animal health surveillance system. Particularly, the future research may focus on the appropriate legal and organizational structures that can enhance the interoperability of the systems, data sharing and usage. That goes hand in hand with strengthening of communication between and within participating institutions.

ii. Multiple data sources can strengthen animal health surveillance, and the findings have indicated that the more, the better because they all have strengths and weaknesses. This study has made some propositions on making better use of multiple data sources, including incentivization of reporting and integration of animal health services. In that regard, implementation research may provide context on appropriate incentive mechanisms to surveillance actors and cost-effective modality for linking animal health services to surveillance.

iii. The proposed prototype focused on the data generation elements of the surveillance system, which are data collection, management and analysis for early detection but interpretation and use of those data is another critical component that needs to be thought through. This kind of integration comes with large data volumes that require capacity to package and disseminate surveillance information generated from the system so that mandated people will understand and act. Therefore, the data use domain can be explored further to practically link the data generation processes with the responses or interventions.

iv. The ideal WARN needs to be piloted in the field in order to assess its acceptability and usability. Further research can consider the behaviour of various actors in surveillance, social networks and information exchange that may impact the proposed interoperable system.

v. The high cost surveillance vis-à-vis the allocated budget needs rethinking. Through the applied stakeholder mapping, the government may identify resource-based influential stakeholders at sub-national level and leverage them to support surveillance activities.

vi. This research was limited to animal health surveillance systems, but its output makes a provision for integration with other surveillance systems, including aquatic, environmental and public health surveillance systems. It also provides an opportunity to integrate and process data from other syndromic surveillance systems for early warning. Therefore, this should be considered in the future to experiment on how we can move from single- to multi-sectoral health surveillance systems in the direction of One Health.

This thesis strived to demonstrate the application of integrative approaches to addressing animal health surveillance. The proposed prototype serves as an exemplar to integrative solutions. I hope this thesis will inspire further research towards long-lasting solutions to complex systems particularly health surveillance.

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APPENDICES

Appendix 1: Interview guide for key informant interviews

Situational analysis of the existing animal health and related surveillance systems
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Consent statement
The following statement will be read to all individuals asked to participate in the key informants' interviews.

Checklist audio code………………..
My name is **Janeth George,** A PhD student from Sokoine University of Agriculture in Morogoro. My research work focus on development of prototype for Cost-effective integration of animal health surveillance systems in Tanzania system thinking approach. As one of the key players in this system, I would like to get some of the information from you as key informant regarding various aspects of the system you are working with. The information you will provide me with, will help to inform the designing of the prototype. I am therefore kindly requesting you to contribute in the process by sharing the invaluable data on how the system works. If you participate, you are free to skip any questions you do not wish to answer or to stop at any time.
Also for the purpose of this study, I would also like to get your consent to record our interview in order to make sure that all the details are well captured while saving time.

a.	Respondent's code	
b.	Respondent's designation	
c.	Date of interview	
d.	Starting time	
e.	Finishing time	

Section A: Brief Description of the system

i. Can you please give me a brief description of one your surveillance system? Probe on hazards and species, data capture mechanisms, data transmission, storage, cleaning and checking, data usage and analysis, reporting and feedback
ii. If this is not a surveillance system per se, what role does this system play in animal health surveillance in Tanzania?
iii. What is the purpose and objective of the system? Probe on why this system is necessary and what is trying to accomplish. How is the surveillance information used
iv. What is the geographical coverage of the system? Is part of any national or international system?
v. When did the system start?
vi. What are the legal procedures under which which the system operates? Probe if there are any communication restrictions.

Section B: Resources for the system

i. *I understand that for any system to be functional you need to have all the necessary resources.* What are the critical resources for this system? Probe on the current resources vs resources needed
ii. ***Financial resources:*** What is an average annual operation cost for the system? How much was your budget allocated for this system last year? What are the main sources of funds?
iii. ***Human resource:*** What is the composition of human resources in terms of the expertise, working on the system? Probe on the quantity for each expertise and working time
iv. ***Technology use:*** Does this system use ICT in its operation? If yes, what is it? How useful is it?

