

**EPIDEMIOLOGY OF *Neospora caninum* INFECTION AND THE  
ECONOMIC IMPACT OF ABORTIONS IN LIVESTOCK: A CASE  
STUDY FROM NORTHERN TANZANIA**

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**A Thesis Submitted in Fulfilment of the Requirements for the Award of the Degree of  
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## ABSTRACT

Livestock abortions pose a significant challenge to animal health, food security and rural livelihoods, particularly in low- and middle-income countries such as Tanzania. This study aimed to: (a) Assess the status of surveillance and sero-epidemiology of abortigenic agents in ruminants across Africa and Asia through a systematic review; (b) Estimate the seroprevalence, risk factors, and reproductive impact of *Neospora caninum* in northern Tanzania; and (c) Quantify the economic burden of ruminant abortions in this region. A systematic review of the literature was conducted to evaluate surveillance and sero-epidemiological data on abortigenic pathogens. Additionally, a cross-sectional seroprevalence survey targeting *N. caninum* in northern Tanzania was carried out. Questionnaire data for variables on individual-level seropositivity were collected from 360 households and assessed using logistic regression, geo-coordinates were used to extract satellite-derived environmental variables. Association between herd-level seroprevalence and abortion rates was explored using negative binomial regression. Serum samples were tested using an indirect ELISA. Furthermore, a mobile phone-based surveillance platform was deployed to capture real-time abortion reports. Data from these cases, along with control households and national ministry sources, were used to estimate the direct economic losses associated with abortion event. The review revealed widespread endemicity of bacterial, viral, fungal, and parasitic abortigenic agents in Africa and Asia, with limited structured surveillance. In Tanzania, the adjusted *N. caninum* seroprevalence was 21.5% (95% CrI: 17.9–25.4). The Body mass index identified age >18 months (OR = 2.17), restricted grazing (OR = 0.72), high cattle density (OR = 0.69), and surrounding shrub or forest cover (OR = 1.37) as significant risk factors. A strong positive association was found between *N. caninum* seroprevalence and abortion rates (IRR = 1.03, 95% CrI: 1.00–1.06). Economically, annual losses from abortions were estimated at TZS 300 billion. These findings highlight the urgent need for improved diagnostic capacity, integrated surveillance systems and targeted control strategies for livestock abortions. The study provides vital evidence to inform policy and intervention planning for reproductive diseases control in Tanzanian livestock systems.

## DECLARATION

I, George Peter Semango do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this thesis is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

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George Peter Semango

Date

The above declaration is confirmed by:



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Prof. Joram Buza

Date



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Prof. Sarah Cleaveland

Date



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Prof. Felix Lankester

Date



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Prof. Jonathan Yoder

Date

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## CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology (NM-AIST) a thesis entitled *'Epidemiology of Neospora Caninum Infection and the Economic Impact of Abortions in Livestock: A Case Study from Northern Tanzania'* in fulfillment of the requirements for the Award of the degree of Doctor of Philosophy in Life Sciences of the Nelson Mandela African Institution of Science and Technology.



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## **DEDICATION**

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## LIST OF ABBRIVIATIONS AND SYMBOLS

A <sub>ij</sub>	Number of abortions as collected from project data in S1 survey.
AU-IBAR	African Union-InterAfrican Bureau for Animal Resources
BCS	Body Condition Score
B <sub>ij</sub>	Number of Cattle, Sheep, and Goats Born by Region (Census data)
BMA	Bayesian Model Averaging
BoHV-1	Bovine Herpes Virus 1
BVD/MD	Bovine Viral Diarrhea/ Mucosal Disease
BVDV	Bovine Viral Diarrhea Virus
CI	Confidence Interval
CrI	Confidence Interval
d,δ	Discount Factors for the Number of Days Between Pregnant Cow Market Sale and Due Date, and One-Year Old Calf at Marketable Age as Described in the Text
DVO	District Veterinary Officer
DVS	Director of Veterinary Service
EMA-i	Event Mobile Application
ES	Expert Survey
f	Proportion of Households Who Choose not to Consume Milk After an Abortion
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
G <sub>ij</sub>	Number of Pregnancies in the Last Year as Collected from Project Data in S1 And S2 Which Included All Pregnancies Noted for the Project Period of 2 Years
g <sub>ij</sub>	Pregnancy rate $g_i = G_i/R_i$ from Control Group Data, Survey S2
GPS	Global Positioning System
HS1	Household Survey 1
HS2	Household Survey 2
HS3	Household Survey 3
IBR/IPV	Infectious Bovine Rhinotracheitis/Infectious Pustular Vulvovaginitis
ICC	Intra-Cluster Correlation Co-efficient
IRR	Incidence Rate Ratio

KCMC	Kilimanjaro Christian Medical Centre
LFO	Livestock Field Officer
LKS	Livestock Keepers Survey
LMICs	Low- and Middle-Income Countries
LMS	Livestock Market Survey
MOR	Median Odds Ratio
NADIS	National Animal Disease Information Service
NASA	National Aeronautical and Space Administration
NIMR	National Institute for Medical Research
OD	Odds Ratio
OIE	Office International des Epizooties (World Organization for Animal Health)
OR	odds ratios
PBST	Phosphate Buffered Saline and Tween
Picj	Average Market Price of a 12-Month-Old-Animal by Stock Type Ij
pimj	Average Milk Price (Per Liter) Received by a Farmer, by Stock Category
Pisj	Market Price of a Stock Animal Used to Estimate the Value of Pregnancy
PRISMA	Preferred Reporting Items For Systematic Reviews And Meta-Analyses
QGIS	Quantum Geographic Information System
ra	Annual Discount Rate Assumed to be 2.5%
rd	Daily Discount Rate, Calculated from Annual Discount Rate
Rij	Number of Reproductive-Age Female Cattle and Small Stock, by Region
RVFV	Rift Valley Fever Virus
S/P	Sample-to-Positive
SDGs	Sustainable Development Goals
SEBI-TZ	Supporting Evidence Based Intervention in Tanzania
SEEDZ	Social Economic and Environmental Drivers of Zoonoses
SMS	Short Messaging Service
SSA	Sub-Saharan Africa

$T_i^d$	Estimated Period Between Sale Date and Due Date of a Pregnant Animal That are Usually Sold
$T_{imj}$	The Number of Days of Milk Offtake Attributable to an Individual Pregnancy
$T_i^m$ (A = 0)	Average Number of Days of Milking after Successful Birth
$T_i^m$ (A = 1)	Average Number of Days of Milking after an Abortion (If milked)
TZS	Tanzanian Shillings
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environmental Program
USA	United States of America
USD	United States of America Dollar
WOAH	World Organization for Animal Health
ZELS	Zoonoses and Emerging Livestock Systems
ZVC	Zonal Veterinary Centre
ZVCD	Zonal Veterinary Centre Director
$\alpha_j$	Abortion rate
$\rho$	Share of reproduction husbandry costs attributable to a successful birth

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background of the problem

The livestock sector forms the basis of the livelihoods of almost one out of three people in Low- and Middle-Income Countries (LMICs) (Panel, 2020). Despite its significant support for the livelihoods in large proportion of the population in many LMICs, including Tanzania, the livestock sub-sector has not been realized into its fullest potential (World Bank, 2024). This is mainly because the livestock sub-sector is plagued by numerous challenges including lack of access to good quality veterinary care, limited diagnostic infrastructure and poor extension services especially in rural areas (Gustafson *et al.*, 2015).

Likewise, these are some of the reasons that underlie poor animal health and high disease prevalence within these regions (Boto & La Peccerella, 2009; FAO, 2019). Among the syndromes that have been a stagnating factor in the realization of the livestock sub-sector's potential is abortion in the livestock. Livestock abortions have been reported in other parts of the world to contribute to low livestock productivity (Gädicke *et al.*, 2010; Gurmu *et al.*, 2024; Keshavarzi *et al.*, 2020), but also receive relatively little attention in those parts as well (Keshavarzi *et al.*, 2020). Abortion is an important bottleneck on the livestock production and livelihoods (Gelalcha *et al.*, 2021) particularly in Africa, where a large proportion of the population is heavily dependent on livestock for food security and well-being (FAO *et al.*, 2023). Several factors have been reported to associate with livestock abortion. These factors are broadly classified as non-infectious or infectious causes (National Animal Disease Information Service [NADIS], 2022). Infectious causes are the leading abortigenic agents in livestock, and mainly include: Bacteria (Bruning-Fann *et al.*, 2004), protozoa (Gallagher, 2024), and Viruses (Bruning-Fann *et al.*, 2004; Murcia *et al.*, 2009).

Livestock abortigenic organisms are differently distributed across the globe. The Common abortigenic pathogens with worldwide distribution include *N. caninum*, *T. gondii*, *C. abortus*, *C. burnetii*, *B. abortus*, Rift Valley Fever Virus and Blue Tongue Disease Virus. For instance, in the UK, the most prevalent abortigenic pathogens are: The *N. caninum*, *S. Dublin*, *T. pyogenes* and Bovine Viral Diarrhea virus (Otter, 2020) whereas in South Africa, common reported abortigenic pathogens include *B. abortus*, *N. caninum*, BVD/MD virus, IBR/IPV, *T. fetus*, and *C. fetus* (Jonker & Michel, 2021). In Tanzania, these pathogens include *Brucella spp*

with a prevalence of 1.4% in cattle, *N. caninum* with a prevalence of 12.7% in cattle and 1% in goats, *T. gondii* with a prevalence of 2.3% in sheep, *C. burnetii* with a prevalence of 5% in goats and 2.3% in sheep, and Bovine Herpes Virus with a prevalence of 4.1% (Thomas *et al.*, 2022).

The *N. caninum* is an obligate intracellular protozoan parasite with worldwide distribution. The reported seroprevalence of *N. caninum* exposure in cattle ranges between 7.6 and 41% in the Americas (Cedeño & Benavides, 2013), 10.7 and 19.6% in Africa (Ghalimi *et al.*, 2012), 4.1 and 43% in Asia (Koiwai *et al.*, 2006; Nazir *et al.*, 2013), 0.5 and 27.7% in Europe (Imre *et al.*, 2012), and 10.2% in Oceania (Hall *et al.*, 2005). In East Africa, *N. caninum* seropositivity was recently found in 17.9% of farm dogs and 25.6% of cattle in the Nakuru District of Kenya, with exposure in farm dogs associated with free-roaming (Okumu *et al.*, 2016). In Kenya, serological evidence for *N. caninum* infections has also been reported in wild animals, including zebra (*E. quagga*), eland (*T. oryx*), buffalo (*S. caffer*), gazelle (*G. thomsonii*), impala (*A. melampus*), and warthog (*P. africanus*), as well as spotted hyena (*C. crocuta*) and cheetah (*A. jubatus*) (Ferroglia *et al.*, 2003). Following its global distribution and its abortigenic effect on cattle, *N. caninum* is among of the most cited pathogen with economic impact in the livestock industry. However, in Tanzania, little is known about *N. caninum* seroprevalence, especially in northern Tanzania, although it has been reported in northwestern and southern Tanzania by Latham (2003) and Mathew (2017), respectively.

Economic impact of abortions in livestock is a major cause of economic losses to the livestock owners (Semango *et al.*, 2024). Abortions lead to livestock owners to lose the abortive calf as well as milk off take associated to the lost pregnancy making it an important phenomenon to monitor and control. It is worth noting that some abortions occur early on in the pregnancy and go unnoticed. It is also wrongly perceived by many livestock owners that an animal will simply be bred again following an abortion and hence the loss of a pregnancy does not necessarily lead to losses. This has led to abortions being neglected and not given priority in surveillance and response mechanisms of the responsible authorities. Economic losses due to abortigenic agents have been documented in a number of countries. For instance, *N. caninum* causes estimated losses of \$ 33.1 million for the dairy industry and \$ 12.9 million for the beef industry in the Pampa region of Argentina (Moore *et al.*, 2013) with a livestock industry worth approximately \$13 billion (Deryng, 2021). In Turkey, estimated losses of \$ 509 per animal are attributed to abortions caused by bovine herpesvirus 1 (BoHV-1) (Can *et al.*, 2016). Based on data from Mexico, which has a \$ 26.1 billion livestock sector (Ministerie, 2022), the cost of an abortion

during the first trimester was estimated at \$262, whereas fetal loss between days 91 and 180 was estimated to cost between \$483 and \$1098 for pregnancies over 181 days (Albuja *et al.*, 2019).

The research gaps that were the focus of this thesis included: (a) Explore the current status of ruminant abortigenic agents' surveillance in Asia, Africa and Tanzania (b) Determination of the *N. caninum* seroprevalence, (c) Determination of the associated risk factors and its association with abortions in Tanzania, and (d) Quantification of the direct economic losses resulting from livestock abortions to the livestock owners as no reported values are available for northern Tanzania. This study has been conducted in Northern Tanzania mainly because: (a) The area is characterized by a diversity of agro-ecological systems, livestock management practices, and crop cultivation, (b) The area comprises a range of ethnicities, including the Maasai tribe, for whom livelihoods are traditionally based on extensive livestock production with limited crop agriculture (pastoralists), Waarusha and Iraqw tribes who have traditionally combined extensive cattle grazing and crop production (agropastoralists), and the Meru and Chagga tribes who have traditionally reared small numbers of livestock that are closely integrated with crop-based agriculture (smallholders), and (c) The Arusha, Kilimanjaro and Manyara regions combined have the largest livestock population of any region in Tanzania, with more than 5.6 million heads of cattle, sheep and goats.

## **1.2 Statement of the problem**

Infectious livestock abortigenic agents have been impacting the livestock industry in Tanzania for years (Lankester *et al.*, 2024), leading to reduced animal productivity and poor animal health. Due to their impact, numerous epidemiological studies have been conducted to investigate them, with the most commonly researched pathogen being *Brucella spp.* In Tanzania, more published epidemiological studies have been focusing on *Brucella spp.* (Semango & Buza, 2024) leaving *N. caninum* less explored and investigated. Few comprehensive studies have investigated *N. caninum* in Tanzania resulting in *N. caninum* receiving little attention by epidemiologists and other stakeholders in the region, and thus lack of any form of interventions being devised despite the fact that it has global distribution similar to *Brucella spp.* This thesis explored the seroprevalence of *N. caninum* in northern Tanzania as well as its associated risk factors and disease impact in cattle.

Despite the massive economic impact at household and national level, livestock abortions receive little attention from livestock owners, stakeholders and the government in Tanzania.

The burden of the livestock abortions has also not been documented in northern and whole of Tanzania. The present study explored the lack of data on ruminant abortigenic agents' surveillance in Asia, Africa and Tanzania, and data void on the seroprevalence of *N. caninum*, its associated risk factors and association with abortions in northern Tanzania. Furthermore, there are very few studies globally that estimate the economic impact of abortions based on rigorous epidemiological and economic data collected from a randomly selected population (Deka *et al.*, 2018). This thesis explored this research gap to quantify the direct economic losses resulting from livestock abortions to the livestock owners as no reported values are available for northern Tanzania, similar to most other African countries from a randomly selected population.

### **1.3 Rationale of the study**

Livestock abortions are a cause of economic losses to the livestock owning communities in many parts of the world. Quantification of the economic losses due to abortions is strong evidence of the burden of abortions at household and national level. This information highlights the need for continued monitoring of livestock abortions as it weighs in on the economic losses arising from their presence. Additionally, data on the economic impact of the abortions will also inform policy and decision makers to weigh out the feasibility of implementing evidence-based interventions in addition to bringing to light the burden of abortion at household and national level.

Additionally, evidence of the presence of abortigenic pathogens in livestock is key information to livestock owners and stakeholders. Documentation of the presence of organisms such as *N. caninum* within apparently healthy cattle will bring to light the livestock abortion plight. This study aimed at amassing data on the sero-epidemiology of *N. caninum* in northern Tanzania. This data on the sero-epidemiology of this pathogen will inform the livestock owners, stakeholders, and decision makers to give more attention to such pathogens as well as abortions at large.

Furthermore, data on the sero-epidemiology and economic impact will be able to convince policy makers to implement surveillance programs for abortigenic pathogens circulating in the regions in order to inform the decision makers on the appropriate time and space to implement appropriate interventions. The gathered information from this study will be useful to the livestock owning communities, the government as well as the scientific community as it aims at putting abortions in livestock on the spotlight as well as informing the policy makers on

prioritization of interventions for the control of pathogens. These interventions aimed at abortigenic agents' control and elimination will contribute to the general improvement of animal health in Tanzania. Improved animal health is critically important as it also contributes to important aspects in the sustainable development goals (SDGs) such as climate action through reduction of emissions (SDG 13) as well as zero hunger (SDG 2) through sustainable livestock production and reproduction (United Nations [UN], 2023).

## **1.4 Research objectives**

### **1.4.1 General objective**

To determine the epidemiology of *Neospora caninum* infection and economic impact of livestock abortions in Northern Tanzania.

### **1.4.2 Specific objectives**

- (i) To explore the current status of ruminant abortigenic agents' surveillance and sero-epidemiology in Asia, Africa and Tanzania.
- (ii) To determine the sero-prevalence of *N. caninum* as an abortigenic agent in northern Tanzania.
- (iii) To determine the risk factors and disease impact of *N. caninum* as an abortigenic agent in northern Tanzania.
- (iv) To determine the economic burden of livestock abortions in Kilimanjaro, Arusha and Manyara regions of northern Tanzania.

## **1.5 Research questions**

- (i) What is the sero-epidemiology and surveillance systems for livestock abortigenic agents in Africa and Asia?
- (ii) What is the sero-prevalence of *N. caninum* in Cattle in northern Tanzania?
- (iii) What are the risk factors and disease impacts of *N. caninum* as an abortigenic agent in northern Tanzania?
- (iv) What is the economic impact of livestock abortions in northern Tanzania?

## **1.6 Significance of the study**

This study aimed to determine the sero-epidemiology of *N. caninum*, as one of the neglected abortifacients, and the economic impact of abortions in northern Tanzania and extrapolation to national-level. The *N. caninum* is a pathogen that is distributed globally and is reported to cause high economic losses in many parts of the world. This thesis aimed to bring to light its presence in northern Tanzania, where it was never reported prior to this thesis. Data on the presence of *N. caninum* in northern Tanzania will bring livestock abortions to the attention of policy makers, livestock owners and other stakeholders.

Additionally, livestock abortions economic analysis data will bring to light the magnitude of economic losses resulting from abortions to policy makers, livestock owners, livestock sector personnel and other. Furthermore, this economic analysis data will form the basis for cost benefit analysis for interventions against abortions in general geared towards control and elimination of abortigenic pathogens. Cost benefit analysis will be useful information for policymakers to base on during formulation of policies. This data may also be used by livestock owners to weigh out on benefits of change of practice. Evidence based interventions based on informed policies, proper animal management practices will lead to reduced abortion events and eventually improved animal health and productivity. Improved animal health and productivity will increase government revenue and boost the national economy.

## **1.7 Delineation of the study**

In this thesis literature was reviewed and data compiled to show the common abortigenic pathogens in Africa. Additionally, this thesis has brought forward the direct economic loss estimates due to abortion in livestock in three regions of northern Tanzania and at national level. The thesis has also reported the sero-prevalence, associated risk factors and disease impact of *N. caninum* in northern Tanzania for the first time. This study has focused mainly in northern Tanzania because the three northern Tanzania regions combined have the largest population of livestock. Northern Tanzania also forms a good area for this study as it boasts of three distinct livestock systems within close proximity namely: Pastoral, agropastoral and small holder settings.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Livestock sector overview

Livestock serve many functions in the livelihoods of livestock-owning communities, including being a source of proteins in the nutrition, especially, for childhood growth and development. In addition, livestock is also serves as assets, draught power, transport, soil nutrients, social security, insurance and social capital (Panel, 2020). The livestock sub-sector in most African countries' economies accounts up to 80% of the agricultural Gross Domestic Product (GDP) (African Union-InterAfrican Bureau for Animal Resources [AU-IBAR], 2015). Africa has a vibrant livestock sector, which is on the rise especially with the projected increase in milk and meat consumption (Pica-Ciamarra *et al.*, 2014; Ritchie *et al.*, 2017; Suzuki, 2019). It is noteworthy that the livestock sub-sector is by far the fastest growing agricultural sub-sector in Africa (Pica-Ciamarra *et al.*, 2014; Ritchie *et al.*, 2017; Suzuki, 2019). In Tanzania, for instance, the annual gross value of livestock production has been fluctuating in recent years, but has trended upwards since 2001 toward an estimated \$448 million in 2020 (Knoema, 2020). However, infectious disease agents including abortigenic agents have been reported to hinder the livestock industry's potential particularly in developing countries including African countries where large proportions of the population depend on livestock for their livelihoods (Muhanguzi *et al.*, 2017; Semango & Buza, 2024; Thomas *et al.*, 2022).

#### 2.2 Livestock abortions

Livestock abortion is defined as the death and expulsion of the foetus before completion of the pregnancy period. Infectious agents frequently lead to abortion, for instance, when they infect the reproductive organs of the animal resulting in the defective attachment of the foetus and thus its premature expulsion (Tibary, 2021), through physiological and pathological pathways which may result in general ill health of the dam leading to foetal rejection and abortion among other pathophysiological mechanisms (Tibary, 2024). Non-infectious factors that may lead to abortion include genetic disorders, trauma and environmental factors such as temperature, nutritional factors as well as iatrogenic factors such as administration of abortigenic drugs (Tibary, 2021). Among these pathogens, cattle in Africa are mainly infected by *Brucella spp.*, BHV-1, *Chlamydia spp.*, *N. caninum* and *W. chondrophila*, whereas *T. gondii* and pestiviruses (BVDV) are important in African goats and sheep, respectively (Semango & Buza, 2024). The most common abortigenic pathogens and their key characteristics include bacterial agents

such as *Brucella* spp. which is endemic in many African countries mainly across sub-Saharan Africa with higher prevalence in East Africa (Kenya, Tanzania and Ethiopia) especially in pastoral and agropastoral systems. The *B. abortus* (cattle), *B. melitensis* (goats), and *B. suis* are most commonly involved. These pathogen are mainly transmitted through ingestion of contaminated feed/water, direct contact with aborted materials, and venereal transmission and well as zoonotic (Ntirandekura *et al.*, 2020). Another important bacterial abortigenic agent is *Campylobacter* spp. (e.g., *C. fetus*) which causes bovine genital campylobacteriosis, endemic in many cattle rearing regions.

Campylobacteriosis is transmitted venereally via infected bulls or contaminated semen. It is mainly detected across multiple African countries, particularly in communal grazing areas. Other bacterial abortigenic agents include *Chlamydiales* (e.g., *C. abortus*) which causes enzootic abortion in ewes and goats. It is transmitted through inhalation or ingestion of contaminated birth fluids or placenta or close animal contact. It has been documented in North and East Africa, especially in small ruminant populations. The *C. burnetii* (Q Fever) is another important abortigenic agent. It is widely underdiagnosed and is known to cause abortion storms in ruminants. Mostly transmitted through aerosolized birth products, contaminated dust and ticks; zoonotic. Emerging reports in Kenya, Nigeria and South Africa have been published. *Leptospira* spp. causes leptospirosis, leading to abortion, stillbirth, or infertility and is transmitted through contact with urine-contaminated water or materials. The pathogen is common in tropical, wet environments in West and Central Africa. The *L. monocytogene* causes listeriosis, particularly in sheep and goat, transmitted by ingestion of contaminated silage or water. It is sporadically reported in East and Southern Africa. Other bacterial pathogens include: *Mycoplasma* spp., *Salmonella* spp. and *E. coli*.

Important viral agents that cause abortions in livestock include; Bovine Herpesvirus 1 (BHV-1) which causes infectious bovine rhinotracheitis and abortion. It is transmitted through direct contact, respiratory secretions and venereal. Its seroprevalence has been reported in Nigeria, Ethiopia and Tanzania. Bovine Viral Diarrhea Virus (BVDV) / Mucosal Disease Virus is another important pathogen that is found in cattle in Africa including Egypt and Ghana. It is transmitted through vertical transmission in utero and through horizontal transmission via secretions. The BVDV causes immunosuppression, abortion and congenital defects. Rift Valley Fever Virus (RVFV) is another important abortigenic pathogen that causes endemic and epidemic outbreaks reported in East Africa (Kenya, Tanzania), Sahel region and Egypt. The RVFV is a mosquito-borne zoonotic virus that causes abortion storms. It is transmitted though

mosquito vectors (e.g., *Aedes*) and contact with infected tissues. Parainfluenza-3 Virus is another important viral abortigenic agent that causes respiratory disease and may contribute to abortion. It is transmitted via aerosolized droplets and globally distributed with serological evidence in African ruminants although underreported.

Protozoal agents are also responsible for abortions in livestock. These protozoa including the *N. caninum* which is a major cause of bovine abortion worldwide. Its transmission occurs by vertical (transplacental) and horizontal (ingestion of oocysts from canid feces). It has been reported in Kenya, Tanzania, Ethiopia and South Africa. Another protozoa of abortigenic importance is *T. gondii* which causes abortion and neonatal mortality in sheep and goats. It is transmitted through ingestion of sporulated oocysts from cat feces and is commonly found in areas with high cat populations in west and north Africa. The *W. chondrophila* is another important protozoal abortigen found in cattle in Africa.

Lastly, fungal agents are also responsible for abortions in livestock. These pathogens include: *Aspergillus*, *Candida*, *Mucor*, *Rhizopus*, *Penicillium* and *Fusarium*. They are more common in humid environments and underdiagnosed in Africa. They are transmitted through inhalation or ingestion of fungal spores, especially from contaminated bedding or feed.

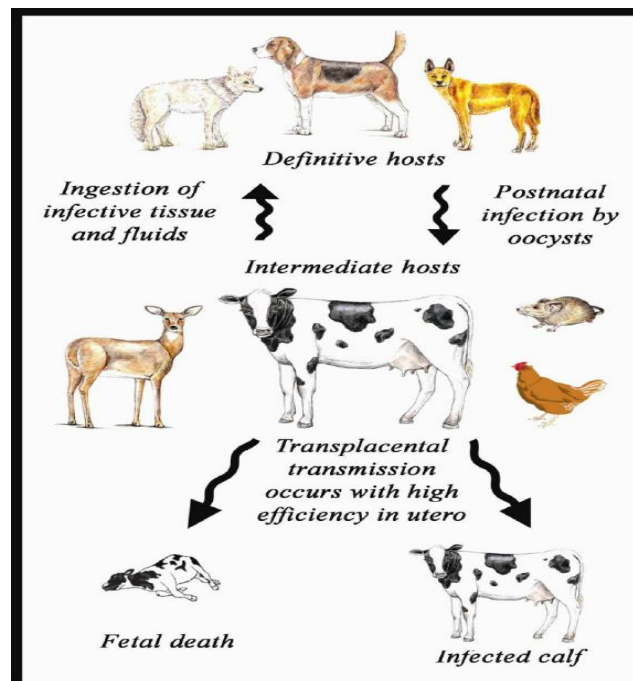
### **2.3 Economic impact of livestock abortions**

Abortions in livestock lead to massive economic losses globally. Global economic losses due to *N. caninum* to the beef and dairy industries are estimated at up to one billion US dollars annually (Dubey *et al.*, 2007; Reichel *et al.*, 2013). The *N. caninum* is therefore regarded as a major, economically important pathogen of cattle (Reichel *et al.*, 2013). The magnitude of the economic losses have been quantified in some specific parts of the world for specific pathogens, these include South America, where the annual losses for the dairy industry, due to Neosporosis, were estimated to be \$43.6 million USD (ranging \$15.62-194.41 million USD) in Argentina and \$51.3 million (ranging \$35.8–111.3 million USD) in Brazil (Nicolino *et al.*, 2015; Moore *et al.*, 2013; Reichel *et al.*, 2013). In Turkey, estimated losses of \$509 per animal are attributed to abortions caused by bovine herpesvirus 1 (BoHV-1) (Can *et al.*, 2016), whereas in Mexico, the cost of an abortion during the first trimester was estimated at \$262, fetal loss between days 91 and 180 was estimated to cost between \$483 and \$1098 for pregnancies over 181 days (Albuja *et al.*, 2019). Aggregate economic losses due to abortion have been estimated in a few countries in Africa, including Swaziland, where annual economic loss arising from abortion due to *Brucella* spp. was estimated to be approximately \$2.8 million

(Akakpo *et al.*, 2009). It is worth noting, that many LMICs, including Tanzania, have not documented economic losses due to livestock abortions.

## 2.4 Overview of *Neospora caninum*

Most research has been done on infectious agents particularly *Brucella* which stands out as one of the pathogens that has been receiving most of attention in Africa and other parts of the world (Semango & Buza, 2024). However, some pathogens that have worldwide distribution have been receiving little attention including *N. caninum*. This parasite causes disease in cattle and small ruminants, with cycles involving domestic dogs (*Canis lupus familiaris*), coyotes (*Canis latrans*), and the Australian dingo (*Canis lupus dingo*) as definitive hosts reported (King *et al.*, 2012; McAllister *et al.*, 1998). Cattle can become infected when they feed on pastures contaminated by wild or domestic canine feces containing sporulated *Neospora* oocysts (Dubey *et al.*, 2007). Transmission can also occur trans-placentally when a cow is infected during pregnancy or following the reactivation of a latent infection in a pregnant animal (Benavides *et al.*, 2012; González-Warleta *et al.*, 2018). Figure 1 summarizes the life cycle of *Neospora caninum*.



**Figure 1:** Life cycle of *Neospora caninum*

In cattle, the parasite causes abortions, stillbirths, neonatal deaths, early fetal loss and embryo reabsorption (Dubey *et al.*, 2007; Dubey & Schares, 2011) with reproductive losses usually observed during the second trimester of pregnancy. The parasite can also cause disease early in gestation which may increase the calving interval or present as infertility (Goodswen *et al.*,

2013). Congenital infection can also lead to the birth of weak, premature calves, or calves with neurological disease, or they may be born with no obvious clinical signs. Recent reports suggest that *N. caninum* can also cause disease in small ruminants (Gazzonis *et al.*, 2016; González-Warleta *et al.*, 2014; Liu *et al.*, 2015; Nie *et al.*, 2018); however, the potential economic impacts are yet to be assessed. Despite the economic importance of neosporosis in cattle, there are no treatments or vaccines currently commercially available (Semango *et al.*, 2019). Prevention and control therefore relies on reducing exposure of cattle to infectious *N. caninum* oocysts (Marugan-Hernandez, 2017), culling out seropositive dams, or restricting breeding to seronegative dams (Dubey *et al.*, 2007).

Reported risk factors for *N. caninum* infection in cattle include the presence of dogs in cattle-keeping households, farm history of abortion, herd size, hygiene practices (Ghalmi *et al.*, 2012), handling of abortus (Cedeño & Benavides, 2013), introduction of new cattle to the herd (Llano *et al.*, 2018), grazing practices (Wang *et al.*, 2010), production system (Dubey *et al.*, 2007) and dogs having access to cattle placentas and fetuses (Robbe *et al.*, 2016; Vanleeuwen *et al.*, 2010).

Other reported risk factors to *N. caninum* include breed of cattle; with some breed being more susceptible than others. In a South African study, Holstein–Friesian cattle exhibited significantly higher odds of seropositivity compared to Jersey cattle. Specifically, Holstein–Friesians were found to be 24.2 times more likely to be seropositive than Jerseys (OR = 24.2; 95% CI: 2.7–220.8;  $p = 0.006$ ). This suggests that certain breeds may have inherent differences in susceptibility to *N. caninum* infection (Cao *et al.*, 2022; Dubey *et al.*, 2007; Tagwireyi *et al.*, 2024). The practice of segregating cattle into different age groups has also been associated with varying risks of *N. caninum* infection.

In the same South African study, farms that practiced segregation of cattle into different age groups had higher odds of seropositivity (OR = 14.1; 95% CI: 1.1–182.8;  $p = 0.043$ ). The reasons for this association are not entirely clear, but it may relate to management practices that inadvertently increase exposure to the parasite. Conversely, other studies have found that segregation can be protective. For instance, a study in Colombia reported that segregating animals by herd reduced the risk of neosporosis infection (OR = 0.53), possibly by optimizing health management and preventing horizontal transmission. These contrasting findings suggest that the impact of segregation may depend on specific management practices and environmental factors (Murcia-Mono *et al.*, 2024; Tagwireyi *et al.*, 2024). The lack of a

designated calving area on farms has been identified as a significant risk factor for *N. caninum* infection. Farms without specific calving locations had higher odds of seropositivity (OR = 0.1; 95% CI: 0.03–0.8;  $p = 0.024$ ). This may be due to increased environmental contamination with infectious materials such as placenta and amniotic fluid, which are potential sources of *N. caninum* oocysts.

Proper disposal and disinfection of these materials become challenging without a dedicated calving area, potentially increasing the risk of horizontal transmission (Dubey *et al.*, 2007; Tagwireyi *et al.*, 2024). Little is currently known about the epidemiology and impacts of *N. caninum* in Tanzania. This study aimed to establish the seroprevalence of *N. caninum* in cattle across northern Tanzania and the association between its seropositivity and a range of potential risk factors. The economic importance of *N. caninum* and other abortifacient agents necessitates constant monitoring of these pathogens in order to devise control methods.

## **2.5 Current status of abortion surveillance in Tanzania**

In most developed countries, reporting of abortion events to the responsible authorities is mandatory (Bronner *et al.*, 2013a). This has led to the eradication of most of the abortifacient agents in these countries. However, in most African countries including Tanzania, currently, there is no emphasis on reporting of livestock abortions. In Tanzania, the ministry responsible for livestock development does not collect data on abortion events on regular basis. There is a surveillance system in place for animal diseases and syndromes, however, abortion events are not reportable events in the ministry system. This has led to underreporting of abortion events and its impact undermined.

Livestock diseases and syndromes are normally reported to the government by Livestock Field Officers (LFOs) situated at the village level, who report to District Veterinary officers (DVOs) who report to Zonal Veterinary Centers (ZVCs) who then report to the Director of Veterinary Services (DVS) at the ministry level who then report to the global platforms at the World Organization for Animal Health (WOAH). The system is paper based from the LFO up to the ZVCs. This surveillance system is also meant to capture abortion events which may be a sign of an ongoing outbreak in the vicinity. For reportable diseases such as hemorrhagic fevers, the system usually captures and the government through the responsible ministries may then respond accordingly in order to curb an outbreak.

