RIFT VALLEY FEVER RISK MAPPING AND MODELLING IN TANZANIA

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

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EXTENDED ABSTRACT

Rift Valley fever (RVF) was first reported in Tanzania in 1930 and the last outbreak occurred in the country in 2006/07. Besides the long history of RVF in the country, little is known about its spatial and temporal epidemiology and habitat suitability for its occurrence. This study was conducted to determine potential risk factors and develop the country RVF risk map. Enzyme-linked immunosorbent assay was used to examine the presence of antibodies specific to RVF virus (RVFV) in serum samples from domestic ruminants, humans and wild animals. Logistic regression modelling was used to analyze RVF outbreak data and RVFV seropositivity. Space-time permutation and MaxEnt modelling were used to identify clusters and habitat suitability for RVF occurrence, respectively. Between 1930 and 2007, there were a total of 10 RVF outbreaks with overlapping of clusters that continuously covered more parts of the country. Overall, the seroprevalence of IgG specific to RVFV in domestic ruminants (n = 1435) was 25.8% (95% CI: 23.52, 28.05) and in humans (n = 541) was 10.7% (95% CI: 8.11, 13.34). The IgG specific to RVFV was detected in nine (n = 22) and one (n = 3) serum samples from African buffalo and African elephant, respectively. The potential risk factors for RVF occurrence included eastern Rift Valley ecosystem (OR = 6.14, CI: 1.96, 19.28), rainfall during the previous two months >405.4mm (OR = 12.36, CI: 3.06, 49.88), clay (OR =8.76, CI: 2.5, 30.5) and loam (OR = 8.8, CI: 2.0, 37.8) soil texture, introduction of domestic ruminants into the herd (OR = 5.08, CI: 2.74, 9.44; p< 0.001), human contact with aborted foetus materials (OR = 2.89, CI: 1.48, 5.60), human participation in the slaughtering of animals (OR = 2.65, CI: 1.39, 5.04), human having consumed meat from dead animals (OR = 2.06, CI: 1.05, 4.00). The findings of this study have shown that the north-eastern, central and lake zones of the country have larger amount of suitable habitat for RVF occurrence than the north-western and southern zones. These research findings

can be applied to guide risk-based cost-effective RVF surveillance and interventions strategies in the country.

DECLARATION

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

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DEDICATION

This is work is dedicated to my much-loved wife Dogeneth, my daughter Ivana and sons Novert and Jovan in recognition of their love, understanding, prayers and support in their own special way during the entire period of my study. Thank you all for putting up with me during my study period.

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Status: Published in ***Tanzania Journal of Health Research***, Volume 13. (Supplementary 1) DOI: http://dx.doi.org/10.4314/thrb.v13i5.1.

Paper II: Sindato C, Karimuribo ED, Pfeiffer DU, Mboera LEG, Kivaria F, Dautu G, Bernard B. and Paweska JT. (2014). Spatial and Temporal Pattern of Rift Valley Fever Outbreaks in Tanzania; 1930 to 2007.

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Paper III: C. Sindato, E.S. Swai, E.D. Karimuribo, G. Dautu, D.U. Pfeiffer, L.E.G. Mboera and J.T. Paweska. (2013). Spatial distribution of non-clinical Rift Valley fever viral activity in domestic and wild ruminants in northern Tanzania.

Status: Published in ***Tanzania Veterinary Journal*** Volume 28: DOI: http://dx.doi.org/10.4314%2Ftvj.v28i0.

Paper IV: Sindato C, Stevens KB, Karimuribo ED, Mboera LEG, Paweska JT, Dautu G. and Pfeiffer DU. Spatial heterogeneity of habitat suitability for Rift Valley fever occurrence in Tanzania; ecological niche modelling and relative risk mapping.

Status: Manuscript (submitted to ***PloS ONE*** peer reviewed journal).

Paper V: Sindato C, Pfeiffer DU, Karimuribo ED, Mboera LEG, Rweyemamu MM. and Paweska JT. (2015). A spatial analysis of Rift Valley fever virus seropositivity in domestic ruminants in Tanzania.

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Paper VI: Sindato C, Karimuribo ED, Pfeiffer DU, Dautu G, Paweska JT. and Mboera LEG. Assessment of potential behavioural health-risky practices and their association with Rift Valley fever virus seropositivity among pastoralists in Ngorongoro Conservation Area, Tanzania.

Status: Manuscript (submitted to ***PLoS ONE*** peer reviewed journal).

DECLARATION

I, CALVIN SINDATO, do hereby declare to the Senate of Sokoine University of Agriculture that the listed papers above that make this thesis summarize my independent work efforts, it is my own original work and will not be part of another thesis in the "Published Paper" format in any other institution.

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

AIC	Akaike`s information criterion
AIC_c	Sample-size corrected Akaike`s informationn criterion
asl	Above sea level
AUC	Area under the curve
AUC_{Diff}	AUC difference between training and test data
BIC	Bayesian information criterion
CDC	United States Centers for Disease Control and Prevention
CERF	Central Emergency Response Fund
CI	Confidence interval
ELISA	Enzyme-Linked-ImmunoSorbent Assay
EMPRESS	Emergency Prevention System for Animal Health
ENM	Ecological niche models
ENMTools	Ecological niche modelling tools
ENSO	El Nino-Southern Oscillation
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization
GIS	Geographical Information System
GPS	Geographical Positioning System
HRPO	Horseradish peroxidase
IEP	Inter-epidemic period
IgG	Immunoglobulin G
IgM	Immunoglobulin M
ILRI	International Livestock Research Institute
MaxEnt	Maximum entropy-based niche modelling algorithm

MoHSW	Ministry of Health and Social Welfare
MoLFD	Ministry of Livestock and Fisheries Development
NCA	Ngorongoro Conservation Area
NCAA	Ngorongoro Conservation Area Authority
NDVI	Normalized Difference Vegetation Index
NICD	National Institute for Communicable Diseases
NIMR	National Institute for Medical Research
OD	Net optic density
OIE	World Organisation for Animal Health
p	Probability value
PBS	Phosphate-buffered saline
PCR	Polymerase chain reaction
PI	Percentage inhibition
PP	Percentage positivity
ROC	Receiver operating characteristic curves
RT-PCR	Real Time-polymerase chain reaction
RVC	Royal Veterinary College
RVF	Rift Valley fever
RVFV	Rift Valley fever virus
SACIDS	Southern African Centre for Infectious Disease Surveillance
SDS	Sodium dodecyl sulphate
Spp	Species
SUA	Sokoine University of Agriculture
TAD	Transboundary animal diseases
TAWIRI	Tanzania Wildlife Research Institute
TMA	Tanzania Meteorological Agency

UK	United Kingdom
URT	United Republic of Tanzania
US$	United States of America dollar
UTM	Universal Transverse Mercator
WHO	World Health Organization
^{o}C	Celsius or Degree centigrade
%	Percent
<	Less than sign
>	Greater than sign
≤	Less than or equal to sign
≥	Greater than or equal to sign

CHAPTER ONE

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Background information

Rift Valley fever (RVF) is an acute arthropod-borne viral zoonotic disease caused by RVF virus (RVFV) belonging to the genus *Phlebovirus* of family *Bunyaviridae,* a group of enveloped RNA-viruses (Woods *et al*., 2002; Flick and Bouloy, 2005). The disease is named after the Great Rift Valley system of East Africa, where RVFV was first isolated in 1931 during an outbreak of abortions and deaths in exotic wool sheep in Kenya after heavy rainfall (Daubney *et al*., 1931). It is endemic in sub-Saharan Africa (Chevalier *et al*., 2005; Rich and Wanyoike, 2010; Dar *et al*., 2013), but it has also been reported outside this region (Morvan *et al*., 1992; Shoemaker *et al*., 2002; Balkhy and Memish, 2003) and it is considered to have potential for global spread (European Food Safety Authority, 2005; Hartley *et al*., 2011; Versteirt *et al*., 2013).

1.2 Affected species

The disease affects a wide range of vertebrates, but the clinical disease is limited to primarily domestic ruminants and humans, and non-clinical form of the disease in wildlife (OIE, 2008; Pepin *et al*., 2010). The capacity of RVFV to cause large and severe outbreaks in animal and human populations and to cross significant natural geographic barriers, as exemplified by the virus spread over the Indian Ocean, Sahara desert, and the Red Sea in the past three decades, is of great concern for veterinary and public health authorities worldwide. The RVFV is one of the most important emerging zoonotic threats, particularly to vulnerable African communities with low resilience to economic and environmental challenges (Pepin *et al*., 2010; Grobbelaar *et al*., 2011; Murithi *et al*., 2011).