Section B: Data collection processes

i. What are the means for data acquisition? Probe whether it is passive, active or combined
ii. Who are the stakeholders involved?
iii. What are major sources of surveillance data?
iv. How frequent is the sampling?
v. What are the testing methods?
vi. What is the design prevalence?
vii. How frequent is the analysis and interpretation of results?
viii. How do you communicate results and if relevant an action?

Section C: Coordination of the system

i. Who is the coordinator of the system?
ii. Who are the users of the generated surveillance information?
iii. Which institutions/organizations or people contributing to surveillance data?
iv. What is the communication mode with stakeholders in surveillance system? Probe on the communication channel and frequency

Section D: One Health inclusion

i. Have you heard of the One Health concept? If yes, what is your understanding of One Health?
ii. If not, OH can be defined in the following way:
iii. Does your system apply the One Health concept? If yes, in what way?

Section E: System integration

i. Which other animal related surveillance systems are you aware of?
ii. Which other surveillance system(s) are you collaborating with?
iii. Do you see the need for integration (***define what is integration***) of surveillance systems/ components?
iv. If you are to integrate this system, what are the potential components for integration and why?
v. What are the potential systems for integration and why?
vi. What do you see as the potential challenges for integration of animal health surveillance systems?

Section F: Challenges in surveillance system

i. What challenges do you encounter in the implementation of surveillance activities?

Appendix 2: Structured questionnaire

Process evaluation of the current national animal health surveillance system

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CONSENT DECLARATION

Process evaluation of the current national animal health surveillance system

The following statement will be read to all individuals asked to participate in the survey and key informants' interviews.

My name is **Janeth George,** A PhD student from Sokoine University of Agriculture in Morogoro. I am conducting research study on development of model for Cost-effective integration of animal health surveillance systems in Tanzania system. As one of the key players in this system, I would like to invite you to participate in short interview administered through questionnaire regarding various aspects of the system you are working with. The information you will provide me with, will help to inform the designing of the prototype.

The main goal of this activity is to understand how the current animal health surveillance system works and factors affect its performance. This interview will last approximately 30mins.

The interview will be kept private and confidential. I will never associate your name with any of the information that you share. I will also make sure that when I share information gathered from you, that I never disclose any personal information or details that would identify you in any way. It is important that you understand that participation in this interview is completely voluntary. This means that you do not have to participate if you do not want. Also, if at any time you feel uncomfortable with the subject matter, you can choose not to answer any question. You may also stop participation in the overall process at any time that you wish.

a.	Respondent's code	
b.	Region name	
c.	Region code	
d.	District name	
e.	District code	
f.	Ward name	
g.	Ward code	
h.	Date of the interview	
i.	Start time	
j.	Finishing time	

Section A: Demographic characteristics of the respondent
A1. Respondent's designation:________________________________ i) Livestock field officer ii. Ranch manager iii. District Veterinary Officer iv. ZVC Manager v. TVLA Manager vi. Ministerial official vii. Others…mention
A2. Age of the respondent:________________________________
A3. Gender of the respondent: :________________________________ 0. Male 1. Female
A4. Education level: ________________________________ i. Primary school ii. Secondary School iii. Certificate level iv. Diploma v. Bachelor degree vi. Higher degrees
A5. Years of experience in the field: ________________________________
A6. Years of experience in the current position: ________________________________

SECTION B: Implementation of surveillance activities		
B1. What is your area coverage	*One village*	*1*
	Two villages	*2*
	Three villages	*3*
	More than three villages	*4*
B.2 The closest site/village is how many kms from your work station?		
B.3 The furthest site/village is how many kms from your work?		