## 2.6 Potential abortion surveillance platforms for Africa

In Africa, several surveillance technologies have been tested with varying successes. For most African, as well as Asian countries, mobile phones hold great potential as tools for an integrated surveillance system for zoonotic diseases (Walker, 2013). Most recent advances in cellular technologies have been at the forefront in Africa, these technologies include use of electronic devices and mobile phone (digital and analogue) technologies (Omeni, 2024). Digital technologies using a variety of hand-held devices have been trialed in a number of countries in different human disease conditions, however, mobile phones have had the highest impact. The latter have shown a lot of success in human medicine and are used as the basis for most surveillance-response systems (Aranda-Jan *et al.*, 2014; Brinkel *et al.*, 2014; Karimuribo *et al.*, 2017; Mtema *et al.*, 2016; Mwabukusi *et al.*, 2014; Owoyemi *et al.*, 2021; Robertson *et al.*, 2010). New types of medical health surveillance systems rely on mobile phones. Between 2006 and 2016 a total of 487 mobile health programs have been implemented in 48 sub-Saharan Africa countries (Lee *et al.*, 2017), this is the highest globally (Gorski *et al.*, 2016).

Short messaging services (SMS) interventions has been used in disease prevention mostly in South Africa, Kenya and India (Déglise *et al.*, 2012; Githinji *et al.*, 2014, 2015; Hill *et al.*, 2023; Pfammatter *et al.*, 2016; Talisuna *et al.*, 2017), with Kenya showing the most outstanding growth (Njoroge *et al.*, 2017). Mobile phone based surveillance particularly favors sub-Saharan Africa due to the growing network coverage (Betjeman *et al.*, 2013; Brinkel *et al.*, 2014) and the high average mobile cellular subscription rate, approximated to be 82.9 per 100 people by 2015 (World Bank, 2022). Thus, in most LMICs, including Tanzania, mobile phones hold great potential as tools for an integrated surveillance for zoonotic diseases (Walker, 2013).

Several mobile technologies-based surveillance systems have been trialed in Africa. Notably in Tanzania is the Smartphone App (AfyaData) for Innovative One Health Disease Surveillance from Community to National Levels in Africa (Karimuribo *et al.*, 2017) which has been successfully trialed in some parts of Tanzania (Karimuribo *et al.*, 2016). Another recent development in mobile technologies based surveillance is the Event Mobile Application (EMA-i) platform developed by the Food and Agriculture Organization (FAO) for surveillance and early warning in zoonotic and livestock diseases of public health importance (FAO, 2015) which is being trialed in some parts of Africa. These technologies have had varied success in different countries, mainly because they involve introduction of sophisticated gadgets or software. This is among the major factors that causes these surveillance platforms not to be

well adapted in many countries. These systems may also not be practical in certain settings due to lack of financial resources, infrastructure as well as expertise.

Use of a simple mobile phone-based systems is hypothesized to involve more people in the community and does not cause an extra burden to the already overwhelmed budgets of these countries. It should also not bring an extra load to the involved personnel who are already greatly overwhelmed by the geographical challenges and the large communities they are required to attend to, as Mbugi *et al.* (2012) pointed out that to successfully set up of a surveillance system, all stakeholders must work collaboratively. Mtema *et al.* (2016), demonstrated a successful implementation of mobile phone surveillance for rabies in Southern Tanzania. The mobile based surveillance system they developed was based on community and stakeholder involvement.

Mobile technologies based surveillance systems have been previously implemented in human health studies in resource limited settings (Bernabe-Ortiz *et al.*, 2008; Diero *et al.*, 2006; Missinou *et al.*, 2005; Shirima *et al.*, 2007). In addition to human health, mobile based surveillance has also been reported to be used in veterinary health in Sri Lanka (Robertson *et al.*, 2010). A suitable surveillance system will go a long in determining the burden of disease at real time and thus assist in the implementation of interventions. Another good example of the use of mobile phone technology was noted in the recent Ebola cases in Sierra Leone whereby mobile phone text messages were used to report cases to the government .

Livestock owning communities in sub-Saharan Africa, including Tanzania, are faced by a high burden of zoonotic infectious diseases that are circulating from their animals to humans and vice versa some of which are responsible for causing abortions. These marginalized communities usually do not have access to good veterinary as well as medical services. However, most of these communities have access to mobile phones as well as mobile phone network coverage. Community involvement through use of their mobile phones has shown to be a successful way of acquiring real time information on disease occurrence.

## **2.7 Project-run livestock abortion surveillance platform in northern Tanzania**

Alongside the SEBI-TZ project, which was funded by the Bill and Melinda Gates foundation through the University of Glasgow, UK, a mobile-phone based system was established. The system was the communication pathway which facilitated the livestock owners to report abortion events and initiate an investigation on the cause of the abortion. Sensitization meetings

were held with livestock keepers in each ward. During these meetings, livestock keepers were encouraged to report any abortion or peri-natal mortality event observed in cattle, sheep or goats to their local livestock field officer (LFO).

The LFOs are veterinary technicians employed by the Tanzanian Ministry of Livestock and Fisheries to provide basic veterinary services and implement animal health surveillance and veterinary public health measures in Tanzania. The LFOs were recruited to participate in the study with one LFO responsible for a single ward. The LFOs were asked to disseminate information about the study to the community living within their respective wards, requesting livestock owners to report any instances of livestock abortion to them so that a questionnaire could be carried out. Following receipt of a report, the LFO was asked to pass on the information to the research team for investigation. For the purposes of this study, an abortion event was defined as: Farmer reported visual evidence of premature fetal loss or stillbirth in cattle, goats or sheep. `

## **2.8 Research gaps**

Abortions in livestock receive little attention in Tanzania albeit their economic importance to the livestock sector at global level. More research needs to be carried out into the economic impact abortions cause in order to be able to determine the cost effectiveness of interventions aimed at their control and possible elimination. More epidemiological studies also need to be conducted to unearth more neglected abortigenic pathogens in addition to *N. caninum* in different parts of Tanzania as these pathogens play a critical role in other phenomenon of global importance such as climate change as they are directly in linkage with animal health productivity which is a key parameter in carbon emission.

Most developed countries have been successful in the control and elimination of abortigenic agents through surveillance systems and devising and implementing evidence-based interventions. These surveillance systems capture abortion events as quickly and accurately as possible and appropriate interventions are implemented. The implemented surveillance systems include the use of statutory testing as well as mandatory reporting of livestock abortion events to a veterinary inspector by the livestock owners. In order for a surveillance system to be useful, appropriate responses are also required in order to quickly intervene and control the further spread of the pathogen.

Livestock abortigenic agents require constant monitoring in order to determine and implement evidence-based interventions aimed at their control and elimination. For successful set up of a

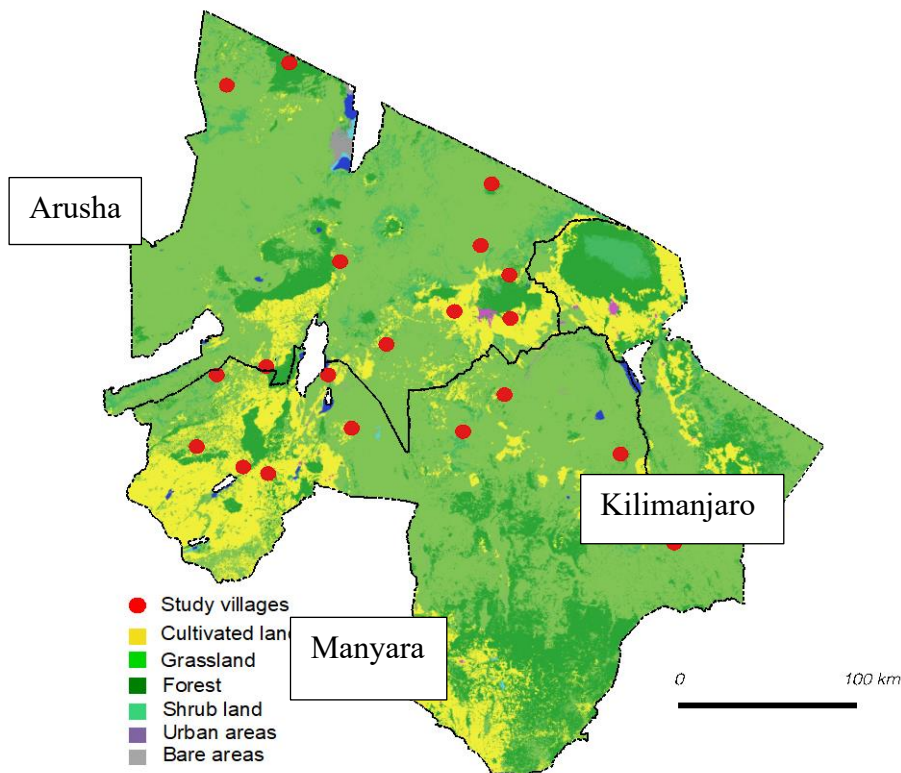
monitoring system, all involved stakeholders must work collaboratively. However, it has been noted that one of the major constraints for control of pathogens in LMICs is absence of qualitative and quantitative information. Furthermore, most of the currently available disease information is dependent on active disease search by researchers and limited or passive participation by the community. Pathogen monitoring platforms of different forms are needed for the effective control and elimination of these pathogens. These surveillance platforms ideally should be able to capture the presence of a pathogen circulating in the community at real-time. This information is then used to devise the appropriate response or intervention for the control or elimination of the pathogen. Several monitoring methods are available which may broadly be classified as either active or passive methods. Active methods are more accurate and quicker but more expensive compared to passive methods which are less expensive to run but risk under-reporting of some pathogens or syndromes.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Study site description

This study was carried out in three regions in North Tanzania namely: Kilimanjaro, Arusha and Manyara (Fig. 1). These are part of the regions which the Zoonoses and emerging livestock systems (ZELS) program has been working for the past 15 years and hence there is a lot of baseline data available for the region. This study was conducted in these regions due to the following: (a) The study area is characterized by a diversity of agro-ecological systems, livestock management practices, and crop cultivation, (b) The area comprises a range of ethnicities, including the Maasai tribe, for whom livelihoods are traditionally based on extensive livestock production with limited crop agriculture (pastoralists), Waarusha and Iraqw tribes who have traditionally combined extensive cattle grazing and crop production ("agropastoralists"), and the Meru and Chagga tribes who have traditionally reared small numbers of livestock that are closely integrated with crop-based agriculture (smallholders), and (c) The Arusha, Kilimanjaro and Manyara regions combined have the largest livestock population of any region in Tanzania, with more than 5.6 million heads of cattle, sheep and goats.



**Figure 2: Map of the study sites included in this study**

### 3.2 Scholarly databases literature search for current status of ruminant abortions surveillance in low and middle income countries (in Asia, Africa and Tanzania)

In order to determine the current status of ruminant abortions surveillance in Low and Middle income countries, a systematic review of available literature was conducted. This review of literature aimed at determining the abortigenic agents reported in the various countries in Africa and Asia, the reported seroprevalence, detection method and husbandry methods. For the systematic literature search, references were sought and identified following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Moher *et al.*, 2009; Appendix 5; Supplementary File 1 checklist). Studies were searched in PubMed and google scholar published between 1<sup>st</sup> January 1990 and 1<sup>st</sup> May 2024 as this was maximum timeframe from when the databases were developed and the time the search was being conducted. Search terms are listed in Table 1.

**Table 1: Literature search strategies**

Search string	Database or further sources	Results	Date	Comments
(((ASIA[Text Word]) OR (AFRICA[Text Word]) AND (1990/1/1:2024/5/1[pdat])) AND (((GOATS[Title/Abstract]) OR (SHEEP[Title/Abstract]) OR (CATTLE[Title/Abstract]) AND (1990/1/1:2024/5/1[pdat]))) AND (ABORT*[Title/Abstract] (1990/1/1:2024/5/1[pdat]))) AND (surve*[Title/Abstract])	PubMed	37	2024-05-01	PubMed search
abortion surveillance cattle OR sheep OR goats * * * * "Asia OR Africa" -human -people -persons -man -woman -Europe -americas -australia -pacific -"south america"1990-2024	Google Scholar	240	2024-05-01	Google Scholar search though NM-AIST

### 3.3 Search strategy

In the review of literature for the status of abortigenic agents surveillance in Africa and Asia, article titles and abstracts were screened for suitability for inclusion. Full text articles were included once the abstracts passed the initial screening. They were selected for full text review if the studies investigated abortigenic pathogens, reported on samples collected from cattle, goats or sheep, involved surveillance of the abortigenic pathogens and data collection took place in African or Asian regions or countries as defined by the United Nations (UN) statistics

division (UN, 2021). Asia and Africa were both included due to the low number of studies identified in the initial skimming of literature databases. Full text articles were reviewed independently to determine if each article met pre-determined inclusion and exclusion criteria (Appendix 6; Supplementary File 2). When required, a third reviewer served as a tiebreaker, independently reviewing articles to resolve disagreement between the two primary reviewers.

### **3.4 Inclusion criteria**

Articles were included for full text review:

- (i) If the full text article could be retrieved,
- (ii) If it reported primary data,
- (iii) If the article reported surveillance data, in sheep, goats and sheep, regardless of laboratory methods used,
- (iv) If the prevalence of abortigenic pathogens could be calculated from information available in the paper from any sample type,
- (v) If the articles were published between January 1990 and May 2024 as this is about the longest time in most databases where articles were published online.

The search included the whole of Africa and Asia as search for only northern Tanzania was deemed too narrow. Africa and Asia were selected based on the fact that the climatic conditions and livestock management systems are mainly similar in most of these parts. Additionally, Africa and Asia are lagging behind compared to other parts of the world like Europe and the Americas in terms of disease control and elimination. Africa and most parts of Asia are also classified together as developing countries and studying them together provides a unique experience of how they compare to each other in terms of disease surveillance efforts. Lastly, African and most Asian populations are heavily dependent on livestock for their livelihoods.

### **3.5 Exclusion criteria**

- (a) If the numerator (i.e. number positive) and denominator (i.e. number tested) information were not reported at the species and sample type level.
- (b) If they were in a language other than English.

### **3.6 Article selection and data extraction**

From each included article, information on species of the affected animal, sample type, the total number of samples tested, total positive samples and the number of pathogens detected was extracted in order to determine the pathogen seroprevalence. Sample location data, including UN statistics division African and Asian geographic region countries (UN, 2021) was also extracted.

### **3.7 Study design for *Neospora caninum* seroprevalence survey**

This was a cross-sectional survey conducted in six districts in Arusha Region (Arusha, Karatu, Longido, Meru, Monduli and Ngorongoro) and four districts in Manyara Region (Babati Rural, Babati Urban, Mbulu and Simanjaru) of northern Tanzania, between February and December 2016. The included districts were randomly selected to include pastoral, agropastoral and small holder livestock systems in the sampling frame.

### **3.8 Inclusion and exclusion criteria for *Neospora caninum* seroprevalence survey**

This study included cattle of the age above 6 months. Cattle less than 6 months of age were excluded from the sampling. Cattle were aged by dentition.

### **3.9 Sampling design for *Neospora caninum* seroprevalence survey**

A multistage sampling design was used, with village as the primary sampling unit. Twenty villages were selected from a spatially referenced list of all villages in the study area (from the Tanzanian National Bureau of Statistics) using generalized random tessellation stratified sampling (Stevens & Olsen, 2004). Livestock sampling was conducted at two to three sites within each village using a central point approach, with livestock owners invited to bring animals to a pre-selected point by notifying them of the event through traditional village-level communication routes (i.e., a network of village elders) at least 24 hours before the event.

Central point sampling events were run in collaboration with the Tanzanian Ministry of Livestock and Fisheries as part of village-level disease control activities, including the provision of anthelmintics. Up to 10 households were selected at random from all who attended each central point event using a random number generator. Similarly, 10 cattle were randomly selected per household using a random number generator in order to detect infection with 90% confidence assuming a within-herd prevalence of 25% (Cameron & Baldock, 1998).

### **3.10 Data and sample collection**

Livestock samples and household questionnaire data were collected as per protocol described elsewhere (Herzog *et al.*, 2019). The study involved a target sample of 400 households in order to address a range of questions relating to disease transmission.

### **3.11 Household questionnaire data**

Livestock keepers were visited in their homes and a questionnaire was conducted with the household head within one week. Questions focused on household demographics, economics, livestock management and livestock health. Household co-ordinates were collected using a handheld GPS (Garmin eTrex, Garmin Ltd, Olathe, Kansas, USA). Pre- tested household surveys were conducted in Kiswahili or Maa using Open Data Kit data collection software ([https:// opendatakit.org/](https://opendatakit.org/)) on tablet computers.

### **3.12 Biological sample collection for serological determination**

Ten milliliters of blood were collected using jugular venipuncture into plain vacutainers. The cattle were physically restrained for the blood sample collection. Samples were allowed to clot before serum extraction on the day of collection.

### **3.13 Preparation of recombinant *Neospora caninum* SRS2**

Serum samples were heat treated at 56°C for 2 hours and stored at -80°C prior to export under dried ice for serological testing. Testing was performed at the Moredun Research Institute, UK, using an in-house ELISA. This is because the preparation of antibodies for the in-house ELISA required advanced techniques of cloning, an expertise limited in Tanzania.

Forward (5' TCG GTA CCG GTG TCG GGT GCG CCG TTC AAG 3') and reverse (5' ATC CCG GGT CAG TAC GCA AAG ATTG CCG TTGC 3') primers were designed for the *N. caninum* SRS2 antigen gene. The primers were used to amplify a region of the gene SRS2 that encodes amino acids 20 to 354. The PCR amplicon was cloned directionally into the pQE31 expression vector (QIAGEN, UK) using restriction enzymes *KpnI* and *XmaI*. After confirming the validity of the expression clone by sequence analysis, the construct was used to express and purify the recombinant His- tagged *N. caninum* SRS2 antigen in the *E. coli* strain M15, containing plasmid pREPP4, following the QIAexpressionist™ (QIAGEN) instructions.

### 3.14 Detection of *Neospora caninum* antibodies in cattle sera

Microwells of 96-well medium binding plates (Greiner Bio- One, UK) were coated at 4°C overnight with recombinant *N. caninum* SRS2 antigen (amino acids 20-354) at a concentration of 0.5 µg/ml in 0.1 M sodium carbonate buffer. Following washing, wells were blocked for 1h at 37°C with 4% Marvel dried milk powder diluted in phosphate buffered saline containing 0.05% Tween-20 (PBST). Plates were washed and 200 µl of control and test sera were added in duplicate at a dilution of 1:500 in 2% Marvel diluted in PBST and incubated for 2 h at 37°C. Following washing, Horse Radish Peroxidase-conjugated rabbit anti-bovine IgG (Sigma, UK) was added at a dilution of 1:2000 in PBST and incubated for 2 h at 37°C before washing and the addition of substrate (tetramethylbenzidine). Reactions were stopped by the addition of 2M H<sub>2</sub>SO<sub>4</sub> and the optical density of each plate was measured at 450 nm using a microplate reader.

Duplicate samples of positive and negative control sera were included on each plate. The positive control sample was pooled sera from three cows from a farm in Scotland which had each suffered an abortion, were positive for *Neospora* antibodies with a commercial ELISA, and in which histopathology indicated neosporosis. The negative control sample was pooled sera from three cows which had no history of *N. caninum* infection and which were negative with a commercial ELISA. Test thresholds for defining positive and negative results on the basis of ELISA sample to positive (S/P) ratios were determined using a bimodal latent class mixture model implemented within a Bayesian framework, as previously described (Opsteegh *et al.*, 2010; Stefano, 2018).

The resulting S/P ratio cut-off that maximized diagnostic sensitivity and specificity was 18.3, with an estimated sensitivity of 74.3% (95% CrI 67.3–81.3) and specificity of 95.7% (95% CrI 93.6–97.5). Given limited information on the epidemiology of *N. caninum* in cattle in Tanzania, S/P ratio threshold of 25 was also derived which maximized specificity [99.9% (95% CrI 99.8–1.0)] at the expense of sensitivity [58.7% (95% CrI 50.3–66.7)] (Stefano, 2018). This higher threshold ensured a high level of confidence in positive results, particularly given the low to moderate expected seroprevalence in the region (Latham, 2003; Mathew, 2017; Okumu *et al.*, 2019). The conservative threshold was used for inference, and include results derived using the more liberal threshold for reference.

### **3.15 Determination of economic impact of livestock abortigenic agents in northern Tanzania**

#### **3.15.1 Market value of livestock in northern Tanzania**

##### **(i) Livestock market price survey (LMS)**

For the local breeds, data on price and select characteristics of livestock for sale were collected from livestock markets, of which four were visited in the Kilimanjaro region (Moshi Urban, Moshi Rural, Mwanga and Hai) and two were visited in the Arusha region (Longido and Monduli). The livestock markets were conveniently selected based on their locality in either pastoral or agropastoral settings, their accessibility, and prior knowledge of the markets. In the livestock markets, young animals (less than twelve months of age) were identified and data collected from their owners. These animals were not selected randomly, rather young animals were spotted by the research team and the owners asked if they were willing to be questioned.

Age of the selected animals was approximated by the team and confirmed by asking their owners and observing the dentition of the animal. In each livestock market the aim was to collect data from a minimum of twenty young animals of each species. This number was driven by budgetary and time constraints. Each animal that was selected the following data was collected: The owner's lowest acceptable sale price (in Tanzanian Shilling (TZS)), body condition score (BCS) (ranging from 1 (emaciated) through to 5 (obese)), breed, age (determined by eruption of incisors), gender and pregnancy status.

##### **(ii) Livestock keeper price survey (LKS)**

Exogenous and crossbreeds (non-local breeds) are not frequently sold in primary and secondary livestock markets, so data for these breeds was collected by visiting twenty privately owned farms where such breeds were kept. These farms were identified by LFOs and were selected based on accessibility and convenience for the research team to visit. Since the targeted farms kept between two and fifteen animals, price and demographic data was collected for all animals in each farm visited. All the owners of the farms visited consented to participate in the study.

#### **3.15.2 Economic impact of livestock abortion cohort study in northern Tanzania**

An economic impact of abortion cohort study was conducted from October 2017 to September 2019 in 13 randomly selected wards in Arusha, Kilimanjaro and Manyara regions of northern Tanzania to collect data from households that reported an abortion through the established

mobile-phone based surveillance platform described above. The abortion was considered eligible for inclusion in this study if the project field team or LFO could attend it within 72 hours of the event occurring. Peri-natal mortality was defined as the birth of a calf, lamb or kid that died prior to, during or within 48 hours of parturition. Following project specific training given in data collection, LFOs were asked to report cases of abortion or peri-natal mortality (hereafter termed as a ‘case’) to the project team and, in response to this event, LFOs or members of the study field team visited the household in order to collect data.

To determine the socio-economic impact of abortion on livestock keeping households, household data were collected in parallel with the SEBI-TZ data by a separate research team. The data were collected through the following surveys:

**(i) Household survey one (HS1)**

The HS1 was carried out within 72 hours of a reported abortion event at a SEBI-TZ household. A household in which an abortion event occurred was included as a “case household” by virtue of an abortion event occurring during the study period. Survey HS1 included a wide range of questions focusing on household demographics, livestock management, breeding history, animal illness history, and the abortion case that triggered the household visit.

**(ii) Household survey two (HS2)**

The same case households that suffered abortion events that triggered an HS1 survey were revisited 28-days after the case occurred and a survey covering HS1 topics as well as topics such as the fate of aborting dam, animal replacement information, information on milk yield, feeding practice and abortus handling.

**(iii) Household survey three (HS3)**

In order to assess predisposing risk factors, a survey of “comparison households” was carried out. Comparison households were defined as households in the same village as a case household, but which had not had an abortion or peri-natal mortality event in the 12 months preceding the commencement of the study. This survey (HS3) contained the same questions as HS2, except it did not include specific abortion event questions, because no specific abortion event triggered the survey as was the case for HS1 and HS2. The HS3 was carried out in a comparison household the same day on which an HS2 was carried out in a corresponding case household (28 days after S1 was carried out). To select comparison households, a list of all

livestock keeping households in each village was generated by the LFO in collaboration with the village administration. Three households per case were then selected from this list using a random number generator. If three comparison households were not available in the same village the research team collected HS3 data from as many comparison households as were available and willing to participate. The geographic co-ordinates of all households were captured using a hand-held GPS (Garmin Etrex).

The case and control survey dataset were made up of two surveys per case household (HS1 and HS2) and one survey per comparison household (HS3). All surveys were conducted with the household heads as they were considered to be the most knowledgeable members of households with regard to livestock management and disease history. However, if needed, input and clarification was sought from other household members.

#### **(iv) Expert survey (ES)**

Some parameters used in the cost estimation model were obtained through a survey carried out by the research team targeting livestock owners and LFOs from pastoral, agro-pastoral and urban settings in northern Tanzania. For each setting, 20 surveys were carried out. Respondents were selected from the database of livestock owners and LFOs which the study team had visited over the course of this study based on convenience and availability for a telephone call.

Parameters collected from this survey include estimated milk offtake for human consumption ( $M(A,F)$ ). Specifically, for each stock type data on milk offtake with successful birth ( $M(A=0,F=1)$ ) was collected, and the difference in milk offtake following an abortion versus after a successful birth ( $\Delta M(F = 1)$ ). From these data the average reduction in milk offtake after abortion was calculated (local cattle 0.31, non-local cattle 2.40, local small stock 0.25 and non-local small stock 0.79 liters per day). This amounts to a 10%, 30%, 8.3% and 26.3% reduction in milk as a proportion of local, non-local cattle, local and non-local small stock milk offtake, respectively. This percentage was used to estimate the with-abortion milk offtake as  $\Delta M(F = 1) * M(A=0,F=1)$  for each category of stock.

Data on the market price per liter received by livestock owners for their milk ( $p_m$ ) was also collected and used the averaged reported prices for each stock type. Other parameters include the number of days of milk offtake attributable to an individual pregnancy ( $T_m$ ) either after a successful birth or an abortion ( $T_m$  (days, A)) and period between sale date and due date of a pregnant animal ( $T_d$  (days)). These parameters are presented in Table 2.

A conservative annual discount rate of 2.5% was assumed, and that one quarter of the total husbandry costs of a successful pregnancy (i.e.  $\rho = 0.25$ ) are attributable directly to the newborn (for example, newborn vaccination costs) and three quarters are attributable to the pregnancy (for example, extra feed and food supplementation). This implies that the cost of newborn husbandry is  $C_n = 0.25C$  and the cost of pregnancy (independent of birth success) is  $C_p = 0.75C$ . A  $\rho < 0.5$  was chosen by assumption, hypothesizing that most resource costs are incurred to support the mother after pregnancy prior to weaning. Results were reported with different  $\rho$  to illustrate implications of the distribution of husbandry costs. These parameters are presented in Table 12.

#### (v) **Data for aggregate estimates**

Data from the current study was combined with data from the Census data (Ministry of Agriculture, 2020) to estimate aggregate effects for both northern Tanzania (Arusha, Kilimanjaro and Manyara regions) and all of Tanzania. Census data were collected for a 12 month period between 1<sup>st</sup> October 2019 and 30<sup>th</sup> September 2020. The following information was extracted from Census data of the Ministry of Agriculture (MoA) taken 2020; The number of local (Table 4.11 in the census date of MoA, 2020 and nonlocal Table 4.58 (from the same report); reproductive-age female cattle (heifers and cows; Table 4.6 & 4.7, pp. 593–594 from MoA; 2020) and reproductive-age female goats and sheep (Table 4.33, p. 644 and Table 4.55 on p. 679 from the same report; MoA, 2020); the number of male and female calves born (Table 4.10 pp. 599–600 from the same report; MoA, 2020), male and female goat kids born (Table 4.37, p. 649 from the same report; MoA, 2020), and male and female sheep lambs born (Table 4.50, p. 677, from the same report; MoA, 2020; indigenous only); average prices for cows, heifers, male and female calves (Table 4.11, pp. 601–602, from the same report; MoA, 2020); average prices for adult male (billy, not castrated), female and kid male and female goats (Table 4.38, p. 650, from the same report; MoA, 2020); and average prices for adult male (ram, not castrated) and female sheep and male and female lamb (Table 4.58, p. 683 from the same report; MoA, 2020). Missing Census stock values were replaced with zero. Missing price values were replaced with the average of the non-missing regional prices by stock type.

### **3.16 Model of the value of livestock pregnancy and costs of abortion**

Given pregnancy, a livestock abortion results in an economic loss equivalent to the expected net benefit of a successful birth relative to the expected net benefits from an abortive pregnancy. Focus was placed on the two most relevant categories of value: The loss of the value of birthed

offspring and the difference in milk production value. Production costs differ as well. Husbandry and feeding of a pregnant animal differ from nonpregnant stock (Lukuyu *et al.*, 2012), and feeding and caring for newborns represent an up-front investment. The value of pregnancy was defined in two ways as shown in Equation (1):

$$\begin{aligned} V(\text{Preg}) &= V(\text{Female}|\text{Preg}) - V(\text{Female}|\text{Not Preg}) \\ &= d[\alpha V(\text{Preg}|A = 1) + (1 - \alpha)(V(\text{Preg}|A = 0) - C_n) - C_p]. \end{aligned} \quad (1)$$

First, the *ex ante* value of pregnancy  $V(\text{Preg})$  is the difference between the value of a pregnant female,  $V(\text{Female}|\text{Preg})$ , and an otherwise similar nonpregnant female,  $V(\text{Female}|\text{Not Preg})$ , evaluated before the pregnancy outcome (Equation (1), line 1), and estimable with market data. Second, the *ex ante* value of pregnancy can also be described in terms of the expected value of the *ex post* net benefits of a pregnancy (Equation (1), line 2). The value  $\alpha V(\text{Preg}|A=1) + (1 - \alpha)V(\text{Preg}|A=0)$  is the expected benefits from a pregnancy prior to the delivery outcome, where  $\alpha$  is the probability of abortion given pregnancy;  $V(\text{Preg}|A=1)$  is the value of benefits from an abortive pregnancy, and  $V(\text{Preg}|A=0)$  is the value of benefits from a successful pregnancy. The discount factor  $d = (1 + r_d)^{-T_d}$  accounts for the number of days  $T_d$  between the market transaction and the due date, and  $r_d$  is the daily discount rate. The  $C_n$  are costs incurred to care for a live newborn up to the time it can be sold on the market, and  $C_p$  are additional expected costs of supporting a pregnancy.

Equation (1) implies a relationship between the *ex ante* value of pregnancy measurable by the difference in livestock prices and the elements of the expected net value accrued *ex post* after either a successful birth or abortion. The basis for estimating the value accrued *ex post* after a live birth or abortion and then show how husbandry costs may be inferred using both *ex ante* and *ex post* information is explained next.

#### (i) Ex post value of pregnancy depending on outcome

The primary value of a successful birth is the sum of the present value of the newborn animal and the milk offtake provided by the pregnancy. The value of the milk consumed by the newborn is implicit in the value of the newborn, and in the event of abortion, the abortus is assumed unused and costless to dispose. Given data from the current study, the gross present value of a calf at successful birth is estimated as the present value of a one-year-old calf, discounted and adjusted for the probability of calf death:

$$V(\text{calf} | A = 0) = (1 - \pi_d) \times P_c \times \delta, \quad (2)$$

Whereby,  $\pi_d$  is the probability that a successfully birthed calf dies before it is 12 months old, so  $(1 - \pi_d)$  is the probability that it lives to 12 months. The  $P_c$  is the market price of a 12 months-old-calf, representing the value of a calf at that age, and  $\delta = 1/(1 + r_d)$  is the one-year discount factor where  $r_d$  is an annual discount rate (Haacker *et al.*, 2020). Discounting to one year was done because the market value of one-year-old animals was used, and the temporal reference point as noted before is the due date for a pregnancy.

Milk offtake for household use may differ after an abortion versus a successful birth because of: (a) A difference in production, (b) The fact that a calf is consuming milk in the one case but not the other, and (c) Because data from the current study suggests that households sometimes do not milk for human consumption from recently abortive stock. When milk is taken for human consumption, the assumption is that it is acquired daily so its value can be modelled as a daily annuity. The present value of milk offtake depending on status is:

$$V(\text{milk} | A, F) = M(A, F) \times P_m \times \sigma, \quad (3)$$

Whereby,  $F \in (\text{Offtake}=1, \text{No offtake}=0)$  indicates whether a household milks a livestock for human consumption in the household or for sale and  $\sigma = (1 - (1 + r_d)^{-T_m})/r_d$  is the daily annuity formula where  $r_d$  is the daily discount rate and  $T_m$  represents the number of days of milk offtake attributable to an individual pregnancy (until milk is no longer produced or is attributable to the next pregnancy cycle). The  $M(A, F)$  is the average amount of offtake for human consumption conditional on abortion status, and  $P_m$  is the market price received by livestock owners for their milk (this price also represents the opportunity cost of household consumption). Data from the current study suggests that sometimes households choose not to use milk for consumption after an abortion. In this case  $M(A = 1, F = 0) = 0$ .<sup>1</sup> The difference in the present value of milk offtake value after a successful birth versus an abortion is:

$$\Delta V(\text{milk}) = \Delta M \times P_m \times \sigma, \quad (4)$$

Whereby,  $\Delta M = M(A = 0, F = 1) - M(A = 1, F)$  is the difference in milk offtake after an abortion versus after a successful birth. For a household that does not consume milk from

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<sup>1</sup> People choose not to consume milk after an abortion for a reason. Whatever the reason, they choose to forego benefits from the milk. Reasons for not using milk after an abortion (i.e. the perceived harm that might occur from consuming or selling it) are not accounted for in these calculations due to data limitations.

abortive stock, the difference in milk offtake is equal to the value of milk from a non-abortive stock:  $\Delta V(\text{milk}) = V(\text{milk}|A = 0, F = 1) - 0 = V(\text{milk}|A = 0, F = 1)$ . The *ex post* gross value of pregnancy conditional on birth outcome is the sum of the value of the newborn (or abortus), and the value of milk offtake:

$$V(\text{preg}|A, F) = V(\text{calf}|A, F) + V(\text{milk}|A, F) \quad (5)$$

People choose not to consume milk after an abortion for a reason. Whatever the reason, they choose to forego benefits from the milk. Reasons for not using milk after an abortion (i.e. the perceived harm that might occur from consuming or selling it) are not accounted for in these calculations due to data limitations.