1.3 Disease transmission

There are significant differences in the ecology and transmission patterns of RVFV in endemic regions. In eastern and southern Africa large outbreaks of RVF occur at irregular intervals of up to 15 years, after heavy rainfall and floods (Grobbelaar *et al*., 2011; Murithi *et al*., 2011). The fate of the virus during inter-epidemic period (IEP) is not well understood, but cryptic maintenance and transmission cycles have been postulated. Isolation of RVFV from Aedes mcintoshi mosquitoes collected during IEP periods in Kenya (Linthicum *et al*., 1983), led to generally accepted hypothesis that, the virus is maintained in nature by transovarial transmission in aedine mosquitoes. However, demonstration that the larvae of *Culex pipiens, Ae. mcintoshi* and *Ae. circumluteolus* become infected after feeding on liver homogenates from an experimentally inoculated hamster might also be of epidemiological importance (Turell *et al*., 1990). Flooding provides suitable habitat for infected aedine mosquito eggs to hatch. While the floodwater *Aedes spp*. tend to remain in the immediate vicinity of dambos and only feed at dusk and dawn, the more nocturnal *Culex spp* and *Anopheles spp*. disperse more widely to find vertebrate hosts for blood feeding. Flooding also contributes to concentration of animals and humans on areas of dry land, thus further increasing the potential for virus transmission (Pepin *et al*., 2010).

Rift Valley fever virus isolates from one geographic area tend to cluster together, but genetic variants with distant origins are found within different genetic lineages, suggesting that the movement of infected livestock and the natural dispersal of mosquitoes allow the spread of the virus throughout continental Africa, Madagascar, and the Arabian Peninsula (Grobbelaar *et al*., 2011). The bite from infected mosquito is the principal infection mechanism of RVF in animals (Métras *et al*., 2012). Humans are mainly infected by close contact with blood, excreta of infected animals, consumption of poorly prepared meat/milk from infected animals and through bites from infected mosquitoes (LaBeaud *et al*., 2011).

In countries where RVFV activity was not previously detected, outbreaks of the disease in animal and human populations commonly result from the spread of a single lineage of the virus (Bird *et al*., 2008; Grobbelaar *et al*., 2011). Recent molecular epidemiology studies in East Africa indicate ongoing RVFV activity and evolution during the IEP, and highlight the importance of a cryptic enzootic transmission cycle that allows for the establishment of RVFV endemicity and to precipitate explosive outbreaks (Bird *et al*., 2008; Nderitu *et al*., 2011). The RVFV transmission during IEP without noticeable outbreak or clinical cases has been reported in different species of African wildlife (Evans *et al*., 2008; LaBeaud *et al*., 2011; Britch *et al*., 2013), in cattle in Mayotte (Cêtre-Sossah *et al*., 2012), in sheep and goats in Mozambique (Fafetine *et al*., 2013), in humans in Kenya (LaBeaud *et al*., 2011), Gabon (Poourrut *et al*., 2010) and Tanzania (Heinrich *et al*., 2012). The specific role that domestic and wild animals play in virus maintenance between outbreaks and virus amplification prior to noticeable outbreaks needs, however, to be described. Likewise it is unknown why a low level of virus circulation during IEP does not result in clinical manifestations in livestock and humans. One explanation could be that sporadic clinical cases occurring during IEP are either underreported or misdiagnosed as other related diseases. Furthermore, the possibility of circulation of less virulent strain of RVFV in many countries including Tanzania is poorly understood.

1.4 Clinical manifestation

Host susceptibility depends on age and animal species. Infections can be in-apparent and animals may have no sickness or febrile reactions. Susceptible animals may develop high viraemia, severe prostration and death. In general, breeds that are less susceptible are those indigenous to the tropical and subtropical zones in Africa, while those highly susceptible are the crossbred (hybrid) or imported genotypes exotic to the continent (OIE, 2008). Lambs, calves and kids are highly susceptible to RVFV infection. The mortality rate has

been reported to be 90-100% in lambs and kids under a week old and 70% in calves (Coetzer, 1982; Murithi *et al*., 2011). In young lambs, the common signs include sudden rise of body temperature to 40.5 - 42.2°C, followed by death within 36 hours. This acute form is less common in older sheep and goats which have mortality rate of approximately 20-30% (Coetzer, 1982). Clinical signs in adult sheep and goats are not consistent but may include rise in body temperature, vomiting, mucopurulent nasal discharge, unsteady gait, high abortion rate which gives the characteristic storm of abortion (almost 100% of pregnant ewes) as well as haemorrhages in visible mucous membranes (Coetzer, 1982). Clinical signs in adult cattle include high temperature, salivation, anorexia, general weakness, fetid diarrhoea, a rapid decrease in lactation and abortion. Abortion may be the only marked sign in cattle and mortality in adult cattle is usually less than 10% (Murithi *et al*., 2011). The incubation period in young domestic ruminants is between 12 and 24 hours (Coetzer, 1982).

The clinical disease in humans presents with mild to severe influenza-like illness. Patients are likely to suffer from the mild form of the disease that is characterized by sudden fever (37.5^{o}C), face flushing, eye congestion, headache, general muscles and joint pain, and photophobia. Patients are likely to recover between 4 and 7 days. Severe form of the disease in humans might present with influenza-like illness, jaundice, encephalitis, ocular lesions, permanent loss of vision and fatal haemorrhagic state (Pepin *et al*., 2010). While RVF was originally associated with mainly the livestock mortality, there is evidence of increased fatality rates in humans during the recent outbreaks (Adam *et al*., 2009).

1.5 Diagnosis

Use of clinical case definition in the diagnosis of RVF is constrained mainly by its non specific clinical signs/symptoms. Furthermore, RVFV may circulate at a very low level,

silently, without or with few clinical signs, which is extremely difficult to detect (FAO, 2003). These limitations therefore suggest that, while syndromic surveillance may be a useful and cost-effective tool to minimize under-reporting and delay in diagnosis, laboratory confirmation of probable or suspected case is critical. Confirmation of the disease in humans and domestic ruminants is commonly carried out using enzyme linked immunosorbent assay (ELISA) methods that detects type-specific anti-RVFV immunoglobulins (Paweska *et al*., 2003a; Paweska *et al*., 2003b; Paweska *et al*., 2005a; Paweska *et al*., 2005b; Jansen van Vuren and Paweska, 2009) and polymerase chain reaction (PCR) that detects RVFV nucleic acid (Pepin *et al*., 2010) in blood.

1.6 Prevention and control

The preventive and control measures for RVF is mainly through effective vaccination of livestock before the onset of an outbreak, commonly using Smithburn vaccine that confers life-long protection in animals (Anyamba *et al*., 2010). Other preventive and control measures include public education, mosquito vector control and restriction of animal movements (Anyamba *et al*., 2010). To control occupational hazards, protective gear such as gloves and other appropriate protective clothing should be worn and care taken when handling sick animals, patients, their tissues or any other suspected biological materials (Anyamba *et al*., 2010). By following up the international RVF early warning alerts of heavy rains, flooding, mosquito blooms and RVF events, it is likely that preventive initiatives are implemented timely (Anyamba *et al*., 2009). There is no specific treatment for RVFV infection in humans and animals, and therefore management of clinical cases is only through supportive therapy (Pepin *et al*., 2010).

1.7 Occurrence of RVF in Tanzania

Currently, it is not known how RVF was introduced to Tanzania. However, all the necessary animal hosts and vectors required for its occurrence, spread and persistence are

present in the country. The occurrence of RVF is associated with the Great Rift Valley system which is a long depression in the earth that runs down the eastern side of Africa. It extends from Syria in the Middle East, right down to Mozambique in south-eastern Africa. The well-expressed Eastern branch traverses Ethiopia, Kenya and reaches north Tanzania, where it forms the north Tanzania divergence (Morley, 1999). Although epidemiological features of RVF in Tanzania do not seem to be fundamentally different compared with the neighbouring countries, it is unique that, this is the only country with the two branches of the Great Rift Valley system. This system forms the eastern and western ecosystems with a branch running through the western of Tanzania. This is the one in which Lake Tanganyika is located. The eastern branch runs through the centre of Tanzania forming important internal drainage ecosystem basins (Morley, 1999). The eastern branch finally rejoins the western branch in Mbeya region fading progressively towards Lake Nyasa (Figure 1: in paper II).