B.4 What are your roles in surveillance activities? (tick all that are relevant)	*Collecting data from the primary sources*	*1*
	Data compilation and integration	*2*
	Data quality assurance	*3*
	Database management	*4*
	Data analysis and interpretation	*5*
	Dissemination	*6*
	Response	*7*
B.5 What are your sources of surveillance information (Tick all mentioned)	*Livestock keepers*	*1*
	Slaughter facilities	*2*
	Veterinary centers/clinics/facilities	*3*
	Vet shops	*4*
	Livestock markets	*5*
	Zoo sanitary checkpoints	*6*
	Milk collection centres	*7*
	Livestock field officers	*8*
	District veterinary officers	*9*
	Zonal veterinary centres	*10*
	Diagnostic facilities	*11*
	Others….mentioned	*12*

B.6	**How frequent do you collect data from the mentioned sources? Read out** *1. Daily 2. Weekly 3. Bi-weekly 4. Monthly 5. Upon occurrence of suspected cases 6.Not applicable*	
	Source	**Frequency**
1.1	Livestock keepers	
1.2	Slaughter facilities	
1.3	Veterinary centers/clinics/facilities	
1.4	Vetshops	
1.5	Livestock markets	
1.6	Zoosanitary checkpoints	
1.7	Milk collection centres	
1.8	Livestock field officers	
1.9	District veterinary officers	
1.10	Zonal veterinary centres	
1.11	Diagnostic facilities	
1.12	Others	

B.7 Which tools do you use to surveillance data? (Tick all mentioned)	*Field surveillance forms (Paper-based)*	*1*
	Digitized surveillance forms (E-Mai)	*2*
	Digitized surveillance forms (AfyaData)	*3*
	Others…mentioned	*4*
B.8 How do you transmit surveillance information? (Tick all mentioned)	*Transporting them to the respective authority*	*1*
	Electronic data transmission (real-time)	*2*
	Electronic data transmission (emails)	*3*
	Making phone calls to the respective authorities	*4*

B.9	**For the last six months, how many times did you transmit data by;**		
9.1	**Transmission mode**	**Frequency**	
9.2	Transporting them to the respective authority	*(trips)*	
9.3	Electronic data transmission (real-time)	*(number of forms sent)*	
9.4	Electronic data transmission (emails)	*(Number of emails sent)*	
	Making phone calls to the respective authorities	*(number of phone calls made)*	

B.10 How do you compile surveillance data from the source/lower level?	*Manually from the sources*	*1*
	Real-time compilation into central repository (electronic)	*2*

	I don't compile	*3*
B. 11 How often do you compile data from the lower levels?	*Real-time*	*1*
	Daily	*2*
	Weekly	*3*
	Monthly	*4*
	More than a month	*5*
B.12 How do you store surveillance data	*Physical files*	*1*
	Electronic file system	*2*
	Database	*3*
B. 13 How often do you check data for quality assurance and cleaning? (*Ask this from DVOs and higher)*	*Real-time*	*1*
	Daily	*2*
	Weekly	*3*
	Monthly	*4*
	More than a month	*5*
B.14 How often do you do analysis and interpretation of surveillance data? (For those responsible for this role)	*Real-time*	*1*
	Daily	*2*
	Weekly	*3*
	Monthly	*4*
	Quarterly a year	*5*
	Semi-annually	*6*
	Annually	*7*
	When need be	*8*
	Never	*9*
B.15 When was the last time you did the analysis and interpretation?	*In the last 24hours*	*1*
	Within this week	*2*
	Last week	*3*
	Last month	*4*
	Last quarter	*5*
	In the last six month	*6*
	Last year	*7*
	Never	*8*
B.16 Who are the recipient of the surveillance information that you collect?	*Livestock field officer*	*1*
	Ranch manager	*2*
	District Veterinary Officer	*3*
	ZVC Manager	*4*
	TVLA Manager	*5*
	DVS	*6*
	International organizations	*7*
	Business people	*8*
	Others….mention	
B.17 Do you normally share surveillance information with officers/actors in other sectors?	*Yes*	*1*
	No	*0*
If B.17 yes, who are they?….mention		

B.18 What are the communication channels do you use to communicate surveillance information to stakeholders?
1. Real-time 2. Daily 3. Weekly 4. Monthly 5. Quarterly a year 6. Semi-annually 7. Annually 8. When need be 9. Never

	Channel	Frequency
18.1	Real time reports through mobile technologies	
18.2	Telephone calls	
18.3	Case reports	
18.4	Monthly reports	
18.5	Quarterly surveillance bulletin	
18.6	Formal meetings	
18.7	Word of mouth	
18.8	Press release	