In Equation (5) the augmented notation for the value of pregnancy in Equation (1) to indicate offtake status  $F$ . The *ex post* gross economic loss from an abortion is equal to the difference between the gross value of a pregnancy given a successful birth and the gross value of a pregnancy given an abortion:

$$\begin{aligned} V(\text{preg}|A = 0, F = 1) - V(\text{preg}|A = 1, F) &= V(\text{calf}|A = 0, F = 1) + \Delta V(\text{milk}) \quad (6) \\ &= V(\text{abortion loss}|\text{preg}), \end{aligned}$$

Whereby,  $\Delta V(\text{milk})$  is defined in Equation (4). Equation (6) shows that the gross loss of value due to an abortion is the *ex post* value of a newborn and the difference in the value of milk offtake. In Equation (6), the value of a pregnancy given an abortion,  $V(\text{preg}|A = 1, F)$ , depends on if the household uses milk after an abortion. If not, the gross value of pregnancy ending in abortion is zero:  $V(\text{preg}|A = 1, F = 1) = 0$  and the *net* value of pregnancy would necessarily be negative if additional husbandry costs were incurred during pregnancy. The net value of pregnancy and the net loss associated with abortion is defined next.

## (ii) Husbandry costs and net abortion loss

Rearranging Equation (1) after substituting the second row of Equation (6) provides the implied *combined* expected costs of pregnancy and newborn care ( $EC$ ):

$$EC = V(\text{preg}|A = 0) - \alpha V(\text{abortion loss}|\text{preg}) - V(\text{preg})/\delta \quad (7)$$

Equation (7) is estimable with data from the current study. However, to estimate the net loss  $C_p$  and  $C_n$  were estimated separately, which requires an additional assumption and manipulation. First, define *ex post* total husbandry costs given a successful birth as  $C = C_n +$

$C_p$ . Then note that another representation of *expected* husbandry costs is  $C = C_p + (1 - \alpha)C_n = C - \alpha C_n$ . The additional assumption is introduced here: Define the unknown share of  $C$  accrued through raising a newborn as  $\rho$ . Then  $C_n = \rho C$  and  $C_p = (1 - \rho)C$ . Substituting these two values provides  $C = \frac{EC}{1 - \alpha\rho}$ ,  $C_n = \rho \frac{EC}{1 - \alpha\rho}$ , and  $C_p = (1 - \rho) \frac{EC}{1 - \alpha\rho}$ . So, for estimable values of  $EC$  from Equation (7), an estimate of  $\alpha$ , and an assumed  $\rho \in (0,1)$ , allow estimation of  $C_p$  and  $C_n$ . Next, the net value of pregnancy and net loss abortion loss were estimated.

The *ex post* net value of a successful pregnancy is the value of a successful birth minus pregnancy and newborn husbandry costs:

$$NV(\text{preg}|A = 0, F = 1) = V(\text{preg}|A = 0, F = 1) - C. \quad (8)$$

Given an abortion the cost of pregnancy ( $C_p$ ) are incurred but  $C_n$  is not, so the *ex post* net value of pregnancy given abortion is:

$$NV(\text{preg}|A = 1, F) = V(\text{preg}|A = 1, F) - C_p. \quad (9)$$

The *ex post* loss from an abortion given a pregnancy is the difference in the *ex post* net value of a successful pregnancy and an abortive pregnancy:

$$\begin{aligned} NV(\text{abortion loss}|\text{preg}) &= NV(\text{preg}|A = 0, F = 1) - NV(\text{preg}|A = 1, F) \\ &= V(\text{abortion loss}|\text{preg}) - C_n, \end{aligned} \quad (10)$$

Whereby,  $V(\text{abortion loss}|\text{preg})$  is defined in Equation (6).

### (iii) Population-level abortion losses

The aggregate economic losses with pregnancy and abortion rate estimates were estimated from the current study in combination with Census data (Ministry of Agriculture, 2020) that provides the number of reproductive age animals and other useful data. Abortion loss is calculated as:

$$L_{ijkl} = v_{ijkl} \times A_{ij} \quad (11)$$

$$A_{ij} = \alpha_{ij} \times G_{ij} \quad (12)$$

$$G_{ij} = g_{ij} \times R_{ij}, \quad (13)$$

Whereby,  $L_{ijkl}$  is total abortion loss (net or gross) for livestock species  $i$  (cattle or small stock are loosely referred to as small stock sheep and goats as a “species” for conciseness); breed  $j$  local or nonlocal, which were used to be synonymous with indigenous versus hybrid or improved breeds;  $v_{ijkl}$  is the per-abortion loss for stock species and breed  $i$  and  $j$ ;  $k$  indicates whether a household consumes milk after an abortion, and the  $l$  index indicates whether  $v$  represents either a gross loss or net loss (net of husbandry costs) per animal. The per-pregnancy loss values  $v_{ijkl}$  are calculated based on Equations (6) and (10) and supporting equations. Using compound index  $ij$  to indicate a stock type (species, breed),  $A_{ij}$  is the number of abortions for stock type  $ij$ ,  $\alpha_{ij} = A_{ij}/G_{ij}$  is the abortion rate for stock  $ij$ ,  $G_{ij}$  is the number of pregnancies in the region for stock  $ij$ ,  $g_{ij} = G_{ij}/R_{ij}$  is the pregnancy rate for stock type  $ij$ , and  $R_{ij}$  is the number of reproductive-aged female animals of stock type  $ij$ . Summing over all stock types provides the total abortion loss (net or gross):

$$L_{kl} = \sum_{i=1}^2 \sum_{j=1}^2 (\alpha_{ij} \times g_{ij}) \times (v_{ijkl} \times R_{ij}), \quad (14)$$

Whereby,  $(\alpha_{ij} \times g_{ij})$  is the abortion rate per reproductive-age female of stock type  $ij$  and  $(v_{ijkl} \times R_{ij})$  is the value of the population of reproductive-age female of stock type  $ij$  for household type  $k$ . The elements of  $(\alpha_{ij} \times g_{ij})$  are estimated from data from the present study but can also be calculated for any population given local stock numbers and price data, and so can be calculated for any population to which  $\alpha_{ij}$  and  $g_{ij}$  apply with sufficient accuracy. Given the proportion of households who choose not to consume milk after an abortion ( $f$ ), total losses are:

$$L_l = fL_{nl} + (1 - f)L_{ml}. \quad (15)$$

Index  $k$  from Equation (14) takes one of two values in Equation (15):  $k = n$  indicates values for households that choose not to consume milk after an abortion ( $F = 0$ ) from Equation (4), and  $k = m$  represent households that do ( $F = 1$ ). Again,  $l$  indicates net or gross loss.

Given aggregate abortion losses based on Equation (15) and the sample estimates of  $v_{ijkl}$ ,  $\alpha_{ij}$ ,  $g_{ij}$ , and  $f$ , aggregate losses are estimable for any population given data on the number of reproductive age female animals  $R_{ij}$  and either the pregnancy rate  $g_{ij}$  or the number of pregnancies  $G_{ij}$ . In the application, the Census data do not provide data on the number of pregnancies  $G_{ij}$ , but it does provide data on the number of animals born by category, so these data were used to scale the estimates to be consistent with the numbers born reported in the

Census data. This process is described in the next section. The accuracy of the aggregate estimates for any population therefore depends on whether the estimates of  $v_{ijkl}$ ,  $\alpha_{ij}$ ,  $g_{ij}$ , and  $f$  are sufficiently close to the values and rates in a focus population, and the precision and accuracy of the estimates and supporting population data.

Aggregate losses  $L_l$  for a population can be compared for scale as a percent of any economic metric of interest for that population as  $l_{l,z} = 100 \times \frac{L_l}{V_z^N}$ , where  $V_z^N$  is any aggregate monetary metric of interest relating to livestock category  $z$  in regions  $N$ . In the application, losses to the value of reproductive-aged female stock and the value of juveniles born in the last year were compared, for northern Tanzania and for Tanzania as a whole (in US Dollars).

### **3.17 Data, parameters, and empirical methods for economic impact of abortion in Tanzania analysis**

Parameters collected, calculated, or estimated to calculate abortion loss as represented by Equations (1) through (15) are described in Table 2 and usage is described below.

Parameters in Table 2 and values in Table 12 of the results section are either calculated as sample averages (often by category), or calculated from information received from the literature. The exception is  $V(\text{Preg})$ , the ex ante value of pregnancy, which were estimated with hedonic regression analysis using market price data from the LMS survey. The market price premium of a pregnant over a nonpregnant stock reflects expected but uncertain future benefits from that pregnancy. The expected present value of a pregnancy  $V_{ij}(\text{Preg})$  (the left-hand-side of Equation (1)) and an element on the right-hand-side of Equation (7) is estimable using a hedonic regression on market prices.

Consider a hedonic regression explaining the factors affecting the market price of stock with various characteristics  $\mathbf{X}$  and associated parameters  $\beta_x$ , and a dummy variable  $P$  that takes the value of 1 for pregnant stock, and zero otherwise. The value of pregnancy may differ across breeds, so a dummy variable  $H$  taking the value 1 for a non-local (hybrid) breed and zero for a local breed was include (the two categories were included in the regressions).

**Table 2: Summary descriptions variables and model parameters for the abortion cost estimation and their definitions**

<b>Parameter</b>	<b>Definition</b>
$r_a$	Annual discount rate assumed to be 2.5%.
$r_d$	Daily discount rate, calculated from annual discount rate.
$\rho$	Share of reproduction husbandry costs attributable to a successful birth (costs that do not accrue after an abortion). Assumed.
$f$	proportion of households who choose not to consume milk after an abortion.
$d, \delta$	Discount factors for the number of days between pregnant cow market sale and due date, and one-year old calf at marketable age as described in the text.
$\pi_i^d j$	Probability that a successfully birthed $n$ dies before it is 12 months old derived from literature (Chenyambuga and Mseleko, 2009).
$P_i^c j$	Average market price of a 12-month-old-animal by stock type $ij$ (Source: Livestock Markets Survey, Livestock Keepers' Survey); Average prices for juveniles, by region used for aggregation (Census data).
$P_i^s j$	Market price of a stock animal used to estimate the value of pregnancy (Livestock Markets Survey and Livestock Keepers' Survey); Average prices for male and female stock by region used for aggregation (Census data).
$p_i^m j$	Average milk price (per liter) received by a farmer, by stock category (Experts Survey).
$M_{ij}(A = 0, F = 1)$ $= -\Delta M_{ij}(F = 0)$	Average milk offtake given a successful birth (Experts Survey). For households who chose not to consume milk after an abortion, this is equal to the loss in milk if an abortion occurs.
$\Delta M_{ij}(F = 1)$	Milk offtake given a successful birth minus milk offtake after an abortion given that the abortive animal was milked (Experts Survey).
$T_i^m j$	The number of days of milk offtake attributable to an individual pregnancy (until the milk runs out or is attributable to the next pregnancy cycle) (Experts Survey).
$T_i^m j (A = 0)$	Average number of days of milking after successful birth (Experts Survey).
$T_i^m j (A = 1)$	Average number of days of milking after an abortion (if milked) (Experts Survey).
$T_i^d j$	Estimated period between sale date and due date of a pregnant animal that are usually sold (Experts Survey)
$V_{ij}(\text{Preg}) = (\beta_{ij}, \beta_{ij} + \gamma_{ij}) g_{ij}$	Expected Present Value of pregnancy prior to pregnancy completion. Estimated via regression analysis (Livestock Markets Survey).
$G_{ij}$	Number of pregnancies in the last year as collected from project data in S1 and S2 which included all pregnancies noted for the project period of 2 years.
$B_{jj}$	Number of cattle, sheep, and goats born by region (Census data).
$A_{ij}$	Number of abortions as collected from project data in S1 survey.
$\alpha_{ij}$	Abortion rate $\alpha_i = A_i/G_i$ as collected from project data S1 and S2.
$g_{ij}$	Pregnancy rate $g_i = G_i/R_i$ from control group data, survey S2
$R_{ij}$	Number of reproductive-age female cattle and small stock, by region (Census data).

Index  $i$  indicates species (cattle or small stock) and index  $j$  indicates breed (local or nonlocal; synonymous with indigenous or hybrid/improved). Compound index  $ij$  is referred as type for conciseness

Preliminary analysis suggests the random error of the model approximates a lognormal distribution, so use the natural logarithm of the market price  $P_s$  as the dependent variable, providing a Gaussian random error term  $\varepsilon$ . The regression written compactly is:

$$\ln(P_s) = \beta'_x X + \beta P + \lambda H + \gamma(H \times P) + \varepsilon \quad (16)$$

The parameter  $\beta$  represents the percentage price premium for a pregnant animal of local breed at the time of sale relative to an otherwise similar nonpregnant animal. The approximate percentage price premium for a hybrid pregnant animal is  $\beta + \gamma$ . The parameter  $\lambda$  is the approximate percentage premium for a nonpregnant hybrid breed compared to a local breed. The Stata glm package with a log link function was used to estimate the model for cattle and small stock separately. The price premium (value of) pregnancy in levels rather than percentages  $EPV(\text{Preg})$  in Equations (1) and Equation (7) was calculated using the Stata Margins routine (StataCorp, 2021). Sheep and goat data were combined and termed as ‘small stock’. If factors other than calf and milk loss affect the ex ante value of a pregnancy, the estimates of the pregnancy premium and by extension  $C_p$  and  $C_n$  will implicitly reflect these unobserved factors.

Aggregate loss estimates for northern Tanzania and all Tanzania are calculated using a combination of Census data, which provides data by region for 31 regions in Tanzania, including Zanzibar, and the study data. First, the process generates estimates for each northern Tanzania region (Arusha, Kilimanjaro and Manyara region), which were aggregated to the northern Tanzania study area, and finally data for all regions (including Zanzibar) are aggregated to represent Tanzania as a whole.

Based on Equations (14) and (15) and given available data, there are two ways to estimate the number of abortions for each stock type (by region):  $A_{ij} = \alpha_{ij} \times G_{ij}$ , or  $A_{ij} = (\alpha_{ij} \times g_{ij}) \times R_{ij}$ . All right-hand side elements  $\alpha_{ij}$ ,  $g_{ij}$ ,  $G_{ij}$ , and  $R_{ij}$  are available from the study sample. Of these, only the number of reproductive females  $R_i$  is also available in the Census data. While the number of pregnancies  $G_{ij}$  are not included in the Census data, the number of livestock born ( $B$ ) during the census period is provided, but only by species (cattle, small stock), not differentiated by breed.

When the number of pregnancies by species as  $G_i = g_i R_i$  (Equation (13)) is estimated using  $g_i$  from the sample and  $R_i$  from the Census, aggregate pregnancies for each species are smaller than the Census-reported number of stocks born. This cannot be true and must be an artifact of

sampling error. Given that the sample is more limited than the Census sample, a scaling process is carried out to generate pregnancy estimates using Census data on births, and then estimate abortions based on these scaled pregnancy estimates. To do so the number of births was first estimated by species as:

$$B_i^0 = (1 - \alpha_{iL})G_{iL}^0 + (1 - \alpha_{iN})G_{iN}^0, \quad (17)$$

Whereby, indexes  $iL$  and  $iN$  represent Local and Nonlocal breeds for species  $i$ ,  $G_{ij}^0 = g_{ij}R_{ij}$  estimated pregnancy rates based on the number of reproductive-aged females in the Census and pregnancy rate estimates from the current study, and  $\alpha_{ij}$  and  $g_{ij}$  are abortion and pregnancy rates from the sample, respectively. Superscript 0 on  $G_{ij}^0$  and  $B_i^0$  identifies them as preliminary unscaled estimates. The scaling factor  $\gamma_i = \frac{B_i^c}{B_i^0}$ , was then defined where  $B_i^c$  are Census-reported births for each region. The number of abortions consistent with Census-reported births is:

$$A_{ij} = \alpha_{ij}(\gamma_i G_{ij}^0) = \alpha_{ij}(\gamma_i g_{ij} R_{ij}), \quad (18)$$

Whereby, the terms in parentheses are different representations of adjusted pregnancy estimates. The estimates of  $A_{ij}$  (Equation (18)) and  $L_{kl}$  (Equation (14)) are calculated for each of the 31 Tanzanian regions, and these are summed over northern Tanzania regions or for all Tanzania.

For context and scale, abortion loss estimates were compared to: (a) The value of reproductive-age females and (b) The value of juveniles. The Census provides market price estimates to generate value estimates for each stock type for each region. Let  $V_z^n$  represent the value of some category of livestock  $z$  for region  $n$ . In this case,  $V_z^n =$  the total value of reproductive female stock or  $V_z^n =$  the total value of juvenile stock. For a set of regions  $n \in N$ , the aggregate value of a category of livestock is:

$$V_z^N = \sum_{n=1}^N \sum_{i=1}^S P_{i,n}^z z_{i,n}, \quad (19)$$

Whereby, the inner sum is the market value of stock category  $z$  (price  $P_{i,n}^z$  times quantity  $z_{i,n}$ ) over stock types  $i \in S$  for each region  $n \in N$ , and the outer summation sums over all regions. Losses as a percent of  $V_z^N$  is calculated as  $l_{k,z,N} = 100 \times \frac{L_k}{V_z^N}$ .

### **3.18 Data analyses**

#### **3.18.3 *Neospora caninum* sero-prevalence estimation**

The “observed” prevalence estimates at both the conservative (Hall *et al.*, 2005) and liberal (18.3) S/P thresholds were adjusted by diagnostic specificity and sensitivity in order to derive “true” prevalence estimates (Dohoo *et al.*, 2003). Adjustment for diagnostic test performance was performed using the *prevalence* package (Devleeschauwer *et al.*, 2015) in the R statistical environment version 3.6.0 (R Core Team, 2017).

#### **3.18.4 General contextual analysis for *Neospora caninum***

Given the hierarchical nature of the study design, in which sampled cattle were clustered by household and village, a general contextual analysis was first performed to examine the relative effects of these grouping-levels in explaining variation in the odds of *N. caninum* seropositivity (De Glanville *et al.*, 2018). A null logistic regression model was run with random effects at the household- and village-level but without fixed effects. The median odds ratio (MOR) and intra-cluster correlation coefficient (ICC) were calculated using the estimated variance in household- and village-level intercepts. The MOR provides an estimate of the magnitude of heterogeneity in odds of infection at each level while the ICC provides an estimate of the correlation in infection probability at each level (Larsen & Merlo, 2005). The ICC was estimated using the latent variable approach (Austin & Merlo, 2017). The residual log odds of infection at the village-level were also examined whether they showed evidence of spatial autocorrelation using the Moran’s I statistic.

#### **3.18.5 *Neospora caninum* risk factor assessment**

The null logistic model was extended to explore potential risk factors for *N. caninum* seropositivity. Risk factors were identified from questionnaire and open-source environmental and demographic data. These included: Village-level livestock production system; household- and village-level dog ownership; feeding parturient materials from cattle to dogs; wildlife contact; environmental conditions expected to influence *N. caninum* oocyst survival;

household management of grazing; herd size; household ownership of small ruminants and chickens; cattle introductions in the past 12 months; and local cattle population density. Village-level livestock production system was defined as “pastoral” (the majority of livelihoods based primarily on livestock production) and “mixed” (the majority of livelihoods based on a mixture of livestock and crop production) by local experts (district veterinary officers). The village-level dog ownership variable was the median number of dogs kept by households surveyed in each village.

A number of potential proxies for wildlife contact were used. These were: Farmer reports of observing any wild ungulate or carnivore (since wild canid observations were very rare) over the past 12 months; whether the household was within a wildlife area (conservation area, game controlled area, game reserve, national park, nature reserve, or wildlife management area) according to the world database on protected areas (UNEP-World Conservation Monitoring Centre, <https://protectedplanet.net/>); and the proportion of an 80 km area surrounding households (a circle with 5 km radius) that was classified as shrub or forest land (NASA Landsat Program, 2003) (<http://glcf.umd.edu/data/landsat/>). Environmental variables that were hypothesized to influence oocyst survival were annual mean temperature and the average precipitation in the wettest quarter of the year, the clay, sand and organic carbon content of soil (Hengl *et al.*, 2015).

Altitude was derived from shuttle radar topography mission data (Jarvis *et al.*, 2008). Grazing management was split into two categories: Restricted grazing in which cattle were tethered on pasture around the household or zero grazing in which fodder is brought to confined animals, and extensive grazing with a herdsman. Local cattle population density was extracted at the household-level from the Food and Agriculture Organization’s 2010 gridded livestock of the world data (Gilbert *et al.*, 2018). All spatial data were manipulated in QGIS (version 2.14.3). Individual-level risk factors were cattle age (<18 months or  $\geq 18$  months on the basis of dentition), sex, and breed (indigenous or improved dairy cross).

The relationship between potential risk factors and individual level *N. caninum* seropositivity was first examined using univariable logistic regression. Given the large number of potential predictors and the fact that several of these predictors were included to represent similar features (e.g., wildlife contact, soil characteristics, etc.), model selection was performed. Bayesian model averaging (BMA) approach for model selection (Hooten & Hobbs, 2015) was used. Model averaging was performed using an indicator variable with the Gibbs variable

selection formulation (O’Hara & Sillanpää, 2009). Briefly, this involves including a latent indicator variable ( $w$ ) for each variable ( $m$ ) in the model,  $w_m$ .

In a Bayesian context, the value of  $w_m$  is 1 if the linear predictor includes  $m$  and 0 if it does not. Hence, the posterior estimate for  $w_m$  represents the probability of inclusion of a particular variable in the regression equation and therefore an indication of its importance in explaining observed variation in the outcome of interest (i.e., the proportion of times the variable contributes to the posterior estimate). The model averaged co-efficients for predictors represent a sample from all possible models that are defined by all possible combinations of  $w$  indicator variables (Kery & Royle, 2016). Where  $w_m$  is close to 0, the co-efficient for  $m$  will also be shrunken toward 0, where  $w_m$  is close to 1, its effect will be preserved.

Given the low expected sensitivity of the diagnostic assay used, the null, univariable and multivariable logistic regression models were adjusted for test performance using the following formula (Dohoo *et al.*, 2003):

$$pai = pi \times Se + 1 - pi \times (1 - Sp)$$

Whereby,  $pai$  is probability of a positive test result in individual  $i$  (i.e. the “true” seroprevalence) given the predicted probability of being seropositive,  $pi$  (the “observed” seroprevalence), and the sensitivity ( $Se$ ) and specificity ( $Sp$ ) of the diagnostic test. Positives and negatives defined using the conservative S/P cut-off were used, and therefore an estimated  $Se$  of 0.587 and  $Sp$  of 0.999 for adjustment.

Null, univariable and multivariable logistic regression models were run in JAGS via the *R2jags* package (Su & Masanao, 2012). Random effects were included at the household and village-level in all models. Weakly informative normal priors were used for all fixed and random effects. Convergence after a minimum burn-in of 50 000 and at least 100 000 iterations with a thinning interval of 20 was assessed by visual examination of three MCMC chains. The log of the number of cattle owned by a household was used on the expectation of a non-linear relationship with *N. caninum* seropositivity. All continuous predictors were standardized to have a mean of zero and standard deviation of one.

Pairs of continuous variables were examined for collinearity using a Spearman’s rank correlation coefficient: One of a correlated pair ( $\rho > 0.65$ ) was excluded based on relative biological importance. Assessment of goodness of fit for the final multivariable model selected

by BMA was made using a posterior predictive check (the “Bayesian  $p$ -value”) (Gelman *et al.*, 1996). This involves a comparison of the sum of the observed squared Pearson’s residuals with the sum of squared Pearson’s residuals expected from a distribution matching that specified by the model under assessment. Values close to 0.5 (and away from 0 and 1) suggest reasonable model fit (Kery & Royle, 2016). The Moran’s I statistic for the null logistic regression model was calculated from village-level residuals using the *ape* package (Paradis, 2019) in R.

### **3.18.6 Assessment of disease impacts of *Neospora caninum***

A mixed effects negative binomial regression was used to examine the relationship between the reported number of cattle abortions over the past 12 months and the within-herd prevalence of exposure to *N. caninum*. The log of the number of female cattle owned by the household at the time of the survey was included as an offset so that the abortion rate was modeled. Village was included as a random effect. Village-level production system was included to control for potential confounding. Negative binomial models were run in JAGS using the settings described above. Adjustment for test misclassification was not performed, instead results derived using the conservative (Hall *et al.*, 2005) and liberal (18.3) S/P cut-offs were compared. Goodness of fit for models using each cut-off was assessed using the Bayesian  $p$ -value, as described above.

### **3.18.7 Regression analysis for livestock market value determination**

Hedonic regressions to estimate the marginal value of a pregnancy while controlling for other characteristics of livestock was applied. The dependent variable is the logarithm of the market price of an animal. The results of these regressions for cattle, sheep and goats combined (“Small Stock All”), goats, and sheep are presented in Table 9. These regressions were estimated using the Stata *glm* regression package with the link(log) option (StataCorp, 2021). The parameter of interest in Table 9 is associated with the indicator variable *Pregnant*. Because the logarithm of the dependent variable is used, the parameter estimates do not directly represent the marginal value of pregnancy. Table 10 provides the marginal value of pregnancy based on these regressions. The estimates were calculated using the Stata 17 *margins* routine.

## **3.19 Ethical clearance**

This project was implemented as part of SEBI-TZ project which was granted ethics approval by Kilimanjaro Christian Medical Centre (KCMC) Ethics Committee (No. 535 and No. 832);

National Institute of Medical Research (NIMR), Tanzania (NIMR/HQ/R.8a/Vol.IX/1522 & NIMR/HQ/R.8a/Vol.IX/2028).

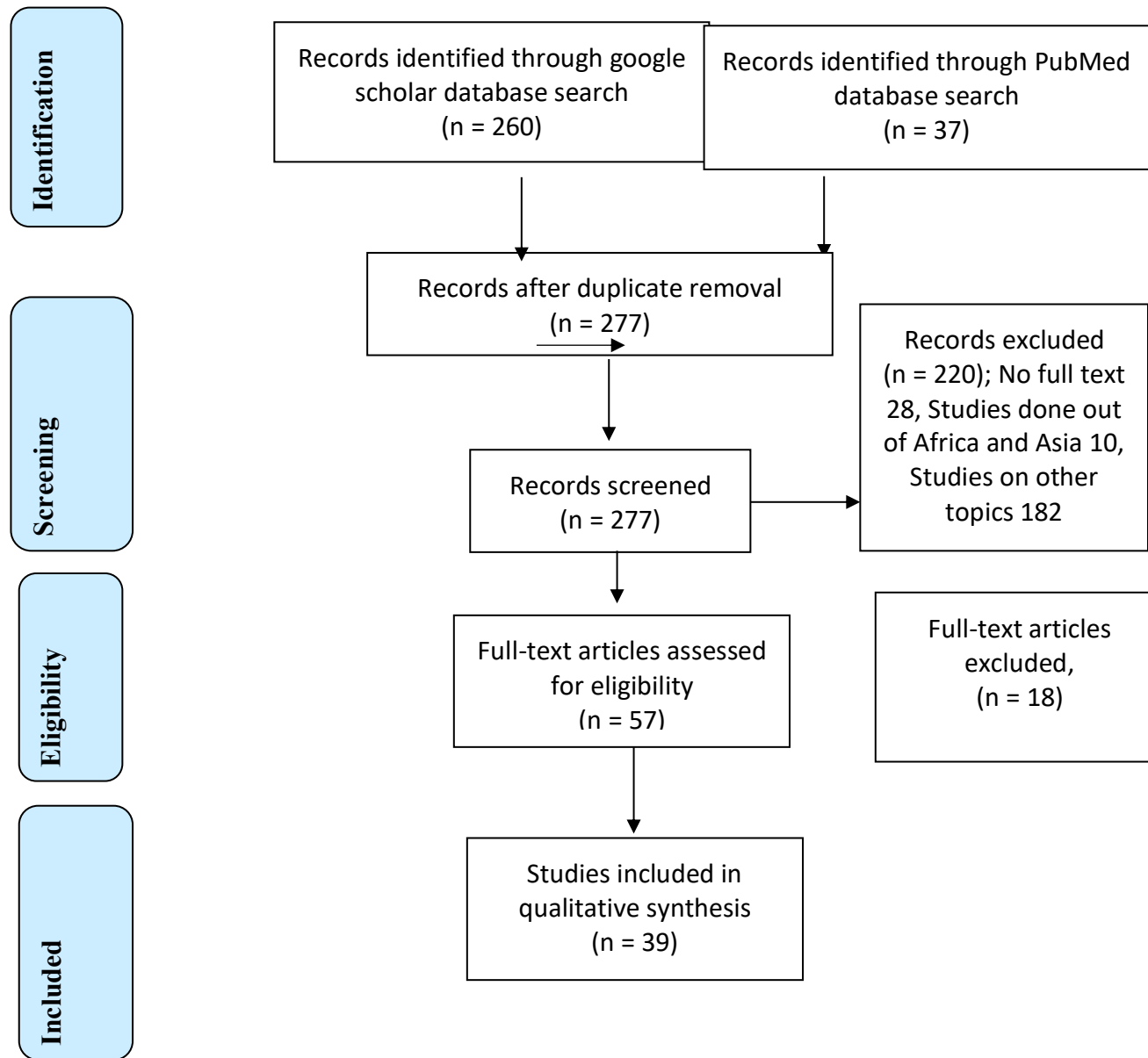
## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Results

##### 4.1.1 Current status of ruminant abortigenic agents' surveillance in Asia, Africa and Tanzania

The literature search resulted in 277 articles, of which, 57 (20.6%) were identified as potentially relevant and 39 (14.1%) were eligible for inclusion after full text review (Fig. 2). Majority of the studies 18 (46.2%) were on *Brucella spp.*, whereas Rift valley fever virus were 9 (23.1%) *Coxiella burnetii* 7(17.9%), *N. caninum* and BVDV were each 6 (15.4%) of all the studies as summarized in Table 3. The number of studies from each country and the animal species investigated are listed in Table 3. Two studies (5.1%) of the 39 included were embedded in the national surveillance programs of the respective countries they were conducted, South Korea and South Africa, whereas majority 94.9% were stand-alone cross-sectional studies. Most studies, 30 (76.9%) were reported from Africa and 9 (23.1%) were done in Asia.



**Figure 2:** The PRISMA Flow diagram showing identification, screening and selection of eligible articles for inclusion in Systematic review, 1990 – 2024

Table 3 shows the summary of the information extracted from the 39 full text articles included from the literature search in the two databases. Information on the country where the study was conducted, year of publication, species from which samples were collected, the number of positive samples among the total number of samples tested, the pathogen detected, the type of animal husbandry method of the species tested, the type of study as well as the diagnostic method used was extracted.