Unpublished records available at the Ministry of Livestock and Fisheries Development (MoLFD) in Tanzania indicate that, RVF-like disease in domestic ruminants occurred for the first time in 1930. The last RVF outbreak was reported in the country in 2006/07. Despite the long history of RVF in Tanzania, little is known about its spatial and temporal epidemiology and habitat suitability for the disease occurrence. In addition, relatively little is known about risk factors associated with its occurrence in animals and humans partly because of long inter-epidemic periods and poor surveillance based on limited resources. Spatial and temporal heterogeneity in the risk of RVF occurrence in Tanzania should inform cost-effective disease surveillance, prevention and control strategies. Decision making in the control of diseases is constrained by cost-benefit considerations. Under inadequate surveillance systems, decision makers are grossly misinformed and may lose opportunities for the implementation of cost-effective strategic control measures. For

instance, in order to prevent RVF outbreaks, animal vaccination must occur prior to epizootics, which can be difficult to implement cost-effectively in the absence of scientific guidance. In these situations, description of the spatial and temporal pattern and characterisation of habitat suitability for RVF occurrence, and investigation of the associated risk factors, are the crucial steps.

The increased development and availability of geographic information systems (GIS) and integrated software packages (including, but not limited to, Microsoft Excel, SaTScan, Maxent, Ecological niche modelling tools and Stata), have facilitated the investigations of spatial and temporal variations of diseases and the associated risk factors.

The assessment of the spatial and temporal pattern of RVF, highlighting areas at high risk, detecting significant disease clusters in space and time, and identifying disease risk factors are important for cost-effective usage of control resources that are generally limited. A wide range of spatial and temporal methods exist, including disease risk mapping, clustering and characterisation of habitat suitability for disease occurrence. Therefore, this study was conducted to identify potential RVF risk factors and develop country RVF risk map. The findings of this study will provide guidance on surveillance plans and the cost-effective-usage of disease control resources, by targeting the areas at high risk of disease transmission.

1.8 Problem statement and justification of the study

1.8.1 Problem statement

Rift Valley fever is a resurgent threat in Tanzania with severe negative socio-economic impacts to people's livelihoods and the country at large when it occurs in outbreak form. Rift Valley fever-like disease occurred for the first time in the country in 1930. However,

previous outbreaks were very sporadic with little awareness on the disease that made improper documentation of disease occurrence in the country (Kivaria, F. personal communication, 2011). Contrary to the last disease outbreak in 2006/07, sporadic cases of RVF during the previous outbreaks were confined to mainly livestock and mostly affecting northern parts of Tanzania (Kondela *et al*., 1985; Woods *et al*., 2002; WHO, 2010). The last disease outbreak was reported mainly in the northern and central zones of the country, involving both human and domestic ruminants (WHO, 2010).

It is becoming increasingly difficult to ignore the possibility of the next RVF outbreak to expand to new areas within the country, which had never reported outbreaks. The disease control resources are generally limited, and therefore their cost-effective usage by targeting the high risk areas is crucial. The level of disease risk in various locations of the country is unclear. In addition, little is known about behavioural exposure risk practices in the community, which is important for prevention of disease transmission. In order to prevent RVF outbreaks, vaccination of domestic ruminants must occur prior to outbreaks. However, routine and wider coverage of the vaccination programmes has faced a major drawback because of the vaccine being prohibitively expensive (Balkhy *et al.* 2003). The available epidemiological data does not provide better understanding of the epidemiology of RVF county-wise, which is important for cost-effective usage of control, prevention and surveillance resources.

1.8.2 Justification of the study

Rift Valley fever is one of the most important Transboundary Animal Diseases (TADs), with devastating effect on animal and human health, and food security. It is a zoonotic and high priority disease because of its potential for severe economic harm as it jeopardises the international trade (including effect on tourism industry) and loss of livelihoods. Huge

economic losses both nationally and internationally are the consequence. Past RVF outbreaks had dramatic socio-economic losses in Tanzania and these impacts were heavier on pastoral communities as they could not use milk or meat from their livestock. The disease damaged pastoralist livelihoods through livestock deaths and abortions. In addition to pastoralists, the disease threatened the livelihoods of those who were depending on livestock products and related activities such as labour opportunities and livestock export trade. Besides mortalities, RVF caused long-term illnesses in people, impairing them to resume their normal economic activities.

The disease is among the most threatening of all tropical viral infections because it can infect so many different species of animals and be carried by many vectors. It is reasonable to suggest that control of the disease in animals is a prerequisite to prevent human cases. During the period of active outbreak waves, intensive efforts have been made to control the disease mainly through vaccination of domestic ruminants, restriction of animal movements and public education. However, there was poor scientific guidance in the allocation of resources, which were generally limited, because the risk profile for RVFV transmission and its suitable habitat in the country was poorly understood. The facts on what types of animal exposure are most risky, and what non-animal exposures are important, have not yet been elucidated. In addition, little is known about behavioural risk practices in the community important for controlling disease transmission at community level. In developing strategies for prevention of this important disease before, it is critical to determine the pattern of outbreaks over space and time, and suitable habitat where RVF is likely to occur. Ultimately, mapping and modelling of the risk of RVF occurrence in the country will provide guidance to policy makers, planners and other stakeholders in prioritizing, designing and implementing cost-effective and sustainable RVF control initiatives.

1.9 Objectives of the study

1.9.1 Main objective

To carry out risk mapping and modelling of RVF in Tanzania with ultimate goal of providing guidance for designing cost-effective disease surveillance, prevention and control strategies that will reduce the risk of infection in animals and humans.

1.9.2 Specific objectives

i) To determine the epidemiological features and socio-economic impacts associated with RVF outbreaks in Tanzania.

ii) To determine the spatial and temporal patterns of RVF outbreaks and RVFV activity during the inter-epidemic periods in Tanzania, and identify potential risk factors associated with these patterns.

iii) To determine potential behavioural health-risky practices, and analyze their association with RVFV seropositivity among the pastoralists within Ngorongoro Conservation Area.

1.10 Organization of the thesis

This thesis is organised in three chapters preceded by an abstract which summarizes the objectives, materials and methods, principal research findings and conclusion of this study. Chapter one consists of introduction, problem statement, justification of the study and study objectives. Chapter two presents the results obtained from each specific objective which are synthesised into either published papers (papers I, II, III and V) or written manuscripts (papers IV and VI) submitted for publication in peer reviewed scientific journals. The format and writing style of the individual papers is according to the targeted peer reviewed journal. Chapter three provides the conclusions and recommendations based on the finding of this study.

REFERENCES

Adam, A.A., Karsany, M.S. and Adam, I. (2009). Manifestations of severe Rift Valley fever in Sudan. *International Journal of Infectious Diseases* 14: 179 – 180. doi: 10.1016/j.ijid.2009.03.029.

Anyamba, A., Chretien, J.P., Small, J., Tucker, C.J., Formenty, P., Richardson, J.H., Britch, S.C., Schnabel, D.C., Erickson, R.L. and Linthicum, K.J. (2009). Prediction of Rift Valley fever outbreak in the horn of Africa 2006–2007. *Proceedings of the National Academy of Sciences of the United Staes of America USA* 106: 955 – 959.

Anyamba, A., Linthicum, K.J., Small, J., Britch, S.C., Pak, E. and de La Rocque, S.E. (2010). Prediction, assessment of the Rift Valley fever activity in East and Southern Africa 2006-2008 and possible vector control strategies. *American Journal of Tropical Medicine and Hygiene* 83(2 Suppl): 43 - 51.

Balkhy, H.H. and Memish, Z.A. (2003). Rift Valley fever: an uninvited zoonosis in the Arabian Peninsula. *International Journal of Antimicrobiological Agents* 21: 153 – 7.

Bird, B.H., Githinji, J.W., Macharia, J.M., Kasiiti, J.L., Muriithi, R.M., Gacheru, S.G. (2008). Multiple virus lineages sharing recent common ancestry were associated with a large Rift Valley fever outbreak among livestock in Kenya during 2006–2007. *Journal of Virology* 82: 11152 – 11166.

Britch, S.C., Binepal, Y.S., Ruder, M.G., Karithi, H.M., Linthicum, K.J. and Anyamba, A. (2013). Rift Valley fever risk map model and seroprevalence in selected wild ungulates and camels from Kenya. *PLoS ONE* 8(6): e66626.

Cêtre-Sossah, C., Pédarrieu, A., Guis, H., Defernez, C. and Bouloy, M. (2012). Prevalence of Rift Valley Fever among Ruminants, Mayotte. *Emerging Infectious Diseases* 18: 6. DOI: 10.3201/eid186.111165.