SECTION C: Mechanisms of impact and contextual factors

C1. If you are to rank in a scale of 1-100% of your working time, how much goes to surveillance activities?		
C2. In your typical week, how many days of the week are you involved in surveillance activities?		
C3. In case you are using digital tools for surveillance activities, are you using your own or was/were provided to you?	*Mine*	*1*
	Was/were provided to me	*2*
C4. In case of mobile phones, do you receive any token for surveillance activities or it's out of your pocket?	*I receive token*	*1*
	Out of pocket	*2*
C5. If the answer in C4 is 1, how often do you receive the token for surveillance activities?	*Daily*	*1*
	Weekly	*2*
	Monthly	*3*
	Quarterly	*4*
	Not consistent	*5*
	Never received	*6*
C6. For those who transport physical surveillance forms, who facilitate transport costs?	*Government*	*1*
	Out of pocket	*2*
	Donor funded	*3*
C7. If receiving transport facilitation, How often?	*Upon delivery of the documents*	*1*
	Weekly	*2*
	Monthly	*3*
	Quarterly	*4*
	Not consistent	*5*
	Never received	*6*
C8. In case of electronic database, who facilitate maintenance cost?	*Government*	*1*
	Out of pocket	*2*
	Donor funded	*3*
C9. What is the estimated costs of maintaining the database per year?		
C10. What was the estimated budget of maintaining the database for the last financial year?		
C11. How much did you received from the budgeted?		
C12. How many officers responsible for surveillance do you have in your scope of work?		
C13. What is the required workforce in relation to you scope of work?		
C14. Have you ever received any training related to surveillance?	*Yes*	*1*
	No	*0*
If yes, when was the last time (Year)		
If yes, what was it skills? (mention)		
C15. Have you ever attended any Continuous Professional Development (CPD) program?	*Yes*	*1*
	No	*0*
If yes, when was the last time (Year)		
If yes, what was it skills? (mention)		
C16. In the scale of 1-5, (1 very dissatisfied at all and 5 very satisfied), how do you rank your satisfaction on the current animal health surveillance system?	*Very dissatisfied*	*1*
	Dissatisfied	*2*
	Neutral	*3*
	Satisfied	*4*
	Very satisfied	*5*
Can you give reason for your answer		
C17. What are the challenges do you face when implementing surveillance activities in your area?		
C18. What do you think need to be improved for the system to work better?		

Thank the respondent and end interview.

Comments:

Appendix 3: Process evaluation- observation checklist for surveillance infrastructures

1	**Do you have the following surveillance structures in your ward (Only for LFOs)** *Available: 1.Yes, 0.No Condition: 1. Good 2. Satisfactory 3. Poor (Mark after observation)*			
	Structure	**Available**	**Number**	**Condition**
1.1	Temporary/permanent crushes			
1.2	Livestock Development Centres			
1.3	Slaughter slabs			
1.4	Wildlife laboratories			
2	**Do you have the following surveillance structures in your District (Only for DVOs)**			
2.1	Diagnostic facility			
2.2	Veterinary centers/clinics/facilities			
2.3	Slaughter facilities			
2.4	Transport facilities			
2.5	Milk collection centers			
2.6	Check points			
3	**Do you have the following surveillance structures in your zone (Only for ZVC managers)**			
3.1	Diagnostic facilities			
3.2	Zoo sanitary check points			
3.3	Information Communication Technology- networking			
3.4	Cold chain facilities			
3.5	Transport facilities			
3.6	Quarantine station/holding ground			
4	Do you have the following surveillance structures in the country (Only for MoLF officials)			
4.1	Referral diagnostic facilities			
4.2	Meat processing plants/Abattoirs			
4.3	Milk processing plants			

Appendix 4: Process evaluation- checklist for Veterinary shops

a.	Name of the shop		
b.	Region name		
c.	Region code		
d.	District name		
e.	District code		
f.	Ward name		
g.	Ward code		
h.	Location of the shop		
i.	Average number of customers saved per week		
j.	Is there any information collected before disbursing the medicine?	*Yes*	*1*
		No	*0*
k.	Which information do you collect before disbursing medicine		
l.	How do you store sales information?	*Manual/paper*	
		Computer	
		Phone	
n.	Date of the interview		
o.	Start time		
p.	Finishing time		
q.	GPS coordinates		