**Table 3: Summary of the information extracted from the full text articles that were included in the meta-analysis**

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
1	Tanzania	East Africa	1996	Cross bred bulls Taurine breeds (Friesian, Ayshire, Simmental crossed with Tanzanian short-horn zebu, boran and Sahiwal)	<i>Campylobacter fetus</i> 3/58, <i>Trichomonas foetus</i> 0/58	<i>Campylobacter fetus</i> subsp. <i>Venerealis</i> , <i>Trichomonas foetus</i>	Sero-survey	Small holder dairy farms (zero-grazing)	Culture and Biochemical tests	Swai <i>et al.</i> (2005)
2	Uganda	East Africa	2000	Cattle (ankole, crosses- Fresian, Boran)	<i>Brucella</i> – 41/143 <i>Anaplasma</i> 3/454	<i>Brucella</i> , <i>Anaplasma</i>	Cross-sectional	Pastoral communities	RBPT, ELISA	Otim <i>et al.</i> (2004)
3	India	Asia	2002 - 2004	Cattle	35/427 (9.6%)	<i>N. caninum</i>	Cross sectional survey	Dairy farms	ELISA, IFAT	Sandhu <i>et al.</i> (2007)
4	Senegal	West Africa	2003	Sheep	7/260 (2.7%)	RVFV	Serological survey	Nomadic	Sero Neutralization test	Chevalier <i>et al.</i> (2007)
5	Zimbabwe	Southern Africa	2004 - 2005	Cattle	71/1291 (5.5%)	<i>Brucella</i>	Cross-sectional	Smallholder	RBT, ELISA	Matope <i>et al.</i> (2011)

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
6	Sudan	Central Africa	2005	Sheep and Goats	Sheep 3/270 (1.1%)	RVFV	Sero-surveillance	Nomadic pastoralist	ELISA, Haemagglutination	Kroc and Ochi (2009)
7	South Africa	Southern Africa	2006 - 2016	Cattle 193, Goats 39 and Sheep 57	63/288 ; Brucella 21/288 (7.3%) Cattle, <i>Trueperella pyogenes</i> 5/288 Cattle, 1/288 sheep,	<i>Brucella</i> , <i>Trueperella pyogenes</i> , <i>E.Coli</i> , <i>Salmonella</i> , <i>L. monocytogenes</i> , <i>C. Burnetii</i> , <i>B. licheniformis</i> , <i>Rhizopus</i> , <i>B. abortus</i> , <i>Leptospira</i> , <i>C. pecorum</i> , <i>Campylobacter</i>	Observational retrospective study	Archived samples	Microbiology, necropsy, histopathology, PCR	Jonker and Michel (2021)
8	Ethiopia	East Africa	2008 - 2009	Sheep and Goats	0/270 Sheep, 2/230 Goats	<i>Brucella</i>	Cross sectional	Mixed farming	Rose Bengal Plate Test, Complement Fixation Test	Ferede <i>et al.</i> (2011)
9	Ethiopia	East Africa	2009 - 2010	Cattle	2/370 (0.05%)	<i>Brucella</i>	Cross-sectional survey	Mixed farming	Rose Bengal, Complement Fixation Test	Degefa <i>et al.</i> (2011)

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
10	Tunisia	North Africa	2010 - 2012	Cattle	214 blood, vaginal swabs, milk. <i>Brucella</i> 47/150 (31.3%) RBPT, DANA PCR 46/150 (30.6%). <i>Chlamydia</i> 27/150 (18%), <i>L. monocytogenes</i> 7/150 (4.6%), <i>Salmonella</i> 5/150 (3.3%). Vaginal swabs; <i>Brucella</i> 46/150 (30.6%), <i>Chlamydiales</i> 27/150 (2.65%), <i>L. monocytogenes</i> 4/150 (2.6%)	<i>Brucella</i> , <i>Chlamydiales</i> ( <i>C. abortus</i> , <i>C. pecorum</i> ), <i>Listeria</i> , <i>Salmonella</i> , <i>Coxiella burnetii</i> , <i>Campylobacter</i>	Cross-sectional survey	Limited pasture or tethered	PCR, Rose Bengal	Barkallah <i>et al.</i> (2014)
11	Mozambique	Southern Africa	2010 - 2016	Cattle, Goats and Sheep	Cattle 149/404 Goats 45/223 Sheep	RVFV	Sero-survey	Mixed farming	ELISA, PRNT	Moiane (2017)

S/ N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
12	Zimbabwe	Southern Africa	2011	Cattle (mixed breeds)	81/1440 (5.6%)	<i>Brucella</i>	Cross- sectional survey	Small holder, Mixed farming (strict separate pastures)	ELISA	Matope <i>et al.</i> (2011)
13	Iran	Asia	2011 - 2012	Sheep and Goats	PCR: Sheep 101/274. Goats 10/25 Culture Sheep 76/274. Goats' 9/25	<i>Mycoplasma spp</i>	Cross- sectional	Mixed farming	PCR, bacterial culture	Jafarizadeh <i>et al.</i> (2016)
14	India	Asia	2012 - 2014	Cattle	11/61 (18.03%)	<i>Trypanosoma evansi</i>	Sero- survey	Mixed farming	ELISA	Ligi <i>et al.</i> (2015)
15	South Korea	Asia	2012 - 2013	Cattle (Holstein breed)	37/171 and 85/466	Blue Tongue Virus	Serologi- cal survey from National Surveilla- nce Program	Mixed farming	ELISA, BTV neutralization test, RT-PCR	Hwang <i>et al.</i> (2019)
16	Cameroon	West Africa	2013	Cattle	117/1498	RVFV	Cross- sectional survey	Pastoralists	ELISA	Bronsvoort <i>et al.</i> (2022)

S/ N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
17	Tanzania	East Africa	2013 - 2016	Cattle, Goats and Sheep	<i>Brucella</i> Cattle 1/71, <i>Coxiella</i> Goats 5/100, Sheep 1/44, <i>Neospora</i> Cattle 9/71, Goats 1/100, <i>Toxoplasma</i> Sheep 1/44, BHV-1 Cattle 2/49, BVDV Cattle 2/71, Goats 1/100, Sheep 6/44, RVFV Cattle 14/71,	<i>Brucella</i> , <i>Chlamydia</i> <i>abortus</i> , <i>Coxiella</i> <i>burnetii</i> , <i>Leptospira</i> <i>hardjo</i> , <i>N.</i> <i>caninum</i> , <i>Toxoplasma</i> <i>gondii</i> , Bluetongue Virus, Bovine Herpes Virus 1, Pestiviruses (BVDV/BD), RVFV	Cross- sectional survey	Pastoral, Agro-pastoral and Small holder	ELISA, PCR	Thomas <i>et al.</i> (2022)
18	South Africa	Southe rn Africa	2013 - 2018	Cattle	359 026 (22.1%)	<i>Brucella</i>	Cross- sectional survey, Provinci al surveilla nce program	Mixed farming	CFT, Rose Bengal Plate Test	Govindasamy <i>et al.</i> (2021)

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
19	Mozambique	Southern Africa	2014	Goats	Serology: 31/127 (24.4%)	RVFV	Outbreak investigation	Mixed farming	ELISA, PCR	Fafetine <i>et al.</i> (2016)
20	India	Asia	2014	Cattle	160 RBPT 3/160 (1.8%), Standard Tube Agglutination Test (STAT) 5/160 (3.13%)	<i>Brucella</i>	Sero-epidemiological survey	Mixed farming	RBPT, STAT, Bacterial culture, Milk Ring Test	Khajuria <i>et al.</i> (2014)
21	Nigeria	West Africa	2015	Cattle	11/97 (11.3%)	RVFV	Cross-sectional survey	Nomadic pastoral	ELISA	Alhaji <i>et al.</i> (2018)
22	Kenya	East Africa	2016	Cattle	100/955, 10.5%	<i>Coxiella burnetii</i>	Cross-sectional survey	Mixed crop-livestock, Bimodal climate	ELISA	Wardrop <i>et al.</i> (2016)
23	Egypt	North Africa	2016 - 2018	Cattle	165/176 (93.86%)	BHV-1	Transboundary, Import from Sudan	Nomadic	ELISA	Hekal <i>et al.</i> (2019)
24	Tajikistan	Central Asia	2016	Cattle	570 (58 PCR, 12 ELISA)	<i>Brucella</i>	Sero-prevalence	Small-holder	ELISA, qPCR, DNA sequencing	Lindahl-Rajala <i>et al.</i> (2017)
25	Tunisia	North Africa	2017	Cattle, Sheep	Cattle <i>Waddlia</i> 12/27, Parachlamydiae	<i>Waddlia chondrophil</i> ,	Cross-sectional survey	Small-holder (Mediterranean)	PCR	Barkallah <i>et al.</i> (2018)

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
					8/27, Chlamydiaceae 7/27, Sheep P. acanthamoebae 9/164, C. pecorum 6/164	<i>C. abortus</i> , <i>C. pecorum</i>				
26	Algeria	North Africa	2017 - 2019	Atlas brown cows	650 pregnant (235(36.2%))	<i>N. caninum</i>	Sero-prevalence	Small-holder (Mediterranean)	ELISA	Abdeltif <i>et al.</i> (2022)
27	Tanzania	East Africa	2017 - 2019	Cattle	14/63 (23%)	RVFV	Prospective cohort	Pastoral, agropastoral and smallholder	ELISA, RT-qPCR	De Glanville <i>et al.</i> (2022)
28	Benin	West Africa	2017	Sheep and goats	Goats 83/153, Sheep 3/215	<i>Toxoplasma gondii</i>	Sero-epidemiological survey	Steppe climate and topical humid climate	ELISA	Tonouhewa <i>et al.</i> (2019)
29	Guinea	West Africa	2017 - 2019	Cattle, Goats and Sheep	<i>Brucella</i> ; Cattle 52/463, Sheep 2/486. <i>Coxiella</i> ; Cattle 95/463, Goats 18/408, Sheep 11/486. RVF; Cattle 76/463, Goats 4/408, Sheep 5/486	<i>Brucella</i> , <i>Coxiella burnetii</i> , RVFV	Sero-survey from archived samples	Intensive farms Samples from different Prefectures	ELISA, Virus Neutralizing Ab	Troupin <i>et al.</i> (2022)

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
30	Algeria	North Africa	2018 - 2019	Cattle	201/460 (43.7%)	Bovine Herpes Virus 1	Abortion investigation	Mixed farming (Mediterranean climate)	ELISA	Djellata (2023)
31	Saudi Arabia	Asia	2018 - 2020	Sheep, Goats	Goat 3/84 (3.5%) Serum	BVDV	Sero-prevalence- Abattoir surveillance	Abattoir, semi-closed management	ELISA	Al-Mubarak <i>et al.</i> (2022)
32	Ethiopia	East Africa	2018 - 2019	Cattle Cross, Pure breeds Boran-Fresian cross, Boran-Jersey, Pure Jersey and Boran	BHV-1 68/86(79.1%), BVD 33/86 (38.4%), <i>Neospora</i> 3/86 (3.5%), <i>Coxiella</i> 1/86 (1.2%)	<i>Brucella spp.</i> , <i>N. caninum</i> , BVD, BHV-1, <i>Coxiella burnetii</i>	Reproductive problem investigation	Semi-intensive farming system (grazing and indoor feeding)	ELISA	Messele <i>et al.</i> (2021)
33	Ethiopia	East Africa	2018 - 2019	Cattle (Zebu, Holstein, Fresian and crossbreed)	0/882 (ear notch samples)	BVDV	Cross-sectional survey	Peri-urban dairy farms, mixed crop livestock farms (small holder extensive management system), pastoral herds	ELISA	Yitagesu <i>et al.</i> (2021)

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
								(seasonal mobility)		
34	India	Asia	2019	Cattle Crossbreed, Exotic, indigenous	BHV-1 425/1004, BVDV 604/1004, <i>Brucella</i> 176/1004, <i>Coxiella</i> 57/1004, <i>Anaplasma</i> 363/1004, <i>Neospora</i> 9/1004	BHV-1, BVDV, <i>Brucella</i> , <i>Coxiella</i> <i>burnetii</i> , <i>N.</i> <i>caninum</i> , <i>Anaplasma</i> <i>marginale</i>	Cross-sectional	Intensive dairy farms	ELISA	Naveena <i>et al.</i> (2022)
35	Nigeria	West Africa	2020	Cattle	61/1810 (3.37%)	<i>Brucella</i>	Cross-sectional	Mixed farming	SAT	Mohammed <i>et al.</i> (2020)
36	Egypt	North Africa	2020	Cattle	<i>Neospora</i> 35/116 (30.17%), BVDV 31/116(26.72%)	<i>N. caninum</i> , BVDV	Cross sectional	Medium sized farms	ELISA	El-Mohamady <i>et al.</i> (2021)
37	Kenya	East Africa	2020 - 2021	Cattle	6593(449)	<i>Brucella</i>	Sero-prevalence	Agro-alpine, high and medium potential, semi-arid,	ELISA	Akoko <i>et al.</i> (2023)

S/N	Country	Region	Year	Species	Number of Species (positive)	Pathogen(s) detected	Study type	Husbandry method (Climatic zone)	Detection method	Ref
								arid and very arid		
38	Bangladesh	Asia	2023	Cattle (local, cross)	66/386 (17.09%)	<i>Brucella</i>	Cross-sectional	Transboundary area, mixed farming	RBPT, Plate agglutination test, serum agglutination	Deb Nath <i>et al.</i> (2023)
39	South Africa	Southern Africa	2023	Cattle	2/770	<i>Brucella</i>	Cross-sectional survey, abattoir survey	Communal, Commercial and non-commercial farms	RNT, CFT, Milk Ring Test	Marumo <i>et al.</i> (2023)

**Table 4: Seroprevalence of abortigenic pathogens by species**

Abortigenic pathogen	Species	Cases (n)		Total tested (N)		Median Sero-Prevalence		
		Africa	Asia	Africa	Asia	Africa	Asia	
<i>Anaplasma</i>	Cattle	3	363	454	1004	0.7	36.2	
BHV-1	Cattle	436	245	771	1004	56.5	24.4	
Bluetongue virus	Cattle	0	122	0	637	0	19.2	
<i>Brucella spp.</i>	Goats	2	0	230	0	0.87	0	
	Sheep	2	0	754	0	0.27	0	
	Cattle	80	165	305	372	127	2120	21.5
BVDV	Goats	1	3	100	84	1	3.6	
	Sheep	6	0	44	0	13.6	0	
	Cattle	66	604	1155	1004	5.7	60.2	
<i>Campylobacter</i>	Cattle	3	0	58	0	5.2	0	
<i>Chlamydia abortus</i>	Cattle	34	0	177	0	19.2	0	
<i>Chlamydia pecorum</i>	Sheep	6	0	164	0	3.7	0	
<i>Coxiella burnetii</i>	Goats	23	0	508	0	4.5	0	
	Sheep	12	0	530	0	2.3	0	
	Cattle	196	54	1504	1004	13	5.4	
<i>Listeria</i>	Cattle	7	0	150	0	4.7	0	
<i>Mycoplasma</i>	Goats	0	10	0	25	0	40	
	Sheep	0	101	0	274	0	36.9	
<i>N. caninum</i>	Goats	1	0	100	0	1	0	
	Cattle	282	44	923	1431	30.6	3.1	
RVFV	Goats	80	0	758	0	10.6	0	
	Sheep	15	0	1016	0	1.5	0	
	Cattle	381	0	2596	0	14.7	0	
<i>Salmonella</i>	Cattle	5	0	150	0	3.3	0	
<i>Toxoplasma gondii</i>	Goats	83	0	153	0	54.2	0	
	Sheep	4	0	259	0	1.5	0	

Abortigenic pathogen	Species	Cases (n)		Total tested (N)		Median Sero-Prevalence	
		Africa	Asia	Africa	Asia	Africa	Asia
<i>Trichomonas foetus</i>	Cattle	0	0	58	0	0	0
<i>Trypanosoma evansi</i>	Cattle	0	11	0	61	0	18
<i>Waddlia chondrophila</i>	Cattle	12	0	27	0	44.4	0

### **(i) Median sero-prevalence of abortigenic pathogens**

Adjusted median prevalence calculations estimated *Brucella* in Africa at 21.5% of 372 127 cattle, 0.27% and 0.87% in sheep and goats, respectively. *Coxiella* at 13.0%% in cattle, 2.3% and 4.5% in sheep and goats, respectively. The most prevalent abortigenic pathogens with sero-prevalence greater than 10% were BHV-1, *Brucella*, *Chlamydia abortus*, *N. caninum*, RVFV, *Waddlia chondrophila* in cattle and BVDV in sheep, RVFV and *Toxoplasma gondii* in goats in Africa. In Asia, *Anaplasma*, BHV-1, Bluetongue virus, *Brucella* and BVDV in cattle whereas *Mycoplasma* was important in goats and sheep. Other pathogens detected in low sero-prevalence were *Anaplasma*, BVDV, *Campylobacter*, *Listeria* and *Salmonella* in cattle, *Brucella*, *Coxiella burnetii* in goats and sheep, BVDV and *N. caninum* in goats, *Chlamydia pecorum*, RVFV and *Toxoplasma gondii* in sheep in Africa. In Asia, pestiviruses (BVDV) in goats, *Coxiella burnetii* and *N. caninum* in cattle. This data is summarized in Table 4.

#### **4.1.2 To determine the sero-prevalence of *Neospora caninum* as an abortigenic agent in northern Tanzania**

In this study, 3015 cattle serum samples were tested, out of which 379 [12.6%, 95% Confidence Interval (CI) 11.4–13.8] were seropositive for *N. caninum* antibodies. Adjustment for test performance resulted in a true seroprevalence of 21.5% (95% CrI 17.9–25.4). On the basis of the liberal cut-off, the observed prevalence was 22.0% (95% CI 20.5–23.5), and the true prevalence was 25.3% (95% CrI 21.1–29.7). Of the 380 households sampled, 186 (49.0%, 95% CI 43.8–54.1) had at least one seropositive animal. This was 67.9% (95% CI 62.9–72.5) on the basis of the liberal cut-off. There was substantial variation in the true prevalence of infection between villages [3.2% (95% CI 0.3–9.2) to 60.3% (95% CI 43.6–79.1)] (Fig. 3).

The MOR and the ICC at the household level were 4.2 (95% CrI 3.0–6.7) and 39.9% (95% CrI 28.3–54.8), respectively; the MOR and ICC at the village level was 2.8 (95% CrI 1.9–4.8) and 19.7% (95% CrI 8.9–38.2), respectively. To put the household MOR into context, it is expected that, all else being equal, when comparing cattle in two different households anywhere in the study area, the odds of *N. caninum* seropositivity would be, in median, over four times higher for an animal in the household with higher within-herd prevalence than for an animal in the household with lower within-herd prevalence. In terms of ICC, it can be said that around 40% of the differences in individual animal *N. caninum* exposure risk is at the household-level. Both of these measures suggest high levels of clustering of infection risk at the household level.

Village was less important in structuring variation in infection risk. There was no evidence in autocorrelation (and therefore spatial clustering) in village-level residual odds of seropositivity (Moran's  $I = -0.08$ ,  $p = 0.57$ ).

The number and proportion of *N. caninum* seropositive samples and associated univariable odds ratios (OR) in relation to each categorical variable is shown in Table 5. A description of the continuous variables and the association with *N. caninum* seropositivity is shown in Table 6. Questionnaires were conducted in 360 households, representing 2838 individual animals. Annual mean temperature was very strongly inversely correlated with altitude ( $\rho = -0.99$ ). Altitude can be expected to be linked to a range of environmental effects, including temperature, and therefore altitude is used as the predictor of interest. Sand content of soil was inversely correlated with silt ( $\rho = -0.80$ ) and clay ( $\rho = -0.95$ ) content. While all soil properties can be expected to influence moisture content, which in turn can be expected to influence oocyst survival, sand content of soil was used in the multivariable analysis to reflect relatively high levels of water filtration and relatively low levels of water saturation (i.e., drier soils).

#### **4.1.3 Risk factors for *Neospora caninum* as an abortigenic agent**

The outputs from the BMA procedure are summarized in Table 7. Variables with a probability of inclusion  $>0.5$  were age  $>18$  months; the local cattle population density; the percentage cover of shrub or forest land in the environment surrounding a household; and household use of restricted grazing. Older animals had more than two times the odds of being *N. caninum* seropositive compared to younger animals [Odds ratio (OR) = 2.17, 95% CrI 1.45–3.26]. While there was no evidence for a relationship with household herd size, local cattle population density was negatively associated with *N. caninum* seropositivity (OR = 0.69, 95% CrI 0.41–1.00). Cattle in households that reported using restricted grazing had reduced odds of seropositivity (OR = 0.72, 95% CrI 0.25–1.16).

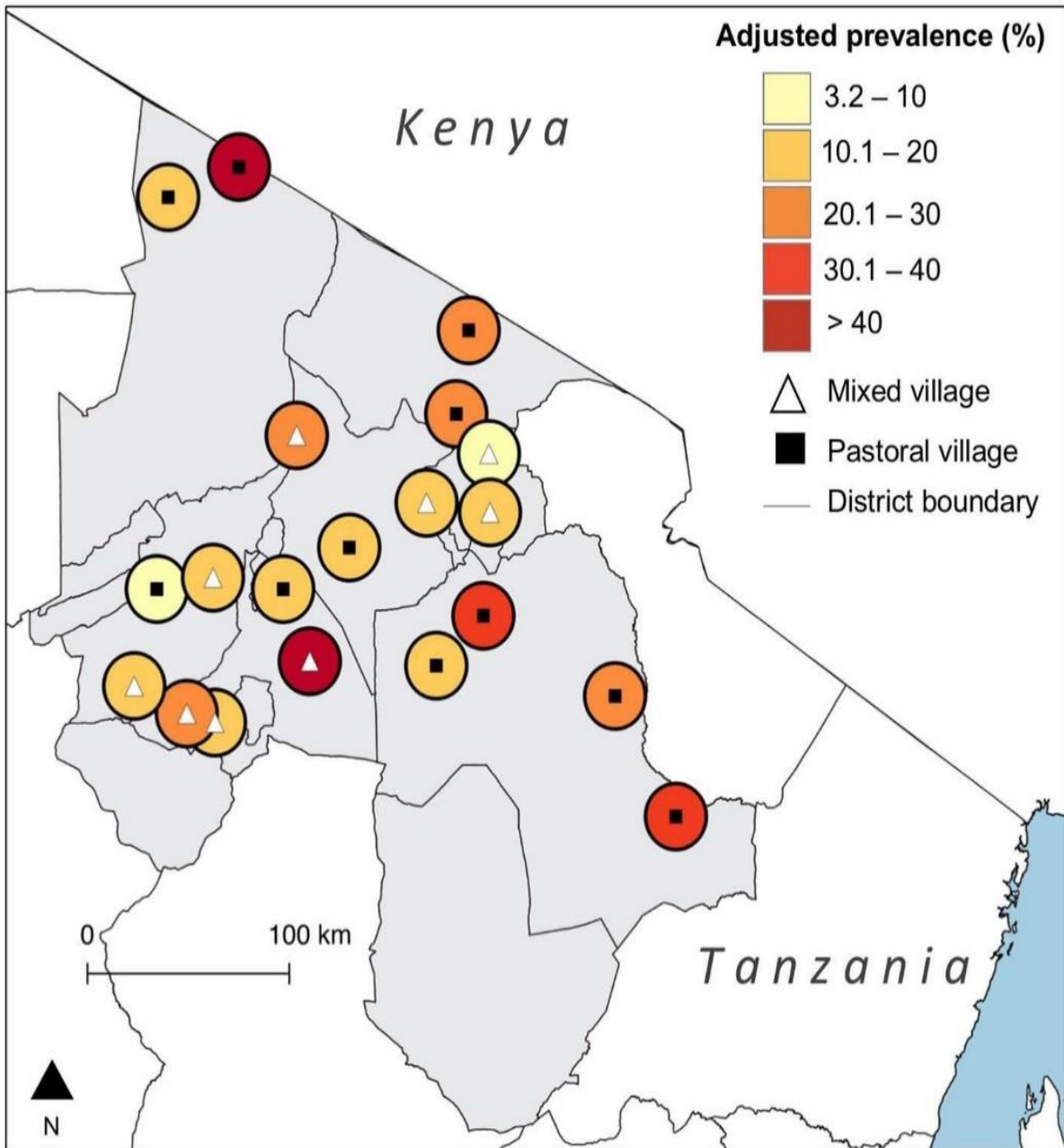
The credibility intervals for this variable broadly overlap one, so while it can be considered a moderately important predictor in explaining variation in *N. caninum* seropositivity (with a 0.63 probability of being in the model), the evidence for the size and direction of the effect should be considered weak. There was no evidence of a relationship between farmer reports of observing wildlife in the past 12 months or household location within a wildlife area and *N. caninum* positivity, but cattle kept in households in areas with a high percentage of shrub or forest cover were more likely to be *N. caninum* seropositive (OR 1.37, 95% CrI 1.00–2.14).

There was no evidence for a difference in *N. caninum* seropositivity between production systems.

#### **4.1.4 Disease impact of *Neospora caninum* as an abortigenic agent**

The reported number of abortions in the past 12 months in study households ranged from 0 to 162. The seroprevalence of *N. caninum* in herds with at least one positive animal ranged from 8 to 100%, with an average of 24.6% (28.6% using the more liberal cut-off). There were five households in which the number of reported abortions over the past 12 months exceeded the number of adult female animals present at the time of the survey. These were treated as having 100% abortion rates (i.e., reduced the number of abortions to match the number of females).

The multivariable negative binomial regression resulted in an of 1.03 (95% CrI 1.00–1.06). Hence, for every 10% increase in within-herd *N. caninum* seroprevalence, the rate of abortion could be expected to increase by around 1.3 times. Production system was strongly associated with abortion rate, with this being considerably higher in households in pastoral villages than in mixed villages (IRR = 16.7, 95% CrI 3.6–133.5). The positive relationship between abortion rate and within-herd *N. caninum* prevalence was observed when the five households with 100% abortion rates were excluded from the dataset (IRR = 1.02, 95% CrI 1.00–1.05). There was not an important difference in results derived using the conservative and liberal cut-offs (data not shown). The Bayesian p-value for negative binomial models using different ELISA cut-offs ranged between 0.4 and 0.47.



**Figure 3:** Map showing the village-level prevalence of *N. caninum* seropositivity in northern Tanzania with adjustment for diagnostic test performance (Created using QGIS version 2.14.3, shapefiles from <https://gadm.org/>)

**Table 5: Individual and household-level characteristics of categorical variables and their relationship with the seroprevalence of *Neospora caninum* in cattle in northern Tanzania**

Risk factor		Total N (%)	Neospora seropositive n (%)	Univariable regression OR (95% CI)
<b>Individual level</b>				
Age	<18 months	835 (29.4)	70 (8.4)	Ref
	>= 18months	2003 (70.6)	285 (14.2)	2.49 (1.73-3.69)
Breed	Indigenous	2567 (90.5)	334 (13.0)	Ref
	Cross	271 (9.5)	21 (7.7)	0.61 (0.24-1.55)
Sex	Female	1894 (66.7)	248 (13.1)	Ref
	Male	944 (33.3)	107 (11.3)	0.79 (0.56-1.10)
<b>Household level</b>				
Keep chickens	No	412 (14.6)	41 (10.0)	Ref
	Yes	2404 (85.4)	312 (13.0)	1.15 (0.63-2.15)
Keep small ruminants	No	207 (7.3)	28 (13.5)	Ref
	Yes	2631 (92.7)	327 (12.4)	0.85 (0.40-1.81)
Keep dogs	No	801 (28.2)	98 (12.2)	Ref
	Yes	2037 (71.8)	257 (12.6)	1.03 (0.62-1.70)
Feed placentas to dogs	No	463 (16.3)	66 (14.3)	Ref
	Yes	2375 (83.7)	289 (12.2)	0.88 (0.49-1.59)
Cattle introduction	No	1974 (69.6)	246 (12.5)	Ref
	Yes	864 (30.4)	109 (12.6)	1.09 (0.70-1.71)
Restricted grazing	No	2637 (93.0)	349 (13.2)	Ref
	Yes	198 (7.0)	6 (3.0)	0.22 (0.07-0.65))
Production system	Mixed	1223 (43.1)	148 (12.1)	Ref
	Pastoral	1615 (56.9)	207 (12.8)	1.15 (0.40-3.41)
Wildlife area	No	1477 (52.5)	163 (11.0)	Ref
	Yes	1339 (47.5)	190 (14.2)	1.50 (0.67-3.49)
See wildlife	No	1091 (38.4)	130 (11.9)	Ref
	Yes	1747 (61.6)	225 (12.9)	1.36 (0.79-2.36)

**Table 6: Household-level characteristics of continuous variables and their relationship with the seroprevalence of *Neospora caninum* in northern Tanzania**

<b>Risk factor</b>	<b>Median, Mean (range)</b>	<b>Univariable regression OR (95% CrI)</b>
Number of dogs in village	2.00, 1.63 (0.00-3.00)	1.11 (0.78-1.58)
Cattle number	20, 63.96 (1.00-1200)	1.15 (0.66-1.98)
Local cattle population density	0.8, 40.30 (0.2-5.820)	0.55 (0.34-0.87)
Sand content of soil (%)	48, 49 (31-66)	0.95 (0.60-1.44)
Organic content of soil (%)	14, 15 (1-55)	1.42 (1.07-1.89)
Clay content of soil (%)	33, 32.63 (18.00-47.00)	0.99 (0.65-1.57)
Silt content of soil (%)	18, 18.89 (11.00-28.00)	1.03 (0.71-1.51)
Precipitation of wettest quarter (mm)	406, 420 (251-719)	1.02 (0.64-1.71)
Mean annual temperature (°C)	19.5, 19.3 (14.5-24.1)	0.97 (0.58-1.62)
Altitude (m)	1410, 1470 (610-2,420)	1.06 (0.62-1.82)
Shrub or forest land (%)	0.12, 0.19 (0.00-0.99)	1.59 (1.08-2.38)

**Table 7: Risk factors to *Neospora caninum* in cattle in northern Tanzania selected using Bayesian model averaging**

<b>Variables</b>	<b>Indicator variable</b>	<b>OR</b>	<b>95% CrI</b>
Age	1.00	2.17	1.45-3.26
Local cattle population density	0.81	0.69	0.41-1.00
Shrub or forest land	0.78	1.37	1.00-2.14
Restricted grazing	0.62	0.72	0.25-1.16
Production system (pastoral)	0.48	0.89	0.36-1.51
Breed (cross)	0.39	0.95	0.51-1.50
Feed placenta to dogs	0.39	0.95	0.60-1.28
Keep small ruminants	0.38	0.99	0.64-1.52
Wildlife area	0.36	1.03	0.67-1.78
Keep chickens	0.36	1.05	0.79-1.67
Number of dogs in village	0.36	1.06	0.84-1.66
See wildlife	0.33	1.02	0.74-1.49
Keep dogs	0.31	1.00	0.73-1.36
Sex (male)	0.28	0.98	0.75-1.17
Cattle introduction	0.27	1.01	0.78-1.33
Organic carbon	0.19	1.01	1.00-1.05
Sand content of soil	0.05	1.00	1.00-1.00
Altitude	0.02	1.00	1.00-1.00
Precipitation of wettest quarter	0.01	1.00	1.00-1.00
Cattle number	0.00	1.00	1.00-1.00

Economic burden of livestock abortions: Value of livestock in northern Tanzania. In order to assess the impact an abortion event has on a household, community and nation, data on the value of livestock to the livestock owners was collected. Data on market value of young livestock was also collected. Table 8 shows the market value of livestock in northern Tanzania.

In the six livestock markets and 20 farms of non-local livestock owners' households visited, the average prices of the different animals were as summarized in Table 8.

**Table 8: Livestock prices,  $P_s$ , from livestock markets and owners**

Category of livestock		N	Market price [TZS] (Min - Max)	SD
Local Cattle	All ages (Male & Female)	124	575 161.3 (200 000 – 1 700 000)	309 672
	Pregnant Female	17	538 235.3 (350 000 – 650 000)	107 310.0
	Non-Pregnant Female	49	405 918.4 (200,000 – 900 000)	151 050.7
	Female	66	440 000 (200 000 – 900 000)	151 931.2
	Male	58	728 965.5 (220 000 – 1 700 000)	367 951.6
	≤12 months	14	337 142.9 (200 000 – 650 000)	155 979.7
	≤12 months Female	12	329 166.7 (200 000 – 650 000)	160 819.4
	≤12 months Male	2	385 000 (270 000 – 500 000)	162 634.6
Non-Local Cattle	Average (Male & Female)	20	937 500 (450 000 – 2 000 000)	376 575.6
	Pregnant Female	4	1 300 000 (1 000 000 – 1 500 000)	244 949.0
	Non-Pregnant Female	14	850 000 (600 000 – 2 000 000)	348 071.6
	Female	18	950 000 (600 000 – 2 000 000)	374 558.6
	Male	2	825 000 (450 000 – 1 200 000)	530 330.1
	≤ 24 months	6	925 000 (450 000 – 1 500 000)	373 831.5
	≤ 24 months Female	5	1 020 000 (700 000 – 1 500 000)	327 108.5
	≤ 24 months Male	1	450 000 (NA)	NA
Local Small Stock	Average (Male & Female)	257	81 194.6 (30 000 – 300 000)	37 157.9
Small Stock	Pregnant Female	27	85 370.4 (50 000 – 180 000)	29 869.1
	Non-Pregnant Female	86	74 697.7 (30 000 – 160 000)	27 094.9
	Female	118	76 517.0 (30 000 – 180 000)	27 695.8
	Male	139	85 165.5 (30 000 – 300 000)	43 317.4
	≤ 6 months	9	37 222.2 (30 000 – 45 000)	5651.9
	≤ 6 months Female	4	33 750 (30 000 – 35 000)	2500.0
≤ 6 months Male	5	40 000 (30 000 – 45 000)	6123.7	
Non-Local Small stock	Average Male & Female	37	103 918.9 (30 000 – 200 000)	43 030.0
Local Small stock	Pregnant Female	27	120 000 (80 000 – 150 000)	33 303.0
Small stock	Non-Pregnant Female	11	106 363.6 (50 000 – 150 000)	40 068.1
	Female	37	103 918.9 (30 000 – 200 000)	43 030.0

**(i) The value of a pregnancy given abortion risk: Regression results**

Furthermore, the significance of different parameters to the market value of livestock in northern Tanzania was estimated by doing hedonic regression modelling of the livestock market prices against the variables that affect the price (Table 9).

**Table 9: Hedonic regression for market price (Dependent variable: ln[Price], 1000s TZS)**

	Cattle		Small Stock All		Goats		Sheep	
Pregnant	0.36	***	-0.034		0.02		-0.00026	
Hybrid	0.39	***	0.36	**	0.33	**		
Pregnant hybrid	X		0.18		0.12			
Agesq	0.000064	***	0.000093	**	0.00017	***	-0.00019	
BCS	0.18	***	0.15	***	0.17	***	0.39	***
LONGIDO	-0.16		-0.12		-0.24	**	0.2	*
MGAGAO	-0.72	***	-0.25	**	-0.22	*	0.092	
MTO WA MBU	-0.43	***	-0.36	**	-0.31	*	-0.063	
NAMANGA			0.034		-0.16		0.28	***
NJIA PANDA	-0.31	***	-0.32	***	-0.41	***	0.21	
SELELA	-0.28	***	-0.35	***	-0.31	***	-0.3	**
WERUWERU	0.18	***	0.046		-0.056			
Intercept	5.6	***	3.9	***	3.9	***	2.7	***
N	84		154		110		44	

\*\*\* p<.01, \*\* p<.05, \* p<.1

Table 10 shows that the value of pregnancy for a local cattle breed averages TZS 171 366, while the value of pregnancy for hybrid cattle averages TZS 622 288. The rest of the conditional estimates in Table 10 are not statistically different from zero, and some are negative. Given that it is hypothesized that pregnancy generally provides positive value, the differences in the raw averages by breed is provided in Table 11.

**Table 10: Estimated marginal value of pregnancy in TZS, based on regressions in Table 9**

	Cattle	Small Stock All	Goats	Sheep
Local	171 366***	-2614	1670	-17
Hybrid	622 288***	15 967	14 436	

\*\*\* p<.01, \*\* p<.05, \* p<.1

**Table 11: Raw difference in sample means of pregnant versus not-pregnant animals**

	Cattle	Small Stock All	Goats	Sheep
Local	132 317***	11 160*	16 434**	5639
Hybrid	450 000**	23 800	23 800	

\*\*\* p<.01, \*\* p<.05, \* p<.1

The differences in the unconditional means between pregnant and non-pregnant animals shown in Table 11 Indicates that on average in the study sample, pregnant animals tend to be more valuable than non-pregnant animals in all cases, and in contrast to Table 12, the estimated value of pregnant small stock is positive and significant at the 10% level and at the 5% level for goats alone. For the purposes of the calculations, the estimates from Table 10 were used for cattle, and the estimates from Table 9 for small stock.

**(ii) Economic impact of livestock abortion in northern Tanzania**

In order to estimate the loss accrued following an abortion event, a series of 19 Equations were used as outlined in Section 3.7 and descriptions in Table 2. Table 12 outlines the parameters used in the model estimation (Equations 1 to 19).