Chevalier, V., Lancelot, R., Thiongane, Y., Sall, B., Diaite, A. and Mondet, B. (2005). Rift Valley fever in small ruminants, Senegal, 2003. *Emerging Infectious Diseases* 11: 1693 – 1700.

Coetzer, J.A.W. (1982). The pathology of Rift Valley fever. Lesions occurring in field cases in adult cattle, calves and aborted foetuses. *Onderstepoort Journal of Veterinary Research* 49: 11 – 17.

Dar O., McIntyre, S., Hogarth, S. and Heymann, D. (2013). Rift Valley fever and a new paradigm of research and development for zoonotic disease control. *Emerging Infectious Diseases* 19(2): 189 - 193.

European Food Safety Authority, (2005). Opinion of the Scientific Panel on Animal Health and Welfare on a request from the commission related to the risk of a Rift Valley fever incursion and its persistence within the community. *European Food Safety Authority Journal* 238: 1 – 128.

Evans, A., Gakuya, F., Paweska, J.T., Rostal, M., Akoolo, L., VAN Vuren, P.J., Manyibe, T., Macharia, J.M., Ksiazek, T.G., Feikin, D.R., Breiman, R.F. and Kariuki Njenga, M. (2008). Prevalence of antibodies against Rift Valley fever virus in Kenyan wildlife. *Epidemiology and Infection* 136: 1261 – 1269. doi: 10.1017/S0950268807009806.

Fafetine, J., Neves, L., Thompson, P.N., Paweska, J.T., Rutten, V.P.M.G. and Coetzer, J.A.W. (2013). Serological Evidence of Rift Valley Fever Virus Circulation in Sheep and Goats in Zambézia Province, Mozambique. *PLoS Neglected Tropical Diseases* 7(2): e2065. doi:10.1371/journal.pntd.0002065.

FAO, (2003). Preparation of Rift Valley fever (RVF) contingency plans. [http://www.fao.org] site visited on 12/9/2011.

Flick, R. and Bouloy, R. (2005). Rift Valley Fever Virus. *Current Molecular Medicine* 5: 827 - 834.

Grobbelaar, A.A, Weyer, J., Leman, P.A., Kemp, A., Paweska, J.T. and Swanepoel, R. (2011). Molecular epidemiology of Rift Valley fever virus. *Emerging Infectious Diseases* 12: 2270 - 2276.

Hartley, D.M., Rinderknecht, J.L., Nipp, T.L., Clarke, N.P. and Snowder, G.D. (2011). National Centre for Foreign Animal and Zoonotic Disease Defense Advisory Group. Potential effects of Rift Valley fever in the United States. *Emerging Infectious Diseases* 17. [http://www.dx.doi.org/10.3201/eid1708.101088] site visited on 13/5/2013.

Heinrich, N., Saathoff, E., Weller, N., Clowes, P., Kroidl, I., Ntinginya, E., Machibya, H., Maboko, L., Thomas, Loscher, Dobler, G. and Hoelscher, M. (2012). High Seroprevalence of Rift Valley Fever and evidence for endemic circulation in Mbeya Region, Tanzania, in a cross-sectional study. *PLoS Neglected Tropical Diseases* 6(3): e1557.

Jansen van Vuren, P and Paweska, J.T. (2009). Laboratory safe detection of nucleocapsid protein of Rift Valley fever virus in human and animal specimens by a sandwich ELISA. *Journal of Virological Methods* 157: 15 - 24.

Kondela, A., Loretu, K. and Mella, P.N.P. (1985). Isolation of Rift Valley Fever virus from cattle abortions in Tanzania (Short Communication). *Tropical Animal Health and Production* 17: 185 – 186.

LaBeaud, A.D., Muiruri, S., Sutherland, L.J., Dahir, S., Gildengorin, G., Morrill, J., Muchiri, E.M., Peters, C.J. and King, C.H. (2011). Post-epidemic analysis of Rift Valley Fever virus transmission in Northeastern Kenya: a village cohort study. *PLoS Neglected Tropical Diseases* 5:e1265.

Linthicum, K.J., Davies, F.G. Bailey, C.L. and Kairo, A. (1983). Mosquito species succession dambo in an East African forest. *Mosquito News* 43: 464 - 470.

Métras, R., Porphyre, T., Pfeiffer, D.U., Kemp, A., Thomson, P., Collins, L.M. and White, R.G. (2012). Exploratory space-time analyses of Rift Valley fever in South Africa in 2008-2011. *PLoS Neglected Tropical Diseases* 6: e1808.

Morley, C.K. (1999). Tectonic evolution of the East African Rift System and the modifying influence of magmatism: a review. *Acta Vulcanologia* 11: 1–19.

Morvan, J., Rollin, P.E., Laventure, S., Rakotoarivony, I. and Roux, J. (1992). Rift Valley fever epizootic in the central highlands of Madagascar. *Research Virology* 143: 407 – 415.

Murithi, R.M., Munyua, P., Ithondeka, P.M., Macharia, J.M., Hightower, A. and Luman, E.T. (2011). Rift Valley fever in Kenya: history of epizootics and identification of vulnerable districs. *Epidemiology and Infectious Diseases* 139: 372 - 80.

Nderitu, L., Lee, J.S., Omolo, J., Omulo, S., O'Guinn, M.L., Hightower, A., Mosha, F., Mohamed, M., Munyua, P., Nganga, Z., Hiett, K., Seal, B., Feikin, D.R., Breiman, R.F. and Njenga, M.K. (2011). Sequential Rift Valley fever outbreaks in eastern Africa caused by multiple lineages of the virus. *Journal of Infectious Diseases* 1203(5): 655 - 665.

OIE, (2008). Rift Valley Fever Terrestrial Manual 2.1.14. [http://www.oie.int/ Eng/Normes/Mmanual/2008/] site visited on 3/6/2011.

Paweska, J.T., Burt, F.J. and Swanepoel, R. (2005a). Validation of IgG-sandwich and IgM-capture ELISA for the detection of antibody to Rift Valley fever virus in humans. *Journal of Virological Methods* 124: 173 - 181.

Paweska, J.T., Burt, F.J., Anthony, F., Shirley, J., Smith, S.J., Grobbelaar, A.A., Janice, E., Croft, T. and Swanepoel, R. (2003a). IgG-sandwich and IgM capture enzyme-linked immunosorbent assay for the detection of antibody to Rift Valley fever virus in domestic ruminants. *Journal of Virological Methods* 113: 103 – 112.

Paweska, J.T., Mortimer, E., Leman, P.A. and Swanepoel, R. (2005b). An inhibition enzyme-linked immunosorbent assay for the detection of antibody to Rift Valley fever virus in humans, domestic and wild ruminants. *Journal of Virology Methods* 127:10 – 18.

Paweska, J.T., Smith, S.J., Wright, I.M., Willliams, R., Cohen, A.S. and Van Dijk, A.A. (2003b). Indirect enzyme-linked immunosorbent assay for the detection of antibody against Rift Valley Fever virus in domestic and wild ruminant sera. *Onderstepoort Journal of Veterinary Research* 70: 49 - 64.

Pepin, M., Bouloy, M., Bird, B., Kemp, A. and Paweska, J. (2010). Rift Valley fever virus (Bunyaviridae: Phlebovirus): an update on pathogenesis, molecular epidemiology, vectors, diagnostics and prevention. *Veterinary Research* 41: 61 DOI: 10.1051/vetres/2010033.

Poourrut, X., Nkoghe, D., Souris, M., Paupy, C., Paweska, J., Padilla, C., Moussavou, G. and Leroy, E.M. (2010). Rift Valley fever seroprevalence in human rural populations of Gabon. *PLoS Neglected Tropical Diseases* 4: e763.

Rich, K.M. and Wanyoike, F. (2010). An assessment of the regional and national socioeconomic impacts of the 2007 Rift Valley fever outbreak in Kenya. *American Journal of Tropical Medicine and Hygiene* 83: 52 – 57.

Shoemaker, T., Boulianne, C., Vincent, M.J., Pezzanite, L., Al-Qahtani, M.M., Al-Mazrou, Y., Khan, A.S., Rollin, P.E., Swanepoel, R., Ksiazek, T.G. and Nichol, S.T. (2002). Genetic analysis of viruses associated with emergence of Rift Valley fever in Saudi Arabia and Yemen, 2000–2001. *Emerging Infectious Diseases* 12: 1415 - 1420.

Turell, M.J., Linthicum, K.J. and Beaman, J.R. (1990). Transmission of Rift Valley fever virus by adult mosquitoes after ingestion of virus as larvae. *American Journal of Tropical Medicine and Hygiene* 43: 677 - 680.