Appendix 5: Stakeholder mapping tool

Information exchange and stakeholder's analysis in animal health surveillance system in Tanzania

STAKEHOLDERS' COLLABORATION MAPPING (ADOPT USAID COLLABORATION MAPPING)
https://usaidlearninglab.org/sites/default/files/resource/files/collaboration_mapping_facilitation_guide_formatted_201806_508.pdf

Section I: Objective of the mapping
We want to visualize and depict the list of stakeholders in the animal health surveillance in the district and how we can leverage on the current status or establish the new ones in order to improve stakeholder' engagement in animal health surveillance

Section II: Stakeholders identification
Identify all potential stakeholders and collaborators (Central point- Livestock officers)

- Who are the key stakeholders in animal health in your district?
- On which level do they operate?
- Who have we worked with in the past on animal health and surveillance related activities?
- Who else is already engaged on animal health or surveillance?
- Who has expertise, influence, or resources that could be leveraged to achieve our surveillance objective?
- What other organizations also support the change we are seeking?
- What other organizations may oppose the change we are seeking?

Section II: Stock taking of the current relationship
Frequency of interaction (Ukaribu wa mchangamano) : Next, determine the current status of the relationship between each potential collaborator and the Animal health practitioners (LFOs and DVO) creating the collaboration map
Have each participating staff member rank each of the potential collaborators on a 10-point scale according to the following: 1–2 = No Interaction (***hakuna mahusiano/mchangamano***) 3–4 = Rare (***mara chache sana***) 5–6 = Intermittent (***hakuna mpangilio maalum***) 7–8 = Regular (***mara kwa mara)*** 9–10 = Constant and Consistent (***mara zote na kwa utaratibu unaeleweka)***

For the facilitator*: On the map, this will be represented by the relative proximity of each stakeholder circle to the center—the CLOSER to Animal health practitioners, the more interaction/closer the current relationship. Discuss the visual representation with the group to make sure everyone understands and agrees with the results*

Interaction characteristics: Next, for each potential collaborator, determine strength and quality of the relationship. As a team, discuss the following questions:

- Who has the relationship with X (refer stakeholder)?
- Does the relationship rely on just one contact (at either LFO or the other stakeholder)?
- If that key person leaves on either end, does the circle (i.e., relationship) begin to move away from LFO?
- How many people do we interact with at X?

Financial exchange (Optional): Finally, in some cases, there may be value in representing whether or not there is a financial element to the relationship between LFO and the stakeholder. If so, in what direction is the financial exchange?
On a hand-drawn map, this will be represented by the directional arrows on the line connecting the stakeholder circle to LFO. If there is ***no financial exchange****, leave the* ***line without arrows****. If LFO is* ***receiving funds*** *from this stakeholder, add an arrow* ***pointing toward LFO****. If LFO is jointly* ***investing in working*** *with the stakeholder, add* ***arrows on both ends of*** *the line.*

Section III: Determine resource-based influence
How much money, time, and staff this stakeholder already invests or potentially has to invest in the animal health and surveillance related activities?
After having a group discussion, each participating member will rank each of the potential collaborators on a 10-point scale: 1=low resource-based influence, 10=high resource-based influence. The facilitator then averages these rankings for an overall score for each stakeholder and lead a group discussion of the results to allow for any adjustments or to address any disagreements

Section IV: Determine non-resource-based influence
Non-resource-based influence can include political power, traditional and/or social media voice, name recognition, membership size, access to other resources, leadership in key working groups, etc.

To determine how much non-resource-based influence the stakeholders hold over the achievement of the objective, first have an open discussion with the group to reach a joint definition of non-resource-based influence. After this discussion, each participant will rank each of the potential collaborators on a 10-point scale: 1=low, 10=high. Discuss the average results as a group after they are calculated to allow for any adjustments or to address any disagreements.