**Table 12: Parameter estimates used in model estimation**

Parameter	Cattle		Small stock	
	Local	Non-Local	Local	Non-Local
$r_d$			0.00006765	
$r_a$			0.025	
P			0.25	
$f$			0.30	
$\pi_d$	0.056	0.120	0.227	0.058
$P_c$ , TZS <sup>1</sup> (study data)	337 142	925 000	37 222	90 000
$P_s$ , TZS <sup>1</sup> (study data)	575 161	937 500	81 195	103 919
$P_m$ , TZS <sup>1</sup>	1050	1050	2000	2000
$M(A=0) = -\Delta M(C=0)$	3	8	3	3
$M(A=1)$	2.688	5.596	2.75	2.214
$\Delta M(F=1)$	-0.3125	-2.404	-0.25	-0.7857
$T_m$ (days, A=1 and A=0)	108	110	50	50
$\sigma$	107.6	109.6	49.91	49.91
$T_d$ (days)	165	165	105	105
$d$	0.9889	0.9889	0.9929	0.9929
V(preg), TZS <sup>1</sup>	171 366	622 288	1670	14 436
$R_{ij}$ : Reprod. Age females (Control)	3228	368	10 774	418
$G_{ij}$ : Pregnancies (Control)	1383	181	5309	192
$A_{ij}$ : Abortions (Control)	89	16	1093	16
$g_{ij}$ : Pregnancy rate = $G/R$ (Control)	42.84%	49.18%	49.28%	45.93%
$\alpha_{ij}$ : Abortion rate = $A/G$ (Control)	6.44%	8.84%	20.59%	8.33%

<sup>1</sup>Divide this value by 2300 TZS/\$to calculate an estimate in \$.

Table 12 shows the actual parameters used in the model estimation (Equations 1 to 19) and below are the outputs generated from the model estimation in the Tables 13 to 16.

**(iii) Abortion loss estimation using ministry of agriculture census data of 2019/2020 for all of Tanzania**

Table 13 provides relevant summary statistics for all of Tanzania analogous to those presented in Table 14. These are calculated in exactly the same way as those in Table 13, but summed or averaged over all Tanzanian regions rather than just the three Northern Tanzania regions.

Table 13: provides the estimates of primary interest in this article, including the value of newborn (and loss thereof given abortion) inferred from data applied to Equation (2), the

estimated value of milk offtake loss from Equation (4), and the gross and net losses from an abortion depending on whether a household chooses to consume milk offtake after the event of an abortion based on Equations (6) and (10).

**Table 13: Ex post values per abortion in TZS and \$ (2300 TZS/\$) ( $v_{ijk}$  in Equations 11-15)**

Estimate	1000 TZS				\$			
	Cattle		Small stock		Cattle		Small stock	
	Local	Non-local	Local	Non-local	Local	Non-local	Local	Non-local
Value of newborn (Equation 2)	311	794	28	83	135	345	12	36
Value of milk, no abortion (Equation 3-5)	339	921	299	299	147	400	130	130
Value of milk given abortion (Equation 3-5)	304	644	275	221	132	280	119	96
Value of difference in milk (Equation 5)	-35	-277	-25	-78	-15	-120	-11	-34
Value of successful pregnancy with milk	649	1715	328	382	282	746	142	166
Value of abortive pregnancy, with milk	304	644	275	221	132	280	119	96
Gross abortion loss, milk offtake (Equation 7)	346	1071	53	161	150	466	23	70
Gross abortion loss, no milk offtake (Equation 7)	649	1715	328	382	282	746	142	166
Net abortion loss, milk offtake (Equation 11)	230	817	-30	71	100	355	-13	31
Net abortion loss, no milk offtake (Equation 11)	519	1418	200	278	226	616	87	121

**Table 14: Data for calculating and interpreting the number of abortions in Northern Tanzania (Arusha, Kilimanjaro and Manyara regions)**

Variables	Cattle			Small stock		
	Local	Nonlocal	Total	Local	Nonlocal	Total
Reprod. females <sup>1</sup>	2 870 461	206 577	3 077 038	4 222 867	125 807	4 348 674
Pregnancies <sup>5</sup>	1 229 816	101 604	1 331 421	2 080 861	57 787	2 138 648
Born <sup>6</sup>	1 394 388	112 240	1 506 628	2 268 331	72 714	2 341 045
Pregnancies scaled <sup>7</sup>	1 490 292	123 124	1 613 416	2 856 397	79 324	2 935 721
Abortions scaled <sup>8</sup>	95 905	10 884	106 788	588 066	6610	594 676
Pregnancy rate % <sup>2</sup>	42.8%	49.2%	43.5%	49.3%	45.9%	49.2%
Abortion rate % <sup>3</sup>	6.4%	8.8%	6.7%	20.6%	8.3%	20.2%
Abort's % rep. fem. <sup>4</sup>	3.6%	5.6%	3.6%	13.1%	5.0%	13.0%
$\gamma_i$ (mean) <sup>9</sup>	.	.	1.212	.	.	1.373

<sup>1</sup>Census data Tables 4.7 and 4.8 as per MoA (2020), summed over three northern regions.

<sup>2</sup>Pregnancy rate from study sample:  $g_{ij} = 100 \times G_{ij}/R_{ij}$

<sup>3</sup>Abortion rate from study sample:  $\alpha_{ij} = A_{ij}/G_{ij}$ .

<sup>4</sup>Abortions as a percent of reproductive animals =  $(A_{ij}/R_{ij}) \times 100 = (\alpha_{ij} \times g_{ij}) \times 100$ .

<sup>5</sup>Number of pregnancies is calculated as the number of reproductive age females from Census data times the pregnancy rate from this study  $G_{ij}^0 = R_{ij} \times g_{ij}$ .

<sup>6</sup>Number of animals born. Census data provided the number cattle, sheep, and goats born, but not broken down to local versus nonlocal. Table 4.10 for calves born and Table 4.37 for goats and sheep. Estimates for individual breed are

$$B_{ij}^0 = \gamma_j(1 - \alpha_{ij})g_{ij}R_{ij} \text{ (Equation (17)).}$$

<sup>7</sup>The number of pregnancies scaled to be consistent with Census data birth estimates is calculated.

$$G_{ij} = \gamma_i G_{ij}^0 \text{ Summed over three northern regions.}$$

<sup>8</sup>The number of abortions is calculated as  $A_{ij} = G_{ij}\alpha_{ij} = \gamma_i g_{ij}\alpha_{ij}R_{ij}$ .

<sup>9</sup>Scaling factor  $\gamma_j$  such that  $B_i^c = \gamma_i B_i^0$ , where  $B_i^c$  is the number of births for species  $i$  reported in the Census data and  $B_i^0 = B_{iL}^0 + B_{iN}^0$  is the sum of local and nonlocal births for species  $i$ .

Table 14 and 15: summarize the non-monetary data and calculations for the three regions of northern Tanzania in which this study data were collected, including pregnancy and abortion rates, the number of reproductive females, pregnancies, and births, and estimated number of abortions. Values for northern Tanzania and for all Tanzania were calculated in the same way: They were calculated for each region, then depending on the metric either summed or averaged over the applicable regions.

**Table 15: Census data for all Tanzania, analogous to Census data presented in Table 14**

	Cattle			small stock		
	Local	Nonlocal	Total	Local	Nonlocal	Total
Reprod. females <sup>1</sup>	15 176 525	632 679	15 809 204	18 083 923	243 004	18 326 927
Pregnancies <sup>2</sup>	6 502 210	311 182	6 813 392	8 911 040	111 619	9 022 659
Born <sup>3</sup>	6 083 774	283 674	6 367 448	7 076 464	102 317	7 178 781
Pregnancies scaled <sup>5</sup>	8 388 624	401 461	8 790 085	11 528 667	144 407	11 673 074
Abortions scaled <sup>5</sup>	539 832	35 488	575 320	2 373 485	12 034	2 385 519

<sup>1</sup>Census data Tables 4.7 and 4.8 as per MoA (2020). Summed over three northern regions.

<sup>2</sup> The number of pregnancies is calculated as the number of reproductive age females from the Census data times the pregnancy rate from this study (This table and Table 2).

$G_{ij}^0 = R_{ij} \times g_{ij}$ .

<sup>3</sup> Number of animals born. Census data provided the number cattle, sheep, and goats born, but not broken down to indigenous versus hybrid. Table 4.10 for calves born and Table 4.37 for goats and sheep. Estimates for individual breed are

$B_{ij}^0 = \gamma_j (1 - \alpha_{ij}) g_{ij} R_{ij}$  (see Equation 17).

<sup>4</sup> Scaling factor  $\gamma_j$  such that  $B_i^c = \gamma_i B_i^0$ , where  $B_i^c$  is the number of births for species  $i$  reported in the Census data and  $B_i^0 = B_{iL}^0 + B_{iN}^0$  is the sum of local and nonlocal births for species  $i$ .

<sup>5</sup> The number of pregnancies scaled to be consistent with Census data birth estimates is calculated.

$G_{ij} = \gamma_i G_{ij}^0$  Summed over three northern regions.

<sup>6</sup> The number of abortions is calculated as  $[A_{ij} = G]_{ij} \alpha_{ij} = \gamma_i g_{ij} \alpha_{ij} R_{ij}$ . Summed over three northern regions.

Table 16 shows that total gross losses for Northern and all of TZ were about \$60 million and \$263 million, respectively. Net losses are estimated at \$28.3 million and \$131 million, for northern and all of Tanzania, respectively. Aggregate gross losses are dominated by local stock losses, which comprise about 89% of northern Tanzania losses (\$52.8 million of \$59.5 million) and 92.1% in all of Tanzania. Similarly, net losses comprise about 82% local breeds for northern Tanzania and 88% for all of Tanzania.

Table 16 provides estimates of the aggregate losses for the gross and net losses for northern Tanzania and all-Tanzania. Values are calculated using data from Table 12 through 14 and based on Equation (15 relying on Equations (11 through (14). Table 15 shows that total gross losses for Northern and all of TZ were about \$60 million and \$263 million, respectively. Net losses are estimated at \$28.3 million and \$131 million, for northern and all of Tanzania, respectively. Aggregate gross losses are dominated by local stock losses, which comprise about 89% of northern Tanzania losses (\$52.8 million of \$59.5 million) and 92.1% in all of Tanzania. Similarly, net losses comprise about 82% local breeds for northern Tanzania and 88% for all of Tanzania. These large percentages are mainly due to the large proportion of stock value that local breeds represent. Small stock losses represent about 59% and 54% of gross losses in northern and all of Tanzania, respectively, and about 37% and 31% of net losses in northern and all of Tanzania.

**Table 16: Aggregate gross and net losses due to abortion at the population-level in the three regions of northern Tanzania (North TZ), and losses for all of Tanzania (All TZ) \$=2300 TZS**

Variables	Gross loss (\$ Millions)		Net loss (\$ Millions)	
	North TZ	All TZ	North TZ	All TZ
Cattle, local	18.2	102.5	13.2	74.4
Cattle, nonlocal	6.0	19.5	4.7	15.4
Small stock, local	34.6	139.7	10.0	40.2
Small stock, nonlocal	0.7	1.2	0.4	0.7
<b>Total</b>	<b>59.5</b>	<b>262.9</b>	<b>28.3</b>	<b>130.7</b>

Based on reproduction and abortion rates from this study and Census data for the 12-month period from 1 October 2019 through 30 September 2020

Table 17 provides additional context for interpreting the scale of results in Table 5. In the first two lines it repeats the totals for gross and net losses for northern Tanzania and Tanzania as a whole. The subsequent two rows show the sum of the value of reproductive aged cattle and small stock, and the last four rows provide the gross and net losses as a percent of the value of both reproductive aged stock and of juvenile stock as reported by the Census data (Ministry of Agriculture, 2020).

**Table 17: Gross and net losses as a proportion of the value of reproductive age female stock, and of juvenile stock as reported in the Census data (Ministry of Agriculture, 2020)**

Variables	North TZ	All TZ
Gross Aggregate Losses (\$M)	59.5	262.9
Net Aggregate Losses (\$M)	28.3	130.7
Value of all reproductive age female stock (\$M)	687.4	1,794
Value of juvenile stock (\$M)	237.6	999.4
Gross Loss, average % value of reproductive age females	8.7	14.7
Net Loss, average % value of reproductive age females	4.1	7.3
Gross Loss, average % value of juvenile stock	25	26.3
Net Loss, average % value of juvenile stock	11.9	13.1

Table 18 provides results showing the sensitivity of economic losses due to 10% decreases or increases in abortion rates ( $\alpha$ ), pregnancy rates ( $g$ ), the share of husbandry costs to newborn ( $\rho$ ), the share of households who chose not to consume milk after an abortion ( $f$ ), the ex ante value of pregnancy ( $V_{preg}$ ), and the annual discount rate ( $r_a$ ).

**Table 18: Sensitivity analysis**

parameter	Gross Loss (L, % $\Delta$ )				Net Loss (L, % $\Delta$ )			
	-10%		+10%		-10%		+10%	
	L	% $\Delta$	L	% $\Delta$	L	% $\Delta$	L	% $\Delta$
$\alpha$	53.5	10.0	65.4	-10.0	25.5	-10.0	31.1	10.0
$g$	53.5	10.0	65.4	-10.0	25.5	-10.0	31.1	10.0
$\rho$	59.5	0.0	59.5	0.0	31.0	9.8	25.5	-9.8
$f$	56.9	4.4	62.1	-4.4	26.1	-7.9	30.5	7.9
$V_{preg}$	59.5	0.0	59.5	0.0	28.0	-0.96	28.6	0.96
$P_m$	55.9	5.94	63.0	-5.94	27.6	-2.46	29.0	2.46
$p_c$	57.1	4.06	61.9	-4.06	26.4	-6.58	30.1	6.58
$r_a$	59.5	0.00	59.4	-0.1	28.3	0.0	28.2	0.3%

Losses (L) for Northern Tanzania and change in Loss from baseline in response to a 10% reduction or increase in the parameter ( $-10\%$  or  $+10\%$ , respectively), holding all other parameters constant. Baseline values for Gross and Net losses are \$59.5 million and \$28.3 million, respectively

Table 17 shows, for example, that when abortion and pregnancy rates  $\alpha_{ij}$  and  $g_{ij}$  (for each stock type and breed) are 10% lower or higher than the baseline abortion rate estimates, total gross and net losses decrease or increase by 10%, respectively. This is because in both cases, abortion rates work proportionately in the model through the livestock population. A change in the share of husbandry costs attributable to the newborn ( $\rho$ ) does not change gross losses, but net losses are higher if the newborn share is lower and the pregnancy share of husbandry costs are higher. Gross losses also do not change if the market premium for a pregnant animal ( $V_{preg}$ ), but net losses increase by only about 1% if  $V_{preg}$  is 10% higher, because it implies

higher implicit husbandry costs and; therefore, lower net benefits of successful pregnancy and therefore lower losses from abortion as well.

A 10% higher proportion of households choosing not to consume milk after an abortion ( $f$ ) leads to a lower abortion loss by 4.4%. Aggregate losses vary inversely to the price of milk ( $P_m$ ) and the price of newborns ( $P_c$ ), but are more responsive to differences in the price of milk gross losses increase by about 6% with a 10% increase in the price of milk. Changing the annual discount rate by 10% has very little effect on the outcomes because the time frames to which the discount rate applies are short (time between market sale and expected newborn delivery, and one year between birth and potential sale at 12 months old. If the discount rate is set to 5% instead of the baseline 2.5, gross loss falls to \$58.8 million (-1%), and net loss falls to \$27.9 million (-1%).

Table 17 shows sensitivity of aggregate losses for all of Tanzania in response to increases or decreases in decreases or increases in abortion rates ( $\alpha$ ), pregnancy rates ( $g$ ), the share of husbandry costs to newborn ( $\rho$ ), and the share of households who chose not to consume milk after an abortion ( $f$ ), the *ex ante* value of pregnancy ( $V_{preg}$ ), and the annual discount rate ( $r_a$ ). For example, that when abortion and pregnancy rates  $\alpha_{ij}$  and  $g_{ij}$  (for each stock type and breed) are 10% lower or higher than the baseline abortion rate estimates, total gross and net losses decrease or increase by 10%, respectively.

## 4.2 Discussion

Livestock abortions pose a significant challenge to animal health, food security, and rural livelihoods, particularly in low- and middle-income countries such as Tanzania. Despite the significant economic and health impacts of livestock abortions in Tanzania, there is a lack of attention and surveillance data on the burden of abortigenic agents and abortions in livestock especially *N. caninum*. This thesis addresses these gaps by investigating the status of surveillance and sero-epidemiology of abortigenic agents in ruminants across Africa and Asia through a systematic review, seroprevalence, risk factors of *N.caninum* and economic impact of abortions in Tanzania.

Findings on the systematic literature review for abortion causing pathogens in ruminants in Africa and Asia, indicate that livestock abortigenic pathogens are still a burden. The most important abortigenic pathogens determined included *Brucella spp.*, BHV-1, *Chlamydia spp.*, *N. caninum* and *W. chondrophila* in African cattle. The RVFV was found important in both

African cattle and goats. *Toxoplasma gondii* and pestiviruses (BVDV) were important in African goats and sheep respectively. As for Asia, *Anaplasma*, BHV-1, Bluetongue virus, *Brucella spp.*, and BVDV were important in cattle and *Mycoplasma* in sheep. *Brucella*, BHV-1 and pestiviruses were important in both Asia and Africa as were *Anaplasma*, Bluetongue and *Mycoplasma* in Asia only. *Brucella* research in goats and sheep in Asia seems to be minimally conducted, probably because of the ongoing surveillance activities aimed at the pathogen for instance in India (Chethan *et al.*, 2021).

Similarly, for *Leptospira*, there was no study that detected the pathogen in both Africa and Asia, but is also under constant surveillance in India (Chethan *et al.*, 2021). Presence of this surveillance program in India and other parts of Asia may also explain the lack of studies in pathogens such as *Brucella spp.* in goats and sheep. *Brucella spp.* have been reported to be prevalent in India and the finding of 14.4% sero-prevalence are similar to a recent meta-analysis which reported a pooled sero-prevalence of 16.6% in cattle (Jaismon *et al.*, 2023). Anaplasmosis is prevalent in Asia with different countries reporting different rates of occurrence such as Iran 37.3% (Mohammadian *et al.*, 2021) which is similar to the pooled sero-prevalence found in this study. As for Bluetongue virus, which is endemic in Asia and Africa, there is lack of published data on it in Africa as also stated elsewhere (Chambaro *et al.*, 2020) with very few African countries reporting its occurrence.

However, in Asia, BTV has been documented to occur as it is endemic in the region. There are also consortia conducting research on the pathogen such as the research efforts in Indonesia and Malaysia in collaboration with Australia (Daniels *et al.*, 2004). *Brucella spp.*, BVDV, Chlamydia, Coxiella, Neospora and RVFV were not reported at all in Asia in sheep and goats while present in Africa. This is unexpected as the Asia pacific region has over 49% of goats and 22% of sheep in the world (FAO, 1984). For RVFV, this virus has not yet been spread to most parts of Asia and hence explains the lack of published data from Asia (Rahman *et al.*, 2023). On the other hand, *Mycoplasma*, *Trypanosoma* and *Trichomonas* are not as well documented as other pathogens. This may be due to their low sero-prevalence or due to being neglected as there are other more prevalent pathogens.

Furthermore, surveillance systems for livestock abortigenic pathogens in many African and Asian countries are so far not optimal with the exception of few countries such as South Africa, India, South Korea and Saudi Arabia which reported to have national surveillance programs. The African and Asian regions have the the highest rate of growth in surveillance systems using

mHealth technology in human medicine. Additionally, most studies employed the serological surveillance approach in single timepoints using cross sectional study design. These studies demonstrated the burden of abortigenic pathogens but were not embedded in the national surveillance systems which would provide continuous real time information except for a few countries; namely India, South Korea, Saudi Arabia and South Africa which had national Brucella surveillance programs (Semango & Buza, 2024). The current review has some major strengths in terms of outlining the abortigenic pathogens in ruminants that are found in Africa and Asia, however, the main limitations was that that it was limited to a few databases.

Establishment of effective surveillance systems for zoonotic diseases has been in the developing world's research agenda for some time (Grace *et al.*, 2012). This is because it is estimated that 75% of human epidemics and 60% of human pathogens are of animal origin. These facts point out the importance of surveillance of zoonotic pathogens, among which, abortigenic agents belong (Woolhouse *et al.*, 2001). These abortigenic agents also cause economic losses in instances where they may not have caused disease to a human being.

Several different modes of surveillance have been proposed for zoonotic pathogens in different settings of the world with varying successes. For instance in France, it is mandatory for livestock keepers to report abortion events to the veterinary department by calling (mobile based technologies), failure to which a fine of 1500 euro is imposed (Bronner *et al.*, 2014). However, even with advanced response systems in place in France, there are still many keepers that do not report abortions (Bronner *et al.*, 2014).

The documented major drawbacks of mobile based technologies include unclear benefits, uncertain long term results (Chang *et al.*, 2011; Githinji *et al.*, 2013; Haberer *et al.*, 2010; L'Engle *et al.*, 2013; Leon *et al.*, 2012; Wakadha *et al.*, 2013) and unknown cost-effectiveness (Horvath *et al.*, 2012; L'Engle *et al.*, 2013). Furthermore, there are still issues of under-reporting (Chang *et al.*, 2011; Githinji *et al.*, 2013). However, even with the drawbacks, mhealth is by far the most promising surveillance method especially for zoonotic diseases especially in Tanzania with the increasing mobile network coverage and mobile phone ownership in both rural and urban areas. Most of developing countries where feasibility studies for the application of mhealth and ehealth have been done have reported that most mhealth programs are done in silos without involvement of key stakeholders and hence unsustainability of the mhealth programs (Kiberu *et al.*, 2017; Njoroge *et al.*, 2017).

In this study evidence of the presence of one of the neglected pathogens, *N. caninum* in northern Tanzania is presented for the first time. The pathogen was detected circulating in apparently healthy livestock. The serological data was collected in the regions where the surveillance platform for abortion events was eventually set up, where the present study was also able to show presence of the pathogen. In this study, an overall sero-prevalence of *N. caninum* seropositivity of 21.5% among apparently healthy cattle was reported in northern Tanzania (Semango *et al.*, 2019). While the seroprevalence of *N. caninum* exposure varies between study villages and appears to be linked to environmental and demographic conditions, there was no evidence for a difference in prevalence between pastoral and mixed production systems (Semango *et al.*, 2019).

The moderately high seroprevalence observed suggests neosporosis is likely to be an important cause of reproductive losses in cattle in northern Tanzania. Indeed, there is evidence for a positive association between within-herd *N. caninum* seroprevalence and abortion rates a finding that provides possible association of *N. caninum* and abortion events. This is probably due to free roaming of dogs as well as free ranging of cattle in the respective communities. A recently published study in neighboring Kenya provides further support for the importance of *N. caninum* as a cause of abortion in the region, with seropositivity of the pathogen reported to be associated with a greater proportion of fetal loss than either *Brucella* spp. or bovine viral diarrhea virus (Okumu *et al.*, 2019).

There was no evidence for an association between individual cattle *N. caninum* seropositivity and household- or village-level dog ownership, or with households reporting feeding placenta to dogs. The absence of a relationship between *N. caninum* seropositivity with dog ownership was also reported from the southern highlands of Tanzania (Mathew, 2017). Infection can be maintained in cattle populations by transplacental transmission (Williams *et al.*, 2009), but there is no reason to suspect that dogs do not act as reservoirs of *N. caninum* for cattle in Tanzania, and a high seroprevalence of infection has been found in dogs in both Kenya and Tanzania (Barber *et al.*, 1997; Latham, 2003; Okumu *et al.*, 2016, 2019). The lack of an observable effect for household-level dog ownership may point to the importance of contamination of grazing areas by free roaming dogs. Dogs in Tanzania are owned by specific households, but often roam far during the day (Sambo *et al.*, 2018). This mechanism is thought to be important for the transmission of other dog-mediated pathogens to livestock in northern Tanzania (Hughes *et al.*, 2019).

Data from the current study provides evidence for a negative relationship between cattle population density and *N. caninum* seropositivity in northern Tanzania. The biological explanation for this relationship is unclear, particularly since cattle population density is strongly correlated with human population density (Robinson *et al.*, 2014) which, in turn, tends to be correlated with dog population density (Gsell *et al.*, 2012). Dog population density has been found to predict *N. caninum* seropositivity in other settings (Schaes *et al.*, 2003). The observed negative effect with cattle population density in this study may represent a lack of confounding control by production system. In the study area, small holder production systems (i.e., mixed crop and livestock, with small cattle herd sizes) are found primarily in peri-urban areas with high human and cattle population density.

These are also the areas in which restricted grazing predominates (none of the pastoral households in the current study reported restricted grazing). It could therefore be expected that cattle reared in small holder households are at lower risk of *N. caninum* exposure than cattle reared in pastoral households, which are found in low cattle population density areas and practice extensive grazing. The lack of an observable effect by production system in this study (and the potential lack of control for the effect of cattle population density) may be due to the non-specific nature of the definitions used. The mixed farming category includes both small-holder and agro-pastoral households. Agro-pastoral households practice mixed crop and livestock production but tend to have larger herd sizes and are found in more rural, low cattle population density locations than small holder households in the study area. Livestock reared in agro-pastoral households could therefore be expected to have a different *N. caninum* risk than those reared in small holder households.

While there was no evidence for a relationship between either cattle being reared in a wildlife area or farmer reports of seeing wildlife in the past 12 months and *N. caninum* seropositivity, there was evidence for a strong association with levels of forest and shrub cover in the area surrounding households. It could be hypothesized that such areas would support the largest wildlife populations, and particularly small and medium sized members of the *Carnivora* order, who could be important reservoir once they feed on infected fetuses. Currently, there are no studies that have directly evaluated the role of wildlife as reservoirs for *N. caninum* in cattle in Tanzania, but serological studies have demonstrated positivity in cheetah and spotted hyena in Kenya (Ferroglio *et al.*, 2003).

These wild carnivores, among others, are found in northern Tanzania, particularly in pastoral settings. Sylvatic cycles have been demonstrated in other settings, including in the Australian dingo (King *et al.*, 2012; McAllister *et al.*, 1998), water buffalo (Neverauskas *et al.*, 2015) as well as those involving rodents (Ferroglia *et al.*, 2007; Macháčová *et al.*, 2016; Meerburg *et al.*, 2012). The forest and shrub cover variable was included to represent wildlife habitat suitability, however alternative explanations for its effect on *N. caninum* exposure risk should also be considered. These include the reduced availability of grassland in forest and shrub areas, resulting in greater concentration of cattle grazing in smaller areas. Alternatively, while there was no relationship with precipitation, altitude or soil type, the microclimatic conditions that are particular to forest and shrub areas may favor *N. caninum* oocyst maturation and survival. Unsporulated *N. caninum* oocysts are said to be highly resistant in the environment (Dubey *et al.*, 2004) and are thought to survive for several years (Dubey *et al.*, 2007). However, limited work has been conducted on the impact of macro or micro-climatic conditions on oocyst survival or rates of maturation (Dubey *et al.*, 2007), particularly in the African context.

It was observed that animals >18 months were more likely be *N. caninum* seropositive than juvenile animals. A similar relationship with age has been reported widely (Davison *et al.*, 1999; Guimarães *et al.*, 2004; Okumu *et al.*, 2019). Cattle are infected with *N. caninum* for life, and this effect is likely to represent the cumulative exposure risk to sporulated oocysts in the environment as animals age (Dubey *et al.*, 2007).

Findings from the current study have a number of implications for disease control in Tanzania. Despite the moderately high prevalence of infection detected in this study, there is limited availability of routine testing for neosporosis in either government or commercial laboratories in Tanzania. Provision of such testing would assist farmers and veterinarians with herd health planning and may be particularly valuable for the growing dairy industry in Tanzania. There is some evidence of a relationship between within-herd seroprevalence and herd-level abortion rates, suggesting that the control of *N. caninum* could contribute to reduced reproductive losses among cattle in the region. Recent research from northern Tanzania demonstrates that cattle abortions are negatively associated with schooling expenditure and positively associated with food expenditure (Haseeb *et al.*, 2019). The *N. caninum* infection and associated abortions can be expected to contribute to this negative impact on household welfare.

Results from the current study indicate several potential control points. There is some evidence that restricted grazing is associated with reduced risk of *N. caninum* infection and may therefore

be a strategy cattle-keepers can use to reduce their abortion risk. It is important to note, however, that restricted grazing requires greater resources in terms of labor and the purchase or collection of fodder. This management system is therefore likely to be impractical for many households, and particularly those in pastoral systems, with large herds relying on extensive grazing in often marginal environments. Reducing contamination of the environment with dog feces could also be expected to contribute to reduced infection risk. Such an approach may be possible in areas where dogs are well-controlled, but in the presence of free ranging dogs, preventing contamination of communal grazing areas is likely to be challenging. Village dogs in these settings may also play an important role in reducing contamination of the grazing environment by deterring the wild canids from the grazing areas close to community settlements. Overall, further work is required in Tanzania, and East Africa more broadly, to explore approaches that can be used, and their applicability to different production systems, in order to control this economically important parasite.

The current study has several limitations that should be considered. While there is weak evidence for a relationship between within-herd seroprevalence and abortion rate within a household, it should be noted that these seroprevalence estimates are based on a maximum sample of 10 animals per household. Estimates of within-household seroprevalence are therefore based on small sample sizes and associated with very low precision. Additionally, these data are likely to be strongly influenced by recall bias. This is likely to be a particular issue for abortions associated with *N. caninum*, which tend to occur in the second trimester and may therefore be missed or not recollected by livestock keepers. Cattle breeding in the study area is often unplanned and pregnancy diagnosis rare, hence it is likely that only a proportion of abortions will be noticed and reported by participating farmers.

Data collection followed a central point procedure in which farmers were invited to attend the sampling event and which may therefore have introduced selection bias: any farmer who did not attend was not included in the sample. This was reduced as much as possible by running several sampling events at different points within the same village and by linking sampling with village-level disease control to incentivize attendance. Finally, while the focus of this study was on cattle, there is growing evidence that sheep and goats can be affected by neosporosis (Gazzonis *et al.*, 2016; González-Warleta *et al.*, 2014, 2018; Liu *et al.*, 2015; Nie *et al.*, 2018). Since the majority of cattle-keeping households in rural Tanzania also keep small ruminants, and the majority of these are freely grazed on communal grazing lands, there is a

great need for future studies in the country to incorporate sheep and goats into assessments of the epidemiology and impacts of *N. caninum*.

Importantly, this study describes for the first time the economic burden of livestock abortions in livestock keeping households in northern Tanzania as well the community. Livestock abortions lead to financial losses to livestock keeping communities and hamper the potential of the sector. The losses due to abortions comprise of the loss of the expected benefits of the lost animal which include milk as well as costs accrued during the husbandry of the abortive animal. A drop in milk offtake associated with abortion was observed, as indicated by  $\Delta M(F = 1) < 0$  (Table 2). This observation is consistent with previous research that noted a drop in milk production in animals that had a new or repeating abortion (Keshavarzi *et al.*, 2020b). In addition to reported milk yield decline, about 30% of households surveyed reported that they do not use milk from an animal that had an abortion. Reasons for this are not investigated in the present study but the speculation is that it may be because of the perceived harm to consumers that might occur from consuming or selling milk that might contain abortigenic pathogens (Infonet Biovision, 2022).

In this study it was observed the value of milk lost due to an abortions, the difference in milk offtake following an abortion compared to a successful birth was considerably higher in non-local breeds of cattle and small stock. This is most likely because of the higher milk productivity of non-local breeds of livestock compared to the local breeds. Gross and net abortion losses are generally larger for nonlocal (hybrid and exotic) stock because they are more valuable in the marketplace, produce more milk, and based on data from the current study, nonlocal cattle suffer higher abortion rates (although the small stock local breed abortion rate is larger than the small stock nonlocal rate in the control arm data). For example, if a household uses milk from a cow after an abortion, estimated gross abortion loss per abortion for local and nonlocal cattle are TZS 345 807 (\$ 150.35) and TZS 1 070 751 (\$ 465.54; data row 6 in Table 13, rounded to the nearest 1000 TZS and 1 \$). For local and nonlocal small stock, gross loss per abortion is TZS 53 028 (\$ 23.06) and TZS 161 148 (\$ 70.06) for local and nonlocal small stock, respectively, if milk is used.

If a household chooses not to use milk after an abortion, estimated gross abortion losses are higher, illustrating the importance of milk in the livestock breeding enterprise. For example, a household faces a gross loss from one nonlocal cattle abortion of TZS 1 714 686 (\$ 745.52), compared to the loss shown above of TZS 1 070 751 (\$ 465.54) if milk is utilized after an

abortion (Table 13 data row 8; this comparison assumes that milk is not different in quality and or market value after an abortion than before). Netting out the implicit husbandry costs associated with reproduction, the net abortion losses are lower than gross losses. If a household chooses not to use milk after an abortion, net abortion loss is an estimated TZS 519 222 (\$ 225.75) and TZS 1 417 741 (\$ 616.41) for local and nonlocal cattle, and TZS 199 854 (\$86.89) and TZS 277 645 (\$ 120.72) for local and nonlocal small stock, respectively.

The small value on the local small stock estimate follows from the combination of a low market value of pregnancy in small stock (from the regressions shown in Table 9), a relatively high abortion rate, and the (as with the rest) assumed cost share  $\rho$ . Note that the estimated net loss for local small stock is negative if a household chooses to use milk after a sheep or goat abortion (TZS -29 983; \$ -13.04, based on  $\rho = 0.25$ ). Net losses for local small stock abortions turns positive if  $\rho$  is more than less than 0.1627 (newborn costs less than 16.27% of all husbandry costs). More generally, a larger newborn share of husbandry costs is associated with lower net abortion loss. The negative sign on net loss for  $\rho > 0.1627$  suggests that when the share of newborn husbandry costs is sufficiently high, abortions are financially beneficial because the household receives milk offtake without net negative costs of newborn husbandry. Regardless, without additional data there is little basis for knowing  $\rho$ .

This study provides estimates of aggregate losses for northern Tanzania and for Tanzania as a whole, including metrics that relate abortion losses to the scale of the livestock industry in these regions. Table 14 summarizes the non-monetary data and calculations for the three regions of northern Tanzania in which the study data were collected, including pregnancy and abortion rates, the number of reproductive females, pregnancies, and births, and estimated number of abortions. Values for northern Tanzania and for all Tanzania were calculated in the same way: They were calculated for each region, then depending on the metric either summed or averaged over the applicable regions.

Abortion rates  $\alpha$  and pregnancy rates  $g$  were calculated from the study control group. Because pregnancy rates hover just under 50% for all stock types, abortions per reproductive-aged animal are approximately half of the abortion rates and range from just under 4% (for local cattle) to about 14% (for local small stock). To make full potential use of the Census data (which is based on a much larger sample than the trial data), the pregnancy estimates were scaled to be consistent with the Census data on the number of animals born. These numbers indicate that there were approximately 1.6 million cattle pregnancies and 3 million small stock

pregnancies in northern Tanzania over 12 months. Based on these numbers, 106 788 cattle abortions and about 594 676 small stock abortions were estimated, most in local stock due to the larger numbers of pregnancies in local animals.