Versteirt, V., Ducheyne, E., Schaffner, F. and Hendrickx, G. (2013). Systematic literature review on the geographic distribution of Rift Valley Fever vectors in the Europe and the neighbouring countries of the Mediterranean Basin. Supporting Publications. [www.efsa.europa.eu/publications] site visited on 13/5/2013.

Woods, C., Karpati, A., Grein, T., McCarthy, N., Gaturuku, P., Muchiri, E., Dunster, E., Henderson, A., Khan, A., Swanepoel, R., Bonmarin, I., Martin, L., Mann, P., Smoak, B. and Ryan, M. (2002). An outbreak of Rift Valley fever in northeastern Kenya 1997–1998. *Emerging Infectious Diseases* 8: 138 – 144.

CHAPTER TWO

PAPER ONE

The Epidemiology and Socio-economic Impact of Rift Valley fever Epidemics in Tanzania: A review

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PAPER TWO

Spatial and Temporal Pattern of Rift Valley Fever Outbreaks in Tanzania; 1930 to 2007

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PAPER THREE

Spatial Distribution of Non-Clinical Rift Valley Fever Viral Activity in Domestic and Wild Ruminants in Northern Tanzania

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PAPER FOUR

Spatial Heterogeneity of Habitat Suitability for Rift Valley Fever Occurrence in Tanzania: An Ecological Niche Modelling Approach

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PAPER FIVE

A Spatial Analysis of Rift Valley Fever Virus Seropositivity in Domestic Ruminants in Tanzania

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PAPER SIX

Assessment of Potential Behavioural Health-risky Practices and their Association with Rift Valley Fever Virus Seropositivity among Pastoralists in Ngorongoro Conservation Area, Tanzania

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CHAPTER THREE

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

The findings of this study demonstrate the value of retrospective spatio-temporal analysis of RVFV activity, prediction of habitat suitability for RVF occurrence, assessment of potential behavioural health-risk practices amongst pastoralists and triangulation of these observations using cross-sectional RVFV serological studies. This study has shown that, past RVF outbreaks and the risk of disease occurrence were distributed heterogeneously, and transmission dynamics appeared to vary even between areas within a few kilometres apart in Tanzania. All past RVF outbreaks were reported between December and June. There was overlapping of human and livestock primary clusters in the northern zone of the country. Successive RVF outbreaks had a tendency to cover increasing areas of the country. Whenever RVFV infection has been introduced into an area, it is likely to be involved in future outbreaks. The north-eastern, central and lake zones of the country (mainly in the eastern Rift Valley ecosystem), characterized with impermeable soils, bimodal rainfall pattern and high livestock densities, have larger amount of suitable habitats for RVF occurrence than the western and southern parts of the country (mainly in the western Rift Valley ecosystem). The past disease outbreaks had dramatic negative socio-economic impacts on people's livelihoods and the country at large. This study confirmed high prevalence of potential behavioural health-risky practices in the pastoral community, most of which were associated with RVFV seropositivity.

Occurrence of RVF in Tanzania is associated with multiple factors. The major determinants of RVF suitability habitat in the country were: the eastern compared with the western Rift Valley ecosystem, locations with impermeable soil types compared with locations with permeable soil types, areas with clay and loam soil compared with sandy soil texture, low lying compared with highland areas, bimodal compared with unimodal

rainfall pattern. Other determinants were livestock density and proximity to forest. In addition to these country-wide disease determinants, the risk of RVF occurrence in the areas selected for serological studies were (a) for livestock: introducing domestic ruminants into the herd and increasing animal age, and (b) for humans: increasing age, being a male, handling of aborted foetus materials, participation in the slaughtering of animals and consumption of meat from dead animals. The observed geographical spread of RVF over the period of 77 years, and high frequency of behavioural health-risky practices reported in this study provides an alarm warning for permissive environment for an expected wide spread of the next outbreak to large populations of humans and domestic animals, potentially even involving the entire country.

3.2 Recommendations

3.2.1 Disease surveillance, prevention and control

The research findings reported in this study can provide guidance on cost-effective surveillance and interventions strategies by targeting the identified high risk areas.

i. The MoLFD can strategically implement the pre-emptive vaccination of livestock before December by targeting the identified high risk areas using limited resources.
ii. Given that RVF is a zoonotic disease and that its occurrence is associated with multiple risk factors; public health risk management in Tanzania should adapt inter-sectoral collaboration approach in the surveillance, design and implementation of evidence-based RVF control measures in animals and humans.
iii. Based on the high level of human behavioural risky practices reported in this study, there is a need for socio-anthropology to increase community awareness and behavioural risk modification. There is a need for the Regional and District leaders to assist in enhancing awareness in controlling transmission of the disease from livestock to humans by stressing on proper boiling of milk, thorough roasting and

cooking of meat, as well as avoiding the consumption of non-inspected meat, meat from dead animals and proper incineration of any carcass unfit for human consumption.

iv. Livestock movement permits issued by the MoLFD should consider including a requirement for RVF testing as part of disease surveillance and control strategies.

v. The MoLFD should advocate and monitor the use of established system for animal identification and traceability.

vi. The MoLFD can strategically set up sentinel surveillance system in the identified high risk areas.

vii. Deliberate efforts should be made to use integrated vector control measures that should be placed under vector control units in the respective ministries responsible for human and animal health. There should be a policy on the use of broad-spectrum insecticide compounds used for animal dipping. Such compounds like synthetic pyrethroids would act against a wider spectrum of biting insects/flies including mosquitoes which are vectors for RVFV.

viii. The Government of Tanzania through its ministries responsible for human and livestock health should consider establishing the capacity to produce RVF diagnostic reagents within the country, and should advocate use of available local laboratories to avoid unnecessary delays and costs for confirmation of RVF suspects.

ix. The government of Tanzania should consider providing alternative food to victims during disease outbreaks to limit consumption of dead animals.

3.2.2 Future studies

i. Future studies should consider fine-tuning the RVF predictive algorithm, geographical vulnerability and mechanism of RVFV dispersal in the country. This

can be achieved through modelling the distribution and role of potential vectors and other reservoir hosts, network modelling of animal and human movements, modelling socio-economic aspects and potential role of wind velocity, direction and convergence on vector dispersal.

ii. There is a need for a better understanding of mosquito resting behaviour, feeding behaviour, feeding pattern and host feeding preferences.

iii. There is a need to investigate whether by keeping livestock in proximity to household dwellings provides the risk or rather the protective effect to RVFV vectors.

iv. The burning of cow dung to repel mosquitoes is also an interesting area for further research.

v. Future studies should explore methods to incorporate seasonality in the country static RVF suitability map to develop dynamic suitability maps important for forecasting models. This can be achieved through country-scale observation of time series data on rainfall and normalized difference vegetation index (NDVI).

vi. There is a need to establish whether different RVF viruses are circulating between the eastern and western Rift Valley ecosystems.

vii. There is a need to establish the level of antibody response which is likely to confer immunity in animals and humans following natural exposure to RVFV.

viii. There is a need to develop a method to discriminate between naturally infected and vaccinated animals which is important for disease surveillance and evaluation of vaccination programmes.

APPENDICES

Appendix 1: Informed Consent Form (English version)

Name of Principal investigator: Dr. Calvin Sindato

Title: Rift Valley fever risk mapping and modelling in Tanzania

***READ*: Hello. My name is_____**. I am part of a research team from Sokoine University of Agriculture. You have been invited to take part in this research study. Before you decide whether to participate, you need to understand why this research is being done and what it would involve. Please take time to read or listen as I read the following information. You may talk to others about the study if you wish. Please feel free to ask me about anything that is not clear or if you would like more information. When all your questions have been answered and you feel that you understand this study, you will be asked if you would like to participate in the study, and if yes, to sign this informed consent form. You may request a signed copy to keep.

Purpose of the study

What is the study? We are conducting a study to assess the potential risk factors associated with Rift Valley fever (RVF) occurrence in Tanzania and generate a country disease risk map. Findings from this study will inform the risk-based cost-effective RVF surveillance and intervention strategies. This study has been approved by the Medical Research Coordinating Committee of the National Institute for Medical Research in Tanzania. Permission to conduct this study has also been sought from authorities at the regional and district levels as well as local leaders.

Why am I invited to take part?

You have been invited because you are the resident/have lived in this place. We would want to talk to key stake holders like you who can help responding to a few questions related to RVF in this area.

What will happen if I take part in this study?