Higher market premiums for pregnant animals are associated with higher net losses because higher premiums imply a higher net value of successful birth, all else constant. Aggregate losses vary inversely to the price of milk ( $P_m$ ) and the price of newborns ( $P_c$ ), but are more responsive to differences in the price of milk gross losses increase by about 6% with a 10% increase in the price of milk. Differences in the assumed discount rate affect results very little due to the short duration of intertemporal effects. More details are provided along in the Table 17.

The sensitivity analysis indicates that the aggregate results are influenced by input measurement errors, such as recall bias, in proportion to their magnitude. As with most recall-based studies, the data are subject to bias, with herd owners potentially remembering more significant or costly abortion events such as those involving valuable non-local cattle while overlooking less impactful ones, like abortions in low-value local small stock. Sampling error is also a concern due to the relatively small sample size, and the nature of the simulation limits the ability to generate credible confidence intervals for most estimates. Additionally, since the model and data are based on northern Tanzania, extrapolating the results to other regions may introduce unknown inaccuracies. Another limitation is the uncertainty surrounding the proportion of husbandry costs attributed to newborns ( $\rho$ ). Some parameter ranges suggest abortions could yield net positive outcomes, which, while not impossible, is unlikely in this context even if pregnancy benefits are largely derived from milk production.

Across the three study regions of northern Tanzania, 106 788 cattle and 594 676 small ruminant abortions were estimated imposing a gross and net annual economic loss of \$60 Million (TZS 138 billion) and \$28.3 million (TZS 56.1 billion), respectively. Findings from the current study indicate that aggregate gross losses are dominated by local stock losses, which comprise about 89% of northern Tanzania losses (\$52.8million of 59.5 million USD) and 92.1% in all of Tanzania. Similarly, net losses comprise about 88% local breeds for northern Tanzania and 90% for all of Tanzania. This is in large part due to the large proportion of all stock value that local breeds represent. Small stock losses represent about 59% and 54% of gross losses in northern and all of Tanzania, respectively, and about 37% and 31% of net losses in northern and all of Tanzania, respectively.

For all of Tanzania approximately 575 320 cattle abortions and 2.4 million small ruminant abortions were estimated. For context, the value of all reproductive-aged female stock (cattle and small stock, local and non-local combined) is worth approximately \$ 687 million in northern Tanzania and \$1.8 billion for all of Tanzania. Gross abortion losses of an estimated \$ 59.5 million average about 9% of the value of reproductive females in northern Tanzania regions. Estimated gross losses summing to about \$ 263 million averages 15% of the value of all reproductive female stock for all regions of Tanzania as well. Net losses amount to \$ 28 million and \$ 130 million, or 4% and 7% of the value of reproductive females for northern and all of Tanzania. Juvenile stocks are worth about \$238 million in Northern Tanzania and \$1 billion in all of Tanzania. Gross loss and net losses amount to about 26% and 13%, respectively of the value of all juvenile stock for the north and for all Tanzania. Thus, gross losses are a bit under one quarter of all live juvenile value and net losses just under one sixth.

The overall net loss estimates due to abortion in livestock in Tanzania of \$131 million are about one-third of annual national loss due to Tick Born Diseases (TBD) estimated at \$364 million by Kivaria (2006). Foot and mouth disease was estimated to cause annual burden ranging between \$351 000 and \$531 000 (Häsler *et al.*, 2021), mastitis was estimated to cause \$4700 with an estimated loss of \$21.5 per quarter (Komba & Kashoma, 2020) and PPR was estimated to cause direct economic loss of \$19.1 million in sheep and goats in one region of Kenya (Kihu *et al.*, 2015).

Finally, the analysis from the current study is based on *observed* abortions. Because many abortive pregnancies may go unnoticed by herd owners, the total number of abortions (observed plus unobserved) could be substantially higher than the estimates presented. For example, observed livestock abortions are estimated to account for between 20% and 30% of all cases (Bronner *et al.*, 2013b). While an estimate of the unobserved abortions for Tanzania is not available, the implication is that total abortions are almost certainly higher than the presented estimates, which should be interpreted as an estimate of observed abortions, not total abortions.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

The aims of the present study were to: (a) Explore the current status of ruminant abortigenic agents' surveillance in Asia, Africa and Tanzania, (b) Determine the seroprevalence of *N. caninum*, (c) Determine the associated risk factors and association with abortions in Tanzania and (d) Quantify the direct economic losses resulting from livestock abortions to the livestock owners as no reported values are available for northern Tanzania. The conducted systematic literature search revealed that the most important abortigenic pathogens in African and Asian cattle, goats and sheep. Furthermore, the conducted systematic literature search for surveillance systems for livestock abortigenic pathogens in many African and Asian countries revealed that there are no optimal surveillance systems with the exception of few countries which reported to have national surveillance programs. The African and Asian regions have the the highest rate of growth in surveillance systems using mHealth technology in human medicine. With *N. caninum* seroprevalence, an overall seropositivity of 21.5% was detected among apparently healthy cattle in northern Tanzania. The risk factors for the *N. caninum* seropositivity were cattle population density, age of cattle and forest and shrub cover. The present study also found a significant relationship between within-herd seroprevalence and herd-level abortion rates, suggesting that the control of *N. caninum* could contribute to reduced reproductive losses among cattle in the region. Finally, the present study provides evidence of the economic burden of livestock abortion in livestock keeping households in northern Tanzania as well at the national level. It was also observed that a drop in milk offtake was associated with abortion.

#### 5.2 Recommendations

The current status of livestock abortion surveillance in Africa is not optimal. Most African countries have no surveillance platforms in place for abortigenic pathogens. Near real-time active surveillance platforms coupled with qualified response teams may assist in the detection of abortigenic pathogens through providing a timely alerting and appropriate interventions.

Livestock abortigenic pathogens are still prevalent in northern Tanzania with a case study of *N. caninum*. Evidence of relationships between livestock seropositivity and shrub and forest habitats may suggest a role for wildlife in the epidemiology of *N. caninum* in Tanzania. This

would be a valuable area for future studies aimed at controlling the pathogen through controlled interaction between wild infection, suggesting contamination of communal grazing areas may be an important source of infection. These findings suggest the need for more education to the community regarding better livestock husbandry practices in Tanzania especially in the pastoral and agro-pastoral systems. Further work to explore the effect of production system on *N. caninum* risk in Tanzania, including better control for the range of livestock production systems that exist in the region, would be valuable as the current study used only serology. Attribution studies are also recommended for further association between *N. caninum* and risk factors abortion events.

Abortigenic pathogens need to be given more attention as they lead to large economic losses to the livestock owning households as well as the country. Livestock abortions cause annual economic losses in the order of approximately TZS 300 billion to the livestock industry in Tanzania for cattle and small ruminants combined. Investments that lead to improved control of abortigenic agents, for example through establishment of surveillance systems, strengthening of veterinary services, and improvement of access and uptake of these services, may reduce the substantial losses that occur due to abortion. These findings suggest that investments that lead to improved control of abortigenic agents, for example through establishment of surveillance systems, strengthening of veterinary services, and improvement of access and uptake of these services, may reduce the substantial losses that occur due to abortion. Lastly, timely dipping to prevent Tick Born Diseases among other diseases as well as vaccination against various abortion-inducing diseases could reduce mortality losses estimated at \$65.2 million up to around \$20 million (Ministry of Livestock and Fisheries, 2022). While the promise of reducing abortion by investing in prevention and pre-abortion animal healthcare generally is substantial, investment in abortion prevention represent an important category of health-related costs that are beyond the scope of this study (Bennett *et al.*, 1999; Surve *et al.*, 2023).

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## APPENDICES

### Appendix 1: Livestock abortion case questionnaire

#### Economic impact of abortion questionnaires (*Dodoso la athari za kiuchumi za utupaji mimba*)

##### Questionnaire 1 – Time point 1(*Dodoso 1 - Alama muda 1*)

1. Investigator name(*Jina la Mtafiti*): \_\_\_\_\_
2. Date of abortion (*Tarehe ya tukio la utupaji mimba*): \_\_\_\_\_
3. Date of Questionnaire (*Tarehe ya kujaza dodoso*): \_\_\_\_\_

#### Household Demographics

4. Household ID no.(*Namba ya Utambulisho ya kaya*) \_\_\_\_\_
5. District (*Wilaya*) \_\_\_\_\_ Ward (*Kata*) \_\_\_\_\_ Village (*Kijiji*) \_\_\_\_\_  
Village (*Kijiji*) \_\_\_\_\_
6. Coordinates of household (*Namba za utambulisho za kijiografia za kaya*)  
Eastings \_\_\_\_\_ Northings \_\_\_\_\_ Elevation \_\_\_\_\_ Wayppoint \_\_\_\_\_
7. What is the head of compound's tribe (*Kabila la mkuu wa kaya ni lipi*)?  
 Arusha  
 Barabaig  
 Chagga  
 Iraqw  
 Pare  
 Maasai  
 Sambaa  
 Other (specify) (*Nyingine (taja)*) \_\_\_\_\_
8. What is the head of compound's highest level of education (*Elimu ya juu zaidi ya mkuu wa kaya ni ipi*)?  
 No formal education(*hana elimu rasmi*)  
 Some primary school(*elimu ya msingi kidogo*)  
 Completed primary school(*amekamilisha elimu ya msingi*)  
 Some secondary school(*elimu ya sekondari kidogo*)  
 Completed secondary school(*amekamilisha elimu ya sekondari*)  
 Post secondary qualifications(*elimu zaidi ya sekondari*)  
 Some university(*elimu ya chuo kikuu kidogo*)  
 University completed(*amekamilisha chuo kikuu*)  
 Post graduate(*elimu ya shahada ya juu*)
9. What type of toilet system do members of this compound use (*Ni aina gani ya mfumo wa choo ambao unatumika kawaida na kaya yako*)?  
 Flush or pour toilet with septic tank, including squat toilet (*Choo cha kuvuta au cha kumwaga maji cha kuchuchumaa na mfumo wa shimo la maji taka*)

- Flush or pour toilet connected to sewer pipe, including squat toilet (*Choo cha maji kilichounganishwa na bomba la maji taka, pamoja na choo cha kuchuchumaa*)
- Pit latrine with covering slab (*Choo cha shimo kilichosakafiwa*)
- Pit latrine without covering slab (*Choo cha shimo bila kusakafiwa*)
- Ventilated improved pit latrine (VIP) (*Choo cha shimo bora chenya bomba la kutoa hewa chafu*)
- Bucket or plastic bags (*Ndoo au mifuko ya plastiki/Rambo*)
- No facilities or field or bush (*Hakuna choo, kwenda porini*)
- Other (specify)/Vingine (taja) \_\_\_\_\_

10. What sources of drinking water does your compound use during the wet or dry season (*Ni chanzo kipi cha maji kaya yako huwa wanatumia wakati wa masika*)?

- Piped water into the home (*Yanayosukumwa kwa bomba mpaka ndani nyumbani*)
- Public/communal well or standpipe (*Kisima au pampu ya jumuiia*)
- River or creek (moving water) directly (*Moja kwa moja kutoka mto au mfereji (maji yanatotembea)*)
- Lake, pond, dam (standing water) directly (*Moja kwa moja kutoka Ziwa, dimbwi bwawa (maji yaliyosimama)*)
- Private well or pump (*Kisima au pampu ya binafsi*)
- From a spring (*Kutoka katika chemchem*)
- Rainwater (*Maji ya mvua*)
- Tanker truck (*Tanki la gari*)
- Cart of wheelbarrow with small tank or drum (*Mkokoteni na tanki dogo au madumu/pipa*)
- Bottled water (*Maji ya chupa*)
- Other (specify)/Vingine (taja) \_\_\_\_\_

## LIVESTOCK QUESTIONS

### General livestock management questions

#### (Maswali ya usimamizi wa mifugo kwa ujumla)

11. Are any cattle currently kept at this compound (*Je, kuna ng'ombe wowote wanafugwa kwenye boma hili kwa sasa*)?

- Yes (*Ndio*)    No (*Hapana*)

12. What is the total number of cattle that are managed together at this compound (*Kuna jumla ya ng'ombe wangapi wanaotunzwa pamoja katika boma hili*)? ( )

13. Of these ( ) cattle (above), how many are in the following breeds (*Wangapi kati yangombe hawa wako katika jamii zifuatazo*)?:

- Local (*Kienyeji*)( )
- Mixed (*Chotara*)( )
- Exotic (*Kisasa*)( )

14. Of the (NUMBER) cattle, how many are the following types (*Wangapi kati ya ng'ombe hawa ni wa kienyeji*):

- Adult male (*wakubwa wa kiume*) \_\_\_\_\_
- Adult female (*wakubwa wa kike*) \_\_\_\_\_
- Juvenile male (*wadogo wa kiume*) \_\_\_\_\_
- Juvenile female (*wadogo wa kike*) \_\_\_\_\_

15. Are any goats currently kept at this compound (*Je, kuna mbuzi wowote wanafugwa kwenye boma hili kwa sasa*)?

Yes (*Ndio*)  No (*Hapana*)

16. What is the total number of goats that are managed together at this compound (*Kuna jumla ya mbuzi wangapi wanaotunzwa pamoja katika boma hili*)? ( )

17. Of these ( ) goats (above), how many are in the following breeds (*Wangapi kati ya mbuzi hawa wako katika jamii zifuatazo*):

Local (*Kienyeji*)( )

Mixed (*Chotara*)( )

Exotic (*Kisasa*)( )

18. Of the ( ) goats, how many are the following types (*Wangapi kati ya mbuzi hawa ni wa kienyeji*):

Adult male (*wakubwa wa kiume*) \_\_\_\_\_

Adult female (*wakubwa wa kike*) \_\_\_\_\_

Juvenile male (*wadogo wa kiume*) \_\_\_\_\_

Juvenile female (*wadogo wa kike*) \_\_\_\_\_

19. Are any sheep currently kept at this compound (*Je, kuna kondoo wowote wanafugwa kwenye boma hili kwa sasa*)?

Yes (*Ndio*)  No (*Hapana*)

20. What is the total number of sheep that are managed together at this compound (*Kuna jumla ya kondoo wangapi wanaotunzwa pamoja katika boma hili*)? ( )

21. Of these ( ) sheep (above), how many are in the following breeds (*Wangapi kati yakondoo hawa wako katika jamii zifuatazo*):

Local (*Kienyeji*) ( )

Mixed (*Chotara*) ( )

Exotic (*Kisasa*) ( )

22. Of the ( ) sheep, how many are the following types (*Wangapi kati ya kondoo hawa ni wa kienyeji*):

Adult male (*wakubwa wa kiume*) \_\_\_\_\_

Adult female (*wakubwa wa kike*) \_\_\_\_\_

Juvenile male (*wadogo wa kiume*) \_\_\_\_\_

Juvenile female (*wadogo wa kike*) \_\_\_\_\_

23. How are cattle in this compound grazed during the wet and dry season (*Unawalishaje ng'ombe wa boma hili kipindi cha mvua na kiangazi*)?

Free ranging (*Wanajichunga wenyewe*):

Dry (*Kiangazi*)

Wet (*Masika*)

Both wet and dry seasons (*Vipindi vyote*)

Kiangazi na masika

Neither (*Si kipindi chochote*)

Herded on communal land (*Wanachungwa kwenye ardhi ya jumuiya*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Grazed on land used exclusively by the household only (*Wanachungwa kwenye ardhi ya kaya tu*): :

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Tethered (*Wanaofungwa*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Zero grazed (*Hawachungwi*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

24. How are goats in this compound grazed during the wet and dry season (*Unawalishaje mbuzi wa boma hili kipindi cha mvua na kiangazi*)?

Free ranging (*Wanajichunga wenyewe*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Herded on communal land (*Wanachungwa kwenye ardhi ya jumuiya*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Grazed on land used exclusively by the household only (*Wanachungwa kwenye ardhi ya kaya tu*): :

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Tethered (*Wanaofungwa*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Zero grazed (*Hawachungwi*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

25. How are sheep in this compound grazed during the wet and dry season (*Unawalishaje kondoo wa boma hili kipindi cha mvua na kiangazi*)?

Free ranging (*Wanajichunga wenyewe*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Herded on communal land (*Wanachungwa kwenye ardhi ya jumuiya*):

Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Grazed on land used exclusively by the household only (*Wanachungwa kwenye ardhi ya kaya tu*): :

- Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Tethered (*Wanaofungwa*):

- Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

Zero grazed (*Hawachungwi*):

- Dry (*Kiangazi*)  Wet (*Masika*)  Both wet and dry seasons (*Vipindi vyote Kiangazi na masika*)  
 Neither (*Si kipindi chochote*)

26. Which of the following best describes the way you manage the herding of animals in this compound (*Ipi kati yafuatayo inaeleza vizuri jinsi unavyotunza kundi la wanyama katika boma hili*):

- Cattle, sheep and goats together (*ng'ombe, kondoo, na mbuzi pamoja*)  
 Cattle separately, sheep and goats together (*ng'ombe pekee yao, kondoo na mbuzi pamoja*)  
 Cattle with goats, sheep separately (*ng'ombe na mbuzi, kondoo pekee yao*)  
 Cattle with sheep, goats separately (*ng'ombe na kondoo, mbuzi pekee yao*)  
 All species separately (*Kila aina inachungwa tofauti*)  
 Other (*Nyinginezo*) \_\_\_\_\_

27. Which of the following best describes the way you manage animals at night in this household (*Ipi kati ya yafutatayo inaeleza vizuri jinsi unavyotunza wanyama wako katika kaya hii wakati wa usiku*):

- Cattle, sheep and goats together (*ng'ombe, kondoo, na mbuzi pamoja*)  
 Cattle separately, sheep and goats together (*ng'ombe pekee yao, kondoo na mbuzi pamoja*)  
 Cattle with goats, sheep separately (*ng'ombe na mbuzi, kondoo pekee yao*)  
 Cattle with sheep, goats separately (*ng'ombe na kondoo, mbuzi pekee yao*)  
 All species separately (*Kila aina inachungwa tofauti*)  
 Other (*Nyinginezo*) \_\_\_\_\_

### CASE INFORMATION

28. What species was the abortion/still birth in (*Ni aina gani ya wanyama walipata kutupa mimba/kuzaa vichanga wafu*)?

- Cattle (*Ngombe*)  
 Sheep (*Kondoo*)  
 Goat (*Mbuzi*)

29. What breed is the dam (*Mnyama alikuwa wa jamii gani*)?

- Local (*Kienyeji*)  
 Mixed (*Chotara*)  
 Exotic (*Kisasa*)

30. What was the sex of the aborted/still born calf/kid/lamb (*Nini ilikuwa jinsia ya ndama/mwana mbuzi/mwana kondoo ambaye mimba imetupwa/kichanga mfuu aliyezaliwa*)?
- Male (*Dume*)  
 Female (*Jike*)  
 Unknown (*Haijulikani*)
31. Will you purchase an animal to replace the aborted/still born animal you expected to have (*Je utanunua mnyama wakuchukuwa nafasi ya mimba iliyotupwa/ kichanga mfu aliyezaliwa ambaye ulitegemea kumpata*)?
- Yes (*Ndio*)       No (*Hapana*)       I don't know yet (*sijui kwa sasa*)
32. If yes to the question above, when will you purchase the replacement (*Kama ndio kwa swali la hapo juu, lini utanunua mnyama mbadala*)?
- Within the next week (*ndani ya wiki ijayo*)  
 Within next month (*ndani ya mwezi ujao*)  
 I don't know (*sijui*)  
 Other (specify) (*Nyingine (taja)*) \_\_\_\_\_
33. What were you planning to do with this calf/kid if it had been a male (*Kama jinsia ya ndama/kichanga mfuu aliyezaliwa ilikuwahaijulikani, ulikuwa unapanga kufanya nini na huyu ndama/mwana mbuzi kama angekuwa dume*)?
- Sell after weaning (*Uza baada ya kuacha kunyonya*)  
 Keep in herd (*Tunza kwenye kundi*)  
 Give it away (*Gawa*)  
 Lend it to another family (*Azimisha kwa familia nyingine*)  
 Other (specify) (*Nyingine (taja)*) \_\_\_\_\_
34. What were you planning to do with this calf/kid if it had been a female (*Kama jinsia ya ndama/kichanga kilichozaliwa mfuu haijulikani, nini ulikuwa umepanga kufanya na huyu ndama/mwana mbuzi kama angekuwa jike*)?
- Sell after weaning (*Uza baada ya kuacha kunyonya*)  
 Keep in herd (*Tunza kwenye kundi*)  
 Give it away (*Gawa*)  
 Lend it to another family (*Azimisha kwa familia nyingine*)  
 Other (specify) (*Nyingine (taja)*) \_\_\_\_\_
35. Has this dam aborted before (*Huyujike alishawai kutupa mimba hapo awali*)?
- Yes (*Ndio*)       No (*Hapana*)       I don't know (*sijui*)
36. Has this dam had a stillbirth before (*Je huyu jike alishawai kabla kupata kichanga kilichozaliwa mfuu*)?

- Yes (*Ndio*)       No (*Hapana*)

37. What will you do with the dam (*Utafanya nini na huyu jike*)?

- Keep the dam and breed from her again (*Mtunza jike na kumzalisha tena*)  
 Sell alive to another herd owner (*Uza akiwa hai kwa mmiliki wa kundi lingine*)  Sell at market (*Uza kwenye soko*)  
 Slaughter and sell meat – if yes, in how many months time? (*Chinja na kuuza nyama-kama ndio, katika muda gani wa mwezi*)? \_\_\_\_\_  
 Slaughter for home consumption. If yes, in how many months time? (*Chinja kwa ajili ya kula nyumbani. Kama ndio, katika muda gani wa mwezi*)? \_\_\_\_\_  
 Give it away. If yes, in how many months time (*Gawa. Kama ndio, katika muda gani wa mwezi*)? \_\_\_\_\_  
 Other (specify) (*Nyingine (taja)*) \_\_\_\_\_

38. If the answer to the above question was “Keep the dam and breed from her again”, how long will you wait before you mate her (*Kama jibu la swali la juu ni “kutunza jike na kumzalisha”, utasubiri muda gani kabla hajapandwa*)?

- We will breed her again as soon as possible (*Tutamzalisha tena haraka iwezenavyo*)  
 We will breed from her in (*Tutamzalisha tena ndani ya*) \_\_\_\_\_ months (*miezi*)  
 I don't know (*sijui*)

39. Compared to if the calf/kid had survived, what do you expect will happen to the milk yield available to the family or to sell that this dam will produce (*Ikilinganishwa na kama ndama/mwana mbuzi aliishi, nini unatarajia kitatokea kwenye upatikinaji wa maziwa yanayotoka kwa huyu jike kwa familia/ kwa kuuza*)?

- The milk yield will be the same as if the dam did not abort/still birth (*Utoaji wa maziwa utakuwa sawa kama vile jike hakutupa mimba/kuzaa kichanga mfuu*)  
 Milk yield will be reduced by (*Utoaji maziwa utapunguwa kwa*) \_\_\_\_\_ litres/day (*lita/siku*)  
 Milk yield will be increased by (*Utoaji maziwa utaongezeka kwa*) \_\_\_\_\_ litres/day (*lita/siku*)  
 We don't use/sell the milk (*Hatutumi maziwa*)  I don't know (*sijui*)

#### **BREEDING**

40. How was service of livestock done in this compound in the past 12 months (*Huduma yaupandishaji wa mifugo ilitolewa namna gani katika kundi lako kwa miezi 12 uliopita*)?

Question	Cattle	Sheep	Goats
Males from own herd ( <i>Madume (dume) kutoka kundi lako</i> )			
Males hired ( <i>Madume (dume) wakukodisha</i> )			
Males borrowed ( <i>Madume (dume) ya kuazima</i> )			
Males from other herds during grazing/watering ( <i>Madume</i>			

<i>kutoka makundi mengine wakati wa malisho / kunywa maji)</i>			
Artificial insemination (Uzalishaji kwa chupa)			
Females taken elsewhere (Jike lilipelekwa kwingine)			
No service performed in past 12 months (Hatukupandisha katika miezi 12 iliyopita)			
Species not owned or service not performed (Mifugo usiyonayo au huduma ya kupandisha haikufanyika)			
Other specify (Nyinginezo taja)			

41. Have you identified infertile male or female livestock in this compound in the past 12 months (*Je, umegunduwa mfugo wowote dume au jike amaybe ni tasa katika boma hili miezi 12 iliyopita (ikihusisha boma lako)*)?  
 Yes (*Ndio*)                       No (*Hapana*)
42. How many male cattle have been identified as infertile in the past 12 months (*Nimadume mangapi ya ng'ombe wa kundi la kaya yako wamegundulika kuwa tasa miezi 12 iliyopita*)?  
( )
43. How many female cattle have been identified as infertile in the past 12 months (*Nimajike mangapi ya ng'ombe wa kundi la kaya yako wamegundulika kuwa tasa miezi 12 iliyopita*)?  
( )
44. How many male goats have been identified as infertile in the past 12 months (*Nimadume mangapi ya mbuzi wa kundi la kaya yako wamegundulika kuwa tasa miezi 12 iliyopita*)?  
( )
45. How many female goats have been identified as infertile in the past 12 months (*Nimajike mangapi ya mbuzi wa kundi la kaya yako wamegundulika kuwa tasa miezi 12 iliyopita*)?  
( )
46. How many male sheep have been identified as infertile in the past 12 months (*Nimadume mangapi ya kondoo wa kundi la kaya yako wamegundulika kuwa tasa miezi 12 iliyopita*)?  
( )
47. How many female sheep have been identified as infertile in the past 12 months (*Nimajike mangapi ya kondoo wa kundi la kaya yako wamegundulika kuwa tasa miezi 12 iliyopita*)?  
( )
48. What actions do you take when you discover an animal is infertile (*Unachukua hatuagani kwa kawaida wakati mnyama ni tasa*)?

Question	Cattle	Sheep	Goats
Send animal for slaughter ( <i>Kuchinja</i> )			
Sell animal ( <i>Kuuza</i> )			
Give animal away ( <i>Kumgawa</i> )			
Get advice/treatment from outside household ( <i>Ushauri au matibabu yanatafutwa nje ya kaya</i> )			
Treat the animal myself ( <i>Kutibu mnyama mwenyewe</i> )			
Never owned or had infertility in this species( <i>Sijawahi kumiliki au kutokuwa na ujingakatika aina hii</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			
Nothing( <i>Kinachofanyika- wanyama walioadhirika wanatunzwa kama wengine</i> )			

49. Do you think you would be more likely to sell animals that you know are infertile than those that are not (*Je, unafikiri kuna uwezekano mkubwa kuuza wanyama ambayo ni tasa kulikowale ambao sio tasa*)?

- Cattle (*Ng'ombe*)
- Goats (*Mbuzi*)
- Sheep (*Kondoo*)

50. Do you think you would be more likely to slaughter animals that you know are infertile (*Je, unafikiri kuna uwezekano mkubwa kuchinja wanyama ambayo ni tasa kuliko wale ambao sio tasa*)?

- Cattle (*Ng'ombe*)
- Goats (*Mbuzi*)
- Sheep (*Kondoo*)

51. Who do you normally go to for advice/treatment when an animal in your herd is infertile (*Kwa kawaida unakwenda kwa nani kupata ushauri/matibabu wakati mnyama wako ni tasa*)?

- Neighbour (*Jirani*)
- Paravet (*Daktari msaidizi wa mifugo*)
- Veterinarian (*Daktari wa mifugo*)
- Animal health assistant (*Bwana afya msaidizi wa mifugo*)
- Agroveter (*Bwana kilimo na mifugo*)
- Traditional healer (*Mganga wa jadi*)
- Spiritual/faith healer (*Imani/mponyaji wa imani*)

- Local livestock expert (*Mtaalamu wa mifugo wa hapahapa*)  
 Other (*Nyinginezo*) \_\_\_\_\_

52. In the past 12 months, how many livestock owned by this compound were born in the following places (*Je, indani wa miezi 12 iliyopita, mifugo wanao milikiwa na boma hili wamezaliwa wapi*)?

Question	Cattle	Sheep	Goats
In a (human) house in this compound ( <i>Ndani ya nyumba (ya binadamu) kwenye boma hili</i> )			
In the compound (outside a house) ( <i>Ndani ya boma (nje ya nyumba)</i> )			
Outside the compound in this village ( <i>Nje ya kaya ndani ya kijiji</i> )			
Outside the compound in a different village ( <i>Nje ya boma katika kijiji kingine</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			

53. Do cattle that have just given birth usually get separated from the main herd (*Je, n'gombe ambao wamezaa wanatenganisha na kundi/wanyama wengine*)?

- Yes (*Ndio*)                       No (*Hapana*)

54. For how many days (*Kwa siku ngapi*)( )

55. Do goats that have just given birth usually get separated from the main herd (*Je, mbuzi ambao wamezaa wanatenganisha na kundi/wanyama wengine*)?

- Yes (*Ndio*)                       No (*Hapana*)

56. For how many days (*Kwa siku ngapi*)( )

57. Do sheep that have just given birth usually get separated from the main herd (*Je, kondoo ambao wamezaa wanatenganisha na kundi/wanyama wengine*)?

- Yes (*Ndio*)                       No (*Hapana*)

58. For how many days (*Kwa siku ngapi*)( )

59. What normally happens to the placenta and foetal membranes after one of your animals (sheep, cattle, or goats) gives birth (*Kwa kawaida inakuwaje kwa kondo la nyuma baada yamojawapo ya wanyama wako (ng'ombe, mbuzi, au kondoo) wanapozaa*)?

- Nothing, material left (*Hakuna – viliachwa*)  
 Eaten by family (*Vililiwa na wakazi katika familia*)

- Buried (*Vilifukiwa (zikwa)*)
- Burned (*Vilichomwa*)
- Given to dogs (*Vilipewa mbwa vikiwa vibichi*)
- Thrown in bush (*Vilitupwa porini*)
- Other (*Nyinginezo*) \_\_\_\_\_

60. How many cattle in this compound have aborted or delivered still born offspring in the past 12 months (*Ni ng'ombe wangapi katika kaya yako wametupa mimba au kuzaa mtoto mfukatika miezi 12 iliyopita*)? ( )

61. How many goats in this compound have aborted or delivered still born offspring in the past 12 months (*Ni mbuzi wangapi katika kaya yako wametupa mimba au kuzaa mtoto mfukatika miezi 12 iliyopita*)? ( )

62. How many sheep in this compound have aborted or delivered still born offspring in the past 12 months (*Ni kondoo wangapi katika kaya yako wametupa mimba au kuzaa mtoto mfukatika miezi 12 iliyopita*)? ( )

63. What normally happens to the foetus, placenta and/or membranes after one of your livestock has an abortion or stillbirth (*Kwa kawaida inakuwaje kwa kichanga, kondo lanyuma baada ya moja ya mifugo wako kutupa mimba au kuzaa mtoto mfu*)?

- Nothing, material left (*Hakuna – viliachwa*)
- Eaten by family (*Vililiwa na wakazi katika familia*)
- Buried (*Vilifukiwa (zikwa)*)
- Burned (*Vilichomwa*)
- Given to dogs (*Vilipewa mbwa vikiwa vibichi*)
- Thrown in bush (*Vilitupwa porini*)
- Other (*Nyinginezo*) \_\_\_\_\_

64. What do you normally do with an animal after it has an abortion (*Kwa kawaida unachukuwa hatua gani kwa mnyama baada ya kutupa mimba*)?

Question	Cattle	Sheep	Goats
Separate animal from herd for <24 hours ( <i>Namtenganisha mnyama kutoka kundini kwa muda usiofika masaa 24</i> )			
Separate animal from herd for >24 hours ( <i>Namtenganisha mnyama kutoka kundini kwa zaidi ya masaa 24</i> )			
Send animal for slaughter ( <i>Namchinja mnyama</i> )			
Sell animal ( <i>Namuuzua mnyama</i> )			

Give animal away( <i>Namgawa mnyama</i> )			
Get advice/treatment from outside household( <i>Natafuta ushauri/ matibabu nje ya kaya</i> )			
Treat the animal myself( <i>Namtibia mnyama mimi mwenyewe</i> )			
Never owned or had an abortion in this species( <i>Sijawahi kumiliki au kupata tukio la kutupa mimba katika mifugo hawa</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			
Nothing( <i>Sifanyi kitu</i> )			

65. Have you ever had a case of retained fetal membranes in livestock kept in this compound (*Je, kulishawai kuwa na matukio ya kondo la nyuma kuacha kutoka katika mifugo inayotunzwa katika boma hili (ikihusisha kaya yako)*)?

Yes (*Ndio*)

No (*Hapana*)

66. How many cattle in this compound have had a case of retained fetal membrane in the past 12 months (*Ni ng'ombe wangapi wa kundi la kaya yako wamepata matukio ya kondo lanyuma kuacha kutoka katika miezi 12 iliyopita*)? \_\_\_\_\_

67. How many goats in this compound have had a case of retained fetal membrane in the past 12 months (*Ni miezi mingapi iliyopita mara ya mwisho kuwepo tukio la kondo la nyumakuacha kutoka katika kundi la mbuzi wa kaya hii*)? \_\_\_\_\_

68. How many sheep in this compound have had a case of retained fetal membrane in the past 12 months (*Ni kondoo wangapi wa kundi la kaya yako wamepata matukio ya kondo lanyuma kuacha kutoka katika miezi 12 iliyopita*)? ( )

69. What actions do you take when an animal has a retained FOETAL MEMBRANES (*Je, unachukua hatuagani kama mnyama akishindwa kutoa kondo la nyuma*)?

Question	Cattle	Sheep	Goats
Separate animal from herd for <24 hours( <i>Namtenganisha mnyama kutoka kundini kwa muda usiofika masaa 24</i> )			
Separate animal from herd for >24 hours( <i>Namtenganisha mnyama kutoka kundini kwa zaidi ya masaa 24</i> )			
Send animal for slaughter( <i>Namchinja mnyama</i> )			
Sell animal( <i>Namuuza mnyama</i> )			
Give animal away( <i>Namgawa mnyama</i> )			
Get advice/treatment from outside household( <i>Natafuta ushauri/ matibabu nje ya kaya</i> )			
Treat the animal myself( <i>Namtibia mnyama mimi mwenyewe</i> )			
Never owned or had an abortion in this species( <i>Sijawahi kumiliki au kupata tukio la kutupa mimba katika mifugo hawa</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			
Nothing( <i>Sifanyi kitu</i> )			

70. Who do you normally go to for advice/treatment when your animal has a retained FOETAL MEMBRANES (*Kwa kawaida unakwenda kwa nani kupata ushauri/matibabu wakati mnyama wakoameshindwa kutoa kondo la nyuma*)?

- Neighbour (*Jirani*)
- Paravet (*Daktari msaidizi wa mifugo*)
- Veterinarian (*Daktari wa mifugo*)
- Animal health assistant (*Bwana afya msaidizi wa mifugo*)
- Agroveter (*Bwana kilimo wa mifugo*)
- Traditional healer (*Mganga wa jadi*)
- Spiritual/faith healer (*Imani/mponyaji wa imani*)
- Local livestock expert (*Mtaalamu wa mifugo wa hapahapa*)
- Other (*Nyinginezo*) \_\_\_\_\_



- ECF If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Ndigana kali*) [ ]
- LSD If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Ugonjwa wa mapele*) [ ]
- RVF If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Homa ya bonde la ufa*) [ ]
- Other If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Nyingine*) [ ]
- 

77. Do you take any precautions to prevent abortion/foetal loss/perinatal death in SHEEP (*Je unachukuwa tahadhari yoyote kuzuia kutupa mimba/ kupoteza kichanga/kufa vichanga*)?

- Yes (*Ndio*)       No (*Hapana*)       I don't know (*sijui*)

78. If yes (to above), what precautions do you take (*Kama ndio (hapo juu) tahadhari gani unachukua*)?

- Vaccinate my animals (*Chanja wanyama wangu*)
- Purchase new stock from herds that have no history of abortion (*Nunua kundi jipya kutoka kundi ambalo halina historia ya kutupa mimba*)
- Treat animals with antibiotics during pregnancy (*Tibu wanyama na antibiotic wakati wa ujauzito*)
- Treat animal with herbal medicine during pregnancy (*Tibu mnyama na dawa za asili wakati wa ujauzito*)
- Provide additional feeding during pregnancy (*Mpa chakula cha ziada wakati wa ujauzito*)
- Provide supplements during pregnancy (*Mpa jalizo wakati wa ujauzito*)
- Separate animals that have aborted from the rest of the herd/flock (*Tenganisha wanyama waliotupa mimba na kundi lililosalia*)
- Other (*Nyingine*) \_\_\_\_\_

79. If answer is vaccinate to the Q78 above, What diseases do you vaccinate your sheep against (*Unachanja kondoo/mbuzi wako dhidi ya magonjwa gani*)?

- PPR If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Mapafu kwa ngombe*) [ ]
- Anthrax If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Kimeta*) [ ]
- BQT If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Chambavu*) [ ]
- FMD If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Ugonjwa miguu na midomo*) [ ]
- Sheep/goat pox If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Ndui*) [ ]
- RVF If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Homa ya bonde la ufa*) [ ]
- Other If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Nyingine*) [ ]
- 

80. Do you take any precautions to prevent abortion/foetal loss/perinatal death in GOATS (*Je unachukuwa tahadhari yoyote kuzuia kutupa mimba/ kupoteza kichanga/kufa vichanga*)?



Animal health assistant ( <i>Bwana afya msaidizi wa mifugo</i> )			
Agrovet ( <i>Bwana kilimo na mifugo</i> )			
Traditional healer ( <i>Mganga wa jadi</i> )			
Spiritual/faith healer ( <i>Imani/mponyaji wa imani</i> )			
Local livestock expert ( <i>Mtaalamu wa mifugo wa hapahapa</i> )			
Other ( <i>Nyinginezo</i> )			

### ANIMAL ILLNESS

85. Have any cattle been unwell in the last 12 months(*Kuna ng'ombe yeyote amekuwa mgonjwa ndani ya miezi 12 iliyopita*)?

Yes (*Ndio*)       No (*Hapana*)

86. How many cattle were unwell in the last 12 months but did not die (*Ng'ombe wangapi waliathirika*)? ( )

87. How many cattle of each category have been unwell in the last 12 months but did not die(*Rika lipi liliathirika*)?

Local (*Kienyeji*)

Mixed  
Chotara)

Exotic (*Kisasa*)

Adult male (*wakubwa wa kiume*)

Adult female (*wakubwa wa kike*)

Juvenile male (*wadogo wa kiume*)

Juvenile female (*wadogo wa kike*)

88. What signs did you observe(*dalili gani ulizona*)?

Milk drop (*upungufu wa maziwa*)

Staring coat

Regurgitation(*kucheua*)

Diarrhoea(*Kuharisha*)

Nasal discharge

Coughing(*Kukohoa*)

Listlessness

Recumbancy

Abdominal pain(*maumivu ya tumbo*)

Jaundice(*manjano*)

Inappetance

Lameness(*ulemavu*)

- Weight loss (*kupungua uzito*)
- Other specify/ (*zingine taja*)

89. Have any goats been unwell in the last 12 months (*Kuna mbuzi yeyote amekuwa mgonjwa ndani ya miezi 12 iliyopita*)?

- Yes (*Ndio*)       No (*Hapana*)

90. How many goats were unwell in the last 12 months but did not die (*Ng'ombe wangapi waliathirika*)? ( )

91. how many goats of each category have been unwell in the last 12 months but did not die (*Rika lipi liliathirika*)?

	Local ( <i>Kienyeji</i> )	Mixed <i>Chotara</i> )	Exotic ( <i>Kisasa</i> )
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Adult male (*wakubwa wa kiume*)

Adult female (*wakubwa wa kike*)

Juvenile male (*wadogo wa kiume*)

Juvenile female (*wadogo wa kike*)

92. What signs did you observe (*Uliona dalili gani*)?

- Milk drop (*upungufu wa maziwa*)
- Staring coat
- Regurgitation (*kucheua*)
- Diarrhoea (*Kuharisha*)
- Nasal discharge
- Coughing (*Kukohoa*)
- Listlessness
- Recumbancy
- Abdominal pain (*maumivu ya tumbo*)
- Jaundice (*manjano*)
- Inappetance
- Lameness (*ulemavu*)
- Weight loss (*kupungua uzito*)
- Other specify/ (*zingine taja*)

93. Have any sheep been unwell in the last 12 months (*Kuna kondoo yeyote amekuwa mgonjwa ndani ya miezi 12 iliyopita*)?

- Yes (*Ndio*)       No (*Hapana*)

94. How many sheep were unwell in the last 12 months but did not die (*Ng'ombe wangapi waliathirika*)? ( )

95. How many of each category of sheep have been unwell in the last 12 months but did not die (*Rika lipi liliathirika*)?

	Local ( <i>Kienyeji</i> )	Mixed <i>Chotara</i> )	Exotic ( <i>Kisasa</i> )
--	---------------------------	---------------------------	--------------------------

Adult male (*wakubwa wa kiume*)  
 Adult female (*wakubwa wa kike*)  
 Juvenile male (*wadogo wa kiume*)  
 Juvenile female (*wadogo wa kike*)

96. What signs did you observe (*Uliona dalili gani*)?

- Milk drop (*upungufu wa maziwa*)
- Staring coat
- Regurgitation (*kucheua*)
- Diarrhoea (*Kuharisha*)
- Nasal discharge
- Coughing (*Kukohoa*)
- Listlessness
- Recumbancy
- Abdominal pain (*maumivu ya tumbo*)
- Jaundice (*manjano*)
- Inappetance
- Lameness (*ulemavu*)
- Weight loss (*kupungua uzito*)
- Other specify/ (*zingine taja*)

97. Have any species had joint problems in the past 12 months (*Kuna wanyama wa aina yoyote wamekuwa na matatizo ya viungo katika miezi 12 iliyopita*)?

- Yes (*Ndio*)                       No (*Hapana*)

**Accidental slaughter of calves**  
**(*Maswali juu uchinjaji bahati mbaya wa ndama*)**

98. In the past 5 years, have you slaughtered a pregnant animal without knowing that she was pregnant (*Katika miaka 5 iliyopita ulishachinja mnyama mwenye mimba bila kujua alikuwa na mimba*)?

- |                          |                     |                          |                      |                          |
|--------------------------|---------------------|--------------------------|----------------------|--------------------------|
| Cattle ( <i>Ngombe</i> ) | Yes ( <i>Ndio</i> ) | <input type="checkbox"/> | No ( <i>Hapana</i> ) | <input type="checkbox"/> |
| Sheep ( <i>Kondoo</i> )  | Yes ( <i>Ndio</i> ) | <input type="checkbox"/> | No ( <i>Hapana</i> ) | <input type="checkbox"/> |
| Goat ( <i>Mbuzi</i> )    | Yes ( <i>Ndio</i> ) | <input type="checkbox"/> | No ( <i>Hapana</i> ) | <input type="checkbox"/> |

99. If yes to 95, please rank (1 most common, 3 least common) which species this happens most commonly in (*Kama ndio kwa 95, tafadhali pangilia (1 kawaida zaid, 3 kawaida kidogo) wanyama gani matukio haya hutokea zaidi*):

- |                            |                            |                            |                          |
|----------------------------|----------------------------|----------------------------|--------------------------|
| 1 <input type="checkbox"/> | 2 <input type="checkbox"/> | 3 <input type="checkbox"/> | Cattle ( <i>Ngombe</i> ) |
| 1 <input type="checkbox"/> | 2 <input type="checkbox"/> | 3 <input type="checkbox"/> | Sheep ( <i>Kondoo</i> )  |
| 1 <input type="checkbox"/> | 2 <input type="checkbox"/> | 3 <input type="checkbox"/> | Goat ( <i>Mbuzi</i> )    |

100. If yes to 95, would your decision to slaughter have changed if you had known the animal was pregnant (*Kama ndio kwa 95, Je uamuzi wako wa kuchinja ungebadilika kama ungejuwa mnyama ana mimba*)?

Cattle ( <i>Ngombe</i> )	Yes ( <i>Ndio</i> ) <input type="checkbox"/>	No ( <i>Hapana</i> ) <input type="checkbox"/>
Sheep ( <i>Kondoo</i> )	Yes ( <i>Ndio</i> ) <input type="checkbox"/>	No ( <i>Hapana</i> ) <input type="checkbox"/>
Goat ( <i>Mbuzi</i> )	Yes ( <i>Ndio</i> ) <input type="checkbox"/>	No ( <i>Hapana</i> ) <input type="checkbox"/>

101. What methods do you currently use to determine whether your female cows are pregnant (*Ni njia gani unatumia kwa sasa kuamua kama ngombe jike ana mimba*)?

- A veterinarian / LFO visits regularly to test with rectal examination (*Veterinari/afisa mifugo anatembelea mara kwa mara na kupima kwa uchunguzi wa uke*)
  - Visual assessment of the body of the females (*Kadiria mwili wa jike kwa kuangalia kwa macho*)
  - Pregnant cows don't go back into oestrus (heat) (*Ng'ombe mwenye mimba harudi kwenye joto*)
  - We monitor breeding activity so we know which females are likely to be pregnant (*Tunafuatilia shughuli za uzalishaji kwa hiyo tunajua majike yapi yanauwezekano kuwa na mimba*).
  - We control breeding activity so we know which females are likely to be pregnant (*Tunadhibiti shughuli za uzalishaji kwa hiyo tunajua majike yapi yanauwezekano kuwa na mimba*).
  - Other (e.g. behaviour) (*Nyingine (mfano, tabia)*)
- 

102. What methods do you currently use to determine whether your female goats are pregnant (*Ni njia gani unatumia kwa sasa kuamua kama mbuzi jike wana mimba*)?

- Visual assessment of the body of the females (*Kadiria mwili wa jike kwa kuangalia kwa macho*)
  - Pregnant goats don't go back into oestrus (heat) (*Mbuzi mwenye mimba harudi kwenye joto*)
  - We monitor breeding activity so we know which females are likely to be pregnant (*Tunafuatilia shughuli za uzalishaji kwa hiyo tunajua majike yapi yanauwezekano kuwa na mimba*).
  - We control breeding activity so we know which females are likely to be pregnant (*Tunadhibiti shughuli za uzalishaji kwa hiyo tunajua majike yapi yanauwezekano kuwa na mimba*).
  - Other (e.g. behaviour) (*Nyingine (mfano, tabia)*)
- 

103. If there was a pen side test available that would accurately indicate whether or not a female was pregnant, would you use it (*Kama kingepatikana kipimo cha bomani/zizini ambacho kinaonyesha kwa usahihi kama jike ana mimba au hapana, je ungekitumia*)?

Cattle ( <i>Ngombe</i> )	Yes ( <i>Ndio</i> ) <input type="checkbox"/>	No ( <i>Hapana</i> ) <input type="checkbox"/>
Sheep ( <i>Kondoo</i> )	Yes ( <i>Ndio</i> ) <input type="checkbox"/>	No ( <i>Hapana</i> ) <input type="checkbox"/>
Goat ( <i>Mbuzi</i> )	Yes ( <i>Ndio</i> ) <input type="checkbox"/>	No ( <i>Hapana</i> ) <input type="checkbox"/>

## Appendix 2: Economic impact of livestock abortion questionnaire

### Economic impact of abortion questionnaires (*Dodoso la athari za kiuchumi za utupaji mimba*)

#### Time point 2 (One month after time point 1)

(*Alama muda 2 (mwezi mmoja baada ya alama muda 1)*)

1. Investigator name(*Jina la mtafiti*): \_\_\_\_\_
2. Date (*Tarehe*) \_\_\_\_\_
3. Barcode number from abortion investigation (*Number ya msimbo kutoka utafiti wa kutupa mimba*) \_\_\_\_\_
4. Household ID(*Utambulisho wa kaya*) \_\_\_\_\_
5. What happened to the dam (*Nini kilitokea kwa jike*)?
  - Remains in herd (*Amebaki kwenye kundi*)
  - Sold alive to another herd owner (*Uzwa akiwa hai kwa mmiliki wa kundi lingine*)
  - Sold at market (*Uzwa kwenye soko*)
  - Slaughtered and sold meat (*Kuchinjwana nyama kuuzwa*)
  - Slaughtered for home consumption (*Kuchinjwa kwa ajili ya kula nyumbani*)
  - Gave it away (*Kugawa*)
  - Other (specify) (*Nyingine (taja)*)  
\_\_\_\_\_
6. If you sold or slaughtered the dam, why did you sell/slaughter the dam (*Kama uliuzwa au kuchinja jike, kwanini uliuzwa/chinja jike*)?
  - Concern about repeat abortions/still births (*Shaka kuhusu kujirudia kutupa mimba/kuzaa vichanga wafuu*)
  - Concern about disease (*Shaka kuhusu ugonjwa*)
  - Both (*Yote mawili*)
  - Other (specify) (*Nyingine, taja*)  
\_\_\_\_\_
7. If sold or slaughtered, did you buy a replacement dam (*Kama aliuzwa au kuchinjwa, je ulinunua jike mbadala*)?
  - Yes (*Ndio*)  No (*Hapana*)
8. If yes above, what age was the replacement animal (*Kama ndio hapo juu, umri wa mnyama mbadala ulikuwa miezi mingapi*)?  
In months \_\_\_\_\_
9. What breed was the replacement animal (*Mnyama mbadala alikuwa jamii gani*)?
  - Local (*Kienyeji*)
  - Mixed (*Chotara*)
  - Exotic (*Kisasa*)
10. Have you mated the replacement animal yet (*Umempandisha mnyama mbadala*)?
  - Yes (*Ndio*)  No (*Hapana*)

11. If no, why not (*Kama Hapana, kwa nini*)?

---

12. If dam remains in the herd, has it been mated (*Kama jike alibaki kwenye kundi, ameshapandwa*)?

Yes (*Ndio*)       No (*Hapana*)

13. Do you think it is pregnant (*Unafikiri ana mimba*)?

Yes (*Ndio*)       No (*Hapana*)       I don't know (*sijui*)

14. If not mated, when will it be mated (*Kama hajapandwa, atapandwa lini*)?

As soon as possible (*Haraka iwezekanavyo*)

In (*Ndani ya*) \_\_\_\_\_ months (*miezi*)

I don't know (*sijui*)

15. Did you buy a calf/kid to replace aborted calf/kid (*Je umeshanunua au utanunua ndama/mwana mbuzi kuchukua nafasi ya mimba iliyotupwa ya ndama/mwana mbuzi*)?

Yes (*Ndio*)       No (*Hapana*)

16. If yes to above, what was the date that you purchased a replacement calf/kid (*Kama ndio hapo juu, tarehe ngapi ulinunua ndama/mwana mbuzi mbadala*)?

---

17. If yes to 15 what sex was the replacement calf / kid (*Kama ndio kwa 11, nini ilikuwa jinsia ya ndama/mwana mbuzi mbadala*)?

Male (*Dume*)

Female (*Jike*)

18. If yes to 15, what age was the replacement calf/kid (*Kama ndio kwa 11, nini ulikuwa umri wa ndama/mwana mbuzi mbadala*)?

\_\_\_\_\_ months (*miezi*)

19. What breed was the replacement animal (*Jamii ya mnyama mbadala itakuwa nini*)?

Local (*Kienyeji*)

Mixed (*Chotara*)

Exotic (*Kisasa*)

20. If no to above, why have you not replaced it (*Kama hapana hapo juu, kwa nini bado haujapata mnyama mbadala*)?

We had no money to buy a replacement (*Hatukuwa na pesa ya kununua mbadala*)

We have not found a suitable replacement animal (*Hatujapata mbadala muafaka*)

We have not visited the market yet (*Bado hatujaenda sokoni*)

Other (specify) (*Nyingine (taja)*) \_\_\_\_\_

21. If the respondent lost an exotic / mixed breed animal and purchased a local / mixed breed animal, why was this (*Kama mfugaji alipoteza mnyama wa kisasa/ chotara na kisha kununua mnyama wa kienyeji au chotara, kwa nini alifanya hivyo*)?

The exotic/mixed animals were too expensive (*Wanyama wa kisasa/ chotara walikuwa ghali sana*)

- There were no exotic/mixed animals available (*Wanyama wa kisasa/ chotata hawapatikani*)
- Other (specify) (*Nyingine (taja)*) \_\_\_\_\_
- Not applicable (because they replaced like for like) (*Halihusiki (kwa sababu walinunua mnyama aliyefanana na wa awali)*)

22. If no to Q15. Will you buy a calf/kid to replace aborted calf/kid (*Je umeshanunua au utanunua ndama/mwana mbuzi kuchukua nafasi ya mimba iliyotupwa ya ndama/mwana mbuzi*)?

- Yes (*Ndio*)
- No (*Hapana*)

23. If yes to Q22, when will you purchase a replacement calf/kid in months? (*Kama ndiokwa 22 hapo juu, lini utanunua ndama/mwana mbuzi mbadala, katika miezi*)?

\_\_\_\_\_ months/ miezi

- I don't know (*sijui*)

24. If yes to Q22, what sex will the replacement calf / kid be (*Kama ndio kwa 22, jinsia ya ndama/mwana mbuzi mbadala itakuwa ipi*)?

- Male (*Dume*)
- Female (*Jike*)

25. In the last month, what happened to the milk yield that this dam produced compared to if the calf / kid had lived (*Nini kilitokea kwa maziwa ambayo jike anatoa na kupatikana kwa ajili ya familia ukilinganisha na kama ndama/mwana mbuzi angeishi*)?

- Same as if did not abort/still birth (*Sawa kama vile hakutupa mimba/ kuzaa kichanga mfuu*)
- Milk yield reduced by (*Maziwa yanayotoka yamepungua kwa*) \_\_\_\_\_ litres/day (*lita/siku*)
- Milk yield increased by (*Maziwa yanayotoka yameongezeka kwa*) \_\_\_\_\_ litres/day (*lita/siku*)
- I don't know (*sijui*)

26. In the last month, what happened to the milk yield available to the family as a result of this abortion / foetal loss (*Katika mwezi uliopita, nini kimetokea kwenye kiasi cha maziwa yaliyopatikana kwa ajili ya matumizi ya familia baada ya kutupa mimba/ kuzaa kichanga mfu*)?

- We don't use the milk (*hatutumii maziwa*)
- Same as if did not abort/still birth (*Sawa kama vile hakutupa mimba/ kuzaa kichanga mfuu*)
- All the family drank less milk (*familia nzima ilikunywa maziwa kidogo*)
- Children drank less milk (*watoto walikunywa maziwa kidogo*)
- Children drank the same milk as always but there was less for the adults (*watoto walikunywa maziwa sawa kama kawaida ila watu wazima walikunywa kidogo*)
- Because the milk yield was less we purchased milk from a duka (*Tulinunua maziwa dukani*)
- Because the milk yield was less we purchased milk from a neighbour (*Tulinunua maziwa kwa jirani*)
- Other (specify)/ *nyingine(taja)*

27. If answer to above was 'purchased milk from duka or neighbour', how many litres of milk per day did they buy (*Kama jibu la swali la juu ni 'Tulinunua maziwa dukani au kutoka kwa jirani', lita ngapi za maziwa ulinunua?*) \_\_\_\_\_ litres / day (*lita/ siku*)

28. In the last month what happened to the milk available to sell? (*Katika mwezi uliopita, nini kimetokea kwenye kiasi cha maziwa yaliyopatikana kwa ajili ya kuuza?*)

We don't sell the milk (*Hatuuzi maziwa*)  
 Same as if did not abort/still birth (*Sawa kama vile hakutupa mimba/ kuzaa kichanga mfuu*)

We had less milk to sell (*tulikuwa na maziwa pungufu ya kuuza*) .....ltr/day (*lita/siku*)

We had more milk to sell (*tulipata maziwa zaidi ya kuuza*) .....ltr/day (*lita/siku*)

Other (specify)/ *nyingine(taja)* \_\_\_\_\_

29. If the dam remains in the herd, have you changed the way you feed this animal after the stillbirth/ abortion? (*Je, hii ni tofauti na jinsi ulivyoweza kusimamia wanyama wengine wakubwa katika kundi hili?*)

Yes (*Ndio*)       No (*Hapana*)  Not in herd (*hayuko zizini*)

30. If yes, what have you changed (*Kama ndio, nini umebadilisha?*)? (check all that apply/ *Chagua vyote vinavyohusika*)

Reduced the amount of concentrate feed by (*nimepunguza kiasi cha lishe mseto kwa*) .....kg/day (*kilo/ siku*)

Reduced the amount of forage by (*nimepunguza kiasi cha lishe ngumu kwa*) .....kg/day (*kilo/ siku*)

Increased the amount of grazing by (*nimeongeza kuchunga kwa*) .....hrs/day (*masaa/ siku*)

Increased the amount of concentrate feed by (*nimeongeza kiasi cha lishe mseto kwa*) .....kg/day (*kilo/siku*)

Increased the amount of forage by (*nimeongeza kiasi cha lishe ngumu kwa*) .....kg/day (*kilo/siku*)

Other (specify)/ *nyingine(taja)* \_\_\_\_\_

31. If you have increased the concentrate feed given to this animal where was it from (*Kama umeongeza kiasi cha lishe mseto, ulitoa wapi?*)

Grown on the shamba (*nimepanda shambani*)

Waste from the homestead (*takataka za nyumbani*)

Purchased from a feed mill (*nimenunua kutoka dukani la vyakula vya mifugo*)

Purchased from a neighbour (*nimenunua kutoka kwa jirani*)

Other (specify)/ *nyingine(taja)* \_\_\_\_\_

32. If you have increased the amount of forage fed to this animal where was it from (*Kama uliongeza kiasi cha lishe ngumu, ilitoka wapi?*)

Grown on the shamba (*nimepanda shambani*)

Cut by the family away from the shamba (*Kukatwa na mwanafamilia mbali na shamba*)

- Purchased from a neighbour and collected by a family member(*Nunuliwa kutoka kwa jirani na kufuatwa na mwanafamilia*)
- Purchased from a neighbour and delivered(*Nunuliwa kutoka kwa jirani na kuletwa*)
- Purchased from elsewhere(*Nunuliwa kutoka kwingineko*)
- Other (specify)/ *nyingine(taja)*

33. Did you also change the way you managed the rest of the herd(*Ulibadili namna hudumia mifugo wako wengine*)?

- Yes (*Ndio*)
- No (*Hapana*)

34. If yes to Q33, how were the rest of the adult animals managed? (*Kama ndio kwa swali la 33, wanyama wengine wakubwa walisimamiwa vipi*)?

- Kept at home and fed (no grazing) (*Tunzwa nyumbani na kulisha (hakuna kuchungwa)*)
- Tethered for grazing (*Kufungwa kamba machungani*)
- Mainly provided with feed, with some grazing (*Kupewa chakula haswa, na kuchungwa kidogo*)
- Mainly grazed, with some supplemental feeding (*Kuchungwa haswa, na malisho nyongeza kidogo*)
- Only grazing (*Kuchungwa tu*)

35. If yes in Q33, how long did you manage the animal in this different way (*Kama ndio kwa swali la 33, ni kwa muda gani umesimamia mnyama kwa njia hizi tofauti*)?

Days (*siku*) \_\_\_\_\_

36. Were fetal membranes expelled within 24hrs of abortion/calving (*Je kondo lilitoka ndani ya masaa 24 toka kutupa mimba/kuzaa ndama*)?

- Yes, fetal membranes were expelled within 24hrs (*Ndio, kondo lilitoka ndani ya masaa 24*)
- No, fetal membranes were retained after 24 hrs (*Hapana, kondo halikutoka baada ya masaa 24*)
- Don't know (*Sijui*)

37. If fetal membranes were retained for more than 24 hours, what did you do (*Kama kondo lilibaki (halikutoka), ulifanya nini*)?

- Manual removal (*Toa kwa mkono*)
- Gave antibiotics (*Nilimpa antibiotics*)
- Gave traditional (herbal) treatment (*Mpa matibabu ya dawa za asili*)
- Called an LFO(*Nilimpigia afisa mifugo*)
- Called a private veterinarian (*Nilimpigia daktari ya mifugo wa binafsi*)
- Called another professional(*Nilimpigia mtaalam mwingine*)
- Other (describe) - (*Nyingine (eleza)*)

38. When foetal membranes were expelled what did you do with them? (*Unafanya nini na kichanga/kondo la nyuma baada ya utupaji mimba/kupoteza kichanga/kufa kichanga*)?

- Nothing, material left (*Hakuna, inaachwa*)
- Buried (*Zika*)
- Burned (*Chomwa*)

- Given raw to dogs (*Mbwa anapewa mbichi*)
- Thrown into bush (*Tupwa porini*)
- Other (*Nyingine*)\_\_\_\_\_

39. Have you treated this animal with anything since the abortion/still birth event (*Je umetibu mnyama huyu na kitu chochote toka tukio la kutupa mimba/ kuzaa kichanga mfuu*)?

- Yes (*Ndio*)     No (*Hapana*)

40. If yes, what was this treatment (*Kama ndio, tiba ilikuwa nini*)?

- Antibiotics (name) (*Antibiotic (jina)*)

- \_\_\_\_\_
- Herbal medicine (name)(*Dawa za asili (jina)*)

- \_\_\_\_\_
- Vitamins (name) (*Vitamini (jina)*)

- \_\_\_\_\_
- Other (describe) (*Nyingine, taja*)

- \_\_\_\_\_
- I don't know (*sijui*)

41. If yes, how much did the treatment cost in Tshs (*Kama ndio, matibabu yaligharimu kiasi gani*)?

- \_\_\_\_\_ Tshs
- I don't know (*sijui*)

42. If yes, how many daily doses were given? (*Kama ndio, dozi ngapi kwa siku alipewa*)?

- \_\_\_\_\_
- I don't know (*sijui*)

### Appendix 3: Economic impact of livestock abortion in northern Tanzania; Control Households questionnaire

#### Questionnaire 2 : Control Household

Dodoso 2

1. Investigator name(*Jina la mtafiti*): \_\_\_\_\_
2. Date(*Tarehe*) \_\_\_\_\_

#### Household Demographics

3. Household ID no.(*Namba ya Utambulisho ya kaya*) \_\_\_\_\_
4. District (*Wilaya*) \_\_\_\_\_ Ward (*Kata*) \_\_\_\_\_ Village (*Kijiji*) \_\_\_\_\_  
Village (*Kijiji*) \_\_\_\_\_
5. Coordinates of household (*Namba za utambulisho za kijiografia za kaya*)  
Eastings \_\_\_\_\_ Northings \_\_\_\_\_ Elevation \_\_\_\_\_ Wayppoint \_\_\_\_\_
6. What is the head of compound's tribe (*Kabila la mkuu wa kaya ni lipi*)?  
 Arusha  
 Barabaig  
 Chagga  
 Iraqw  
 Pare  
 Maasai  
 Sambaa  
 Other (specify) (*Nyingine (taja)*) \_\_\_\_\_
7. What is the head of compound's highest level of education (*Elimu ya juu zaidi ya mkuu wa kaya ni ipi*)?  
 No formal education(*hana elimu rasmi*)  
 Some primary school(*elimu ya msingi kidogo*)  
 Completed primary school(*amekamilisha elimu ya msingi*)  
 Some secondary school(*elimu ya sekondari kidogo*)  
 Completed secondary school(*amekamilisha elimu ya sekondari*)  
 Post secondary qualifications(*elimu zaidi ya sekondari*)  
 Some university(*elimu ya chuo kikuu kidogo*)  
 University completed(*amekamilisha chuo kikuu*)  
 Post graduate(*elimu ya shahada ya juu*)
8. What type of toilet system do members of this compound use (*Ni aina gani ya mfumo wa choo ambao unatumika kawaida na kaya yako*)?  
 Flush or pour toilet with septic tank, including squat toilet (*Choo cha kuvuta au cha kumwaga maji cha kuchuchumaa na mfumo wa shimo la maji taka*)  
 Flush or pour toilet connected to sewer pipe, including squat toilet (*Choo cha maji kilichounganishwa na bomba la maji taka, pamoja na choo cha kuchuchumaa*)  
 Pit latrine with covering slab (*Choo cha shimo kilichosakafiwa*)  
 Pit latrine without covering slab (*Choo cha shimo bila kusakafiwa*)  
 Ventilated improved pit latrine (VIP) (*Choo cha shimo bora chenya bomba la kutoa hewa chafu*)

- Bucket or plastic bags (*Ndoo au mifuko ya plastiki/Rambo*)
- No facilities or field or bush (*Hakuna choo, kwenda porini*)
- Other (specify)/*Vingine (taja)* \_\_\_\_\_

9. What sources of drinking water does your compound use during the wet or dry season (*Ni chanzo kipi cha maji kaya yako huwa wanatumia wakati wa masika*)?

- Piped water into the home (*Yanayosukumwa kwa bomba mpaka ndani nyumbani*)
- Public/communal well or standpipe (*Kisima au pampu ya jumuiia*)
- River or creek (moving water) directly (*Moja kwa moja kutoka mto au mfereji (maji yanatotembea)*)
- Lake, pond, dam (standing water) directly (*Moja kwa moja kutoka Ziwa, dimbwi bwawa (maji yaliyosimama)*)
- Private well or pump (*Kisima au pampu ya binafsi*)
- From a spring (*Kutoka katika chemchem*)
- Rainwater (*Maji ya mvua*)
- Tanker truck (*Tanki la gari*)
- Cart of wheelbarrow with small tank or drum (*Mkokoteni na tanki dogo au madumu/pipa*)
- Bottled water (*Maji ya chupa*)
- Other (*) (Vyanzo vinginevyo)*

#### LIVESTOCK QUESTIONS

10. Are any cattle currently kept at this compound (*Je, kuna ng'ombe wowote wanafugwa kwenye boma hili kwa sasa*)?

- Yes (*Ndio*)
- No (*Hapana*)

11. What is the total number of cattle that are managed together at this compound (*Kuna jumla ya ng'ombe wangapi wanaotunzwa pamoja katika boma hili*)? ( )

12. Of these ( ) cattle (above), how many are in the following breeds (*Wangapi kati yangombe hawa wako katika jamii zifuatazo*)?:

- Local (*Kienyeji*) ( )
- Mixed (*Chotara*) ( )
- Exotic (*Kisasa*) ( )

13. Of the (NUMBER) cattle, how many are the following types (*Wangapi kati ya ng'ombe hawa ni wa kienyeji*):

- Adult male (*wakubwa wa kiume*) \_\_\_\_\_
- Adult female (*wakubwa wa kike*) \_\_\_\_\_
- Juvenile male (*wadogo wa kiume*) \_\_\_\_\_
- Juvenile female (*wadogo wa kike*) \_\_\_\_\_

14. Are any goats currently kept at this compound (*Je, kuna mbuzi wowote wanafugwa kwenye boma hili kwa sasa*)?

- Yes (*Ndio*)
- No (*Hapana*)

15. What is the total number of goats that are managed together at this compound (*Kuna jumla ya mbuzi wangapi wanaotunzwa pamoja katika boma hili*)? ( )

16. Of these ( ) goats (above), how many are in the following breeds (*Wangapi kati ya mbuzi hawa wako katika jamii zifuatazo*):

Local (*Kienyeji*)( )  
Mixed (*Chotara*)( )  
Exotic (*Kisasa*)( )

17. Of the (NUMBER) goats, how many are the following types (*Wangapi kati ya mbuzi hawa ni wa kienyeji*):

- Adult male (*wakubwa wa kiume*) \_\_\_\_\_  
 Adult female (*wakubwa wa kike*) \_\_\_\_\_  
 Juvenile male (*wadogo wa kiume*) \_\_\_\_\_  
 Juvenile female (*wadogo wa kike*) \_\_\_\_\_

18. Are any sheep currently kept at this compound (*Je, kuna kondoo wowote wanafugwa kwenye boma hili kwa sasa*)?

Yes (*Ndio*)  No (*Hapana*)

19. What is the total number of sheep that are managed together at this compound (*Kuna jumla ya kondoo wangapi wanaotunzwa pamoja katika boma hili*)? ( )

20. Of these ( ) sheep (above), how many are in the following breeds (*Wangapi kati yakondoo hawa wako katika jamii zifuatazo*):

Local (*Kienyeji*) ( )  
Mixed (*Chotara*) ( )  
Exotic (*Kisasa*) ( )

21. Of the (NUMBER) sheep, how many are the following types (*Wangapi kati ya kondoo hawa ni wa kienyeji*):

- Adult male (*wakubwa wa kiume*) \_\_\_\_\_  
 Adult female (*wakubwa wa kike*) \_\_\_\_\_  
 Juvenile male (*wadogo wa kiume*) \_\_\_\_\_  
 Juvenile female (*wadogo wa kike*) \_\_\_\_\_

#### LIVESTOCK INTRODUCTIONS AND LOSSES

22. How many cattle were born in this compound in the past 12 months (*Ng'ombe wangapi wamezaliwa katika boma hili katika miezi 12 iliyopita*)? ( )

23. How many cattle have been introduced into this compound in the past 12 months (*Kunang'ombe yeyote aliyeliletwa katika kundi lenu kwa kipindi cha miezi 12 iliyopita*)

24. How many cattle kept in this compound died from disease in the past 12 months (not through slaughter) (*Kuna ng'ombe yoyote anayefugwa kwenye boma lako amekufa katika miezi 12 iliyopita (siyo kwa kuchinjwa)*)?