If you agree to take part in the study, we will ask you to sign this form. You will then participate in personal interview that will cover questions about the occurrence of RVF in this area. You will be requested to donate your blood sample (about 5ml), or blood sample from your children (about 2ml), or blood sample from your livestock (about 5ml)

including 10 cattle, 5 sheep and 5 goats from your herd. We will examine the collected blood samples for the presence of antibodies specific to RVF virus. We will in addition request you to provide demographic information for yourself, your children or your livestock taking part in this study. Furthermore, you, your children or your livestock will be examined for the clinical features suggestive of RVF.

How long will the interview and blood sampling exercise last?

The interview and blood sampling exercise will take about one hour to complete.

Risks

What are the risks of this study?

An inconvenience may be the time and effort you take to be a participant. You might be embarrassed by some of our questions. You may choose not to answer any specific question we ask. If you feel uncomfortable at any time, let me know and we can move on to a different question. You may wish to end an interview at any time without penalty.

Benefits

What are the benefits of participating?

There is no direct benefit that you will get through your participation into this study. However, you will be helping us to learn the epidemiological features of RVF in this area. This will in turn help us to understand how we can design the risk-based cost-effective RVF surveillance and intervention strategies.

Confidentiality

Will the respondent's participation in this study be kept confidential?

The information collected will be kept private. We will not write down your name or any information that could identify and link you with the information you provide. We will not tell your name to other people we speak with at any place. This is an anonymous discussion. Your answers cannot be linked to you. Your name will not be written in any report or publication. Data and sample will be stored in a locked location dedicated to this study that only the study team can access.

Voluntariness

What are the rights as a research participant?

Participation in this study is completely voluntary. You do not have to speak with us if you do not want to. This will not affect the health care and other services you always receive. You may wish to end participation at any time without penalty.

What will I receive for participating?

You will not be paid nor will you have to pay for your participation in this study. We would greatly appreciate your participation.

What will happen to the results of the study?

The results of the study will be used by public health authorities and policy makers so they may better provide programs related to control and prevention of RVF in this area and other locations in the country.

What if I need more information?

If you have any concern/questions about any aspect of this research, you should ask to speak to researchers who will do their best to answer your questions. You may contact the Principal Investigator, Dr. Calvin Sindato at 0754 056 806, 0786 500 705 or 0655 056 806.

VOLUNTEER AGREEMENT

I would like to remind you that participating in research is voluntary. You have the right to say no to this research. You can also stop taking part at any point. If you choose not to participate in this research, there will be no penalty or loss of any services that you usually receive at this place/community.

Subject statement

I have read/been read the informed consent for this study. I have received an explanation of the planned research, procedures, risks and benefits and privacy of my personal information and blood sample. All my questions have been answered. I agree to take part in this study. I understand that my participation is completely voluntary.

I agree to participate as a volunteer.

Name of participant_____

Signature (or thumbprint)_____Date_____

FOR CHILDREN UNDER SEVEN YEARS OLD (Consent should be sought from parent/guardian)

I agree that my child take part in this study on voluntary basis.

Name of a child _____

Name of parent/guardian_____

Signature of parent/guardian (or thumb print) _____Date_____

Investigator or person who conducted informed consent discussion:

I confirm that I have personally explained the nature, purpose, extent of planned research, the potential benefits, and possible risks and confidentiality of personal information.

Name of person obtaining consent_____

Signature_____Date_____

If participant cannot read the form him/herself, a witness must sign here:

I hereby confirm that the purpose of this research has been explained, all questions were answered and particpants has agreed to take part in the study.

Name of witness_____

Signature_____Date_____

Appendix 2: Informed Consent Form (Kiswahili version)

Fomu ya ridhaa

Jina la Mtafiti Mkuu: Dk. Calvin Sindato

Utafiti: Tathmini ya mahali na muda juu ya viashiria vya kutokea kwa homa ya Bonde la Ufa, Tanzania.

***SOMA*: Halo. Jina langu ni_____**. Nimeambatana na timu ya utafiti kutoka Chuo Kikuu cha Kilimo cha Sokoine. Umealikwa kushiriki katika utafiti huu. Kabla ya kuamua kushiriki unahitaji kufahamu sababu za kufanya utafiti huu na majukumu yake. Tafadhali chukua nafasi usome ama usikilize ninaposoma maelezo yafuatayo. Unaweza kuwaambia wengine kuhusu utafiti huu. Tafadhali niulize ikiwa hujaelewa juu ya utafiti huu, ama ikiwa unataka maelezo zaidi. Baada ya kujibiwa maswali yote na kujihisi kuwa umeelewa kabisa, utaulizwa ikiwa utapenda kushiriki katika utafiti huu. Ukikubali utaombwa kuweka sahihi yako katika fomu hii kama kibali cha kushiriki. Unaweza ukapewa nakala yako uliyoweka sahihi ikiwa utahitaji.

Je kusudi la utafiti huu ni nini?

Kusudi la utafiti huu ni kufanya tathmini ya mahali na muda juu ya viashiria vya kutokea kwa homa ya Bonde la Ufa (RVF) Tanzania. Utafiti huu umepata kibali toka Kamati ya uratibu wa tafiti za afya Tanzania. Utafiti huu umepata pia ruhusa kutoka mamlaka husika katika mkoa, willaya na viongozi wa eneo lako. Matokeo ya utafiti huu yatatupatia uelewa juu ya epidemiolojia ya RVF kwa malengo makuu ya kubaini mapema viashiria vya uwezekano wa kutokea kwa ugonjwa, njia sahihi za kudhibiti na kuzuia maambukizi ya ugonjwa huu kwa binadamu na wanyama.

Kwa nini ninalikwa kushiriki?

Unaalikwa kushiriki kwa kuwa wewe ni mkazi wa/ulishaishi eneo hili na ni mmojawapo wa wafugaji. Kwa kuwa hatutaweza kuhusisha wafugaji wote, wewe ni mmojawapo wa wachache watakaowakilisha wafugaji wa eneo hili katika utafiti huu.

Itakuwaje kama nitashiriki katika utafiti huu?

Tutaomba kuchukua sampuli ya damu yako (kiasi cha mil 5), ama sampuli ya damu ya wanao (kiasi cha mil 2), ama sampuli ya damu ya baadhi ya mifugo yako (kiasi cha mil 5) kutoka kwa angalau ng'ombe 10, mbuzi 5 na kondoo 5 kutoka kwenye zizi lako. Katika sampuli ya damu tutachunguza ili kubaini uwepo wa viashiria vya maambukizo ya homa

ya Bonde la Ufa. Utashiriki katika kutupatia taarifa fupi, ama ya kwako, ama ya wanao, ama ya mifugo tutakayochukua sampuli ya damu. Pia tutachunguza afya yako, ama ya wanao, ama ya mifugo yako tutakayochukua sampuli ya damu ili kubaini kama kuna dalili za homa ya Bonde la Ufa kwa wakati huu. Ukikubali kushiriki katika utafiti huu tutakuomba uweke sahihi yako/ama alama ya dole gumba katika fomu hii.

Mahojiano na zoezi la uchukuaji sampuli vitachukua muda gani?

Mahojiano na zoezi la kuchukua sampuli vitachukua takriban saa moja.

Athari

Utafiti huu una athari zipi?

Utafiti huu hauna athari yoyote ya moja kwa moja ila tu itagharimu muda wake. Baadhi ya maswali yangu yanaweza kukubughuji. Unaweza kuamua kutojibu swali fulani. Ikiwa utajisikia vibaya wakati wowote tafadhali nijulishe na tutaweza kuendelea na swali lingine. Unaweza kusitisha ushiriki wako wakati wowote pasipo kushurutishwa.

Faida

Je kuna faida gani ya kushiriki?

Faida pekee ya moja kwa moja unayoweza kupata kwa kushiriki katika utafiti huu ni kujua hali ya afya yako, ama ya wanao, ama ya mifugo yako kuhusiana na homa ya bonde la ufa. Taarifa hii itatumika kushauri wadau na wataalamu wa sekta ya afya ya binadamu na mifugo juu ya maambukizi na umuhimu wa kudhibiti homa ya bonde la ufa katika eno lako. Kwa ujumla utatusaidia kuelewa juu ya uwezekano wa kuwepo maambukizi ya homa ya Bonde la Ufa katika eneo hili ili kutengeneza mikakati kudhibiti mapema kutokea kwa milipuko ya homa ya bonde la ufa katika eneo hili na maeneo mengine.

Siri

Je kushiriki kwangu kutafanywa kuwa siri?

Taarifa na sampuli tutakazochukua zitafanywa kuwa siri. Ripoti itakayotolewa haitakuwa na jina lako. Taarifa na sampuli zote zitahifadhiwa mahali salama ambapo ni watafiti pekee wanaweza kuzifikia.

Hiari

Je nina haki gani kama mshiriki katika utafiti huu?

Ushiriki wako katika utafiti huu ni wa hiari. Hutakiwi kuzungumza nasi ama kuruhusu kuchukua sampuli za damu yako, ama ya wanao, ama ya mifugo yako pengine kama

hutaki. Uamuzi huo hautadhuru kwa namna yoyote huduma za afya yako pamoja na huduma nyinginezo za mifugo yako ambazo umekuwa ukizipata. Unaweza kusitisha ushiriki wako muda wowote bila madhara yoyote.

Nitalipwa nikishiriki?

Hutalipwa wala hutalipa chochote kwa kushiriki katika utafiti huu. Tutafurahi endapo utashiriki.

Matokeo ya utafiti huu yatapelekwa wapi?

Matokeo ya utafiti huu yatatumiwa na wenye mamlaka juu ya afya ya mifugo na jamii na watengeneza sera ili kujenga mikakati ya kudhibiti na kuzuia kutokea kwa homa ya Bonde la Ufa.

Nitafanyaje ikiwa nitahitaji taarifa zaidi?

Ikiwa una jambo lolote kuhusu utafiti huu, tafadhali waulize watafiti ambao watajitahidi kadri ya uwezo wao kujibu maswali yako. Ikiwa utahitaji maelezo zaidi kuhusu utafiti huu unaweza kuwasiliana na mtafiti mkuu wa utafiti huu ambaye ni Dk. Calvin Sindato kupitia simu namba 0754 056 806, 0786 500 705 ama 0655 056 806.

MAKUBALIANO YA USHIRIKI

Ningependa kukumbusha kuwa ushiriki wako katika utafiti huu ni wa hiari. Unayo haki ya kukataa kushiriki katika utafiti huu. Unaweza pia kusitisha ushiriki wako muda wowote. Kama utaaamua kutoshiriki katika utafiti huu hutashurutishwa wala hutapoteza huduma zozote ambazo umekuwa ukizipata katika eneo hili/jamii hii

Kauli ya mkataba

Nimesoma/nimesomewa kauli yote ya utafiti huu, kusudi, utaratibu wake, athari na faida zake pamoja na usiri wa ushiriki wangu na sampuli za damu zitakazochukuliwa kutoka ama kwangu, ama kwa wanangu, ama kwa mifugo yangu. Maswali yangu yote yamejibiwa. Nimeelezwa kuwa ushiriki wangu ama wa watoto wangu katika utafiti huu ni wa hiari na ninaweza/mtoto anaweza kusitisha ushiriki wake muda wowote bila kudhurika na maamuzi hayo. Ninaridhia mimi binafsi kushiriki katika utafiti huu. Ninaridhia pia mtoto/watoto wangu kushiriki katika utafiti huu. Ninaridhia sampuli za damu kuchukuliwa ama kwangu, ama kwa watoto wangu, ama kwa mifugo yangu.

Ninakubali kushiriki kwa kujitolea

Jina lako_____

Sahihi yako ama alama (alama ya dole gumba)_____Tarehe_____

KWA WATOTO CHINI YA UMRI WA MIAKA SABA (Ridhaa ya ushiriki itolewe na mzazi/mlezi)

Ninakubali mtoto wangu kushiriki katika utafiti huu kwa kujitolea.

Jina la mshiriki (mtoto) _____

Jina la mzazi/mlezi_____

Sahihi ya mzazi/mlezi ama alama (alama ya dole gumba) _____Tarehe_____

Mtafiti aliyeomba idhini ya mshiriki:

Ninathibitisha kwamba nimemwelezea mshiriki kwa kinaganaga kusudi la utafiti huu, utaratibu, athari na faida na usiri wa taarifa binafsi pamoja na sampuli za damu zitakazochukuliwa ama kwa mtu mzima, ama mtoto, ama mifugo.

Jina la mwenye kupewa idhini_____

Sahihi_____Tarehe_____

Ikiwa mshiriki hawezi kusoma fomu ya ridhaa, basi shahidi ni lazima aweke sahihi hapa

Nathibitisha kuwa mshiriki ameelezwa juu ya utafiti huu, maswali yake yamejibiwa na mshiriki ameridhia kushiriki katika utafiti huu.

Jina la Shahidi_____

Sahihi_____Tarehe_____

Appendix 3: Questionnaire for the assessment of potential behavioural health-risky practices for RVF exposure among the pastoralists within Ngorongoro Conservation Area.

Principal Investigator: Dr. Calvin Sindato

Date (DD/MM/YYYY)_____

Name of the interviewer: _____

PART I.

BW	**ID. of the human blood sample**	___ ___ ___
BX	**Body temperature (^{o}C)**	

ID number of the interviewee (No. ya mshiriki)_____

Name of village:_____Ward:_____

Region:_____District:_____

Altitude (m)_____

Geographical coordinates of the village:

Latitude								
Longitude								

STEP 2. Obtain written informed consent and complete the interview

Section 1: Socio-demographic information of participant

Thank you for agreeing to participate in this study. I would like to begin by asking you some general demographic questions.		
1	Sex of respondent ***(Jinsia ya mshiriki)***	☐ Male ☐ Female
2	Age of respondent ***(Umri wa mshiriki)***	_____years
3	Relation to house hold head ***(Uhusiano wa***	1=House hold head; 2=Spouse;

	mshiriki na mkuu wa kaya)	3=Son/Daughter 4=Sister in law; 5=Brother in law; 6=Other, specify_____
4	Were you living in this village between 2006 and 2007***? (Je ulikuwa unaishi katika kijiji hiki kati ya mwaka 2006 na 2007)***	1=Yes 2=No 3=NA (for children under-five yrs)
5	How many years/months have you lived in this village? ***(Je umeishi katika kijiji hiki kwa miaka/miezi mingapi?***	Years_____ Months_____
6	On average how much time do you spend in this village in a year? ***(Kwa wastani huishi katika kijiji hiki kwa muda gani kwa mwaka)***	1=<6 month 2=6-12months (permanent resident)
7	Occupation of the respondent ***(Kazi ya mshiriki)***	1=Livestock keeper 2=Farmer/peasant 3=Informal employment (Daily labored/self employed) 4=Formal employment (Public service, /private sector/NGOs) 5=Home marker 6=Student 7=Others, specify _____ 8=NA (for children under three years old)

8	How many people usually live in your household or are staying with you now? ***(je nyumbani kwenu mnaishi watu wangapi?)***	Adults (≥18 yrs)_____ Children_____
9	Educational level of the respondent ***(Elimu ya mshiriki)***	1= primary school; 2= drop out; 3=secondary school 4=post-secondary school; 5=vocational training school; 6= Adult education; 7=no schooling; 8=Before school age child

Section 2: Non-animal exposure (Parents/guardians to respond for children below seven years old

10	(i) Do you normally work within or close to forest ***(je, katika shughuli zako huwa unaingia ama kujishugulisha karibu na misitu?***	1=Yes rarely 2=Yes often 3=No 4=N/A
11	(ii) Are you living in the flooding prone area? ***(je unaishi eneo ambalo hukumbwa kukumbwa na mafuriko?)***	1=Yes 2=No 3=DN
12	Are you sleeping in the houses without mosquito proof gauze in the windows	1=Yes 2=No
13	Do you rest outdoors in the evening (Je huwa unapumzika nje ya nyumba wakati wa jioni kabla ya kulala?	1=Yes rarely 2=Yes often 3=No

14	Do you maintain water retaining objects at homesteads **(*Je, nyumbani kwenu huwa kuna vitu vilivyosagaa vinavyoweza kutuamisha maji wakti wa mvua kama vifuu vya nazi, makopo, sufiria mbovu?***	1=Yes rarely 2=Yes often 3=No
15	Do you use mosquito net? ***(Je, huwa unatumia chandarua cha kujikinga na mbu?)***	1=Yes 2=No
16	How frequently do you use mosquito net? ***(Je ni kwa kiasi gani hutumia chandarua cha kujikinga na mbu?)***	1=Rarely; 2=Often; 3=Never
17	Do you use other forms of mosquito control? ***(Je, huwa unatumia njia yoyote nyingine ya kujikinga na mbu?)***	1=Yes 2=No If yes, specify_____
18	Do you experience mosquito bites while living at this area? ***(Je, huwa unaumwa na mbu katika eneo unaloishi?)***	1=Yes 2=No
19	If Yes, how often (Kama ndiyo, ni kwa kiasi gani huwa unaumwa na mbu?)	1=Rarely; 2=Often;
20	If yes, at what time of the day do you experience much mosquito bites ***(Kama ndiyo, je ni wakati gani wa siku huumwa zaidi na mbu?***	1=morning 2=afternoon 3=evening 4=mid-night
21	Have you had any personal illness with fever in the past three months? ***(Je, uliwahi kujisikia kuwa na homa kwa kipindi cha miezi mitatu iliyopoita?)***	1=Yes 2=No