25. How many goats were born in this household in the past 12 months (*mbuzi wangapi wamezaliwa katika boma hili katika miezi 12 iliyopita*)? \_\_\_\_\_

26. How many goats have been introduced into this household in the past 12 months? (*Kuna mbuziyeyote aliyeliletwa katika kundi lenu kwa kipindi cha miezi 12 iliyopita*)?

27. How many goats kept by your household died of disease in the past 12 months (not throughslaughter) (*Kuna mbuzi yoyote anayefugwa kwenye boma lako amekufa katika miezi 12iliyopita (siyo kwa kuchinjwa)*)?

28. How many sheep were born in this household in the past 12 months (*kondoo wangapiwamezaliwa katika boma hili katika miezi 12 iliyopita*)? \_\_\_\_\_

29. How many sheep have been introduced into this household in the past 12 months (*Kunakondoo yeyote aliyeliletwa katika kundi lenu kwa kipindi cha miezi 12 iliyopita*)?

30. How many sheep kept by your household died from disease in the past 12 months (not throughslaughter) (*Kuna kondoo yoyote anayefugwa kwenye boma lako amekufa katika miezi 12iliyopita (siyo kwa kuchinjwa)*)?

### ANIMAL ILLNESS

31. Have any cattle been unwell in the last 12 months (*Kuna ng'ombe yeyote amekuwa mgonjwa ndani ya miezi 12 iliyopita?*)

Yes (*Ndio*)       No (*Hapana*)

32. How many cattle were unwell in the last 12 months but did not die (*Ng'ombe wangapi waliathirika*)? ( )

33. How many cattle of each category have been unwell in the last 12 months but did not die(*Rika lipi liliathirika*)?

	Local ( <i>Kienyeji</i> )	Mixed <i>Chotara</i> )	Exotic ( <i>Kisasa</i> )
Adult male ( <i>wakubwa wa kiume</i> )			
Adult female ( <i>wakubwa wa kike</i> )			
Juvenile male ( <i>wadogo wa kiume</i> )			
Juvenile female ( <i>wadogo wa kike</i> )			

34. What signs did you observe(*dalili gani ulizona*)?

- Milk drop (*upungufu wa maziwa*)
- Staring coat
- Regurgitation(*kucheua*)
- Diarrhoea(*Kuharisha*)
- Nasal discharge
- Coughing(*Kukohoa*)
- Listlessness
- Recumbancy
- Abdominal pain(*maumivu ya tumbo*)
- Jaundice(*manjano*)
- Inappetance

- Lameness (*ulemavu*)
- Weight loss (*kupungua uzito*)
- Other specify/ (*zingine taja*)

35. Have any goats been unwell in the last 12 months (*Kuna ng'ombe yeyote amekuwa mgonjwa ndani ya miezi 12 iliyopita?*)

- Yes (*Ndio*)       No (*Hapana*)

36. How many goats were unwell in the last 12 months but did not die (*Ng'ombe wangapi waliathirika?*) ( )

37. how many goats of each category have been unwell in the last 12 months but did not die (*Rika lipi liliathirika?*)

	Local ( <i>Kienyeji</i> )	Mixed <i>Chotara</i>	Exotic ( <i>Kisasa</i> )
Adult male ( <i>wakubwa wa kiume</i> )			
Adult female ( <i>wakubwa wa kike</i> )			
Juvenile male ( <i>wadogo wa kiume</i> )			
Juvenile female ( <i>wadogo wa kike</i> )			

38. What signs did you observe (*Uliona dalili gani?*)

- Milk drop (*upungufu wa maziwa*)
- Staring coat
- Regurgitation (*kucheua*)
- Diarrhoea (*Kuharisha*)
- Nasal discharge
- Coughing (*Kukohoa*)
- Listlessness
- Recumbancy
- Abdominal pain (*maumivu ya tumbo*)
- Jaundice (*manjano*)
- Inappetance
- Lameness (*ulemavu*)
- Weight loss (*kupungua uzito*)
- Other specify/ (*zingine taja*)

39. Have any sheep been unwell in the last 12 months (*Kuna ng'ombe yeyote amekuwa mgonjwa ndani ya miezi 12 iliyopita?*)

- Yes (*Ndio*)       No (*Hapana*)

40. How many sheep were unwell in the last 12 months but did not die (*Ng'ombe wangapi waliathirika?*) ( )

41. how many of each category of sheep have been unwell in the last 12 months but did not die (*Rika lipi liliathirika?*)

	Local ( <i>Kienyeji</i> )	Mixed <i>Chotara</i> )	Exotic ( <i>Kisasa</i> )
Adult male ( <i>wakubwa wa kiume</i> )			
Adult female ( <i>wakubwa wa kike</i> )			
Juvenile male ( <i>wadogo wa kiume</i> )			
Juvenile female ( <i>wadogo wa kike</i> )			

42. What signs did you observe (*Uliona dalili gani*)?

- Milk drop (*upungufu wa maziwa*)
- Staring coat
- Regurgitation (*kucheua*)
- Diarrhoea (*Kuharisha*)
- Nasal discharge
- Coughing (*Kukohoa*)
- Listlessness
- Recumbancy
- Abdominal pain (*maumivu ya tumbo*)
- Jaundice (*manjano*)
- Inappetance
- Lameness (*ulemavu*)
- Weight loss (*kupungua uzito*)
- Other specify/ (*zingine taja*)

43. Have any species had joint problems in the past 12 months (*Kuna wanyama wa aina yoyote wamekuwa na matatizo ya viungo katika miezi 12 iliyopita*)?

- Yes (*Ndio*)
- No (*Hapana*)

## LIVESTOCK MANAGEMENT

44. How are cattle in this compound grazed during the wet and dry season (*Unawalishaje ng'ombe wa boma hili kipindi cha mvua na kiangazi*)?

Free ranging (*Wanajichunga wenyewe*):

- Dry (*Masika*)
- Wet (*Kiangazi*)
- Neither (*Si kipindi chochote*)

Herded ON COMMUNUAL LAND (*Wanachungwa*):

- Dry (*Masika*)
- Wet (*Kiangazi*)
- Neither (*Si kipindi chochote*)

GRAZED ON LAND USED EXCLUSIVELY BY THE HOUSEHOLD ONLY:

- Dry (*Masika*)
- Wet (*Kiangazi*)
- Neither (*Si kipindi chochote*)

Tethered (*Wanaofungwa*):

- Dry (*Masika*)
- Wet (*Kiangazi*)
- Neither (*Si kipindi chochote*)

Zero grazed (*Hawachungwi*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

45. How are goats in this compound grazed during the wet and dry season (*Unawalishaje mbuzi wa boma hili kipindi cha mvua na kiangazi*)?

Free ranging (*Wanajichunga wenyewe*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

Herded ON COMMUNUAL LAND (*Wanachungwa*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

GRAZED ON LAND USED EXCLUSIVELY BY THE HOUSEHOLD ONLY:

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

Tethered (*Wanaofungwa*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

Zero grazed (*Hawachungwi*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

46. How are sheep in this compound grazed during the wet and dry season (*Unawalishaje kondoo wa boma hili kipindi cha mvua na kiangazi*)?

Free ranging (*Wanajichunga wenyewe*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

Herded ON COMMUNUAL LAND (*Wanachungwa*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

GRAZED ON LAND USED EXCLUSIVELY BY THE HOUSEHOLD ONLY:

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

Tethered (*Wanaofungwa*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

Zero grazed (*Hawachungwi*):

Dry (*Masika*)Wet (*Kiangazi*)Neither (*Si kipindi chochote*)

47. Which of the following best describes the way you manage the herding of animals in this compound (*Ipi kati yafuatayo inaeleza vizuri jinsi unavyotunza kundi la wanyama katika boma hili*):

Cattle, sheep and goats together (*ng'ombe, kondoo, na mbuzi pamoja*)

Cattle separately, sheep and goats together (*ng'ombe pekee yao, kondoo na mbuzi pamoja*)

Cattle with goats, sheep separately (*ng'ombe na mbuzi, kondoo pekee yao*)

Cattle with sheep, goats separately (*ng'ombe na kondoo, mbuzi pekee yao*)

All species separately (*Kila aina inachungwa tofauti*)

Other (*Nyinginezo*) \_\_\_\_\_

48. Which of the following best describes the way you manage animals at night in this household (*Ipi kati ya yafutatayo inaeleza vizuri jinsi unavyotunza wanyama wako katikakaya hii wakati wa usiku*):

- Cattle, sheep and goats together (*ng'ombe, kondoo, na mbuzi pamoja*)  
 Cattle separately, sheep and goats together (*ng'ombe pekee yao, kondoo na mbuzi pamoja*)  
 Cattle with goats, sheep separately (*ng'ombe na mbuzi, kondoo pekee yao*)  
 Cattle with sheep, goats separately (*ng'ombe na kondoo, mbuzi pekee yao*)  
 All species separately (*Kila aina inachungwa tofauti*)  
 Other (*Nyinginezo*) \_\_\_\_\_

### BREEDING, PARTURITION, AND ABORTION

49. How was service of livestock done in this compound in the past 12 months (*Huduma yaupandishaji wa mifugo ilitolewa namna gani katika kundi lako kwa miezi 12 uliopita*)?

Question	Cattle	Sheep	Goats
Males from own herd ( <i>Madume (dume) kutoka kundi lako</i> )			
Males hired ( <i>Madume (dume) wakukodisha</i> )			
Males borrowed ( <i>Madume (dume) ya kuazima</i> )			
Males from other herds during grazing/watering ( <i>Madume kutoka makundi mengine wakati wa malisho / kunywa maji</i> )			
Artificial insemination ( <i>Uzalishaji kwa chupa</i> )			
Females taken elsewhere ( <i>Jike lilipelekwa kwingine</i> )			
No service performed in past 12 months ( <i>Hatukupandisha katika miezi 12 iliyopita</i> )			
Species not owned or service not performed ( <i>Mifugo usiyonayo au huduma ya kupandisha haikufanyika</i> )			
Other specify ( <i>Nyinginezo taja</i> )			

50. Have you identified infertile male or female livestock in this compound in the past 12 months (*Je, umegundua mifugo wowote dume au jike amabye ni tasa katika boma hili miezi 12 iliyopita (ikihusisha boma lako)*)?

- Yes (*Ndio*)                       No (*Hapana*)

51. How many male cattle have been identified as infertile in the past 12 months (*Nimadume mangapi ya ng'ombe wa kundi la kaya yako wamegundulika kuwa tasa miezi 12iliyopita*)? ( )
52. How many female cattle have been identified as infertile in the past 12 months (*Nimajike mangapi ya ng'ombe wa kundi la kaya yako wamegundulika kuwa tasa miezi 12iliyopita*)? ( )
53. How many male goats have been identified as infertile in the past 12 months (*Nimadume mangapi ya mbuzi wa kundi la kaya yako wamegundulika kuwa tasa miezi 12iliyopita*)? ( )
54. How many female goats have been identified as infertile in the past 12 months (*Nimajike mangapi ya mbuzi wa kundi la kaya yako wamegundulika kuwa tasa miezi 12iliyopita*)? ( )
55. How many male sheep have been identified as infertile in the past 12 months (*Nimadume mangapi ya kondoo wa kundi la kaya yako wamegundulika kuwa tasa miezi 12iliyopita*)? ( )
56. How many female sheep have been identified as infertile in the past 12 months (*Nimajikemangapi ya kondoo wa kundi la kaya yako wamegundulika kuwa tasa miezi 12iliyopita*)? ( )
57. What actions do you take when you discover an animal is infertile (*Unachukua hatuagani kwa kawaida wakati mnyama ni tasa*)?

Question	Cattle	Sheep	Goats
Send animal for slaughter ( <i>Kuchinja</i> )			
Sell animal ( <i>Kuuza</i> )			
Give animal away ( <i>Kumgawa</i> )			
Get advice/treatment from outside household ( <i>Ushauri au matibabu yanatafutwa nje ya kaya</i> )			
Treat the animal myself ( <i>Kutibu mnyama mwenyewe</i> )			
Never owned or had infertility in this species ( <i>Sijawahi kumiliki au kutokuwa na ujingakatika aina hii</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			

Nothing ( <i>Kinachofanyika-wanyama walioadhirika wanatunzwa kama wengine</i> )			
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58. Do you think you would be more likely to sell animals that you know are infertile than those that are not (*Je, unafikiri kuna uwezekano mkubwa kuuza wanyama ambayo ni tasa kulikowale ambao sio tasa*)?

- Cattle (*Ng'ombe*)  
 Goats (*Mbuzi*)  
 Sheep (*Kondoo*)

59. Do you think you would be more likely to slaughter animals that you know are infertile (*Je, unafikiri kuna uwezekano mkubwa kuchinja wanyama ambayo ni tasa kuliko wale ambao sio tasa*)?

- Cattle (*Ng'ombe*)  
 Goats (*Mbuzi*)  
 Sheep (*Kondoo*)

60. Who do you normally go to for advice/treatment when an animal in your herd is infertile (*Kwa kawaida unakwenda kwa nani kupata ushauri/matibabu wakati mnyama wako ni tasa*)?

- Neighbour (*Jirani*)  
 Paravet (*Daktari msaidizi wa mifugo*)  
 Veterinarian (*Daktari wa mifugo*)  
 Animal health assistant (*Bwana afya msaidizi wa mifugo*)  
 Agroveter (*Bwana kilimo na mifugo*)  
 Traditional healer (*Mganga wa jadi*)  
 Spiritual/faith healer (*Imani/mponyaji wa imani*)  
 Local livestock expert (*Mtaalamu wa mifugo wa hapahapa*)  
 Other (*Nyinginezo*) \_\_\_\_\_

61. In the past 12 months, were any livestock born in this compound (*Je, ndani ya miezi 12 iliyopita, kuna mifugo wamezaliwa*)?

- Yes (*Ndio*)       No (*Hapana*)

62. In the past 12 months, how many livestock owned by this compound were born in the following places (*Je, ndani wa miezi 12 iliyopita, mifugo wanao milikiwa na boma hili wamezaliwa wapi*)?

Question	Cattle	Sheep	Goats
In a (human) house in this compound ( <i>Ndani ya nyumba (ya binadamu) kwenye boma hili</i> )			
In the compound (outside a house) ( <i>Ndani ya boma (nje ya nyumba)</i> )			

Outside the compound in this village ( <i>Nje ya kaya ndani ya kijiji</i> )			
Outside the compound in a different village ( <i>Nje ya boma katika kijiji kingine</i> )			
Species not owned/no births in past 12 months ( <i>Sina mifugo hawa/ hakuna uzao ndani ya miezi 12 iliyopita</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			

63. Do cattle that have just given birth usually get seperated from the main herd )*Je, n'gombe ambao wamezaa wanatenganisha na kundi/wanyama wengine*)?  
 Yes (*Ndio*)  No (*Hapana*)
64. For how many days (*Kwa siku ngapi*)( )
65. Do goats that have just given birth usually get seperated from the main herd (*Je, mbuziambao wamezaa wanatenganisha na kundi/wanyama wengine*)?  
 Yes (*Ndio*)  No (*Hapana*)
66. For how many days (*Kwa siku ngapi*)( )
67. Do sheep that have just given birth usually get seperated from the main herd(*Je,kondoo ambao wamezaaa wanatenganisha na kundi/wanyama wengine*)?  
 Yes (*Ndio*)  No (*Hapana*)
68. For how many days (*Kwa siku ngapi*)( )
69. What normally happens to the placenta and foetal membranes after one of your animals(sheep, cattle, or goats) gives birth (*Kwa kawaida inakuwaje kwa kondo la nyuma baada yamojawapo ya wanyama wako (ng'ombe, mbuzi, au kondoo) wanapozaa*)?  
Nothing, material left (*Hakuna – viliachwa*)  
Eaten by family (*Vililiwa na wakazi katika familia*)  
Buried (*Vilifukiwa (zikwa)*)  
Burned (*Vilichomwa*)  
Given to dogs (*Vilipewa mbwa vikiwa vibichi*)  
Thrown in bush (*Vilitupwa porini*)  
Other (*Nyinginezo*)\_\_\_\_\_
70. Have you ever had a case of abortion in livestock kept in thiscompound (*Je, kulishawai kuwa na matukio ya kondo la nyuma kuacha kutoka katika mifugoinayotunzwa katika boma hili (ikihusisha kaya yako)*)?  
 Yes (*Ndio*)  No (*Hapana*)

71. How many cattle in this compound have aborted or delivered still born offspring in the past 12 months (*Ni ng'ombe wangapi katika kaya yako wametupa mimba au kuzaa mtoto mfukatika miezi 12 iliyopita*)? ( )

72. How many goats in this compound have aborted or delivered still born offspring in the past 12 months (*Ni mbuzi wangapi katika kaya yako wametupa mimba au kuzaa mtoto mfukatika miezi 12 iliyopita*)? ( )

73. How many sheep in this compound have aborted or delivered still born offspring in the past 12 months (*Ni kondoo wangapi katika kaya yako wametupa mimba au kuzaa mtoto mfukatika miezi 12 iliyopita*)? ( )

74. What normally happens to the foetus, placenta and/or membranes after one of your livestock has an abortion or stillbirth (*Kwa kawaida inakuwaje kwa kichanga, kondo lanyuma baada ya moja ya mifugo wako kutupa mimba au kuzaa mtoto mfu*)?

- Nothing, material left (*Hakuna – viliachwa*)
- Eaten by family (*Vililiwa na wakazi katika familia*)
- Buried (*Vilifukiwa (zikwa)*)
- Burned (*Vilichomwa*)
- Given to dogs (*Vilipewa mbwa vikiwa vibichi*)
- Thrown in bush (*Vilitupwa porini*)
- Other (*Nyinginezo*) \_\_\_\_\_

75. What do you normally do with an animal after it has an abortion (*Kwa kawaida unachukuwa hatua gani kwa mnyama baada ya kutupa mimba*)?

Question	Cattle	Sheep	Goats
Separate animal from herd for <24 hours ( <i>Namtenganisha mnyama kutoka kundini kwa muda usiofika masaa 24</i> )			
Separate animal from herd for >24 hours ( <i>Namtenganisha mnyama kutoka kundini kwa zaidi ya masaa 24</i> )			
Send animal for slaughter ( <i>Namchinja mnyama</i> )			
Sell animal ( <i>Namuuzza mnyama</i> )			
Give animal away ( <i>Namgawa mnyama</i> )			
Get advice/treatment from outside household ( <i>Natafuta ushauri/ matibabu nje ya kaya</i> )			

Treat the animal myself( <i>Namtibia mnyama mimi mwenyewe</i> )			
Never owned or had an abortion in this species( <i>Sijawahi kumiliki au kupata tukio la kutupa mimba katika mifugo hawa</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			
Nothing( <i>Sifanyi kitu</i> )			

76. Have you ever had a case of retained fetal membranes in livestock kept in this compound (*Je, kulishawai kuwa na matukio ya kondo la nyuma kuacha kutoka katika mifugoinayotunzwa katika boma hili (ikihusisha kaya yako)*)?

Yes (*Ndio*)                       No (*Hapana*)

77. How many cattle in this compound have had a case of retained fetal membrane in the past 12 months (*Ni ng'ombe wangapi wa kundi la kaya yako wamepata matukio ya kondo lanyuma kuacha kutoka katika miezi 12 iliyopita*)? \_\_\_\_\_

78. How many goats in this compound have had a case of retained fetal membrane in the past 12 months (*Ni miezi mingapi iliyopita mara ya mwisho kuwepo tukio la kondo la nyumakuacha kutoka katika kundi la mbuzi wa kaya hii*)? \_\_\_\_\_

79. How many sheep in this compound have had a case of retained fetal membrane in the past 12 months (*Ni kondoo wangapi wa kundi la kaya yako wamepata matukio ya kondo lanyuma kuacha kutoka katika miezi 12 iliyopita*)? ( )

80. What actions do you take when an animal has a retained FOETAL MEMBRANES (*Je, unachukua hatuagani kama mnyama akishindwa kutoa kondo la nyuma*)?

Question	Cattle	Sheep	Goats
Separate animal from herd for <24 hours( <i>Namtenganisha mnyama kutoka kundini kwa muda usiofika masaa 24</i> )			
Separate animal from herd for >24 hours( <i>Namtenganisha mnyama kutoka kundini kwa zaidi ya masaa 24</i> )			
Send animal for slaughter( <i>Namchinja mnyama</i> )			
Sell animal( <i>Namuuza mnyama</i> )			

Give animal away ( <i>Namgawa mnyama</i> )			
Get advice/treatment from outside household ( <i>Natafuta ushauri/ matibabu nje ya kaya</i> )			
Treat the animal myself ( <i>Namtibia mnyama mimi mwenyewe</i> )			
Never owned or had an abortion in this species ( <i>Sijawahi kumiliki au kupata tukio la kutupa mimba katika mifugo hawa</i> )			
Other Specify ( <i>Nyinginezo taja</i> )			
Nothing ( <i>Sifanyi kitu</i> )			

81. Who do you normally go to for advice/treatment when your animal has a retained FOETAL MEMBRANES (*Kwa kawaida unakwenda kwa nani kupata ushauri/matibabu wakati mnyama wakoameshindwa kutoa kondo la nyuma*)?

- Neighbour (*Jirani*)
- Paravet (*Daktari msaidizi wa mifugo*)
- Veterinarian (*Daktari wa mifugo*)
- Animal health assistant (*Bwana afya msaidizi wa mifugo*)
- Agrovvet (*Bwana kilimo na mifugo*)
- Traditional healer (*Mganga wa jadi*)
- Spiritual/faith healer (*Imani/mponyaji wa imani*)
- Local livestock expert (*Mtaalamu wa mifugo wa hapahapa*)
- Other (*Nyinginezo*) \_\_\_\_\_

82. Do you consider abortion/foetal loss/perinatal death in cattle to be (*Je unaona kutupa mimba/ kupoteza kichanga/kufa vichanga kwa ngombe kuwa*):

- Not a major health problem in the area (*Siyo tatizo kubwa la kiafya katika eneo hili*)
- A moderate health problem in the area (*Tatizo la wastani la kiafya katika eneo hili*)
- A major health problem in the area (*Tatizo kubwa la kiafya katika eneo hili*)
- I have no opinion (*sina maoni*)

83. Do you consider abortion/foetal loss/perinatal death in goats to be (*Je unaona kutupa mimba/kupoteza kichanga/kufaa vichanga kwa mbuzi kuwa*):

- Not a major health problem in the area (*Siyo tatizo kubwa la kiafya katika eneo hili*)
- A moderate health problem in the area (*Tatizo la wastani la kiafya katika eneo hili*)
- A major health problem in the area (*Tatizo kubwa la kiafya katika eneo hili*)
- I have no opinion (*sina maoni*)

84. Do you consider abortion/foetal loss/perinatal death in sheep to be (*Je unaona kutupa mimba/ kupoteza kichanga/kufa vichanga kwa kondoo kuwa*):

- Not a major health problem in the area (*Siyo tatizo kubwa la kiafya katika eneo hili*)
- A moderate health problem in the area (*Tatizo la wastani la kiafya katika eneo hili*)

- A major health problem in the area (*Tatizo kubwa la kiafya katika eneo hili*)  
 I have no opinion (*sina maoni*)

85. Do you take any precautions to prevent abortion/foetal loss/perinatal death in cattle (*Je unachukuwa tahadhari yoyote kuzuia kutupa mimba/ kupoteza kichanga/kufa vichanga*)?  
 Yes (*Ndio*)       No (*Hapana*)       I don't know (*sijui*)

86. If yes (to above), what precautions do you take (*Kama ndio (hapo juu) tahadhari gani unachukua*)?

- Vaccinate my animals (*Chanja wanyama wangu*)  
 Purchase new stock from herds that have no history of abortion (*Nunua kundi jipya kutoka kundi ambalo halina historia ya kutupa mimba*)  
 Treat animals with antibiotics during pregnancy (*Tibu wanyama na antibiotic wakati wa ujauzito*)  
 Treat animal with herbal medicine during pregnancy (*Tibu mnyama na dawa za asili wakati wa ujauzito*)  
 Provide additional feeding during pregnancy (*Mpa chakula cha ziada wakati wa ujauzito*)  
 Provide supplements during pregnancy (*Mpa jalizo wakati wa ujauzito*)  
 Separate animals that have aborted from the rest of the herd/flock (*Tenganisha wanyama waliotupa mimba na kundi lililosalia*)  
 Other (*Nyingine*) \_\_\_\_\_

87. What diseases do you vaccinate your cattle against (*Unachanja ngombe wako dhidi ya magonjwa gani*)?

- |  |   |
|--|---|
| <input type="checkbox"/> CBPP<br>( <i>Mapafu kwa ngombe</i> )      | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |
| <input type="checkbox"/> Anthrax<br>( <i>Kimeta</i> )              | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |
| <input type="checkbox"/> BQT<br>( <i>Chambavu</i> )                | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |
| <input type="checkbox"/> FMD<br>( <i>Ugonjwa miguu na midomo</i> ) | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |
| <input type="checkbox"/> ECF<br>( <i>Ndigana kali</i> )            | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |
| <input type="checkbox"/> LSD<br>( <i>Ugonjwa wa mapele</i> )       | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |
| <input type="checkbox"/> RVF<br>( <i>Homa ya bonde la ufa</i> )    | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |
| <input type="checkbox"/> Other<br>( <i>Nyingine</i> )              | If yes, when was last ( <i>kama ndio, lini ilikuwa mwisho</i> ):<br>[ _____ ] |

88. Do you take any precautions to prevent abortion/foetal loss/perinatal death in SHEEP (*Je unachukuwa tahadhari yoyote kuzuia kutupa mimba/ kupoteza kichanga/kufa vichanga*)?  
 Yes (*Ndio*)       No (*Hapana*)       I don't know (*sijui*)

89. If yes (to above), what precautions do you take (*Kama ndio (hapo juu) tahadhari gani unachukua*)?

- Vaccinate my animals (*Chanja wanyama wangu*)

Purchase new stock from herds that have no history of abortion (*Nunua kundi jipya kutoka kundi ambalo halina historia ya kutupa mimba*)

Treat animals with antibiotics during pregnancy (*Tibu wanyama na antibiotic wakati wa ujauzito*)

Treat animal with herbal medicine during pregnancy (*Tibu mnyama na dawa za asili wakati wa ujauzito*)

Provide additional feeding during pregnancy (*Mpa chakula cha ziada wakati wa ujauzito*)

Provide supplements during pregnancy (*Mpa jalizo wakati wa ujauzito*)

Separate animals that have aborted from the rest of the herd/flock (*Tenganisha wanyama waliotupa mimba na kundi lililosalia*)

Other (*Nyingine*) \_\_\_\_\_

90. What diseases do you vaccinate your sheep against (*Unachanja kondoo/mbuzi wako dhidi ya magonjwa gani*)?

PPR If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Mapafu kwa ngombe*) [ ]

Anthrax If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Kimeta*) [ ]

BQT If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Chambavu*) [ ]

FMD If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Ugonjwa miguu na midomo*) [ ]

Sheep/goat pox If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Ndui*) [ ]

RVF If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Homa ya bonde la ufa*) [ ]

Other If yes, when was last (*kama ndio, lini ilikuwa mwisho*):  
(*Nyingine*) [ ]

91. Do you take any precautions to prevent abortion/foetal loss/perinatal death in GOATS (*Je unachukuwa tahadhari yoyote kuzuia kutupa mimba/ kupoteza kichanga/kufa vichanga*)?

Yes (*Ndio*)       No (*Hapana*)       I don't know (*sijui*)

92. If yes (to above), what precautions do you take (*Kama ndio (hapo juu) tahadhari gani unachukua*)?

Vaccinate my animals (*Chanja wanyama wangu*)

Purchase new stock from herds that have no history of abortion (*Nunua kundi jipya kutoka kundi ambalo halina historia ya kutupa mimba*)

Treat animals with antibiotics during pregnancy (*Tibu wanyama na antibiotic wakati wa ujauzito*)

Treat animal with herbal medicine during pregnancy (*Tibu mnyama na dawa za asili wakati wa ujauzito*)

Provide additional feeding during pregnancy (*Mpa chakula cha ziada wakati wa ujauzito*)

Provide supplements during pregnancy (*Mpa jalizo wakati wa ujauzito*)

Separate animals that have aborted from the rest of the herd/flock (*Tenganisha wanyama waliotupa mimba na kundi lililosalia*)

Other (*Nyingine*) \_\_\_\_\_

93. What diseases do you vaccinate your GOATS against (*Unachanja kondoo/mbuzi wako dhidi ya magonjwa gani*)?

PPR If yes, when was last (*kama ndio, lini ilikuwa mwisho*):

- (Mapafu kwa ngombe) [ ]  
 Anthrax If yes, when was last (*kama ndio, lini ilikuwa mwisho*):
- (Kimeta) [ ]  
 BQT If yes, when was last (*kama ndio, lini ilikuwa mwisho*):
- (Chambavu) [ ]  
 FMD If yes, when was last (*kama ndio, lini ilikuwa mwisho*):
- (Ugonjwa miguu na midomo) [ ]  
 Sheep/goat pox If yes, when was last (*kama ndio, lini ilikuwa mwisho*):
- (Ndui) [ ]  
 RVF If yes, when was last (*kama ndio, lini ilikuwa mwisho*):
- (Homa ya bonde la ufa) [ ]  
 Other If yes, when was last (*kama ndio, lini ilikuwa mwisho*):
- (Nyingine) [ ]

94. When buying new FEMALE ADULT stock, do you ask the seller about the abortion history of the animal being sold (*Wakati wa kununua kundi jipya je unamuuliza muuzaji kuhusu historia ya utupaji mimba ya mnyama anayeuzwa*)?

- Yes (*Ndio*)       Sometimes (*wakati mwingine*)       No (*Hapana*)

95. When you have an abortion, DO you call a professional (*Mifugo wako akitupa mimba, je utamuita mtaalam*)?

Question	Cattle	Sheep	Goats
Neighbour ( <i>Jirani</i> )			
Paravet ( <i>Daktari msaidizi wa mifugo</i> )			
Veterinarian ( <i>Daktari wa mifugo</i> )			
Animal health assistant ( <i>Bwana afya msaidizi wa mifugo</i> )			
Agroveter ( <i>Bwana kilimo na mifugo</i> )			
Traditional healer ( <i>Mganga wa jadi</i> )			
Spiritual/faith healer ( <i>Imani/mponyaji wa imani</i> )			
Local livestock expert ( <i>Mtaalamu wa mifugo wa hapahapa</i> )			
Other ( <i>Nyinginezo</i> )			

**Appendix 4: Livestock price in livestock markets survey**

**SEBI-TZ Livestock Market price study**

1. Investigator name(*Jina la mtafiti*): \_\_\_\_\_
2. Date(*Tarehe*) \_\_\_\_\_

n o	Age (in month s)	Gend er (m/f)	Bree d	Speci es	BC S	Selli ng price	Pregnan cy	Mark et name	Distri ct	War d	Villa ge
1.											
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											
11.											
12.											
13.											
14.											
15.											

**Appendix 5: Supplementary file 1 (Criteria list title/abstract)****Criteria list title/abstract**

Criteria	Key element	Comments
Cattle, Sheep, Goats	Population	Any paper that mentions ALL or ANY of these species will be included.
Abortifacient organisms commonly found in Africa and Asia.	Intervention/Exposure	Any
Abortion surveillance	Outcome	Surveillance or studies in support of surveillance of any of the mentioned common abortifacient agents.
English Language	Language	All articles/ abstracts should be in English language.
Africa and Asia	Geographical Region	
Primary Information	Primary peer-reviewed article	Reviews and any article without primary information will be excluded.
None	Comparator	None

## Appendix 6: Supplementary file 2 (Criteria list fulltext)

### Criteria list fulltext

Criteria	Key element	Comments
Cattle, Goats, Sheep	Population	Studies on the species of interest only.
Abortifacient organisms	Intervention/Exposure	Organisms of interest as outlined above.
Abortion	Outcome	Abortion in livestock spp of interest.
Africa and Asia	Region	Only in regions of interest
Surveillance technologies	Surveillance type	
Only English	Language	
Sample used for surveillance	Sample type during surveillance	
Laboratory methodology used to confirm cases	Lab methodology	Any lab confirmation of cases done.
Linkage to formal surveillance system in the region	Survey	Either linked to government systems or independent studies.
Regions	Comparator	Systems will be compared regionwise.

## RESEARCH OUTPUTS

### (i) Publications

Semango, G., Hamilton, C. M., Kreppel, K., Katzer, F., Kibona, T., Lankester, F., Allan, K. J., Thomas, K. M., Claxton, J. R., Innes, E. A., & Swai, E. S. (2019). The sero-epidemiology of *Neospora caninum* in cattle in northern Tanzania. *Frontiers in Veterinary Science*, 6, 327.

Semango, G., Yoder, J., Kibona, T., Claxton, J. R., Buza, J., Mmbaga, B. T., Johnson, S. S., Cleaveland, S., & Lankester, F. (2024). Economic burden of livestock abortions in Northern Tanzania. *Journal of Agricultural and Applied Economics*, 56(2), 195-215.

Semango, G. P., & Buza, J. (2024). Review of the Current Status on Ruminant Abortigenic Pathogen Surveillance in Africa and Asia. *Veterinary Sciences*, 11(9), 425.

### (ii) Poster presentation