Section 3: Animal Exposure (Parents/guardians to respond for children below seven years old)

22	Do you shelter domestic ruminants in your home? ***(je, huwa una mifugo nyumbani kwako?)***	1=Yes 2=No
23	If yes in AS; which domestic ruminants ***(Kama ndiyo; Je unafuga mifugo ipi?)***	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____
24	Do you keep animals within the house you sleep) ***(Je, unafuga mifugo ndani ya nyumba unayoishi?)***	1=Yes 2=No
25	If yes in AU; which animals. ***Kama ndiyo; je unafuga wanyama gani ndani ya nyumba unayoishi?)***	1=Adult sheep 2=Adult goat 3=Adult cattle 4=Young sheep 5=Young goat 6=Young cattle 7=Others, Specify_____ ***Adult: One year and above*** ***Young: Below one year***
26	Do you herd animals to grazing? ***(Je huwa unapeleka mifugo malishoni?)***	1=Yes 2=No 3=NA (for under-seven years old)
27	Have you ever participated in slaughtering of animal? ***(Je, uliwahi kushiriki kuchinja mnyama?)***	1=Yes 2=No 3=NA (for under-seven years old)
28	If yes in AY; when did you participate slaughtering an animal? ***Kama ndiyo; ni lini ulishiriki kuchinja mnyama?)***	1=one month ago; 2=two months ago 3=More than two months ago

29	If yes in AY1; which animal did you slaughter? ***Kama ndiyo; ni wanyama wapi ulichinja?)***	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____
30	If ever participated in slaughtering of animal; what role did you play during slaughtering? ***Endapo ulishashiriki kuchinja mnyama***; ***Je,ni shughuli ipi ulifanya kati ya zifuatazo? Tiki yale yote anayosema)***	1= Restraining the animal 2= Bleeding out (separating the neck from main body) 3= Skinning the animal 4= Removing the offal/viscera of the animal 5= Splitting the carcass 6= Clean the carcass, offal and/ or visceral 7= Hanging the carcass 8= Butchering the carcass 9= Other, specify_____
31	If yes in AY; was the post-mortem inspection made by the Veterinary Officer before the meat was consumed/ sold out? ***Kama ndiyo; je nyama ilikaguliwa na mtaalamu wa mifugo kable ya kuliwa/kuuzwa?)***	1=Yes 2=No 3=Don't know/don't remember
32	Have you ever consumed meat from dead animals? ***(Je, uliwahi kula nyama ya mnyama aliyekufa?)***	1=Yes 2=No

33	If yes in BE; when did you consume meat from dead animal? ***Kama ndiyo; je ni lini ulikula nyama ya mnyama aliyekufa?)***	1=one month ago; 2=two months ago 3=More than two months ago
34	If yes in BE; what was the source of dead meat that you consumed? Kama ndiyo; Je ulikula nyama ya mnyama yupi?)	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____
35	Have you ever milked an animal? ***Je, uliwahi kukamua maziwa kwa mnyama yoyote?)***	1=Yes 2=No 3=NA (for under-seven years old)
36	If yes in BH; when did you milk an animal? ***Kama ndiyo; je ni lini ulikamua maziwa kwa mnyama)***	1=one month ago; 2=two months ago 3=More than two months ago
37	If yes in BH; which animal did you milk? ***Kama ndiyo; je ulikamua maziwa kwa mnyama yupi?)***	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____
38	Have you ever consumed raw animal milk? ***Je, uliwahi kunywa maziwa yasiyochemswa?)***	1=Yes 2=No
39	If yes in BK; when did you last consume raw milk? ***Kama ndiyo; je ni lini ulikunywa maziwa yasiyochemswa kwa mara ya mwisho?)***	1=one month ago; 2=two months ago 3=More than two months ago
40	If yes in BK; from which animal was the milk you consumed? ***Kama ndiyo, je maziwa uliyokunywa yasiyochemshwa yalikuwa ya mnyama yupi?)***	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____

41	Have you ever consumed raw animal blood? ***Je, uliwahi kunywa damu mbichi ya mnyama?)***	1=Yes 2=No
42	If yes in BN1; when did you last consume raw animal blood? ***Kama ndiyo; ni lini kwa mara ya mwisho ulikunywa damu mbichi?)***	1=one month ago; 2=two months ago 3=More than two months ago
43	If yes in BN1; from which animal was the blood you consumed? ***Kama ndiyo; Je ulikunywa damu ya mnyama gani?)***	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____
44	Have you ever cared for animal giving birth? ***Je, uliwahi kumsaidia mnyama wakati wa kuzaa?)***	1=Yes 2=No 3=NA (for under-seven years old)
45	If yes in BQ1; when did you care for an animal giving birth? ***Kama ndiyo; Je ni lini ulimsadia mnyama wakati wa kuzaa?)***	1=one month ago; 2=two months ago 3=More than two months ago
46	If yes in BQ1; which animal did you care for birthing? ***Kama ndiyo, ni mnyama yupi ulimsaidia wakati wa kuzaa?)***	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____
47	Have you ever disposed/handled an aborted animal foetus? ***Je, uliwahi kushika ama kuzika mzoga wa mimba iliyotupwa na mnyama?)***	1=Yes 2=No 3=NA (for under-seven years old)
48	If yes in BS1; when did you handle/dispose an animal foetus? ***Kama ndiyo, ni lini ulishika ama ulizika mzoga wa mimba iliyotupwa na mnyama?)***	1=one month ago; 2=two months ago 3=More than two months ago

49	If yes in BS1; which animal foetus did you handle/dispose? ***Kama ndiyo; ulikuwa mzoga wa mnyama yupi?)***	1=Sheep 2=Goat 3=Cattle 4=Others, Specify_____
50	What do you normally do when there is a dead animal in your farm or among your livestock? ***Je, huwa mnafanya nini endapo mnyama atakufa katika zizi lenu?)***	1=Call a Veterinary/Livestock officer 2=Slaughter and eat 3=Slaughter and share with neighbours 4=Slaughter and sell 5=Dispose the cadaver in a pit 6=Incinerate the cadaver 7=Others, specify_____ 8=NA (for under-seven years old)

Do you have any questions to me (Je una swali lolote? Thank you for your time and cooperation (Asante kwa muda na ushirikiano wako)!

Appendix 4: Questionnaire for the assessment spatial variation in RVFV activity level in domestic ruminants in selected villages in Tanzania

Date *(DD/MM/YYYY)* _____Name of the interviewer_____

A). Study area data

Geographic Coordinates of the village (in Decimal Degrees)

Latitude | | | | | | | | **Longitude** | | | | | | | | |

(a).Rift Ecosystem 0= Western 1=Eastern	(b).Region	(c).District	(d).Village	(e).Village elevation (metres above sea level)	(f).Predominant Soil type in the district	(g). Total average monthly rainfall in the district (mm)	(h). Total average annual rainfall in the district (mm)

(i).Rainfall pattern in the district 0=Unimodal 1=Bimodal	(j).District has reported outbreak 0=No 1=Yes	(k).Cattle density in the district (heads per square km)	(l).Goats density in the district (heads per square km)	(m).Sheep density in the district (heads per sqaure km)

B). Animal level data

Geographic Coordinates of the herd (in Decimal Degrees)

Latitude | | | | | | | | **Longitude** | | | | | | | | |

(a).Animal species 1=Caprine 2=Ovine 3=Bovine	(b).Animal feeding options 1=grazing only 2=combined stall-feeding and grazing	(c).No. Animal species in herd 1=One 2=Two 3=Three	(d).Animal age (years)	(e).Animal breed 1=Indegen-ous 2=Cross breed	(f).Animal source to herd in the district 1=Born 2=Introduced	(g).Animal sex 1=Male 2=Female	(h).Abortion past 12months: 1=No 2=Yes 3=Don't know 4=Not Applicable	(i).Body temperature(^{o}C) on the date of herd visit 1=Normal {37.8-40} 2=Above normal (>40)	(j).Any ill health on the day of herd visit 1=No 2=Yes (if yes; describe)	(k).Blood sample ID.No.